ASTRO 3D

ANNUAL REPORT 2019

ARC CENTRE OF EXCELLENCE
FOR ALL SKY ASTROPHYSICS IN 3D

Australian Government
Australian Research Council

ASTRO 3D

ACKNOWLEDGEMENT

ASTRO 3D acknowledges the support of the Australian Research Council and all of the collaborating and partner institutions in the Centre.

OUR COLLABORATING UNIVERSITIES

Australian National University

Curtin University

The University of Western Australia

Swinburne University of Technology

The University of Melbourne

The University of Sydney

OUR PARTNER INSTITUTIONS

ASTRON Netherlands Institute for Radio Astronomy

California Institute of Technology 1891

Chinese Academy of Sciences

CSIRO

Heidelberg Institute for Theoretical Studies HITS

NCI National Computational Infrastructure

University of Oxford

University of Toronto

University of Washington

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ACRONYMS & ABBREVIATIONS

AAO	Australian Astronomical Observatory
AAL	Astronomy Australia Ltd
AAT	Anglo Australian Telescope
ACFR	Australian Centre for Field Robotics
ADACS	Astronomy Data and Computing Services
ADC	Atmospheric Dispersion Corrector
AGN	Active Galactic Nuclei
ALFALFA	Arecibo Legacy Fast ALFA Survey
ALMA	Atacama Large Millimeter Array
ANU	The Australian National University
AOS	Australian Optical Society
APOGEE	APO Galactic Evolution Experiment
ARC	Australian Research Council
ASA	Astronomical Society of Australia
ASKAP	Australian Square Kilometre Array Pathfinder
ASTRO 3D	Centre of Excellence for All Sky Astrophysics in 3 Dimensions
ASTRON	Netherlands Institute for Radio Astronomy
ASVO	All-Sky Virtual Observatory
ATNF	Australia Telescope National Facility
BoRG	The Brightest of Reionising Galaxies
CAASTRO	Centre of Excellence for All Sky Astrophysics
CAS	Chinese Academy of Sciences
CASDA	CSIRO ASKAP Science Data Archive
CASS	CSIRO Astronomy and Space Science
CIRADA	Canadian Initiative for Radio Astronomy Data Analysis
CMB	Cosmic Microwave Background
COCKATOO	COsmological Chemodynamical simulations with Kinetic AGN feedback and other physics TOO
COO	Chief Operating Officer
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DALiuGE	Data Activated Liu Graph Engine
DECaLS	Dark Energy Camera Legacy Survey
DECRA	Discovery Early Career Researcher Award
DES	Dark Energy Survey
DIAP	Data Intensive Astronomy Program
DINGO	Deep Investigation of Neutral Gas Origins
DSTG	Defence Science and Technology Group
EAGLE	Evolution & Assembly of GaLaxies and their Environments
ECR	Early Career Researcher
EDI	Equity Diversity and Inclusion
EMP	Extremely Metal-poor Stars
EoR	Epoch of Reionisation
ESO	European Southern Observatory
ESPRESSO	Echelle SPectrograph for Rocky Exoplanets and Stable Spectroscopic Observations
FAST	Five-hundred-metre Apeture Spherical Telescope
FLASH	First Large Absorption Survey in HI
GALAH	GALactic Archeology with HERMES
GAMA	Galaxy and Mass Assembly
GRB	Gamma Ray Burst
GMT	Giant Magellan Telescope
HERMES	High Efficiency and Resolution Multi-Element Spectrograph
HI	H one (neutral hydrogen)
HIRAX	Hydrogen Intensity and Real-time Analysis eXperiment
HITS	Heidelburg Institute for Theoretical Studies
HPC	High-Performance Computing
HST	Hubble Space Telescope
IAB	International Advisory Board
ICRAR	International Centre for Radio Astronomy Research
IFU	Integral Field Units
IGM	InterGalactic Medium
JWST	James Webb Space Telescope
K3-LARS	KMOS z=3-4 Lyα reference survey
KAPA	Keck All-sky Precision Adaptive-optics
KIAA	Kavli Institute for Astronomy and Astrophysics
KiDS	Kilo-Degree Survey
KMOS	K-band Object Spectrograph
KPI	Key Performance Indicator
KROSS	KMOS Redshift One Spectroscopic Survey
LIEF	Linkage Infrastructure Equipment and Facilities
LGBTI	Lesbian Gay Bisexual and Transgender (initalism)
LTE	Local Thermodynamic Equilibrium
MANIFEST	Many Instrument Fiber System
MIAPP	Munich Institute for Astro- and Particle Physics
MOSFIRE	Multi-Object Spectrograph For Infra-Red Exploration
MOSEL	MOSfire Emission Line survey
MPIA	Max Planck Institute for Astronomy
MSTO	Main Sequence Turn-off
MUSE	Multi-Unit Spectroscopic Explorer
MWA	Murchison Widefield Array
NASA	National Aeronautics and Space Administration
NCA	National Committee for Astronomy
NCI	National Computational Infrastructure
PEONY	Planetary nebula EvOlutioN ifs surveY
PRISMA	Preferred Reporting Items for Systematic Reviews and Meta-Analyses
PHISCC	SKA Pathfind HI Science Coordination Committee
QSO	Quasi-Stellar Objects
RSAA	Research School for Astronomy and Astrophysics
SAGE	Semi-Analytic Galaxy Evolution
SAIL	Sydney Astrophotonic Instrumentation Laboratory
SAMI	Sydney-AAO Multi-object Integral field unit
SAM	Semi-Analytic Model
SCA	Subsea Communications Australia
SED	Spectral Energy Distribution
SKA	Square Kilometre Array
SMC	Science Management Committee
SOfIA	Stratospheric Observatory for Infrared Astronomy
SPIRIT	SPICE, Physics, ICRAR, Remote Internet Telescope
STEM	Science Technology Engineering Mathematics
TAO	Theoretical Astrophysical Observatory
TESS	Transiting Exoplanet Survey Satellite
TOSCA	Topology and Orchestration Specification for Cloud Applications
UCSD	University of California San Diego
UNSW	University of New South Wales
UAV	Unmanned Aerial Vehicle
UoM	University of Melbourne
UV	UltraViolet
UW	University of Washington
UWA	University of Western Australia
VIKING	VISTA Kilo-Degree Infrared Galaxy Survey
VISTA	Visible and Infrared Survey Telescope for Astronomy
VLT	Very Large Telescope
VO	Virtual Observatory
VR	Virtual Reality
WALLABY	Widefield ASKAP L-Band Legacy Allsky Blind Survey
WiFeS	WideField Spectrograph

IMAGE CREDIT: Cristy Roberts

DIRECTOR'S WELCOME AND REPORT

The ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) is building a comprehensive picture of the evolution of matter, the chemical elements, and energy in the Universe from shortly after the Big Bang to the present day. ASTRO 3D is merging world-leading Australian and international optical, infrared and radio telescope technologies with sophisticated theoretical simulations and ambitious new big data analysis techniques to open a new realm in astrophysics - a 3D understanding of the origins of the Universe and our place within it. Through the Centre, the next generation of scientific leaders are being trained within a cohesive national collaborative framework with leading equity and diversity programs. Our science is being shared with school children and the general public through our successful communications and media operations and far-reaching public education and outreach programs.

SCIENCE AND DISCOVERIES

ASTRO 3D is leading eight core programs that cover the earliest times in the universe to our own Milky Way. The MWA Epoch of Reionisation program uses the Murchison Wide Field Array in Western Australia to take data to ultimately detect neutral hydrogen gas at the Epoch of Reionsation when the first stars in the Universe were forming. In 2019, we improved our ability to detect the Epoch of Reionisation by 10 times!

The First Stars program uses the Skymapper telescope in Coonabarabran and ground-based telescopes in Chile to identify the most metal-poor stars in the universe. In 2019, we detected the most iron-poor star known. We think that this star was enriched by only one supernova prior to its formation.

The First Galaxies program combines the Hubble Space Telescope and ground-based telescopes in Chile (ESO VLT) to search for and identify the first galaxies in the universe and understand their formation. In 2019, this team continued its work finding first galaxies candidates and lining up observations for the world's largest ground-based telescopes.

The Galaxy Evolution program bridges the first galaxies with studies of the local universe, using ground-based telescopes in Chile and Hawaii (ESO VLT, Magellan, Keck, Gemini) and the Hubble Space Telescope to measure how galaxies evolved from the first galaxies to the galaxies that surround us today. MAGPI, a collaboration led by the ASTRO 3D Fellows across five ASTRO 3D nodes received the largest amount of time on MUSE, the top-requested instrument at the European Southern Observatory. This is a fantastic achievement and we are looking forward to the discoveries to be made by MAGPI! Also in 2019, the First Galaxies team began collaborating with the Galaxy Evolution team to understand the spectral emission using detailed photoionisation models developed by the Galaxy Evolution team.

The ASKAP surveys use the Australian Square Kilometre Pathfinder Array (ASKAP) in Western Australia to measure and map the neutral hydrogen in galaxies in the nearby universe. The ASKAP observations continued in 2019, giving enough data to begin science. Follow-up observations are now being made by the FLASH project using the ESO VLT in Chile, in collaboration with the Galaxy Evolution team who have expertise with ESO VLT.

The SAMI/Hector program is measuring the ionised gas and the stars in galaxies in the nearby universe, and building the next generation 3D instrument for the Anglo-Australian Telescope, Hector. We found that the smallest galaxies spin on a different axis to the largest galaxies, and this is related to the large-scale structure in the universe. Follow-up work is now combining ASKAP data and SAMI data for the same galaxies to understand the motions of galaxies in both the neutral and ionised gas.

GALAH uses data from the GAIA satellite and the HERMES instrument on the Anglo-Australian Telescope to measure the chemical abundances and ages of stars in the Milky Way to develop an archaeological picture of how our Milky Way formed and evolved. In 2019, we have made tremendous advances in our understanding of the Milky Way, including the discovery that a massive flare was produced by the supermassive black hole in the centre of our Galaxy 3.5 million years ago. This discovery shows that the black hole in the centre of our Milky Way is more active than previously thought. We also used star quakes to show that the Milky Way is 10 billion years old.

ASTRO 3D has one core theoretical program, Genesis, which relies on the National Computational Infrastructure (NCI) facility in Canberra to run simulations of the formation and evolution of galaxies in the universe. This program feeds into all of the ASTRO 3D observational programs to help us understand how the matter and chemical elements in galaxies formed and evolved across cosmic time. In 2019, Genesis completed its major galaxy evolution theoretical program, and began work on a highly ambitious model run to predict the conditions at the Epoch of Reionisation.

All of this major science and discovery would not be possible without an excellent cohort of professional staff who manage the day to day operations of the Centre. In 2019, we welcomed former Education, Outreach and Communications Manager, Ingrid McCarthy, as our new Chief Operating Officer. Since she became COO, Ingrid has made sweeping changes across the Centre, including new effective professional staff management, efficient Centre-wide communications, KPI reporting via more streamlined smartsheets forms, the development of the new ASTRO 3D website, and the introduction of our Centre-wide mentoring program. Ingrid is supported by an efficient team of professional staff at every node, who are continuing to provide excellent work for the Centre, as well as engaging in Centre activities and committees.

CENTRE EXPANSION

In 2019, ASTRO 3D continued hiring outstanding Postdoctoral researchers and attracting top students. The Centre now has 242 members, including 38 Postdocs, and 69 PhD, Honours, and Masters students. In 2019, we began a process for the consideration of new nodes to ASTRO 3D. Monash University, Macquarie University and the University of New South Wales submitted applications to become nodes of ASTRO 3D. The enthusiasm, support, and interest from astronomers in these three universities highlights the world-leading science and successful national and international collaborations that are integral to ASTRO 3D. When we complete the new node process in 2020, we will be welcoming new nodes that expand our research capability and scientific leadership in our key science areas, as well as

IMAGE CREDIT: Cristy Roberts

positioning the Centre to provide the foundation, or spring-board for a new Centre proposal or proposals.

DIVERSITY AND INCLUSION

One of the goals of ASTRO 3D is to achieve 50% female representation at all levels of the Centre by 2021. At the end of 2019, we have achieved 40% female representation across the Centre. Our core equity policies include family friendly meeting times, all positions available as part time, child care at all Centre run and Centre sponsored events, and 50% female speakers at all Centre sponsored meetings and conferences. Of course, true diversity spans people of all genders, ages, ethnicity, religions, socio economic backgrounds, physical ability, and sexual orientation. In 2019, our Equity, Diversity and Inclusion (EDI) Committee led by Kim-Vy Tran (UNSW) developed a framework for holding diverse and inclusive workshops and conferences, and they began work on a framework and guidelines for inclusive hiring practices that we hope will be introduced in astronomy and physics departments across Australia. I am looking forward to the new initiatives that our EDI committee will develop and implement in 2020!

To support and promote diversity and inclusion practices across Australia and world-wide, in 2019 I wrote an invited article for Nature Astronomy on Diversity in Australian Astronomy, and a commissioned white paper for the Mid-Term Review of the Astronomy Decadal Plan on Gender and Diversity in Australian Astronomy. These papers highlight the excellent and broad range of diversity initiatives that have been introduced into Australian astronomer institutions and departments over the past few years, and I provide recommendations and guidelines to help achieve broader diversity and more fair gender ratios at the higher levels at universities. In 2020, ASTRO 3D will spearhead some Australia-wide initiatives including astronomer exit surveys, and developing our own diversity workshops designed to provide participants with a deeper understanding of the issues and situations faced by members of minority groups. These initiatives will go beyond the Centre, and aim to improve diversity and inclusion in the broader Australian and global astronomy community.

SUSTAINABILITY

In 2019, it became clear that sustainability is an important and fundamental goal for many of our Centre members, especially our Postdocs and students who are deeply concerned about our carbon footprint and the future impact on our climate. In 2019, we established a Sustainability Committee led by Andy Casey (Monash). The sustainability committee is investigating ways that we can reduce our carbon footprint including sustainable merchandise, virtual conference software, and holding a carbon neutral (or carbon negative conference). I am looking forward to running our first carbon negative conference in the near future!

IMAGE CREDIT: Ingrid McCarthy

EDUCATION AND OUTREACH PROGRAMS

ASTRO 3D now has a full complement of education and outreach staff, with one education/outreach officer at every node in Australia. In 2019, we welcomed Delese Brewster as our new Senior Education and Outreach Coordinator. The Education and Outreach team, led by Delese, is working together on a complement of far-reaching education and outreach programs.

In 2019, ASTRO 3D extended its Telescopes in Schools program to rural areas led by ASTRO 3D Associate Investigator Brad Tucker. The Telescopes in Schools rural program began in the rural towns that showed the highest engagement in Stargazing Live. Stargazing Live broke the world record of the most people simultaneously observing the night sky, with >40,000 people across Australia observing the moon simultaneously. The Telescopes in Schools program was also introduced in Western Australia, using the UWA SPIRIT Telescope. The Telescopes in Schools program targets under-privileged schools and girls schools across Australia, and we plan to expand into the ACT and NSW over 2020-2021.

Our Uluru Astronomer-in-Residence program completed in 2019. This program has been a great opportunity to support the local Indigenous community in Uluru, particularly during its inception in CAASTRO when the resort was struggling. The resort has now developed a suite of extremely successful programs including star-gazing and other astronomy programs. The resort is now at almost 100% capacity from tourists year-round. Given this success, we decided that our Uluru funding could now be re-routed to another area of need: Indigenous pathways into STEM. In 2020, we will be developing an Indigenous work experience program to bring Indigenous students together to a university environment to work on research projects. This program will include mentoring both during and after the work experience program.

In 2019, we began work on our Virtual Reality Education experience. This program will be developed in collaboration with the Virtual Reality Laboratory at Deakin University, with an advisory group of educators and teachers, and a scientific steering committee to ensure that the science developed is based on our current understanding of the Universe. This program is aimed at supporting the physics and astronomy curriculum for high school students.

Research shows that girls develop stereotypes about scientists before grade 3. To provide a balanced set of role models to counteract stereotypes, in 2020 and 2021, we will be developing ASTRO-in-the-Classroom, a Zoom-meeting classroom program targeting early and mid- primary school students. ASTRO in the Classroom is being designed to link in with the K-4 curriculum in NSW, Victoria, ACT, and WA, as well as providing Q&A sessions with astronomers.

TOWARDS 2020

The coming year will be an exciting year for ASTRO 3D, with major discoveries to be made in most of our surveys and projects as they begin to reach critical mass of data. The expansion of the Centre to include new nodes will bring in new scientific expertise and leadership capacity, and invigorate the Centre. The planned discussions of the science and technology to be included in a new Centre proposal or proposals will propel us to think a decade into the future. And finally, our legacy to the Australian education and public is the development and expansion of our new education/outreach programs, which will be in full swing in 2020!

Lisa Kewley

Centre Director

IMAGE CREDIT: Cristy Roberts

"ASTRO 3D is certainly living up to its title as a Centre of Excellence - its researchers have made impressive progress in studying the evolution of matter, light and the elements over cosmic time. World-class research has been published, using vast computer simulations, or observations with cutting-edge instrumentation built in Australia such as SAMI and GALAH, and facilities such at the AAT, MWA and ASKAP. ASTRO 3D members have been enormously successful in obtaining time on international telescopes, making the most of Australia's access to the ESO Very Large Telescopes.

One of the great strengths of ASTRO 3D is the linking of research across different fields: astrophysical theory and simulations; observations across the spectrum; building and exploiting instruments; and big data. By bringing together researchers across these topics, and across Australia and its international partners, ASTRO 3D is more than the sum of its parts - big questions such as first light in the universe and the reionisation of the gas between the galaxies deserve a multi-prong approach, and ASTRO 3D is doing exactly that, linking 21cm radio observations at high redshift with simulations of galaxy evolution, observations of the first galaxies, and searches within our own galaxy for the relics of the first stars to be born.

It is clear that people are at the heart of ASTRO 3D. I witnessed the great spirit of co-operation at the Annual Retreat in Ballarat, and the importance attached to mentoring young researchers, their career development, and the supportive and inclusive environment ASTRO 3D has fostered for all its members. There is great motivational leadership from the Director and across the Nodes. The excellent research done is also inspiring the next generation through an active public outreach program.

ASTRO 3D has already made great progress on important topics in astrophysics, and we are only half-way through - I will be very excited see what big results the research uncovers in the second half. ASTRO 3D truly is a Centre of Excellence!

Andy Bunker - Partner Investigator, University of Oxford

IMAGE CREDIT: Andy Bunker

ABOUT THE CENTRE

The ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) commenced in July 2017 and is a Research Centre of Excellence led by the Australian National University (ANU) from its Research School of Astronomy and Astrophysics at Mt Stromlo.
The Centre is comprised of six collaborating universities — ANU, the University of Melbourne, the University of Sydney, Swinburne University of Technology, the University of Western Australia and Curtin University — and a number of world-class Australian and international partners, including:

- Commonwealth Scientific and Industrial Research Organisation (CSIRO)
- The Australian Astronomical Observatory (AAO)
- National Computational Infrastructure (NCI)
- California Institute of Technology, USA (Caltech)
- University of Washington, USA (UW)
- University of Toronto, Canada
- Netherlands Institute for Radio Astronomy (ASTRON)
- Heidelberg Institute for Theoretical Studies (HITS)
- Chinese Academy of Sciences (CAS)
- University of Oxford, UK

The Centre has been funded over seven years with a $30.3m grant from the Australian Research Council (ARC), $8.4m in cash from the six Australian universities and $144m of in-kind resources from across the collaborating and partner institutions.

OUR VISION

To unlock the mysteries of the Universe using innovative 3D technology, while sharing the excitement and wonder of astronomy to inspire the broader community.

OUR MISSION

- To propel Australia to the forefront of astronomical research by combining Australia's radio, optical and theoretical expertise to understand the origins of our Universe and the galaxies within it.
- To train future Australian astronomers to lead breakthrough science on the next generation of telescopes.
- To share our discoveries and passion for research with the broadest possible audience and inspire the scientists of the future.

IMAGE CREDIT: Cristy Roberts

OUR STRATEGIC GOALS

1. TRANSFORM OUR UNDERSTANDING OF THE UNIVERSE AND HOW WE GOT HERE

- We will conduct ground breaking new 3-Dimensional surveys alongside an observationally-driven theory program with dedicated telescope and supercomputing facilities.
- We will develop new data intensive astronomy infrastructure to analyse the petabytes (1 petabyte = a billion megabytes, or a million gigabytes) of data that will ensue from the Square Kilometre Array.
- We will translate this research into high-impact publications with broad and far-reaching international dissemination of our results, through our unified and cohesive scientific collaborations and our efficient administrative structure.

2. BUILD AND MAINTAIN THE INFRASTRUCTURE, SKILLS AND EXPERTISE REQUIRED TO MAXIMISE AUSTRALIA'S INVESTMENT IN THE NEW ERA OF MEGA-SCALE OPTICAL AND RADIO TELESCOPES

- Through our research programs, skills workshops, mentoring, leadership and succession planning, we will train young Australian scientists to drive the future world-leading programs on the next generation of telescopes.
- Through the long-term investment and continuity that ASTRO 3D provides, we will ensure that the Federal government's investment in the Square Kilometre Array and Giant Magellan telescopes is realised.

3. INSPIRE, TRAIN AND MENTOR THE NEXT GENERATION OF DIVERSE AUSTRALIAN SCIENTIFIC LEADERS

We will inspire students to study science, technology, engineering and mathematics (STEM) through new teacher education programs and our ambitious nation-wide public outreach campaigns.

4. PROVIDE YOUNG AUSTRALIAN SCIENTISTS WITH TRANSFERABLE SKILLS FOR THE MODERN WORKFORCE

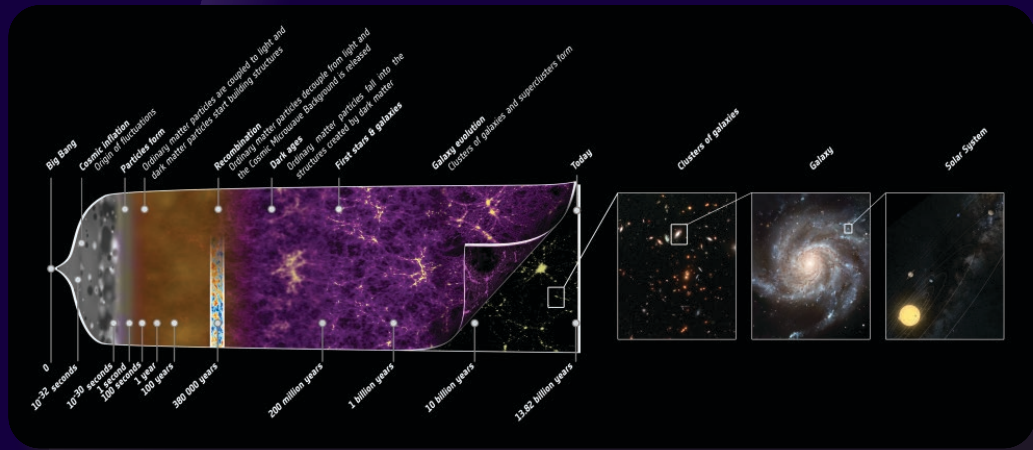
We will train the new generation of young Australian astrophysicists in transferable skills including data intensive science, providing a broad range of career options outside astrophysics, including market analysis, population statistics, medical science, bioinformatics, genomics, and commercial sector data analytics.

5. CREATE AN INNOVATION CULTURE TO FACILITATE THE TRANSFER AND COMMERCIALISATION OF ASTRONOMICAL TECHNOLOGY TO OTHER DISCIPLINES

We will identify fresh ideas and aid the commercialisation of new astronomical technology through our Intellectual Property and Innovation Committee, comprised of experts in commercialisation.

IMAGE CREDIT: Cristy Roberts

WHY ASTRO '3D'?



This illustration summarises the almost 14-billion-year-long history of our universe. It shows the main events that occurred between the initial phase of the cosmos - where its properties were almost uniform and punctuated only by tiny fluctuations - to the rich variety of cosmic structure that we observe today, ranging from stars and planets to galaxies and galaxy clusters. ***IMAGE CREDIT:*** NASA

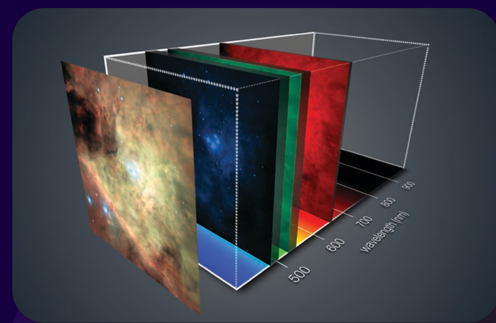
The most fundamental question in astrophysics, "How Did We Get Here?", covers vast ground - from the Big Bang and the stars that first lit the cosmos, to the evolution of the diverse Universe that surrounds us today. No single telescope or theoretical simulation can answer this question. This problem requires new panchromatic all-sky surveys that cover thousands of square degrees of sky to capture the light from hundreds of thousands of galaxies.

Critically, it also requires 3D; the extra dimensions of time and motion are required addition to the typical space or frequency dimensions in previous surveys. Using new 3D Integral Field Technology (IFU), for every pixel of light we receive from a telescope, we can generate a datacube, that gives us information about:

- spatial properties (what is where)
- spectral properties (what chemical elements are present)
- velocity information (are the stars and the gas moving away from us or towards us)

ASTRO 3D strategically combines new 3D radio, optical, and infrared technology with new supercomputing infrastructure. 3D surveys allow us to track how the different phases of matter, neutral hydrogen gas, ionised gas, stellar mass, and dark matter accumulated and spread across the history of the Universe.

As a consequence of this cutting-edge 3D data and modelling, ASTRO 3D will be able to utilise tools such as Virtual Reality, 3D movies, 3D printed models and files, coupled with links to school curriculum to help both the general public and students understand and appreciate the new era of discovery in astrophysics.



This image shows how the MUSE IFU instrument on ESO's Very Large Telescope gives a three-dimensional depiction of the Orion Nebula. For each of part of the spectacular star formation region, the light has been split up into its component colours, revealing in detail the chemical and physical properties of each pixel ***IMAGE CREDIT:*** ESO

GOVERNANCE

We have established a collaborative and cohesive structure that focuses on the effective and efficient delivery of the Centre's Strategic Goals and meeting our Key Performance Indicators.

EXECUTIVE MANAGEMENT COMMITTEE

The Executive Management Committee works collaboratively to oversee day-to-day operations, including financial and risk management, the development of the strategic plan and monitoring performance against agreed outcomes. All collaborating universities are represented on the Committee, which is comprised of in 2019:

Centre Director - Prof. Lisa Kewley (ANU)

Centre Deputy Director - Prof. Stuart Wyithe (Melbourne)

Node Leaders at each collaborating university - Prof. Scott Croom (Sydney), Prof. Karl Glazebrook (Swinburne), Prof. Lister Staveley-Smith (UWA), Prof. Cathryn Trott (Curtin)

Chief Operating Officer - Ms Ingrid McCarthy

Business Manager - Ms Denise Castle

Collaboration Leader - Prof. Joss Bland-Hawthorn (Sydney)

Representatives from other Committees (EDI - Kim-Vy Tran, Snr and Jnr ECRs, Students and Sustainability Committees - rotating reps).

In 2019, the ASTRO 3D Executive Committee met 10 times, including face-to-face meetings at ANU and the Science Meeting at CSIRO, Marsfield, Sydney.

INTERNATIONAL ADVISORY BOARD

The IAB meet at least annually to provide support and advice to the Director and Executive Committee on the effectiveness of the Centre in reaching its scientific, technical, and operational goals. In 2020, we will have one Advisory Board with International and National Members.

INTERNATIONAL ADVISORY BOARD

The Chair of the International Advisory Board is:

Professor Tim de Zeeuw, Professor of Theoretical Astronomy at Leiden University and former Director General of the European Southern Observatory

2019 IAB members:

Professor Meg Urry, Israel Munson Professor of Physics and Astronomy; Director, Yale Center for Astronomy & Astrophysics; President, American Astronomical Society

Dr Linda Tacconi, Scientist, Max Planck Institute for Extraterrestrial Physics

Professor Lars Hernquist, Mallinckrodt Professor of Astrophysics, Harvard-Smithsonian Centre for Astrophysics

IMAGE CREDIT: Cristy Roberts

IMAGE CREDIT: Cristy Roberts

International Advisory Board Chair's Report

ASTRO 3D is carrying out an ambitious science programme addressing the nature of the ionised Universe, the formation of galaxies, and the origin of the elements. The Director has put together a strongly motivated, diverse set of researchers in various career stages, who work on the interrelated projects in multi-site teams, with expertise in optical and radio observations as well as in analysis enabled by numerical simulations.

The International Advisory Board participated in the science meeting at CSIRO in Marsfield on 20-23 May. It heard all the science presentations, had lively discussions with the students and Postdocs, and met separately with senior management. The ASTRO 3D programme is at the forefront of astrophysics, and many of the projects, in particular First Stars, GALAH, and MWA, showed exciting new results. The leadership continues to work together constructively to make the multi-site science projects a success. Further progress in this area was evident during the strategic retreat in Creswick, in early November.

ASTRO 3D has a broad range of engaged students and Postdocs who are involved in key research topics and are mentored by more senior scientists. Internal communication has improved significantly, and resources are made available for training sessions and writing retreats. The IAB supports the proactive approach taken by the leadership to achieve a diverse and inclusive Centre, and a collaborative work environment. A code of conduct for the Centre is in place, and external ombudspersons have been appointed. The executive team consists entirely of women, and women have key leadership roles in many of the scientific projects. This year, five out of six continuing positions in astronomy were won by female researchers. This is an encouraging development.

The partnership continues to increase its use of ESO's observing facilities. A highlight in this area was the approval of MAGPI, a large program on galaxy evolution with MUSE on the Very Large Telescope, led by young ASTRO 3D astronomers.

ASTRO 3D's excellent progress is described in this beautifully arranged annual report covering 2019. The Director, the Chief Operating Officer, and the entire leadership team are to be lauded for establishing a world-class astrophysics Centre.

Tim de Zeeuw

IAB Chair

SCIENCE MANAGEMENT COMMITTEE

The Science Management Committee (SMC), chaired by Stuart Wyithe, met twice during 2019 to assess the scientific progress against the Centre's goals, assess cross-node and cross-project collaborations, and set Key Performance Indicators (KPIs) and milestones for the coming year. This SMC concentrates the Centre's extensive science survey management expertise and is composed of two Theme Leaders, two Thread Leaders, a Collaboration leader, and key CIs and PIs who ensure that all scientific areas of the Centre are represented on the Committee.

2019 Membership:

Chair - CI Stuart Wyithe

Theme Leader (Origin of Matter & the Periodic Table) - CI Elaine Sadler

Theme Leader (Origin of the Ionised Universe) - CI Lisa Kewley

Thread Leader (The Genesis Simulations) - CI Chris Power

Thread Leader (Data Intensive Astronomy) - CI Lister Staveley-Smith

Collaboration Leader - CI. Joss Bland-Hawthorn

Key CIs and PIs - CI Martin Asplund, AI Kim Vy Tran, CI Cathryn Trott and PI Phil Edwards

The SMC is tasked with:

Ensuring that ASTRO 3D meets its science goals;

Driving the translation of ASTRO 3D science into maximum measurable outcomes; and

Maintaining focus on training and supporting early career researchers to lead Australia's future science programs on the next-generation telescopes.

The SMC is aided in its planning and assessment by work plans prepared by project leaders for the coming 12 months and reviews of progress against the previous year's plans.

In 2019 the success of the second year of ASTRO 3D science in each project was assessed by the SMC against a series of outcome-focused milestones (Activity Plans), identified areas of collaboration with international partners and identified areas of cross-project collaboration.

Overall ASTRO 3D projects were found to have achieved >80% of their set key objectives, with those not achieve being due to a strategic change of direction. As part of the assessment process, the SMC identified areas of risk, competition and opportunities for collaboration. These outcomes fed into other areas of ASTRO 3D governance, including the risk register.

The SMC also investigated the particular areas of focus for achieving the ASTRO 3D goal of gender equity at all levels. The membership category of Associate investigator has the poorest female representation. The SMC and project leads have identified female researchers across all projects who are making active contributions to ASTRO 3D science but are not yet recognised through membership. We are now encouraging the females to become members to receive recognition for their work.

In 2019 the SMC will run a process of science review to be presented to the Advisory Board in preparation for the mid-term review. This review will focus on the progress, achievements and opportunities in each ASTRO 3D project.

Stuart Wyithe

SMC Chair

"As a community, there is a lot of opportunity to share our science with each other - links and cross-node/theme collaborations are useful." ~anonymous Science Meeting feedback

EQUITY, DIVERSITY AND INCLUSION COMMITTEE

The ASTRO 3D Equity, Diversity & Inclusion (EDI) Committee is committed to cultivating a sense of belonging for all ASTRO 3D members. We strive to engage with individuals and institutions to identify best practices and empower everyone to make positive change. Chair Kim-Vy Tran (UNSW) issued a call for members and assembled the new EDI team in February 2019. The EDI Committee includes 22 voices across the full spectrum of career stages and represents all of the ASTRO 3D collaborating universities.

The establishment of the new EDI committee was ideally timed with the circulation of the updated EDI Action Plan and the results from the Climate Survey released in March 2019. One of the highlights in the Climate Survey was that ASTRO 3D members strongly believe they are respected at work, their contributions are valued, and they have a flexible, friendly, and inclusive workplace. The Climate Survey also identified areas of improvement that include fostering a Centre-wide environment free from discrimination and unwanted behaviours.

To realise the goals of the 2019 EDI Action Plan and guided by the responses in the Climate Survey, the EDI committee is consolidating and sharing resources to provide best practice strategies and assessments. The EDI Committee have Zoom meetings on the second Wednesday of every month and agenda include links to resources spanning a broad range of topics within the EDI landscape. Several ASTRO 3D members have also attended international EDI conferences in Baltimore (October 2019) and Tokyo (November 2019) and brought back ideas and best practices with new perspectives.

The EDI team achieved several milestones in 2019. The first major milestone was developing the ASTRO 3D "Guidelines for Inclusive

The second annual ASTRO 3D East Coast Writing retreat is an example of the diverse and inclusive environment that is characteristic of all ASTRO 3D meetings. The retreat was held in Coogee, NSW in August 2019 and hosted by K. Tran (UNSW). The participants spanned the range from PhD students to senior faculty and achieved gender parity. The retreat included over 20 hours of dedicated writing time as well as professional development seminars and team building activities. ***IMAGE CREDIT:*** Kim-Vy Tran

Meetings" led by Ingrid McCarthy. The Guidelines were approved by the Executive Committee and circulated to the ASTRO 3D members in mid-2019. The "Guidelines for Inclusive Meetings" are available on the ASTRO 3D website for all to use, and the EDI Committee will revisit the Guidelines annually to incorporate feedback and improvements.

The second major milestone for the EDI Committee was providing feedback on ASTRO 3D standardised forms. The newly adopted forms are used for conference registration, post-event feedback, and the member database. The information collected in the standardised forms are critical for tracking demographics across the ASTRO 3D collaboration of more than 225 members and reporting Key Performance Indicators for the annual reports as well as the Mid-Term Review.

The third major milestone for the EDI Committee is preparing the ASTRO 3D proposal for becoming a Women in STEM Decadal Plan Champion. This initiative by the Australian Academy of Science brings together STEM organisations to help achieve gender equity within the decadal plan. Led by Pascal Elahi, the EDI Committee have developed the ASTRO 3D proposal which is based on the 2019 EDI Action Plan. The ASTRO 3D proposal is currently under review by the Executive Committee and will be submitted to the Australian Academy of Science by January 2020.

Kim Vy-Tran

EDI Committee Chair

"The Committee is committed to cultivating a sense of belonging for all ASTRO 3D members."

IMAGE CREDIT: Cristy Roberts

EQUITY DIVERSITY AND INCLUSION HIGHLIGHT

INCREASED DIVERSITY IN AUSTRALIAN ASTRONOMY

Ensuring research opportunities for indigenous, disabled and LGBTI astronomers is essential if Australian research is to succeed in the new era of "mega-telescopes", a major analysis has found.

In a paper published in the journal *Nature Astronomy*, Professor Lisa Kewley, director of the ARC Centre of Excellence in All Sky Astrophysics (ASTRO 3D), finds that encouraging astronomers from marginalised communities will increase the chances of significant research discoveries.

"Studies show that increased diversity up to the highest levels of organisations, and effective diversity management, leads to organisations outperforming their competition in innovation, productivity and profit because more ideas are produced," she says.

"These might be ideas for new experiments, products, or new ways to become more efficient or profitable."

Fresh approaches will be crucial if Australia is to fully exploit the potential of powerful new facilities soon to start operating. These include the Square Kilometre Array in Australia and South Africa, and the Giant Magellan and Extremely Large Telescopes, both in Chile.

Professor Kewley finds that recent programs to improve gender equality have met with success.

There are about 500 working astronomers in Australia, of whom 27% are women with PhD degrees, and 37% are women studying for a PhD or lesser degree. A decade-long plan for the field published in 2016 by the Australian Academy of Science recommends that women fill 33% of positions at all levels by 2025.

Although that target is still some way off, Professor Kewley describes progress as "striking".

"There has been a dramatic change in the culture of Australian astronomy," she says. "Diversity and inclusion are improving across the sector."

She cites an initiative called the Pleiades Awards, run by the Astronomical Society of Australia (ASA), as particularly important. Put into place in 2014, the scheme accords bronze, silver or gold ratings to institutions based on the participation of women at all levels. The idea is to move up through the scale.

"The broad uptake of Pleiades Awards is remarkable," she notes. "Institutions are not required to do so, and there is no financial incentive for receiving one."

Professor Kewley finds that many astronomy departments are moving beyond a focus on female participation to include active recruitment of indigenous, LGBTI, disabled, and chronically ill scientists.

"There is a statistically significant correlation between greater levels of diversity in company leadership and a greater likelihood of outperforming the relevant industry peer group on key measures such as profit," she says.

"It is reasonable to infer that greater levels of diversity in astronomy organisations will also produce a greater likelihood of outperforming competition in astronomy key performance measures in major discoveries and advances."

SENIOR EARLY CAREER RESEARCHERS COMMITTEE

The Senior Early Career Researchers (ECRs) Committee was established mid 2019 in light of the different career stage priorities among Postdocs. The Committee is composed of four members from different ASTRO 3D nodes: Bi-Qing For (ICRAR/UWA), Michael Hayden (University of Sydney), Philip Taylor (ANU), and Tiantian Yuan (Swinburne). Trevor Mendel (ANU) also served on the Committee until the end of 2019.

During the Annual Retreat in Ballarat in November, the Senior ECRs Committee has focused its attention on understanding what the most pressing needs of our community are. We held a fruitful discussion during the retreat, and have followed up on the issues raised with a questionnaire to all senior Postdocs. Separately, senior Postdocs were also polled on what computational skills and techniques they would be most interested in learning, with a view to organising a workshop run by the senior Postdocs on this topic. The community also welcomes other early career researchers to participate in our activities.

Looking ahead to 2020, the Senior ECRs Committee will hold monthly meetings, with a focus on helping the senior Postdoc community achieve their career goals identified from the questionnaire. We will organise workshops to this end, a key aspect of which will be inviting people who left astronomy at a similar stage of their career in order to better understand the benefits and difficulties of such a move. The committee will continue to ensure effective and efficient communication between the senior Postdoc community and the ASTRO 3D executive.

Phillip Taylor

On behalf of the Senior ECR Committee

Senior and Junior ECR Committee members *IMAGE CREDIT:* Ingrid McCarthy

JUNIOR EARLY CAREER RESEARCHERS COMMITTEE

The new Junior Early Career Researchers Committee within ASTRO 3D was formed because of the need to more accurately represent the interests and needs of students and Postdoctoral researchers who are still establishing the foundations of their career. The role of the committee is to provide support and develop the future leaders of research.

The Committee is composed of Katie Grasha (ANU), Henry Poetrodjojo (Sydney), Nicha Leethochawalit (Melbourne), Lilian Garratt-Smithson (UWA), Sam Vaughan (Sydney) and Nichole Barry (Melbourne).

The Junior ECR committee had its first official meeting at the 2019 ASTRO 3D retreat. At this meeting, preliminary tasks were assigned to committee members to ensure the smooth operation and future effectiveness of our efforts. We have since established a mailing list to allow us to communicate with those that identify as an ECR and organised monthly meetings to discuss their concerns.

In the future, we hope to have a significant impact in the operation and success of ASTRO 3D.

Henry Poetrodjojo

On behalf of the Junior ECR Committee

STUDENT COMMITTEE

The ASTRO 3D Student Committee is a body of student representative, at least one from each node, which works as a liaison between the Executives and the students. The role of the Student Committee is to act as a bridge between the senior staff and the students, be a body where students can bring up their problems or appreciation of ASTRO 3D, organise events for students (e.g. ASTRO 3D Student Retreat) and forward any new ideas the students might have.

The Student Committe is composed of Bella Nasirudin (Curtin), Di Wang (Sydney), Ellert van der Velden (Swinburne), Garima Chauhan (UWA), Keven Ren (Melbourne), Lucie Bakels (UWA), Piyush Sharda (ANU) and Yifei Jin (ANU).

The Student Committee was formed in late May 2019, and so far, has had regular meetings and mainly discussed what the role of the Committee is going to be, and made students aware of it as well. We had a successful meeting with the student body during the ASTRO 3D Annual Retreat, where some issues and suggestions were made, which we have made to be our goals of this year. These include: setting up a student fund for travelling to encourage more student collaborations, work on student-oriented workshops and have a successful ASTRO 3D Student Retreat 2020.

Garima Chauhan

On behalf of the Student Committee

Student Committee members *IMAGE CREDIT:* Ingrid McCarthy

SUSTAINABILITY COMMITTEE

The ASTRO 3D Sustainability Committee wants to introduce practical measures that will have a positive impact on our climate. The group first formed at the 2019 Annual Retreat, where interested astronomers shared their concern for the warming climate, and practical ideas for reducing our carbon footprint.

Astronomers have a special role in helping society to reduce greenhouse gas emissions. On average we produce more greenhouse gas emissions than other professions, in part due to supercomputers and increased flight travel. At the same time, astronomers are also known for being excellent scientific communicators. That gives us a unique opportunity to help communicate the scientific method, and new results, to the public.

In 2020 the Committee will run monthly (remote) Sustainability Seminars on a range of sustainability topics. The Committee will also introduce practical measures to reduce the climate footprint of astronomy as a profession. This includes switching to supercomputers that are only electrified by renewable energy, and introducing negative carbon conferences to ensure early career researchers continue to benefit from face-to-face meetings.

Andy Casey

On behalf of the Sustainability Committee

COLLABORATION HIGHLIGHT

2019 SCIENCE MEETING

In May 2019, CSIRO Astronomy and Space Science (CASS) hosted the 2nd ASTRO 3D Science Meeting at their Marsfield, Sydney campus. Again, we highlighted the depth and breadth of our latest discoveries, Nearly 90 researchers from PhD students to Chief Investigators were in attendance, including 3 of our International Advisory Board members,

ASTRO 3D researchers, from around the country had a chance to update their colleagues on their latest results from all the Projects and Surveys. Some highlights included:

- **Genesis Theoretical Simulations** were outlined by Postdoc Lilian Garratt-Smithson, from UWA; and this was followed by updates from students working on thermal memory of reionisation, predictions of cosmic star formation rate density, how HI populates halos, quick model analysis, quenching timescales, orbits and interactions of satellite galaxies, and mock observations.
- **GALAH & First Stars** were outlined by AI Gayandhi de Silva from Macquarie, followed by updates on the GALAH survey & Gaia Data Release 2, chemodynamics of the Milky Way, giant waves in our Galaxy, the discovery of the star with the lowest iron abundance ever measured, and unusual spectra in GALAH data.
- The **ASKAP HI Surveys** were given an overview by Postdoc Jonghwan Rhee from UWA, followed by updates on WALLABY early science results and quantifying HI profile asymmetries.
- The **SAMI/Hector surveys** were outlined by AI Nic Scott from Sydney University, followed by updates on drivers of stellar population evolution, how galaxies are transformed in groups, kinematics of galactic bulges and disks, using spin-ellipticity radial tracks, reconciling strong emission line metallicty diagnostics, recovering instrinsic gas kinematics, the current status of the Hector instrument, and a HI KOALA IFS Dwarf galaxy survey.
- The **First Galaxies** were overviewed by PhD student Stephanie Bernard from Melbourne, followed by updates on the brightest galaxies at cosmic dawn from the scatter in the galaxy luminosity versus halo mass relation.
- The **Galaxy Evolution** overview was given by Postdoc Nell Byler from ANU, followed by updates on what triggers strong AGN feedback, dust in semi-analytic models, electron column densities of the IGM, electron denisity in different environments at redshift 1.6, the MOSEL survey, improving stellar models of photoionised HII regions, MAGPHYS+photo-z, formation of the highest redshift ring and spiral structures, K3-LARS survey, and massive quiescent galaxies.
- The MWA & EoR overview was given by Postdoc Jack Line from Curtin and included updates on the impact of realistic foreground and instrument models on 21cm EoR experiments, role of feedback in reionisation and the origin of carbon-enhanced stars, first results from the long baseline EoR survey, coupling Galaxy Evolution & EoR, developing connections between Meraxes and 21cmMC, the future of the EoR power spectrum measurements, the on-going search for Lyman continuum at z=3-4, and gas in galaxies hosting massive star explosions.

IMAGE CREDIT: Cristy Roberts

"I liked the focus on science updates and the opportunities for younger researchers to present their work." ~ anonymous feedback

IMAGE CREDIT: Cristy Roberts

We also had updates on the Equity Diversity and Inclusion Committee, our Education and Outreach programs, and how our International and National Partner engagement is going.

We had a discussion panel on time management, Meet the Press media training and a LGBTI Awareness session.

The conference dinner also included awards for the best science talks and social media engagement.

SPOTLIGHT ON KATE HARBORNE

PHD STUDENT FROM THE UNIVERSITY OF WESTERN AUSTRALIA

"There are lots of projects that have come to me to ask if they can use SimSpin for their own research"

"I'm a theoretical astrophysicist – I'm working as part of the Genesis team and collaborating with SAMI as well.

I did my undergraduate degree in the UK at the University of Nottingham, and in my third year, one of my professors stood up, and he was telling us about these cosmological simulations. He was very excited and hugely emotive about this piece of work and so myself and my friend decided we wanted to do our Masters project with him. Through that work, we developed a way of looking for galaxy mergers and we were trying to design something that an observer could use as well.

I'm one of the first PhD students working between the Genesis Simulations and SAMI Survey teams. I've been acting as a bit of a "translator" because we tend to find that theorists and observers, whilst we are describing very similar properties, we use different language to describe the same thing.

I don't get to spend my time looking through a telescope on a mountain somewhere – I build models of galaxies inside computers and then observe them with my "telescope" which is called SimSpin.

I designed SimSpin because observations have this inherent and unfortunate limitation that they are a 2D projection of a 3 dimensional object. Imagine you have a pizza and you are looking down onto the surface of this pizza, and you can see all the toppings and the crust all laid out in a big circle. But if you pick the pizza up and look at it edge on, all you can see is the crust and no toppings at all. So the same is true for galaxies – except we can't pick our galaxy up; we can't move it around. We are stuck with one projection. Now, with my galaxy models that I build inside computers, I can manipulate them, I can project at any angle you want and make an observation using SimSpin. This means I can help an observer determine whether or not that edge on crust is actually just pepperoni pizza or something new and exciting.

My role in the SAMI project is helping them interpret some of their velocity measurements. They work with an Integral Field Unit (IFU) which takes a spectrum from across the surface of the galaxy, and you record velocity measurements from those spectra at gridded positions across the galaxy. Now, unfortunately, the atmosphere is a bit of a pain – it gets in the way when you are doing your observations, and this can change the way you measure velocity along those grids along the surface of the galaxy. So I have been using SimSpin, my "boring" coded telescope, to try and design a mathematical equation that allows you to reverse those effects of the atmosphere. Atmosphere makes your velocities look smaller, and I've designed a mathematical equation that brings them back to their true values.

There are lots of projects that have come to me to ask if they can use SimSpin for their own research. When I started building SimSpin, it was something that was very simplistic and now there's a lot of added elements that can be incorporated into that code to make it work for lots of different projects. So I'm actually quite excited to start incorporating some of those.

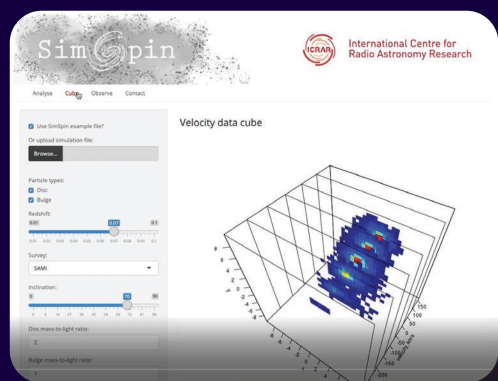


IMAGE CREDIT: Kate Harborne

OUR RESEARCH

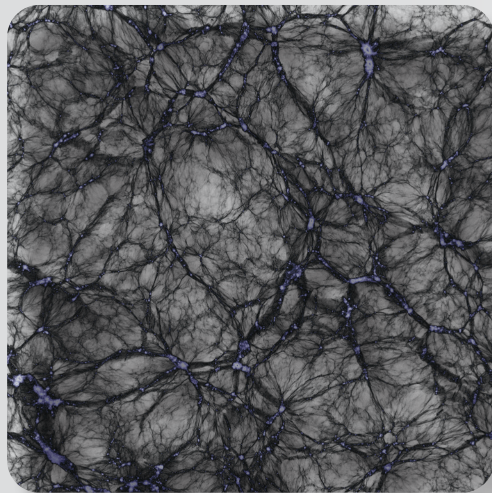
RESEARCH THREADS

1. GENESIS THEORETICAL SIMULATIONS

The ASTRO 3D Genesis Simulation program focuses on three key science areas:

- Simulating the birth of the first stars and their impact on early universe chemical enrichment, proto-galaxy formation, reionisation and the evolution of the IGM.
- Tracking galaxy growth through star formation and mergers, and the build-up of angular momentum at all galactic scales, leading to the emergence and evolution of large-scale structure and the epoch of quasars.
- Uncovering the history of the local galaxy population, including radio galaxies and AGN, by following the dynamical, stellar and chemical evolution of the galaxies across cosmic time to the present day.

These questions are being addressed through the concurrent development of a new generation of integrated N-body/hydrodynamical galaxy formation simulations coupled to sophisticated semi-analytic galaxy models, the "Genesis Suite". Genesis will be available to both the ASTRO 3D and wider astronomical community through an update to the Theoretical Astrophysical Observatory (TAO++), opening up Genesis to be easily usable to address all the key ASTRO 3D science goals.



An example of the hydrogen density field at z=15, colour coded according to projected hydrogen density. The white spheres are the first stars which ionise the surrounding hydrogen gas, making the universe transparent for the first time
IMAGE CREDIT: Simon Mutch/Meraxes

The initial phase of the Genesis Simulations thread has focused on generating a suite of large N-body simulations that will be coupled to semi-analytical models to produce synthetic galaxy populations across cosmic time.

The first set of runs consist of volumes of between 35 Mpc/h and 500 Mpc/h on a side, with approximately 10 billion particles, allowing us to reliably resolve low-mass dark matter halos of approximately 10^9 solar masses. The Genesis team is now working with our partners at the National Computational Infrastructure (NCI) and the developers of the Swift simulation code to exploit the new NCI peak facility upgrade, Gadi, and run a 210 Mpc/h volume with 6270^3 particles. This simulation will have the resolution to resolve low-mass dark matter halos that powered the growth of the ionising background during the Epoch of Reionisation (EoR). The simulations will also have a volume large enough to capture not only reionisation by ultra-violet radiation from the first stars, but also X-rays generated by the first black holes.

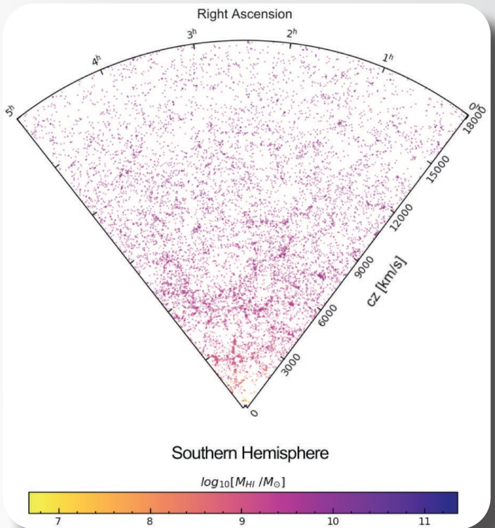
The Genesis N-body runs have been designed to cater for a range of projects, from the EoR to galaxy evolution with the HI and optical 3D surveys in the present-day Universe.

Genesis Postdoc, Simon Mutch, has developed his semi-analytical model (SAM), Meraxes, to predict self-consistently the structure of the neutral and ionised hydrogen density field produced by the sources of reionisation.

Meraxes is now being used to predict the properties of the first galaxies and their association with the distribution of HI during the EoR, and is feeding into the MWA EoR project to predict the properties of astrophysical foregrounds when modelling 21cm emission from the EoR. During 2019 applications of Meraxes have included studies by ASTRO 3D PhD students Madeline Marshal who investigated the sizes, angular momenta, and morphologies of high-redshift galaxies, and Yisheng Qiu who made predictions of infrared excess and cosmic star formation rate density from UV luminosity functions during the EoR.

Similarly, ASTRO 3D fellow, Claudia Lagos, and her PhD student, Garima Chauhan, have used her SAM, Shark, to predict the HI properties of galaxies and to create mock galaxy catalogues for the ASKAP WALLABY and DINGO surveys. An example of one of the mock catalogues is shown below, which shows a wedge of the galaxy distribution plotted as right ascension against redshift for a mock ALFALFA survey.

ASTRO 3D PhD student Dian “Pipit” Triani has combined a test set of dark matter simulations with the SAGE semi-analytic model to build a theoretical picture of how the light from galaxies, dust and AGN evolve across time. This work will focus on galaxy SEDs at early to intermediate epochs, when the majority of the stars in today’s Universe were formed. The new model, called Dusty-SAGE, is being finalised, with a current focus on dust attenuation, grain size, and extinction. This new model will feed directly into a new SED generation codebase called Mentari that can produce SEDs for many millions of Genesis simulated galaxies across cosmic time.

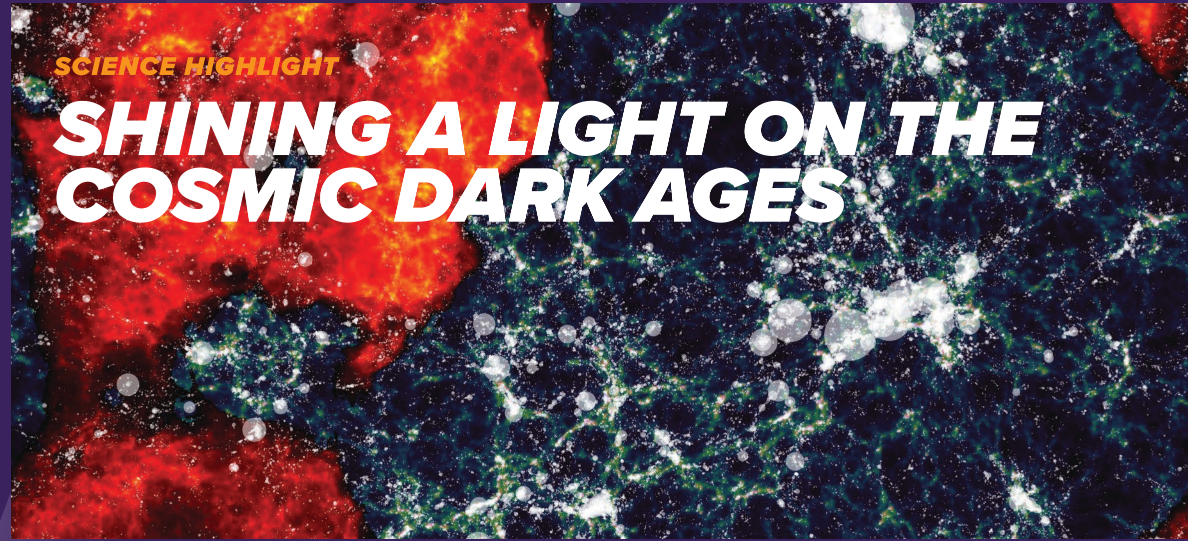


Galaxy distribution, coloured by HI mass of galaxy, in a mock ALFALFA survey. From Chauhan et al. 2019.

In parallel to the N-body programme, the Genesis team has exploited access to the EAGLE and Illustris TNG simulations to study neutral atomic and molecular hydrogen in and around galaxies. These datasets have the resolution to capture the multiphase medium on galaxy scales, whilst also having the statistics to allow for meaningful comparison with observations. Highlights of this work include the study of the covering fraction of neutral hydrogen in galaxies and groups, supporting the work of the FLASH survey, and investigation of the environmental dependence of neutral atomic and molecular hydrogen in galaxies.

Supplementing this work using cosmological volumes are new simulations of individual galaxies, both non-cosmological and cosmological zooms. The non-cosmological runs have been used to understand how different implementations of galaxy formation prescriptions influence galaxy properties, while the cosmological zooms utilise these insights and target individual systems, ranging in mass from dwarf galaxies to galaxy clusters.

These zoom simulations are particularly useful for studying feedback, particularly chemical enrichment of the circumgalactic medium and the potential variation in the escape fraction of ionising photons, both of which have implications for measurements of quasar absorption line systems and the build up of the ionising background during cosmological reionisation.



SCIENCE HIGHLIGHT

SHINING A LIGHT ON THE COSMIC DARK AGES

In this image of the Epoch of Reionisation, neutral hydrogen, in red, is gradually ionised by the first stars, shown in white. The image was made by the University of Melbourne’s Dark-ages Reionisation And Galaxy Observables from Numerical Simulations (DRAGONS) program. ***IMAGE CREDIT:*** Paul Geil and Simon Mutch

ASTRO 3D astronomers are closing in on a signal that has been travelling across the Universe for 12 billion years, bringing them nearer to understanding the life and death of the very earliest stars.

In a paper published in the Astrophysical Journal, a team led by Dr Nichole Barry from Australia’s University of Melbourne reports a 10-fold improvement on data gathered by the Murchison Widefield Array (MWA) – a collection of 4096 dipole antennas set in the remote hinterland of Western Australia.

The MWA, which started operating in 2013, was built specifically to detect electromagnetic radiation emitted by neutral hydrogen – a gas that comprised most of the infant Universe in the period when the soup of disconnected protons and neutrons spawned by the Big Bang started to cool down.

Eventually, these hydrogen atoms began to clump together to form stars – the very first ones to exist – initiating a major phase in the evolution of the Universe, known as the Epoch of Reionisation, or EoR.

The neutral hydrogen that dominated space and time before and in the early period of the EoR radiated at a wavelength of approximately 21 centimetres. Stretched now to somewhere above two metres because of the expansion of the Universe, the signal persists – and detecting it remains the theoretical best way to probe conditions in the early days of the Cosmos.

However, doing so is fiendishly difficult.

“The signal that we’re looking for is more than 12 billion years old,” explains ASTRO 3D member and co-author Associate Professor Cathryn Trott, from the International Centre for Radio Astronomy Research at Curtin University in Western Australia.

“It is exceptionally weak and there are a lot of other galaxies in between it and us. They get in the way and make it very difficult to extract the information we’re after.”

Using 21 hours of raw data Dr Barry, co-lead author Mike Wilensky, from the University of Washington in the US, and colleagues explored new techniques to refine analysis and exclude consistent sources of signal contamination, including ultra-faint interference generated by radio broadcasts on Earth.

The result was a level of precision that significantly reduced the range in which the EoR may have begun, pulling in constraints by almost an order of magnitude.

2. DATA INTENSIVE ASTRONOMY (DIA) PROGRAM

The Data Intensive Astronomy Program (DIAP) facilitates better access to tools, technology, infrastructure and training for ASTRO 3D researchers working with large datasets and in High-Performance Computing (HPC) environments. It does this by working with national infrastructure providers, and by the sharing of expertise between ASTRO 3D researchers. As much of the ASTRO 3D science involves world-leading surveys and large data sets, our ability to process our data in a timely and efficient manner is critical to our success.

The DIA Program is also managing two key projects:

- **Data Flow and Process Management**

  This project aims to analyse data flow requirements of ASTRO 3D surveys and provide support for the implementation of optimised data transfer and storage paths. It will develop techniques to assist the implementation of pipelines for ASTRO 3D surveys.

- **Virtual Observatory (VO) and Theoretical Astrophysical Observatory (TAO)**

  The VO project aims to promote interoperability between the ASTRO 3D data sets that exist on ASVO nodes, especially those of most interest to ASTRO 3D - ADC, CASDA, MWA and TAO. The latter (TAO: Theoretical Astrophysical Observatory) is an online eResearch laboratory that allows ASTRO 3D researchers to construct their own mock light cones from a range of different simulation and galaxy formation model data, including Genesis, filter the output through virtual telescopes and download the results for their own scientific use.

Highlights during 2019 include the implementation of a fast calibration solver by Vitaliy Ogarko for the ASKAPsoft data reduction pipeline used by the ASKAP HI surveys project. Alongside optimisation of the pipeline by our CSIRO partners, the pipeline is now only a factor of about two slower than real time. Planned Pawsey upgrades will mean that all ASTRO 3D's HI surveys will be able to proceed as planned. Vitaliy is working on further modifications by adding frequency constraints to the solver, which appear to reduce calibration errors by a factor of 5.

Planning work relating to the cross-matching and querying of heterogeneous ASTRO 3D data sets held on ASVO nodes is proceeding. With funding having been provided by AAL, a pilot project involving the design of visualisation tools and the creation of a common authorisation and authentication layer between ADC and CASDA has begun.

The TAO team has mostly finished the ingestion pipelines of the Genesis simulation data products and galaxy formation models. As the Genesis team completes each simulation, and the modelling groups produce their output, we are ready to make this data available within the TAO infrastructure, along with all the enhancement tools available there (light cone generation, image module, SED generation).

ASTRO 3D has also provided input to AAL and NCA efforts to increase the availability of HPC to astronomy researchers, and to provide a national focus to the delivery and interoperability of data centres, and their governance and technical coordination.

In 2020, the DIA program team will work on implementing newly developed algorithms for the further reduction of ASKAP bandpass calibration errors and, supported by ADACS and AusSRC, translation of the WALLABY and DINGO post-processing pipelines into an HPC environment. Supported by the Canadian CIRADA grant (let by PI Gaensler), the team will also help develop a kinematic pipeline for HI data. TAO data will also become available to the entire astronomy community.

We are also intending to further develop data visualisation tools for use with radio, optical and simulated datasets for deployment on CASDA, ADC and TAO. These tools will expand the ease with which any data hosted can be explored by ASTRO 3D members, and the wider community.

SPOTLIGHT ON PROF LISTER STAVELEY-SMITH

CHIEF INVESTIGATOR FROM THE UNIVERSITY OF WESTERN AUSTRALIA

"As of this year (2019), it's become really exciting because we have the full ASKAP telescope - we have all beams, all antennas"

I'm working on ASKAP HI surveys – ASKAP is the Australian SKA Pathfinder, which is a brand new radio telescope based here in Western Australia – and we're using that telescope to conduct a very large survey for hydrogen gas in galaxies.

Hydrogen is the most abundant element in the Universe – lots of it was created after the initial "Big Bang" and it's basically the building stuff of stars. All the stars we see in the sky come from this hydrogen gas after it has gravitationally collapsed and fusion is initiated. So understanding where this gas comes from, how it gets into galaxies, how it gets into star formation, how it's expelled from galaxies by the activity of stars and supernovae is what we hope to study with this project.

My role is mainly with the WALLABY project – not the animal (actually an acronym Widefield ASKAP L-Band Legacy Allsky Blind SurveY) – it uses the amazing widefield capability of this ASKAP telescope to conduct a survey for galaxies all over the sky. So it's not a deep survey; it's not a survey that's looking in one place, but looking at the whole sky. So in that sense, it will give a very unique view of the sky in gas – one that we haven't been able to have before in such a sensitivity and such a resolution.

We started collecting data in a serious way about 2 years ago. Processing that data took us a long time. Initially we only had 12 of ASKAP's full complement of 36 antennas. So we had a slow start, a slow ramp up. But even in that ramp up, we've been able to do some significant studies of individual groups of galaxies. We have about 6 refereed papers published through that process, through these discoveries.

But now, as of this year (2019), it's become really exciting, because we have the full ASKAP telescope – we have all beams, all antennas, so it's really firing on all cylinders. And we've just started the next phase which we call "pilot surveys". So it's the full ASKAP capability – just testing that everything works; from the top of the telescope to the data reduction pipeline, which is running on the supercomputers in Perth. So far everything's going quite well, so we're really excited about that.

We're already finding some galaxies that don't seem to have any stars in them. Perhaps they shouldn't be called "galaxies" without stars. But we're seeing clumps of gas, just sitting there out in inter-galactic space, which shouldn't really exist. There's a lot of radiation out in intergalactic space which should basically "fry" neutral gas and strip the electrons off the atoms and just create ionised gas, but we're seeing these clumps of gas occasionally. Maybe they are "dark galaxies" – maybe a new sort of galaxy, maybe what we call a piece of "tidal debris" – a piece of galaxy that's been torn apart by a collision. In some cases, it's not obvious where the colliding galaxies are, if that's the cause.

The ASKAP HI project produces massive amounts of data and having to deal with that data is similar to problems that other projects in ASTRO 3D have with large data sets. So literally we collect about 100 terabytes of data a night and we will eventually be collecting many hundreds of nights of data. So rapidly, we become overwhelmed with data with this project.

I really enjoy working with students and young postdocs – they are very energetic and it's very satisfying seeing them start with very little knowledge about the project, about the science and building that up over a couple of years, and finally seeing them become masters in a very important area of science. If they don't get other high-profile research jobs, they go into industry and take up usually positions in data science, which I think it also very important contribution to the community these days.

RESEARCH PROJECTS AND SURVEYS

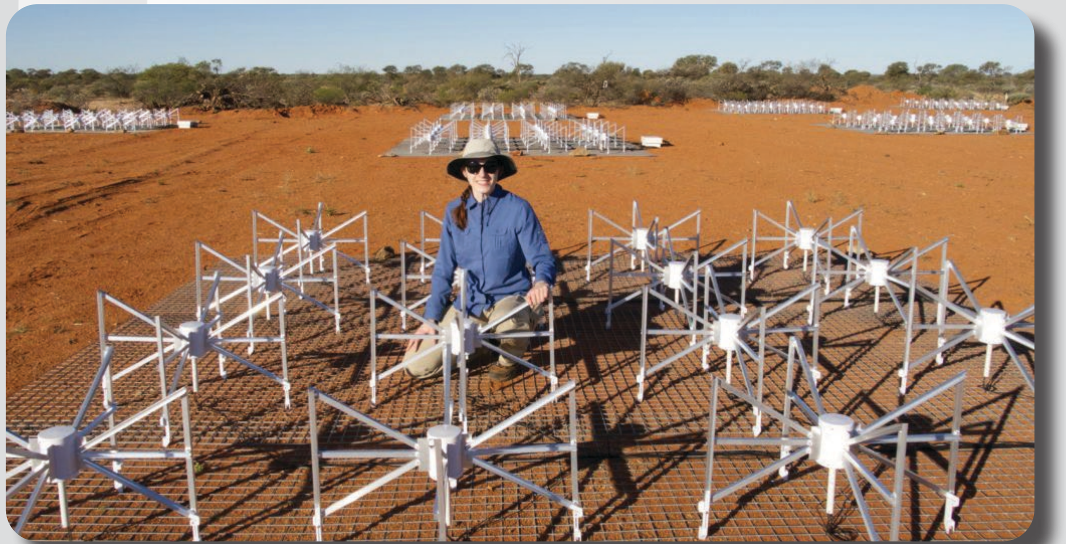
1. THE MWA EOR SURVEY

The Murchison Widefield Array (MWA) is a low-frequency radio telescope in the Western Australian desert. Operating between 80 and 300 MHz, it explores many scientific questions. One of the primary objectives of and MWA and future Square Kilometre Array is the search for signals from neutral hydrogen gas that resides between galaxies in the first billion years of the Universe. During this crucial evolutionary period, the first stars and galaxies in our Universe were born in the Cosmic Dawn, followed by a transformation of the Universe from neutral to ionised in the Epoch of Reionisation (EoR). Understanding these evolutionary periods complete our understanding of the full history of the Universe. The hydrogen signal encodes key information about the spatial location and evolution of these first astrophysical objects, but its detection remains elusive due to the weakness of the signal compared with the foreground radio sky, and the complexity of the instrumental measurement.

The ASTRO 3D EoR program provides new measurements of this period of the Universe. During 2019, the team published two major papers placing strong limits on the size of the signal, including the most stringent upper limit ever published to constrain the end of the reionisation period. This work was led by Dr Nichole Barry, an ASTRO 3D Postdoctoral researcher at the Melbourne node. Then, utilising a database of data quality metrics developed in 2018, the team were able to choose the cleanest data to create a full census of four years of the MWA's observations across different observing fields, periods of time in the early Universe. This work is being led from the Curtin node.

These science outputs were underpinned by key theoretical and observational studies, which served to understand the relationship between the model used for the telescope and the data quality, an improved understanding of the sky in front of the early Universe signal, better correction of the data caused by ionospheric distortion, and increased data processing efficiency. The combined theoretical, software and observational efforts are a hallmark of the ASTRO 3D program, and provide the structure required to tackle this difficult problem.

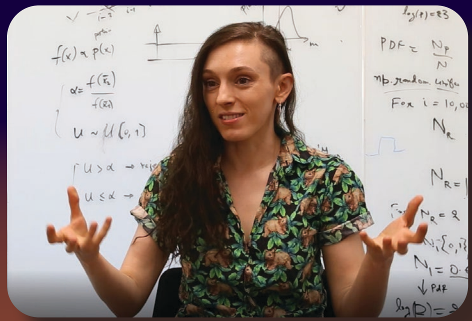
Finally, ASTRO 3D creates key connections between the EoR theorists at the University of Melbourne, observers at Melbourne and Curtin University, and the Genesis Simulation Thread members at Melbourne, the University of Western Australia and Swinburne University. With joint student projects, we use the sophisticated Genesis simulations to guide our observational program, simulating targeted experiments that allow more science to be achieved.



Dr Nichole Barry at the Murchison Widefield Array (MWA) Telescope ***IMAGE CREDIT:*** Ruby Byrne

SPOTLIGHT ON DR NICHOLE BARRY

POST-DOCTORAL RESEARCHER FROM THE UNIVERSITY OF MELBOURNE



"It's really difficult to measure something that's 13 billion light years away and that's extremely faint."

I try to make measurements of the Epoch of Reionisation. So instead of looking at this time in the Universe theoretically, trying to understand "what" it is, I'm trying to actually "see" it.

The Epoch of Reionisation is a time period in the beginning of the Universe, when the first stars and galaxies started to form. It's the time period where we went from darkness, near-nothingness, just hydrogen floating in space, to a modern universe, full of stars and galaxies and gas. So it's a very interesting phase transition for us to study.

We don't know much about it because it's a very difficult time period to study. There's not a lot of sources of light when the first stars and galaxies are forming; they're just coming online. I use the Murchison Widefield Array (MWA) to try to make those observations and we work really hard to make those precision measurements. Instead of trying to look for the first stars and galaxies, we look for the hydrogen that's in between them to try to make a negative-image of the Universe as it's becoming the modern Universe.

The hydrogen gas that we're looking for emits a very specific wavelength (of electromagnetic energy) and as the Universe expands, so does that wavelength. So by the time it reaches us, it's in the radio – so it's about 2 metres in wavelength – right in the FM radio and TV bands, all that fun stuff! So we try to use radio instruments that are, for lack of a better term, in the middle of nowhere – as far away from people as possible, but still accessible. So that we don't pick up FM radio – we don't want to measure that, but still be able to get to the site to do engineering work. So we use radio telescopes, like the Murchison Widefield Array, which is in Western Australia.

The gas from the early Universe is 13 billion light years away – that's what we're trying to measure. So it's really difficult to measure something that's 13 billion light years away and that's extremely faint, and so we actually haven't measured it...yet. It's a big data challenge in that you need a whole lot of data in order to see something that faint. And it's also a precision challenge – we have to measure it to a precision that really hasn't been attempted before in astronomy. So it's been a long time that we've been trying to measure this, because we're developing new things as we go along. We're learning how do we make these measurements, instead of actually doing the measurement right away.

It is exciting – everyday has a new bug, a new problem. It's exciting because we're going for this one measurement, and it's taken decades. So once we finally do take the measurement, it's going to be a big deal! So it is a very exciting field to be in.

We're getting closer – we've made huge strides this past year. Especially within Australia – Australia is pushing the forefront of the Epoch of Reionisation measurements. I just had a paper that got released and Cath Trott just had a paper that got released, that are the closest measurements to the Epoch of Reionisation we've ever gotten, so it's exciting.

The Epoch of Reionisation observations overlaps very well with theory, because we kind of have an idea of what we're looking for, but at the same time, we don't! So we need a lot of input from theorists to determine what frequency ranges we look at and how deep we look. So there's a lot of overlap with the Genesis team, the First Stars and First Galaxies teams, to try to understand what it is we are looking for.

I really enjoy being part of ASTRO 3D – I've never really been part of something like this before. I really love how it brings together astronomers from a variety of different fields. I find myself collaborating with astronomers, scientifically, that I normally wouldn't be able to. It's really opened up my horizons, for who I actually collaborate with.

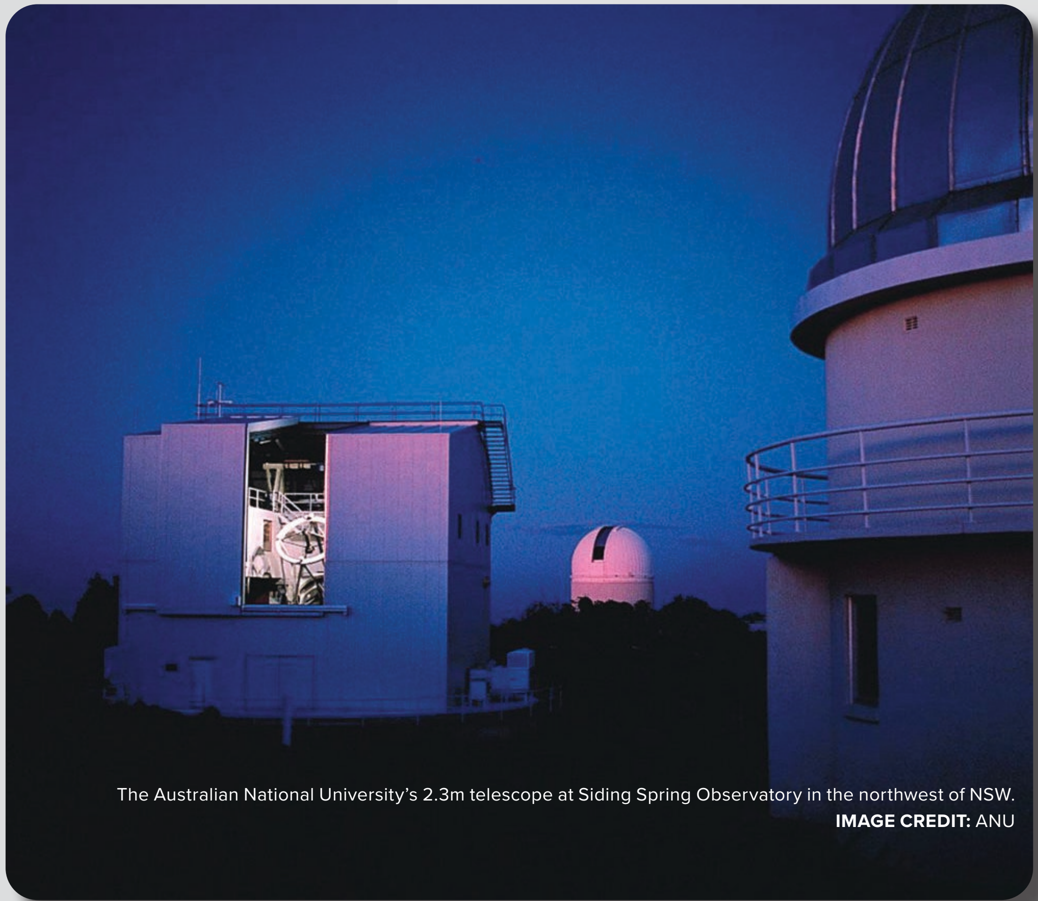
2. THE FIRST STARS PROJECT

The Universe was created in the Big Bang some 13.8 billion years ago. The very first stars formed within a few hundred million years, which ushered in the epoch of re-ionisation and thus shaped how subsequent stars and galaxies could form. The first stars were also responsible for producing the first elements heavier than hydrogen, helium and lithium, which also had a profound impact on the cosmic evolution. One of the hottest topics in modern cosmology and astrophysics is the nature of these first stars and how they transformed the Universe. But have any of these stars survived to the present-day? If so, these stars would contain crucial clues to our own cosmic origins.

ASTRO 3D's First Stars team is searching for the most ancient stars in the Universe by scouring the Milky Way and its surroundings. Even if a true first star has not yet been found, by studying the oldest surviving stars the conditions during the formation of the first galaxies, how the cosmic dark ages ended, and even the Big Bang itself can be probed. Studying relic stars in our Galactic neighbourhood thus complements observations of the most distant galaxies in our quest to understand the early Universe.

To find these exceptionally rare relic stars, the First Stars team make use of ANU's SkyMapper telescope at Siding Spring Observatory. The SkyMapper telescope is surveying the whole southern sky with multiple colour filters. The very oldest stars in the Milky Way have extremely low content of elements heavier than helium – somewhat confusingly referred to by astronomers as "metals". This metal-deficiency results in characteristic colours in the SkyMapper data, which can therefore be used to identify candidates for the oldest stars.

From the many millions of stars in the SkyMapper catalogue, the First Stars team winnow it down to several thousand interesting objects, which are further studied spectroscopically with the WiFES instrument on ANU's 2.3m telescope in order to confirm their metal-poor nature. Finally, the most interesting objects are then observed with the largest optical telescopes in the world such as European Southern Observatory's Very Large Telescope (VLT) high in the Chilean Andes to determine their detailed chemical composition based on high-resolution spectroscopy.


The Australian National University's 2.3m telescope at Siding Spring Observatory in the northwest of NSW.
IMAGE CREDIT: ANU

In 2019, the ASTRO 3D team published a comprehensive description of its observational program with the SkyMapper telescope. Of the more than 2600 stars studied spectroscopically, almost a fifth has an iron content a mere 1/1000th of the solar abundance, making it the most efficient survey in the world. Interestingly, the team has found that the most metal-poor stars are even more rare than previously thought, which suggests that forming low-mass stars which have survived until today required a minimum metal content.

ASTRO 3D Postdoc Thomas Nordlander (ANU) analysed the remarkable star SMSS1605-1443, which he discovered last year. This star has the lowest ever measured iron and magnesium content of any star, implying it contains the nuclear ashes of just a single supernova. The detailed elemental abundance pattern suggests that the supernova progenitor was relatively low mass, <20Msun, which exploded with surprisingly low energy with much of the gas falling back into the newly formed black hole. He has secured additional observations with the VLT to obtain an even higher-quality spectrum to determine the abundances of carbon, nitrogen and oxygen since this star likely contain crucial clues to understand the nature of the first stars.

Visiting PhD student Giacomo Cordoni (ANU and Padova University, Italy) together with the ASTRO 3D team has investigated the motions of the most metal-poor stars in the Milky Way. While it had been expected that these stars all had wide orbits predominantly in the outskirts of the Milky Way, in the so-called Milky Way halo, to his surprise he found that a significant fraction (~20%) of them are confined within the disk of the Milky Way. The origin of these stars is not yet understood but they could be the remains of an ancient and metal-poor dwarf galaxy having been swallowed by the much larger Milky Way galaxy.

One of the most enigmatic and enduring challenges in modern cosmology is why the oldest stars contain much less lithium than predicted from Big Bang nucleosynthesis. Undergraduate student Ella Wang (ANU) has studied this cosmological lithium problem using both the most sophisticated supercomputer calculations of how these stars emit their light and with some of the best observations ever taken of a star. This has enabled her to determine the abundances of both lithium isotopes in two very metal-poor stars, an extraordinarily challenging undertaking. Her results suggest that the stars have destroyed most of the lithium they were born with and therefore there is no need to significantly modify the Big Bang theory to explain the shortage of lithium.


Artist's view of star formation in the early Universe ***IMAGE CREDIT:*** Adolf Schaller

SPOTLIGHT ON ELLA WANG

HONOURS STUDENT FROM THE AUSTRALIAN NATIONAL UNIVERSITY

"I really enjoy coding in my project…I get to develop my own algorithms as well, which I've found fascinating."

I had two projects for my Honours thesis – one of them was looking at all the stars in the sky and figuring out how much lithium abundance was in them. This is hard, because we need to use simulations to do this, and each simulation is very costly. If we want to simulate each star in the sky, it's basically not going to happen. So my job was taking existing simulations and turning them into some of the stars that we can see.

My second project was looking at the lithium-6 and lithium-7 abundances in one star (we only had time to analyse one star). For these stars, the idea is that that should be no lithium-6 in them, but we see some. Which is bad, because this doesn't match up with theory. So my job was to look at this and figure out if these detections are real, because we now have new models and new observations.

Lithium is the 3rd element, on the periodic table and the first "metal" (or what astronomers call metal!) and it's the only element that's produced in Big Bang nucleosynthesis, cosmic rays and stars. This makes it very unique in that we don't see any other elements like this, which means if we can understand lithium, we can understand everything else in the Universe – we can understand stars, galaxies and the formation of the Universe.

It's hard with lithium – it's a very fragile element, which means it gets destroyed inside the cores of stars that are anywhere above 2.5 million Kelvin. So this means figuring out how much lithium is produced in stars, destroyed in stars is very hard, because they depend very heavily on simulating initial conditions. Additionally, observing lithium is very hard, because it's very faint, so we need very high resolution observations. To figure observations of lithium, you need to have a simulation and these simulations are very costly, needing the use of supercomputers – we actually use GADI, the new supercomputer, that's on the main ANU campus.

To get the high resolution spectra, usually the Very Large Telescope (VLT) is used – it's one of the biggest telescope currently in operation. We are actually using a new instrument – ESPRESSO (Echelle Spectrograph for Rocky Exoplanet- and Stabel Spectroscopic Observations) – it only came online about 2 years ago, and its testing isn't fully complete I think. They've had updates to the pipeline and the hardware very recently. Unfortunately, our observations were taken before the updates to the hardware, so maybe the issues are fixed now. In terms of the previous observations,

The observations were pushing the limits of what's possible, with an estimated S/N approaching 2000. Unfortunately, it turns out the science data of this quality is many times better than the calibration data. This shortcoming of the calibration data causes small "bumps" (due to fringing) to become visible in our extremely high-quality data. This resulted in me measuring an amount of lithium-6 that is less than zero, which doesn't make sense.

I really enjoy coding in my project. I've always had an interest in writing code and telling a computer to do things and seeing the results come out. I get to develop my own algorithms as well, which I've found fascinating. Some people find my algorithms a bit "out of left field" because they're not something you usually see. But they produce the results that we want, so my supervisor supports me on it, so I've found that to be great.

I got started in astronomy when I was really young, like seven, eight years old – just seeing the pictures in books and on the news and thinking "I want to know about that – what is this?" I also enjoyed physics in high school, so I decided to pursue science, at least, in university. And somehow, I ended up in astronomy – I figured astronomy was the most interesting field I wanted to be in, so I ended up staying.

SCIENCE HIGHLIGHT

ANAEMIC STAR CARRIES THE MARK OF ITS ANCIENT ANCESTOR

A newly discovered ancient star containing a record-low amount of iron carries evidence of a class of even older stars, long hypothesised but assumed to have vanished.

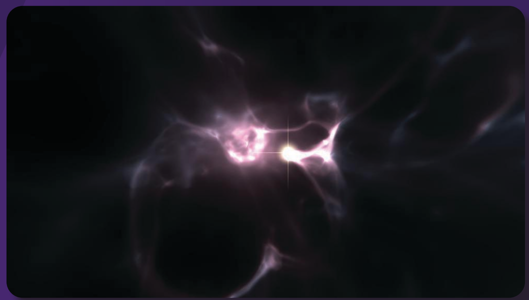
In a paper published in the journal Monthly Notices of the Royal Astronomical Society: Letters, researchers led by Dr Thomas Nordlander of the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) confirm the existence of an ultra-metal-poor red giant star, located in the halo of the Milky Way, on the other side of the Galaxy about 35,000 light-years from Earth.

Dr Nordlander, from the Australian National University (ANU) node of ASTRO 3D, together with colleagues from Australia, the US and Europe, located the star using the university's dedicated SkyMapper Telescope at the Siding Spring Observatory in NSW.

Spectroscopic analysis indicated that the star had an iron content of just one part per 50 billion.

"That's like one drop of water in an Olympic swimming pool," explains Dr Nordlander.

"This incredibly anaemic star, which likely formed just a few hundred million years after the Big Bang, has iron levels 1.5 million times lower than that of the Sun."



A visualisation of the formation of the first stars.
IMAGE CREDIT: Wise, Abel, Kaehler (KIPAC/SLAC)

Its diminutive iron content is enough to place the star – formally dubbed SMSS J160540.18–144323.1 – into the record books, but it is what that low level implies about its origin that has the astronomers really excited.

The very first stars in the Universe are thought to have consisted of only hydrogen and helium, along with traces of lithium. These elements were created in the immediate aftermath of the Big Bang, while all heavier elements have emerged from the heat and pressure of cataclysmic supernovae – titanic explosions of stars. Stars like the Sun that are rich in heavy elements, therefore, contain material from many generations of stars exploding as supernovae.

As none of the first stars have yet been found, their properties remain hypothetical. They were long expected to have been incredibly massive, perhaps hundreds of times more massive than the Sun, and to have exploded in incredibly energetic supernovae known as hypernovae.

Dr Nordlander and colleagues suggest that the star was formed after one of the first stars exploded. That exploding star is found to have been rather unimpressive, just ten times more massive than the Sun, and to have exploded only feebly (by astronomical scales) so that most of the heavy elements created in the supernova fell back into the remnant neutron star left behind.

Only a small amount of newly forged iron escaped the remnant's gravitational pull and went on, in concert with far larger amounts of lighter elements, to form a new star – one of the very first second generation stars, that has now been discovered.

3. THE FIRST GALAXIES PROJECT

The First Galaxies project is focussed on discovering galaxies during the first billion years after the Big Bang, characterising their properties, and investigating how these objects evolve into today's galaxies. These goals are achieved through a combination of observations by some of the world's most powerful telescopes (space and ground-based) with theoretical and numerical modelling. We are also working on the design on Australia's first space telescope, tiny but powerful, which will contribute to identify some of the very first stellar nurseries in the Universe.

The inflow of Hubble Space Telescope data continued throughout the year, with about one week's worth of data collected (about 150 orbits) as part of the Wide Field Camera 3 Brightest of Reionising Galaxies (BoRG) survey, led by ASTRO 3D CI Michele Trenti. They searched for galaxies within the first 700 million years after the Big Bang. While our team completes the hard search for tiny red dots that are galaxies more than 13 billion light years away, we focussed on follow-up observations from the ground with the Keck MOSFIRE and VLT KMOS spectrographs of galaxies previously discovered by the Hubble Space Telescope (HST). In particular, ASTRO 3D PhD student Alex Cameron (UoM) was awarded two nights of observing time with KMOS to characterise the build-up of chemical elements in distant dwarf galaxies whose light is magnified by foreground galaxy clusters that act as gravitational lenses or "cosmic telescopes".

On the modeling front, PhD student Keven Ren (UoM) investigated how stochasticity in the star formation processes impacts the luminosity function of the first galaxies. This was just one among the 12 peer-reviewed articles published by the team in the last 12 months on a wide range of topics related to formation and evolution of stars and galaxies across cosmic time.

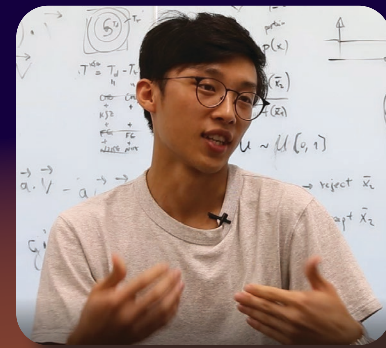
In 2019 we also welcomed a new member of the team based at the Melbourne node, Dr. Nicha Leethochawalit. Dr. Leethochawalit received her PhD from Caltech this July, and she is an expert on spectroscopic observations of galaxies across cosmic time to characterise their chemical composition. Dr. Leethochawalit's strengthens the team's research focus on data from ground based telescopes to complement space-based observatories, and her expertise will also be ideal to explore additional collaborative opportunities with the Galaxy Evolution team.

The team is also busy developing the mission concept for Australia's own space telescope, the SkyHopper CubeSat. This is an international project led by CI Trenti to design, build and operate a small but powerful infrared space telescope that fits into a 22kg nano-satellite (a "shoe-box" space telescope). SkyHopper is being designed to rapidly observe the infrared counterparts of Gamma Ray Burst (GRB) explosions, to find those originating from galaxies at more than 13 billion light years from us. While waiting for GRBs, SkyHopper will carry out surveys to measure the Cosmic Infrared Background radiation, and to search for Earth-sized potentially habitable planets around nearby low-mass stars. In 2019, A/Prof. Trenti received $800,000 in seed funding from the University of Melbourne for the spacecraft design, and SkyHopper could be launched in 2023 pending award of funding for construction.

Artist view of 22kg SkyHopper Space Telescope, a concept for an Australian nano-satellite mission to launch and operate a 15cm aperture telescope optimised for infrared imaging from 0.8 to 1.7 microns that has the potential to contribute to the First Galaxies and Galaxy Evolution projects.
IMAGE CREDIT: S. Barraclough, M. Trenti (UoM) and the SkyHopper team

SPOTLIGHT ON KEVEN REN

PHD STUDENT FROM THE UNIVERSITY OF MELBOURNE



"These super-high redshift objects are very far away... so we rely on simulations to have a baseline to compare my models to."

I model the brightest and rarest galaxies at the super-high redshift universe - around the first billion years after the Big Bang.

I'm interested in the distribution of these objects. So I answer questions such as "how many of these bright, or even brighter, objects do we expect to see?" and "what are the kind of environments they live in."

I work more on the theory side. These super-high-redshift objects are very far away, so therefore, they are really faint. So we have to rely on simulations to have a baseline that I can compare my models to. I do a lot of my work using the dark matter catalogs that are part of the Genesis project.

I'm trying to calculate the number densities of these very bright early galaxies we see. So I calculate how many of them we expect to see in a certain patch of sky of a certain size and then I also look at the kind of environments they live in – so what kind of neighbours they might have, and how bright are these neighbours and how many of these neighbours there are.

The brightness is important because when it comes to extremely bright objects, we have an expectation that they live inside very large dark matter halos, that they have a lot of gas to fuel their very intense luminosity output. Therefore, we have this expectation that these very bright objects live in certain types of environments – extremely overdense environments, with plenty of bright neighbours surrounding them. My work was to basically test that assumption and model what we would expect to see.

The interesting thing is when it comes to these bright objects, we expect them to be in these overdense regions. However, they tend to be more like the suburbs, where we have a variety of population densities. So what we found is different from what we thought we'd find.

I thank the Hubble Space Telescope people for initiating my project – they've done the Large Candle Survey, which served as a starting point for my PhD. Most of my work was done on redshifts 5 and 6 – so the first billion years after the Big Bang. So to follow this work up, we will have to rely on the future pointing of the James Webb Telescope (I hope!). Perhaps in the future with the JWST we'll be able to takea look at one of these extremely bright galaxies at high redshifts and see the environment they're in and verify the work we've been doing. Maybe rule out some parameters or assumptions we've been making.

I overlap with the Genesis project. I really can exploit the resources that they have with my simulations – I can have a baseline to compare my models with. But it could also extend to galaxy evolution to an extent. The high redshift universe is much easier to model and these super-luminious objects could be seeds for protoclusters of galaxies, and there could be a link that the Galaxy Evolution Project could fill in when it comes to what the progenitors of these massive clusters could be.

The biggest challenge I've faced is bugs - bugs in my code for sure! Most of my work uses a lot of coding – I do a lot of theoretical modelling. So, I start with some fundamental assumptions and then I try to predict some kind of output. So for example, number densities of galaxies starting from a few fundamental assumptions.

Perhaps in the future with the JWST we'll be able to take a look at one of these extremely bright galaxies at high redshifts and see the environment they're in and verify the work we've been doing. Maybe rule out some parameters or assumptions we've been making. If we assume these brightest galaxies are in the most overdense regions, then naturally there may be seeds or large clusters at much later times – this might give us an understanding of seeds of protoclusters.

4. GALAXY EVOLUTION PROJECT

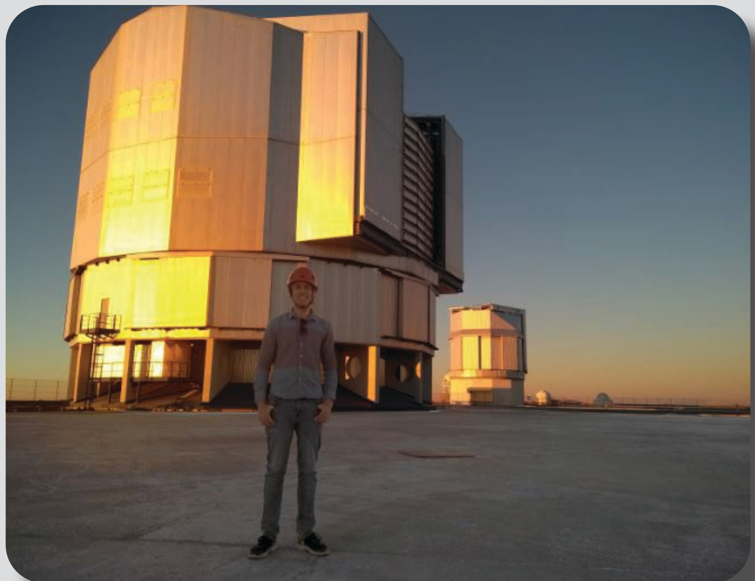
The Galaxy Evolution project increased momentum in 2019 by linking science goals across members and strengthening existing collaborations within the team. The proposal busy week in February 2019 hosted by Swinburne was a particularly effective catalyst that culminated in an impressive number of successful telescope proposals that were awarded time on highly competitive facilities including the European Southern Observatory's Very Large Telescope in Chile and Keck Observatory in Hawai'i. As a testament to the remarkable research abilities within the team, the successful observing proposals were led by the full spectrum of members from PhD students to Chief Investigators.

From discussions during the monthly Zoom meetings, combined with the science meeting in May 2019 and the retreat in November 2019, the Galaxy Evolution team has identified a unique opportunity to establish a transformative study from ASTRO 3D.

The exciting new MAGPI survey is a notable highlight for the ASTRO 3D Galaxy Evolution team, harnessing the many diverse strengths within the team. This large Australian-led proposal was awarded an astonishing 340 hours of observing time with the cutting-edge MUSE instrument on the VLT. The five co-Chief Investigators for the MAGPI survey are all ASTRO 3D Fellows at multiple nodes who utilised the collaborative nature of the Galaxy Evolution team to its fullest. The MAGPI survey is an outstanding example of the kind of revolutionary science that the Galaxy Evolution project will deliver in the next 2-4 years.

The Galaxy Evolution project continues to make excellent progress on tracking the mass assembly, chemical evolution, and ionising radiation of galaxies across cosmic time. Having further clarified the main science themes in October 2018, project members are now better able to integrate across virtually all of the ASTRO 3D projects, i.e. with SAMI, GENESIS, GALAH, ASKAP, and First Galaxies.

By leveraging Australia's access to the VLT, the ambitious new survey identifies cosmic magnifying glasses at a key epoch in galaxy formation. The Galaxy Evolution team will confirm and study gravitational lenses that boost the brightnesses of dwarf galaxies when the Universe was only 2 to 6 billion years old ($1<z<5$). By delivering a benchmark study of dwarf galaxies during this pivotal epoch, we obtain new insight into the chemical build-up, kinematic assembly, and ionising history of systems that are the building blocks of galaxies like our own Milky Way. In parallel, we are developing a complementary study that bridges the Galaxy Evolution team with the GALAH project to link high redshift (z~3-4) galaxies with the Milky Way.



Dr Rob Bassett from Swinburne University of Technology during his observing run at the Very Large Telescope (VLT) in Chile, operated by the European Southern Observatory (ESO) in October 2019.

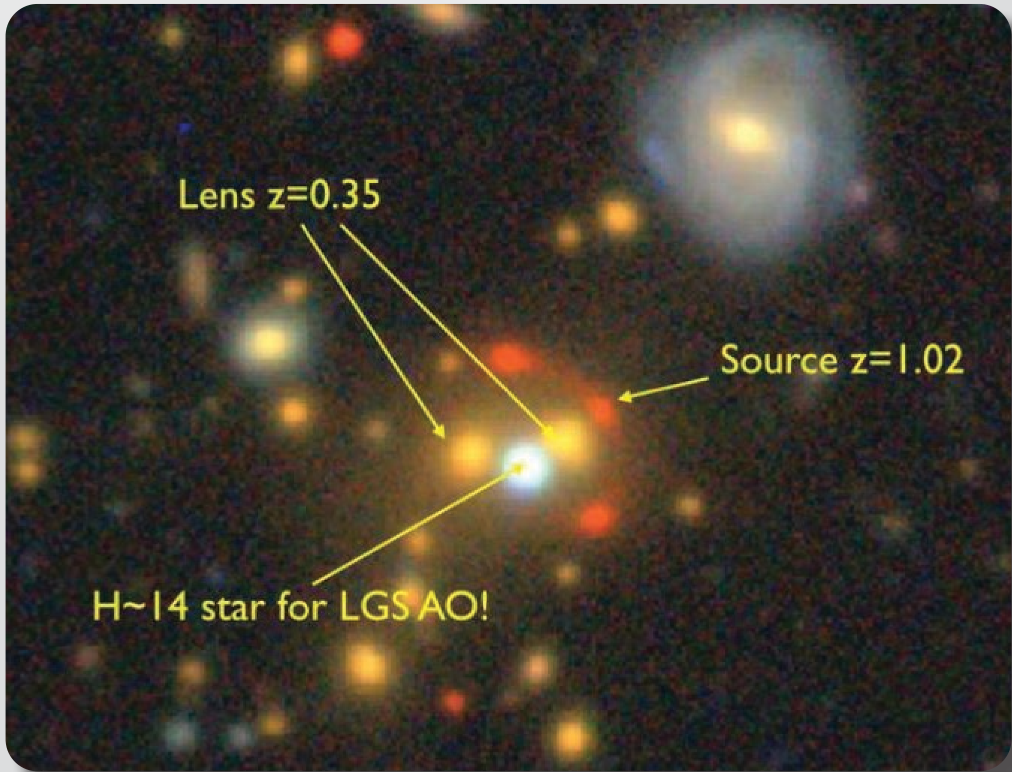
IMAGE CREDIT: Rob Bassett

What is emerging over the monthly Zoom meetings is a unifying theme for the Galaxy Evolution project of "Galactic Physics from the sub-kpc to kpc scale".

The Galaxy Evolution team will continue to work with existing ASTRO 3D projects to contribute expertise and vice versa. The focus from now through early 2020 is preparing HST and JWST proposals. AI Kim Vy Tran was asked to take over the leadership for the Galaxy Evolution team in April 2019 and since then she has focused on defining the Galaxy Evolution identity. While all the individual projects continue to progress, the focus has been on establishing a more structured team that is currently composed of many different loosely connected projects.

With contributions from the newly appointed leadership composed of Vice-Chairs, Deputy Chairs, and Project Liaisons, the Galaxy Evolution team now has a living directory, project website, and monthly videoconferences. The team now has regular updates with the other ASTRO 3D projects via the liaisons which is facilitating development of cross-project collaborations.

The Galaxy Evolution project currently has approximately 20+ actively engaged members and 20+ additional contributors across most of the Nodes and many of the Partner Institutions. Several members are primarily affiliated with other ASTRO 3D projects and their contributions help develop Galaxy Evolution as a collaborative force across the ASTRO 3D science themes.



The Swinburne members led by Karl Glazebrook have discovered a unique red giant arc in their DECaLS using neural networks that they have named 'The Rosetta Stones' because it allows a singular highly magnified (factor of 22) view of a lensed dwarf elliptical at a redshift of z=1.016 (work led by Sarah Sweet et al, in prep). Such a system has never been found before, but fortunately the lens also has a bright guide star within a few arcseconds which is perfect for the MUSE instrument on the VLT. This unusual configuration enables the team to spectroscopically map the lensed background galaxy at an astounding resolution of 40 parsec. The lensing cluster is at redshift z=0.353.

SPOTLIGHT ON PROF KARL GLAZEBROOK

CHIEF INVESTIGATOR FROM THE SWINBURNE UNIVERSITY OF TECHNOLOGY

"We had to sift through 8 million images. And we didn't sift through them one at a time...we actually had to train a computer to find them. "

What we're trying to do is find lots of high redshift gravitationally lensed systems, which are really interesting for studying galaxy evolution. What we are looking at is this phenomenon, predicted by Einstein, where light is bent around a massive object. So a massive galaxy can bend the light and amplify the light of the galaxies behind it, so we see a highly amplified view of the early Universe.

We use this technique to look at galaxies in the early Universe in extreme detail. You can see features you couldn't see without lensing, we can see very fine details, we can see very faint things that you can't see without lensing. We can also use it to measure the mass of the object bending the light, which is really important, because there are very few ways to measure the mass of galaxies.

In terms of challenges, lenses are a very rare phenomena – to find our catalogue of 500 new lenses in the sky, we had to sift through 8 million images. And we didn't sift through them one at a time, looking at images on a screen, we actually had to train a computer to find them. We used a convolution neural network to look at the images automatically. It looked through the 8 million images and flagged several thousand for us to look at. This is one of the first applications to use neural networks in lens finding in astronomy and that's why our catalogue has been quite high impact in the field.

For discovering the lenses, we are using the new data from the Dark Energy Survey which is a big imaging survey of the southern sky from the telescopes in Chile – the 4m Blanco Telescope at CTIO (Cerro Tololo Inter-American Observatory) and then we're following these lenses up using telescopes such as the VLT (Very Large Telescope) in Chile and the Keck Telescope in Hawaii, to get the redshift (which is how far away they are) and their structure at very high resolution.

The most exciting thing we've found so far is this very red lens – where the lensed object is quite red – you see a red arc in the sky. And we think what we are seeing is dwarf elliptical galaxy in the early Universe being lensed. And that, I don't think, has been seen before. Most lensed galaxies are dwarf regular galaxies, so they're blue and star-forming. But this one is a dwarf and it's quiescent and red. So, it's a unique object, unknown outside the local Universe, and it's really interesting to look at further.

The work we do in lensing in Galaxy Evolution has a very strong overlap with other ASTRO 3D projects. Galaxy Evolution is trying to understand metallicity of galaxies, the composition, and the kinematics. It wants to understand the properties of the earliest galaxies through a variety of observations. It wants to understand what galaxies are made of, how they come to be and how they are changing. Lensing provides a view into the Universe where we can see very small galaxies, in a lot of detail, and this helps with the comparison of galaxies in the nearby Universe, being explored by the ASKAP or SAMI surveys. It also helps with the comparison of the Milky Way. And it helps with the very galaxies in the Universe – so there's a link with the First Galaxies Project in ASTRO 3D.

We also have strong links with the theory and simulation component of ASTRO 3D. We provide very high resolution properties of galaxies. One of the key goals of the vertical modelling is to increase the resolution of the simulation of galaxies – to understand how they are forming and evolving.

5. THE ASKAP SURVEYS

The ASKAP Surveys project track the evolution and buildup of neutral hydrogen in galaxies over the past 7–8 billion years. Neutral hydrogen gas (HI) provides the reservoir of material from which new stars can form in galaxies, and so is key to understanding how galaxies evolve over cosmic time. ASTRO 3D researchers are members of several ASKAP HI survey teams, using the new Australian SKA Pathfinder to map out the cosmic distribution of HI in unprecedented detail via three different but interlinked ASKAP surveys.

- The WALLABY survey (led by CI Lister Staveley-Smith) will cover three-quarters of the sky and is expected to detect the 21cm HI emission line from up to 500,000 galaxies, looking back 2 billion years in cosmic time.
- The DINGO survey (led by AI Martin Meyer) focuses on the evolution of galaxies and the gas-rich universe out to 4 billion years ago and expects to detect up to 100,000 galaxies through deep ASKAP observations spanning 60 square degrees of sky.
- The FLASH survey (led by CI Elaine Sadler and James Allison) will search for the 21cm HI line in absorption against bright continuum sources across the whole southern sky, and will probe the neutral gas content of several hundred individual galaxies between 4 and 8 billion years ago, where the HI emission line is too weak to be detectable in even the deepest ASKAP surveys.

In 2019, CIs carried out pilot or test observations against bright continuum backround sources with the full 36-antenna ASKAP array which will probe the neutral hydrogen gas content.

WALLABY

WALLABY had a big year in 2019. The survey reached its first milestone by concluding the ASKAP early science phase (ASKAP-12) and publishing five papers. Paper I was led by PhD student Tristan Reynolds on the NGC 7162 galaxy group and its past history. Paper II was led by AI Karen Lee-Waddell on the interacting NGC 7232 triplet system, including tidal debris and one tidal dwarf candidate. Paper III was led by PhD student Ahmed Elagali on the spiral galaxy, NGC 1566, in the Dorado field. This study found that ram-pressure stripping was likely the cause of its asymmetric and warped disc. Paper IV was led by Dane Kleiner on a nearby spiral galaxy, IC 5201, which shows a warped disk most likely the result of a close fly-by of an irregular galaxy. Paper V, led by Bi-Qing For, examined the Lyon Group of Galaxies 351, finding 40 HI sources - the largest WALLABY sub-sample to date. All the above data has now been released publicly via CASDA.

The next set of WALLABY data was taken using 28 ASKAP antennas in March 2019 in the Eridanus field. Instead of the data being processed by WALLABY team members, this set of data was processed by the ASKAP operations team, which allowed the full resources of the Pawsey Galaxy supercomputer to be used to process the full band. The data will again be made publicly available.

On the technical side there has been major progress in our data quality assessment and source-finding efforts. The WALLABY data quality assessment tool has been developed by Bi-Qing For, and will be embedded in the ASKAP processing pipeline in the near future. AI Tobias Westmeier has been awarded 3 months of ADACS support for the development of the 3D Source Finding Application SoFiA in order to increase processing speed in a supercomputer environment.

In the middle of the year, ASKAP pilot surveys began. WALLABY chose three cluster/group fields at different declinations: Hydra, Norma and NGC 4636. The NGC 4636 field is part of a joint project which uses the giant FAST telescope in China, led by Jing Wang at KIAA, Peking University. The pilot survey is crucial for the WALLABY team to verify technical performance and scientific feasibility prior to full survey commencement. In anticipation of the pilot survey, the WALLABY science and technical working groups have been re-organised, and new chairs appointed. A call for pilot survey paper proposals resulted in 23 unique proposals.

WALLABY team members have given presentations at many conferences during the year, including the SKA science meeting in Manchester and the Munich Institute for Astro- and Astroparticle Physics workshop and the PHISCC science meeting in Perth.

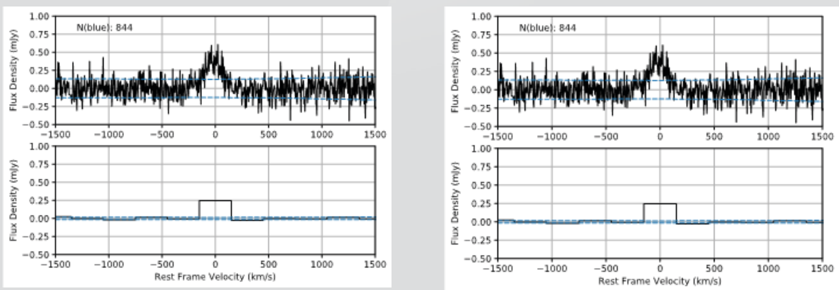
DINGO

With the first full ASKAP data for DINGO now in hand, utilising data from all 36 antennas in the array, 2019 marks an exciting new phase for the project. Alongside these new observations, work has also progressed on processing and science analysis on early science observations, continuing the development of an advanced uv-grid pipeline, and welcoming new team members into the survey team and ASTRO 3D.

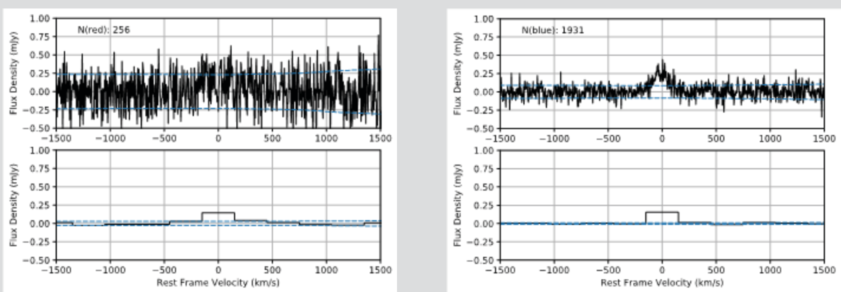
Completing the processing of ASKAP early science observations in G23, ASTRO 3D Postdoctoral researcher Jonghwan Rhee has analysed the HI content of galaxies z < 0.09 using HI stacking. This has included the dependence of HI content on third parameter dependencies such as colour and central/satellite status for 1100 and 2819 galaxies in spectral windows 3 and 4 of the ASKAP data as well as using redshifts from the GAMA G23 catalogue (see Figures). . These results show the power of this method going forward, even with just 18h of data compared to the up to the max 2500h that will be invested in the deepest DINGO fields.

Also on the early science front, ICRAR PhD student Qingxiang Chen completed his analysis of data from the DINGO-VLA survey with ASTRO 3D researchers Martin Meyer and Lister Staveley-Smith. This work involved stacking the HI signals for 3622 galaxies z < 0.1 in 267 VLA pointings in the GAMA G09 field. Crucially, this work also developed a new cubelet stacking technique to enable source cleaning and the accurate recovery of fluxes for resolved sources in interferometric surveys.

Building on these efforts going forward, the DINGO team was delighted to welcome two new members to ASTRO 3D in 2019: Sambit Roychowdhury, joining as an ASTRO 3D Postdoctoral researcher with a focus on the baryon cycle and galaxy groups, and Kristof Rozgonyi, who is undertaking his PhD on developing an advanced uv-grid pipeline for optimising deep imaging. Kristof's work has also been supported over the past half year through the ADACS program and the work of Graeme Wong, who will translate the developed pipelines into a production framework on the HPC systems at Pawsey and associated commercial providers.



The stacked HI spectra of blue (left) and red (right) galaxies in SPW3. The bottom panel shows the re-binned spectra of the upper with a velocity width of 300km/s. HI mass of the blue same is 0.9 x 10^9 $M_{\odot}$ and 0.5 x 10^9 $M_{\odot}$ is measured for the red sample. ***IMAGE CREDIT:*** Jonghwan Rhee



The stacked HI spectra of blue (left) and red (right) galaxies in SPW4. The bottom panel shows the re-binned spectra of the upper with a velocity width of 300km/s. HI mass of the blue same is 1.2 x 10^9 $M_{\odot}$ and 0.2 x 10^9 $M_{\odot}$ is measured for the red sample. ***IMAGE CREDIT:*** Jonghwan Rhee

On a technical front, DINGO also established new collaborative efforts with both the SKA office and the Shanghai Astronomical Observatory to investigate new methods for processing ASKAP data, assisting with the big data challenges presented by spectral line data in the SKA era.

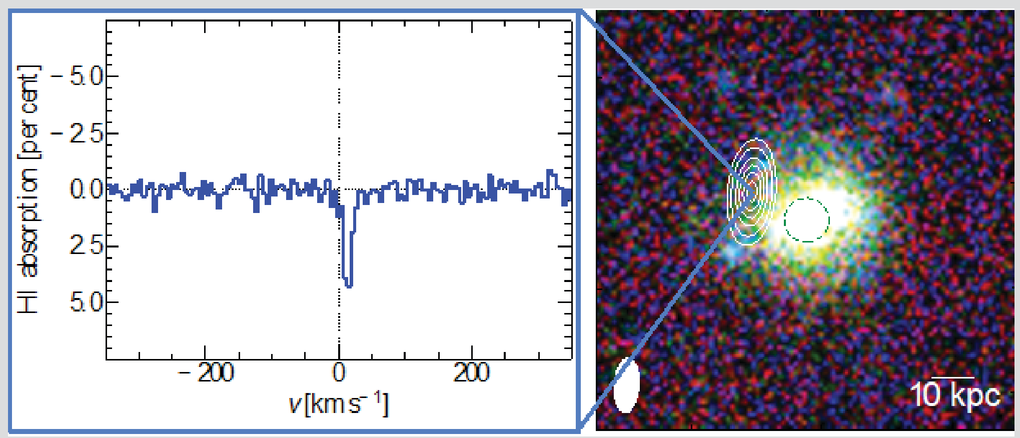
Similarly to the other ASKAP HI surveys, DINGO team members presented science highlights at a number of conferences in 2019, including the SKA science meeting in Manchester, the PHISCC science meeting in Perth, and participating in the MIAPP workshop on HI galaxy evolution surveys in Munich.

FLASH

The FLASH survey team submitted their first ASKAP early science paper in 2019. We used the ASKAP-12 sub-array to search for HI 21-cm absorbers between z = 0.3 and 0.8 over the entire 50 square degree GAMA 23hr field. This was a new milestone - the first wide-field spectroscopically untargeted search for HI absorption at cosmological distances. The team detected intervening 21-cm absorption in an early-type galaxy at redshift z=0.35 that appears to be gas rich, dusty, and forming stars at the rate of a few solar masses per year. The absorption line was detected at an impact parameter of 17 kpc with an estimated HI column density of more than 1020 cm-2, suggesting that this sightline may be probing a massive HI disk surrounding the galaxy.

In early 2019, we also published a second paper on the young radio galaxy PKS1740-517, in which we had previously detected HI absorption with ASKAP. We used ALMA to detect CO(2-1) absorption, revealing a reservoir of both cold atomic and molecular gas (107 -108 solar masses) within a few kpc of the central black hole. The radio source is only a few thousand years old and 300pc in extent. At least one interacting companion galaxy is evident in optical imaging and spectroscopy with the Gemini South Telescope. We conclude that gas accretion started approximately 50 Myr ago at the point of closest approach, but has only recently reach the black hole and triggered the AGN. This is consistent with the paradigm that radiatively-efficient radio galaxies are typically triggered by galaxy interactions and mergers.

Optical follow-up of our earlier ASKAP commissioning observations is continuing, and we were awarded ESO MUSE time to study a redshift z = 0.45 galaxy group discovered in HI absorption along the line of sight to the background radio source PKS 1610-77 at z = 1.71. These observations should provide us with detailed information on both



A recent early science result from FLASH (Allison et al. submitted). The spectrum on the left shows an HI absorption line detected towards a background radio source (white contours) in the outskirts of an early-type galaxy (colour image) over 4.5 billion light years away. Evidence of blue star forming regions at the same galacto-centric radius suggests that the absorber is part of a massive disk of cold gas. FLASH will establish a census of this fuel for star formation at cosmological distances.

the star-formation rate and the distribution and kinematics of ionised gas in a distant galaxy group selected by its HI content rather than its optical properties.

The FLASH team are now preparing for the start of Pilot Survey observations in late 2019. These observations will allow us to validate our observing strategy for the full FLASH survey, and should also produce exciting new science results from high-redshift HI absorption observations at full ASKAP sensitivity across roughly 1000 deg2 of sky.

This year we welcomed ASTRO 3D Postdoc Hyein Yoon to the FLASH team. Hyein recently completed her PhD at Yonsei University in Korea, and will be working on analysis of absorption-line systems in the ASKAP Pilot Survey fields. Members of the FLASH team gave presentations at several international conferences during the year, including the SKA science meeting in Manchester, the Munich Institute for Astro- and Astroparticle Physics (MIAPP) workshop and the Australia-Italy Pietro Baracchi meeting in Florence.

IMAGE CREDIT: CSIRO

SPOTLIGHT ON DR CLAUDIA LAGOS

RESEARCH FELLOW

FROM THE UNIVERSITY OF WESTERN AUSTRALIA

"Because our challenges are so big, we can't do this alone. We need to make sure we use the expertise of everybody involved in the group."

I am a theoretical astrophysicist and I'm part of the Genesis Project. Genesis works with several other ASTRO 3D projects - we help them interpret a lot of their observations. So, for example, the AKSAP surveys, SAMI survey and Galaxy Evolution Project. A little bit of everything but under the umbrella of Theoretical Astronomy simulations.

In Genesis, what we are trying to do is learn about how we are going to connect the laws of physics in the Universe with what we observe of galaxies. We are really trying to understand the formation of galaxies from a physical point of view. In practice, what we're trying to do is improve the physical modelling of different key processes of galaxy formation in our simulations. For example how stars form, how stars interact with the gaseous medium around them, how that actually shaped the formation of the entire galaxy across cosmic time.

Genesis is quite a big group, so there are people for example, in University of Melbourne, Swinburne, here in UWA and we're trying to focus on different aspects of ASTRO 3D. For example, the group in Melbourne are more focussed on the Epoch of Reionisation – so first stars, first galaxies and using our simulations to try and understand that. Here (UWA) we're more focussed on the Galaxy Evolution aspect, so we want to see how we connect observations of these early galaxies to what we observe these days – so our simulations are going to focus more on surveys like ASKAP, SAMI, some Galaxy Evolution.

I am the main person working with the ASKAP survey and also some of the Integral Field Spectroscopy survey. So really looking at a 3D view of galaxies. My role is to make sure we can take our simulations and put them in a way that galaxies are actually observed, so we can compare one-to-one and try to understand what are the limitations of our simulations and at the same time what kind of predictions are we making? Can we make a specific observation to distinguish between two competing mechanisms that explain for example how galaxies cease to form stars. So that's mostly my role - to make sure we connect the simulations with the observational projects.

Generally these are long term projects – we know where we are going to be in a few years but breaking the whole goal down into more manageable pieces that we can achieve in shorter terms – 1 month, 1 year for example. That can be quite difficult, sometime there can be a lot of unexpected results as well in this process. We have enough expertise in our team, we can rely on each other for different challenges. Breaking down that long term goal into more achievable ones, it can be quite difficult but I think we're getting there.

I think the Genesis team is a very interesting group of people, international people from everywhere, and we work quite in a collaborative way. And I really enjoy that to actually know that everyday I'm interacting with people - it's not that I go to my office and I'm there alone the whole day. And I really enjoy actually because he feels like we have this common goal, and we're all working towards that. I think people generally think science is a lone person kind of job. But I think that because our challenges are so big, we can't do this alone. So we need to make sure we use the expertise of everybody that is involved in the in the group, and that be, like to make sure that we're more than just a sum of our individual abilities and we can actually work together and take advantage of that.

I really like ASTRO 3D for several reasons. One is the science excellence, I feel like I am surrounded by people who are excellent, in what they do – they are leaders – everyone in the world knows them. There's an additional thing that I haven't found elsewhere, it's really that part of the more nurturing aspect. They really empower you to take the lead of things, to really be part of a lot of different projects. They make you feel like you are contributing, more than just your scientific aspect but that you are really contributing to a bigger project. – this is, to me, something I haven't seen in other countries.

6. SAMI/HECTOR SURVEYS

The SAMI Galaxy Survey has now completed its observational program to obtaining 3D data cubes for over 3000 galaxies in the nearby Universe. Integral field spectroscopy with SAMI allows the measurement of a huge range of galaxy properties that are impossible to obtain from single fibre surveys and allows direct tests of the latest galaxy formation simulations. SAMI observables include gas and stellar internal and bulk kinematics, the spatial distribution of star formation, stellar metal content and age gradients, gas oxygen abundance distributions, resolved ionisation diagnostics and many others. This is the first integral field sample that is sufficiently large to disentangle the competing roles of galaxy mass and environment. As a result, we can address the following three key questions:

1. What is the physical role of environment in galaxy evolution?

2. What is the interplay between gas flows and galaxy evolution?

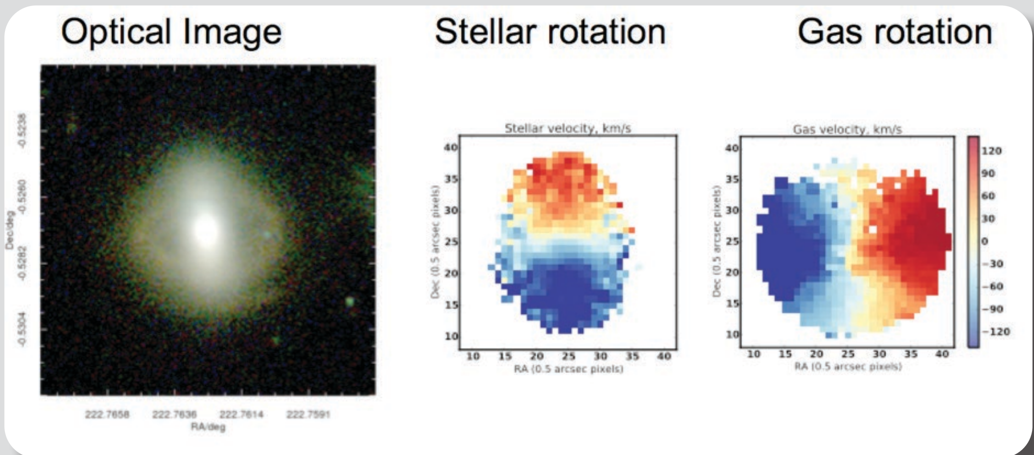
3. How are mass and angular momentum built up in galaxies?

In 2019 SAMI work has focused in two areas. First is preparing for a final data release that will occur in 2020. The team has made substantial improvements to the data pipeline to improve the overall legacy of the project. We are also developing a new and innovative approach to data cube reconstruction, in collaboration with data scientists.

The SAMI team is working to publish final results using the full sample. At the time of writing, there have been 14 journal papers published from the SAMI team in 2019. Below we highlight a few key results.

In a collaboration with the high redshift KROSS survey the SAMI team (Tiley et al., 2019) showed that when selection biases are accounted for there is no evidence of evolution in the Tully-Fisher relation that connects dynamical and baryonic mass for disk galaxies. Bryant et al. (2019) showed that the misalignment of gas and stellar kinematics is most strongly correlated with galaxy morphology. There is currently ongoing work to understand this from a simulations perspective.

Van de Sande et al. (2019) has provided the most comprehensive comparison yet between integral field data and simulations, particularly focusing on how simulations are able to recover reliable stellar kinematics. This showed that although there has been great progress in building more realistic hydrodynamic simulations in the last few years, clear differences remain.



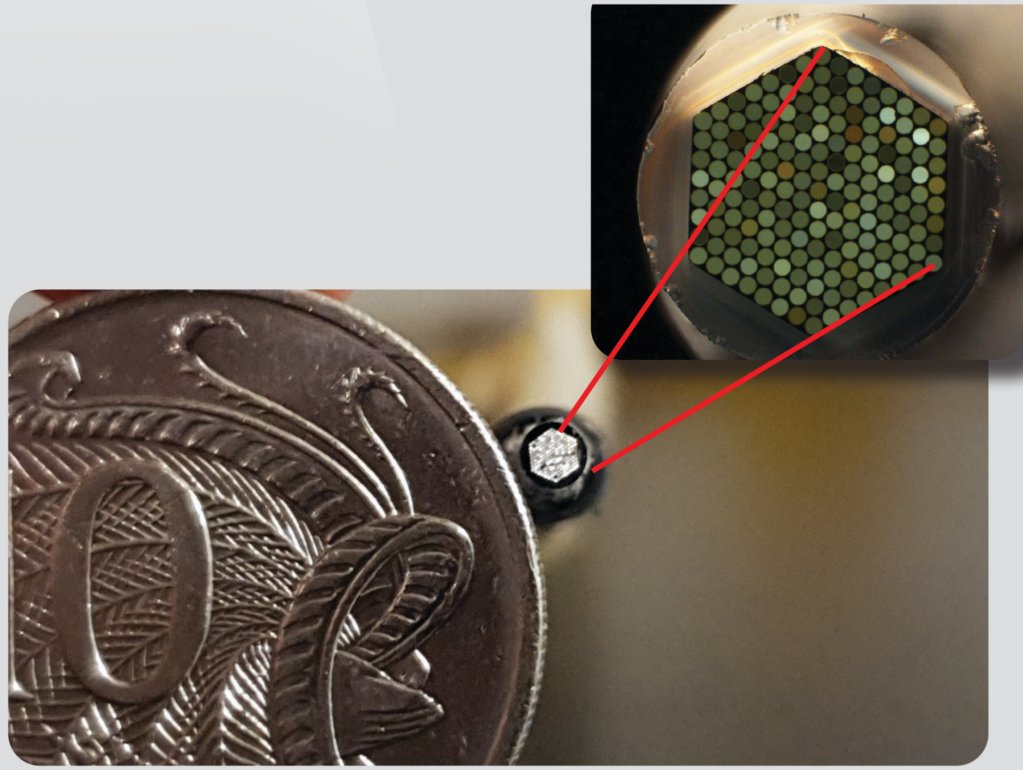
One of a number of SAMI galaxies found to have gas and stellar kinematics misaligned. In this case the gas and stellar rotation are at 90 degrees to each other. Studying the statistics of kinematic misalignments helps to shed light on the accretion of gas into galaxies (Bryant et al.).

In Cortese et al. (2019) the SAMI team have combined information on galaxy quenching with stellar kinematics to demonstrate that satellite galaxies show little dynamical change as they quench. By using phase-space analysis Owers et al. (2019), collaborating with ASTRO 3D distinguished visitor Mike Hudson, showed that cluster galaxies in the process of quenching have recently fallen into the cluster.

Recently, the SAMI team has published the first detection of mass dependent galaxy spin orientation with respect to large-scale structure (Welker et al. 2019). They find that low-mass galaxies align their spin with their nearest filament, while higher mass counterparts are more likely to display an orthogonal orientation. This first detection with SAMI bodes well for future analysis of a much larger sample with Hector.

In 2020 our key focus will be completing SAMI Data Release 3 and publishing key papers using the final SAMI sample. We will also be transitioning to greater focus on Hector as the instrument is completed during 2020.

Development of new-format larger, high fill-fraction optical fibre imaging bundles – hexabundles - for Hector is well underway due to our dedicated ASTRO 3D students Rebecca Brown and Adeline Wang. 15 out of 18 of the large optics for the new Hector spectrograph have arrived and the spectrograph will be assembled through 2020. The complex 6-axis positioning system, is well advanced, along with the associated software. In parallel, preparation of the observing catalogues, target selection, and data reduction continue, bolstered by the recent ASTRO 3D hire of Sam Vaughan who has taken over the target selection effort.



The first prototype hexabundle in the largest size of 169 cores, subtending 27 arcsec on-sky. Each core is 103 microns, and achieving perfect hexagonal packing within a 2mm footprint is exacting work.

SPOTLIGHT ON DR NICHOLAS SCOTT

ASSOCIATE INVESTIGATOR FROM THE UNIVERSITY OF SYDNEY

"I describe my research as being a bit like that of a historian of the Universe - my goal is to reconstruct the histories of nearby galaxies."

I grew up in the English countryside and spent a lot of time outdoors, climbing, hiking and camping, which I think gave me a real appreciation for being out under the stars. Despite this, I didn't really see astronomy as a career until quite late on, initially intending to pursue aeronautical engineering, then quantum physics, before deciding on a PhD in astronomy almost at the last minute. In the end I think it was a combination of really enjoying problem solving and having a strong connection with the night sky that led me to study astronomy.

I describe my research as being a bit like that of a historian of the Universe. My goal is to reconstruct the histories of nearby galaxies by looking for patterns in composition and structure that tell us about what happened to them in the past. I do this mainly through optical spectroscopy, which lets us study how the stars within galaxies are moving, how old they are and what chemical elements they are composed of. Of course, simply telling the stories of nearby galaxies isn't enough – once we have all this information I also try to identify the laws that govern galaxy evolution and tie these back to fundamental physics like gravity, thermodynamics and radiation.

Within ASTRO 3D I work on the SAMI and Hector galaxy surveys, which use the Anglo-Australian Telescope to obtain spatially resolved spectroscopy of thousands of galaxies. These large samples let us do population studies – galaxy demographics – so we can learn how typical galaxies behave by averaging over a large number of galaxies. SAMI has a larger team of researchers both within Australia and across the wider world, and getting to work closely with such a diverse, smart and motivated bunch of people is really exciting.

SAMI has changed the way we see galaxies, giving us a truly 3D perspective on thousands of nearby objects. This revolutionary view has let us make exciting discoveries about how galaxies form and evolve. For example, Dr Jesse van de Sande (ASTRO 3D AI) and myself published a paper last year on the discovery of a connection between the shape and age of galaxies. We found that the older a galaxy is, the rounder and more puffed-up it is. There's two possible explanations for this; either galaxies that formed a very long time ago formed much rounder than galaxies do today, or most galaxies form in flattened disks, but over time they thicken and become more spheroidal, so that the older a galaxy is the more time it has had to puff up

To distinguish between these two possibilities we're turning to our colleagues within ASTRO 3D. A detailed study of our own Milky Way galaxy from the GALAH team has shown the same relationship between individual generations of stars and the thickness of the structure they live within. Observations of distant galaxies from the Galaxy Evolution team show that billions of years ago galaxies formed their stars in much thicker structures than they typically do today. State-of-the-art simulations from the Genesis team let us watch the formation and evolution of galaxies happen in real time, but sped up many billions of times so we don't have to wait millions of years for the action to happen!

Being part of ASTRO 3D expands this sphere of interaction beyond the relatively small group of people working on my exact science topic and provides an opportunity to engage with astronomers with much broader interests. I think this is really important for astronomers transitioning into the middle of their careers who are trying to identify the big problems that astronomy should be tackling in the decades to come. ASTRO 3D enables a cross-pollination of ideas and techniques that just doesn't happen outside the Centre framework. To me this is both the most exciting thing about being part of ASTRO 3D, and it's biggest challenge – how can we take all these diverse topics from individual researchers and craft them into cohesive science programs that are more than the sum of their parts.

SCIENCE HIGHLIGHT

SPIN DOCTORS: ASTROPHYSICISTS FIND WHEN GALAXIES ROTATE, SIZE MATTERS

The direction in which a galaxy spins depends on its mass, researchers have found. A team of astrophysicists analysed 1418 galaxies and found that small ones are likely to spin on a different axis to large ones. The rotation was measured in relation to each galaxy's closest "cosmic filament" – the largest structures in the universe.

Filaments are massive thread-like formations, comprising huge amounts of matter – including galaxies, gas and, modelling implies, dark matter. The filaments are why the universe looks a little like a honeycomb, or a cosmic Aero chocolate bar.

"It's worth noticing that the spine of cosmic filaments is pretty much the highway of galactic migration, with many galaxies encountering and merging along the way," says lead researcher Charlotte Welker, an ASTRO 3D researcher working initially at the International Centre for Radio Astronomy Research (ICRAR) and now at McMaster University in Canada.

Using data gathered by an instrument called the Sydney-AAO Multi-object Integral-field spectrograph (SAMI) at Australia's Anglo-Australian Telescope (AAT), Dr Welker, second author and ASTRO 3D principal investigator Professor Joss Bland-Hawthorn from the University of Sydney, and colleagues from Australia, the US, France and Korea studied each of the target galaxies and measured its spin in relation to its nearest filament.

They found that the less massive ones tended to rotate in direct alignment to the filaments, while higher mass ones spun at right angles to the filament. The alignment changes from the first to the second as galaxies, drawn by gravity towards the spine of a filament, collide and merge with others, thus gaining mass.

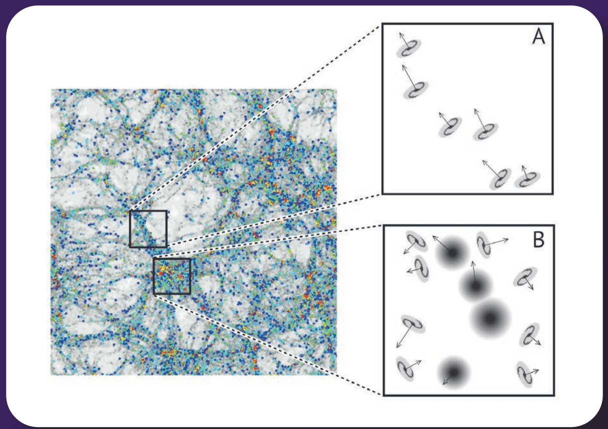
Co-author Scott Croom from the University of Sydney, also an ASTRO 3D principal investigator, says the result offers insight into the deep structure of the Universe.

"Virtually all galaxies rotate, and this rotation is fundamental to how galaxies form," he says.

"For example, most galaxies are in flat rotating disks, like our Milky Way. Our result is helping us to understand how that galactic rotation builds up across cosmic time."

He adds that a new instrument, called Hector, set to be installed at the Anglo Australian Telescope in 2020, will enable a significant expansion of research in the field.

"Hector will be able to carry out surveys five times larger than SAMI," he says. "With this we will be able to dig into the details of this spin alignment to better understand the physics behind it."



In the densest regions of the Universe – known as galaxy clusters – the spins of galaxies are expected to be pointing in random directions. But along the flow channels into clusters, our most advanced simulations predict the spins to be aligned along the filament, an effect seen for the first time in the SAMI survey. ***IMAGE CREDIT:*** Joss Bland-Hawthorn

7. GALAH SURVEY

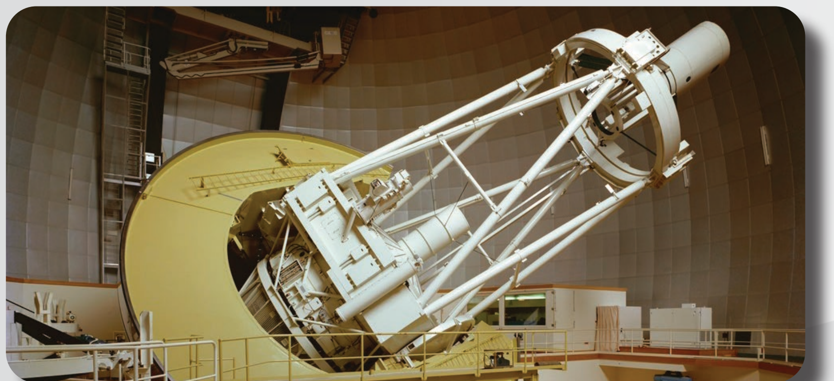
The GALactic Archaeology with HERMES (GALAH) survey is aiming to unravel the assembly, star formation, dynamical and chemical history of the Milky Way through the nucleosynthetic fingerprints encoded into the chemical compositions of up to a million stars. GALAH uses the Anglo-Australian Telescope (AAT) and the HERMES spectrograph, with which 400 stars can be observed simultaneously at high spectral resolution, a unique astronomical instrument world-wide. To date, more than 600,000 stars have been observed, already the largest high-resolution spectroscopic survey ever undertaken.

The GALAH observations and data reduction are led out of Sydney (Joss Bland-Hawthorn, Sanjib Sharma, University of Sydney; Sarah Martell, UNSW; Gayandhi De Silva, Macquarie University; among others) while the spectrum analysis pipeline to determine stellar parameters and elemental abundances is developed at ANU (Martin Asplund, Jane Lin, Sven Buder and Thomas Nordlander) and Stockholm University, Sweden (Karin Lind). These data are complemented by more than 100,000 stars observed by NASA's extended Kepler (K2) mission and TESS, two major satellites used for exoplanetary science and asteroseismology (programs led by Sanjib Sharma, and Dennis Stello, UNSW). Many of these stars thus have asteroseismic information on stellar masses and ages, vital for Galactic archaeology.

2019 has been an eventful year. An entirely new strategy was adopted by the GALAH survey team in view of the incredible advances made possible with the second data release from the Gaia satellite. A new large observing program for AAT was approved, specifically targeting stars near the main sequence turn-off such that accurate stellar ages can be determined using stellar evolutionary models.

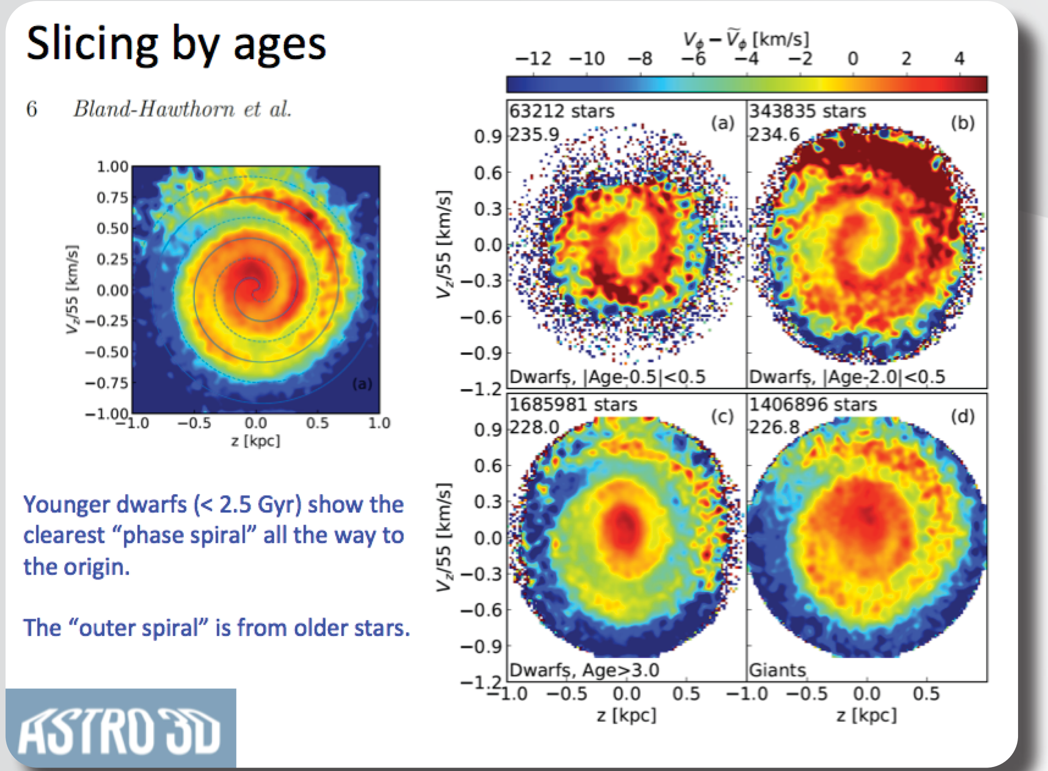
The GALAH survey will be the only large spectroscopic survey world-wide with a focus on such stars for which age information will be invaluable. In addition, significant improvements were made to the spectroscopic analysis pipeline, including incorporating the new Gaia parallaxes. Thus new and improved stellar parameters and abundances have been computed, which will provide the foundation for the third data release of the GALAH survey, which will become public in mid-2020. Unfortunately technical issues with the AAT prevented much of the GALAH observations in 2019. The problems have now been rectified and the GALAH Phase 2 underway.

In spite of the observational difficulties, science has progressed impressively. Sven Buder and Shourya Khanna both submitted their PhD dissertations and have taken up Postdoctoral positions. Sven moved to the ANU to work with the GALAH team as part of ASTRO 3D. Shourya has moved to the University of Groningen to work with Prof. Amina Helmi on Gaia data. In their place, we are happy to welcome new PhD students Boquan Chen and Purmortal Wang (both University of Sydney), who will be developing chemodynamic models to interpret the GALAH data. ANU PhD student Jane Lin published her work on deriving accurate ages for almost 200,000 stars to investigate how the chemical enrichment has proceeded in the Milky Way Galaxy over the past 10 billion years.



The Anglo-Australian Telescope (AAT) was the last of a series of 4m-class equatorial telescopes of similar design. Seen here pointing low in the east, the telescope "has a remarkably wide 2 degree field of view

IMAGE CREDIT: David Malin, AAO



Some of the latest kinematic results using GALAH stars, which highlights the phase spiral structure in our Milky Way disk.
IMAGE CREDIT: Joss Bland-Hawthorn

One of the GALAH science highlights of the year was Shourya Khanna's study of the power spectrum of kinematic substructure in the Milky Way disk, which showed unexpected kinematic that may be due to the transitory nature of spiral arms. Sanjib Sharma has investigated the structure and origin of the enigmatic Milky Way thick disk using stellar ages from Kepler asteroseismology in conjunction with GALAH abundances. The combination of asteroseismology with stellar spectroscopy for Galactic archaeology is a field in which ASTRO 3D and GALAH have a significant lead world-wide.

Jeffrey Simpson (UNSW) has investigated the viability of chemical tagging – the prospect of identifying stars now dispersed stars from their chemical compositions – using pairs of stars orbiting the Galaxy together. He has also succeeded in chemically tagging two stars in a large-scale Galactic stellar stream as originating in the Omega Centauri globular cluster, further evidence that this globular cluster was once the core of a dwarf galaxy colliding with the Milky Way billions of years ago.

Marusa Zerjal (ANU) has used GALAH spectra to identify young and very cool stars from the presence of a prominent spectral feature due to lithium. Such stars are of particular interest in studying how star forming groups disperse over time across the Galaxy as well as for the quest to search for Earth-like planets around other stars. PhD student Xudong Gao (MPIA, Germany) has used the same spectral line to determine how lithium has been destroyed in more than 100,000 GALAH stars. Excitingly, this has provided an elegant solution to the very long-standing cosmological lithium problem, namely that the oldest stars seem to have a factor of three less lithium than was produced in connection with the Big Bang according to the standard concordance cosmological model. Rather than a problem with the Big Bang, it seems like the solution was an incomplete understanding of how stars work.

SPOTLIGHT ON
ASSOC PROF AMANDA KARAKAS
AFFILIATE INVESTIGATOR FROM MONASH UNIVERSITY

"I loved astronomy as a kid. When I got to university, I was torn between doing Arts and Science. I couldn't decide, so I did both."

I am interested in where the elements came from - so looking at how stars make elements and how they can be dispersed within the Milky Way Galaxy. This is linked directly to what GALAH does, observing elements within different locations of the Galaxy. We are hoping to tie their observational data with my theoretical models.

My theoretical models start by solving equations that determine how stars change with time and how, through nuclear reactions, they can make elements inside them. I follow the star's life essentially as a function of time over time. I then look at how those stars will release elements into the Galaxy.

The most exciting discovery we've made so far is we've looked at the production of heavy elements inside stars and we have found surprisingly that there might be a different nucleosynthesis pathway of making heavy elements than what we thought of up until now. We think there may be a process that occurs in low mass stars like our Sun that makes heavy elements that's really only been around for the last few years. So with a student that's also involved ASTRO 3D, we're looking at how these elements can be made.

To do my work I use just computers. I have been to telescopes and have taken observational data, but that's definitely not the main thing I do. Most of my work I will be sitting in front of a desk - it's kind of boring, but I just use computers. How much computing power is needed to make the sort of models I make? These days, a standard desktop computer is enough. It is more efficient if you can use a big supercomputer, you could run many of your simulations at once, but you don't need to. I could even run it on my phone these days.

The theoretical simulations I do tie into GALAH. GALAH is focused on the origin and evolution of our Milky Way Galaxy and this is interesting because we see it now, of course. Other projects within ASTRO 3D are looking at galaxies in different snapshots in time - so how they have evolved in the distance past. By tying in the very detailed information we get in GALAH, which is a snapshot of the Galaxy today, but in very high detail, we can connect that information to the galaxies we see at very far distances without the high detail, so we can put these together and understand where all the elements came from in the Universe.

I was always good at mathematics and mathematics was fun, so I pursued that pathway. At that time the university was offering an astrophysics major, which I completed and kept on that path until here I am.

I'm still learning about ASTRO 3D and how it works, but I really like it. I like the collaborative nature of ASTRO 3D. It's a very friendly environment and doing great science. It connects well with my science, so it's the perfect fit!

Amanda giving a Plenary Talk for the IAU Symposium 343: Why Galaxies Care about AGB Stars: a Continuing Challenge through Cosmic Time, in Vienna, 2018
IMAGE CREDIT: Lendület AGB Nuclei and Dust group

SCIENCE HIGHLIGHT
STAR-QUAKE VIBRATIONS LEAD TO NEW ESTIMATE FOR MILKY WAY AGE

Star-quakes recorded by NASA's Kepler space telescope have helped answer a long-standing question about the age of the "thick disk" of the Milky Way.

In a paper published in the journal Monthly Notices of the Royal Astronomical Society, a team of 38 scientists led by researchers from Australia's ARC Centre of Excellence for All Sky Astrophysics in Three Dimensions (ASTRO 3D) used data from the now-defunct Keppler satellite to calculate that the disk is about 10 billion years old.

"This finding clears up a mystery," says lead author Dr Sanjib Sharma from ASTRO 3D and Australia's University of Sydney.

The data delivered by the telescope during the four years after it was launched in 2009 presented a problem for astronomers. The information suggested there were more younger stars in the thick disk than models predicted.

"Earlier data about the age distribution of stars in the disk didn't agree with the models constructed to describe it, but no one knew where the error lay – in the data or the models. Now we're pretty sure we've found it."

The Milky Way-like many other spiral galaxies – consists of two disk-like structures, known as thick and thin. The thick disk contains only about 20 per cent of the Galaxy's total stars and, based on its vertical puffiness and composition, is thought to be the older of the pair.

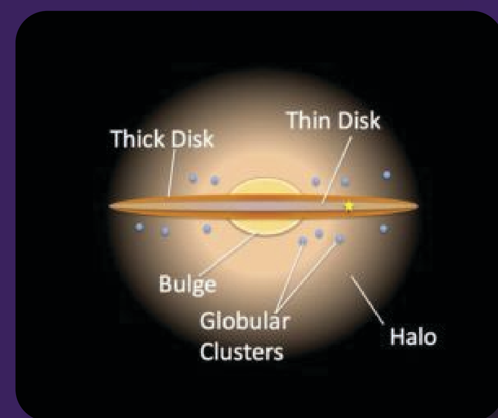
To find out just how much older, Dr Sharma and colleagues used a method known as asteroseismology – a way of identifying the internal structures of stars by measuring their oscillations from starquakes.

"The quakes generate soundwaves inside the stars that make them ring, or vibrate," explains co-author Associate Professor Dennis Stello from ASTRO 3D and the University of New South Wales.

"The frequencies produced tell us things about the stars' internal properties, including their age. It's a bit like identifying a violin as a Stradivarius by listening to the sound it makes."

This age-dating allows researchers to essentially look back in time and diskern the period in the Universe's history when the Milky Way formed; a practice known as Galactic-archaeology.

Not that the researchers actually hear the sound generated by star-quakes. Instead, they look for how the internal movement is reflected in changes to brightness.



An artist impression of the Milky Way, showing the thick and thin disks.
IMAGE CREDIT: NASA/JPL Caltech/R.Hurt/SSC

ACTIVITY PLAN 2020

RESEARCH PROJECTS AND SURVEYS

ACTIVITY	ACTION
Genesis Simulations - Chris Power (UWA)	• Build sample of 30 gas-rich galaxy mass systems in range of environments to look at HI and IFU properties • Process BLUETIDES simulation to access relevant observables for hydrogen and molecular gas distributions • Direct ingestion of Genesis data by SAGE • Development of tools to incorporate Genesis data into TAO • Provide SAMI/Hector teams with all IFU-like data calculated for EAGLE and EAGLE-XL • Incorporate initial Genesis single-galaxy simulations and generate mock images for the Huntsman telescope. • Integrate initial mock generator code with a AAO-MQ python package, gunagala • Mock MUSE pipeline (released with metal absorber paper) • Develop suite of controlled non-cosmological simulations, cosmological zoom counterparts, and small cosmological volumes
Data Intensive Astronomy (DIA) - Lister Staveley-Smith (UWA)	• Pilot implementation of DINGO and WALLABY pipelines using DALiuGE • Database for SoFiA source finder supporting WALLABY • Pilot cross-matching and querying of heterogeneous ASTRO 3D data sets across ASTRO 3D data centres • Design visualisation tools for scientifically meaningful interpretation of the ADC-CASDA cross-matched data based on user requirements • Ingestion of first set of Genesis SAM galaxy models into TAO and available to the ASTRO 3D team. • Investigate possible DIA role in future visualisation/VR projects
MWA EoR Survey - Rachel Webster (Melbourne), Cath Trott (Curtin)	• Explore and define methods for assessing and correcting for diffuse polarised emission • Charaterisation of the MWA beam A complete characterisation of 14 tiles, both polarisations and all pointings will be undertaken. • Process EoR2 field data through independent pipeline to test systematics introduced by RTS • Process MWA Moon data for EoR global signal detection or limit • An improved MWA limit on the 21cm power spectrum at z=12-17 • An improved limit from MWA EoR1 highband data • Define RTS v2 software pipeline

Continued

RESEARCH PROJECTS AND SURVEYS

ACTIVITY	ACTION
First Stars Project - Martin Asplund (ANU)	• Analyse AAOmega@AAT observations of bulge EMP stars • Perform 3D non-LTE spectral line formation calculations of EMP stars for elements of key astronomical and cosmological importance, e.g. Na, Mg, Al • Perform 3D non-LTE spectral line formation calculations for keyelements to improve inferred elemental abundances • Investigate 3D non-LTE spectral line formation for key elements using new atomic data on collisional cross-sections • Search for and chemically analyse extremely metal-poor stars in Local Group ultra-faint dwarf galaxies
First Galaxies Project - Michele Trenti (Melbourne)	• Pipeline and data reduction for BoRG cycle 25 survey • Analysis of Spitzer BoRG data • Analysis of environment around the most distant galaxies and quasars • Analysis of Hubble Space Telescope Data for the most distant galaxies and quasars • Modeling of intermediate redshift metallicity measurements from SAMI data • Characterisation of the connection between GRB rate and star formation from the ILLUSTRIS TNG simulation • Genesis collaboration: Environment of high-z QSOs • Galaxy evolution collaboration: Mass-metallicity relation of dwarf galaxies at z~1
Galaxy Evolution Project - Kim-Vy Tran (UNSW)	• Reduce XSHOOTER data – final list of lens and source redshifts • Assemble and process the single star HII region WiFeS data (M42, LMC, SMC) • Using TOSCA stellar data, run models to compare with observations to identify how well model results fit data • Run new simulations, the COCKATOO suite (COsmological Chemodynamical simulations with Kinetic Agn feedback and other physics TOO • Initial application of machine learning lens identification to KiDS/VIKING data and spectroscopic confirmation
ASKAP FLASH Survey	• Delivery and verification of FLASH end-to-end data processing pipeline • Analysis of ASKAP-36 Pilot Survey data • Collaborate with WALLABY to search for HI absorption in galaxies at z<0.26 • Apply Genesis simulations to FLASH data

Continued

	ACTIVITY	ACTION
RESEARCH PROJECTS AND SURVEYS	**ASKAP DINGO Survey**	• Carry out alternative pipeline tests (cloud, non-Pawsey HPC) for data processing • Initial processing of DINGO ASKAP-36 Pilot survey data
	ASKAP WALLABY Survey	• Submit review documentation • Investigate processing options for data outside of the Pawsey Centre • Analysis of pilot survey data
	SAMI/Hector Survey	• Final SAMI internal data release using updated pipeline • Identify link between instrinsic shape of visible and dark matter by combining simulations and observations • Apply stellar population analysis to the decomposed bulges and disks from the SAMI sample • Hector input catalogue and pilot survey design • Hector data reduction pipeline phase 1 complete and end-to-end processing operational • Continue manufacture Hector fibre cable and hexabundles • Hector positioning system creation and development • Hector commissioning and survey operations begin
	GALAH Survey	• Complete GALAH data release 3 • Complete high-resolution Galaxy simulation study • Develop new tools in preparation for new GALAH “MSTO” sample • Identify stellar twins in GALAH survey • Investigate the chemical enrichment history of the solar neighbourhood using GALAH abundances and stellar ages • Determine the efficiency of stellar radial migration using the most metal-rich stars

IMAGE CREDIT: Cristy Roberts

	ACTIVITY	ACTION
RESEARCH AND LEADERSHIP TRAINING	**Professional Development**	Deliver the following professional development training: • Professional Astronomical Skills Training Workshop • Diversity Training Workshops at every node • Early Career Researcher Training Day • Transferable Skills Workshop • Writing Workshops and Project Busy Weeks Implement the following ongoing programs: • Centre-wide Mentoring Program • Emerging Leaders Program • Women’s Career Advancement Program
	Workshops and Conferences	Deliver a workshop and conference program that includes: • 2 international conferences • 2 national conferences/workshops • Attendance at at least 40 professional conferences and workshops
	Visitor Program	• Deliver a Visitor Program promoting effective collaboration and development
GOVERNANCE	**Advisory Board(s)**	• Set up one Advisory Board (combine International and National) • Organise meetings, as per the terms of reference, of the Advisory Board
	Committees	• Ensure the Executive Management, Science Management and Equity, Diversity & Inclusion, Senior ECR, Junior ECR, Student and Sustainability Committees contribute effectively to the work of the Centre
	Equity and Diversity	• Continue to implement the ASTRO 3D Diversity and Inclusion Action Plan
	Financial Management	• Revise the ASTRO 3D budget and ensure that proper controls are implemented to ensure sound financial management practices
	Reporting	• Ensure that ASTRO 3D meets all its financial and KPI reporting obligations

SCIENCE HIGHLIGHT

MAGPI SOARS FAR BACK INTO THE COSMIC MIDDLE AGES

Australian astronomers have secured one of the largest time allocations on the groundbreaking MUSE instrument at the Very Large Telescope to discover how galaxies have evolved over cosmic time.

A team of early-career astronomers as part of the ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) will observe the composition and motions in galaxies 4 billion light years away to better understand how the Universe's galaxies evolved over time.

ASTRO 3D fellows Caroline Foster (University of Sydney), Claudia Lagos (the University of Western Australia, Trevor Mendel (Australian National University), Emily Wisnioski (Australian National University) and Tiantian Yuan (Swinburne University of Technology) have secured over 300 hours on the MUSE instrument which uses the Very Large Telescope in Chile to see beyond the pretty pictures.

"Eight billion years ago, galaxies spun faster and appeared clumpier than their modern descendants," Dr Foster said.

"The pathways that transformed them from clumpy and chaotic to the diverse range of organised systems we see today are an ongoing mystery."

The European Southern Observatory recently announced that this group of young astronomers have been successful in their application to use the telescope for over 300 hours as part of the Middle Ages Galaxies Properties with Integral field spectroscopy (MAGPI) survey. The survey will double the distance of current similar 3D surveys of galaxies to catch galaxy transformation 'in the act'.

Dr Lagos explains "by mapping the movement of gas and stars in hundreds of galaxies 4 billion light years away we can fill a gap in our understanding of how the Universe came to look like it does now. The starlight in these galaxies is difficult to observe in detail, because they are very faint and in some cases hidden by the star's internal gas."

Galaxies in the "adolescent Universe beyond 8 billion lightyears were clumpy and chaotic in appearance and spun much faster than their modern counterparts.
IMAGE CREDIT: Hubble Space Telescope (HST), the CANDELS collaboration and G. Barro (Berkeley)

In contrast, a selection of nearby galaxies imaged with the Hyper Suprime Camera on the Subaru Telescope in Hawaii show how modern galaxies appear much smoother and organized.
IMAGE CREDIT: National Astronomical Observatory of Japan (NAOJ), the SAMI collaboration, C. Foster (U. Sydney) and D. Taranu (Princeton).

	ACTIVITY	ACTION
OUTREACH AND COMMUNICATIONS	**Indigenous Work Experience Program**	• In partnership with our Node Universities, provide scholarships to allow Indigenous students in Year 10 to attend astronomy/ astrophysics work experience programs.
	Public Outreach	• Participate in science outreach events and develop public outreach activities for National Science Week in August 2020 • Participate in major astronomy events and festivals around Australia where there is a strategic benefit to the Centre • Deliver public talks on the research work of the Centre and astronomy in general as well as ASTRO 3D gender equity programs
	Public Relations and Media	• Ensure that the research outcomes of the Centre are communicated through the media to reach the broadest possible audience • Share discoveries and promote discussion and comment on the activities of the Centre and astronomy in general via social media platforms such as Facebook, Twitter, Instagram, YouTube • Continue to create video resources that highlight the Centre's achievements
	Website	• Launch the new ASTRO 3D website and intranet
EDUCATION	**ASTRO 3D in the Classroom (Teacher and Student Resources)**	• Set up live-streaming Q&A sessions with schools • Develop lesson plans on spectroscopes, Epoch of Bubbles, CMB Maze and 3D printing that can be downloaded by teachers • Update and transfer CAASTRO teaching resources to the ASTRO 3D website
	Telescopes in Schools	• Provide funding to buy additional Dobsonian telescopes for schools in regional Australia • Provide solar filers and mobile phone holders to all existing TiS schools • Edit and upload "how to" video on setting up and using your telescope to our YouTube channel and website • Provide online resources to existing schools on how to use their telescopes
	Space Squad	• Continue to provide spectroscope activity and astronomer talk for the YMCA Canberra Space Squad in January, April, July and October
	Virtual Reality app	• In partnership with Deakin University's CADET Virtual Reality Lab, create a VR tool for high school students in Years 9 and 10, and a 360 3D video for public outreach, that explains the breadth of ASTRO 3D's research. The school app will also have curriculum-linked teaching resources.

SCIENCE HIGHLIGHT

NOT LONG AGO, THE CENTRE OF THE MILKY WAY EXPLODED

A titanic, expanding beam of energy sprang from close to the supermassive black hole in the centre of the Milky Way just 3.5 million years ago, sending a cone-shaped burst of radiation through both poles of the Galaxy and out into deep space.

That's the finding arising from research conducted by a team of scientists led by Professor Joss Bland-Hawthorn from Australia's ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) and published in The Astrophysical Journal.

The phenomenon, known as a Seyfert flare, created two enormous 'ionisation cones' that sliced through the Milky Way – beginning with a relatively small diameter close to the black hole, and expanding vastly as they exited the Galaxy.

So powerful was the flare that it impacted on the Magellanic Stream – a long trail of gas extending from nearby dwarf galaxies called the Large and Small Magellanic Clouds. The Magellanic Stream lies at an average 200,000 light years from the Milky Way.

The explosion was too huge, says the Australian-US research team, to have been triggered by anything other than nuclear activity associated with the black hole, known as Sagittarius A, or Sgr A*, which is about 4.2 million times more massive than the Sun.

"The flare must have been a bit like a lighthouse beam," says Professor Bland-Hawthorn, who is also at the University of Sydney.

"Imagine darkness, and then someone switches on a lighthouse beacon for a brief period of time."

Using data gathered by the Hubble Space Telescope, the researchers calculated that the massive explosion took place little more than three million years ago.

In Galactic terms, that is astonishingly recent. On Earth at that point, the asteroid that triggered the extinction of the dinosaurs was already 63 million years in the past, and humanity's ancient ancestors, the Australopithecines, were afoot in Africa.

An artist's impression of the massive bursts of ionising radiation exploding from the centre of the Milky Way and impacting the Magellanic Stream.
IMAGE CREDIT: James Josephides/Thorsten Tepper-Garcia/ASTRO 3D

COLLABORATION HIGHLIGHT

STEM AMBASSADOR PROGRAM

DR SIMON MUTCH
FROM THE UNIVERSITY OF MELBOURNE

In 2018, I was privileged to be selected as one of Science and Technology Australia's inaugural STEM Ambassadors. The aim of the Ambassador program is to foster long-lasting relationships between members of the STEM community and their local Federal parliamentarian, with a view to building awareness and support for the sector and evidence-based policy.

As researchers funded by the public, we have a responsibility to make sure our work is accessible and that we share our findings and expertise. We also need to ensure that we keep our policy and decision-makers informed of the importance of STEM. These are the people who can affect change now.

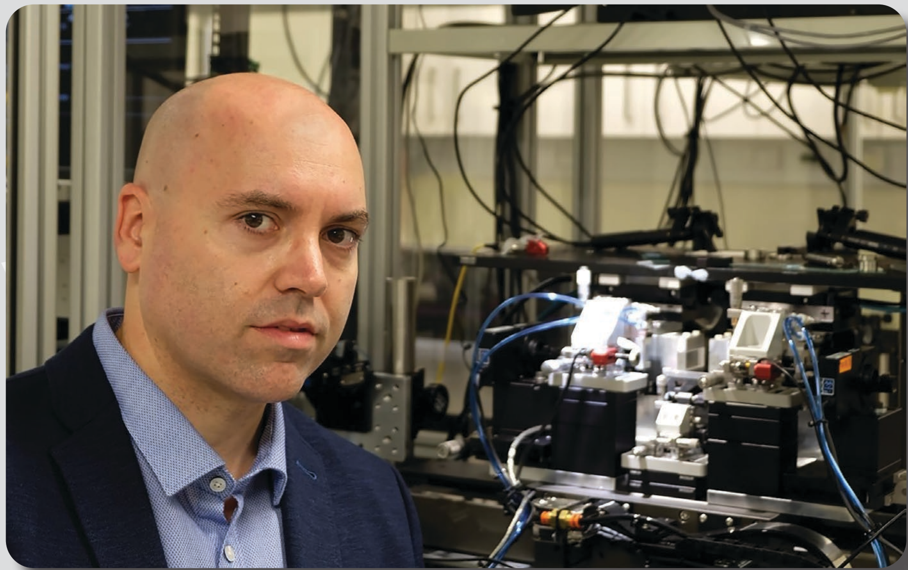
As a resident of Gellibrand, in Melbourne's inner west, I have been paired with Mr Tim Watts. Over the course of the last year and a half we have had a number of discussions, both at his constituency office and at Parliament House in Canberra. Our conversations have been varied, covering topics such as support for basic research and the impact of funding announcement delays on researchers. In March, I also organised for Mr Watts to visit the School of Physics at the University of Melbourne, to see some of the leading research being carried out and to speak with academics and students. This involved a number of ASTRO 3D members and AIs.

Through the STEM Ambassador program, I've had the opportunity to attend both the Parliamentary Friends of Science and Science Meets Parliament events in Canberra. These have provided a unique opportunity to engage with a number of different parliamentarians and their staff, from a broad range of different electorates, each with their own unique interests and issues. The annual Science Meets Parliament event was a particular highlight for me. The event spanned two days. The first provided delegates with valuable professional development on topics such as how to "hone your pitch" and how to interact with parliamentarians and decision makers. The second day then allowed us to take what we had learned and apply it during a face-to-face meeting with a federal parliamentarian. I was fortunate to be given the opportunity to meet with Karen Andrews, the current Minister for Industry, Science and Technology, and I took the opportunity to discuss the research being done within the Genesis team and ASTRO 3D to understand the Epoch of Reionisation and the formation and evolution of galaxies in the early Universe.

Simon Mutch meets with Jeremy Brownlie (STA President) and the Hon Karen Andrews (MP) Minister for Industry, Science, and Technology. ***IMAGE CREDIT:*** Bradley Cummings

I continue to enjoy my time as a STEM Ambassador and the opportunity it gives me to contribute to the success and recognition of Australian STEM. I highly recommend anyone who is interested to keep an eye out for future application rounds. In the meantime, why not get in touch with your local MP and speak with them about the value of STEM for your electorate and Australia? If you are keen to find out more about, visit the STA website or reach out to me for chat.

COMMERCIAL TRANSLATION



Sergio Leon-Saval *IMAGE CREDIT:* University of Sydney

The Sydney Astrophotonic Instrumentation Laboratory (SAIL) is a group led by Collaboration Leader CI Joss Bland-Hawthorn and is based at the University of Sydney. The group collaborates with ASTRO 3D and other research groups around the world to develop new materials and devices for astronomical instrumentation. The labs are directed by Affiliate A/Prof Sergio Leon-Saval (above), this year's sole recipient of the AOS John Love Award, specifically for his excellence in commercial translation.

SAIL is part of the newly funded $4.6M ARC Training Centre for CubeSats, Unmanned Aerial Vehicles (UAV) and Their Applications. The centre is training the next generation of workers in collaboration with industry partners in cutting-edge advanced manufacturing, entrepreneurship and commercial space and UAV applications. SAIL leads the technological development, in collaboration with the Australian Astronomical Observatory (AAO), the Defence Science, Technology Group (DSTG) and HyVista (NSW based company). The first research outcome led by Dr Chris Betters (SAIL) is the cubesat CUAVA-1 slated for launch in March 2020. By then, SAIL will deliver on the CUAVA-HS1 payload, an integrated imager and integral field spectrograph (see below).

IMAGE CREDIT: SAIL Labs

SAIL has an emerging area of research in advanced photonics sensors for the farming industry using robotic platforms. This work is in collaboration with Prof Salah Sukkarieh, formerly of the Australian Centre for Field Robotics (ACFR). He has now set up his own company Agerris that specialises in intelligent robotics platforms and SAIL is currently in discussions on future concepts and collaborative projects.

In 2018-19, SAIL landed a two-year $1.27M grant from the Grains Research & Development Corporation to develop a compact laser-weeding system that would be deployed on a farm robot. The aim is to target and isolate weeds with solar-powered lasers thereby avoiding the need for harmful chemicals that are less able to isolate weeds. The first prototype has already been demonstrated and field trials are ongoing. In recognition of ongoing success, Leon-Saval was awarded a further $150K by the University of Sydney in support of this work.

As a consequence of initial research in 2017-18 with Melbourne Water and Draco Analytics, SAIL has now submitted a $1M ARC Linkage proposal to pursue further developments in portable greenhouse spectroscopic sensors for the water industry. The first successful prototype is shown above (below). In collaboration with the AAO, Bland-Hawthorn and CI Matthew Colless have also submitted an ARC Linkage grant to fund the MANIFEST positioner in collaboration with the Giant Magellan Telescope.

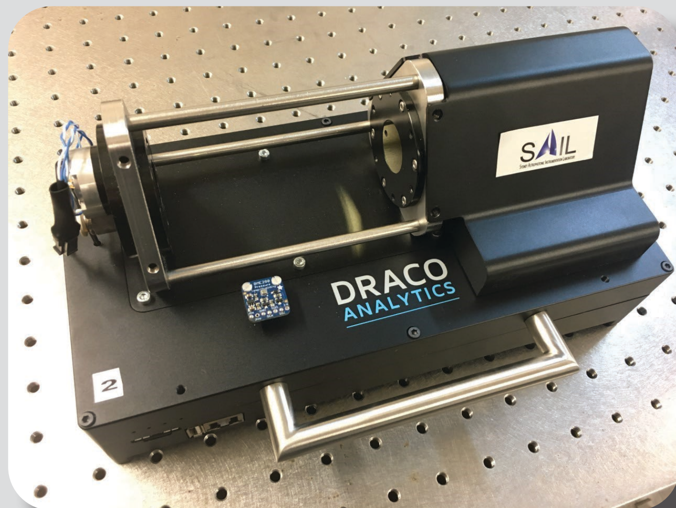


IMAGE CREDIT: SAIL Labs

In 2018-19, CI Bland-Hawthorn and AI Julia Bryant were awarded a $650K ARC LIEF grant to complete the development of the Hector instrument for the AAT. In addition, AI Julia Bryant was awarded $500K through an ARC Future Fellowship and the University of Sydney to ensure the SAIL labs have sufficient funds to complete the instrument development.

Since its foundation in 2015, the refurbished SAIL labs have attracted a total of $2M cash and $300K in equipment and research materials from external research and consultancy contracts to the University of Sydney. Industry and research organisation clients include national and international organisations: Horticulture Innovation Australia (Hort Innovation), Melbourne Water, Ocular Robotics, Draco Analytics, Nokia Bell Labs, and the Universities of Maryland and North Carolina. Many of these projects have assisted SAIL's developments in astronomical instrumentation – the benefits go both ways. Moreover, the SAIL labs have emerged as an ideal training ground for students, post-docs and staff to pick up some experimental training, in particular, in prototyping R&D.

SAIL is always working to upgrade or extend its capabilities. Upcoming collaborative developments include a closer relationship with Subsea Communications Australia (SCA) now that the parent company TE-Subcom is returning to the USA. The present plan is to include them as part of the core lab facilities at the University of Sydney. This will complete our technology base to print complex structures into multicore fibres. We anticipate that SAIL will start to spin off technology companies within the next two years. Some of the related technologies at SAIL are under contract with the University of Maryland and NASA.

COLLABORATIONS

ASTRO 3D has continued with our focus on strengthening collaborations. This was achieved through a combination of key investigators in each survey/project directly engaging partners, and our visitor and student exchange programs.

Our Centre includes seven international partners - University of Washington, Caltech, University of Toronto, the Heidelberg Institute of Advanced Studies, the ASTRON Institute in the Netherlands, Oxford University and the Chinese Academy of Sciences. In 2019, a successful strategy has been to build collaborations around major new observing programs (e.g. MAGPI, PEONY, GALAH Phase 2) and instrument development projects (e.g. Hector spectrograph, MWA calibrators). We have also forged closer ties with simulation groups at Washington, Harvard, UC Davis and Max Planck Institute, Munich that have specific skills to aid active ASTRO 3D science programs.

Our national partner institutions are CSIRO Astronomy and Space Science (CASS), the National Computational Infrastructure (NCI), and the Australian Astronomical Observatory (AAO). We maintain our strong connection with CASS through the ASKAP surveys.

The ASTRO 3D nodes have been collaborating closely with researchers based at the Australian Astronomical Observatory, particularly through science projects like SAMI and GALAH, and instrument builds like Hector. We welcome the new AAO/Macquarie Director Mark Casali from ESO who will help us forge stronger links with ESO countries. The AAO Consortium, a collaboration between Macquarie University, the University of Sydney and the Australian National University, has strong links to ASTRO 3D. AAO/Sydney Director Julia Bryant has maintained strong links with the Blue-MUSE team with a view to joining the construction project and ensuring strong scientific links.

Our collaborations with NCI are underpinning a number of ASTRO 3D flagship projects. CIs Chris Power, Darren Croton and Stuart Wyithe have already engaged with NCI staff to optimise the Genesis simulations for NCI computers that carry the Genesis simulation runs. Many projects from earlier years have now matured to the point of producing published work. Outcomes in 2019 include Phillip Taylor (ANU), working with Michael Hayden (Sydney), using the COCKATOO suite to predict metallicity structure functions to compare with the GALAH simulations. The Genesis/ASKAP, DINGO & WALLABY collaboration (PI Garima Chauhan), with assistance from Clauda Lagos and Daniel Obreschkow (ICRAR/UWA) have been producing mock galaxy light cone simulations. LilianGarratt-Smithson (ICRAR/UWA) has been leading hydrodynamical simulations to identify analogue galaxy populations in support of galaxy evolution observing proposals. The Genesis/Bluetides project, led by Stuart Wyithe (UoM) with Tiziana di Matteo (Carnegie Mellon), is ongoing with a view to publishing papers in 2020. A study of 21cm galaxy correlations in the EoR (Student James Davies) and of quasar host galaxies (student Madeline Marshall) also have broad national support.

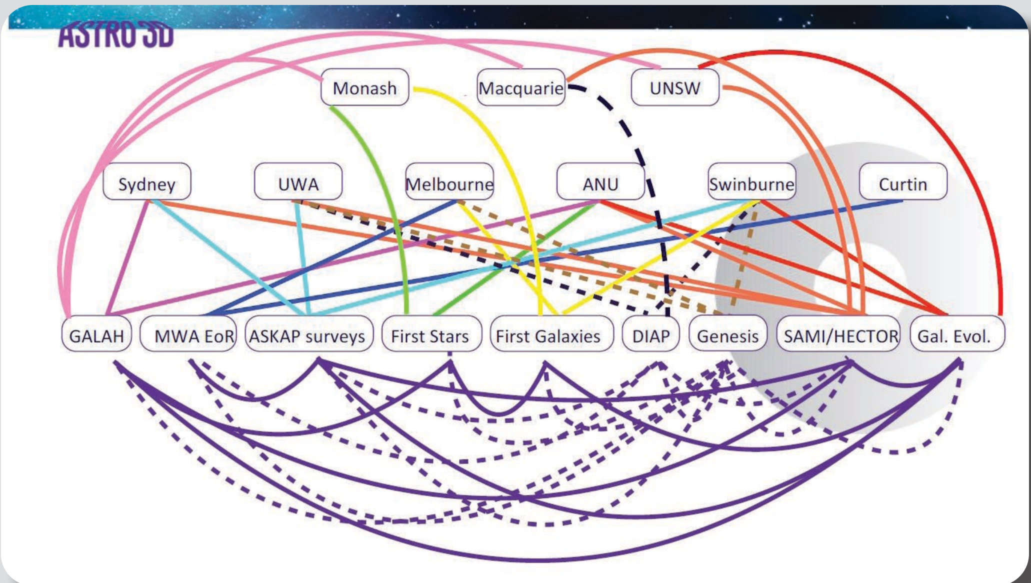


IMAGE CREDIT: Stuart Wyithe

IMAGE CREDIT: Cristy Roberts

Our discussions with the Chinese Academy of Sciences on the synergies between the FAST telescope and ASKAP surveys are progressing well. Professor Di Li (FAST PI) twice visited UWA, CASS and the University of Sydney in 2019. This led to an MNRAS paper (March 2020) with Thorsten Tepper-Garcia and Joss Bland-Hawthorn (University of Sydney) on the predicted gas distribution around our neighbour, the Andromeda galaxy. The FLASH team (PI Sadler) have formed a joint ASKAP/FAST collaboration to look at OH/HI absorption in distant galaxies. This work involves a Chinese PhD student based at Shanghai. The CAS/ASTRO 3D PhD student exchange program is strong, with several student exchanges with student-led papers now in preparation. Members of the ASKAP survey team attended the 2019 MIAPP HI galaxy evolution program in Munich. For the FLASH team, this allowed them to build a new collaboration with Celine Peroux (Marseille) and Martin Zwaan (ESO) to work on joint MUSE and ALMA studies of distant galaxies with 21cm HI absorption detected by ASKAP.

Arguably the most successful new collaboration – MAGPI – has emerged from one of the largest ESO time allocations to be approved with MUSE, the instrument with the highest demand across ESO institutions. A team of early-career ASTRO 3D astronomers (alphabetical: Caroline Foster, Claudia Lagos, Trevor Mendel, Emily Wisnioski, Tiantian Yuan) came together in 2019 to build a large team of galaxy researchers with the goal of studying the 3D kinematics, chemistry and properties of 50+ galaxies in a diverse range of environments at z ~ 0.3. The first major team workshop is already planned for April 2020.

The SAMI project continues to motivate collaborations across ASTRO 3D. Working with Sydney and UWA astronomers, Charlotte Welker (McMaster University) completed and published her long-running study to trace how galaxy spins are correlated with large-scale structure. In July, Glenn van de Ven (Vienna) and Ling Zhu (Shanghai) led a workshop at the University of Sydney on galaxy model building that was attended by 25 participants across ASTRO 3D. The SAMI team also welcomed a visit from collaborator Tom Quinn (Washington) as part of ongoing simulations focused on SAMI data. Sukyoung Yi (Yonsei) is another return visitor in 2019, work that led to two published research papers. In October 2019, a SAMI/Genesis workshop brought members of all nodes across Australia together at UWA as part

The MAGPI Leadership Team - Caroline Foster (University of Sydney), Claudia Lagos (University of Western Australia), Trevor Mendel (Australian National University), Emily Wisnioski (Australian National University) and Tiantian Yuan (Swinburne University of Technology).

of ongoing simulation work. As part of the First Galaxies/Galaxy Evolution project, Michele Trenti (UniMelb) and Tiantian Yuan (Swinburne), looked at directly resolved metallicities of a local analog of a high-redshift galaxy, using SAMI data.

IMAGE CREDIT: Cristy Roberts

As part of the Hector science case, Jesse van de Sande and Joss Bland-Hawthorn were invited to speak at a workshop held at the Lorenz Institute, Leiden. This led to the CosmicFlows-3 team (PI Hélène Courtois) proposing to develop the full 3D flow model of galaxies within the Hector volume. This will revolutionise our approach to galaxy environmental studies with the full Hector database.

IMAGE CREDIT: Cristy Roberts

Harvard theorist Lars Hernquist visited the ANU and University of Sydney twice in 2019 to discuss on-going and new collaborations around the Illustris cosmological simulations. Hernquist attended a GALAH workshop at the University of Sydney where many Gaia-motivated ideas were discussed. New work has now started with PhD student Gus Beane with a focus on galactic archaeology.

IMAGE CREDIT: Cristy Roberts

The PEONY team, led by Rob Bassett (Swinburne), is built around observations with the KOALA instrument. These detailed studies of planetary nebulae also bring together scientists from Monash and Melbourne. Single star HII regions to investigate Lyman continuum escape led by Rob Bassett (Swinburne), involves ANU and Gonzalo Diaz (Gemini).

In 2019, a new collaboration has emerged between Swinburne and ANU scientists, and Tucker Jones (UCSD) to follow up gravitational lenses identified in all-sky DES and DECALS imaging. Their goal is to use the new Keck adaptive optics system (KAPA) to obtain stellar and emission-line spectroscopy of z = 1-3 targets that have been magnified by the intervening galaxies.

Ronniy Joseph (Curtin) is now working with members of the CHIME and HIRAX collaborations looking at new MWA calibration techniques and a joint generalised framework for performing radio interferometer calibration. This involved collaborations with Liu and Sievers (McGill University), Kittiwisit (University of KwaZulu-Natal) and Murray (Arizona State).

IMAGE CREDIT: Cristy Roberts

COLLABORATION HIGHLIGHT

2019 ANNUAL RETREAT

Our third Annual Retreat was held over four days in November 2019 at the RACV Goldfields Resort, Creswick, Victoria. It was another great opportunity for 94 of our ASTRO 3D members from around the country and overseas to update on Theme, Thread and Project/Survey achievments and build on collaborative relationships.

The focus of this meeting was on highlighting our main science achievements in 2019, working on collaborative opportunities and growing as a team. Highlights included:

- Director Lisa Kewley gave an overview of the State of the Centre, including feedback from the Executive, and IAB;
- Chief Operating Officer Ingrid McCarthy updated us on our improvements and acheivements in our operations and of our Professional Staff;
- Stuart Wyithe outlined our Year 3 Scientific Strategic Plan;
- Project/Survey updates by Chris Power, Darren Croton, Cath Trott, Thomas Nordlander, Kim-Vy Tran, Elaine Sadler, Scott Croom, and Michael Hayden;
- Breakout sessions for survey/project strategic planning, committees, and cross project/survey collaborations;
- Education and Outreach update by Ingrid McCarthy;
- Updates on Committees and Education and Outreach;
- Professional Staff meeting;
- Initial face-to-face meetings for our Mentoring Program;
- A student and Postdoc day with training sessions on leadership, interview skills and CV polishing; and
- Social activities, Trivia night and an Awards Evening!

"Was the best combination of science planning/ discussion with team building that I have ever experienced!"
~ anonymous feedback

IMAGE CREDIT: Cristy Roberts

EDUCATION PROGRAMS

REGIONAL TELESCOPES IN SCHOOLS

In 2018, ASTRO 3D partnered with AI Dr Brad Tucker and ANU to fund the purchase and delivery of 8-inch telescopes into regional communities in Queensland and northern Western Australia. Brad gives a public talk and spends time with the teachers, students and where possible, local astronomical societies at a stargazing night, where the teachers and students can start to see the potential of their new instrument.

These telescopes are an economical option, that have great light gathering ability, allowing faint objects to be seen relatively easily, and allowing manual methods of finding objects to be learned and have the potential for many projects linked to the Australian curriculum to be undertaken by the students.

In 2019, Brad and several PhD students took the telescopes to schools in Victoria, Tasmania, South Australia and southern Western Australia. In the latter part of 2019 new Education and Outreach Coordinator, Dr Delese Brewster, undertook an evaluation of the schools that had been given telescopes, to better inform the program going forward.

2020 will see us providing each of the existing telescopes with a solar filter, allowing daytime viewing of solar activity, along with a mobile phone holder, which will allow astrophotography projects to be carried out.

We are currently editing an instructional series of videos to demonstrate telescope setup and use, while in 2020 we will be providing teacher education and resources and rolling out telescopes to more regional and remote schools.

Brad Tucker giving a public talk at Buderim Mountain State School,
IMAGE CREDIT: Brad Tucker

UWA SPIRIT IN SCHOOLS TELESCOPE PROGRAM

To compliment the Regional program, ASTRO 3D at University of Western Australia is partnering with ICRAR to deliver the SPIRIT in Schools program. This program is designed for female students and students from lower socioeconomic backgrounds.

Classroom teachers will be given the tools and support to aid their students to design, implement and complete an astronomy project using the SPIRIT remote internet telescope.

The students start by choosing a target and then observe it. They need to manipulate their images and even extrapolate information from the data to solve a question, such as “what is the mass of Jupiter?”

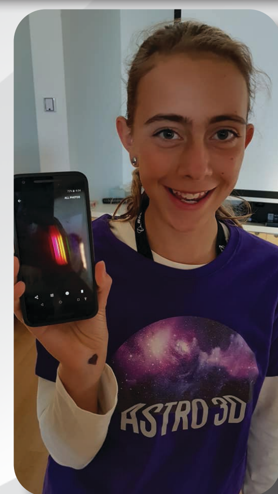
The final outcome of the project can be designed by the teacher to better reflect their class’ aptitudes and interest. The most important outcome is that students realise they can design and implement an astronomy-based project.

SPACE SQUAD

ASTRO 3D has been partnering with YMCA Canberra Space Squad since the start of 2018. Space Squad is a school holiday immersion program for students aged between 12 and 15, where they learn about space exploration and astronomy, as well as meet Canberra-based engineers, astronomers, astrophysicists and scientists who work on all things space-related.

As part of their experience, students come to Mt Stromlo Observatory (ANU Research School of Astronomy and Astrophysics) where they listen to an ASTRO 3D astronomer give a talk about their research, find out more about how our researchers collect 3D datacubes of spectral information on surveys like SAMI and GALAH. Students also find out more about the chemical composition, spin and motion of stars and galaxies.

In 2019 we had visits from Space Squad in January, April, July and October, with talks from Post-Doc Katie Grasha, Student Ayan Archayya, CI Lisa Kewley, and Post-Doc Nell Byler.



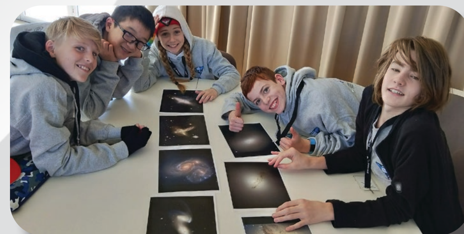


IMAGE CREDITS: Ingrid McCarthy

EDUCATION HIGHLIGHT

PHYSICS DEPTH STUDIES AT SIDING SPRING

2018 saw the introduction of Depth Studies to the NSW Year 11 and 12 Physics Curriculum to provide the opportunity for students to pursue their interests in science, acquire a depth of understanding, and take responsibility for their own learning. In collaboration with Siding Spring Observatory and ANU's Research School of Astronomy and Astrophysics, ASTRO 3D developed a 3-day excursion for Year 12 Physics students and their teachers. Matt Dodds from Farrer Memorial Agricultural High School in Tamworth created a schedule of activites that addressed Module 7 and 8 of the Physics curriculum - the physics of spectroscopy.

IMAGE CREDIT: Matt Dodds

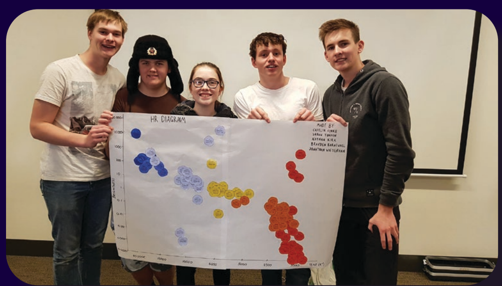


IMAGE CREDIT: Matt Dodds

The 20 students spent time with:

- Dilyar Barat (PhD student from ANU), learning about how spectroscopy can be used to provide information about the identification of elements, along with how the spectra of stars can provide information on surface temperature, rotational/translational velocity, density and chemical composition of stars.
- Dr Chris Lidman, visiting the Anglo Australian Telescope (AAT) and the SAMI spectrograph. Chris also explained the key features of stellar spectra and the classification of stars and nucleosynthesis reactions in Main Sequence and Post-Main Sequence stars
- Tash Marshall from Sydney University learning about photographing spectra and looked at 2DF and SAMI data
- Rebecca Brown from Sydney University talked about the new Hector Instrument as well as her career path within engineering/ instrumentation.

IMAGE CREDIT: Matt Dodds

The students thoroughly enjoyed their excursion and the feedback we received was extremely positive. Plans are being made for a 2020 event, as well as Year 11 Physics Depth Study excursions.

"Our students were so impressed and engaged throughout the two very full days and night of quality teaching and learning experiences. You have helped open their eyes to possible career paths as well as increase their knowledge of astronomy, astrophysics and engineering!"

OUTREACH AND ENGAGEMENT

ASTRO EVENTS

ASTRO 3D outreach staff had another great year in 2019, developing more activities and stalls for large public outreach events that reached approximately 45,000 people! Curtin Node Outreach Officer Teresa Slaven-Blair developed a Cosmic Microwave Background maze - light tries to escape the particle soup of the early Universe, where it can then avoid obstacles easily and get to us on Earth. Participants roll a four-sided dice which determines where the photon of light goes (up, down, right or left). All the participants then entered the number of rolls it took into a database, so we could see the distribution - maths, physics, data all in one!

2019 Highlights included:

- AstroFest in Perth in February
- InterACTive Science in Canberra in August
- Governor General's Design Challenge in Canberra in August
- Perth Science Festival in August.

IMAGE CREDITS (above and below): Teresa Slaven-Blair

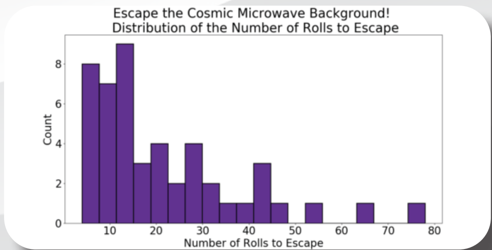


IMAGE CREDIT (above): Ingrid McCarthy

IMAGE CREDIT (above): Teresa Slaven-Blair

ULURU ASTRONOMER IN RESIDENCE

ASTRO 3D continued to work in partnership with Voyages Indigenous Tourism Australia to deliver this program in 2019. This year, we developed a “cosmic cocktail” event in the schedule, where the public listened to a more in-depth discussion from our astronomer about their research.

Astronomers from our team were in residence from April to October on a fortnightly roster, engaging with the general public, sharing their research, as well as general astronomy knowledge at our booth in the Town Square, at a movie Q&A session and during night-sky tours.

IMAGE CREDIT: Anshu Gupta

IMAGE CREDIT: Ingrid McCarthy

OUTREACH HIGHLIGHT

U4D - THE UNIVERSE IN 4 DIMENSIONS

U4D is a unique performance piece combing dance, astronomy, photography, and music.

Funded through the 2019 National Science Week grants, our Education and Outreach Manager, Ingrid McCarthy worked with Artistic Director Liz Lea to create a journey of discovery through space and time.

We utilised ASTRO 3D theoretical simulations, projected on three walls of a ‘black box’ theatre. Dance and music, combined with videography from Jen Brown and violin from indigenous musician and dancer Eric Avery combined to attract a new audience for our science.

Between scenes, Ingrid chatted to theoretical astrophysicist, Dr Phil Taylor, from the Australian National University, to uncover what the simulations and the science were telling us.

Dancers Natasha Rogers and Alana Stenning were mesmerising in their contemporary dance performances and we spread our dance wings with belly dancing from ASTRO 3D’s own administrator Kirsty Waring.

Animator James Josephides from Swinburne Astronomy productions added to the atmosphere by combining animations and simulations.

We had excellent feedback from the audience, most of whom had never attended a Science Week event.

Postdoc Phil Taylor explains the simulations to COO Ingrid McCarthy during the live performance

IMAGE CREDIT: Cristy Roberts

Dancers Natasha Rogers and Alana Stenning in front of animated siumulations by James Josephides during the live performance

IMAGE CREDIT: Cristy Roberts

“I didn’t know very much about Theoretical Astronomy and this performance has made me interested in learning more.” ~ anonymous feedback

Eric Avery playing in the burnt out Yale Columbia dome at Mt Stromlo Observatory

IMAGE CREDIT: Jen Brown

MEDIA AND SOCIAL MEDIA

During 2019, ASTRO 3D and its members had great media coverage, in print, radio, TV and online.

WEBSITE

The Centre's website www.astro3d.org.au was populated with news stories and highlights from the Centre's activities and our new COO began significant work redesigning our website, with a member's survey, new design, new structure and functioning and new content. It will go live in early 2020.

MEDIA RELEASES - HIGHLIGHTS

- MAGPI soars far back into the Cosmic Middle Ages
- Anaemic Star Carries the Mark of Its Ancient Ancestor (First Stars project)
- And then there was light: looking for the first stars in the Universe (EoR MWA project))
- Spin doctors: Astrophysicists find when galaxies rotate, size matters (SAMI Survey)
- Star-quake vibrations lead to new estimate for Milky Way age (GALAH survey)
- Not Long ago, the centre of the Milky Way exploded (Galaxy Evolution)
- Science needs true diversity to succeed – and Australian astronomy shows how we can get it

SOCIAL MEDIA AND MEDIA

Social media engagement grew substantially, with the Centre's Twitter audience growing to 780 followers (238 new followers in 2019) and our Facebook page "Likes" increasing to 345.

We also started producing our own social media videos to highlight our researchers and our science. To this end, we now have our own YouTube channel where all our videos are compiled.

Centre Director, Lisa Kewley has had a busy year for media appearances on behalf of the Centre. With press releases for her Diversity in Astronomy paper which was picked up by many media outlets, she has also given interviews for JJJ radio, ABC radio and a live TV interview on ABC National News.

Prof Lisa Kewley live on ABC News
IMAGE CREDIT: ABC News

Associate Investigator Brad Tucker was also popular in the media, with TV interviews on ABC, Sky News, 7:30, Good Morning Britain, Sunrise, radio interviews on ABC, 2CC Canberra, 6PR Perth, 4BC Brisbane, 2GB Sydney and many public outreach and school talks, including our Regional Telescopes in Schools pilot.

Dr Brad Tucker getting ready for a radio interview with ABC Radio
IMAGE CREDIT: Jack Fox, ANU

RESEARCH TRAINING & PROFESSIONAL DEVELOPMENT

ASTRO 3D Research training programs are focused on both research skills and other professional skills needed to develop an exceptional team of researchers and students.

WRITING RETREATS

Writing retreats were held again in August at Coogee and in November at Curtin University. The retreats are designed to provide an exceptional opportunity for ASTRO 3D members to focus on writing an academic paper in the supportive company of peers from across the country.

The rationale behind a 'retreat' model of writing workshop is that it helps our members to:

- develop a collegial network across the Centre of Excellence;
- become comfortable in a peer-supported culture of academic writing;
- affirm their identity as a research scientist who seeks to communicate their findings; and
- share knowledge, practices and experiences related to writing and publishing.

This five-day slice out of usually busy workplaces was just the thing to get the writing juices flowing:

- "Peer review has been amazing. I received good feedback and that made writing so much better and easier."
- "The talk on tips to improve writing was very useful. I was able to change a bunch of words in my paper that were used incorrectly."
- "The talks regarding resilience and writing tips were useful. The writing time was well organised and people were courteous of others concentrating on their own work."

"Peer review has been amazing. I received good feedback and that made writing so much better and easier."
~ anonymous feedback

IMAGE CREDIT: Kim-Vy Tran

PROPOSAL WRITING WORKSHOP

ASTRO 3D ran a 3-day workshop at Mt Stromlo Observatory in September, where 20 members (both in person and via Zoom-meeting) attended sessions on:

- how to write effective DECRA and Future Fellowship applications;
- successfully applying for telescope time; and
- post-doctoral research job applications.

The sessions had successful proposal writers discuss their experiences, provide tips and advice for new applicants.

In the afternoons, they reviewed sample proposals to discuss what made them compelling and how to incorporate the same strategies in new proposals.

One-on-one sessions with past applicants proved to be an invaluable resource and excellent mentorship opportunity.

IMAGE CREDIT: Ingrid McCarthy

WOMEN'S LEADERSHIP

In late October, we ran a Trajectories in Women's Leadership at Bowral, facilitated by Dr Beth Beckman. A total of 15 female members from across different nodes and seniority levels attended, including researchers and professional staff.

The workshop was orientated to the individual with a focus on personal values, communication styles, and approaches to the different styles of others. The interactive sessions allowed time for self-reflection, mindfulness and also some fun, plus the opportunity to spend time outside enjoy the amazing gardens at Milton House. Participants left the workshop, not only with great strategies and insights to use and develop in their work and personal lives, but also having developed stronger relationships and connections across the group.

IMAGE CREDIT: Beth Beckmann

"I have a plan and a clearer picture of who I am as a leader and my style." ~ anonymous feedback

UNCONSCIOUS BIAS WORKSHOP

This workshop, facilitated by Gender Matters, was held in our Melbourne, Sydney, Perth and Canberra Nodes in February and March.

Unconscious bias exists outside our awareness. Despite our best efforts to be fair and transparent, it can unconsciously influence our decision-making. It is important that everyone in ASTRO 3D is able to identify potential unconscious biases and how they impact our behaviour and interactions with others.

We ran this workshop to help staff to look beyond unconscious bias, develop skills and strategies to interrupt and minimise the impact of unconscious bias and tap into and achieve the most from the diverse talents of one's team.

Participants explored the following areas:

- Unconscious bias: what is it? and what are some of the bias 'hot spots'?
- Why is it important to address unconscious bias?
- How to identify your own unconscious biases and how they impact your behaviour?
- What skills and strategies can we utilise to interrupt and minimise the impact of unconscious bias?
- Benefits of addressing bias including improved participation and workplace performance.

IMAGE CREDIT: Cristy Roberts

DYNAMICAL MODELS OF OBSERVED GALAXIES

The University of Sydney hosted a successful and highly productive workshop on "Dynamical Models of Observed Galaxies" on June 3-7 in Sydney, sponsored by the Hunstead Fund for Astrophysics and the ASTRO 3D Science Visitor Program. The morning sessions were filled with excellent invited and contributed talks. The invited speakers presented an overview on the ins-and-outs of Schwarzschild modelling, what we have learned from fitting these models, and how we can interpret the latest results in the broader context of galaxy evolution. There was a wide range of contributed talks from Galactic Archaeology in the Milky Way with GALAH to the dynamical evolution of galaxies out to z~3. With expertise in all these areas, almost every talk ran (purposely) overtime due to an overload of questions combined with fruitful discussions. A special mention to one of the invited speakers who ran 30 minutes overtime on a 30 minute talk, without a single complaint from the chair or audience due to the excellence of the talk.

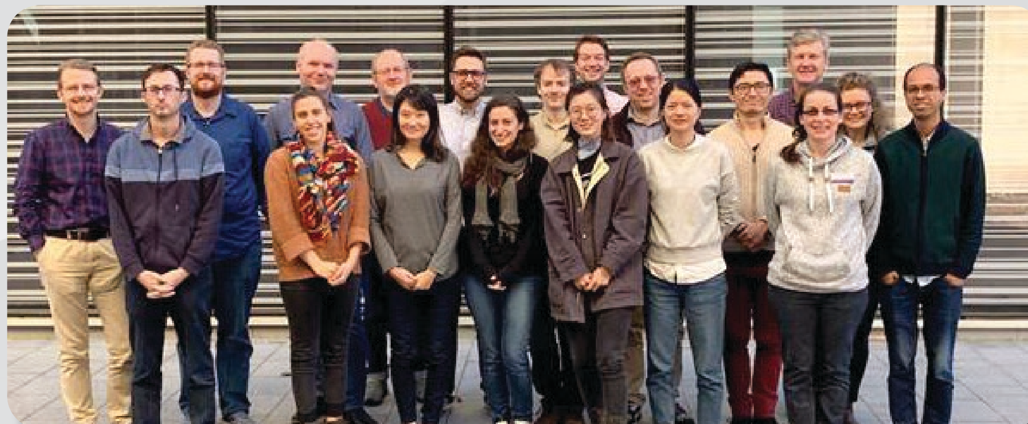


IMAGE CREDIT: Jesse van de Sande

LIFE AND DEATH OF STAR-FORMING GALAXIES

The extremely successful life and death of star-forming galaxies conference took place on March 18-22 in Scarborough, Perth. We had 93 participants, mostly international (69%).

This 5-day workshop sponsored by ASTRO 3D and ICRAR focussed on 4 key themes (under the general topic of star formation of galaxies across cosmic age), with the aim of summarising the state of the field, identifying current challenges and discussing ways forward to make significant progress over the life-time of ASTRO 3D.

It was an engaging and lively workshop to discuss the status, challenges and prospects for these specific areas of galaxy evolution. We had 1-1.5 days focused on each theme, each ending with a discussion/ brainstorm to summarise where we are, what we do not understand, what is controversial and how can we make progress in the next few years. Each discussion will be co-led by members of the SOC.

IMAGE CREDIT: Kim Dorrell

BAREFOOT EOR

The goal of this meeting was to bring together a wide community of observers and theorists to discuss both recent progress as well as future perspectives for galaxy studies within the first billion years and for cosmic reionisation. Building on the success of the inaugural EoR conference held at Uluru, NT in 2013, this year's meeting convened international experts in simulations, theory and observations of the first billion years of the Universe in a beautiful Great Barrier Reef location.

Invited speakers included Tiziana Di Matteo (Carnegie Mellon), Andrei Mesinger (Scuola Normale Superiore), Marusa Bradac (UC Davis), and Judd Bowman (Arizona State University). Sponsored by ASTRO 3D and ICRAR, the event saw some significant changes over the past six years, in both demographics and advances in the field of knowledge.

IMAGE CREDIT: Aman Choski

STUDENT RETREAT

The Student Retreat ran from 17-19th of May 2019 at YMCA Sydney Olympic Park Lodge. The Students organised the entire event themselves and was designed to help them bond as a cohort and provide appropriate professional skills.

After arriving the Friday evening, with dinner and social activities, Saturday was dedicated to improving their Presentation Skills. Dr Phil Dooley (Science Communication expert) hosted a 1 hour Zoom-meeting session before the Retreat on Captivating Presentations, which covered general principles of good presentations and then also ran a session in the morning to warm up the speakers and provide physical tips and tricks.

Each student then gave a 5-Minute-Thesis style talk, where they outlined their research. To set this apart from conference talks, no science questions were asked.

Feedback was given after each talk by:

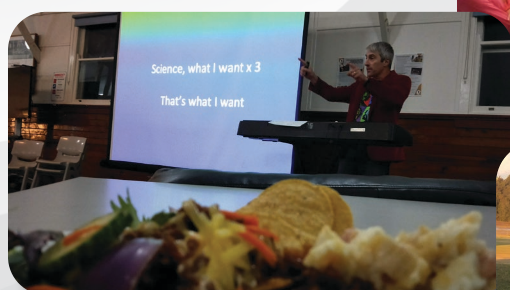
- Phil Dooley (voice and body)
- Claudia Lagos - UWA (science content)
- Caitlin Adams - Data Scientist and PhD in Astrophysics from Swinburne (slide design and narrative structure)

Ingrid McCarthy (language and suitability for audience)

On Sunday, Students were splits into collaborative groups of three or four, who had similar science interests. The main goal of the day was to get the Students to learn more about the research happening at different nodes, that may be applicable to their research. Claudia Lagos (UWA) led the day and helping the groups come up with a potential cross-node project idea.

Additionally, there was plenty of time for social activities, including archery, board games, chatting by the fire and a very interactive sing-along led by Phil Dooley.

IMAGE CREDITS: Ingrid McCarthy



MENTORING PROGRAM

2019 saw us kick off our ASTRO 3D Mentoring Program. Our aim is to see higher engagement of our members, a more positive and inclusive Centre and workplace cultures, and better leadership development.

We are using the Mentorloop online platform to empower our members to improve. We created matching criteria (experience, research interests, career goals) and created pairs or groups of Mentors and Mentees who have similar interests and needs.

At our Annual Retreat, the groups got to meet in person and we shared some resources to get the most out of the program, including checklists and learning resources to help them achieve the outcomes they are after.

At that meeting, we use Mentorloop as a software platform to help participants stay connected, develop their goals, track their activity and provide resources and checklists to make sure they get the most out of their mentoring group.

- Check out your Mentor's/Mentee's digital footprint – are they on Twitter or LinkedIn? Do they have a blog?
- Consider your goals for the mentoring relationship – why have you signed up, and where do you want to be in 6 months or 12 months?
- Start to think about how your Mentor could best assist you/how you can best assist your Mentee.

We currently have 20 participants, with the program open for ongoing sign ups and matching. We look forward to working with them in 2020 to achieve their goals!

IMAGE CREDIT: Ingrid McCarthy

IMAGE CREDITS: Cristy Roberts

GENDER EQUITY AND DIVERSITY

	GENDER EQUITY NUMBER OF FEMALES	DIVERSITY NUMBER OF INDIGENOUS PERSONNEL	TOTAL PERSONNEL
Chief Investigators	6	0	16
Partner Investigators	3	0	13
Associate Investigators	13	0	54
Affiliates	13	0	26
Postdoctoral Fellows	4	0	8
Postdoctoral Researchers	13	0	27
Students	26	0	72
Professional staff	14	0	16
TOTAL:	***92***	***0***	***232***
Advisory Board Membership	7	0	11

IMAGE CREDITS: Cristy Roberts

2019 AWARDS AND GRANTS

Elaine Sadler (University of Sydney) - Officer of the Order of Australia (AO) for distinguished service to science as an astrophysicist, in the field of galaxy evolution, and to gender equity.

Sarah Sweet (Swinburne University of Technology) - SUT FSET Travel Grant

Colin Jacobs (Swinburne University of Technology) - Microsoft Cloud Software Fellowship, which includes $3000 of Azure credits and $2000 travel support.

Julia Bryant, (University of Sydney) - SOAR Prize - to do a time-critical early data release from Hector, using optical imaging fibre bundles (hexabundles) she developed.

Bland-Hawthorn J, Leon-Saval S, Sharp R, Bryant J, Croom S, Lawrence J, Owers M, Australian Research Council (ARC)/Linkage Infrastructure, Equipment and Facilities (LIEF)

Jesse van de Sande (University of Sydney) - Discovery Early Career Researcher Award (DECRA), - The mysterious thick disk: Unifying Galactic and extragalactic dynamics.

Alan Duffy & Virginia Kilborn (Swinburne University of Technology) - Swinburne's Vice-Chancellor's Community Engagement Award - Team award

Deanne Fisher (Swinburne University of Technology) Swinburne's Vice-Chancellor's Inclusion and Diversity Award Team award Winner: Gender Agenda: Gender Diversity Support Group Julia Prendergast, Deanne Fisher (ASTRO 3D).

Sergio Leon-Saval (University of Sydney) - Australian Optical Society John Love Award for substantial achievement in translational optical research and/or development towards industrial applications and commercialisation by an individual or small team

Danail Obreschkow (University of Western Australia) - Australian Research Council (ARC) Future Fellowship - of how galactic spin drives observable galaxy properties and interacts with invisible dark matter.

Adam Thomas (Australian National University) - 2019 ASA Charlene Heisler Prize for best PhD thesis on The ionising radiation and gas-phase metallicity in the narrow-line regions of Seyfert galaxies

Mark Krumholz (Australian National University) - 2019 Anne Green Prize for contributions to our understanding of the origin of turbulence in the interstellar medium of galaxies, and its relationship to star formation and mass transport.

Jeffrey Simpson (UNSW) - 2019 ASA Student Prize for Best Poster - The GALAH Survey: Chemical tagging globular clusters to stellar streams

Nicholas Scott (University of Sydney) - Australian Research Council (ARC)/Discovery Early Career Researcher Award (DECRA) - Extragalactic Archaeology,

OUR PEOPLE

CHIEF INVESTIGATORS

CENTRE DIRECTOR

PROF LISA KEWLEY

Institution: Australian National University

Theme Leader: Origin of the Ionised Universe

Centre Director Lisa Kewley is an established world leader in the theoretical modelling and observation of star-forming and active galaxies. Her recent research combines stellar evolution and photoionisation models with cosmological hydrodynamic simulations to predict how the ionising radiation in galaxies changes over time. Her work has shown that there have been dramatic changes in ionising radiation in galaxies over the past 6 billion years.

Lisa's expertise covers both optical and radio astronomy, observation and theory, as well as understanding local and distant galaxies. She will bring this expertise into her Theme leader role that connects the MWA Epoch of Reionisation project with simulations of the ionising radiation seen in the first galaxies and examines how the ionising radiation evolved over cosmic time to the point where is observed in nearby galaxies with SAMI.

DEPUTY DIRECTOR

PROF STUART WYITHE

Institution: University of Melbourne

Thread Leader: Genesis Simulations

Node Leader: University of Melbourne

Professor Stuart Wyithe is an international leading authority in the theoretical simulation of the Epoch of Reionisation and Gravitational Lensing and also currently the Head of the School of Physics at the University of Melbourne.

Stuart's theoretical expertise spans the Epoch of Reionisation to first star and galaxy formation and evolution, and he also brings important strategic planning experience to ASTRO 3D.

Stuart is working closely with Lister Stavely-Smith to ensure the Genesis Simulations are incorporated into the Data Intensive Astronomy infrastructure, an mock data are produced for the Centre's surveys.

His research interests lie in the field of quasar formation and reionisation in the early universe. In particular, he is interested in the evolution of the earliest galaxies and how this evolution may be studied with the next generation of radio telescopes.

PROF MARTIN ASPLUND

Institution: Australian National Univeristy

Project Lead: The First Stars

Survey Lead: GALAH

Node Leader: Australian National University

Professor Martin Asplund is an international leading authority in stellar/solar astrophysics, the Milky Way and the origin of the elements.

Martin and his First Stars team are using the ANU SkyMapper Telescope to discover the oldest stars in the Universe. A few of these stars have survived to the present day and can be found in and around the Milky Way Galaxy. Their chemical compositions reveal the nature of the first stars and the conditions in the early Universe.

Martin is also a leader of the GALAH survey, the largest stellar spectroscopic inventory of the Milky Way. By determining the chemical make-up of up to a million stars with the Anglo-Australian Telescope, the history of our own Galaxy can be unraveled.

He is also an active mentor for young researchers both in observations with the largest telescopes and advanced supercomputer simulations.

PROF JOSS BLAND-HAWTHORN

Institution: University of Sydney

Collaboration Leader

Survey Lead: GALAH

Professor Joss Bland-Hawthorn is an ARC Laureate Fellow renowned for innovative and broad-reaching science of both theoretical and observational astronomy, covering optical, infrared and radio wavelengths. Joss also develops astronomical instrumentation, having developed SAMI and HERMES instruments that will be used in the SAMI and GALAH surveys.

Joss and his team are using the GALAH survey to trace the chemical and mass assembly history of the Milky Way. In combination with the Genesis dynamical models, Joss is untangling the many complex processes involved in shaping a typical spiral galaxy like ours.

He is also identifying the science areas that require more collaboration. He is prioritising visits for these areas, identifying, and directing key participants to facilitate and encourage collaboration.

DR BARBARA CATINELLA

Institution: University of Western Australia

Project Lead: ASKAP

Senior Research Associate Barbara Catinella is a radio astronomer passionate about understanding how galaxies form and evolve.

She leads state-of-the-art legacy surveys using the largest radio telescopes in the world to investigate how cold gas - the raw fuel for star formation - cycles in and out of galaxies. These surveys provided the deepest observations of cold gas in the local Universe, uniquely probing the vastly unexplored gas-poor regime and yielding strong constraints to theoretical models and simulations of galaxy evolution. Barbara also pioneered the applications of the spectral stacking technique to the study of gas scaling relations.

Her mission within ASTRO 3D is to make sure that the next-generation cold gas surveys with the Australian Square Kilometre Array Pathfinder (WALLABY and DINGO) will be scientifically exploited to the fullest potential and to maximise their synergy with state-of-the-art optical surveys with integral field spectrographs such as SAMI and Hector.

PROF MATTHEW COLLESS

Institution: ANU

Survey Lead: SAMI/Hector

Professor Matthew Colless has made major contributions to astronomical research in the fields of galaxy evolution, clusters of galaxies, the large-scale structure and motions of galaxies, and observational cosmology. As part of ASTRO 3D, he is leading a research team using the SAMI and Hector instruments to investigate the dynamical structure of galaxies and the accretion of angular momentum and how these affect their star formation histories and stellar populations.

Matthew is also Director of the Research School for Astronomy and Astrophysics (RSAA) at the ANU. He plays a significant role in supporting ASTRO 3D, as RSAA provides some of the Centre's key facilities, through the wide-field optical capabilities of the ANU-owned SkyMapper Telescope and the ANU-operated Anglo-Australian Telescope.

PROF SCOTT CROOM

Institution: University of Sydney

Survey Lead: SAMI/Hector

Node Leader: University of Sydney

Professor Scott Croom brings over a decade of experience leading large spectroscopic surveys to ASTRO 3D.

Scott leads the SAMI and Hector surveys. SAMI results include new insights into galaxy scaling relations, the discovery of outflows in star-forming galaxies, and greater understanding of the formation mechanism behind dispersion-dominated galaxies.

SAMI will be replaced by the Hector spectrograph in 2020. Hector will survey 30,000 galaxies within a five year period and be significantly faster than SAMI.

Scott is also facilitating collaborations with the Genesis team to compare the theoretical star-formation history of galaxies with observation.

PROF DARREN CROTON

Institution: Swinburne University of Technology

Project Lead: Genesis Simulations

Professor Darren Croton is an internationally-known theoretical astrophysicist who works on the formation of galaxies in the nearby and distant Universe. He conducts massive cutting-edge supercomputer simulations and mines large observational data sets from some of the world's largest telescopes.

Darren is using his extensive experience working as a theorist within large survey teams to lead the development of new models, built with SAGE (Semi-Analytic Galaxy Evolution). These models will be applied to the interpretation of the vast amounts of data ASTRO 3D astronomers will have on-hand across the Centre.

Darren will also assist the Data Intensive Astronomy team to create a single, cohesive interface where astronomers can query both the Genesis Simulations and the observational data simultaneously.

PROF KARL GLAZEBROOK

Institution: Swinburne University of Technology

Project Lead: Galaxy Evolution

Professor Karl Glazebrook was the Director of the Centre for Astrophysics and Supercomputing at Swinburne University of Technology in 2019 and is now an ARC Laureate Fellow. His research interests include observational cosmology and the formation and evolutionary history of galaxies.

Karl is leading the Galaxy Evolution project, coordinating Keck observations, analysis and outputs for both the Origin of the Ionised Universe theme and the Origin of Matter and the Periodic Table theme.

He is also leading senior academics in large inter-University research collaborations, matching resources to skills and expertise across ASTRO 3D programs.

A/PROF CHRISTOPHER POWER

Institution: University of Western Australia

Project Lead: Genesis Simulations

Associate Professor Chris Power is a leading computational astronomer who is having a major impact in his field, working on a broad range of problems in galaxy formation and cosmology.

Chris is leading the development of the Genesis Simulations that will track the birth, growth and the ultimate fate of galaxies from the earliest epoch of galaxy assembly, through the Epoch of Reionisation to the present day.

Chris' interests are in dark matter – what is its nature? What kinds of observations will allow us to discriminate between alternative models? How does feedback from stars and black holes (i.e. deposition of energy and momentum into their surroundings) impact the formation and evolution of galaxies? He also has an interest in scientific high performance computing.

Chris models large N-body simulations (comprising of ~100 billion particles) to construct the most detailed and sophisticated prescriptions for galaxy formation that we have.

A/PROF EMMA RYAN-WEBER

Institution: Swinburne University of Technology

Project Lead: Galaxy Evolution

Node Leader: Swinburne University of Technology

Associate Professor Emma Ryan-Weber is an international leader in the observation of metals in the Intergalactic Medium at high redshifts.

Her pioneering near-infrared spectroscopic observation was the first to demonstrate the viability of detecting intergalactic metals towards the end of the Epoch of Reionisation.

Within the Galaxy Evolution Project Emma is overseeing work on ionisation: directly measuring the ionising radiation from galaxies at redshifts in the broad range $z \sim 3-4$ and developing calibration for escaping flux.

The results will be applied to galaxies at higher redshifts to ultimately understand how the Universe was reionised.

PROF ELAINE SADLER

Institution: University of Sydney

Theme Leader: Origin of Matter and the Periodic Table

Survey Lead: ASKAP

Professor Elaine Sadler has extensive expertise in leading large radio astronomy surveys with extremely high international impact.

Elaine's research expertise covers both optical and radio astronomy, and she brings extensive science management experience, including the leadership of major galaxy surveys with significant international impact.

Elaine is the Leader of the Origin of Matter and Periodic Table Theme as well as the ASKAP FLASH survey. She is a Fellow of the Australian Academy of Science, ATNF Chief Scientist and in January 2019 was awarded Officer (AO) in the Order of Australia for distinguished service to science as an astrophysicist in the field of galaxy evolution and to gender equality.

PROF LISTER STAVELEY-SMITH

Institution: University of Western Australia

Thread Leader: Data Intensive Astronomy

Node Leader: University of Western Australia

Professor Lister Staveley-Smith is the Science Director at ICRAR/UWA and has over two decades of experience in leading major surveys on new radio telescope facilities and in developing and applying new software and computation techniques.

Lister is coordinating and leading the Data Intensive Astronomy observational teams at UWA, Curtin, AAO and the University of Sydney to ensure a cohesive Data Intensive Astronomy structure that facilitates the analysis of our petabyte-scale datasets.

He is also co-leader of WALLABY, one of three ASKAP surveys which provide a critical, complementary suite of wide and deep coverage of galaxies through space and time.

A/PROF MICHELE TRENTI

Institution: University of Melbourne

Project Lead: First Galaxies

Associate Professor Michele Trenti is an ARC Future Fellow who has built a strong international reputation for combining theoretical simulations and observations to understand the first galaxies in the Universe.

Michele is using the current Hubble Space Telescope and will use the future JWST to observe the chemical elements within the First Galaxies of the Universe. This involves understanding how much of the elements were produced in the first galaxies and whether they are blown out of these galaxies by massive galactic-scale winds from stars or supermassive black holes.

He is also connecting theorists with observers to understand galaxy formation from both a theoretical and observational practice, aiding in linking the First Galaxies observations with the deep understanding of galaxy evolution that ASTRO 3D will provide.

A/PROF CATHRYN TROTT

Institution: Curtin University

Project Lead: MWA EoR

Node Leader: Curtin University

Associate Professor Cathryn Trott is using the current and expanded MWA and in the future, the SKA to explore the evolution of ionised hydrogen in the early Universe.

Cath is leading the ICRAR MWA Epoch of Reionisation (EoR) project for the Origin of the Ionised Universe Theme. Cath will also use the supercomputing facilities at the Pawsey Centre for EoR data storage, triage and analysis, augmented by existing and future-developed sophisticated signal processing algorithms.

She is also assessing the scientific progress of the Centre against goals as part of the Science Management Committee, and developing her team with leadership and mentoring skills.

PROF RACHEL WEBSTER

Institution: University of Melbourne

Project Lead: MWA EoR

Professor Rachel Webster is a Redmond Barry Distinguished Professor in the University of Melbourne School of Physics. She is a world expert in the field of reionisation and is currently the chair of the Board of Directors for Australian Astronomy Limited (AAL). She brings extensive leadership expertise to ASTRO 3D.

Rachel is leading the data reduction and analysis of the Epoch of Reionisation signals observed with the MWA. The extension of the MWA from 128 tiles to 256 tiles will break open the veil on the Epoch of Reionisation, allowing fundamental parameters of the Early Universe to be constrained.

Professor Webster's other research interests include quasar emission regions, gravitational lensing and cosmology; with a side interest in the physics of geothermal energy.

PARTNER INVESTIGATORS

NAME	ORGANISATION	PROJECT/S
Roberto Abraham	University of Toronto	Galaxy Evolution
Douglas Bock	CSIRO	ASKAP
Andrew Bunker	University of Oxford	First Galaxies, Galaxy Evolution
Julianne Dalcanton	University of Washington	ASKAP, Galaxy Evolution
Roger Davies	University of Oxford	SAMI
Bryan Gaensler	University of Toronto	MWA EoR, ASKAP
Evan Kirby	California Institute of Technology	First Stars, GALAH
Bärbel Koribalski	CSIRO	ASKAP
Di Li	Chinese Academy of Sciences	ASKAP
Christopher Martin	California Institute of Technology	Galaxy Evolution
Miguel Morales	University of Washington	MWA EoR
Raffaella Morganti	ASTRON	ASKAP
Volker Springel	Heidelberg Institute for Theoretical Studies	Genesis
Michael Wise	ASTRON	Data Intensive Astronomy

IMAGE CREDIT: Cristy Roberts

ASSOCIATE INVESTIGATORS

NAME	ORGANISATION/S	PROJECT/S
James Allison	University of Oxford	ASKAP
Sarah Brough	University of NSW	SAMI, Galaxy Evolution
Julia Bryant	University of Sydney	SAMI/Hector
Luca Casagrande	Australian National University	First Stars, GALAH
Andy Casey	Monash University	DIA, First Stars, GALAH, Galaxy Evolution
Xuelei Chen	Chinese Academy of Sciences	DIA
Andrew Connolly	University of Washington	Galaxy Evolution
Jeff Cooke	Swinburne University of Technology	First Stars, Galaxy Evolution
Luca Cortese	University of Western Australia	ASKAP, SAMI/Hector

Continued

ASSOCIATE INVESTIGATORS

NAME	ORGANISATION/S	PROJECT/S
Warrick Couch	Swinburne University of Technology	SAMI/Hector
Elisabete da Cunha	University of Western Australia	Genesis
Gayandhi DeSilva	Macquarie University	GALAH
Alan Duffy	Swinburne University of Technology	Genesis
Christoph Federrath	Australian National University	First Stars, Genesis
Deanne Fisher	Swinburne University of Technology	Galaxy Evolution
Duncan Forbes	Swinburne University of Technology	Galaxy Evolution
Marianne Girard	Swinburne University of Technology	Galaxy Evolution
Brent Groves	University of Western Australia	SAMI, Galaxy Evolution
George Heald	CSIRO	ASKAP
Colin Jacobs	Swinburne University of Technology	Galaxy Evolution
Chris Jordan	Curtin University	MWA EoR
Glenn Kacprzak	Swinburne University of Technology	Galaxy Evolution
Virginia Kilborn	Swinburne University of Technology	ASKAP
Mark Krumholz	Australian National University	Genesis
Emily Levesque	University of Washington	Galaxy Evolution
Aaron Ludlow	University of Western Australia	Genesis
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Ilya Mandel	Monash University	Galaxy Evolution
Sarah Martell	University of NSW	GALAH
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Martin Meyer	University of Western Australia	ASKAP
Danail Obreschkow	University of Western Australia	Genesis
Christoph Pfrommer	Leibniz-Institute for Astrophysics Potsdam	Galaxy Evolution
Kai Polsterer	Heidelburg Institute for Theoretical Studies	First Galaxies
Tom Quinn	University of Washington	Galaxy Evolution, SAMI/Hector
Christian Reichardt	University of Melbourne	First Galaxies
Aaron Robothom	University of Western Australia	ASKAP, Genesis
Friedrich Ropke	Max Planck Institute	First Stars, GALAH

Continued

ASSOCIATE INVESTIGATORS

NAME	ORGANISATION/S	PROJECT/S
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Sanjib Sharma	University of Sydney	GALAH
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Steven Tingay	Curtin University	MWA EoR
Kim-Vy Tran	University of NSW	First Galaxies, Galaxy Evolution
Jesse van de Sande	University of Sydney	Galaxy Evolution, SAMI/Hector
Randall Wayth	Curtin University	MWA EoR
Jessica Werk	University of Washington	SAMI/Hector
Tobias Westmeier	University of Western Australia	ASKAP
Andreas Wicenec	University of Western Australia	DIA
David Yong	Australian National University	First Stars
Ming Zhu	Chinese Academy of Sciences	ASKAP
Daniel Zucker	Macquarie University	GALAH

IMAGE CREDIT: Cristy Roberts

RESEARCH FELLOWS

NAME	ORGANISATION/S	PROJECT/S
Maryam Arabsalmani	University of Melbourne	Galaxy Evolution
Caroline Foster	University of Sydney	Galaxy Evolution, SAMI/Hector
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Claudia Lagos	University of Western Australia	ASKAP, Genesis
Trevor Mendel	Australian National University	Galaxy Evolution, SAMI/Hector
Mahavir Sharma	Curtin University	GALAH, MWA EoR
Emily Wisnioski	Australian National University	Galaxy Evolution, SAMI/Hector
TianTian Yuan	Swinburne University of Technology	Galaxy Evolution

POSTDOCTORAL RESEARCH STAFF

NAME	ORGANISATION/S	PROJECT/S
Nichole Barry	Unversity of Melbourne	MWA EoR
Robert Bassett	Swinburne University of Technology	Galaxy Evolution
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Nell Byler	Australian National University	Galaxy Evolution
Pascal Elahi	University of Western Australia	Genesis
Bi-Qing For	University of Western Australia	ASKAP
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Kathryn Grasha	Australian National University	Galaxy Evolution
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Meridith Joyce	Australian National University	First Stars, GALAH
Nichaa Leethochawalit	University of Melbourne	First Galaxies
Jack Line	Curtin University	MWA EoR
Christene Lynch	Curtin University	MWA EoR
Simon Mutch	University of Melbourne	First Galaxies
Govind Nandakumar	Australian National University	GALAH
Thomas Nordlander	Australian National University	First Stars
Vitaliy Ogarko	University of Western Australia	DIA
Sree Oh	Australian National University	SAMI/Hector
Bart Pindor	University of Melbourne	MWA EoR
Henry Poetrodjojo	University of Sydney	SAMI/Hector
Jonghwan Rhee	University of Western Australia	ASKAP
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Sam Vaughan	University of Sydney	SAMI/Hector
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AFFILIATES

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IMAGE CREDIT: Cristy Roberts

PHD STUDENTS

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Alex Cameron	University of Melbourne	First Galaxies, Galaxy Evolution
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Continued

PHD STUDENTS

NAME	ORGANISATION/S	PROJECT/S
Madeline Marshall	University of Melbourne	First Galaxies
Uros Mestric	Swinburne University of Technology	Galaxy Evolution
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Rhys Poulton	University of Western Australia	Genesis
Yisheng Qui	University of Melbourne	Genesis
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Soniya Sharma	Australian National University	Galaxy Evolution, GALAH
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Ellert van der Velden	Swinburne University of Technology	Genesis
Mathew Varidel	University of Sydney	SAMI/Hector
Di Wang	University of Sydney	SAMI/Hector
Haobing (Adeline) Wang	University of Sydney	SAMI/Hector
Zixian (Purmortal) Wang	University of Sydney	GALAH
Adam Watts	University of Western Australia	ASKAP
Tanner Wilson	Monash University	DIA
Ruby Wright	University of Western Australia	Genesis
Hongwei Xi	University of Western Australia/NAOC	DIA
Patrick Yates	University of Western Australia	Genesis

OTHER STUDENTS

NAME	ORGANISATION/S	PROJECT/S
Rebecca Brown	University of Sydney	SAMI/Hector
Jing Li	Australian National University	Galaxy Evolution
Benjamin Metha	University of Melbourne	First Galaxies
Murray Riding	University of Sydney	SAMI/Hector
Tomas Rutherford	University of Sydney	SAMI/Hector
Diane Salim	Australian National University	SAMI/Hector
Xi (Ella) Wang	Australian National Univeristy	First Stars
Simon Weng	University of Sydney	ASKAP

IMAGE CREDIT: Cristy Roberts

PROFESSIONAL STAFF

NAME	ORGANISATION	ROLE
Delese Brewster	Australian National University	Education and Outreach
Denise Castle	Australian National University	Business Manager
Kim Dorrell	University of Melbourne	Node Administration
Kirsten Gottschalk	University of Western Australia	Education and Outreach
Emily Johnson	Curtin University	Node Administration
Susan Lester	Swinburne University of Technology	Node Administration
Tash Marshall	University of Sydney	Education and Outreach
Ingrid McCarthy	Australian National University	Chief Operating Officer
Marie Partridge	University of Sydney	Node Administration
Clare Peter	University of Western Australia	Node Administration
Cristy Roberts	Australian National University	Node Administration
Gregory Rowbotham	University of Western Australia	Education and Outreach
Tina Salisbury	Curtin University	Node Administration
Teresa Slaven-Blair	Curtin University	Education and Outreach
Kirsty Waring	University of Melbourne	Node Adminstration

PRESENTATIONS IN 2019

INVITED AND CONTRIBUTED TALKS

(includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
GALAH survey	Martin Asplund	Sexten, Italy	January
Disentangling stellar and nebular signatures from the rest-UV spectra of star forming galaxies	Eleanor Byler	Los Angeles, USA	January
GALAH Survey Overview	Michael Hayden	Seattle, USA	January
Imaging Challenges for a Lunar-orbiting array	Benjamin McKinley	Beijing, China	January
The Neutral Hydrogen Content of Central and Satellite Galaxies using an Interferometer Stacking Method	Hu Wenkai	Perth, Australia	January
Tracing the MZ varIation of high z galaxies using GRBs	Maryam Arabsalmani	Sydney, Australia	February
Galaxy formation and evolution as seen by integral field spectroscopy	Scott Croom	Sydney, Australia	February
ASKAP HI imaging of the LGG 351 galaxy group	Bi-Qing For	Perth, Australia	February
Probing the Epoch of Reionisation with Murchison Widefield Array	Christopher Jordan	Nagoya, Japan	February
Connecting observations of the first galaxies and the Epoch of Reionisation	Simon Mutch	Sydney, Australia	February
Galaxy morphology, quenching, and mergers in the cluster environment	Sree Oh	Sydney, Australia	February
Effect of Diffuse Ionised Gas on Metallicity Gradients	Henry Poetrodjojo	Sydney, Australia	February
ASKAP/WALLABY Early Science Observations of the NGC 7162 Galaxy Group	Tristan Reynolds	Perth, Australia	February

Continued

Scott Croom *IMAGE CREDIT:* Cristy Roberts

INVITED TALKS (includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
ASKAP Deep Investigation of Neutral Gas Origin: Early Science Observation and Results	Jonghwan Rhee	Perth, Australia	February
Stellar Kinematics with SAMI	Jesse van de Sande	Sydney, Australia	February
Comparing 3D spectroscopic observations with cosmological hydrodynamical simulations	Jesse van de Sande	Sydney, Australia	February
The build-up of mass and angular momentum in galaxies across morphology and environment with SAMI	Jesse van de Sande	Santiago, Chille	February
What makes a galaxy old and metal rich?	Nicholas Scott	Sydney, Australia	February
The COCKATOO Simulations	Philip Taylor	Melbourne, Australia	February
Model dispersion with PRISM	Ellert van der Velden	Melbourne, Australia	February
On the slope of the HI mass function	Tobias Westmeier	Perth, Australia	February
Compact star-forming galaxies, a stepping stone to quiescence at z~1-3?	Emily Wisnioski	Sydney, Australia	February
Conference Summary (The Life & Death of Star-Forming Galaxies)	Emily Wisnioski	Perth,, Australia	February
Using resolved stellar populations to improve the recovery of star formation histories from galaxy spectra	Eleanor Byler	Perth, Australia	March
Star formation history and progenitor bias	Luca Cortese	Perth, Australia	March
Environmentally driven quenching and morphological transformation as seen by SAMI	Scott Croom	Perth, Australia	March
Connecting observations of the first galaxies and the Epoch of Reionisation	Simon Mutch	Tokyo, Japan	March
What makes a galaxy old and metal rich?	Nicholas Scott	Perth, Australia	March

Continued

Simon Mutch *IMAGE CREDIT:* Ingrid McCarthy

INVITED TALKS (includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
The relative effects of environment on star formation and HI	Adam Stevens	Perth, Australia	March
Gamma Ray Bursts as Probes of Star Formation at the End of the Cosmic Dark Ages	Michele Trenti	Aspen, USA	March
Development and focal ratio degradation optimisation of integral field units on Hector	Adeline Wang	San Diego, USA	March
Constraining the initial mass function with optical HST observations of resolved stellar populations in the outer disc of DDO 154	Adam Watts	Perth, Australia	March
Lessons from Galaxy Kinematics: Open Questions after a Decade of IFS Surveys	Emily Wisnioki	Tokyo, Japan	March
GALAH and Gaia: dissecting the disc by age, action, chemistry and location	Joss Bland-Hawthorn	Santa Barbara, USA	April
GENESIS Mocks	Pascal Elahi	Cordoba, Argentina	April
WALLABY early science: LGG 351 group	Bi-Qing For	Manchester, UK	April
Massive galaxies at cosmic dawn	Karl Glazebrook	Tohoku, Japan	April
Star formation in the local universe	Kathryn Grasha	Tokyo, Japan	April
Theory challenge: Comparing 21cmFAST/ Meraxes/C2Ray	Bradley Greig	Manchester, UK	April
SKA Observing Strategy Forecasts	Bradley Greig	Manchester, UK	April
Simulating MWA/SKA observations with OSKAR	Jack Line	Alderley Edge, UK	April
The Genesis Simulations	Chris Power	Hobart, Australia	April
ASKAP detections of HI absorption in galaxies at redshift $0.4 < z < 1$	Elaine Sadler	Manchester, UK	April
Spatially resolved angular momentum	Sarah Sweet	Melbourne, Australia	April

Continued

Elaine Sadler ***IMAGE CREDIT:*** Cristy Roberts

TALK TITLE	SPEAKER	LOCATION	WHEN
Astrophysics from Space: From Flagship Missions to CubeSats	Michele Trenti	Healesville, Australia	April
The MWA Epoch of Reionisation Project Update	Cathryn Trott	Manchester, UK	April
Model dispersion with PRISM; IMAGINE an alternative to MCMC for rapid analysis of models	Ellert van der Velden	Nijmegen, the Netherlands	April
First Stars	Martin Asplund	Sydney, Australia	May
The Gravitational Potential -- Metallicity relation	Tania Barone	Leiden, the Netherlands	May
Dynamical Drivers of Galaxy Stellar Populations	Tania Barone	Ghent, Belgium	May
Dynamical Drivers of Galaxy Stellar Populations	Tania Barone	Oxford, UK	May
The On-Going Search For Lyman Continuum	Robert Bassett	Sydney, Australia	May
The Intergalactic Medium	Adam Batten	Sydney, Australia	May
MAGPHYS+photo-z: Constraining the Physical Properties of Galaxies with Unknown Redshifts	Andrew Battisti	Sydney, Australia	May
First Galaxies overview	Stephanie Bernard	Sydney, Australia	May
The Hector instrument on the road to science - current status	Rebecca Brown	Sydney, Australia	May
Galaxy Evolution Project Overview	Eleanor Byler	Sydney, Australia	May
Cold gas in galaxies. The legacy of single-dish surveys in the SKA era	Luca Cortese	Pune, India	May
A multiwavelength view of nearby galaxies	Luca Cortese	Bangalore, India	May
WALLABY early science results	Bi-Qing For	Sydney, Australia	May
Genesis Simulations Overview	Lilian Garratt-Smithson	Sydney, Australia	May

Continued

Lilian Garratt-Smithson ***IMAGE CREDIT:*** Cristy Roberts

TALK TITLE	SPEAKER	LOCATION	WHEN
Understanding Photoionised HII Regions with Improved Stellar Evolutionary Models	Kathryn Grasha	Leiden, the Netherlands	May
Developing connections between MERAXES and 21CMMC	Bradley Greig	Sydney, Australia	May
SimSpin	Katherine Harborne	Sydney, Australia	May
All-Sky Astrophysics in 3D	Lisa Kewley	New Plymouth, NZ	May
Simulations of galaxy formation in the LSST era	Claudia Lagos	Sydney, Australia	May
Of galaxies and spinning tops: Role of angular momentum in galaxies	Chandrashekar Murugeshan	Sydney, Australia	May
Genesis semi-analytic models overview	Simon Mutch	Sydney, Australia	May
Impact of Realistic Foregrounds and Instrument on 21cm Parameter Estimation Experiments	Bella Nasirudin	Sydney, Australia	May
Kinematics of galactic bulges and disks	Sree Oh	Sydney, Australia	May
Reconciling Metallicity Calibrations	Henry Poetrodjojo	Sydney, Australia	May
WALLABY Early Science: The NGC 7162 Galaxy Group	Tristan Reynolds	Sydney, Australia	May
ASKAP HI surveys	Jonghwan Rhee	Sydney, Australia	May
Thermodynamics of H2 in the Context of the First Stars	Piyush Sharda	Bern Switzerland	May
Cosmic reionisation and its fossils in the Milky Way	Mahavir Sharma	Sydney, Australia	May
Feedback and its role in reionisation and in the formation of CEMP stars	Mahavir Sharma	Sydney, Australia	May
What triggers strong AGN feedback?	Phillip Taylor	Sydney, Australia	May
Statistically quantifying HI profile asymmetries using xGASS	Adam Watts	Sydney, Australia	May

Continued

Adam Watts ***IMAGE CREDIT:*** Ingrid McCarthy

TALK TITLE	SPEAKER	LOCATION	WHEN
The Hector instrument on the road to science - current status	Adeline Wang	Sydney, Australia	May
K3LARS: The KMOS z=3-4 Lyman Alpha Reference Survey	Emily Wisnioski	Sydney, Australia	May
The highest redshift ring and spiral structures	Tiantian Yuan	Sydney, Australia	May
A SLSN within the bar of a metal-rich galaxy	Maryam Arabsalmani	Lyon, France	June
Stellar chemistry: The way forward	Martin Asplund	Ljubljana, Slovenia	June
MAGPHYS+photo-z: Constraining the Physical Properties of Galaxies with Unknown Redshifts	Andrew Battisti	Viana do Castelo, Portugal	June
15 Years of Galactic Archaeology with RAVE	Joss Bland-Hawthorn	Potsdam, Germany	June
The future of Galactic Archaeology	Joss Bland-Hawthorn	Ljubljana, Slovenia	June
Asteroseismology and better stellar ages	Luca Casagrande	Ljubljana, Slovenia	June
The interplay between star formation and molecular/atomic gas in galaxies	Barbara Catinella	Cape Town, South Africa	June
Discovery of 9 New Stellar Groups in Orion Star Forming Region	Boquan Chen	Padova, Italy	June
Discovery of 9 New Stellar Groups in Orion Star Forming Region	Boquan Chen	Ljubljana, Slovenia	June
Galactic chimney sweeping: the fate of gas in galaxies	Lilian Garratt-Smithson	Spetses, Greece	June
Massive galaxies at cosmic dawn	Karl Glazebrook	Paris, France	June
Theoretically Modelling the Photoionised Region with the Fractal Geometry in Three Dimensions	Yifei Jin	Lyon, France	June
SimSpin	Katherine Harborne	Sydney, Australia	June

Continued

Kate Harborne ***IMAGE CREDIT:*** Ingrid McCarthy

Michael Hayden *IMAGE CREDIT:* Ingrid McCarthy

TALK TITLE	SPEAKER	LOCATION	WHEN
The Structure and Evolution of the Galactic Disk	Michael Hayden	Ljubljana, Slovenia	June
Linking ridges, arches and vertical waves in the kinematics of the MilkyWay	Shourya Khanna	Ljubljana, Slovenia	June
Linking ridges, arches and vertical waves in the kinematics of the MilkyWay	Shourya Khanna	Nice, France	June
Direct Detection of Messy Halos	Grace Lawrence	Brisbane, Australia	June
Connecting observations of the first galaxies and the Epoch of Reionisation	Simon Mutch	Viana do Castelo, Portugal	June
Disc metallicity trends with Galah (iDR3) + APOGEE (DR14)	Govind Nandakumar	Ljubljana, Slovenia	June
New light on metal-poor stars	Thomas Nordlander	Nafplio, Greece	June
The SkyMapper search for extremely metal-poor stars	Thomas Nordlander	Lyon, France	June
The Brightest Galaxies at Cosmic Dawn	Keven Ren	Sydney, Australia	June
Modelling the Milky Way using large observational surveys.	Sanjib Sharma	Sydney, Australia	June
Galactic Archaeology using astero-seismology: Results from Kepler and K2	Sanjib Sharma	Ljubljana, Slovenia	June
Welcome to the dynamical models of observed galaxies workshop	Jesse van de Sande	Sydney, Australia	June
Galaxies with Atypical Kinematics from Cosmological Simulations	Philip Taylor	Perth, Australia	June
KMOS3D: final data release and science overview	Emily Wisnioski	Lyon, France	June
The evolution of galaxy gas kinematics from 0.7 < z < 2.7	Emily Wisnioski	Lyon, France	June
Intergalatic DIspersion Measure in the EAGLE simulations	Adam Batten	Brisbane, Australia	June

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Neutral gas in the close environments of massive star explosions	Maryam Arabsalmani	Munich, Germany	July
MAGPHYS+photo-z: Constraining the Physical Properties of Galaxies with Unknown Redshifts	Andrew Battisti	Brisbane, Australia	July
MAGPHYS+photo-z	Andrew Battisti	Brisbane, Australia	July
How can local cold gas surveys inform the analysis of higher redshift surveys?	Barbara Catinella	Garching, Germany	July
Challenging H2 domination in high-redshift star-forming galaxies	Luca Cortese	Garching, Germany	July
Environmentally driven quenching and morphological transformation as seen by SAMI	Scott Croom	Brisbane, Australia	July
The intricate link between galaxy dynamics and intrinsic shape (or why so-called prolate rotation is a misnomer)	Caroline Foster	Shanghai, China	July
Massive galaxies at cosmic dawn	Karl Glazebrook	Paris, France	July
Massive galaxies at cosmic dawn	Karl Glazebrook	Fitzroy Island, Australia	July
Understanding Photoionised HII Regions with Improved Stellar Evolutionary Models	Kathryn Grasha	Lyon, France	July
Interpreting recent upper limits from MWA and LOFAR	Bradley Greig	Brisbane, Australia	July
Developing links between the 21cm signal and galaxy formation	Bradley Greig	Fitzroy Island, Australia	July
The origin and fate of HI in and around galaxies: the view from simulations	Claudia Lagos	Garching, Germany	July
First Results from the Long Baseline Epoch of Reionisation Survey	Christene Lynch	Brisbane, Australia	July
The Host Galaxies of High Redshift Quasars	Madeline Marshall	Fitzroy Island, Australia	July
The Host Galaxies of High Redshift Quasars	Madeline Marshall	Sao Paolo, Brazil	July
Constraining models for the evolution of the ionising escape fraction	Simon Mutch	Fitzroy Island, Australia	July
The Impact of Realistic Foreground and Instrument Models on 21 cm Epoch of Reionisation Experiments	Ainulnabilah Nasirudin	Fitzroy Island, Australia	July
MWA Observations in the Edges Band	Bart Pindor	Fitzroy Island, Australia	July
Studying the Orbits and Interactions of Satellite Galaxies in the Next Generation of Simulations	Rhys Poulton	Brisbane, Australia	July

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
Predictions of infrared excess and cosmic star formation rate density from UV constraints at z ~ 4 - 7	Yisheng Qiu	Brisbane, Australia	July
MWA EOR Data Analysis	Mahsa Rahimi	Fitzroy Island, Australia	July
New kinematic Sunyaev-Zel'dovich results from the South Pole Telescope.	Christian Reichardt	Fitzroy Island, Australia	July
ASKAP/WALLABY Early Science: The NGC 7162 Galaxy Group	Tristan Reynolds	Garching, Germany	July
An HI-selected galaxy sample at redshift 0.4 < z < 1	Elaine Sadler	Munich, Germany	July
Key Dynamical Results From SAMI: The build-up of mass and angular momentum in galaxies across morphology and environment	Jesse van de Sande	Shanghai, China	July
Thick disks in extragalactic galaxies	Nicholas Scott	Lancaster, UK	July
Key science results from the SAMI Galaxy Survey and the future of IFS with Hector	Nicholas Scott	Groninger, the Netherlands	July
Towards Accurate Modelling of Galaxy Clustering on Small Scales: Testing the Standard LCDM + Halo Model	Manodeep Sinha	Brisbane, Australia	July
Stellar angular momentum distribution sets galaxy morphology	Sarah Sweet	Brisbane, Australia	July
Robust Statistics Towards Detection of the Epoch of Reionisation	Cathryn Trott	Brisbane, Australia	July
PRISM: An alternative to MCMC for rapid analysis of models	Eller van der Velden	Brisbane, Australia	July
K-CLASH: quenching in the densest environments	Sam Vaughan	Brisbane, Australia	July
The average global HI spectrum is not symmetric	Adam Watts	Brisbane, Australia	July

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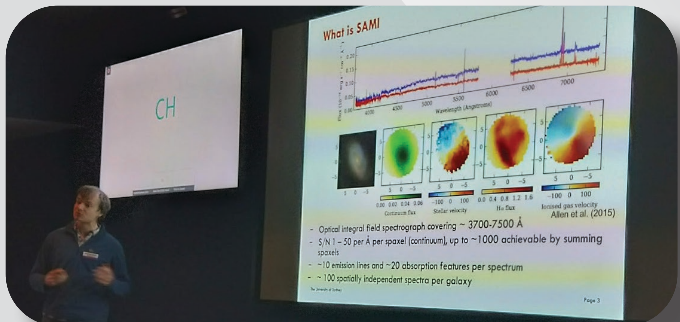

Nicholas Scott *IMAGE CREDIT:* Ingrid McCarthy

INVITED TALKS (includes conferences, workshops, colloquia, and poster presentations)

TALK TITLE	SPEAKER	LOCATION	WHEN
Calibration of AAVS1 & bridging arrays	Randall Wayth	Florence, Italy	July
PRISM: An alternative to MCMC for rapid analysis of models	Ellert van der Velden	Baltimore, USA	July
Dissect the Orion Star Forming Region with Unsupervised Learning	Boquan Chen	Leiden, the Netherlands	August
The HI mass function in simulations	Claudia Lagos	Garching, Germany	August
The Host Galaxies of High Redshift Quasars	Madeline Marshall	Pittsburgh, USA	August
Weaving Dreams in the Dark	Rhys Poulton	Durham, UK	August
Traversing the HI desert	Lister Staveley-Smith	Garching, Germany	August
Low Column Density HI	Lister Staveley-Smith	Garching, Germany	August
Development and focal ratio degradation optimisation for IFUs on Hector	Adeline Wang	San Diego, USA	August
mpi4pyd: MPI for Python dummies	Ellert van der Velden	Baltimore, USA	August
ISM conditions at cosmic noon: new nebular diagnostics and mock IFU observations	Ayan Acharyya	Columbus, USA	September
ISM conditions at cosmic noon: new nebular diagnostics and mock IFU observations	Ayan Acharyya	Baltimore, USA	September
Exciting progress on the Hector instrument	Rebecca Brown	Sydney, Australia	September
The GALAH survey	Sven Buder	Yichang, China	October
Cool stars for extra-galactic archaeology	Luca Casagrande	Sydney, Australia	September
Characterising Radio Telescopes with Satellites	Aman Chokshi	Sydney, Australia	September
WALLABY update	Bi-Qing For	Perth, Australia	September
Science with the WALLABY	Bi-Qing For	Cape Town, South Africa	September

Continued

Ayan Acharyya *IMAGE CREDIT:* Ingrid McCarthy

TALK TITLE	SPEAKER	LOCATION	WHEN
Understanding Photoionised HII Regions with Improved Stellar Evolutionary Models	Kathryn Grasha	Beijing, China	September
New 21cmFAST Organisation, Workflow and Demos	Bradley Greig	Pisa, Italy	September
Massive galaxies at cosmic dawn	Karl Glazebrook	Los Angeles, USA	September
Disk metallicity trends using Galah (iDR3)+APOGEE (DR14)	Govind Nandakumar	Florence, Italy	September
Accurate abundances at the lowest detected iron abundance: SMSS 1605-1443	Thomas Nordlander	Geneva, Switzerland	September
SMSS1605-1443: The lowest detected stellar Fe abundance	Thomas Nordlander	Heidelberg, Germany	September
Challenges in mapping the deep HI Universe	Kristof Rozgonyi	Budapest, Hungary	September
Origin of CEMP stars	Mahavir Sharma	Geneva, Switzerland	September
Origin of the galaxy HI size-mass relation	Adam Stevens	Perth, Australia	September
Spatially-resolved galaxy evolution	Sarah Sweet	Melbourne, Australia	September
Galaxies with Atypical Kinematics from Cosmological Simulations	Philip Taylor	Sydney, Australia	September
The Magellanic System: the puzzle of the leading gas stream	Thorsten Tepper Garcia	Beijing, China	September
The Hector instrument	Adeline Wang	Sydney, Australia	September
Galaxy formation and reionisation	Stuart Wyithe	Rome, Italy	September
Chemodynamical Tagging in the Milky Way	Boquan Chen	Yichang, China	October
Developing connections between reionisation simulations	Bradley Greig	Pisa, Italy	October
Global Signal with a Short Spacing Interferometer	Ronniy Joseph	Montreal, Canada	October
The Host Galaxies of High Redshift Quasars	Madeline Marshall	Beijing, Italy	October

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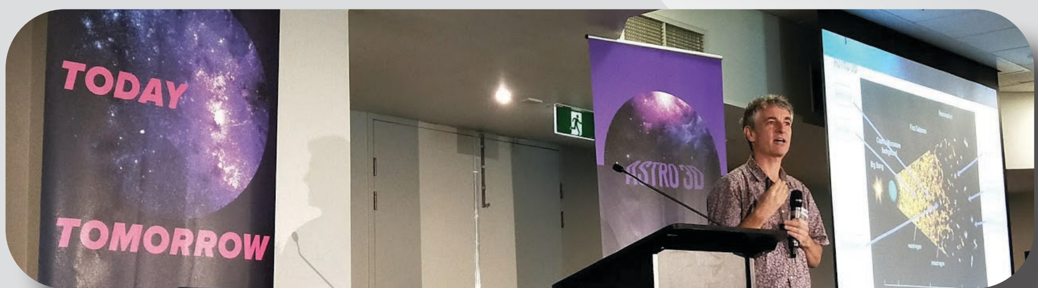

Stuart Wyithe *IMAGE CREDIT:* Cristy Roberts

Cathryn Trott *IMAGE CREDIT:* Cristy Roberts

TALK TITLE	SPEAKER	LOCATION	WHEN
Deep Investigation of Neutral Gas Origin (DINGO_	Jonghwan Rhee	Sydney, Australia	October
Challenges in mapping the deep HI Universe	Kristof Rozgonyi	Budapest, Hungary	October
Toward the Epoch of Reionisation with the MWA	Cathryn Trott	Melbourne, Australia	October
Understanding Calibration Challenges in a Search for a 21-cm Signal from Reionisation	Ronniy Joseph	Montreal, Canada	November
The new Stromlo Star Tracks: impact of elemental abundances on stellar evolution	Kathryn Grasha	Milan, Italy	November
Murchison Widefield Array Epoch of Reionisation project update	Benjamin McKinley	Pune, India	November
Kinematically disentangling bulges and disks using 3D spectroscopy	Sree Oh	Milan, Italy	November
Intervening metals lines towards z~6-7 QSOs: Status of the field	Emma Ryan-Weber	Pisa, Italy	November
The build-up of mass and angular momentum in galaxies across morphology and environment with SAMI	Jesse van de Sande	Melbourne, Australia	November
Stellar angular momentum distribution sets galaxy morphology	Sarah Sweet	Milan, Italy	November
Spatially-resolved galaxy angular momentum	Sarah Sweet	Florence, Italy	November
Epoch of Reionisation Science Regional Centre	Cathryn Trott	Canberra, Australia	November
3D non-LTE lithium measurements in the oldest stars in the Milky Way	Xi Wang	Heidelberg, Germany	November
The primordial 7Li and 6Li problems with exquisite ESPRESSO/VLT observations	Xi Wang	Rome, Italy	November

Continued

TALK TITLE	SPEAKER	LOCATION	WHEN
The primordial 7Li and 6Li problems with exquisite ESPRESSO/VLT observations	Xi Wang	Rome, Italy	November
Newest limits on the EoR structure from the MWA	Nichole Barry	Tempe, USA	December
Understanding Calibration Challenges in a Search for a 21-cm Signal from Reionisation	Ronniy Joseph	Tempe, USA	December
Shapelets. Why bother?	Jack Line	Tempe, USA	December
The Long Baseline Epoch of Reionisation Survey	Christene Lynch	Tempe, USA	December
Understanding Calibration Challenges in a Search for a 21-cm Signal from Reionisation	Ronniy Joseph	Toronto, Canada	December
SMSS 1605-1443 The lowest measured [Fe/H] in a star	Thomas Nordlander	Canberra, Australia	December
Velocity dispersion of stars in the MIlky Way	Sanjib Sharma	Canberra, Australia	December
The Challenges with Estimating Halo Masses for Galaxy Groups	Manodeep Sinha	Melbourne, Australia	December
Spatially-resolved galaxy evolution with MAVIS	Sarah Sweet	Sydney, Australia	December
Measuring Lithium in Stars and the Cosmological Lithium Problems	Xi Wang	Perth, Australia	December
Observing resolved structures of distant galaxies	Tiantian Yuan	Beijing, China	December
How spiral galaxies arise and thrive through cosmic time	Tiantian Yuan	Beijing, China	December

Tiantian Yuan *IMAGE CREDIT:* Ingrid McCarthy

OTHER PRESENTATIONS - includes briefings

SUBJECT	SPEAKER	LOCATION	WHEN
Astronomy at RSAA	Martin Asplund	Canberra, Australia	February
The SkyHopper Space Telescope	Michele Trenti	Sydney, Australia	February
The Genesis simulations suite	Simon Mutch	Canberra, Australia	February
ACAMAR 2019 meeting	Rachel Webster	Healesville, Australia	April
The Hector instrument on the road to science - current status	Adeline Wang	Sydney, Australia	May
SAMI Science Highlights	Matthew Colless	Canberra, Australia	May
Hacky Hour@C3DIS	Manodeep Sinha	Canberra, Australia	May
Digital skills for data-intensive science	Rachel Webster	Cologne, Italy	October
ANU Heritage as Student and Academic and Women in STEM.	Lisa Kewley	Canberra, Australia	May
Successful Mentoring and Strategies to Support Diversity	Lisa Kewley	Canberra, Australia	May
The case of the Research Centre role in higher education institutions and global research networks	Lisa Kewley	Canberra, Australia	May
Recognition and Career Development for Researchers who Code: a Workshop for RSEs	Manodeep Sinha	Canberra, Australia	May
MWA Project	Rachel Webster	Rhode Island, USA	June
Updates on the SKA	Claudia Lagos	Copenhagen, Denmark	July
Benchmarking Code and Writing Parallel Code	Manodeep Sinha	Brisbane, Australia	July
AAL-NCA Data & Computing Workshop	Rachel Webster	Sydney, Australia	September.
Writing successful Future Fellowship proposals	Luca Casagrande	Canberra, Australia	September
How to be (un-)successful in applying for grant-based Postdoc positions	Martin Asplund	Canberra, Australia	September
Postdoc interview skills	Matthew Colless	Canberra, Australia	September
The Astronomy Job Market	Emily Wisnioski	Canberra, Australia	September
Overview of telescope proposals	Emily Wisnioski	Canberra, Australia	September
ESO & 30m telescope white paper summary	Caroline Foster	Sydney, Australia	November
SPIRIT Remote internet telescopes for education	Kirsten Gottschalk	Perth, Australia	November
The Pleiades Awards	Stuart Wyithe	Melbourne, Australia	December
The Pleiades Awards	Daniel Zucker	Tokyo, Japan	November

PUBLIC LECTURES, OUTREACH AND SCHOOL TALKS

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
ASTRO 3D Spectoscopy	Ingrid McCarthy	Space Squad	Canberra, Australia	January
Galactic Archaeology	Martin Asplund	Public briefing	Canberra, Australia	February
STEM Careers	Ingrid McCarthy	Melrose High School, Science Mentors	Canberra, Australia	February
What is Radio Astronomy?	Jack Line	AstroFest	Perth, Australia	March
Journey Through the Universe	Cathryn Trott Christene Lynch Teresa Slaven-Blair	AstroFest	Perth, Australia	March
Women in STEM	Caroline Foster	Women in STEM workshop	Sydney, Australia	March
Women in Space	Lisa Kewley	International Women's Day	Canberra, Australia	March
A Cosmic History Lesson	Chris Power	Shenton College	Perth, Australia	March
ASTRO 3D Spectoscopy	Ingrid McCarthy	Space Squad	Canberra, Australia	April
What happens when galaxies collide?	Lisa Kewley	Uluru Astronomer in Residence	Yulara, Australia	April
Dissecting galaxies in the distant Universe	Trevor Mendel	Uluru Astronomer in Residence	Yulara, Australia	April
Tuning into the early history of the Universe	Nichole Barry	Uluru Astronomer in Residence	Yulara, Australia	April
Interview for Research	Lisa Kewley	ANU Heritage Oral Histories	Canberra, Australia	May
The ghost light that illuminates clusters of galaxies	Mireia Montes	Uluru Astronomer in Residence	Yulara, Australia	May
A star is born - or not!	Diane Salim	Uluru Astronomer in Residence	Yulara, Australia	May
Astrocooking with Telescopes	Piyush Sharda	Uluru Astronomer in Residence	Yulara, Australia	May
Host discussion panel	Ingrid McCarthy	May 4th Star Wars night	Canberra, Australia	May
The Cosmic Reionisers: Identifying the Sources of the Universal Phase Change	Rob Bassett	Uluru Astronomer in Residence	Yulara, Australia	June

Continued

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
The spectacular "ring of fire" in the early universe	Tiantian Yuan	Uluru Astronomer in Residence	Yulara, Australia	June
Save Tonight - Not Just Another Pop Song - a Dark Sky	Duane Hamacher	IESVIC/TAS	Melbourne, Australia	June
Discovering our Universe	Elisabete da Cunha	IAU Symposium 352	Viana do Castelo, Portugal	June
Rings in a tree stump: what stars can tell us about the life of a galaxy	Nell Byler	Uluru Astronomer in Residence	Yulara, Australia	June
Galaxies living in isolation to clusters of galaxies: Does environment matter?	Anshu Gupta	Uluru Astronomer in Residence	Yulara, Australia	June
Moon!	Ben McKinley	Moon Landing 50th Anniversary	Perth, Australia	June
Fluorine: Form The Stars to Your Teeth	Aldo Mura	Uluru Astronomer in Residence	Yulara, Australia	June/July
Indigenous Astronomical Knowledge and Truth-Telling	Duane Hamacher	Walter and Eliza Hall Institute of Medical Research forum	Melbourne, Australia	July
65,000 years of Indigenous Astronomy	Duane Hamacher	Avanade	Melbourne, Australia	July
Visiting Science Communicator	Duane Hamacher	Charleville Cosmos Centre	Charleville, Queensland	July
ASTRO 3D Spectoscopy	Ingrid McCarthy	Space Squad	Canberra, Australia	July
The Cosmic Distance Ladder	Andrew Battisti	Uluru Astronomer in Residence	Yulara, Australia	July
Star Clusters in Nearby Galaxies: Understanding Star Formation in the Local Universe	Katie Grasha	Uluru Astronomer in Residence	Yulara, Australia	July
	Mike Kriele	Perth Science Festival	Perth, Australia	August
Indigenous Astronomy and Preserving Dark Skies	Duane Hamacher	WEEF After Dark Product Party	Brisbane, Australia	August
Anyone else ever wondered how galaxies get their shape?	Caroline Foster	Uluru Astronomer in Residence	Yulara, Australia	August

Continued

SUBJECT	SPEAKER	EVENT	LOCATION	WHEN
Cosmic reionisation and its fossils in the Milky Way	Mahavir Sharma	Uluru Astronomer in Residence	Yulara, Australia	August
PsyTalks Panel Discussion	Duane Hamacher	Royal Society of Victoria	Melbourne, Australia	August
65,000 years of Indigenous Astronomy	Duane Hamacher	McClelland Sculpture Park+Gallery	Melbourne, Australia	August
Meriam Astronomy	Duane Hamacher	Torres Strait AstroFest	Melbourne, Australia	August
ASTRO 3D Spectoscopy	Ingrid McCarthy	Space Squad	Canberra, Australia	September
Rings in a tree stump: what stars can tell us about the life of a galaxy	Nell Byler	Space Squad	Canberra, Australia	September
Spectrographs and the Solar System	Tash Marshall	Light Festival, Barker College	Sydney, Australia	September
Understanding observations of the early Universe: when one simulation is not enough	Bradley Grieg	Uluru Astronomer in Residence	Yulara, Australia	September
Listening to the Creaks and Chirps of the Universe	Teresa Slaven-Blair	Uluru Astronomer in Residence	Yulara, Australia	September
Galactic chimney sweeping: how stars can impact the evolution of a galaxy	Lilian Garratt-Smithson	Uluru Astronomer in Residence	Yulara, Australia	September
SPIRIT Program	Gregory Rowbotham	Willeton State High School	Perth, Australia	October
The supermassive black hole at the Galactic Centre	Joss Bland-Hawthorn	Burbidge Dinner, Auckland Astronomical Society New Zealand	Auckland, New Zealand	November
Informal Q&A and ASTRO 3D activities with school kids years 3-10	Ben McKinley	CSIRO STEM Professionals in Schools	Dalwallinu, Western Australia	November
The explosive history of the Galactic Centre	Joss Bland-Hawthorn	Astronomical Society of South Australia	Adelaide, South Australia	December

INTERNATIONAL VISITORS

WHO	INSTITUTION/AFFILIATION	WHEN
VISITORS TO AUSTRALIAN NATIONAL UNIVERSITY		
Ms Melanie Kaasinen	Max Planck Institute,Heidelberg, Germany	January
Dr Yiqing Liu	University of Oxford, UK	March
Professor Kim Venn	University of Victoria, Canada	March/April
Dr Vera Patricio	Niels Bohr Institute, Denmark	April
Professor Tim de Zeeuw	Leiden University, the Netherlands	May
Dr Ling Zhu	Shanghai Astronomical Observatory, Shanghai, China	May/June
Dr Koki Kakiichi	University College, London, UK	May
Professor Glenn Van de Ven	University of Vienna, Vienna, Austria	June
Professor Chris Martin	Caltech, California, USA	August
Professor Julianne Dalcanton	University of Washington	September
Dr Allison Strom	Carnegie Observatories	October
Dr Gonzalo Diaz	Gemini Observatory, Hawaii, USA	November
Professor Tim de Zeeuw	Leiden University, the Netherlands	November to December
Professor Chiaki Kobayashi	University of Hertfordshire	December
Professor Andy Bunker	Oxford University	December
VISITORS TO UNIVERSITY OF MELBOURNE		
Professor Tom Quinn	University of Washington, USA	February
Dr Koki Kakiichi	University College, London, UK	May
Dr Gonzalo Diaz	Gemini Observatory, Hawaii, USA	July
Dr Anne Hutter	University of Groningen, Groningen, Netherlands	July
Dr Catherine Watkinson	Imperial College, London, UK	July, September
Dr Charlotte Mason	Harvard University, Boston, USA	July
Mr Michael Wilensky	University of Washington, Washington, USA	October
VISITORS TO SYDNEY UNIVERSITY		
Professor Di Li	National Astronomy Observatory of China	February
Dr Yiqing Liu	University of Oxford, UK	February
Professor Tom Quinn	University of Washington, USA	March
Professor Kim Venn	University of Victoria, Canada	April/May
Dr Ling Zhu	Shanghai Astronomical Observatory, Shanghai, China	May/June

WHO	INSTITUTION/AFFILIATION	WHEN
Dr Koki Kakiichi	University College, London, UK	May
Professor Glenn Van de Ven	University of Vienna, Vienna, Austria	June
Professor Julianne Dalcanton	University of Washington, USA	September
VISITORS TO SWINBURNE UNIVERSITY OF TECHNOLOGY		
Ms Melanie Kaasinen	Max Planck Institute,Heidelberg, Germany	February
Ms Aleksandra Hamanowicz	European Southern Observatory, Germany	February
Dr Laura Prichard	Space Telescope Science Institute, USA	March
Dr Vera Patricio	Niels Bohr Institute, Denmark	March
Dr Koki Kakiichi	University College, London, UK	May
Dr Anne Hutter	University of Groningen, Groningen, Netherlands	July
Dr Gonzalo Diaz	Gemini Observatory, Hawaii, USA	July
Professor Chris Martin	Caltech, California, USA	August
Dr Gonzalo Diaz	Gemini Observatory, Hawaii, USA	November
Assoc Prof Sheila Kannappan	University of Northern Carolina	December
VISITORS TO UNIVERSITY OF WESTERN AUSTRALIA		
Ms Aleksandra Hamanowicz	European Southern Observatory, Germany	February
Professor Di Li	National Astronomy Observatory of China	February/March
Professor Tom Quinn	University of Washington, USA	February/March
Dr Rhia Silvia	University Observatory of Munich, Germany	March
Dr Toby Brown	McMaster University, Canada	March
Professor Glenn Van de Ven	University of Vienna, Vienna, Austria	June
Asst/Prof Alan McConnachie	Herzberg Institute for Astrophysics & University of Victoria, Canada	July
Mr Nathan Adams	Oxford University, UK	July
Professor Julianne Dalcanton	University of Washington	September
Dr Allison Strom	Carnegie Observatories	October
VISITORS TO CURTIN UNIVERSITY		
Dr Koki Kakiichi	University College, London, UK	May
Dr Anne Hutter	University of Groningen, Groningen, Netherlands	July
Dr Catherine Watkinson	Imperial College, London, UK	July
Mr Michael Wilensky	University of Washington, Washington, USA	October

VISITS TO INTERNATIONAL INSTITUTIONS AND ASTRONOMY FACILITIES

WHO	INSTITUTION/FACILITY VISITED	WHERE	WHEN
Ben McKinley	International Space Science Institute	Beijing, China	January
Ayan Acharyya	NASA Goddard Space Flight Centre	Greenbelt, Maryland, USA	January
Michael Hayden	University of Washington	Seattle, Washington, USA	January
Martin Asplund	Sexten Centre for Astrophysics	Sexten, Italy	January
Luca Cortese	MacMaster University	Hamilton, Canda	February
Christopher Jordan	Kobayashi-Maskawa Institute	Nagoya, Japan	February
Tiantian Yuan	W.M. Keck Observatory	Waimea, Hawaii, USA	March
Emma Ryan-Weber	University of Tokyo	Tokyo, Japan	March
Bradley Grieg	Scuola Normale Superiore	Pisa, Italy	March-April
Joss Bland-Hawthorn	Kavli Institute for Theoretical Physics, University of California	Santa Barbara, California	April
Caroline Foster	European Southern Observatory headquarters	Garching, Germany	April
Dilyar Barat	Ghent University	Ghent, Belgium	April
Michele Trenti	Aspen Center of Physics and UCLA	Aspen, CO and Los Angeles, CA, USA	
Jesse van de Sande	European Southern Observatory, Very Large Telescope	Paranal, Chile	
Karl Glazebrook	Tohoku University, Dept. of Astronomy	Tohoku, Japan	April
Ellert van der Velden	Institute for Mathematics, Astrophysics and Particle Physics	Nijmegen, the Netherlands	April
Manodeep Sinha	Chiba University	Chiba, Japan	May
Luca Cortese	Indian Institute for Astrophysics, Christ University, The Inter-University Centre for Astronomy and Astrophysics, National Centre for Radio Astrophysics	Bengaluru and Pune, India	May
Luca Casagrande	Kavli Institute for Theoretical Physics, University of California	Santa Barbara, CA, USA	May
Tania Barone	University of Ghent	Ghent, Belgium	May
Tania Barone	University of Oxford	Oxford, UK	May
Boquan Chen	Padova Observatory	Padova, Italy	June
Boquan Chen	International School of Space Science	L'Aquila, Italy	June

Continued

WHO	INSTITUTION/FACILITY VISITED	WHERE	WHEN
Govind Nandakumar	Observatoire de la Cote D'azur	Nice, France	June
Yifei Jin	Heidelberg University	Heidelberg, Germany	June
Michael Hayden	Observatoire de la Cote D'azur	Nice, France	June
Thomas Nordlander	Max Planck Institute for Astronomy (MPIA)	Heidelberg, Germany	June
Yifei Jin	Leiden University	Leiden, the Netherlands	June
Ivy Wong	Sejong University	Seoul, South Korea	June
Cathyrn Trott	SKA Headquarters	Manchester, UK	June
Martin Asplund	University of Ljubljana	Ljubljana, Slovenia	June
Michael Hayden	University of Ljubljana	Ljubljana, Slovenia	June
Shourya Khan	Nice Observatory	Nice, France	June
Rachel Webster	Brown University	Rhode Island, USA	June
Joss Bland-Hawthorn	Observatório Astronômico de Brera, International Institute for Astrophysics	Merate, Italy	July
Joss Bland-Hawthorn	Laboratoire d'Astrophysique Marseille	Marseille, France	July
Maryam Arabsalmani	CEA Paris-Saclay	Paris, France	July
Maryam Arabsalmani	European Southern Observatory	Garching, Germany	July
Christian Reichard	University of Chicago	Chicago, USA	July
Barbara Catinella	University College London	London, UK	July
Luca Cortese	University College London	London, UK	July
Nicholas Scott	Kapteyn Institute for Astronomy	Groningen, the Netherlands	July
Bi-Qing For	European Southern Observatory	Garching, Germany	July/ August
Ainulnabilah Nasirudin	University of Sao Paolo	Sao Paolo, Brazil	July/ August
Ellert van der Velden	Space Telescope Science Institute	Baltimore, Maryland, USA	July/ August
Tristan Reynolds	Munich Institute for Astro- and Particle Physics (MIAPP)	Munich, Germany	July/ August
Boquan Chen	Leiden University	Leiden, the Netherlands	August
Karl Glazebrook	W.M. Keck Observatory	Waimea, Hawaii, USA	August

Continued

WHO	INSTITUTION/FACILITY VISITED	WHERE	WHEN
Elaine Sadler	Max Planck Institute for Astronomy and European Southern Observatory	Munich, Germany	August
Madeline Marshall	Arizona State University	Tempe, AZ, USA	August
Michele Trenti	W.M. Keck Observatory	Waimea, Hawaii, USA	August
Madeline Marshall	Carnegie Mellon University	Pittsburg, USA	August
Scott Croom	Leibniz-Institute for Astrophysics Potsdam	Potsdam, Germany	September
Govind Nandakumar	Observatoire de la Cote d'Azur	Nice, France	September
Thomas Nordlander	Max Planck Institute for Astronomy	Heidelberg, Germany	September
Stuart Wyithe	Geneva Observatory	Geneva, Switzerland	September
Ayan Acharyya	Space Telescope Science Institute	Baltimore, Maryland, USA	September
Bi-Qing For	SAAO, University of Cape Town and University of Western Cape	Cape Town, South Africa	September
Ayan Acharyya	Flatiron Institute, New York University	New York, NY, USA	September
Benjamin McKinley	McGill University	Montreal, Canada	October
Alex Cameron	European Southern Observatory, Very Large Telescope	Paranal, Chile	October
Bradley Grieg	Scuola Normale Superiore	Pisa, Italy	October
Dian Triani	Space Telescope Science Institute and University of Northern Carolina at Chapel Hill	Baltimore, MD and Chapel Hill, NC, USA	October
Virginia Kilborn	University of Northern Carolina at Chapel Hill	Chapel Hill, NC, USA	October
Emma Ryan-Weber	European Southern Observatory	Garching, Germany	November
Sree Oh	Heidelberg University	Heidelberg, Germany	November
Sarah Sweet	Institute of Cosmology and Gravitation - University of Portsmouth	Portsmouth, UK	November
Xi Wang	Max Planck Institute of Astronomy	Heidelberg, Germany	November
Xi Wang	Stockholm University	Stockholm, Sweden	November
Joseph Ronniy	McGill Space Institute	Montreal, Canada	November & December
Christopher Jordan	Arizona State University	Tempe, AZ, USA	December
Luca Casagrande	Observatoire de la Côte d'Azur	Nice, France	December

PUBLICATIONS

REFEREED JOURNAL ARTICLES

1. Acebron, A., Alon, M., Zitrin, A., Mahler, G., Coe, D., Sharon, K., Cibirka, N., Bradač, M., Trenti, M., Umetsu, K., Andrade-Santos, F., Avila, R. J., Bradley, L., Carrasco, D., Cerny, C., Czakon, N. G., Dawson, W. A., Frye, B., Hoag, A. T., Huang, K.-H., Johnson, T. L., Jones, C., Kikuchihara, S., Lam, D., Livermore, R. C., Lovisari, L., Mainali, R., Oesch, P. A., Ogaz, S., Ouchi, M., Past, M., Paterno-Mahler, R., Peterson, A., Ryan, R. E., Salmon, B., Sendra-Server, I., Stark, D. P., Strait, V., Toft, S., Vulcani, B. (2019) "RELICS: High-resolution Constraints on the Inner Mass Distribution of the z = 0.83 Merging Cluster RXJ0152.7-1357 from Strong Lensing", The Astrophysical Journal, 874, 132.

2. Acharyya, A., Kewley, L. J., Rigby, J. R., Bayliss, M., Bian, F., Nicholls, D., Federrath, C., Kaasinen, M., Florian, M., Blanc, G. A. (2019) "Rest-frame UV and optical emission line diagnostics of ionised gas properties: a test case in a star-forming knot of a lensed galaxy at z˜ 1.7", Monthly Notices of the Royal Astronomical Society, 488, 5862.

3. Alcorn, L. Y., Gupta, A., Tran, K.-V., Kacprzak, G. G., Yuan, T., Cohn, J., Forrest, B., Glazebrook, K., Harshan, A., Kewley, L. J., Labbé, I., Nanayakkara, T., Papovich, C., Spitler, L. R., Straatman, C. M. S. (2019) "A Tale of Two Clusters: An Analysis of Gas-phase Metallicity and Nebular Gas Conditions in Proto-cluster Galaxies at z˜ 2", The Astrophysical Journal, 883, 153.

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6. Alsaberi, R. Z. E., Barnes, L. A., Filipović, M. D., Maxted, N. I., Sano, H., Rowell, G., Bozzetto, L. M., Gurovich, S., Urošević, D., Onić, D., For, B.-Q., Manojlović, P., Wong, G., Galvin, T. J., Kavanagh, P., Ralph, N. O., Crawford, E. J., Sasaki, M., Haberl, F., Maggi, P., Tothill, N. F. H., Fukui, Y. (2019) "Radio emission from interstellar shocks: Young type Ia supernova remnants and the case of N 103B in the Large Magellanic Cloud", Astrophysics and Space Science, 364, 204.

7. Alsaberi, R. Z. E., Maitra, C., Filipović, M. D., Bozzetto, L. M., Haberl, F., Maggi, P., Sasaki, M., Manjolović, P., Velović, V., Kavanagh, P., Maxted, N. I., Urošević, D., Rowell, G. P., Wong, G. F., For, B.-Q., O'Brien, A. N., Galvin, T. J., Staveley-Smith, L., Norris, R. P., Jarrett, T., Kothes, R., Luken, K. J., Hurley-Walker, N., Sano, H., Onić, D., Dai, S., Pannuti, T. G., Tothill, N. F. H., Crawford, E. J., Yew, M., Bojičić, I., Dénes, H., McClure-Griffiths, N., Gurovich, S., Fukui, Y. (2019) "Discovery of a pulsar-powered bow shock nebula in the Small Magellanic Cloud supernova remnant DEM S5", Monthly Notices of the Royal Astronomical Society, 486, 2507.

8. Amarantidis, S., Afonso, J., Messias, H., Henriques, B., Griffin, A., Lacey, C., Lagos, C. del P., Gonzalez-Perez, V., Dubois, Y., Volonteri, M., Matute, I., Pappalardo, C., Qin, Y., Chary, R.-R., Norris, R. P. (2019) "The first supermassive black holes: indications from models for future observations", Monthly Notices of the Royal Astronomical Society, 485, 2694.

9. Amarsi, A. M., Nissen, P. E., Asplund, M., Lind, K., Barklem, P. S. (2019) "Carbon and oxygen in metal-poor halo stars", Astronomy and Astrophysics, 622, L4.

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11. Armillotta, L., Krumholz, M. R., Di Teodoro, E. M., McClure-Griffiths, N. M. (2019) "The life cycle of the Central Molecular Zone - I. Inflow, star formation, and winds", Monthly Notices of the Royal Astronomical Society, 490, 4401.

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13. Barry, N., Beardsley, A. P., Byrne, R., Hazelton, B., Morales, M. F., Pober, J. C., Sullivan, I. (2019) "The FHD/εppsilon Epoch of Reionisation power spectrum pipeline", Publications of the Astronomical Society of Australia, 36, e026.

14. Barry, N., Wilensky, M., Trott, C. M., Pindor, B., Beardsley, A. P., Hazelton, B. J., Sullivan, I. S., Morales, M. F., Pober, J. C., Line, J., Greig, B., Byrne, R., Lanman, A., Li, W., Jordan, C. H., Joseph, R. C., McKinley, B., Rahimi, M., Yoshiura, S., Bowman, J. D., Gaensler, B. M., Hewitt, J. N., Jacobs, D. C., Mitchell, D. A., Udaya Shankar, N., Sethi, S. K., Subrahmanyan, R., Tingay, S. J., Webster, R. L., Wyithe, J. S. B. (2019) "Improving the Epoch of Reionisation Power Spectrum Results from Murchison Widefield Array Season 1 Observations", The Astrophysical Journal, 884, 1.

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16. Bassett, R., Ryan-Weber, E. V., Cooke, J., Diaz, C. G., Nanayakkara, T., Yuan, T.-T., Spitler, L. R., Meštrić, U., Garel, T., Sawicki, M., Gwyn, S., Golob, A. (2019) "On the lack of correlation between [O III]/[O II] and Lyman continuum escape fraction", Monthly Notices of the Royal Astronomical Society, 483, 5223.

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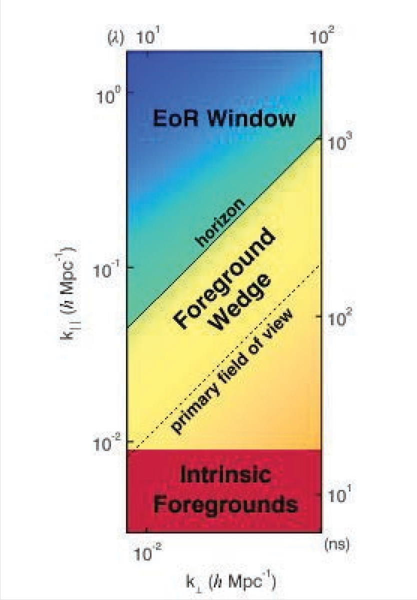

Figure from Barry et al (2019) (no. 13): A schematic representation of a 2D power spectrum. Intrinsic foregrounds dominate low $k_{\parallel}$ (modes along the line-of-sight) for all $k_{\perp}$ (modes perpendicular to the line-of-sight) due to their relatively smooth spectral structure. Chromaticity of the instrument mixes foreground modes up into the foreground wedge. The primary-field-of-view line and the horizon line are contamination limits dependent on how far off-axis sources are on the sky. Foreground-free measurement modes are expected to be in the EoR window.

18. Battisti, A. J., da Cunha, E., Grasha, K., Salvato, M., Daddi, E., Davies, L., Jin, S., Liu, D., Schinnerer, E., Vaccari, M., COSMOS Collaboration (2019) "MAGPHYS+photo-z: Constraining the Physical Properties of Galaxies with Unknown Redshifts", The Astrophysical Journal, 882, 61.

19. Baumgardt, H., He, C., Sweet, S. M., Drinkwater, M., Sollima, A., Hurley, J., Usher, C., Kamann, S., Dalgleish, H., Dreizler, S., Husser, T.-O. (2019) "No evidence for intermediate-mass black holes in the globular clusters ω Cen and NGC 6624", Monthly Notices of the Royal Astronomical Society, 488, 5340.

20. Beardsley, A. P., Johnston-Hollitt, M., Trott, C. M., Pober, J. C., Morgan, J., Oberoi, D., Kaplan, D. L., Lynch, C. R., Anderson, G. E., McCauley, P. I., Croft, S., James, C. W., Wong, O. I., Tremblay, C. D., Norris, R. P., Cairns, I. H., Lonsdale, C. J., Hancock, P. J., Gaensler, B. M., Bhat, N. D. R., Li, W., Hurley-Walker, N., Callingham, J. R., Seymour, N., Yoshiura, S., Joseph, R. C., Takahashi, K., Sokolowski, M., Miller-Jones, J. C. A., Chauhan, J. V., Bojičić, I., Filipović, M. D., Leahy, D., Su, H., Tian, W. W., McSweeney, S. J., Meyers, B. W., Kitaeff, S., Vernstrom, T., Gürkan, G., Heald, G., Xue, M., Riseley, C. J., Duchesne, S. W., Bowman, J. D., Jacobs, D. C., Crosse, B., Emrich, D., Franzen, T. M. O., Horsley, L., and 9 colleagues (2019) "Science with the Murchison Widefield Array: Phase I results and Phase II opportunities", Publications of the Astronomical Society of Australia, 36, e050.

21. Becker, G. D., Pettini, M., Rafelski, M., D'Odorico, V., Boera, E., Christensen, L., Cupani, G., Ellison, S. L., Farina, E. P., Fumagalli, M., López, S., Neeleman, M., Ryan-Weber, E. V., Worseck, G. (2019) "The Evolution of O I over 3.2 < z < 6.5: Reionisation of the Circumgalactic Medium", The Astrophysical Journal, 883, 163.

22. Bland-Hawthorn, J., Maloney, P. R., Sutherland, R., Groves, B., Guglielmo, M., Li, W., Curzons, A., Cecil, G., Fox, A. J. (2019) "The Large-scale Ionisation Cones in the Galaxy", The Astrophysical Journal, 886, 45.

23. Bland-Hawthorn, J., Sharma, S., Tepper-Garcia, T., Binney, J., Freeman, K. C., Hayden, M. R., Kos, J., De Silva, G. M., Ellis, S., Lewis, G. F., Asplund, M., Buder, S., Casey, A. R., D'Orazi, V., Duong, L., Khanna, S., Lin, J., Lind, K., Martell, S. L., Ness, M. K., Simpson, J. D., Zucker, D. B., Zwitter, T., Kafle, P. R., Quillen, A. C., Ting, Y.-S., Wyse, R. F. G. (2019) "The GALAH survey and Gaia DR2: dissecting the stellar disc's phase space by age, action, chemistry, and location", Monthly Notices of the Royal Astronomical Society, 486, 1167.

24. Bluck, A. F. L., Bottrell, C., Teimoorinia, H., Henriques, B. M. B., Mendel, J. T., Ellison, S. L., Thanjavur, K., Simard, L., Patton, D. R., Conselice, C. J., Moreno, J., Woo, J. (2019) "What shapes a galaxy? - unraveling the role of mass, environment, and star formation in forming galactic structure", Monthly Notices of the Royal Astronomical Society, 485, 666.

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27. Bryant, J. J., Croom, S. M., van de Sande, J., Scott, N., Fogarty, L. M. R., Bland-Hawthorn, J., Bloom, J. V., Taylor, E. N., Brough, S., Robotham, A., Cortese, L., Couch, W., Owers, M. S., Medling, A. M., Federrath, C., Bekki, K., Richards, S. N., Lawrence, J. S., Konstantopoulos, I. S. (2019) "The SAMI Galaxy Survey: stellar and gas misalignments and the origin of gas in nearby galaxies", Monthly Notices of the Royal Astronomical Society, 483, 458.

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29. Byrne, R., Morales, M. F., Hazelton, B., Li, W., Barry, N., Beardsley, A. P., Joseph, R., Pober, J., Sullivan, I., Trott, C. (2019) "Fundamental Limitations on the Calibration of Redundant 21 cm Cosmology Instruments and Implications for HERA and the SKA", The Astrophysical Journal, 875, 70.

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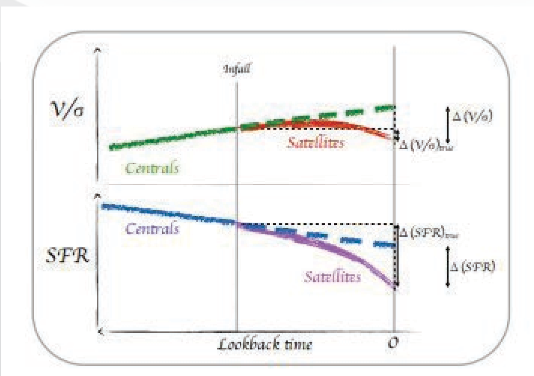

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Figure from Cortese et al (2019) (no. 40): A cartoon summarising the evolutionary scenario emerging from this work and the potential effect of progenitor bias. The top panel shows the increase of V /σ with decreasing lookback time/ redshift for galaxies while being star-forming centrals (solid green line), and the change in V /σ once they become satellites (red line). The green dashed line shows the expected evolution of V /σ in case the galaxy would have remained a starforming central until z ~0. The true Δ(V /σ) and the value obtained via our matching technique are shown by the black vertical arrows. The bottom panel shows the case of SF R, with the changes for centrals and satellites highlighted by the blue and pink lines, respectively. In this case, the observed Δ(SF R) at z ~0 is always smaller than the real value

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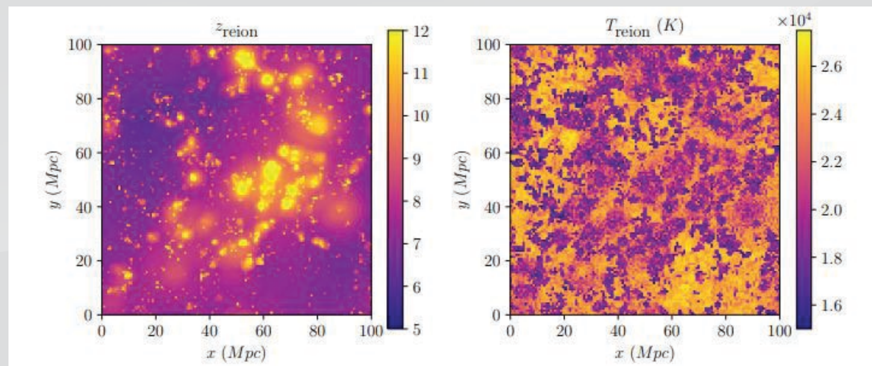

Figure from Davies et al (2019) (no. 47): 100×100×0.8M pc redshift of reionisation slice (left) compared to the temperature just after the region ionises (right), showing an inverse correlation between them, with early reionisation corresponding to low reionsiation temperature. As the ionisation fronts speed up in the cosmic voids, the gas is ionised to a hotter temperature.

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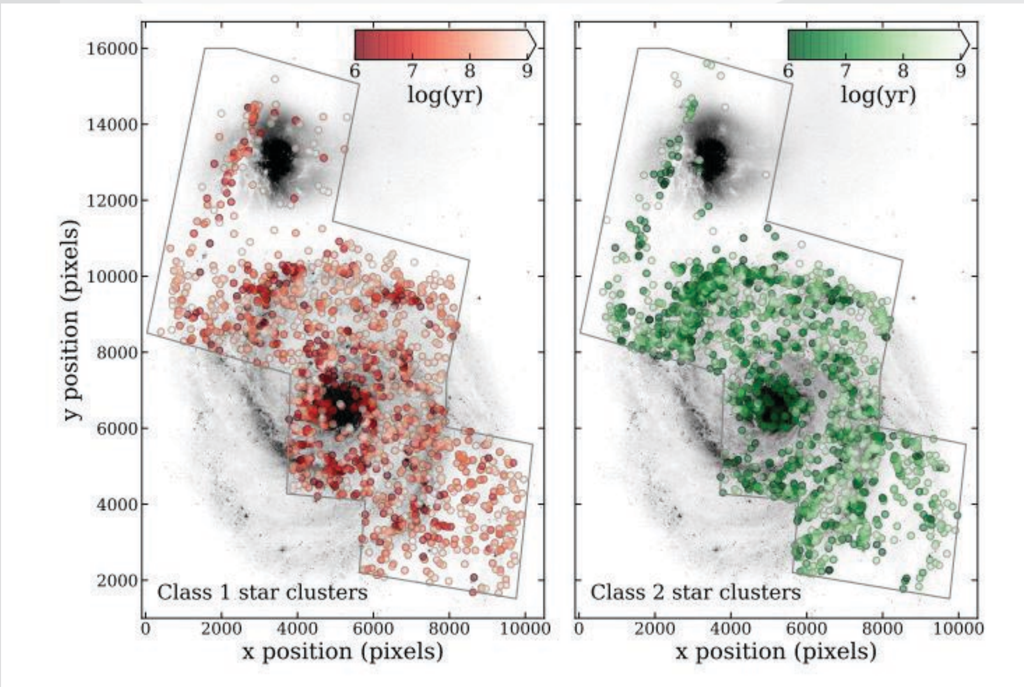

Figure from Grasha et al (2019) (no. 80): The V-band ACS image of NGC 5194 overplotted with the location of the class 1 (left; red) and class 2 (right; green) star clusters. The star clusters are coloured according to their ages with dark colours corresponding to younger ages and all clusters older than 1 Gyr are shown as white. The black outline shows the UVIS footprint. Cluster classifications are based off of morphology and our morphological cluster classification is a good approximation to also a dynamical classification (Adamo et al. 2017; Grasha et al. 2017a; Ryon et al. 2017). The typical ages of class 1 clusters are older and show median ages of 90 Myr than the median age of 20 Myr for the class 2 clusters. The class 1 sources are much more uniformly distributed while the class 2 clusters are predominantly tracing the spiral arms and the centre region. The youngest clusters of both classes are mostly concentrated along the spiral arms.

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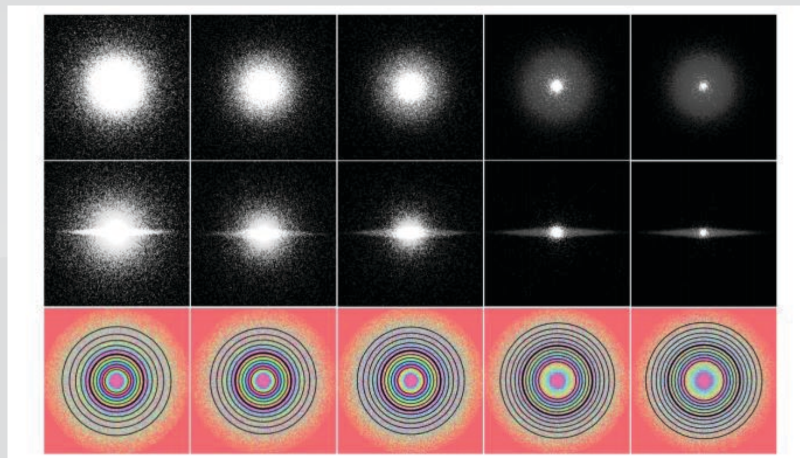

Figure from Harborne et al (2019) (no. 86): The mock catalogue of galaxies investigated in this work. From left to right, we show the S0, Sa, Sb, Sc and Sd models. The top row shows each galaxy inclined to 0° (i.e. face-on) and the middle row demonstrates the same particle distribution projected at 90° (i.e. edge-on). These top two rows demonstrate the particles contained within a radius of 50kpc. The bottom row shows the isophotal images of each galaxy within the SAMI field of view inclined face on at 0° . The overlaid ellipses contain 0.25-0.75 of the total flux at increments of 0.05. The R_{eff} for each galaxy is shown by the bold black line.

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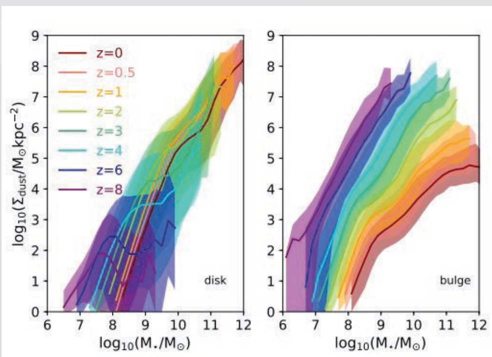

Figure from Lagos et al (2019) (no. 118): Dust surface density as a function of stellar mass from z = 8 to z = 0 for disks and bulges in Shark combined with the model RR14-steep to derive dust masses from the gas metallicity and surface density information. Lines show the medians, while shaded regions show the 16th – 84th percentile ranges.

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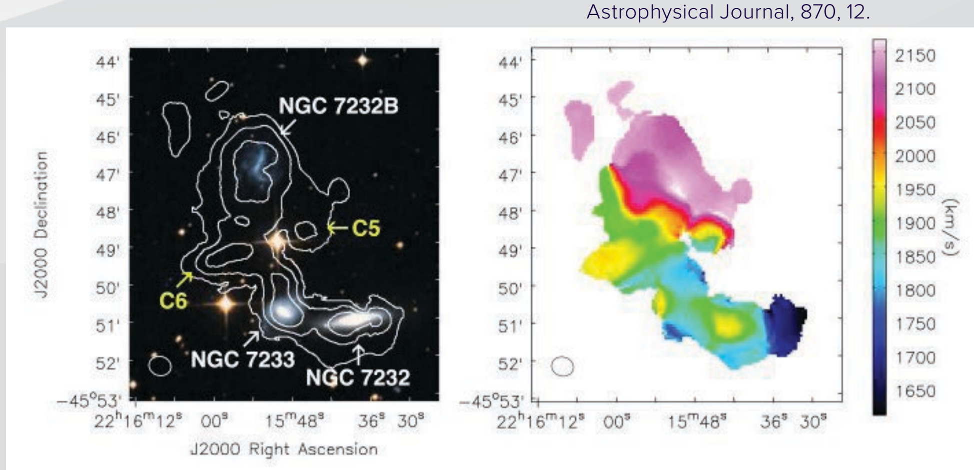

Figure from Lee-Waddell et al (2019) (no. 119): ASKAP HI moment maps of the NGC 7232/3 triplet. Left panel: moment 0 contours – at (1, 3, 6) × 1020 atoms cm−2 – superimposed on DSS2 coloured image. Three HI peaks coincide with the stellar components of the major galaxies. Two additional HI clouds, C5 and C6, are clearly visible in the intervening region connecting the northern spiral, NGC 7232B, to the other two galaxies NGC 7232 and NGC 7233. Right panel: moment 1 map.

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Figure from Ren et al (2019) (no. 156): Modelled cumulative number counts of galaxies with < M_{UV} per square degree at different values of scatter Σ = 0, 0.2, 0.4 (solid, dashed, dotted respectively) and at different redshifts, z ~ 8, 10, 12 (coloured lines). The effects on the UVLF from gravitational lensing along a line of sight is included. The unlensed, intrinsic number counts for z ~ 8 curves are underlaid with slight transparency. Here we assume the scenario that the halo mass to galaxy luminosity relation contains a mass dependent, redshift independent feedback process. The shaded dark region is the WFIRST field of coverage of ~ 2000 deg^2 and the lighter region encompasses the all-sky coverage of ~ 40000 deg^2 . The typical 1σ uncertainty is included for the Σ = 0 cases.

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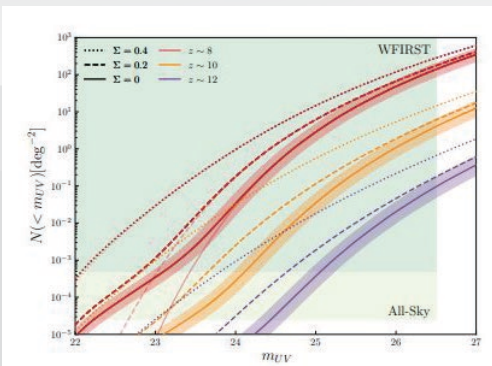

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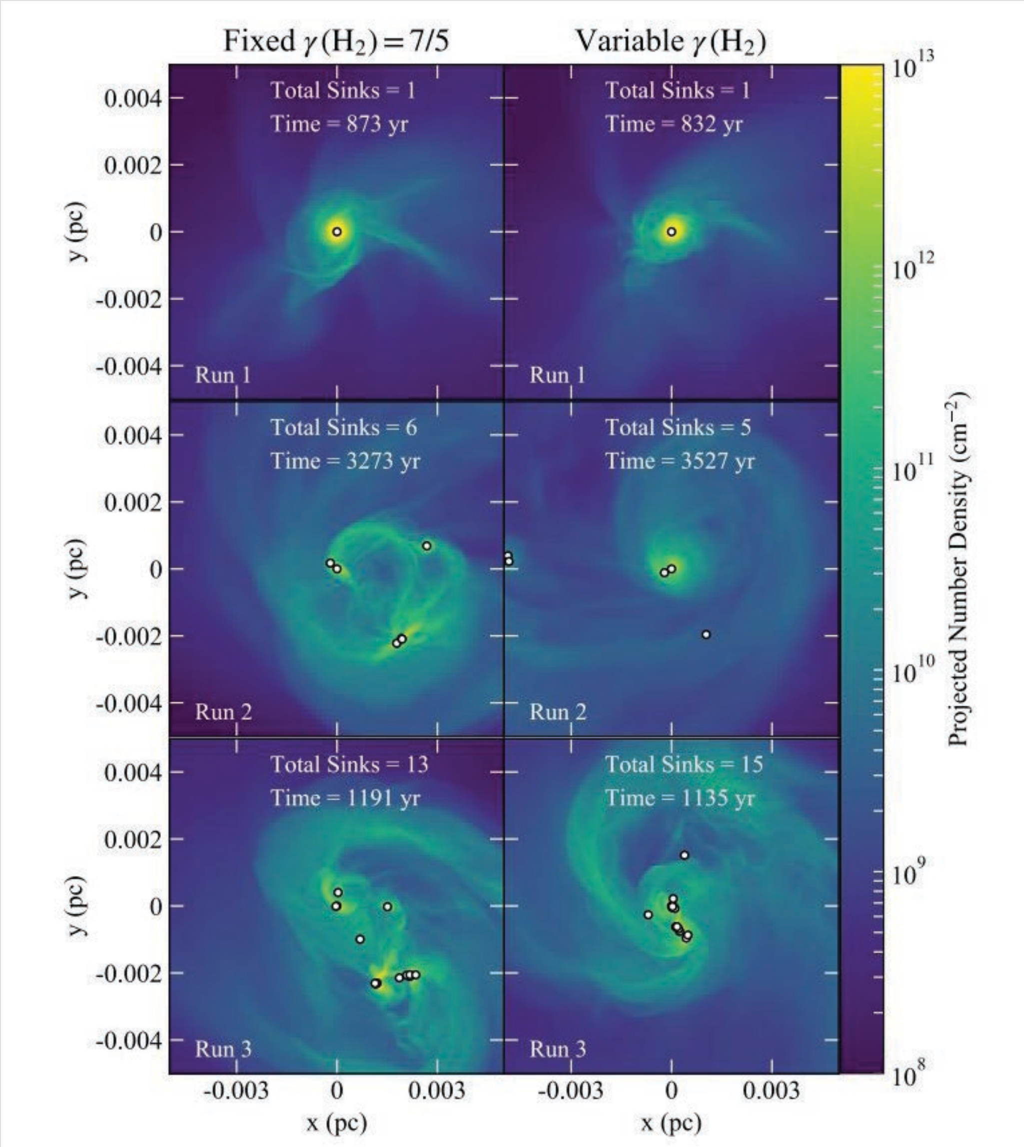

Figure from Sharda, Krumholz and Federrath (2019) (no. 169): Face-on density-weighted projection maps of the number density (through the $\hat{z}$ axis) for a pair of three representative runs showing no (top panels), some (middle panels) and high fragmentation (bottom panels) for fixed (left) and variable (right) γH_2 respectively. All the snapshots are taken when the sink(s) (shown in white circles with black boundaries) have collectively accreted 5 per cent of the initial cloud mass (SFE = 5%, see equation 9). The snapshots cover a spherical region of radius 0.01 pc, centred on the most massive sink in the simulation. The time printed in each panel is the time since the formation of the first sink particle in each run. Each of the paired fixed and variable γH_2 cases shown begins from identical initial conditions, so the differences seen in the corresponding maps are solely due to variations in γH_2 .

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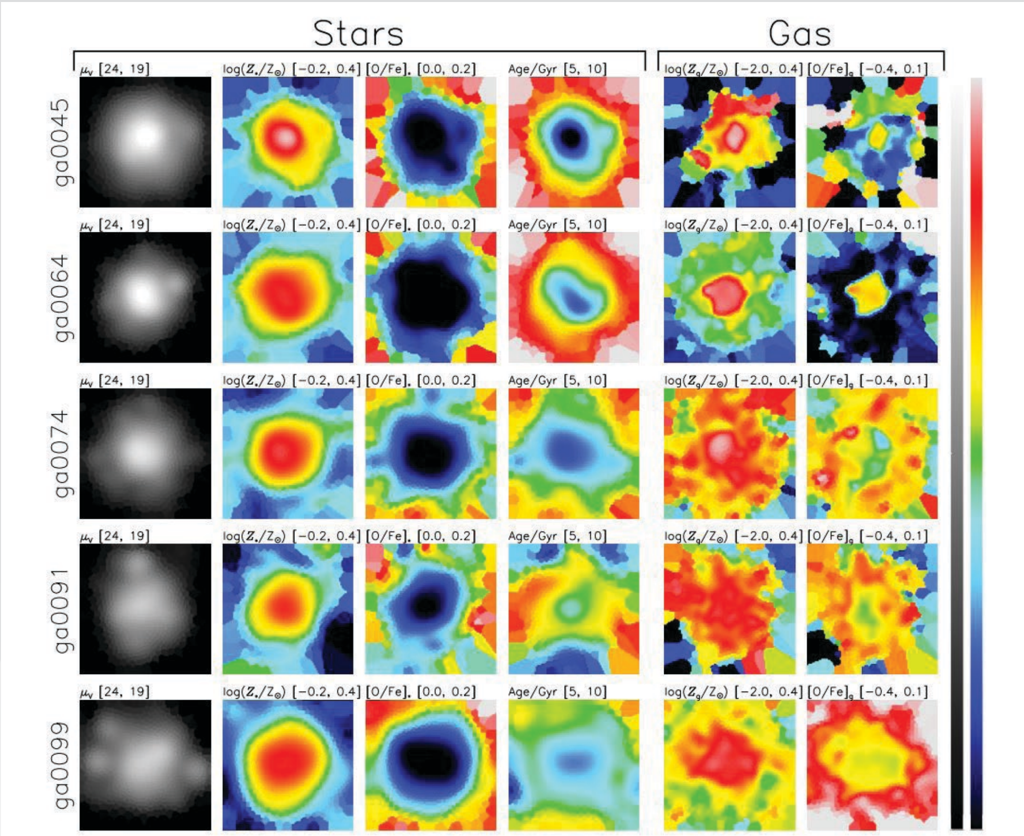

Figure from Taylor, Kobayashi, & Fedderath (2019) (no. 180): Maps of mass-weighted stellar and gas properties for our five simulated galaxies with atypical kinematics. The columns show V -band surface brightness (mag arcsec^{-2}), stellar metallicity log ($Z_*/Z_\odot$), stellar [O/Fe], stellar age, gas metallicity log ($Z_g/Z_\odot$), and gas [O/Fe], respectively. The range of values in each panel is shown in brackets (low values are blue, high are red). Each panel is $6R_e$ on a side.

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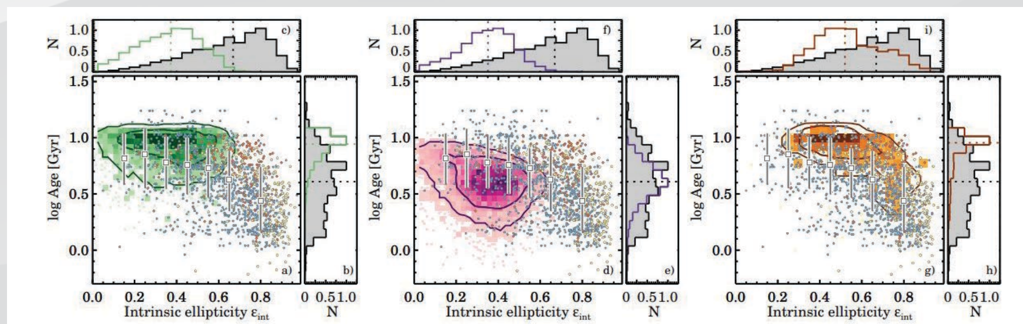

Figure from van de Sande et al (2019) (no. 191): Comparison of simulated and observational data in the age-intrinsic ellipticity diagram. The intrinsic ellipticities from the simulations are derived from the edge-on projection of galaxies, whereas the observational intrinsic ellipticities have been derived using theoretical model predictions of axisymmetric oblate rotators. The trend where younger galaxies are also more flattened is poorly recovered in EAGLE$^+$, slightly more pronounced in HORIZON-AGN, but clearly detected in MAGNETICUM. However, at fixed intrinsic ellipticity, all simulations show offsets in age. In both EAGLE$^+$ and HORIZON-AGN there is a deficit of flattened galaxies with $\epsilon_{intr} > 0.7$, while MAGNETICUM galaxies extend to $\epsilon_{intr} \sim 0.7$.

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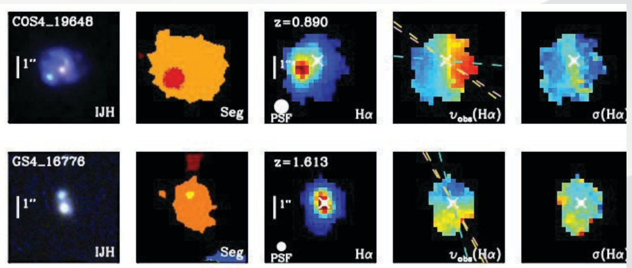

Figure from Wisnioski et al (2019) (no. 201): Example 1– and 2–D kinematic extractions for KMOS3D galaxies with close bright kinematic components at different inclinations. From left to right the panels for each galaxy correspond to an IJH HST colour-composite image, the associated segmentation map from 3D-HST Hα image derived from KMOS, Hα velocity field relative to the systemic redshift, and Hα velocity dispersion corrected for instrumental broadening. In the segmentation map different colours represent different unique IDs from the 3D-HST catalog.

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PERFORMANCE INDICATORS 2019

PERFOMANCE MEASURE		2019 TARGET	2019 ACTUAL	COMMENT
Number of research outputs	Papers in refereed journals	50	213	
	Media releases	6	7	
	Centre Videos	12	15	
	Facebook Page posts	26	73	
	Twitter posts	52	228	
	Exhibition or performance	1	3	
	STEM Education workshops	6	6	
	Website News Updates	12	7	New website being developed
	VR Program Development	1	0*	MOU signed with Deakin University
	SAMI Dataset	1	1	
	ASKAP Dataset	1	1	
Quality of research outputs	% of refereed papers in journals with impact factor > 2.5	80%	100%	
Number of training courses held/offered by the Centre	Professional skills workshop	1	2	
	ECR training day	1	2	
	Writing workshops	6	6	
	Transferrable Skills workshop	1	1	
Number of workshops/ conferences held/ offered by the Centre	International conference	2	2	
	National conference/ workshop	2	2	

Continued

PERFOMANCE MEASURE		2019 TARGET	2019 ACTUAL	COMMENT
Number of *additional* researchers working on Centre research	Postdoctoral researchers	5	3	
	Honours students	2	3	
	Masters by coursework	2	3	
	PhD students	12	20	
Number of presentations/ briefings	Public briefings/lectures	40	230	Many of these were media interviews by Brad Tucker and Alan Duffy
	Government briefings	4	29	
	Industry briefings	4	39	
	Non-government organisation briefings	6	6	
	Briefings to professional organisations & bodies	4	6	
	Professional conferences/ workshops presentations	40	123	
Number of new organisations collaborating with, or involved in, the Centre	New collaborative relationships	4	15	
	New participating organisation	1	0	Will occur in 2020
Maintain a collaborative and cohesive structure	Cross-node authorship of publications	43	83	
	Project team meetings with cross-node collaboration	6	6	
	Centre-wide climate survey	0	0	To be conducted every 2 years

Continued

PERFOMANCE MEASURE		2019 TARGET	2019 ACTUAL	COMMENT
Create a diverse Centre	Females at all levels	40%	**40%**	
	At least 35% travel funds to females	40%	**42%**	
	Female visitors	50%	**58%**	
	Child care at all Centre supported conferences	100%	**100%**	
Build the expertise for the next-generation telescopes	Students working on optical GMT pathfinder instruments	20%	**25%**	
	Students working on radio SKA pathfinder instruments	20%	**31%**	
	Students working on space telescope data	10%	**6%**	
	Students with data intensive research experience	30%	**51%**	
Train the next generation of scientists	% satisfaction with Centre-run skills workshops	80%	**87%**	
	% of PhD students and ECRs attending skills workshops	20%	**31%**	
	% ECRs achieving prestigious fellowships	10%	**28%**	**2 out of 7**
	% PhD students or ECRs achieving high quality jobs in other fields	10%	**28%**	**2 out of 7**

IMAGE CREDITS: Cristy Roberts

CONSOLIDATED FINANCIAL STATEMENT 2019

	2019 ACTUAL ($)
INCOME	**$**
ARC Grant	4,461,645
State Government Grants	
Other Grants	
University Contributions	1,135,091
Partner Contributions	
Other Income	196,823
TOTAL INCOME	**5,793,559**
EXPENSES	**$**
Salaries	4,351,820
Travel and Visitor Support	770,159
Equipment	40,976
Workshops and Conferences	115,009
Management and Administration	306,660
Education, Outreach and Communications	105,647
PHD Support	87,975
TOTAL EXPENSES	**5,765,969**
NET SURPLUS (DEFICIT)	**27,590**
Brought Forward Balance	6,115,895
CARRY FORWARD BALANCE	**6,143,485**

NOTES TO FINANCIAL STATEMENTS

1. ARC CONTRACT & GOVERNANCE

a) ASTRO 3D currently involves six Australian Universities and a further ten Australian and International Partner Organisations. Funding was approved by the ARC for seven years, subject to review after four years. The Centre commenced operation on 1 July 2017, a six month delay on the original 1 January commencement. The mid-term review will be conducted in May 2021

b) From an operational and financial perspective, the Centre operates as a single body, and all funding provided by the ARC is disseminated by the Australian National University as the administering organisation.

c) The Centre's operational and financial affairs are governed under defined policies and procedures.

d) Financial reporting provides institutional expenditure per Node, with the Business Manager for the Centre providing Consolidated Financial Reports for review by the Chief Operating Officer and Director.

2. INCOME

a) Income received from the ARC for 2019 amounted to $4.4m, including an amount relating to indexation of $211k.

b) University Contributions reflects all funds provided at Node level. An anomaly in funding of $90k relating to our Sydney Node was rectified in February 2020.

c) Other income includes a range of sundry costs including reimbursement of salary costs to ANU Node, invoiced costs associated with travel, and a grant received for National Science Week.

3. EXPENDITURE

a) Expenditure for the year was $5.8m against a budget of $6.2. This variance primarily relates to lower than budgeted Education and Outreach program costs due in part to the mid-year start of the new Chief Operating Officer, lower Research salaries due to timing factors and lower than expected PhD support costs.

b) A financial re-forecast will be conducted by mid-year of 2020, as part of a continued review of expenditure and allocation of funds.

c) The implementation of the Virtual Reality Program was deferred to 2020 due to the mid-year start of the new Chief Operating Officer and employment of a new Senior Coordinator for Education and Outreach towards the end of 2019.

d) The carried forward balance also reflects amounts from a late Centre start in the middle of 2017 and the subsequent Centre closing date pushed out to the middle of 2024. Indexation of ARC funding was budgeted at 2% but 5% was received.

4. FINANCIAL MANAGEMENT

a) As part of a sustained review of financial management practices, a review of financial reporting was undertaken in the prior financial year, and subsequently a monthly reporting process was implemented in 2019.

b) Financial management practices will continue to be reviewed in 2020, with a view to adding value to our data collection process.