ASTRO 3D

STRATEGIC PLAN 2017-2023

UNLOCKING THE UNIVERSE
INSPIRING THE FUTURE

Australian Government
Australian Research Council

ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions

Our Collaborating Universities:

Australian National University

THE UNIVERSITY OF MELBOURNE

SWINBURNE UNIVERSITY OF TECHNOLOGY

THE UNIVERSITY OF SYDNEY

THE UNIVERSITY OF WESTERN AUSTRALIA

Curtin University

Our Partner Institutions:

CSIRO

AAO

NCI NATIONAL COMPUTATIONAL INFRASTRUCTURE

CALIFORNIA INSTITUTE OF TECHNOLOGY 1891

UNIVERSITY OF OXFORD

UNIVERSITY of WASHINGTON

ASTRON Netherlands Institute for Radio Astronomy

UNIVERSITY OF TORONTO

Heidelberg Institute for Theoretical Studies | HITS

CHINESE ACADEMY OF SCIENCES

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The ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D) is a $40m Research Centre of Excellence funded over seven years by a grant from the Australian Research Council (ARC) and supported by six collaborating Australian universities - the ANU, Swinburne University of Technology, University of Western Australia, University of Sydney, Curtin University and the University of Melbourne – as well as three national partners – the Australian Astronomical Observatory, CSIRO and the National Computational Infrastructure – and seven international partner institutions – the California Institute of Technology, University of Oxford, University of Toronto, University of Washington, the Netherlands Institute for Radio Astronomy, the Chinese Academy of Sciences and the Heidelberg Institute for Theoretical Studies

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.

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 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.

"We will be investigating how the Universe formed its first matter in the dark moments after the Big Bang, how the first stars and galaxies formed and evolved into galaxies like our Milky Way, and how the stars created the chemical elements in the Universe," said Professor Lisa Kewley, Centre Director

4. Provide young Australian scientists with transferrable skills for the modern workforce

- ✓ We will train the new generation of young Australian astrophysicists in transferrable 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 IP and Innovation Committee of experts in commercialisation. This committee will work closely with our university IP and commercialisation offices to help astronomers navigate the processes required for commercialisation and transfer of technology to other disciplines.

FUNDING

The Australian Research Council has provided $30.3m over 7 years to fund the Centre. A further $8.4m has been committed by the six collaborating universities and the Chinese Academy of Science has committed $140,000.

In–kind support is significant, totalling $144M. The contributions of the individual institutions are detailed below.

	CASH $	IN-KIND $
Australian Research Council	**30,300,000**	-
COLLABORATING UNIVERSITIES		
Australian National University	2,342,001	13,192,953
University of Melbourne	1,319,980	2,680,003
University of Western Australia	1,251,609	1,996,260
University of Sydney	1,290,792	6,982,788
Swinburne University of Technology	1,261,885	10,637,241
Curtin University	965,335	685,885
	8,431,602	**36,175,130**
NATIONAL PARTNERS		
Australian Astronomical Observatory	-	12,056,380
CSIRO	-	61,460,000
National Computational Infrastructure	-	2,368,800
		75,885,180
INTERNATIONAL PARTNERS		
California Institute of Technology	-	1,447,390
University of Oxford	-	525,000
University of Toronto	-	903,994
University of Washington	-	11,082,680
Netherlands Institute for Radio Astronomy	-	817,600
Chinese Academy of Sciences	-	15,960,000
Heidelberg Institute for Theoretical Studies	-	1,492,120
	-	**32,228,784**
	38,731,602	**144,289,094**

GOVERNANCE AND ORGANISATIONAL STRUCTURE

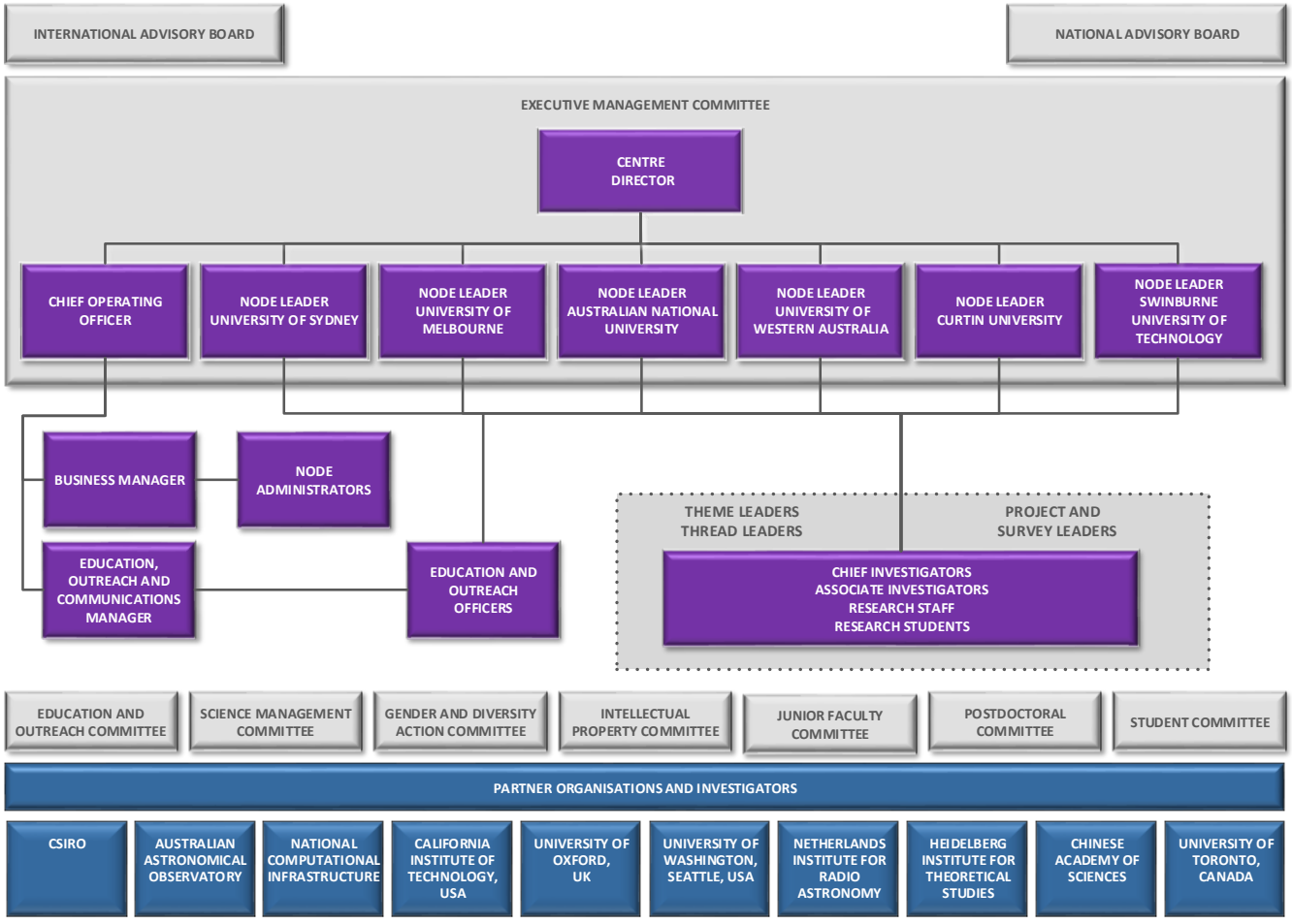
We have established a collaborative and cohesive structure (shown below) that will focus on the effective and efficient delivery of the Centre's Strategic Goals and meeting our Key Performance Indicators (see further pages 18-22).

Two proactive and engaged external Advisory Boards will 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 education/outreach goals.

The ***International Advisory Board*** will provide support and advice to the Director and the Executive Committee on the effectiveness of the Centre in reaching its international goals and ensuring the Centre is known as a world leading scientific research body. It will identify opportunities for international collaboration and innovation, provide feedback on the international competitiveness of the Centre, provide support in benchmarking against comparative centres around the world and contribute to the development of the Centre's strategic direction.

The ***National Advisory Board*** will advise the Director and Executive Committee on the effectiveness of the Centre in training the next generation of scientists, implementing public outreach programs and the strategic management of the Centre. Its role is to provide advice on the Centre's progress towards achievement of the Government's National Science and Innovation Agenda, advise on the development and delivery of education and outreach programs, and identify opportunities for further scientific collaboration and engagement with industry and government.

The management structure is supported by a number of active internal Committees that provide advice in specific areas of focus for the Centre.



SCIENTIFIC RESOURCES

Organisations

We have the critical mass required to conduct the ambitious research of this Centre by uniting Australia's top astronomical universities (ANU, USYD, Swinburne, UMELB, Curtin and UWA) with Australia's national optical observatory (the Australian Astronomical Observatory), Australia's national radio facility (CSIRO Centre for Astrophysics and Space Sciences), and Australia's National Supercomputing Facility (the National Computational Infrastructure - NCI). These Australian partner observatories and facilities are providing immense support for ASTRO 3D both through their deep expertise and their significant in-kind resources.

We have carefully selected a group of seven world-class international partner institutions - Caltech, Oxford, the Heidelberg Institute of Theoretical Studies, the Netherlands Institute for Radio Astronomy (ASTRON), the University of Toronto, the University of Washington and the Chinese Academy of Sciences. These Institutions were selected from a short-list of 18 institutions based on strong existing collaborations, or the potential for strong collaborations across multiple nodes and across the Centre themes/threads. These international partners bring a tremendous amount of expertise and resources, elevating this Centre from an Australian based Centre to a truly international Centre with a sharp focus on internationally competitive and timely science goals. Our international partners will be engaged through regular international video-conferencing, cross-institution postdoctoral positions, joint PhD supervision, and a visitor program where entire research groups will be supported to visit Australian nodes to facilitate collaboration at all levels from PhD students and early career researchers through to academic staff. The Centre Director and Theme/Thread Leaders will foster the international partnerships through regular visits and video conferencing.

Scientists

The Centre concentrates leading Australian astrophysicists and the Directors of Australia's major observatory and supercomputing centres with a tremendous number of Australia's future scientific leaders. This stellar team includes six Fellows of the Australian Academy of Science, four ARC Laureate Fellows, seven ARC Future Fellows, and four Discovery Early Career Award (DECRA) postdoctoral researchers. Our 34 Chief and Partner Investigators and 45 Associate Investigators have committed a substantial fraction of their time to the Centre (0.5 FTE on average for CIs and 0.3 FTE on average for PI/AIs). This large and focused effort will ensure that the Centre science goals are reached. Our large team of Associate Investigators profoundly strengthens the Centre, providing an exceptional range of expertise and support. The expertise of our investigators comprehensively encompasses theory and observation, optical to radio, and data intensive astronomy. The majority of these investigators will contribute to more than project or survey, helping cement the linkages and collaborations across the Centre. The fraction of new Australian CI/PIs to ASTRO 3D is 50%, representing the right balance between the new research direction for this Centre and the continuation of a successful operations model.

Collaboration

We will further cement our cohesive, highly collaborative Centre with the following initiatives.

- ✓ We have a dedicated "Collaboration Leader" to drive collaboration across projects and surveys within nodes, across nodes, and with our international partners.
- ✓ Busy weeks and writing workshops - the multiple nodes and international partners involved in each survey and project will attend regular busy weeks where concentrated collaboration activity is conducted towards specific scientific and data analysis goals. Busy weeks are extremely productive and build cohesiveness within the Centre programs. We will hold cross-program busy weeks during critical periods where surveys/projects require input from one another. During peak output periods, we will hold publication writing workshops which will include scientific writing tutorials, peer review sessions, and focused quiet group writing sessions.
- ✓ One of the flagships of ASTRO 3D will be a prestigious Fellowship Program, similar to which will be operated similarly to the highly successful NASA Hubble and Carnegie-Princeton Fellowship programs in the US. Outstanding, highly motivated young researchers will be recruited from the international job market with priority for those who will collaborate and/or reside at different nodes and partner organisations. These fellows will bridge gaps among institutions and will add to the cohesiveness of the Centre. The postdoctoral Fellows will come together annually for an ASTRO 3D fellowship meeting to enhance collaboration amongst the fellow cohort.

- ✓ Key Performance Indicators for the Centre include milestones for publications with multi-node affiliations, publications with cross project co-authors and PhD student cross-node co-supervision.
- ✓ Cohesion will be maintained across the entire Centre through an annual meeting of all Centre members in a retreat-style environment. These meetings will promote the sharing of exciting new science results with the entire team, assessment of the mentoring and leadership training of early-career researchers, and monitoring of progress against the Centre science goals and Key Performance Indicators.
- ✓ Investigators from all participating organisations will have access to travel funding to promote cross-institution collaboration. Funding will enable entire research groups to visit at the same time, allowing for direct collaboration across all levels from PhD students to senior faculty. The Centre Director, Deputy Director, Collaboration Leader and Chief Operating Officer will undertake frequent visits between nodes and partner organisations to ensure that the Centre researchers are appropriately engaged in Centre activities and to maintain the cross-institution collaborations.
- ✓ Cohesion between theorists and observers will be a major goal for the Centre, with theory embedded within the surveys and observational units through strategic postdoc hiring and active engagement of theorists with observers at every node and at every level. Cosmological hydrodynamic simulations and semi-analytic galaxy-evolution models will bridge the Epoch of Reionisation with the build-up of matter and chemical elements in the Universe. Detailed chemical evolution models are required to interpret the first stars observations, the chemical evolution of galaxies, and chemo-dynamical models are required to inform the galactic archaeology of our Milky Way. The observational and theoretical survey archives will be linked, providing economies of scale, and facilitating the analysis of data across different wavelengths, across theory and observations, and across the science themes. Simulated 3D datasets will be created and made available through the ASVO to be analysed in the same way as observational datasets to help interpret and exploit new data. The embedding of theory within experimental projects gives us a major advantage over competing theory groups who traditionally work separately from observers to produce simulations over periods of years. Theoretical modelling depends on the physics assumed for star formation, and the injection of energy, momentum and the chemical elements into and out of galaxies. Our observations will directly confront the model predictions from multiple different angles, with fast feedback loops, yielding more realistic models and more robust model predictions for our future observations.
- ✓ The cohesiveness of this Centre benefits tremendously from intertwined themes and threads. For example, measuring the ionising radiation in galaxies as a function of time and within galaxies requires a reliable estimate of the chemical elemental history, and vice versa. These measurements require data federation created through our Big Data program. The resulting chemical abundance history and the ionisation history constrain the Genesis Simulations. The Genesis Simulations can then predict the build-up of matter and structure in the Universe, as well as providing a 3-dimensional picture of the foreground structures that is essential for analysing our MWA radio observations of the Universe at the epoch of reionisation.

RESEARCH PROGRAM

RESEARCH THEMES

1. The Origin of Matter and the Periodic Table

The elements transform the way stars are born and how they evolve, how they explode and die, and how they assemble into galaxies. Australia is currently leading research in this field using different experimental and theoretical approaches, targeting different wavelength ranges, and different ages and size scales of the Universe. In ASTRO 3D, these areas will coalesce under the common goal of understanding the origins of the elements of the periodic table and how they built into the galaxies around us.

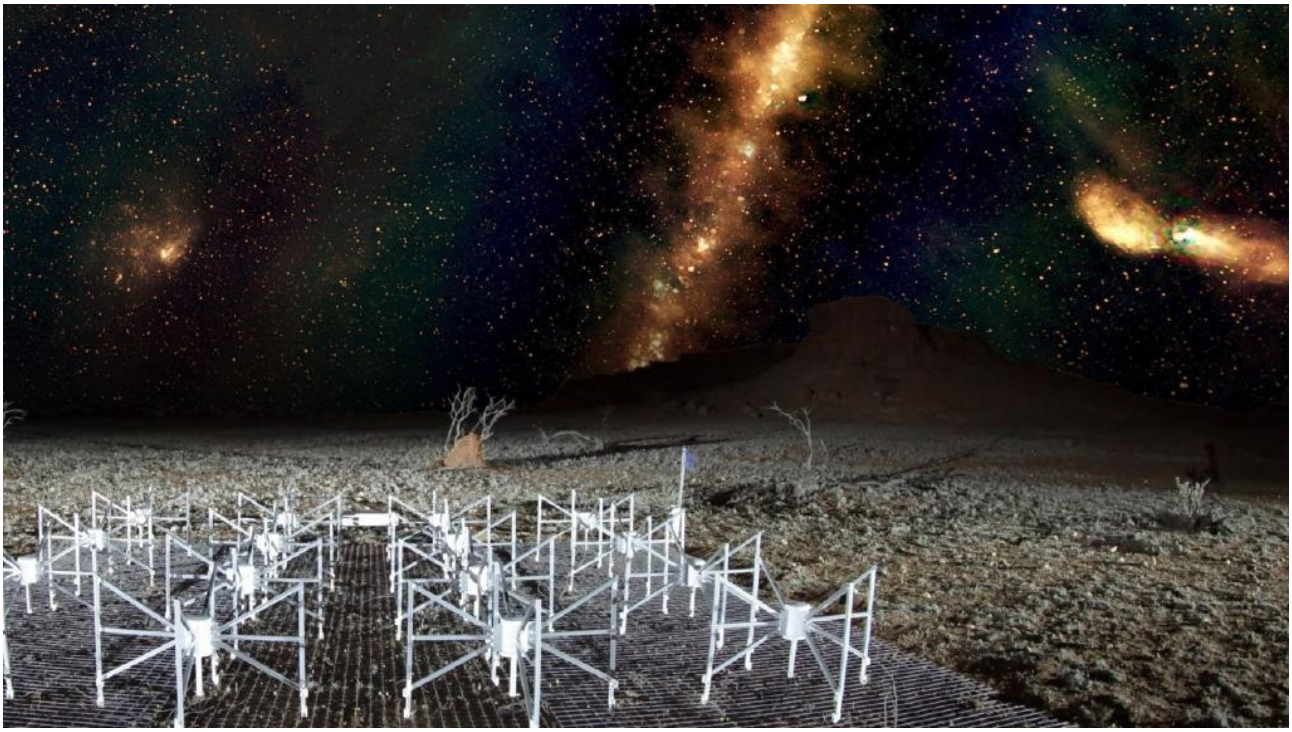
- ✓ We will use state of the art 8-10m telescopes to track the chemical elements in the first stars and within galaxies across cosmic time.
- ✓ We will measure the elements in the first stars, discovered with the ANU SkyMapper telescope.
- ✓ We will map the elements in the earliest galaxies via metal absorption lines viewed through the spectra of background quasars.
- ✓ We will track the growth of the chemical elements and matter using spectroscopy and integral field technology that creates 3-dimensional data cubes, to bridge the Epoch of Reionisation to present day.
- ✓ We will use gravitational lensing, as proposed by Einstein, where the massive gravity of nearby clusters of galaxies magnifies the light of faint background galaxies 10-50x, creating nature's largest telescopes, to probe the most distant galaxies.
- ✓ We will combine integral field technology on the Anglo-Australian Telescope and 8-10m telescopes with 3D data from the Australian Square Kilometre Array Pathfinder (ASKAP) in WA.
- ✓ We will use ASKAP to survey three quarters of the entire sky with unprecedented resolution and depth in neutral Hydrogen, mapping the distribution of gas and dark matter in over 600,000 galaxies through a series of dedicated surveys.
- ✓ We will measure the distribution of mass and angular momentum in the nearby Universe during the first two years of this Centre using the new wide-field instrument, SAMI. With the next generation SAMI (called HECTOR), we will survey an unparalleled 100,000 galaxies across a contiguous volume of the southern sky, revealing how galaxies are distributed across space, their dynamic motions, and how these key properties affect the accumulation of the chemical elements in galaxies.
- ✓ We will compare the observed growth of the elements and matter in spiral galaxies with the archaeological history of our Milky Way, for the first time. The junction of these traditionally separate research areas, alongside theoretical modelling on Australia's most powerful supercomputers, stands to transform our understanding of the chemical Universe. The culmination of this theme will be the first comprehensive picture of the build-up of the chemical elements and matter in the Universe, from the scale of galaxy superclusters to star-forming regions within individual galaxies.

2. The Origin of the Ionised Universe

During the infancy of the Universe, a watershed event dramatically changed the Universe from neutral and dark to being almost completely ionised. This period is when the very first structures in the Universe formed, and is intricately linked to fundamental cosmology. Despite its pivotal role, the Epoch of Reionisation is one of the least understood phases in the history of the Universe. ASTRO 3D is uniquely poised to measure and characterise the beginning and end of reionisation, the sources of reionisation, and the conditions at the Epoch of Reionisation.

- ✓ We will employ the Murchison Widefield Array (MWA) in WA to detect the structure created by the first ionising sources in the Universe using the power spectrum of neutral Hydrogen.
- ✓ We will measure when the reionisation of the Universe occurred, and how long this important process lasted.
- ✓ We will investigate the conditions under which these first stars in the Universe were born with the world's 8-10m telescopes.
- ✓ We will use 8-10m telescopes to track the ionising radiation in galaxies over the past 12 billion years using luminous emission-lines in galaxy spectra created by atoms in gas clouds that are ionised and excited by young, hot stars, massive shock fronts from galactic-scale winds, or supermassive black holes in the centres of galaxies and will bridge the gap between the first galaxies and the local Universe.

These observational studies will set stringent boundary conditions on new state-of-the-art theoretical simulations that span the Epoch of Reionisation to the present day. By combining Australia's theoretical and multi-wavelength observational expertise with innovative instruments and telescopes available on the 2018-2025 timescale, Australia is primed to lift the veil on the Epoch of Reionisation, demonstrating how this landmark event evolved into the Universe that surrounds us today.



A "radio colour" view of the sky above a "tile" of the Murchison Widefield Array radio telescope, located in outback Western Australia.

Radio image: Natasha Hurley-Walker (ICRAR/Curtin) and the GLEAM Team

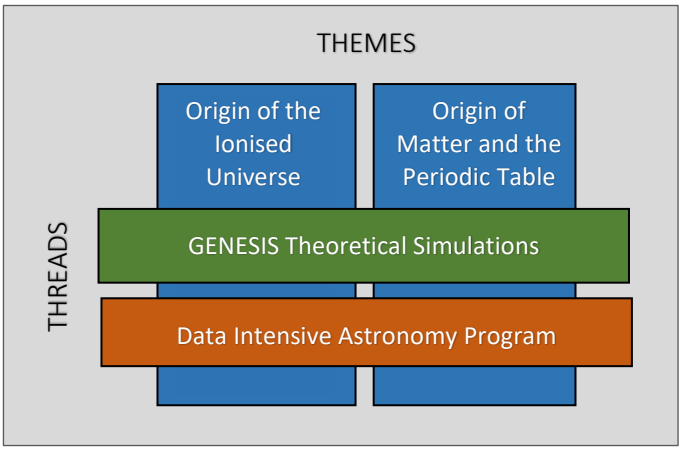
RESEARCH THREADS

There are two threads which provide the glue that melds the research themes together - the *Genesis Theoretical Simulations* and the *Data Intensive Astronomy Program.*

1. Genesis Theoretical Simulations

Large scale super-computer models of galaxy formation are providing an ever increasingly detailed theoretical framework for interpreting observations.

- ✓ We will channel Australian observational and theoretical expertise into new state-of-the art cosmological simulations of galaxy formation and evolution that are directly constrained by our observations across cosmic time.
- ✓ We will track the birth, growth and ultimate fate of galaxies from the earliest epoch of galaxy assembly, through the Epoch of Reionisation to the present day and simulate the first stars, early Universe chemical enrichment, proto-galaxy formation, reionisation, galaxy growth through star formation and mergers, the build-up of angular momentum from the scales of galaxy clusters to star-forming regions within galaxies, the emergence and evolution of large-scale massive structures in the Universe, and the evolution of the material between galaxies.
- ✓ We will combine advanced physical galaxy modelling techniques with realistic 3D radiative transfer models to produce tailored theoretical models to create *synthetic multi-wavelength datasets* that can be used to directly interpret the observations from our major 3D surveys. The models will incorporate "zoom-in" re-simulations that will track the growth of targeted galaxies within the simulation in exquisite detail, allowing us to model the local galaxy population and the imprint of galactic history in the chemistry and structure of the galaxy population to compare directly with our 3D observations.
- ✓ We will cement the observational programs across both themes, giving the theoretical backbone for the interpretation and analysis of our observational surveys. Synergistically, the models will provide predictions for the optical and radio surveys, and the results of the surveys will be used to constrain the models and yield more accurate simulations of galaxy formation and evolution. We will create this synergy by embedding theorists within observational nodes, with theorists and observers working together towards our scientific goals.



2. Data Intensive Astronomy (DIA) Program

The ASTRO 3D flagship telescopes (AAT, ASKAP, MWA, SkyMapper) will collect unprecedented volumes of multi-dimensional data sets, while the *Genesis Simulations* will produce prodigious amounts of theoretical data. These Peta-byte scale data sets require sophisticated data management and access mechanisms as well as new algorithms and visualisation tools to efficiently extract scientific information. Overcoming these "Big Data" problems is critical for scientific exploitation of the MWA, ASKAP, the future SKA, and other major international projects, like the US Large Synoptic Survey Telescope (LSST).

Science verification demands Australia's top supercomputing facilities.

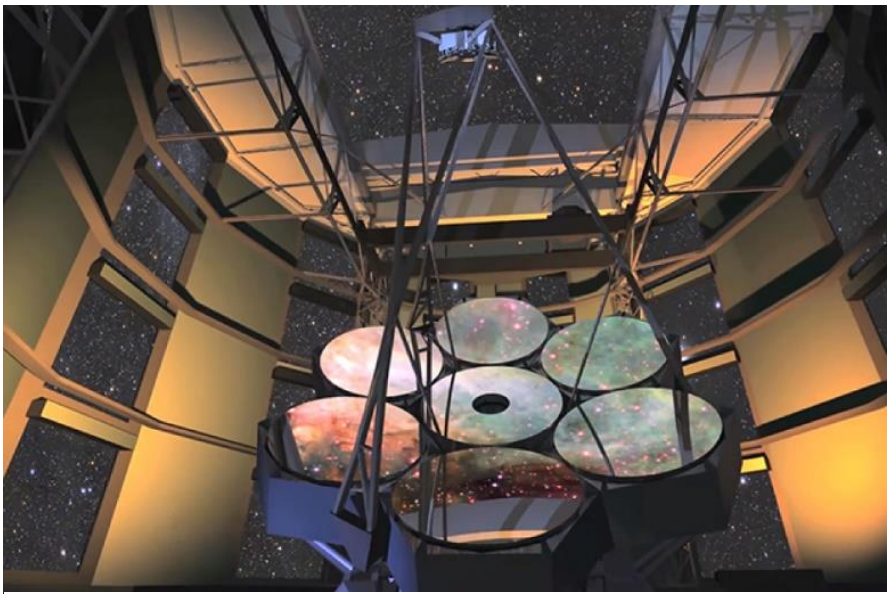
- ✓ We will implement a layered "Data Fabric" plan based on the recommendations of the 2016-2025 Australian Astronomy Decadal Plan. With the three layers of this fabric, we aim to seamlessly federate all ASTRO 3D survey and Genesis simulation data.

  Layer 1 connects the high-performance computing facilities - the National Computing Infrastructure Facility, the GPU Supercomputer for Theoretical Astrophysics and the Pawsey Centre. We will optimise the computing and storage infrastructures within these facilities and connect these facilities to implement a seamless cross-facility data fabric.

Layer 2 is a data-intensive research middleware that joins database systems, high performance storage and high performance computing with advanced scientific data management into a service oriented architecture. We will work with leading astronomical data intensive astronomy institutes (ASTRON, HITS, and U.Washington), with our industry partners (through UWA), and from outside astrophysics (e.g., Bioinformatics, High Energy Physics), to ensure that our projects rely on the latest middleware technologies. We will employ skilled middleware specialists to implement and maintain services at this critical level and to provide training to astrophysicists in data intensive middleware.

Layer 3 incorporates a new set of tightly connected databases to tag and structure the data, as well as high-level Virtual Observatory tools and interfaces for accessing and manipulating observational and theoretical data. We will link the ASVO, the CSIRO ASKAP Science Data Archive, and the TAO that hosts theory data, providing a direct and vital connectivity amongst our program. The TAO will be expanded to incorporate hydrodynamical data and radio data, with new analysis modules for interactively exploring the simulations and creating theoretical mock data cubes for Centre surveys. We will extend the ASVO functionality from 4 institutions to all nodes, facilitating access nationwide and we will provide *International Virtual Observatory Alliance* compliant interfaces for the international astronomical community.

This program aims to meet the data processing and analysis needs for our surveys, provide a single common architecture for the direct comparison between our surveys and the *Genesis Simulations* and build the infrastructure to effectively analyse Petabytes of data in the lead-up to the Square Kilometre Array and other next generation telescopes.



The Giant Magellan Telescope will be one member of the next class of giant ground-based telescopes that promises to revolutionize our view and understanding of the universe. It will be constructed in the Las Campanas Observatory in Chile. Commissioning of the telescope is scheduled to begin in 2022. The GMT will have a resolving power 10 times greater than the Hubble Space Telescope.

The GMT project is the work of a distinguished international consortium of leading universities and science institutions, including ANU.

RESEARCH PLAN

The research plan has been developed with the leaders of each Centre survey and project and will be managed by the Science Management Committee. Progress and achievement of milestones will be assessed annually by the Committee, which will provide recommendations to the Executive regarding the future relative resourcing of surveys and projects.

Each survey and project require input from the other surveys and projects at key dates within the Centre. Cross-project workshops and busy weeks will facilitate this data and knowledge transfer.

RESEARCH PLAN

	2017	2018	2019	2020	2021	2022	2023	OUTCOMES
DATA INTENSIVE ASTRONOMY	Data needs survey	Middleware development		Joint ASVO Database development		ASTRO 3D ASVO data repository		✓ Publications and international impact in Data Science ✓ New ASVO analysis tools ✓ Advances in Data Intensive infrastructure ✓ Data Intensive infrastructure development for the SKA ✓ Skilled workforce in Data Science
	Analysis and design	Processing and storage environment implementation		ASVO analysis tools development				
	Data analysis support for MWA, ASKAP, HECTOR surveys							
MWA EOR	Extended EoR observations						Archiving	✓ Publications and international impact in EoR ✓ New statistical algorithms and Data Intensive astronomy tools ✓ Knowledge in processing petabyte-scale data ✓ Technological breakthroughs from R&D for the MWA extension ✓ Skilled workforce for the SKA-LOW
	Construct and test new EoR processing pipeline							
	New statistical algorithms and Data Intensive astronomy tools			EoR Data Intensive processing			Compare with GENESIS	
	Simulations of EoR sensitivity			Foreground removal, ASKAP surveys, Galaxy Evolution(IGM), GENESIS				
FIRST STARS	Keck Spectroscopy and analysis of First Star candidates							✓ Publications, international impact and public engagement from First Stars discoveries ✓ Skilled workforce development for the GMT
	GENESIS simulations of stellar evolution and nucleosynthesis			GENESIS simulations of first stars and chemical enrichment				
FIRST GALAXIES	Keck observations Hubble z>8 galaxies	Data processing and analysis		JWST and Keck observations			Compare with GENESIS	✓ Publications, international impact and public engagement from First Galaxies discoveries ✓ Knowledge in processing space telescope data ✓ Skilled workforce development for JWST
		GENESIS simulation of galaxy assembly		Compare with GENESIS		Data processing and analysis		
						Compare with MWA EoR		
GALAXY EVOLUTION	Data mining from Dark Energy Survey							✓ Publications, international impact and public engagement from Galaxy Evolution discoveries ✓ Public data archives ✓ Skilled workforce in data mining ✓ Skilled workforce in lens optics theory ✓ Skilled astronomical workforce for leading science programs on the GMT
	Keck observations of Lyman continuum galaxies, IGM and high redshift lensed galaxies						Data Archiving	
		Keck data processing and analysis						
		Lensing Structure and mass models					Compare with GENESIS	
		GENESIS simulations of chemical and ionising radiation evolution						

RESEARCH PLAN

	2017	2018	2019	2020	2021	2022	2023	OUTCOMES
ASKAP SURVEYS	WALLABY - early	WALLABY – full survey					Archiving	✓ Publications, international impact and public engagement from WALLABY, FLASH and DINGO discoveries ✓ ASKAP Public Data archives ✓ Skilled workforce in 3D data mining ✓ Skilled workforce for leading major surveys with the SKA
	Pipeline development		WALLABY processing					
			FLASH processing	FLASH + DINGO + Galaxy Evolution origin of matter and angular momentum				
	FLASH - early	FLASH – full survey						
		DINGO processing					Compare with GENESIS	
		DINGO survey		DINGO ultra –deep				
SAMI/ HECTOR SURVEYS	SAMI survey		HECTOR – early science	HECTOR survey			Data Archiving	✓ Publications, international impact and public engagement from SAMI/HECTOR discoveries ✓ SAMI/HECTOR Public Data archives ✓ Skilled workforce in 3D data analysis ✓ Skilled workforce for leading major 3D spectroscopic programs with the GMT
	SAMI processing			HECTOR processing				
		HECTOR pipeline development		WALLABY + SAMI+ HECTOR origin of matter and angular momentum				
	Galactic winds input into GENESIS			SAMI + HECTOR origin of the periodic table				
		GENESIS simulation of galaxy evolution				Compare with GENESIS		
GALAH	GALAH Milky Way halo survey			GALAH Milky Way bulge survey			Archiving	✓ Publications, international impact and public engagement from GALAH discoveries ✓ GALAH Public Data archives ✓ Skilled workforce for GMT spectroscopy
	GALAH Milky Way disk survey			Chemical tagging				
	GENESIS models: stellar evolution and nucleosynthesis			GENESIS models: chemical evolution		Compare with galaxy evolution		
GENESIS SIMULATIONS	GENESIS model development		First suite of GENESIS ZOOM sims	Subgrid models and input from surveys	ZOOM high res models run to Milky Way	GENESIS dynamical Milky Way assembly simulations		✓ Publications, international impact and public engagement from GENESIS discoveries ✓ GENESIS Theoretical Public Data archives ✓ Skilled workforce for interpreting next generation telescope data ✓ Skilled workforce for theory and supercomputing
	Simulation processing pipeline development					GENESIS full volume high res simulations		
		Mock observations development				Model archiving		

LEGEND

- Surveys and projects
- Data Intensive Astronomy
- GENESIS
- Cross-Program Needs

EDUCATION PROGRAM

ASTRO 3D in the Classroom

We will continue to roll out the popular *CAASTRO in the Classroom* program nationally in the early years of the Centre. The program is currently coordinated by the University of Sydney and engages Australian school students with research scientists and PhD students in a virtual meeting room, taking advantage of the infrastructure provided within the Connected Classroom initiative of the New South Wales Government. The program utilises the Connected Classroom video conferencing, live streaming and Q&A sessions for Australian schools, as well as free classroom resources. Sessions include curriculum-focused astronomy lectures, short research presentations, discussions around a particular aspect of astronomy or physics or forums on life as a scientist.

Telescopes in Schools

We will be rolling out the *Telescopes in Schools* program to all node states during the first 3 years of the Centre. Currently run out of the University of Melbourne and privately funded, the program is targeted at high school students in Years 7 to 9 and provides selected schools with a 12 inch computerised telescope and all the necessary gear to observe the night sky, image the objects in the night sky and conduct small research projects. These telescopes are large enough to view deep sky objects such as nebulae and far away galaxies or zoom in on a crater on the moon. Students engage with an astrophysicist about their research and then learn how to set up and drive the telescope to conduct their own research projects.

As part of our Indigenous Engagement activities, we will engage indigenous schools in our Telescopes in Schools program. For these schools, we will include a new program to explore how different cultures view the night sky.

Teacher training and resources

The 2016-2025 Australian Astronomy Decadal Plan identifies a significant need for effective training of teachers and for implementation of astronomy materials within the new Australian F–10 Science Curriculum. Teacher-training programs, including high-quality astronomy teaching materials, can significantly impact the quality of school education. To this end, we will include large-scale engagement of astronomers in teacher-training and curriculum development at the primary and secondary levels (K-12). This program will begin with the teachers from our CitC and Telescopes in Schools networks, and expand to schools in each node state. We will provide movies, tutorials and Q&A sessions (both on-line and in-person) to train teachers to use astronomy educational materials in their classrooms.

PUBLIC OUTREACH PROGRAM

Uluru Astronomer in Residence and Astronomy Weekend

We will be partnering with Voyages Indigenous Tourism Australia who operate the Ayers Rock Resort at Uluru to deliver the Uluru Astronomer in Residence program from 2018. Astronomers from our team will be in residence between March and November at Uluru, on a fortnightly roster engaging with tourists and the indigenous community, sharing knowledge of the night sky as viewed by different cultures, as well as the latest Centre discoveries. The Indigenous Land Corporation operates Voyages on behalf of the Indigenous community with all profits supporting Indigenous programs across Australia. In addition to the residencies, four prominent ASTRO 3D astronomers also participate in the annual Uluru Astronomy Weekend to talk about a wide range of topics on Australian astronomy.

Public Outreach

We will be undertaking a broad range of public outreach activities including public lectures, TV and radio appearances, popular magazine and newspaper articles, as well as maintaining a strong social media presence.

RESEARCH AND LEADERSHIP TRAINING PROGRAM

Centre-wide Mentoring Program

We will deliver a vibrant and successful individual and group mentoring program that benefits all Centre participants, utilising our team's extensive experience and diversity to build a sense of collegiality, satisfaction, confidence and achievement across the Centre.

We will group early career researchers with networks of multiple "mentoring partners" in non-hierarchical, collaborative partnerships with a trained facilitator to address specific areas such as research, career paths, time management and work-life balance.

We will measure the success of our mentoring program through annual Centre climate surveys that will track self-confidence, career satisfaction, leadership capabilities, communication skills, and achievement of development goals amongst Centre participants.

Professional Astronomical Skills Training Workshops

Astronomy students require a range of professional and personal skills to successfully conduct and lead research on the international stage. Capitalising on the existing experience of our team, we will offer annual workshops in skills such as scientific writing, writing postdoctoral, ARC grant and DECRA applications, professional presentations and time management skills to all students and early career researchers nationwide, both within and outside ASTRO 3D.

Transferrable Skills Program

The Australian Astronomy Decadal Plan identified a critical mismatch between supply and demand in Australian astronomy. Astrophysics PhD students typically finish their studies having gained substantial problem-solving and statistical skills so we will impart them with a set of transferrable skills to provide highly skilled graduates for roles in the wider community.

Data intensive science is a rapid growth field. Training students to manage massive datasets opens an array of new career paths including population statistics, medical science, bioinformatics, banking, media science, and genomics, yielding lasting benefits to the Australian community. We will offer transferrable skills courses in managing large data sets, programming in languages in demand by industry, training in industry practices, and professional project management skills. These workshops will bring in industry and cross-disciplinary experts to train astronomy students and early career researchers with the lateral skills needed to transition to alternative careers.

We will offer an annual workshop where former astronomers who are now working in other disciplines provide insight into their new occupations and how they made the transition away from astronomy. We will also sponsor additional workshops and conferences such as Dotastronomy. Dotastronomy brings together an international community of astronomy researchers, developers, educators and communicators to showcase and build upon web-based projects, from outreach and education to research tools and data analysis.

We will measure the usefulness and success of our transferrable skills program through workshop exit surveys, through Centre exit surveys, and by tracking the careers of former Centre participants. Providing highly skilled scientists with outstanding problem solving and data management experience for the Australian economy is a significant benefit of our transferrable skills program.

Emerging Leaders Program

In the era of mega-scale telescope facilities, astrophysics will shift from relatively small teams and networks (typically a few to a few tens of active researchers) to significantly larger teams and global networks of researchers. We will offer a workshop specifically aimed at developing the skills to work and lead in the mega-scale telescope environment, including large project management, effective team building, risk management, negotiation and conflict resolution, collaborating planning and strategizing, and time management. We will utilise our partner organisations AAO and CSIRO, as well as our university industry partners to bring in experts from each of these areas.

We will provide leadership coaching to our most promising young researchers to help them confidently and successfully transition from researcher to team leader. Our CI/PI team contains many of Australia's most talented scientific leaders. These leaders will be matched up one-on-one with young emerging leaders for individual coaching sessions.

The success of our emerging leaders program will be measured through workshop exit surveys and by tracking the careers of participants throughout the course of the Centre.

Succession Planning

We will incorporate succession planning into our Centre to ensure that there is a clear career progression for the best young researchers as well as a renewal of the scientific drive in the latter half of the Centre.

Diversity and Equity Program

Women's participation in Australian Science, Technology, Engineering, and Mathematical (STEM) fields remains low from high school through to the academic levels. Research shows that women require a safe workplace environment in which they can practice new leadership skills and share personal stories of challenge and vulnerability without having to hold up the role model position as the "first" or "only" woman leader. Being among a community of other accomplished women leaders enhances the sense that "If she can do that, so can I".

We will strive for the Centre plus every node and Australian partner organization to achieve Gold status through the Pleiades Program. This program recognises and rewards astronomical organisations that have taken active steps to advance the careers of women through focused programs, and that are striving for sustained improvement in opportunities for women to achieve positions of seniority, influence and recognition. Gold status recognises a truly outstanding sustained commitment to best practice, and requires demonstrated best practices, novel or high-profile new initiatives, and monitoring of the organization conduct over a period of at least 4 years, among other requirements.

We will introduce Gender Equity initiatives that aim to create a supportive and family-friendly environment as well as to improve and sustain the advancement of women to senior levels. These include family-friendly core meeting times, child care at conferences, support for travel to conferences with children, part-time options for every position, nomination of women for prizes and awards and a target of science outreach programs to girls.

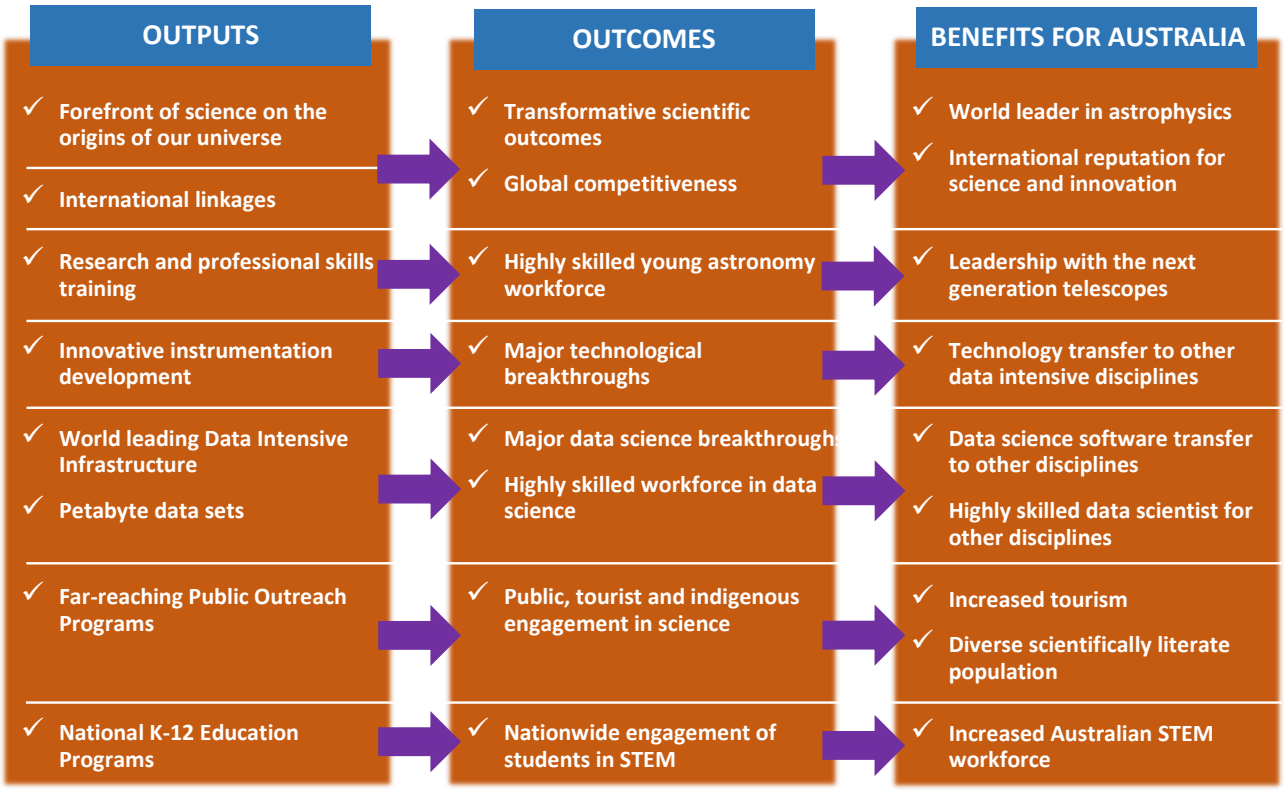
We will introduce Diversity and Equity Mentoring Groups. This program will link with our Centre-wide mentoring program by creating mentoring groups that bring together women in the Centre, as well as additional mentoring groups to cover the range of types of diversity in the Centre including racial minorities, sexual minorities (gay, lesbian, bisexual, and transgender), and people with challenges that affect their ability to conduct full time research, such as illness or disabilities. These mentoring groups will be engaged by a trained facilitator and will address research, career paths, time management, work-life balance, as well as specific topics relevant to the diverse group such as combining children and an academic career, and how to successfully manage a research career part-time.

We will introduce a Women’s Career Advancement Program to further improve the academic environment and advancement of women to senior levels. Women continue to be underrepresented in the higher levels of astrophysics, despite the fact that they have been entering the field in increasing numbers, and have made up approximately 50% of the PhD student cohort for over a decade. Research shows that advancing women into leadership positions requires both a cultural change in the workplace and persistent efforts to sustain the career advancement of women early career researchers. We will offer specific women career advancement seminars and workshops including CV preparation, self-assessment, job application preparation, interview practise, and academic level promotion application and interview advice. We will use our university and participating organization gender centres and networks to source experts for these seminars and workshops.

The success of our diversity and equity program will be measured through Centre climate surveys and through the Centre gender equity KPIs. Over the course of this Centre, we seek to achieve a fraction of 50% females at all levels including the executive, the Advisory committee and at all Centre sponsored events (including speakers), as well as equity in salaries and opportunities.

OUTCOMES

ASTRO 3D has developed and defined a range of outputs with significant outcomes and benefits to Australia.



Transformative research with global impact

- ✓ We will answer some of humankind's most fundamental questions on how the Universe that we see today formed and evolved.
- ✓ We will track how the oxygen atoms that we breathe, and the carbon that we're made of formed and accumulated across cosmic time.
- ✓ We will measure how matter in all of its phases (dark matter, ionized gas, neutral gas) aggregated into galaxies that we see today, including our own Milky Way.
- ✓ We will break down the technological barrier to reveal the Epoch of Reionisation for the first time.

The importance of these questions is underlined by their prevalence in the astronomy Decadal Plans world-wide and in the science goals of the next generation of telescopes. Answering these key questions requires the combination of theory and observation, the combination of radio, optical, and infrared astronomy, and the combination of observations of the most distant stars and galaxies in the Universe with galaxies across the entire age of the Universe including our Milky Way. We will be the only single group in the world to coalesce these areas together into a single cohesive program. This Centre connects Australia's leading astrophysicists, Australia's up-and-coming young stars in astronomy, with leading experts world-wide. Our integrated, state-of-the-art research program will keep Australian technologies at the forefront of high impact astrophysics for the coming decade, and propel young Australian scientists into the mega telescope era.

Highly skilled workforce and leadership of the next generation of telescopes

The next generation of telescopes, including the Giant Magellan Telescope (GMT) and the Square Kilometre Array (SKA), come to fruition around the end of this Centre. Australia has invested over $500M in astronomical infrastructure so far to build these next generation telescopes, and the Federal Government has committed $294M to build the Australian SKA as part of its National Innovation and Science Agenda. We will exploit current Australian telescope innovations to build not only the observational and theoretical leadership, but the overall research capacity, and the technical expertise required to build cutting edge instrumentation and lead large international programs with these next generation telescopes.

The benefits of the Centre extend far beyond its lifetime. Our Succession Planning program will identify future leaders in each theme. These young scientists will be mentored and trained to manage future world leading research programs on the next generation of telescopes and our most significant supercomputing resources. Our international visitor program and world-renowned international partners provide our future leaders with an extensive network of international collaborators and expertise, allowing them to build their own international teams. Our mentoring program and leadership workshops will provide our future leaders with the confidence and skills required to conduct world-leading and internationally competitive research in the new global era of science.

Technological Breakthroughs

In addition to the investment opportunities for Australia, the technology transfer benefits to Australia of constructing of new, innovative instrumentation and facilities are enormous. The construction of a Mega-scale facility, as well as its associated energy and data processing needs, requires significant technological advances in many fields from optics, electronics, computing, and alternative energy. The transfer of these technologies to other industries produces fundamental advances in a wide range of areas. For this reason, astronomy technology has led to fundamental advances in optics, electronics, advanced computing, communications, medicine and alternative energy. Astronomical datasets are complex and the processing of these datasets has required collaboration between astronomy, computer science and statistics.

We will form an ASTRO 3D commercialisation team composed of IP experts in CSIRO, AITC, AAO, and the Institute of Photonics and Optical Science at University of Sydney, who have extensive experience in the commercialisation of research-led IP. This team will help researchers with IP issues, technology transfer and commercialisation of IP developed in the Centre instrumentation and Data Intensive Astronomy programs.

Innovative eScience Infrastructure

One of the top priorities of the Australian Astronomy Decadal Plan is the federation of world-class high performance computing with new software capability for large theoretical simulations and for delivery of Petabyte data sets. The challenges of these datasets are common to all data-rich sciences, resulting in the emergence of the new umbrella field termed ‘eResearch’. The Australian Federal Government has prioritised eResearch, committing almost $100 million to the field through NeCTAR (virtual laboratories) and Research Data Storage Infrastructure initiatives. Our DIA program will drive innovative solutions to these challenges for astronomy, which are critical for handling the tsunami of data that will flow from the SKA. The Decadal Plan also prioritises the provision of transferable skills to astrophysics graduates for roles in wider society. Through our DIA thread, the new generation of young Australian astrophysicists will be trained in data intensive science, providing a broad range of career options outside astrophysics, including population statistics, medical science, bioinformatics, and genomics. We will provide transferable skills to all of our graduates and postdoctoral researchers, providing highly trained data scientists for the broader Australian economy.

Inspiring the next generation of students into Science, Technology, Engineering and Mathematics (STEM)

The future of our country rests on inspiring and training the next generation of scientists and citizens. Communicating astronomical discoveries and achievements to the broadest possible audience engages the general public in astronomy and inspires students to consider a career in STEM research areas. Over the past five years, there have been over 7,800 astronomy outreach activities across Australia attended by over 1.34 million people. Our team has either lead or been involved in the majority of these activities.

In the next decade, greater collaboration and partnership among astronomy research organisations and astronomy outreach providers is essential for expanding the public impact of astronomy. Universities and national observatories typically run their own outreach programs within their own areas. We will bring together outreach experts from each node and observatory with astronomy outreach providers such as planetariums, science education centres, and public observatories to build state-wide and nation-wide campaigns to engage and inspire students into science as a career. See page 10 for details of our ASTRO in the Classroom and Telescopes in Schools Education Programs.

Effective Training of Teachers

We will provide effective training programs for teachers and high-quality astronomy teaching materials within the new Australian Science Curriculum. We will include large-scale engagement of astronomers in teacher-training and curriculum development.

Public Engagement in Science

We will be undertaking a broad range of public outreach activities including the Uluru Astronomer in Residence and annual Astronomy Weekend (see page 10), planetarium productions, public lectures, TV and radio appearances, popular magazine and newspaper articles, as well as maintaining a strong social media presence.

National and International Linkages

We will strengthen existing networks within Australia, the US, and the UK, while building new networks with China, Canada, Germany, and the Netherlands. These strategic links strengthen the science programs of our Centre and have been carefully chosen based on the potential for multiple collaborations within the same organisation across different science areas. Our aim for these linkages is to build major partnerships that extend well beyond the lifetime of the Centre.

National Linkages: We will enhance and cement existing networks amongst the six participating organisations (ANU, USYD, UMELB, Swinburne, Curtin, and UWA), and the three Australian partner organisations (AAO, CSIRO, and NCI). We will maintain close links and connections among the participating organisations by regular video-conferencing, workshops, working groups, busy weeks, and conferences. Our Collaboration Leader will help ensure that these linkages are operating effectively and that potential new collaborations are nurtured.

Australian-Chinese Linkages: The Chinese Academy of Sciences (CAS) has built the largest single-dish radio telescope in the world, FAST. We will conduct collaborative science projects combining the FAST and ASKAP surveys to view the all-sky distribution of HI in the nearby Universe. ASTRO 3D will operate the Australia-China Consortium for Astrophysical Research (ACAMAR) program, begun under CAASTRO. This program is supported by Australia Astronomy Limited, and aims to foster new Australian Chinese collaborations and includes funding for student exchanges and researcher collaborative visits.

Australian-Canadian Linkages: We will forge new Australia-Canadian linkages through our collaborations with the University of Toronto. This collaboration strengthens our Epoch of Reionisation and Galaxy Evolution research through the MWA and ASKAP projects, as well as the Galaxy Evolution research at Swinburne University. The Canadian government is a member of the SKA, providing a natural direction for collaborations beyond the lifetime of this Centre.

Australian-Netherlands Linkages: We will build new linkages with the top institute for radio astronomy in the Netherlands (ASTRON). ASTRON is renowned for its world-class radio astronomy facilities and active development of novel and innovative technologies in the lead up to the SKA. We will build a new collaboration focused on the MWA and DIA programs, as well as strengthening existing collaborations.

Australian-US Linkages: We will expand existing Australian-US linkages within Caltech as well as building a strong new linkage with the Dark Universe Science Centre at the University of Washington. The ANU and Swinburne have existing strong connections with Caltech through their Keck telescope collaborations, as well as large extragalactic survey projects. This Centre will expand these linkages within the Galaxy Evolution and GALAH surveys. The new Dark Universe Science Centre at the University of Washington has an entire suite of experts that considerably strengthen the ASTRO 3D research across both themes and threads. These broad-ranging collaborations stand to create an extremely strong connection amongst the University of Washington and all Australian participating institutions.

Australian-UK Linkages: One of the major goals for CAS is to understand galaxy formation and evolution through optical and infrared 3D instrumentation. We will extend collaboration with Oxford University to the Oxford Centre for Astrophysical Surveys (CAS) into the HECTOR and ASKAP surveys.

International Theoretical Simulation Network: ASTRO 3D requires linkages among different types of theoretical models that are produced by separate groups. Our Centre science goals require us to overcome these segregations to produce one unified simulation with specific capabilities in our Centre survey areas. For example, cosmological hydrodynamic simulations and semi-analytic galaxy-evolution models are required to bridge the Epoch of Reionisation with the build-up of matter and chemical elements in the Universe. Detailed chemical evolution models are required to interpret the first stars observations, the chemical evolution of galaxies, and chemo-dynamical models are required to inform the galactic archaeology of our Milky Way. The new linkages that we will build with HITS and the University of Washington will significantly strengthen Australian theoretical simulation work.

International Data Intensive Astronomy Network: We will forge new linkages with major international Data Intensive Astronomy Centres. The University of Washington, ASTRON, and HITS have a concentration of expertise in data intensive astronomy. The Netherlands Institute for Radio Astronomy (ASTRON) has joined forces with IBM to create a 32.9M Euro Centre (called DOME) to investigate the computational and communications systems needed to read, store and analyse raw data from the SKA. This group is focusing on advanced accelerators and 3D stacked chips for more energy-efficient

computing, novel optical technologies and nanophotonics to optimize large data transfers, as well as high-performance storage systems based on next-generation tape systems and novel phase-change memory technologies. These partnerships provide a vast reservoir of expertise, which, when combined with our Centre Investigators and resources, will ensure that we will construct the world-leading data processing and analysis infrastructure for Petabyte-scale observational and theoretical datasets. The outcomes of this Centre include massive public archives that are accessible to the international community through a single virtual observatory. We will join the observational and theoretical survey archives, providing economies of scale, and facilitating the analysis of data across different wavelengths, across theory and observations, and across the science themes. Simulated 3D datasets will be created and made available through the ASVO to be analysed in the same way as observational datasets to help the international community interpret and analyse the Centre survey and theoretical data.

KEY PERFORMANCE INDICATORS

The Centre is required to report to the ARC on a range of Key Performance Indicators (KPIs) common to all ARC Centres of Excellence as well as a range of Centre-specific KPIs. These quantifiable measures are used to monitor and report on progress of research outcomes.

The agreed KPIs for ASTRO 3D are detailed on the following pages.

STANDARD KPIs FOR ARC CENTRES OF EXCELLENCE

PERFORMANCE MEASURE	TARGET						
	2017	2018	2019	2020	2021	2022	2023
Number of research outputs	• 15 papers in refereed journals • 4 media releases	• 25 papers in refereed journals • 12 media releases	• 50 papers in refereed journals • 12 media releases • 1 planetarium production • 1 SAMI dataset • 1 ASKAP dataset	• 100 papers in refereed journals • 12 media releases • 1 data intensive middleware	• 150 papers in refereed journals • 12 media releases • 1 planetarium production • 1 ASVO software • 1 ASKAP dataset	• 200 papers in refereed journals • 12 media releases • 1 GALAH dataset • 1 Genesis dataset	• 200 papers in refereed journals • 12 media releases • 1 planetarium production • 1 MWA dataset • 1 Galaxy Evol. dataset • 1 ASKAP dataset • 1 SAMI/HECTOR dataset
Quality of research outputs	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5	80% of refereed papers in journals with impact factor > 2.5
Number of training courses held/offered by the Centre	• 1 Professional skills workshop • 6 diversity training workshops (one/node) • 1 ECR training day • 2 writing workshops	• 1 Professional skills workshop • 4 writing workshops • 1 Transferrable skills workshop	• 1 Professional skills workshop • 1 ECR training day • 6 writing workshops • 1 Transferrable skills workshop	• 1 Professional skills workshop • 6 diversity training workshops (one/node) • 1 ECR training day • 6 writing workshops • 1 Transferrable skills workshop	• 1 Professional skills workshop • 1 ECR training day • 6 writing workshops • 1 Transferrable skills workshop	• 1 Professional skills workshop • 1 ECR training day • 6 writing workshops • 1 Transferrable skills workshop	• 1 Professional skills workshop • 6 diversity training workshops (one/node) • 1 ECR training day • 6 writing workshops • 1 Transferrable skills workshop
Number of workshops/ conferences held/ offered by the Centre	• 1 international conference • 1 national conferences/ workshop	• 2 international conferences • 2 national conferences/ workshops	• 2 international conferences • 2 national conferences/ workshops	• 2 international conferences • 2 national conferences/ workshops	• 2 international conferences • 2 national conferences/ workshops	• 2 international conferences • 2 national conferences/ workshops	• 2 international conferences • 2 national conferences/ workshops

PERFORMANCE MEASURE	TARGET						
	2017	2018	2019	2020	2021	2022	2023
Number of additional researchers working on Centre research	• 20 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 6 PhD students • 5 Assoc. Investigators	• 10 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators	• 5 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators	• 10 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators	• 10 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators	• 5 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators	• 5 postdoctoral researchers • 2 Honours students • 2 Masters by coursework • 12 PhD students • 15 Assoc. Investigators
Number of postgraduate completions	0	0	6	8	10	12	12
Number of mentoring programs offered by the Centre	• 1 Centre-wide mentoring program • 1 women's career advancement program	• 1 Centre-wide mentoring program • 1 emerging leaders program	• 1 Centre-wide mentoring program • 1 women's career advancement program	• 1 Centre-wide mentoring program • 1 emerging leaders program	• 1 Centre-wide mentoring program • 1 women's career advancement program	• 1 Centre-wide mentoring program • 1 emerging leaders program	• 1 Centre-wide mentoring program • 1 women's career advancement program
Number of presentations/ briefings	• 20 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 20 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops	• 40 public briefings • 4 government briefings • 2 industry briefings • 6 non-government organisation briefings • 4 briefings to professional organisations & bodies • 40 professional conferences/ workshops
Number of new organisations collaborating with, or involved in, the Centre	• 2 new collaborative relationships	• 4 new collaborative relationships	• 4 new collaborative relationships • 1 new participating organisation	• 4 new collaborative relationships	• 4 new collaborative relationships • 1 new participating organisation	• 4 new collaborative relationships	• 4 new collaborative relationships

CENTRE SPECIFIC KPIs

PERFORMANCE MEASURE	TARGET						
	2017	2018	2019	2020	2021	2022	2023
Maintain a collaborative and cohesive structure	• 50% cross-node authorship of publications • 50% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 65% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 80% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 80% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 80% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 80% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey	• 85% cross-node authorship of publications • 80% cross-node supervised PhD & ECRs • 6 project team meetings with cross-node participation • 1 centre-wide climate survey
Create a diverse Centre	• 30% females at all levels • at least 30% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 35% females at all levels • at least 35% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 40% females at all levels • at least 40% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 45% females at all levels • at least 45% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 50% females at all levels • 50% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 50% females at all levels • 50% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences	• 50% females at all levels • 50% travel funds to females • 50% female visitors & speakers • Child care at all Centre supported conferences
Build the expertise for the next generation telescopes	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 20% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 20% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 30% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 30% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 40% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 40% of students with data intensive research experience	• 20% students working on optical GMT pathfinder instruments • 20% students working on radio SKA pathfinder instruments • 10% of students working on space telescope data • 40% of students with data intensive research experience

PERFORMANCE MEASURE	TARGET						
	2017	2018	2019	2020	2021	2022	2023
Train the next generation of scientists	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops (i.e. 80% attendance over 4 years)	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops • 10% ECRs achieving prestigious fellowships • 10% PhD students or ECRs achieving high quality jobs in other fields	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops • 20% ECRs achieving prestigious fellowships • 20% PhD students or ECRs achieving high quality jobs in other fields	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops • 20% ECRs achieving prestigious fellowships • 20% PhD students or ECRs achieving high quality jobs in other fields	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops • 20% ECRs achieving prestigious fellowships • 20% PhD students or ECRs achieving high quality jobs in other fields	• 80% satisfaction with Centre-run skills workshops • 20% of PhD students and ECRs attending skills workshops • 20% ECRs achieving prestigious fellowships • 20% PhD students or ECRs achieving high quality jobs in other fields