Theoretical Astrophysics in Australia

Submission to the Facilities Working Group

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Introduction

In this document we identify the value of theoretical astrophysicists to the astronomy community and present our vision for the future. In particular, we point out:

- The value of the Australian National Institute for Theoretical Astrophysics (ANITA) as a resource
- The importance of Theoretical Astrophysics for the continued development of the science of astronomy within Australia.

ANITA

ANITA was formed in order to provide a perspective to the astronomical community that is relevant to theoreticians. The mission of ANITA is:

1. Support development of the theoretical astrophysics community in Australia by facilitating communication and collaboration between theorists and providing a focus for the community
2. Raise the national profile of theoretical astrophysics, and raise the international profile of Australian theoretical astrophysics; and
3. Promote linkage with the national astronomical community by assisting in the theoretical interpretation of observations; providing motivation for new observational programmes; and increasing scientific return from national investment in observational infrastructure.

ANITA currently consists of 39 academic/professional staff, 23 student members and is operated by a steering committee consisting of a convenor, an immediate past convenor, seven steering committee members including a student member and *ex officio* the president of the ASA. ANITA has a good relationship with the ASA and the current convenor of ANITA (Bicknell) has been invited to ASA council as an observer. ANITA formally commenced in October, 2003 but had been active for about a year previously. Full details of ANITA's activities may be found at the website anita.edu.au

The core activities of ANITA members, constituting theoreticians throughout the country, but mainly from the research-intensive, group of 8 universities consists of theoretical astrophysics research at the highest level. The following table, summarizing 14 major areas of research in 8 universities, gives a good indication of the scope of Theoretical Astrophysics within Australia. This picture is rounded out by the summary of international projects involving Australian theoreticians in the Appendix.

Field(s)	Institution(s)
Solar and Space Physics (Solar seismology, solar and planetary radio emission, solar radio bursts and flares, auroras)	Sydney, Monash
Plasma astrophysics (Plasma emission, absorption and transfer processes, particle acceleration)	Sydney
Planetary Science	ANU, Monash, Swinburne
Stellar structure and evolution; effects of environment on nuclear fusion	ANU, Monash, UNSW
Star formation	Macquarie, NSW
Interstellar medium (HII regions, Galactic Centre, scintillation, molecular shock waves, photodissociation regions)	ANU, UNSW, Sydney
Astrobiology	Macquarie, UNSW
Compact objects (neutron stars, pulsars, relativistic pulsar winds, accretion disk-magnetosphere interaction)	ANU, Melbourne, Sydney
Extragalactic astronomy (galaxy formation and evolution, active galactic nuclei)	Adelaide, ANU, Monash, UNSW, Swinburne, Sydney, Melbourne
Cosmology (big bang, microwave background, dark matter, dark energy, epoch of reionisation, variation of fundamental constants, Lyman alpha forest)	ANU, Melbourne, UNSW
General relativity (classical and quantum)	ANU, Monash, UNSW
Gravitational lensing (mass models of lensing galaxies, cosmological and statistical lensing, quasar structure)	Melbourne, Sydney
Gravitational waves and their detection	ANU, Melbourne, UNSW
Computational astrophysics	ANU, Macquarie, Monash, UNSW, Swinburne, Sydney

In many of the above areas of activity listed in the above table, theorists have collaborated with observers, adding value to the substantial observational programs carried out using Australian national and university facilities. Other theoretical research contributes to the design of new facilities such as the Square Kilometer Array

Workshops

ANITA's overall aim is to develop a cohesive national approach for theoretical astrophysics. One element of this plan has involved the operation of several workshops in areas of current interest. These have included:

- High Energy Astrophysics. Mt Stromlo, Sept. 2004
- Gravity 2004, University of Sydney, April 2004
- 2nd ANITA workshop on Theoretical Astrophysics, Macquarie University, October 2003
- GCDV: Galactic Chemodynamics V Workshop, Swinburen University, July 2003
- Observing the Theoretical Universe: Theoretical Astrophysics & the VO, Sydney University, January 2003
- Active Galactic Nuclei & Starburst Galaxies – Charlene Heisler Workshop, Mt Stromlo, December 2002
- Nuclear Astrophysics with the Murchisn Meteorite – 6th Torino workshop, Monash University, December 2002

- 1st ANITA workshop on Theoretical Astrophysics, Monash University, Febraury, 2002

Planned:
- Computational Astrophysics, ATNF, April 2005
- Stellar Astrophysics, Swinburne, September, 2005

Multi-wavelength astronomy

The main tradition of Australian astronomical observational research is in radio and optical astronomy. However, both theoreticians and observers realize that qualitatively different information comes from areas such as X–ray and gamma–ray astronomy. In many cases, theoreticians have led in new research in these fields developing important linkages for the community. Below we present a modest proposal as to how this type of activity can be supported.

Graduate education

ANITA also perceives that it is important that our graduate students can be better prepared for a career in science. In Australia we have a number of leading scientists in different institutions who could offer short courses in different areas of research. In a relatively small community such as ours it would be much more effective if the entire Australian graduate student community could benefit from courses from some of our leading scientists.

Therefore, we propose a series of graduate lecture courses, typically extending for 6 lectures, delivered via the Access Grid but also involving a 2 week residential workshop.

ANITA is prepared to coordinate such a series of graduate lectures.

Future prospects

It is pleasing to note that support for positions in theoretical astrophysics has increased over the last few years with recent appointments of Martin Asplund (RSAA), Alina Donea (Monash), Zdenk Kuncic (Sydney), Geraint Lewis (Sydney), Andrew Mealatos (Melbourne), Ralph Sutherland (RSAA), Mark Wardle (Macquarie) and Stuart Wyeth. These appointments have provided an important foundation for the future of theoretical astrophysics.

A vision for the next 10 years

1. The contribution of theory to all aspects of astronomical research should be recognized and supported. Theory is crucial for the interpretation and synthesis of the enormous amounts of data that come from our national facilities.

   The interpretation of data should not be seen as the *only* role of theory. Aspects of astrophysical theory that may not be amenable to immediate

observational tests are nonetheless crucial to our understanding of astrophysical processes. Examples include the dynamical behaviour of clusters of galaxies, the suitability of type Ia supernovae as standard candles, stellar convection and the magnetohydrodynamics of disks surrounding protostars and black holes.

Theorists are also responsible for the development of new techniques that have a wide-ranging impact on astronomy. Australian examples include the theory of thermal and nonthermal emission from astrophysical plasmas and the development of the computational technique, Smoothed Particle Hydrodynamics (SPH). The latter is a good example of an industrial linkage – SPH is used in the move industry for the realistic generation of sequences of moving gases and fluids.

2. New major observational projects (say equivalent in scope to the 2dF project) should factor in budgetary support for theoreticians and should involve theoreticians in the planning stages. This would ensure the flow–on of science to the Australian community, resulting from key observational projects.

3. Approximately 50% of theoretical research in Australia utilizes advanced computation on state of the art computational facilities. We are fortunate that these facilities can b shared across a wide range of sciences.

   We emphasize that it is essential for theoretical astrophysics that support for advanced computation through schemes such as the national Australian Partnership for Advanced Computation (APAC), the Sydney–based Australian Centre for Advanced Coputing and Communications (AC3) and the Victorian Partnership in Advanced Computation (VPAC) be continued.

   Opportunities for the development of computational astrophysics initiatives in University departments should also be supported.

4. Education of our graduate students to an international standard is an important aspect of astrophysics in Australia.

   ANITA is willing to lead an Australia–wide initiative to provie graduate level lectures via the Access Grid, incorporating a 2–week residential workshop and lectures by outstanding international astrophysicists.

5. Many theoreticians and observers participate in scientific projects involving ovserseas–based facilities such as the Chandra X–ray Observatory.

   A find should be established to support this research and to educate other Australian astronomers in the utilization of such international facilities.

6. Theoreticians place great value on the access to new major National Facilities. However, for theorists, major issues revolve around jobs: the creation of new positions, the maintenance of critical mass and the provision of a career structure.

Therefore, the current pattern of new appointments in theoretical astrophysics should be maintained.

7. As a result of the ARC funding program for Centres of Excellence, it is expected that both theorists and observers will seize the opportunity to formulate competitive bids for such centres. The theoretical community is encouraged to take advantage of these opportunities and to formulate internationally competitive and widely-inclusive proposals.

8. There is string interest in some quarters for the creation of a theoretical institute with a mandate to take a leading national role, similar in some respects to the role of our national observational facilities. This would involve a large amount of lobbying of state and federal governments and Universities and would require a dedicated individual or group of individuals to lead such an initiative. Whilst there is no current proposal for such a centre, we also do not wish to rule this out as a possibility within the next ten years.

Appendix: Summary of international projects involving Australian theoreticians

Project	Australian Institutions	International Institutions
CANGAROO Gamma-Ray Observatory	Adelaide, ANU, Sydney	Univ. of Tokyo led consortium of Japanese universities
Hadronic models of active galactic nuclei	Adelaide	Max Planck Institut fuer Radioastronomie, Bonn
Project LUNASKA: UHE neutrino astrophysics with the SKA	Adelaide, ATNF	Univ. of Delaware, University of Santiago de Compostela
Gravitational Wave Detection	Adelaide, ANU, UWA, Monash, Edith Cowan Univ, CSIRO	LIGO (US project), GEO (UK/German project), TAMA (Japanese project)
Project LUNASKA: UHE neutrino astrophysics with the SKA	Adelaide, ATNF	Univ. of Delaware, University of Santiago de Compostela
High energy astrophysics of Active Galaxies	ANU, Sydney	Landessternwarte & Max Planck Institut fuer Astrophysik, Heidelberg, University College, London; Consortium of US astronomers using the Chandra X-ray Observatory
Starburst Galaxies and Galactic Centre	ANU, AAO	Berkeley, Univ. of Maryland, Caltech, Oxford
Epoch of Galaxy Formation	ANU	Berkeley and U. Wisconsin, Royal Obs. Edinburgh
Three Dimensional Stellar Convection	ANU	Michigan State Univ. and Univ. of Copenhagen
Models of Mira Variable Stars	ANU	Univ. of Heidelberg
Laboratory Cosmology	ANU	Victoria Univ. of Wellington, Max-Planck-Institut für Quantenoptik
Supernova remnant masers	Macquarie	Northwestern University, Illinois
Epoch of reionisation	Melbourne	CfA Harvard;Princeton
Neutron star accretion	Melbourne	MIT; Canadian Institute for Theoretical Astrophysics
Solar Active Region Seismology	Monash	Colorado Research Associates, GONG
Solar Tachocline Instabilities	Monash	High Altitude Observatory, Colorado
Evolution of Stellar Populations	Monash	IoA, Cambridge
SPH and MHD	Monash	IoA, Cambridge
Blue Straggler Production in Open Clusters	Monash	IoA, Cambridge and U. Utrecht
Planetary Disruption in Star Clusters	Monash	American Museum of Natural History, IoA Cambridge
Stability and evolution of planetary cores	Monash	University of California, Santa Cruz
Evolution of neutron star binaries	Monash	Oxford
Stability of small-N systems in star clusters	Monash	IoA, Cambridge
Interactions between VLBI jets and the surrounding medium	Monash, Adelaide	Astronomical Institute of the Romanian Academy; University College Cork, Ireland
The effects of voids of primordial origins	NSW	Sussex, Oxford

Formation of the Milky Way	NSW	Tohoku University
Origin of post-starburst galaxies	NSW	Tohoku University
Ultra Compact Dwarf galaxy formation	NSW	U. of Bonn, Space Telescope Science Institute; Univ. of Calif.; Bristol U.; Nottingham Univ.
Cosmological variation of fundamental constants	NSW	Imperial College; Cambridge; UC San Diego; UC Lick Obs.; Penn. State; Novosibirsk
Thick disk sub-structure & halo kinematics	Swinburne	Tuorla Observatory, Finland
Effects of environment on nuclear fusion	NSW	Princeton; Michigan State U.
Galactic Streams	Sydney, Swinburne	Strassbourg Observatory, France; Cambridge University
Cosmological simulations/ SKA	Swinburne, Sydney	Arizona State; Durham University; Univ. of Victoria, BC; Univ. of Washington
Galactic Chemical Evolution	Monash	St Mary's College, Canada Rome Obs.
Accretion onto Magnetised Stars	Sydney, Swinburne	St Andrews, UK
Warped CV Disks	Swinburne	Open University, UK
Building Planets with Dusty Gas	Swinburne	Canadian Institute for Theoretical Astrophysics, Universite de Lyon
Synthetic IR Images of Protostars	Swinburne	Universite de Grenoble
Planets in Binary Systems	Swinburne	Potsdam, Germany
Dusty Debris Disks	Swinburne	Princeton and CfA, USA
Solar system radio bursts	Sydney	UC Berkeley
Sub-mm cosmology	Sydney	Caltech
Gravitational lensing	Sydney	MIT, Heidelberg, NRAO
Giant pulses from pulsars	Sydney	Stanford
Pulsar polarisation	Sydney	Jodrell Bank; GMRT
Interstellar scintillation	Sydney	UCSD; Palermo Univ.; Kapteyn Institute; NAO, Beijing
Pulsar spectra	Sydney	Oberling College, Yamagata U.
Energy balance of the solar corona	Sydney	U. New Hampshire
Solar neutrino time-series analysis	Sydney	Stanford
Magnetic reconnection & solar flare statistics	Sydney	U. Waikato