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Prof J C Lattanzio, President, ASA
School of Physics and Astronomy
10 College Walk,
Monash University, Clayton, Victoria, 3800
Phone: +61 (0)409 959 326
E-mail: john.lattanzio@monash.edu

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Executive Summary:

We argue for fundamental scientific research to be one of Australia's Research Priorities. Fundamental research fuels Australia's Future.

National priorities with a long-term horizon need to not only use science and technology to solve current problems, but also prepare society for dealing with new problems - including unexpected existential threats. A non-exhaustive list includes natural disasters, pandemics, solar flares wiping out electronics and communication systems, or an asteroid on a collision course with the Earth. COVID showed the value of investment in fundamental research, with exceptionally quick development of mRNA vaccines. We strongly argue that supporting broad-based fundamental research must be one the nation's key science and research priorities.

Australian Astronomy holds a unique place among the sciences, and is arguably Australia's most successful science. It also has a track record of benefiting society, with examples ranging from WiFi, STEM engagement and technology transfer through to international partnerships and workforce training. As a nation-building, underpinning science, astronomy is the perfect vehicle for enabling Australia's future scientific and technological capability, with associated social and economic benefits.

Introduction: Australian Astronomy in Context

Australia has a long and proud tradition in astronomy. For over 50 years, Australian astronomers have been at the forefront of the field. Today, it is arguably the nation's most successful science, as measured by research output and international recognition. Especially notable was the Nobel Prize for Physics being awarded to astronomer Brian Schmidt in 2011. In 2020 the Prime Minister's Prize for Science went to four astronomers for their work on gravitational-wave detection. In 2021 an astronomer won the Prime Minister's Malcolm McIntosh Prize for Physical Scientist of the Year. In fact, over the last 20 years astronomers have won 4 McIntosh prizes and 3 Prime Minister's prizes, and the number of astronomers winning international awards is too many to list. In the most recent 2018 ERA exercise (Excellence for Research in Australia) 14 of the 16 institutions working in astronomy were rated as "well above world standard" (the other two were "at" and "above" world standard).

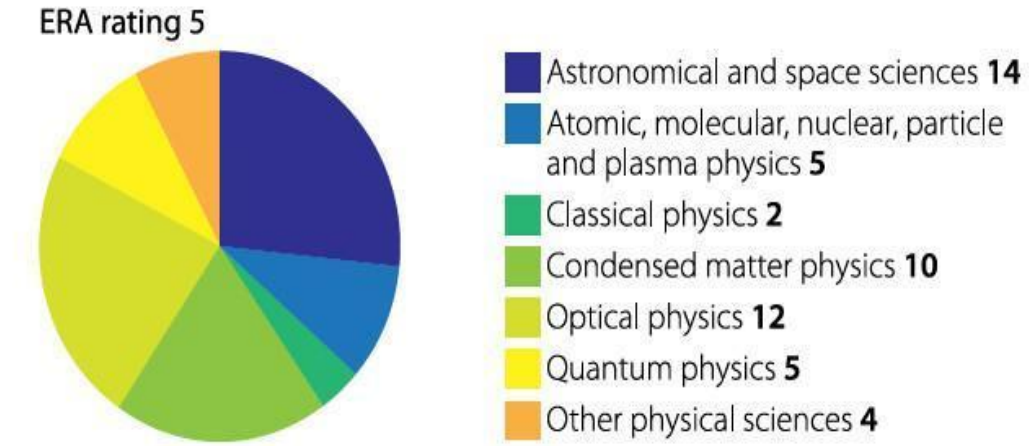
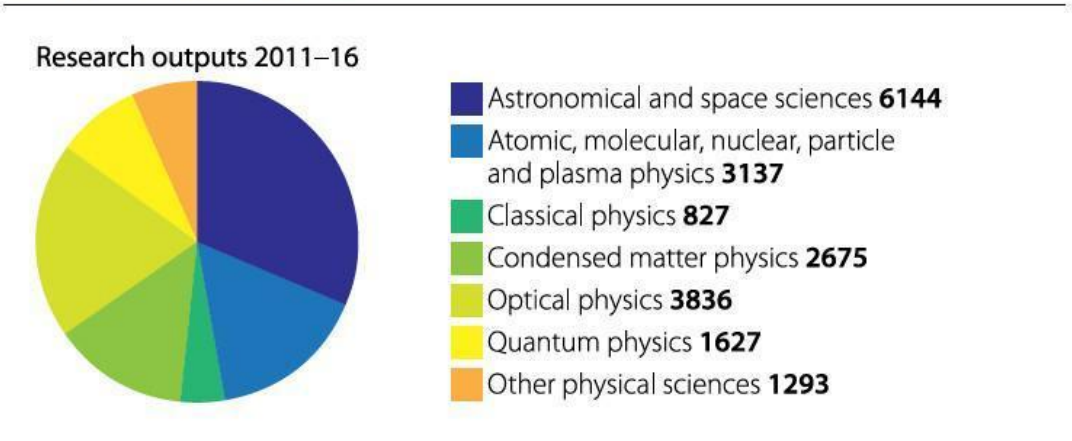


Fig 1: This is Fig 8 from the Mid-Term Review of the Astronomy Decadal Plan. Note that astronomy dominates all other physical sciences in terms of world standing.

The Australian Government recognises astronomy as a flagship science and there has been significant financial investment for new facilities such as the Square Kilometre Array (SKA), our involvement with the detection of gravitational waves via the Laser Interferometer Gravitational-Wave Observatory (LIGO), and especially our strategic partnership with ESO (2017-2026). Australia's investment in astronomy has translated to world leading science and technical innovation, with subsequent national and international recognition together with industrial applications and exports. This excellence has also brought foreign investment into Australia, including $1.8 billion (DISR) for the international Square Kilometre Array, currently under construction in Western Australia.



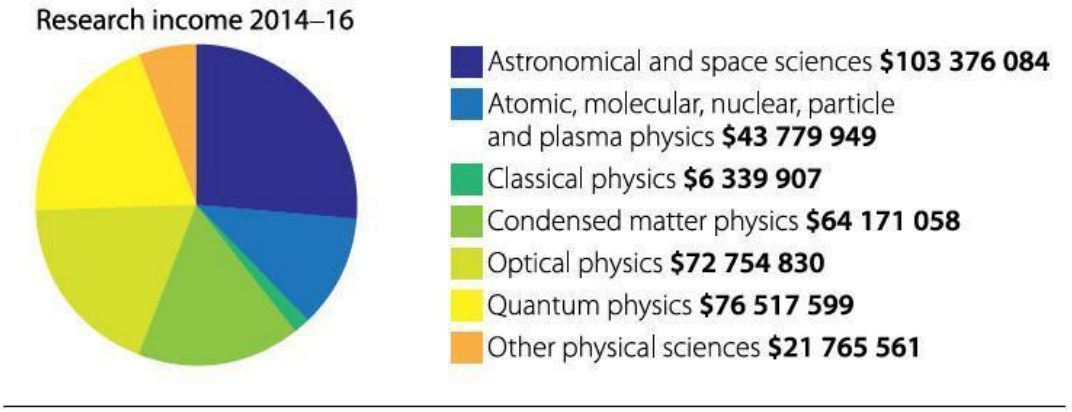


Fig 2: This is Fig 7 from the Mid-Term Review of the Astronomy Decadal Plan

Why Astronomy matters

Most sciences inspire and engage the population. Most sciences lead the development of new technologies and industries. But astronomy is unique in a number of ways, and has a special role in developing Australia's future scientific and technological capability as well as embedding Australian innovation and industry within an international context.

Astronomy inspires people: fascination with astronomy and space is ubiquitous. This attracts students to STEM subjects. Student STEM numbers at undergrad and PhD level are stagnating, but Australia will need an ever-growing number of STEM professionals (e.g. 1.1 million tech jobs by 2030). Astronomy is recognised as a major drawcard into STEM, including broader disciplines such as physics (Massey 2011).

Astronomy trains the workforce: advanced training in astronomy and astrophysics requires students to master mathematics, physics, computational modelling and data science. These are skills that are easily transferred to other disciplines. A large number of staff at CSIRO and US National Laboratories had their training in astronomy, but are now working in other areas using the skills they learned from astronomy. Indeed, at present 30% of Australian astronomy PhD graduates are working in data science in Australian businesses, which are now benefiting from the training they received in astronomy (see the Astronomy Mid-Term Review). As an example, over the lifetime of the ARC Centre of Excellence *Astro3D* (2017–2024), some 33% of former postdoctoral Fellows and students now work in the energy, biotech or medical industries, defence research, supercomputing, business or non-profit enterprises; 67% of this cohort secured employment in science. This highlights the versatility of astronomy training and its broad applicability to the economy.

Astronomy develops and advances technology and manufacturing: Telescopes are only as good as the detectors and instruments attached to them. Astronomy is also one of the most data-intensive sciences, with the SKA due to produce more data than any other science instrument. These demands result in astronomy developing new technologies that are then exploited by other disciplines. Australia is a world leader in developing and building such instruments, gaining us export dollars. Australian astronomers have pioneered some of the most important technological advances in astronomy, including the use of fibre optics and robotics and advanced signal processing techniques. Most famously the work led by Dr. John O'Sullivan from CSIRO in the search for exploding black holes led to the patented technology used for Wi-Fi networks worldwide, resulting in over $0.4 billion in income. Perhaps less well known is the development of CCD detectors for astronomy, which led to cheap and efficient CCDs now present in every smart phone's camera system. The revolution in medical imaging was a result of data analysis of radio astronomy images.

Some examples highlighting the breadth of economic benefits of fundamental research in astronomy and cognate disciplines include:

- **Safeguarding civil infrastructure**. By studying stars, we understand more about our own star, the Sun, and how it interacts with the Earth's upper atmosphere. This knowledge helps minimize disruptions to vital satellite services and electrical power grids.
- **Improved medical imaging**. Software originally created to look at images of highly crowded regions of the sky containing millions of stars has been adapted to search mammograms for signs of breast cancer – a faster and more accurate method than previously used. Sophisticated compression algorithms used for galaxy surveys have been repurposed to speed up analysis of radiology images.
- **Biodiversity monitoring**. Detection systems originally used in astrophysics to interpret thermal-infrared astronomy data have been used with drones to provide efficient, high-precision monitoring of animal populations.
- **Navigation.** General relativity, hypothesized by Einstein and confirmed with astronomical observations, is an essential ingredient for accurate positioning, including via Global Positioning System (GPS) satellites. Radio astronomy observations provide the only way of accurately orienting the Earth in space, enabling studies of planet-scale processes as well as spacecraft navigation.

Astronomy Crosses Cultures: Astronomy is fundamentally a worldwide endeavour, with different parts of the sky visible to different countries throughout the day and also varying over the year. For example, the centre of our Galaxy is only visible from the Southern hemisphere. Worldwide collaborations, across cultures, are essential for advancing the discipline. The fact that every culture has its own relation to the sky gives us an opportunity to engage on a fundamental level with other cultures and nations, especially Australia's First Nations, as highlighted by the award-winning book *Astronomy: Sky Country* by indigenous astronomers Karlie Noon and Krystal De Napoli.

Astronomy is an Underpinning Capability: Astronomy infrastructure and human capital also contribute significantly to adjacent disciplines, such as Earth observation, space domain awareness, and satellite communications. Three priorities in the National Reconstruction Fund (defence, enabling capabilities, medical science) directly benefit from astronomy research; and the remaining four benefit from technology transfer and workforce training enabled by astronomy. As a global science, astronomy provides opportunities for scientific diplomacy - including in the Asia-Pacific region - which are not available in many other disciplines. With Australia's long leadership in astronomy, Australian astronomers and diplomats are able to take influential roles in multinational organisations such as the SKA and ESO. This gives Australia connections, collaboration and leverage internationally. It also demonstrates Australia's national posture, as a forward looking, innovative nation.

While it is understandable that applications of science will be important examples of Australia's upcoming research priorities, there can be no applications without the fundamental research occurring first. Fundamental research must always be a priority for Australia to have a long-term innovation capability.

In summary, astronomy is a fundamental discipline which has a track record of delivering sustained, long-term economic benefits to Australian society. We strongly urge any consideration of national research and science priorities to include capability-building major fundamental disciplines such as astronomy, in which Australia has a competitive advantage.

Fundamental research fuels Australia's Future.