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Astronomy Australia Limited

submission: *Boosting the commercial returns from research.*

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Astronomy Australia welcomes the opportunity to comment upon the discussion paper, **BOOSTING THE COMMERCIAL RETURNS FROM RESEARCH**.

Astronomy is a basic science, aimed at understanding the contents, processes and history of the Universe; however, it is also part of the innovation system. Economic returns from astronomy infrastructure occur through innovation generated in the course of building leading-edge instrumentation. Although the resultant astronomical infrastructure is rarely used by industry, its creation often stimulates the development of new technology and technical skills useful to other parts of the innovation system.

The astronomical research conducted in Australia is internationally competitive. **EXCELLENCE IN RESEARCH FOR AUSTRALIA 2012** classified Astronomical and Space Sciences as a national strength that is exceptionally collaborative, as measured by co-authorship on publications. This research strength is supported by technical groups that are also world-leading. The examples on the following pages demonstrate that these strengths result in astronomy research infrastructure projects developing new technology within Australia, not simply assembling technical components that have been developed elsewhere.

Astronomy Australia agrees that the Australian Government should consider commercial returns and industry linkages when assessing the merits of proposed research infrastructure projects. **BOOSTING THE COMMERCIAL RETURNS FROM RESEARCH** states, "*The Government will take steps to ensure that research infrastructure facilitates increased collaboration between researchers and industry. To achieve this outcome the Government is seeking to: strengthen the existing focus of the NCRIS on outreach to researchers and industry*". (p. 23)

Recommendation: Astronomy Australia recommends that the Government does not limit its assessment of NCRIS investments to the expected use of the proposed research infrastructure by commercial enterprises. *The criteria for assessing proposed research infrastructure projects should also consider the capacity to drive innovation and develop new technology during the design and construction of the infrastructure.* While the resultant use of that technology cannot always be predicted, innovation during construction is potentially more important than commercial use during operation.

Yours sincerely,

Brian Schmidt, Chair AAL.

1. The astronomical endeavour

Astronomy deals with extremes of time, space and energy. Astronomers strive to detect and interpret the most energetic and distant phenomena that exist, usually through almost unimaginably faint radiation. To do so, they develop powerful techniques for finding and extracting signals from the 'noise' generated by the atmosphere, the rest of our galaxy, and human activities. They also conduct subtle tests of fundamental physical theories and hunt for phenomena, such as gravitational waves, predicted by those theories but not yet detected. The technologies and techniques of astronomy are connected to those of other fields such as space science, materials science, photonics, signal processing, visualisation and data processing.

2. Innovation from astronomical research infrastructure

In astronomy, "*what the science can achieve is dictated by what the technology can do—which in turn is driven by advances in science. Consequently science and technology co-evolve in a symbiotic manner*"¹. The development of astronomical instrumentation involves innovation and the generation of new knowledge because of the cutting-edge nature of the science. Astronomical research also provides a protected 'space', not subject to immediate commercial pressures, in which new technologies can be developed to a working state.

2.1 Gravitational waves lead to advanced radar

Technology developed at the University of Western Australia to hunt for gravitational waves has been commercialised for use in advanced radar systems. In the 1990s Professors Michael Tobar and Eugene Ivanov from the University of Western Australia were part of team, led by Professor David Blair, that was building UWA's gravitational wave detector. The 'noise' in one component, the microwave oscillator that provided precise timing, was a limiting factor. Tobar and Ivanov developed new, ultra-low noise oscillators. These were commercialised by the West Australian high-tech company Poseidon Scientific Instruments (PSI) for applications in advanced radar systems. (PSI has since been acquired by defence contractor Raytheon.) A cryogenically cooled version of the oscillator is also now a very important device for keeping atomic clocks accurate.

¹ Mark Matthews and Bob Frater. "Creating and Exploiting Intangible Networks: How Radiata was able to improve its odds of success in the risky process of innovating". Intellectual Property Research Institute of Australia Occasional Paper No. 1/13 (2013), p. 25 http://www.ipria.org/events/seminar/2013/WiFi_Patent/WiFi_Patent.html

When cryogenically cooled, the technology becomes a device known as a 'sapphire clock'. For this invention, in 2003 Professor David Blair received the Clunies Ross Award of the Australian Academy of Technological Sciences and Engineering in 2003, which is given to recognise an outstanding application of science and technology that provides economic, social and/or environmental benefit to Australia. In 2012 the Australian Institute of Physics awarded Professors Tobar and Ivanov its Alan Walsh Medal for Service to Industry, which is given for patents, processes or inventions that have led to significant industrial or commercial outcomes.

Australian expertise in the development of detectors for optical and radio telescopes has been developed over many decades, and is regarded as world-leading. It has allowed Australian institutions to win contracts to build major components and undertake R&D for the next generation of telescopes, including instruments for the Giant Magellan Telescope and phased-array feeds for the Square Kilometre Array radio telescope. A review of the astronomy NCRIS investments to-date has demonstrated the important role of NCRIS in funding the creation of innovative instruments, not just the purchase and assembly of imported technology.

2.2 High-impact science leaves a legacy of contracts

The Giant Magellan Telescope is a next-generation 'extremely large' optical telescope with a diameter of 25 m. The Giant Magellan Telescope Organisation does not employ a *juste retour* policy, but rather selects sub-contractors based upon merit. Australia has been selected to build two of its instruments: the Giant Magellan Telescope Integral-Field Spectrograph and the MANIFEST fibre-optic positioner.

MANIFEST is to be built by the Australian Astronomical Observatory (AAO) and is the latest in a series of international contracts the AAO has won to design and build fibre-optic positioners: previous work has been for the European Southern Observatory's Very Large Telescope in Chile, Japan's Subaru telescope in Hawai'i, and the UK's VISTA telescope in Chile.

The AAO attained its world-leading expertise in this field in the 1990s, when it developed innovative robotic technology with which to map the positions of more than 220,000 galaxies in 3D space. The five-year survey was one of the highest-impact pieces of Australian astronomical research ever done: the top 20 papers from the survey have collectively been cited more than 8,000 times and the top paper alone, more than 1,250 times. In 2014 Professors Shaun Cole and John Peacock, lead researchers of the survey, received the prestigious Shaw Prize for Astronomy for their work on the survey and its use in refining our model of the cosmos.

2.3 ASKAP contract boosts specialist firm

Puzzle Precision is a small company based near Newcastle, NSW, a quality, high-reliability electronic assembly service. Seven years ago CSIRO contracted it to supply a few tens of circuit boards for a CSIRO telescope in NSW. More recently, the company won a contract to supply signal-processor boards for CSIRO's new Australian SKA Pathfinder (ASKAP) telescope in Western Australia, and to

provide related services such as mechanical assembly and testing—thousands of units of work in total. As a result of its work with CSIRO, the company has doubled its staff (from 20 to 40), built new factory space, developed new capabilities and introduced new systems, such as an online portal that allows CSIRO to follow the results of the testing of its components in real time.

Training and collaboration are key underpinnings of innovation, and infrastructure drives both. Analysts of innovation emphasise that it is a systems process, depending on *the circulation of knowledge and its diffusion throughout the economy...* *The network consists of customers, subcontractors, infrastructure, suppliers, competencies or functions, and the links or relationships between them. The point is that competencies that generate innovation are part of a collective activity occurring through a network of actors and their links or relationships*².

This is well illustrated by the case of the Australian development of technology for wireless local area networks (WLAN or, colloquially, Wi-Fi), in which a network of individuals, some with a background in radio astronomy, played an important part. A number of the key actors had acquired their skills at a doctoral level through working with the University of Sydney's Fleurs Synthesis Telescope, a radio telescope formerly located in western Sydney.

2.4 Radio astronomy paves the road to WLAN (Wi-Fi)

In the 1990s a small Australian company, Radiata Communications Pty Ltd, developed a single microprocessor-based wireless Local Area Network (LAN) device that complied with a new international standard for wireless LAN systems. In 2000 Radiata was acquired by Cisco Systems for A\$657m.

The Radiata case has been analysed in detail by Drs Mark Matthews and Bob Frater³. It shows how Australian entrepreneurs were able to harness a pre-existing innovative capacity, created by a domestic network associated with Australian radio astronomy and electronic engineering.

In the late 1980s a number of research teams started to work on wireless LAN technology. Among them were a team at CSIRO's Division of Radiophysics—then involved in building a new radio telescope, the Australia Telescope Compact Array—and members of Macquarie University's Electronics Department. CSIRO and Macquarie began to collaborate on the research.

The central problem to be solved in wireless LAN was to deal with the complex reflections of radio waves inside buildings. The CSIRO team suggested using 'Fast Fourier Transform' (FFT) techniques to handle this: it had already developed a microchip to perform the operation.

The FFT is a mathematical procedure that allows signals to be divided up, transmitted and then recombined in a way that eliminates the problem of complex reflections. The impetus to create an FFT chip came from radio astronomy—specifically from the experience of one researcher, Dr John

² Mariana Mazzucato, "The Entrepreneurial State" (Anthem Press 2013), p. 92, citing Chris Freeman, "The 'National System of Innovation' in Historical Perspective", Cambridge Journal of Economics, 19, no. 1: 5–24 (1995).

³ Mathews and Frater, op. cit.

O'Sullivan. Early in his career, O'Sullivan was part of group of researchers searching for short-period (nanosecond) pulses of radio waves from exploding black holes. The technology of the day did not allow nanosecond pulses to be recorded directly, so O'Sullivan used film as the recording medium and performed optical Fourier transforms on the images. This technique was cumbersome and frustrating, and spurred O'Sullivan to develop a faster, cheaper method—the FFT chip. O'Sullivan also contributed to theoretical work on the sharpening of blurred images in optical astronomy, and the application of this to radio signals fed into CSIRO's development of wireless communication techniques.

By 1995 the CSIRO-Macquarie research team had a demonstration system operating at 100 Mbps. This work led to a US patent being granted to CSIRO in 1995. Radiata Inc. was formed in 1997 and licensed the technology from CSIRO. By 1999 Radiata was working to develop two complementary chips, a modem and a radio-frequency chip, that it intended to integrate.

Radiata possessed a rare, outstanding advantage: the ability to design complex chips with little need to re-work the design. The company benefited from substantial experience gained by AUSTEK Microsystems, a company spun-off by CSIRO from its Very Large Scale Integration (VLSI) program⁴. That program had been critical to the development of a key component of CSIRO's Australia Telescope Compact Array radio telescope—the '*correlator*' chip that processed the signals received simultaneously by the telescope's six antennas. The correlator chip set a substantial challenge for the VLSI Program because it had to house 100,000 transistors—an ambitious goal at the time. The Australia Telescope provided the essential user-focus and first customer for this R&D work, which enhanced Australia's capacity to design VLSI chips.

For at least 40 years there have been linkages between radio astronomers and industry that have been symbiotic rather than involving a linear transfer of knowledge. The linkages include the deliberate creation of an environment for carrying out doctoral research that challenged students to deal with complex projects in which they must use forefront scientific and analytical skills in order to solve real technological problems. This was a capacity-building process that, Matthews and Frater argue,

made the odds of important commercialisation outcomes occurring ... higher than they are in many other areas of R&D.

A number of leading Australian figures in electronic engineering carried out their doctoral research on the University of Sydney's Mills Cross telescope (near Canberra) and the Fleurs Synthesis Telescope (in western Sydney). Their training exposed them to the wide range of engineering challenges generated by an operating radio telescope. It also involved teamwork, an important aspect of R&D. Three of the five members of the CSIRO WLAN team (John O'Sullivan, Terry Percival and Graham Daniels) trained with the Fleurs Synthesis Telescope,

⁴ There were other benefits. AUSTEK also supplied the FFT chip initially used by Cochlear for the bionic ear. In addition, the FFT chip led to the formation of Lake DSP, which developed the technology used to produce 'surround sound' in headphones, a technology subsequently licensed to Dolby. (Mathews and Frater, op. cit.)

as did David Skellern, the Macquarie University researcher who was one of the joint founders of Radiata.

Long-term, the activities that led to a successful commercialisation of the WLAN solution were aimed at both improving radio-telescope performance and developing the industrial capacity to provide the technologies necessary to do this. Rather than aiming at achieving specific commercial outcomes there was a process of '*learning-by-doing*' that generated a range of options for future exploitation. What stands out is: (a) the team-based doctoral training using an operating radio telescope as a means of creating the right type of human capital and, (b) the strategic use of new and major upgrades of radio telescopes to further enhance these skills and add experience.

3. Opportunities in astronomical research infrastructure

Australia's world-leading capability in instrumentation development for radio and optical telescopes would enable future NCRIS investments in astronomy research infrastructure to stimulate the development of new technology.

Data-intensive research complements and extends the traditional areas of observational astronomy: as the fastest growing aspect of modern astronomy it deserves special mention. Large future observing projects will deliver their data through '*data hubs*' serviced by dedicated high performance computing. Large, complex data sets allow qualitatively different kinds of science not possible with small ones, such as data stacking and data mining. High-performance computing makes it possible to explore vast suites of theoretical simulations of different physical phenomena. Australian astronomers have already commenced their engagement with these new challenges and are collaborating with other technical groups to grow Australian capacity in this important area. A review carried out for the National Committee for Astronomy shows that astronomy students will have strong incentives to graduate with excellent skills in database technologies, data mining and machine learning, and the general practices of software engineering.

With its involvement in mega-projects such as the Giant Magellan Telescope and the Square Kilometre Array, the Australian astronomical community is conscious of the need to give close attention to the ways in which it interacts with industry. The National Committee for Astronomy recently tasked a working group, drawn from both the astronomical community and industry, with reviewing the way the two fields engage. The working group has made several recommendations for streamlining the interactions, including development of particular professional skills within the astronomical community and greater opportunities for exchange of personnel between the community and industry.

Australian astronomy's combination of world-leading technical capacity, "*Big Data*", and billion-dollar research infrastructure projects, offers the Australian Government a clear path to invest in projects that stimulate industry and generate new technology.

Astronomy Australia recommends that future research infrastructure funding via NCRIS or similar schemes should:

- support Australia to continue to do great science in existing areas of research strength;
- be directed to projects that, through their unique demands and in-country capacity, will stimulate innovation and produce new technology during the design and construction of that research infrastructure; and,
- be directed to research infrastructure projects that will build innovation capacity in the form of human capital.