2016 National Research Infrastructure Roadmap
Capability Issues Paper

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Question 1: Are there other capability areas that should be considered?

One capability area that should be considered is "Space Research and its Earth Applications". This area naturally encompasses the physics of Earth's space environment (including space weather and Space Situational Awareness [SSA]), the science and engineering of cubesats, other satellites, radars, and advanced instruments to observe the Earth and its space environment, and the myriad uses of remote sensing / "Earth observation from Space" (EOS) and GPS / "position, navigation, and timing" / GNSS observations. These uses include: environmental and ecosystem monitoring and associated modelling for Australia's coastal, marine, and land environments, both natural and not, plus associated agriculture and food resources; exploration, prospecting, and predictions for mineral, oil, and other natural resources; water resources and hydrology; national security and intelligence gathering; and last but not least the Big Data aspects of these applications, from ecosystem productivity to longtime geophysical evolution of the continents to climate change. Relevant national research plans include "An Australian Strategic Plan for Earth Observations from Space" (2009, AAS and ATSE) and the "Decadal Plan for Australian Space Science" (2010, AAS).

The national, economic, and societal benefits of EOS and GPS data are immense and Australia spends $2-4 B per year on space-related data and services, essentially all bought from overseas. Yet Australia's 2013 Satellite Utilization Policy requires assured access to space for the vital EOS and GPS data and services on which our economy, security and governments increasingly rely. The only sustainable way to do this is to develop an indigenous space capability. In addition, Australian needs are often different (e.g., the spectral responses of Australian flora and fora are unique globally) and observations of Australia are less common since northern hemisphere nations prefer to download data. Commercial drivers and opportunities are also increasingly important, with the US company PlanetLabs receiving over A$180 M in venture capital funding in 2015 to provide EOS images and the UK Government investing over $1 B to capture 10% of the international space industry turnover (currently over A$200 B). Using a commercial multiplier for investment in space research / services of a factor of 5, as estimated by the US and UK governments (among others), Australia could expect an improvement in GDP of order $1-2 B per year if 10% of its $2-4 B spend is brought home.

The barriers for Australia developing a space research capability and entering the global space industry have never been lower if the focus is on cubesats. First, the cost of building and launching a cubesat (units of 10 cm x 10 cm x 10 cm volume and 1 kg mass) is typically $0.2 - 0.5 M, much smaller than the $15 – 200 M cost of a standard 1 m^3 - 1000 kg satellite. Second, cubesats carry state-of-the-art instruments, as demonstrated by the INSPIRE-2 /AU03 cubesat (U. Sydney / ANU / UNSW Australia) with its 5 payloads and by its sister Australian cubesats SuSat / AU01 (U. Adelaide, UniSA) and ECO / AU02 (UNSW Australia) for Europe's state-of-the-art 50 cubesat project QB50. Third, the 3 QB50 cubesats and 2 UNSW Canberra – Defence Science and Technology Group cubesats were all built in

Australia and will be delivered to the USA for launch this year, establishing that Australia has the required skills and critical mass. The time is thus right to establish a cubesat-focused capability in Space Research and its Applications and to develop the associated space industry.

Space weather involves the effects of solar and interplanetary disturbances on the Earth's magnetosphere – ionosphere – atmosphere – ground /ocean system, on human technology, and the associated effects on radio communications and on EOS, GPS, and other satellite data. Space situational awareness (SSA) addresses the effects of the space environment on EOS, GPS/GNSS data, and other satellites in orbit. SSA and space weather data / predictions are increasingly vital to safeguarding national security, the international economy, and critical infrastructure like electricity power grids and communications. For instance, recent work predicts over US$1 trillion p.a. economic damage for up to 10 years for a large space weather event comparable to the pre-Space Age "Carrington Event" on 2 September 1859. Predicting the arrival, nature, and consequences of such (and smaller) events in time to take mitigation measures is clearly crucial for Australia's economy, society, and government.

Development of an NCRIS capability area in "Space Research and its Earth Applications" would thus fill a strategic gap in Australia's national research infrastructure between Earth Science and Astronomy, provide new data to address Australia's unique needs and outstanding scientific / policy issues, and underpin the development of an Australian industry in space hardware, data, and services. This capability arguably should have 3 strands:

(1.) **Cubesats for EOS and GPS research and services** involves the design, building, and operation of multiple generations of instrumented small satellites (launched by foreign providers), focusing primarily on EOS/GNSS systems, data, and services, but also on space technology and on space weather / SSA. These cubesats will drive the development of associated hardware and service industries.

- **Motivations.** To provide Australia with a real space capability and to provide new EOS and GPS data and services that: resolve critical scientific, economic, and societal issues; sustainably satisfy Australia's Satellite Utilization Policy; and develop associated space hardware, data, and services corporations. The focus will be on developing indigenous capabilities while still collaborating with foreign partners.
- **Infrastructure:** Build a flexible, long-term, sustainable, near-Earth capability with low altitude (300–1000 km) multi-generation constellations of cubesats with world-first, sensor-web, networked capabilities in EOS/GPS, space technology, and space weather/SSA. These would be designed, built, and integrated by Australian universities and corporations and be tested at the Mt Stromlo Advanced Instrumentation and technology Center (AITC). Plausible progenitors include the 3 QB50 cubesats and the Decadal Plan for Australian Space Science's "Marabibi Constellation" project.

(2.) **Space Technology** involves the development of advanced EOS and GPS instruments for cubesats, as well as digital radars for space weather / SSA research.

- **Motivations:** Photonic technology offers the possibility of extremely small, high resolution, imaging spectrographs that would revolutionise EOS and hyperspectral imaging. Spectral resolutions $\lambda/\Delta\lambda > 10^4$ for instruments weighing 0.1 kg and < 10 cm in size are viable, with INSPIRE-2 / AU03's Nanospec instrument a first stepping stone. Similarly, measuring GPS signals scattering off the sea and land offers new ways to extract the sea state (e.g., waves and winds) and moisture content remotely, while GPS radio occultations probe the atmosphere's structure and water content. Turning to space weather / SSA, Australia's civilian ground-based radars have restricted look directions and are analogue, yet we have developed state-of-the-art digital designs that offer huge advantages in capability and can revolutionise scientific understanding of ionospheric disturbances and their effects on the SKA, other radio telescopes, and the JORN defence radars.

- **Infrastructure:** (i) **Photonics-based Spectrographs and Imagers for EOS** that are much lighter and higher spectral resolution than current devices, revolutionizing EOS and space astronomy; (ii) **GPS receiver & software development,** for which Australia is well recognized. (iii) **Digital radars** that can look 360° around to probe the varying ionosphere & space weather over the SKA and Australia more generally, relevant also to JORN.

(3.) **Space Weather and SSA:** involves measuring and modelling the Sun's steady and transient interactions with the Earth's magnetosphere-ionosphere-atmosphere-ground/ocean system and the ensuing effects on human technology, economies, and society, humanity's environment, and Earth's climate. .

- **Motivations:** To predict and manage the risks of the increasing sensitivity of our/world infra-structure to space weather (e.g., USA damage > $1 trillion if the May 1921 space event occurred today); support and optimize affected critical national infrastructure (e.g., JORN radars & SKA) and Earth observation (EOS) and GNSS services/availability.
- **Infrastructure:** a ground network of radars, magnetometers, radio/GPS/cosmic ray receivers and models to make Australasia the world's best instrumented and modelled region for predicting space weather from the Sun to the ground. These would provide vital data and predictions for optimal operation of SKA, JORN, and GPS and communication networks. It would integrate directly with Astronomy, AuScope, and the proposed Cubesat and Space Technology subcapabilities. A progenitor is the Decadal Plan for Australian Space Science's "SpaceShip Australis" project.

Question 2: Are these governance characteristics appropriate and are there other factors that should be considered for optimal governance for national research infrastructure.

Question 3: Should national research infrastructure investment assist with access to international facilities?

Question 4: What are the conditions or scenarios where access to international facilities should be prioritised over developing national facilities?

Question 5: Should research workforce skills be considered a research infrastructure issue?

Question 6: How can national research infrastructure assist in training and skills development?

Question 7: What responsibility should research institutions have in supporting the development of infrastructure ready researchers and technical specialists?

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Question 9: What should the criteria and funding arrangements for defunding or decommissioning look like?

Question 10: What financing models should the Government consider to support investment in national research infrastructure?

Question 11: When should capabilities be expected to address standard and accreditation requirements?

Question 12: Are there international or global models that represent best practice for national research infrastructure that could be considered?

Question 13: In considering whole of life investment including decommissioning or defunding for national research infrastructure are there examples domestic or international that should be examined?

Question 14: Are there alternative financing options, including international models that the Government could consider to support investment in national research infrastructure?

Health and Medical Sciences

Question 15: Are the identified emerging directions and research infrastructure capabilities for Health and Medical Sciences right? Are there any missing or additional needed?

Question 16: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 17: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Health and Medical Sciences capability area?

Environment and Natural Resource Management

Question 18: Are the identified emerging directions and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed?

Arguably there are critical gaps in the current NCRIS investment, with some reference in the Issues paper. One that represents a significant scientific and economic opportunity is stated above for Q1 and briefly summarised here.

- **Space Research and its Earth Applications.** We advocate the development of a research capability for building flexible, long-term, sustainable, near-Earth Cubesats, operating in low altitude (300–1000 km) multi-generation constellations with leading-edge sensor-web, networked capabilities in EOS/GPS, space technology, and space weather. We suggest that investment in this capability may well feature as a critical step in the nucleation of a successful Australian space industry.

Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Advanced Physics, Chemistry, Mathematics and Materials

Question 21: Are the identified emerging directions and research infrastructure capabilities for Advanced Physics, Chemistry, Mathematics and Materials right? Are there any missing or additional needed?

One capability arguably missing is "Space research and its Earth applications". This links Physics with the Earth, Environmental, Natural Resource, and Natural Security domains. It includes Space Physics, focusing on the physics of the Sun and Solar System and distinct from Astronomy (which focuses on extra-solar system science), and so the effects of solar and interplanetary disturbances on the Earth's magnetosphere – ionosphere – atmosphere – ground /ocean system, on human technology. Space situational awareness (SSA) addresses the effects of the space environment on satellite data, assets, and orbits. SSA and space weather data / predictions are increasingly vital for safeguarding Australia's national security, the international economy, and critical infrastructure like electricity power grids and communications. For instance, recent work predicts over US$1 trillion p.a. economic damage for up to 10 years for a large space weather event comparable to the pre-Space Age "Carrington Event" on 2 September 1859. Predicting the arrival, nature, and consequences of such (and smaller) events in time to take mitigation measures is clearly crucial for Australia. In addition to a subcapability in multi-generational constellations of cubesats and other small satellites focused on EOS and GPS data and associated Earth applications (Q18), subcapabilities in novel hyperspectral EOS and GPS instruments and in measuring and predicting space weather and SSA effects from the Sun to the ground are recommended. More details are provided in the answer to Q1.

Question 22: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 23: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Advanced Physics, Chemistry, Mathematics and Materials capability area?

Understanding Cultures and Communities

Question 24: Are the identified emerging directions and research infrastructure capabilities for Understanding Cultures and Communities right? Are there any missing or additional needed?

Question 25: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 26: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Understanding Cultures and Communities capability area?

National Security

Question 27: Are the identified emerging directions and research infrastructure capabilities for National Security right? Are there any missing or additional needed?

"Space Research and its Earth Applications", as in the answers to Qs 1, 18, and 21.

Question 28: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 29: Is there anything else that needs to be included or considered in the 2016 Roadmap for the National Security capability area?

Underpinning Research Infrastructure

Question 30: Are the identified emerging directions and research infrastructure capabilities for Underpinning Research Infrastructure right? Are there any missing or additional needed?

Question 31: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 32: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Underpinning Research Infrastructure capability area?

Data for Research and Discoverability

Question 33 Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?

Question 34: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

Question 35: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Data for Research and Discoverability capability area?

Other comments

If you believe that there are issues not addressed in this Issues Paper or the associated questions, please provide your comments under this heading noting the overall 20 page limit of submissions.