2016 National Research Infrastructure Roadmap
Capability Issues Paper

Submission No: *(to be completed by Departmental staff)*	
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Would you like your submission to remain confidential, i.e. not published on the website?	**NO**

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

Yes. ***Space research to enable economic, environmental, societal and strategic (including national security) outcomes.***

There is an emerging awareness in Australia of our critical dependency on space-based technologies and space-derived data to meet economic, environmental, societal and national security needs, via Earth Observations from Space (EOS remote sensing), Satellite Communications (SATCOMM), Position, Navigation and Timing (PNT), and Space Situational Awareness (SSA). This awareness has been expressed in several government reviews, "Australia's Satellite Utilisation Policy", the "Decadal Plan for Australian Space Science" (2010, AAS), the Defence White Paper 2016, and the current review of Australia's Space Activities Act.

The uses of space-based services 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". EOS, SATCOMM and PNT services from space are currently worth at least $8B per year improved GDP alone. Ensuring resilient access to space systems is vital for Australia's future well-being. There is a significant risk to that service however, of disruption or denial due to space weather events or in-orbit collisions.

Space weather – disturbances to the near-Earth space environment resulting from solar activity – poses well-known threats to modern technologies, both space-based and terrestrial. Satellite systems can be damaged or destroyed; communication links and GPS signals disrupted; damaging electrical currents can be generated on Earth in metallic networks such as power grids and pipelines; and more. 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 1859 "Carrington Event". Such events are on the national risk registers of countries such as the UK and USA. Predicting the arrival, nature, and consequences of such (and smaller) events in time to take mitigation measures is crucial for Australia's economy, society, and government.*

The risk of in-orbit collisions is also growing and can ultimately limit our use of space. In 2009 a collision between two communications satellites produced thousands of pieces of debris, few of which could be tracked by ground-based sensors. An anti-satellite weapon test in 2007 also generated significant space debris. Such events highlight the importance of the Space Object Catalogue, which contains over 20,000 satellites or debris objects, and will expand by an order of magnitude as new sensors are deployed this decade. The Catalogue seeks to maintain accurate knowledge (and its uncertainty), of the orbit of each object in space, so that close approaches of space objects can be predicted and the probability of collisions computed, for evasive action to be taken (if possible).

At the same time, global space technology is evolving towards the application of resilient, agile swarms of networked low-cost miniature satellites with game-changing capabilities. This includes networks of distributed sensors whose observations can be fused to build up accurate information without the expense and risk of traditional satellites; or networks with secure optical (quantum) communication links. This transformation presents significant opportunity for Australia, to combine innovative technologies with in-country space capability, in an environment where the entrance cost to becoming a space-ready nation is no longer high.

Space research, described in the 2011 Strategic Roadmap for Australian Research Infrastructure as one of seven key Enabling Capability Areas that stimulate cross-disciplinary research, is an essential component of the development of space-based EOS, SATCOMM and PNT services to support activity on Earth, is essential for advancing the state-of-the-art of SSA to mitigate the risks associated with in-orbit congestion, and is essential for the development of the disruptive and game changing space technologies that are within Australia's ability, both scientifically, technically and financially, to play lead roles in.

Australia has the necessary space research heritage, scientific and engineering skills, and strategic location, to advance these areas for national benefit :

- *Australian space physics is internationally recognised for its long-standing expertise in observing and advancing modelling of the key regions of the near-Earth space environment: the passage of CMEs to Earth (University of Sydney; Bureau of Meteorology Space Weather Services); the magnetosphere (University of Newcastle; BoM SWS; Geoscience Australia); the ionosphere (University of Newcastle – which uses radar facilities owned by LaTrobe; University of Sydney; University of Adelaide; RMIT; Curtin University; BoM SWS; DSTO); and the upper atmosphere (University of Adelaide; BoM SWS).*
- *Australia sits longitudinally between North America and Europe, latitudinally south of Asia, and is profoundly radio quiet. As a result the US Strategic Command, NASA and other space agencies have fundamental dependencies on ground stations in Australia. The vast network of ground-based space environment sensors in Australia, Antarctica and elsewhere in our region provides critical input to the world's space weather database. Some of those sensors and ground stations can also be used for space object tracking (e.g. MWA, CSIRO-operated*

Deep Space Network). In addition, considerable investment is being made here by Australia and its partners in laser-tracking and optical and radar surveillance of space objects. This includes US/Australia Defence investments at North West Cape, and the CRC for Space Environment Management (SERC).

- *It is now not only feasible, but is actively being demonstrated within some universities and research organisations in Australia, to bring home highly skilled Australians from the international space sector, and develop and operate sophisticated space-based technologies and spacecraft to help meet national needs. The emphasis is not on re-inventing wheels but rather on procuring off-the-shelf satellite sub-systems from proven national and international suppliers, and integrating these with innovative and potentially game changing Australian instruments and payloads. The cost of doing this for many applications is one to two orders of magnitude less than traditional space missions.*

Consolidation of and investment in these activities through the development of an NCRIS capability area in space research to enable economic, environmental, societal and strategic (including national security) outcomes, would 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, in ways that are well within our reach given the nature of global space transformation.

Separately, given the priorities expressed in the 2016 Defence White Paper, Defence Industry Policy Statement and Defence Integrated Investment Program, towards increased reliance on domestic innovation to support national defence capability, the National Research Infrastructure Roadmap should consider national research infrastructure that may be necessary to support such domestic innovation at a scale beyond individual research laboratories and programs.

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?

Yes. Some forms of research infrastructure relevant to Australian expertise and Australian needs are so large and/or expensive that they require international efforts to develop and sustain them. For example, certain space-based science missions require large spacecraft to support large aperture optics, or to support a range of instrumentation to achieve a given mission, and therefore are of a level of investment beyond what is currently possible in Australia. Very large ground-based telescopes are another example (and the support given to the astronomy community to access such facilities, via Astronomy Australia and Australian Astronomical Observatory, is an excellent example of relevant mechanisms). Investing in such international facilities gives Australia the opportunity to not only benefit from them, but to steer their development so that they can help meet Australian needs, and furthermore gives Australia a voice at the relevant international table.

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

*In the context to the comments above, such priority should only be given when access to international facilities is the **only** way to support the necessary research or strategic outcomes. If development of national facilities can achieve these outcomes, this should be prioritised because it also ensures increased levels of local skills, local innovation and commercial spin-off, and sovereignty over what in some cases could be critical infrastructure to support national security.*

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

Yes. Without the skills base to support research infrastructure of national significance, such infrastructure will either be difficult or impossible to develop, or difficult to maintain. Indeed, it could be argued that research infrastructure is one part of an enabling capability for national innovation and security, that research workforce skills are another part, and that STEM strategies and outcomes are yet another, equally important, part.

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

National research infrastructure implies a higher level of scale, complexity, sophistication and/or expense than "local" research infrastructure. Framed in this way, the level of professionalism required, in terms of scientific, technical and programmatic skills and processes required to support them at world-class standards is high. Such an environment by nature must assist in raising the calibre of the workforce supporting the infrastructure to world-class.

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

Apart from the obvious responsibility of teaching the necessary core knowledge to those researchers and specialists, research institutions should be engaged in supporting the development of and accessing the national infrastructure and using it as part of the well-supervised training ground for the relevant personnel.

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

In general, access should be open and based on scientific / technical merit of the proposed research projects and teams, however there will occasionally be situations where sovereign or national security issues should override open access.

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

As part of the establishment of each element of national research infrastructure, consideration must be given to the entire life-cycle, just as in any large scale engineering project. This includes provision for review gateways at defined points in the life-cycle, where the success and ongoing relevance of the infrastructure is assessed and the case argued and decided as to whether the infrastructure in question should be upgraded, expanded, simply continued as-is, or de-commissioned. The cost of de-commissioning should be estimated and acknowledged in the approval process for establishing the infrastructure, and ideally funds set aside to enable the inevitable de-commissioning when the time comes – possibly analogous to the required funding set aside for environmental rehabilitation before new mining leases are granted.

An option for funding de-commissioning could be to sell or gift certain facilities to interested parties, for example commercial and university consortia, who could take over the operation and maintenance of the facilities (potentially at reduced scale and output, but nevertheless making good use of existing infrastructure).

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

In general, provision of national research infrastructure to support national outcomes should be funded by Government, in some cases public/private ventures could be appropriate to enable certain infrastructure to be developed if the business case permits. On the other hand, anticipating financing national research infrastructure through commercial access fees, on a "build it and they will come" philosophy, would be a high risk proposition unless the necessary rigorous national and international market analysis is performed to confidently predict adequate financial returns.

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

One example of this is when full trace-ability of research results and conclusions is needed, including full calibration of instruments and procedures and methodologies, to support policy and funding decisions at national or international levels – for example, to ensure the integrity and strength of climate change mitigation efforts.

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?

An example is the way that the largest telescopes (eg GMT) are funded and constructed - with institutions, governments, and other interested parties able to buy in early in the planning/building process in return for guaranteed time once the telescope is operational - with early investors getting return on investment than those who invest later - a risk-reward setup, so those willing to invest early, and therefore ensure that the project goes ahead, are rewarded for bearing some of the risk.

The remaining questions relate to the specific priority areas identified in the Issues Paper. Each area asks for feedback on the emerging directions, research infrastructure capabilities, opportunities for international collaboration and other comments. No responses have been drafted for these areas. Please note that the sections **Underpinning Research Infrastructure** (Q30-32) and **Data for Research and Discoverability** (Q33-35) are considered cross-disciplinary.

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?

Australian domestic space-based remote sensing capability is no longer out of reach, in terms of both finances and the local skills base to deliver it. This should be included in national research infrastructure. See below for further information.

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

"An Australian Strategic Plan for Earth Observations from Space", published in 2009 by the Australian Academy of Science and the Australian Academy of Technological Sciences and engineering, describes Australia's needs for Earth observations from space (EOS) remote sensing data. These needs involve meeting urgent national challenges in climate change, water, natural disaster mitigation, transport, energy, agriculture, forestry, ecosystems, coasts, oceans and national security. The Plan identifies the risks associated with our dependency on foreign satellite providers, including our inability to significantly influence international EOS capabilities to meet Australia-specific needs. The Plan identifies the need for Australia to provide EOS satellites for our own purposes and in so doing contribute to the global EOS system. The need for Australia-specific remote sensing data has further increased since 2009, with one key example (of many) being the recent and rapid degradation of the Great Barrier Reef ecosystem.

Hyperspectral remote sensing (HRS), in which the surface of the Earth is imaged at high resolution in many simultaneous wavelength bands, is able to help meet many of the identified EOS needs – in particular, marine and fresh water quality, agriculture / biosecurity, forestry, resources, and national security. HRS is well proven on airborne platforms, with CSIRO and DST Group possessing world-class expertise in the analysis and utilisation of HRS data sets. HRS is now being applied on international spacecraft. An Australian HRS satellite capability would represent critical national research infrastructure that would generate vast amounts of timely, high accuracy, science quality data and information to be incorporated into the Australian Data Cube, to support research and innovation by Australian universities and research organisations active in the identified fields, for the coming decade.

With the current global transformation of space technologies towards miniaturized satellites, and with the significant recent gains in Australia's domestic space technology capabilities (including professional satellite-based remote sensing and space mission expertise), the development and operation of an affordable HRS satellite capability based on a small number of miniature satellites (nanosats, microsats) is feasible today. This would support not only Australian research and innovation, but contribute to the growth of an Australian space ecosystem and to our efforts to ensure national security.

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?

Referring to 7.3.3 Space Science, the statement that the entrance cost to make Australia a space ready nation is significant, is ***not*** *correct. Traditionally, satellites carrying remote sensing and space science instruments have been large, complex, high risk, and extremely expensive. This remains the case where the remote sensing optics must be very large in order to achieve the resolution required for a given purpose, or if the mission requires that the spacecraft venture into deep space. However, the global space sector is currently undergoing rapid transformation due to : the miniaturisation of electronics and certain (many) classes of instrumentation; the introduction of new approaches to harden electronics and sensors to radiation without the extreme cost of traditional radiation-hardened components; the application of distributed capability across many miniature spacecraft rather than small numbers of large ones, thus increasing robustness and reducing cost; the reduced cost and increased opportunity to launch small spacecraft into orbit; and the existence of many highly skilled and experienced Australian space professionals who have either recently returned or would gladly return home from the international space sector. It is now not only feasible, but is actively being demonstrated within some universities and research organisations in Australia, to develop and operate sophisticated space-based technologies and spacecraft to help meet national needs. The emphasis is not on re-inventing wheels but rather on procuring off-the-shelf satellite sub-systems from proven international suppliers, and integrating these with innovative and potentially game changing Australian instruments and payloads. The cost of doing this for many applications is one to two orders of magnitude less than traditional space missions.*

It is also important to note that one of Australia's national facilities that is of critical importance to our emerging capabilities for in-orbit space research is the collection of world-class spacecraft test facilities at ANU's Advanced Instrumentation Technologies Centre. These facilities have been commissioned with the assistance of government funds, and this year have provided test capabilities for some university miniature satellite programs, however there will be a period of some years required to ramp up the income generated from test programs to the point where the facilities are self-sustaining. In the meantime, investment is required to ensure that those national asset facilities are maintained, operational and financially viable.

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?

The following concerns the infrastructure and skilled workforce to underpin it, that represents Australia's world-class ground-based sensor network for observing the near-Earth space environment and the population of satellites and space debris that inhabits and interacts with that environment. It involves space physics, which are dominated by solar processes and critically impact on both space and terrestrial technologies. It also involves the field known as Space Situational

Awareness, which deals with the congestion of the space environment and the associated risk to national security because of the risk to the space-based technologies upon which Australia depends. Thus it applies both to ***Advanced Physics, Chemistry, Mathematics and Materials*** *and to* ***National Security.***

The risks to Australia :

- *Space weather – disturbances to the near-Earth space environment resulting from solar activity – poses well-known threats to modern technologies, both space-based and terrestrial. Satellite systems can be damaged or destroyed; communication links and GPS signals disrupted; damaging electrical currents can be generated on Earth in metallic networks such as power grids and pipelines; and more.*

  Solar disturbances including Coronal Mass Ejections (CMEs) transfer energy and momentum into near-Earth space, triggering magnetic storms. The atmosphere, ionosphere (in which LEO satellites orbit), radiation belts and magnetosphere (where GPS and GEO satellites fly) behave as a complex, highly dynamic coupled system. Our current understanding of this environment is based largely on measurements from discrete locations that provide input to models for specific regions of space. The coupling between regions and aspects of the dynamics are not well understood, with significant gaps existing in the physics and therefore our predictive capability. However, our vulnerability to space weather effects is growing with the increasing reliance on integrated and networked services.

- *The risk of in-orbit collisions is also growing and can ultimately limit our use of space. The Space Object Catalogue, which contains over 20,000 satellites or debris objects, will expand by an order of magnitude as new sensors are deployed this decade. It seeks to maintain accurate knowledge (and its uncertainty), of the orbit of each object in space, so that close approaches of space objects can be predicted and the probability of collisions computed, for evasive action to be taken (if possible).*

The relevant national research infrastructure :

- *Australia sits longitudinally between North America and Europe, latitudinally south of Asia, and is profoundly radio quiet. As a result the US Strategic Command, NASA and other space agencies have fundamental dependencies on ground stations in Australia. Some of these ground stations and sensors are purpose built for and contribute to the US-led Space Surveillance Network, for Space Situational Awareness.*
- *On the other hand, the vast network of ground-based space environment sensors in Australia, Antarctica and elsewhere in our region provides critical input to the world's space weather database. These sensors are predominantly high frequency radar networks such as the SuperDARN radars at Bruny Island, Invercargill and Buckland Park near Adelaide, established as part of a La Trobe-Newcastle-Adelaide consortium. As a result, Australian space physics is internationally recognised for its long-standing expertise in observing and advancing modelling of the key regions of the near-Earth space environment: the passage of CMEs to Earth (University of Sydney; Bureau of Meteorology Space Weather Services); the magnetosphere (University of Newcastle; BoM SWS; Geoscience Australia); the ionosphere (University of Newcastle – which uses radar facilities owned by LaTrobe University; University of Sydney; University of Adelaide; RMIT; Curtin University; BoM SWS; DST Group); and the sensible atmosphere (University of Adelaide; BoM SWS; RMIT).*

The risk associated with the infrastructure (including skilled workforce) :

- *Radio physics has historically been an area of scientific leadership for Australia. The major SuperDARN infrastructure were and have realised new science and new technology. Radio physics has other important contexts to Australia, including to the JORN surveillance network, to radio* *occultation measurements for weather modelling, for space situational awareness, and to radio astronomy via the MWA and SKA.*

- *While Defence has significant capability in radio and ionospheric physics, related to the JORN over-horizon radar network, and BoM Space Weather Services is able to provide excellent space weather operational and forecasting services, there is a looming capability gap in terms of training and expertise in radio and ionospheric physics, and in terms of non-Defence high frequency radar capability, in Australia. We face the real prospect that the SuperDARN radar facilities will soon no longer be able to be supported by their host universities and the associated science and science-informed training capability will be lost.*
- *To counter this, there is a need for ongoing national research infrastructure investment to restore and maintain full operation of these radars, and to make strategic investment in the university-based research groups that run them in order to facilitate operations, foster science and expand training opportunities.*

The opportunity associated with the infrastructure:

- *It has become apparent in recent years that radio astronomy arrays such as Murchison Widefield Array, ASKAP and eventually SKA are capable of conducting sensitive ionosphere measurements and monitoring the passage of spacecraft and space debris. This opens up significant opportunity for Australia to invest further into those facilities such that their "non-traditional" capabilities are explored, tuned and operationalised. In turn, our ability to monitor the space environment and space congestion will increase. Our ability to maintain our associated research leadership will also increase, as will our contribution to international efforts to mitigate the associated risks.*
- *Combining the need to invest in existing radar and the opportunity to expand non-traditional capabilities, Australia should consider establishing as an item of critical national research infrastructure, a distributed national facility of ground-based network of radars, magnetometers, radio/GPS/cosmic ray receivers (including MWA, ASKAP, SKA) and models to make Australasia the world's best instrumented and modelled region for monitoring and predicting space weather from the Sun to the ground, and thus support space research to support national interest.*

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?

Biosecurity requires observation capability. Space based remote sensing capability such as the hyperspectral remote sensing described above is able to provide the necessary whole-of-nation biosecurity coverage required, to provide actionable information from which localised investigation and remediation can be triggered.

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

Quantum technologies to support national security also include quantum communications. The international quantum community sees as part of its long term roadmap the development of global ultra-secure communications networks supported by quantum encryption and quantum key distribution. As an alternative to regularly spaced quantum repeaters in terrestrial networks, secure global communications will include ground-to-satellite, satellite-to-satellite and satellite-to-ground quantum communications. Quantum ground stations (derived from optical tracking telescopes) and quantum-enabled satellites are requisite infrastructure for this. The combination of Australia's quantum, space and telescope expertise and capabilities presents Australia with a unique opportunity to develop (and provide world leadership for) the necessary quantum ground stations and miniature satellites that would form the basis for global quantum communications research.

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?

Enhanced geospatial systems and infrastructure investment can and should include domestic space-based remote sensing capability, for the reasons discussed above, and it should also include the critical capability of moving beyond the storage of vast amounts of most-likely-never-to-be-used (because there is so much of it) data, into processing and transforming the data into usable information banks. The latter requires investment in the computational algorithms and infrastructure needed to perform such processing, involving autonomous decision making to turn data into information.

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.

General comments