Australia in Space: a strategic plan for Australian space science

Space Situational Awareness and Space Weather Working Group Report

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Context

By 2030 there will be at least ten times more satellites in orbit than in 2020. In order to ensure access to and use of a safe, secure, and sustainable space environment Australia requires a tightly integrated and sovereign Space Situational Awareness (SSA) and space weather capability across the defence, civil, and commercial space sectors. The burgeoning growth of commercial space-based activity, the emergence of on-orbit servicing and autonomous maneuvering of satellites, new capabilities for crewed space missions, and the emergence of new nation states into the space sector, mark step changes in how space is utilized, what it is utilized for, and who will be in control of space assets. While much of the emerging national space industry is based on the 'Space 2.0' paradigm using cubesats, these have much lower resilience than larger more expensive spacecraft. Furthermore, the Space 2.0 paradigm has arisen in a very quiet space weather environment compared with the earlier space age. All spacecraft and space-reliant services are at risk from space debris and space weather, while critical infrastructure such as electricity distribution grids and long pipelines are also at risk from space weather effects. Australia is already an international leader in space weather science and prediction. By exploiting our geographical extent and growing our space science and SSA capability Australia can become a medium to major player in managing the global commons of space while securing strategic access to and use of space.

Vision statement

By 2030 a vibrant space situational awareness (SSA), Space Traffic Management (STM), Space Domain Awareness (SDA), and Space Weather community has been established to support the rapid increase in Australian space activity, fueled by a sustainable collaboration between academia, SMEs, primes, defence, and government organisations. At its core is a highly connected and collaborative community of researchers that comprise the vault of long term SSA and Space Weather knowledge and experience within Australia. The community structure has succeeded in rapidly training students and researchers from adjacent fields to transition their skills into the SSA and Space Weather domain. Leveraging its geographic, geopolitical, scientific and technical advantages, Australia provides global leadership in SSA and Space Weather research, through:

1. Detection, tracking, correlation, and prediction of orbits for objects 1cm in size and larger as input to a new cooperative global space catalogue
2. Accurate characterization and change detection for objects in all Earth orbit regimes via a tightly integrated network of novel SSA sensors and algorithms
3. Fundamental and applied science on space environment interactions with ground and space assets to build resilience for communications, precision navigation and timing, satellite orbit uncertainty, over the horizon radar, and damage to critical satellite systems from Space Weather effects
4. Up to 72hr high fidelity predictions of key space weather events
5. A regular cadence of experimental SSA and Space Science spacecraft missions to generate benchmark quality truth data to verify and validate ground-based sensors, data processing, modeling and simulation tools. These missions will provide a low-risk pathway for the development of operational Space-Based Space Surveillance and Space Weather payloads, and will support international strategic alliances.

Background

Currently around 2,700 active satellites are currently in operation around Earth. The small satellite (<500kg) market will grow this figure by approximately an order of magnitude, with over 16,000 small satellites expected to launch into Low Earth Orbit between 2020-2030 (Frost and Sullivan, 2017). Approximately 70% of those launched will be under 250kg and the majority of these satellites will belong to constellations owned by about 30 companies.

Commercially owned satellites in 2020 comprise 54% of all active satellites reported on orbit (UCS 2020), leading the US Department of Defense to actively devolve responsibility for space traffic management (STM) to a civilian/commercial role within the US Department of Commerce. Australia is identified as a crucial partner to contribute to both the commercial and military SSA/STM/SDA system owing to its geographical location, large landmass, clear skies, and growing sovereign SSA expertise.

Legacy SSA/STM/SDA approaches are unable to keep pace with emerging space technology and space utilisation. In addition to the vast increase in the number of objects to catalogue in the coming years, technology such as the Starlink constellation of 12,000 small satellites that feature continuous low-thrust electric propulsion will defeat traditional orbit determination algorithms. New ideas and systems are therefore required to permit safe and secure operations within the space domain of the future.

Knowledge of the space debris population will undergo significant evolution in the coming decade. New sensors offer the potential to detect a larger portion of the 500,000-750,000 pieces of space debris over 1cm in size that are estimated to already exist in orbit today (ESA). Extensive research and development is required to transform these raw detections into accurately catalogued Resident Space Objects (RSO) from which precise and actionable conjunction analyses can be derived.

Change detection in orbit, attitude, and communication behaviour is a key capability to predict on-orbit risk to civilian and defence space assets from space weather, debris, and/or intentional (cyber) attack. Understanding, monitoring, and forecasting space weather is a central component to achieve this goal. The effect of thermospheric density, causing satellite drag, is well known as the biggest contributor to orbit uncertainty in LEO. Ionospheric disturbances can disrupt communications and passive RF sensor performance. High-energy particles and Electrostatic Discharge from lower energy particles in LEO can disrupt or destroy spacecraft subsystems. Interactions between the space environment have been cited as a potential cause for high area-to-mass ratio debris from the GEO graveyard orbit to re-enter the GEO belt.

The defence research community in the USA via DARPA is actively seeking to enhance the forecasting and monitoring capability of mid to small-scale travelling ionospheric disturbances in Earth's upper atmosphere to improve Space Domain Awareness in support of military operations. Australia hosts impressive ground based sensors and world-class expertise to enable the development of such capability. However, to date, there is no rigorous means to attribute spacecraft anomalies to space weather events.

Extensive capability exists within Australia, including: world-class monolithic and distributed sensors spanning optical, passive and active RF, radar, infrared, and laser ranging; astrodynamics; space physics/weather modelling and monitoring; AI and machine learning; and spectrum monitoring. Much of the excellence that exists today did not exist in 2010. We should expect and encourage new capability to emerge within the next decade. A finite window of opportunity is now open for Australia to emerge as a global leader in space domain awareness (of which space weather is a crucial part) and make a lasting contribution to a safe, secure, and sustainable space environment for the benefit of society.

Surveillance and intelligence data collection, analysis and dissemination, specifically involving over-the-horizon radar systems and space situational awareness systems, is a Sovereign Industrial Capability Priority identified in the 2018 Defence Industrial Capability Plan.

The Path Ahead

Insight	Aspiration	Actions	Impacts	Metrics
Community: Diverse pockets of excellence exist throughout Australia in key science, technology, and research areas that can fuel a tightly integrated SDA and Space Weather capability to support Australia's civilian, defence, and commercial space activities. Opportunities to exploit our human capital are lost due to a lack of coordination, common goals, and defined direction to focus effort and resources.	A community of SDA and Space Weather professionals shall form to drive innovations in sensor development, analysis, forecasting, fundamental science, and long term scenario planning. Coordination and alignment of focus areas ensures that the pressing global SDA and Space Weather challenges are tackled holistically and that the systems required to integrate data, algorithms, and approaches are created.	• Connect and coordinate the community to attract significant funding for Australian SSA, STM, SDA and Space Weather research excellence • Up-skill the Australian SDA and Space Weather community through targeted training and education opportunities to fill key knowledge and skills gaps • Create new opportunities for SSA, STM, SDA and Space Weather careers in Australia within academia, industry, civilian, and defence	• Improved funding opportunities for the Australian SSA and Space Weather community • Greater retention of knowledge and skills following the closeout of major SSA and Space Weather research projects • Support development of Defence workforce and sovereign capability priorities • International recognition for our knowledge, skills, and human capital • Better space policy, more commercial opportunities, and greater strategic benefit derived for Australia from space utilization • Contribution to global committees, technical working groups, and decision making bodies on SSA, STM, SDA, and Space Weather	• Levels of funding • Number of PhD students graduated • Number of students enrolled in SSA/SDA related courses • Number of SSA/SDA/STM related jobs filled by Australians • Citations and the use of our research by others • Participation and exhibiting at national and international conferences • Hosting conferences, workshops, events and national challenges • Number and size of collaborative grants between academia, industry, government, and/or defence • Degree of international collaboration with key organisations (NASA, ESA, UK Space Agency, major research laboratories, leading industry players, and defence organistaions)
Measuring, understanding and characterisng the space catalogue: Securing the safety of Australia's current and future activity in space requires monitoring of satellites and debris. Persistent, accurate, and timely monitoring of all objects >10cm in Earth's orbit with a revisit time of <1hr and the pursuit of technology that can reveal the population of objects between 1-10cm is critical to mitigating the risk of on-orbit collision.	Australia shall develop a diverse and resilient network of sensors that exploit our geographical advantage in location, large landmass, and clear skies. Enhanced sensor persistence, accuracy, and coverage of the resident space object population shall provide input to advanced modelling and simulation tools that provide Australian SDA analysts with world leading expertise to understand, protect, and profit from the space domain for Australia's benefit.	• Support and grow our existing world class sensor capability to improve accuracy, persistence, custody and resilience for space surveillance activity • Create a curated pool of diverse and accessible sensor data and information to fuel R&D into new analysis, modelling, and simulation techniques to describe, characterise, and catalogue objects in orbit • Develop dedicated satellite missions to calibrate, benchmark, and accelerate Australian SSA/SDA and Space Weather capability	• Australia becomes a trusted provider of high quality operational SSA data and analysis services • Australia makes a substantial and sustained contribution to the global effort to track all objects in orbit	• High TRL sensors and systems • Number of objects maintained in the catalogue • Revisit/update rate on the catalogue • Number of new sensors and sensor networks created

Monitoring and forecasting the impact from space weather: Space weather threatens the operation and performance of critical space and ground infrastructure. Distinguishing between space weather effects and intentional interference is severely restricted due to a lack of forecasting ability, resolution/accuracy, and fundamental knowledge into how space weather physically interacts with our systems.	A world leading space weather forecasting system is developed to mitigate and attribute impacts from space weather on space and ground systems, space object motion, and effects on humans up to 72hrs in advance.	• Accurately forecast particle densities and medium to small scale disturbances in the thermosphere/ionosphere/magnetosphere system up to 72hrs in advance • Accurately forecast the radiation environment impacting satellite operations in LEO, MEO, HEO, GEO, and cislunar regimes 72hrs in advance • Develop dedicated small satellite research missions to monitor the near-Earth space environment	• Extended mission life of on-orbit satellites • Reduced uncertainty in orbital predictions • Increased resilience of ground and space-based infrastructure, including critical infrastructure, to deleterious space weather events • Greater awareness of the threats from space weather within government and the public sphere	• Fewer disruptions to satellite services • More accurate forecasts of space weather • Higher spatial and temporal resolution for space environment monitoring • Increased number of space weather products used operationally
Assessment and Attribution: SSA and Space Weather data only becomes valuable when it informs action. Understanding the underlying cause or predicting the future consequences arising from those data is central to the safe, secure, and sustainable use of space.	Australia shall have the capability to perform its own high fidelity threat assessments to ensure safety of all its on-orbit assets on short, medium and long-term time frames.	• Fundamental research into the physical effects and impact of space weather on sensors, spacecraft, orbits, and ground infrastructure across all space weather scenarios • Develop systems that can discriminate and attribute changes in space object behaviour to natural or human sources in real time to enable actionable threat assessment • Provide long term modelling to assess the impact from changes in global space utilisation, technology, and policy	• World leaders in spacecraft/space environment research • Improved safety and reliability for on-orbit, ground, and human space systems • Australian-led global space policy and guideline initiatives	• Accuracy of predictions • Fewer false positive collision warnings in Low Earth Orbit • Number of Australian space norms and practices adopted globally • Improved compliance with national and international space policy
SSA Market Opportunities: The US Department of Commerce has been charged with taking on the civilian Space Traffic Management mission. Global and commercial partnerships are central to their approach and Australia is in a prime position to offer services into the new commercial SSA, STM, and SDA system	Australia will develop a range of products spanning sensors, data processing, fusion, and analytics to capitalize on the commercial opportunities arising from the DoC shift to a commercial space traffic management system.	• Demonstrate Australian SSA and Space Weather capability and utility in operationally challenging environments • Streamline transition from low TRL within research institutions to high TRL within industry and defence	• A sustained and profitable SSA/SDA/Space Weather sector • New job opportunities in SSA products and services	• Value of the Australian SSA commercial sector • Number and diversity of Australian SSA products and services
Beyond Near-Earth Space: Australia has the expertise and emerging sensor capability to offer unique SDA and Space Weather support for the upcoming NASA Artemis program to the Moon and beyond	Australia will apply its world leading Near Earth Object (NEO) sensor research and space weather forecasting expertise to become world leaders in deep space and Lunar space domain awareness in 2020-2030 to support crewed and autonomous missions.	• Advance the state of the art for detecting, tracking, and predicting the behaviour of bodies in Lunar and cislunar orbits • Develop strong international partnerships to grow and apply our deep space and lunar SSA and space weather capability	• Secures safe transit between Earth, the Moon and beyond • Preserves the unspoilt orbits of the Moon and other planets • Secures niche capability	• Strong Australian participation in NASA Artemis • Number and persistence of monitoring of objects in lunar and cis-lunar orbits

Recommendations

1. Create an Australian Space Domain Awareness and Space Weather Institute

The institute will align and coordinate a vibrant and tightly integrated community of SSA/STM/SDA and Space Weather professionals who are dedicated to safe, secure, and sustainable Australian space activity into the future. The membership is diverse in background, bringing together people from a broad range of science, engineering, technology, policy, and strategic backgrounds. Members cut across academia, industry, government, and defence. The institute should have a strong governance and leadership structure and foster an inclusive model for participation to capture niche skills and expertise that can provide Australia with the ability to exploit its advantage in the field. The institute should be funded to sustain its activities into the long term, however the institute itself is not a funding body. The institute's goal is to provide the strategic leadership and a united voice to allow its members to attract substantial external research funding that enables world-class research excellence in the field.

The institute should:

- "Act like a cult, not a clique" – easy to join, hard to leave.
- Provide the momentum for world class Australian SSA, STM, and Space Weather R&D
- Facilitate training and skills growth – our real estate is being used by the world's leading experts to site their sensors, we should be seeking to exploit this connection to improve or collective knowledge and skills
- Build strong international collaborations to attract funding and enable secondments/exchanges to fast track knowledge and skills growth
- Have a strategic leadership team that is appointed by the Institute's membership

2. Create an SDA and Space Weather 'technology sand pit' to prototype, test, and integrate SDA and Space Weather innovations

The complete SDA and Space Weather picture only emerges when many diverse sources of data are intelligently combined, analysed, and acted upon. The technology sand pit shall support our SDA and Space Weather community by connecting their capabilities and enabling rapid developments that lead toward operational capability. The intent of the sand pit is to serve the community - not for the community to serve the technology. The sand pit should:

a. Be designed to fit the needs and constraints of individuals within the community
b. Be a **well-funded national facility** that removes the financial and technical barriers from individual groups and companies to participate in an operational-like environment
c. Provide a rich and diverse data set for the research community to use, test, and build upon.
d. Focus on understanding the quality, utility, and reliability of data (not just house a large volume of data)
e. Include all types of data: space weather, sensor data, open source data, spacecraft telemetry, simulation, experiment
f. Embrace new and emerging technology and solutions
g. Drive significant research outputs for the community to establish Australia as a world leader in the field
h. Enable transition of low TRL research to high TRL application within industry, government, and defence

3. Develop ambitious SSA and Space Weather satellite missions/payloads to increase the accuracy and persistence of monitoring the space domain

4. Explore opportunities to lead the world in cislunar, lunar, and deep-space SDA and Space Weather

Australia is partnering with NASA for the Moon to Mars Artemis program. Securing safe and secure flight from Earth through cislunar and into Lunar orbit is essential for crewed flight. Blue-sky research built upon Australia's existing deep space surveillance expertise should be explored and exploited to secure Australia as the world leader in lunar and deep space SSA, STM, SDA and Space Weather.