Space Situational Awareness at the Australian National University

Doris Grosse(1,2), Marcus Lingham(1,2), Francis Bennet(1,2), Michael Copeland(1,2) , Celine d'Orgeville(1,2), Visa Korkiakoski(1,2), Tony Travouillon(1,2), James Webb(1,2), James Gilbert(1), Robert Sharp(1), Craig Smith(3), Moriba K. Jah(4,5)

(1) Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT, 2611, Australia, doris.grosse@anu.edu.au
(2) SERC Limited, Mount Stromlo Observatory, Weston Creek, ACT 2611, Australia
(3) Electro Optics Systems Space Systems, Queanbeyan, NSW, 2620, Australia
(4) Aerospace Engineering & Engineering Mechanics, Cockrell School of Engineering, The University of Texas at Austin, 2617 Wichita St, Austin TX, 78712, United States of America
(5) Research School of Aerospace, Mechanical and Environmental Engineering, Australian National University, Canberra, ACT, 2600, Australia

ABSTRACT

The Advanced Instrumentation and Technology Centre (AITC) of the Research School of Astronomy and Astrophysics of the Australian National University (ANU) has built instrumentation for ground-based astronomical telescopes for many years. In particular, the AITC has been developing instrumentation for the 4-meter Australian Astronomical Observatory telescope in Australia, the 8-10 meter Gemini, Subaru, and Keck telescopes in Hawaii, and the 8-meter Very Large Telescope and 25-meter Giant Magellan Telescope in Chile.
In more recent years, the AITC has expanded its endeavours to include space applications, notably the ground based monitoring of satellites and space debris. Such space situational awareness (SSA) activities are built upon the AITC's mature and internationally recognised expertise in lasers and adaptive optics as well as emergent technologies such as infrared detectors. More recently the ANU Institute for Space (ANU InSpace) was established at ANU to connect all space activities across the university and leverage from synergies created through cross-collaboration of the different colleges and research schools. This paper provides an overview of the capabilities and research areas of the ANU within the field of SSA. In particular, ANU's strengths are in debris and satellite imaging in low Earth orbits using adaptive optics and positioning and tracking of satellites in Geostationary orbit using adaptive optics and lucky imaging.
The paper also summarises ANU's vision to use their astronomical and communication telescopes for SSA tracking purposes to provide Southern hemisphere satellite and debris tracking data. The newly established Research School of Aeronautical, Mechanical and Environmental Engineering will host the proposed Centre for Space Situational Awareness Research (CeSSAR) which will be supported by ANU InSpace to coordinate all SSA activities at ANU.

1 ADAPTIVE OPTICS FOR SPACE SITUATIONAL AWARENESS APPLICATIONS

Adaptive Optics (AO) is a technique initially developed for astronomy to enhance the performance of ground-based telescopes. An AO system measures the distortions of the wave fronts caused by the atmosphere and compensates for them. With the help of this technique, the resolution of the telescope is not seeing limited, but can be diffraction limited depending on the design and performance of the AO system [1]. The following three paragraphs briefly summarise the activities of the ANU within the field of adaptive optics in the context for space situational awareness applications.

1.1 Adaptive Optics for Satellite and Debris Imaging

AO can be applied to resolved images of satellites and debris in Low-Earth Orbit (LEO). The Advanced Instrumentation and Technology Centre (AITC) has developed AO-enhanced imaging capabilities to gather information about the attitude and shape of objects in LEO providing significantly improved accuracy over standard imaging techniques. An AO system for a 1 m telescope, was designed, built and tested [2,3] at the Electro Optics Systems Space Research Centre on Mt Stromlo. The system uses an OCAM2k camera with a frame rate of 2 kHz as wave front sensor and an ALPAO DM-69 deformable mirror (DM) which can match the speed of frame rate of the camera. With a seeing of 2.5 arcseconds, an AO corrected performance of 0.25 arcseconds was achieved while imaging a binary star [2]. Figure 1 shows the on-sky results of a satellite track of Resurs-DK1 during operation of the AO system with a closed AO loop. One can see the satellite's solar panels rare esolved from its main body. When tracking over a period of 30 seconds, the rotation of the satellite can also be identified [3].

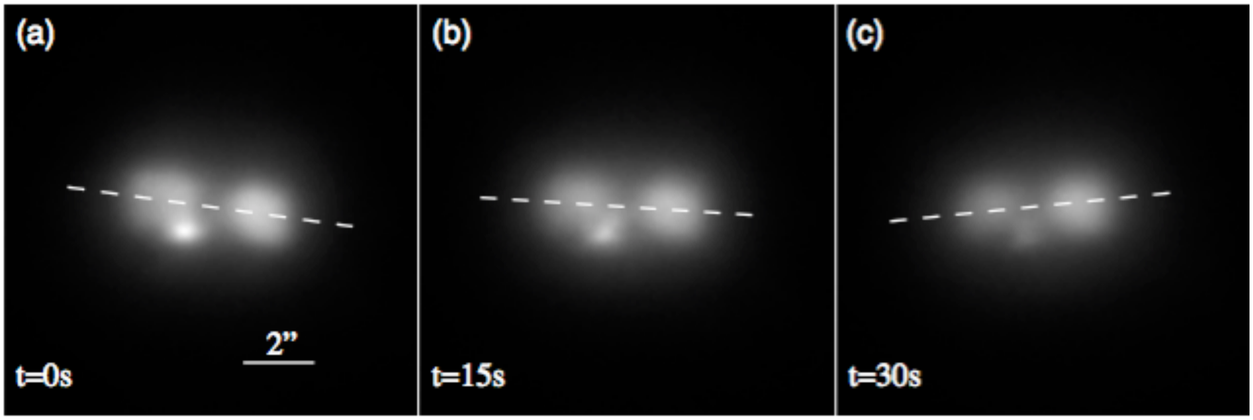

Fig. 1: AO corrected images of Resurs-DK1 satellite. The images show the rotation of the satellite after all field rotation is removed at (a) t = 0 s, (b) t = 15 s, and (c) t = 30 s. [3]

Another AO system was designed, built and tested at the AITC and commissioned at the Electro Optics Systems (EOS) Space Research Centre on Mt Stromlo. This system was funded through the scope of the Space Environment Research Centre (SERC) [4] and was developed to operate at improved resolution with a 1.8 m telescope. The system has been commissioned and tested. First on-sky results showed that the system can perform under moderate seeing conditions with a resolution of 0.098 arcseconds resolving a binary star with a separation of 0.05 arcseconds [5].

1.2 Adaptive Optics for position measurements of satellites and debris in geostationary orbit

AO-enhanced telescopes can also deliver vastly improved position estimates of geostationary orbit (GEO) objects by allowing higher accuracy comparisons with catalogued star positions via astrometry [6]. The AO imaging system designed for a 1.8 m telescope and described in section 1.1 was also designed to perform such a positioning measurement [7]. The commissioning of this feature of the AO system is planned for late 2019.

1.3 Adaptive Optics for photon pressure debris collision mitigation manoeuvre

As the space environment becomes increasingly congested, particularly in orbits around 800 km [8], measures need to be developed to actively mitigate debris collisions in this crowded environment. Simulations have shown that this mitigation can be achieved by engaging high-power lasers through a network of ground based telescopes, using adaptive optics to achieve sufficient photon pressure at the debris object in orbit [9,10]. Within the scope of SERC, ANU is developing an adaptive optics system to conduct a proof-of-principle experiment of this technology with a single system based at the EOS Space Research Centre on Mt Stromlo [4]. The AO system is designed for a 1.8 m telescope and will be operated with a high-power laser combination by a laser provided through Lockheed Martin and EOS Space Systems. Figure 2 depicts the operational schematic of the system. The system requires sufficient reflected sunlight reflected from the object or a beacon on the object, so that it can be acquired and tracked. A laser guide star (see the section 1.4) that is pointed ahead is required to provide information about the atmospheric distortion. Once the laser guide star is acquired and the AO loop is closed on the laser guide star, the high-power laser can be pointed ahead of the object to compensate for the time of flight. A detailed description of the operational principle can be found in [11], an overview of the systems components such as the optical design of the AO system, the laser guide star facility and the high-power laser can be found in [12]. The simulated, expected performance of the AO system is discussed in [13].
The system is near completion with final components to be delivered in early 2020 for system integration, testing and commissioning.

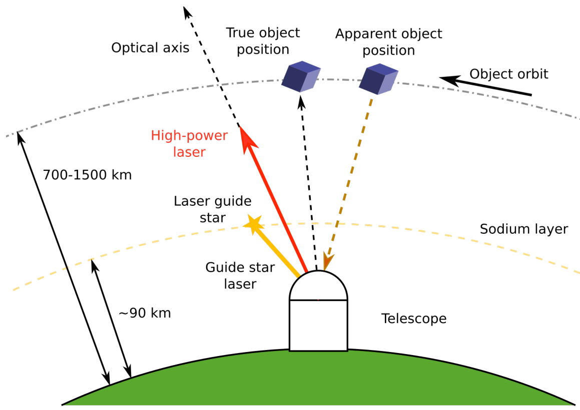

Fig. 2: Operational overview of the AO system for remote debris collision avoidance manoeuvre using photon pressure [11].

1.4 Semiconductor laser guide star development

The number of objects of any astronomical or space situational awareness AO system to be imaged is increased by using a laser to create an ‘artificial star’ at 90 km height called a sodium laser guide star [14]. A laser guide star is particularly needed for enhanced performance for AO systems with space situational awareness applications as the objects (the satellites and debris) must be tracked with high slew rates and reference objects such as reference stars are not available within the field of view. The AITC is currently leading the development of the 4th generation of laser guide star systems making such a system smaller, more affordable and more efficient [15]. The sodium guide star laser will be tested and commissioned at the EOS Space Research Centre on Mt Stromlo in 2020.

2 TELESCOPES AND DETECTORS

Apart from adaptive optics instrumentation development, the ANU is also operating a wide variety of telescopes mainly at their off-site campus at Siding Spring Observatory. The telescopes have been designed for astronomical purposes, but can also be repurposed for space situational awareness applications. Additionally, a planned research telescope dedicated to optical communications with satellites will be able to conduct satellite and debris survey activities when not actively performing communications tasks.
Furthermore, the AITC has been developing several astronomical detector systems that are well suited to dual-use not only for astronomical, but also for space debris and satellites observations. The section 2.1 lists existed and funded ANU telescopes, followed by an overview of ANU’s detector development capabilities in section 2.2 that can be used for SSA activities and applications.

2.1 Existing and funded telescopes with potential for space situational awareness

The well-established ANU 2.3 m telescope (Fig. 3) shows great potential for space situational awareness applications. As the housing is slave to the telescope drives, it is currently not capable to track objects in LEO due to the housing’s limited rate of movement. It is however capable of tracking GEO satellites, which was demonstrated recently (see section 2.2). The ANU 2.3 m telescope will also be undergoing a major equipment upgrade, resulting in an autonomous telescope that can be remotely controlled.

Fig. 3: ANU 2.3 m telescope [16]

The DREAMS telescope [17], a 0.5 m aperture telescope also to be situated at Siding Spring Observatory, will be a performing fully automated all-sky surveys in Y (1µm), J (1.25µm), and H (1.65µm) bands and will be a potential candidate to perform tracking during dusk and dawn due to its infrared detectors.

Situated on Mt Stromlo, directly at the main campus of RSAA in close proximity to the AITC, will be a 0.7 m telescope designed to perform optical laser communication for horizontal propagation and from space to ground. The facility will host several optical benches that can be accessed from the telescope via a Coudé path. This facility will be a test bench facility not only for free space optical laser communication, but has also the capacity and capability to perform LEO tracking activities. The facilities' planning and procurement phases are well underway with construction to begin in mid-2020 and commissioning of the facility planned for late 2020.

2.2 Detector development

In recent years, the AITC has developed expertise in the handling of linear mode avalanche photos diodes (lmAPD). Using SAPHIRA detector technology, this avalanche photodetector technology was originally designed for infrared astronomical imaging and is now being developed further for space based detectors [18,19]. A prototype of the detector has been installed at the ANU 2.3m telescope (Fig. 5). Due to the possible fast low-noise read out, the system can apply lucky imaging techniques not only for astronomical applications, but also to track Geostationary satellites.

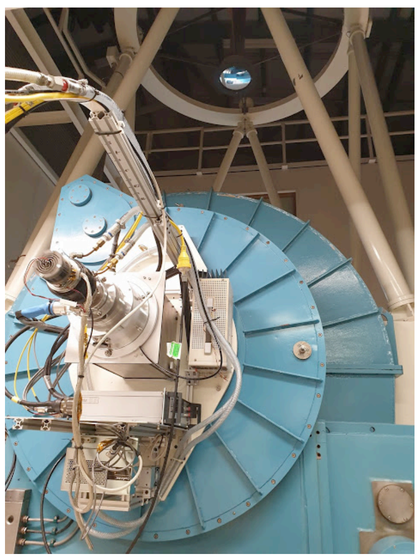

Fig. 5: SAPHIRA lmAPD detector installed at the ANU 2.3 m telescope at Siding Spring Observatory

3 CENTRE FOR SPACE SITUATIONAL AWARENESS RESEARCH AT ANU

To coordinate and leverage capabilities across the entire ANU, the proposed Centre for Space Situational Awareness (CeSSAR) will be situated within the in 2019 newly established Research School of Aerospace, Mechanical and Environmental Engineering. CeSSAR will be supported by the ANU Institute of Space (ANU InSpace) [19] who is coordinating space activities across all colleges and research schools at ANU in general. CeSSAR will be a partner of the Advanced Sciences and Technology Research Institute for Astrodynamics (ASTRIA) [20] program. CeSSAR's focus areas a currently under development. Envisioned work will focus on the creation and expansion of an open access Australian data lake for SSA.

4 SUMMARY

This paper summarizes recent developments in the field of space situational awareness within the Advanced Instrumentation and Technology Centre of the Research School of Astronomy and Astrophysics of the Australian National University. ANU's strengths lie in the development of adaptive optics systems for astronomical instrumentation, of laser guide star technology and infrared detectors. In recent years the development of the adaptive optics systems has been expanded to space situational awareness application such as satellite and debris imaging, positioning and collision mitigation through photon pressure. ANU is also scoping out the application of their expertise in infrared detector technology for the application of space situational awareness. The paper also provides an overview of future telescope developments which can be utilised to grow space situational awareness applications at ANU. The plans for expansion of space situational awareness capability are also reflected in the future development of the Centre for Space Situational Research within the newly created Research School of Aerospace, Mechanical and Environmental Engineering within ANU.

5 ACKNOLEDGEMENT

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