# Development of a new SSA facility at Learmonth Australia

**Craig H. Smith**
EOS Space Systems
**Ben Greene**
*Electro Optic Systems*
EOS Space Systems
**Matt Bold**
*Lockheed Martin Corporation*
**Rod Drury**
*Lockheed Martin Corporation, Australia*

**Abstract**

EOS Space Systems, in partnership with the Lockheed Martin Corporation has constructed a new facility for Optical Space Surveillance at Learmonth, Western Australia. The facility includes four new telescopes to provide passive tracking of space objects from LEO to Deep Space and active (laser) tracking of objects in LEO.

The site is now complete and fully operational undergoing performance testing with prospective customers.

The Learmonth site is the second site (after Mt Stromlo) in a planned roll-out of a SSA network spanning the Australian continent.

The capability and performance of the new sensors will be discussed as well as development of new network command and control, automated data processing, track association and database development.

## 1. INTRODUCTION

EOS Space Systems (EOS) operates a number of active and passive optical satellite and space debris tracking sensors from its Space Situational Awareness (SSA) Observatory at Mt Stromlo (Fig. 1), near Canberra, Australia. This station has been in continuous operation in its current form since 2003. The SSA Observatory is co-located with the Mt Stromlo SLR (MSL7825) system that provides mm level laser ranging to ILRS target sets (compliant targets with retro-reflectors). The 1.8m telescope at this site provided the first published laser ranging tracks to non-compliant objects in low-Earth orbit (LEO) in 2004 and remains the leading tracking station in the world for laser ranging to non-compliant space objects. This sensor has been independently validated for tracking 6mm targets at 350km range.

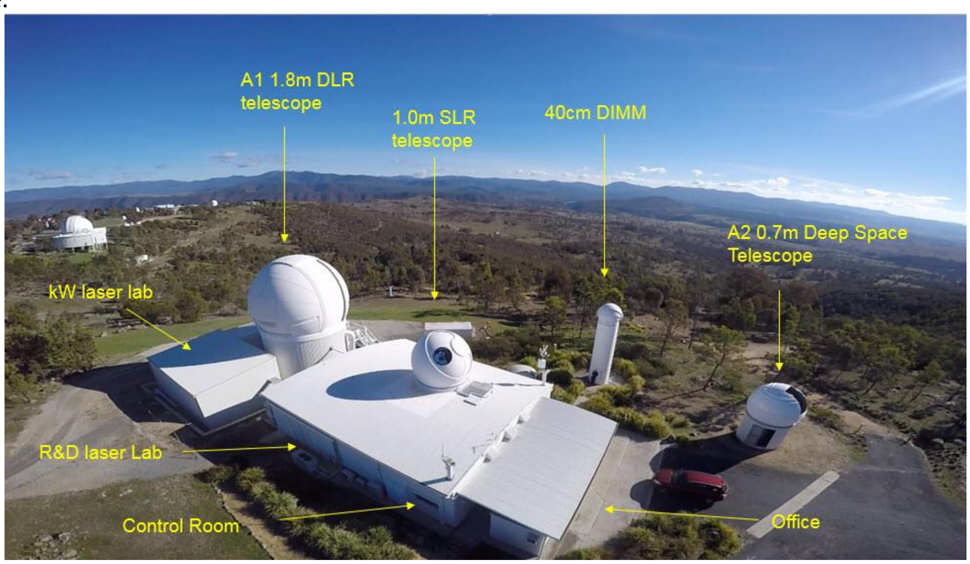


**Fig 1. EOS Space Research Centre at Mt Stromlo, including SSA and Geodetic SLR system.**

To increase capacity as well as gain weather and longitude diversity, EOS has recently completed construction of a new SSA Observatory on the North West Cape of Western Australia. Construction of the site is a combined project between EOS, Lockheed Martin Australia and the Australian Department of Defence. The Learmonth SSA Observatory is the second station (Site B) in a planned 5-6 station network with Mt Stromlo (Site A) as the prototype. SSA sensors at Mt Stromlo are designated A1 (1.8m Laser tracking system) and A2 (0.7m Deep Space tracking system).

## 2. LEARMONTH SSA OBSERVATORY

The Learmonth SSA Observatory is located on the NW Cape of Western Australia on Australian Department of Defence (ADoD) property at Learmonth. Learmonth is an Airport and RAAF Airbase located some 30 km south of the township of Exmouth, WA and the Harold E. Holt Naval Communications station (HEH). The ADoD, in cooperation with USAF has recently installed a C-band space surveillance radar and are currently constructing a site for the relocated Space Surveillance Telescope near the HEH Station. These three facilities co-located provide a significant concentration of SSA assets. Fig 2 shows the locations of the Learmonth, Exmouth, HEH and SST in the North West Cape of Australia.

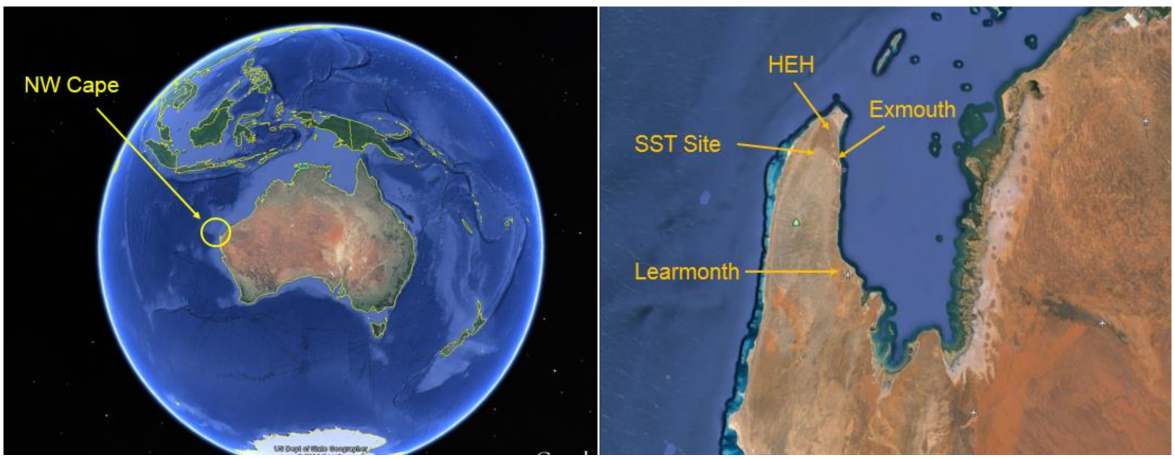


**Fig. 2. Left; NW Cape on the Australian Continent. Right NW Cape showing Learmonth, Exmouth & HEH sites.**

While not a particularly high site for an optical observatory (5-10M AMSL) Learmonth provides a number of attributes that make it an attractive site for the EOS SSA Observatory:

1. Learmonth is some 3.600 km away from EOS's other SSA Observatory at Mt Stromlo. This provides access to completely different weather patterns and it is unusual that both sites would be affected by cloud at the same time.
2. Learmonth is 35 deg away from Mt Stromlo in longitude providing access to a different set of LEO objects.
3. Learmonth is the most westerly location in the region that has good clear weather statistics and provides access to GEO satellites as far west as 50 deg E in longitude.
4. Learmonth is at -22 deg latitude providing better access to the GEO band than Mt Stromlo
5. Learmonth has excellent clear weather (80-85% clear weather stats) and is not significantly affected but monsoonal weather that affects more northerly latitudes.
6. Learmonth has very dark skies being one of the most remote locations on the planet
7. Despite its remoteness Learmonth has fairly good access with two commercial flights per day in and out of the Learmonth (EXM) airport.
8. Learmonth is effectively co-located with the planned SST providing opportunities for backup and follow-up of SST discoveries once that telescope comes into operation.

Construction of the site commenced in late 2015 when EOS entered into a lease with ADoD for the land and a contract for the provision of SSA data services from the site. EOS announced Initial Operating Capability in January 2017. Since then the station has been undergoing tests and trial with a Military Utility Assessment process currently underway but nearing completion.

All facilities construction work was performed by local Exmouth construction companies.

## 3. SITE CONFIGURATION

The initial deployment of sensors to the Learmonth SSA Observatory included 4 optical telescopes plus a control centre, laser facilities and a lab space. An image of the site is shown in Fig 3.

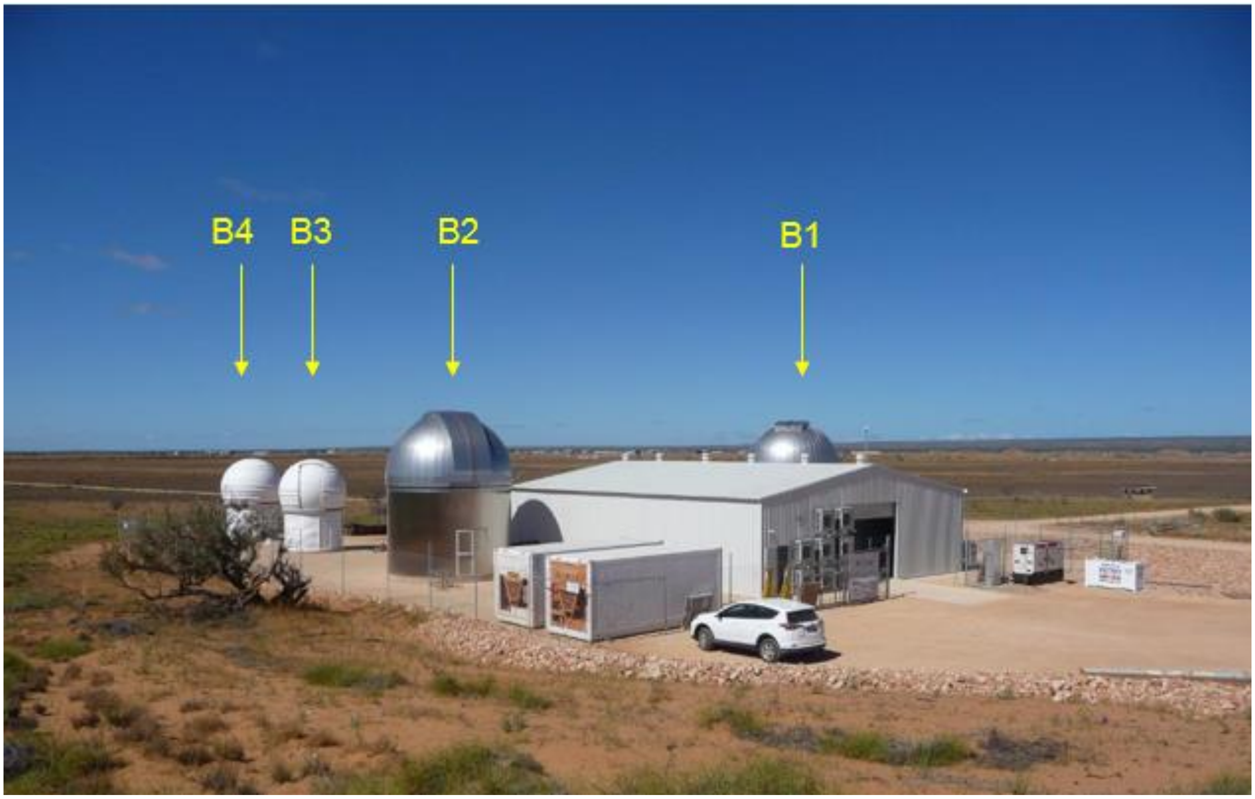


**Fig 3. Learmonth SSA Observatory**

The sensors located at Learmonth include 2 x 1 m sensors (B1 & B2) that are optimized for active laser ranging activities but also perform passive (optical) tracking from LEO to GEO and 2 x 0.7 m sensors (B3 & B4) optimized for wide field deep space tracking. Fig. 4 shows additional site images. Systems optimized for laser tracking have a Coudé path feeding the laser in a Coudé lab. They have relatively small fields of view but provide superb tracking stability (~1 arcsec rms) and absolute pointing accuracy (~2 arcsec rms) even a the closest LEO altitudes where tracking rated exceed 1 deg/s.

**Fig 4. Additional Site Images**

The site also includes a 1 kW, 10ns pulsed laser for laser ranging to uncooperative (no retro-reflectors) targets. This system is able to track virtually any object in the Space Track (TLE) catalogue to ranges from 350 km up to 3,000 km depending on target size. The return signal from laser tracking systems (like radars) is proportional to the range-to-fourth-power. Signals fall below the detection threshold at ranges around 2,000 – 3,000 km. Objects at greater ranges are tracked optically. The optical systems can track objects from ~350 km to deep space (70,000 km). The most distant satellite tracked by these systems was at 70,000 km. We note however, with a cooperative target the laser ranging capability is vastly extended, easily to GEO and EOS has successfully sent optical communications signals to the Hyabusa 2 satellites at over 6.5 million km [1].

The kW laser is a modularized version of the laser found at Mt Stromlo (see Fig 5). The laser uses an Nd:YAG gain medium and has a Master Oscillator Power Amplifier Design (MOPA) [2].Details of the laser tracking parameters can be found in Tab. 1 and an image from the first laser track from the Learmonth facility to an uncooperative object is shown in Fig. 6.

**Fig 5: Left, Modularized laser in Learmonth Clean Room. Right: Laser tracking a MEO Satellite**

**Tab 1: Laser Tracking Parameters**

| **Item** | **Value** | **Unit** |
|---|---|---|
| Type | Solid-state Nd YAG MOPA Design. | |
| Average Power | 1 | kW |
| Repetition Rate | 200 | Hz |
| Pulse Energy | Up to 5 | J |
| Pulse Width | 15 | ns |
| Range Accuracy | ~1.5 | m rms |
| Pointing (angles) accuracy | ~ 2 | arcsec rms |

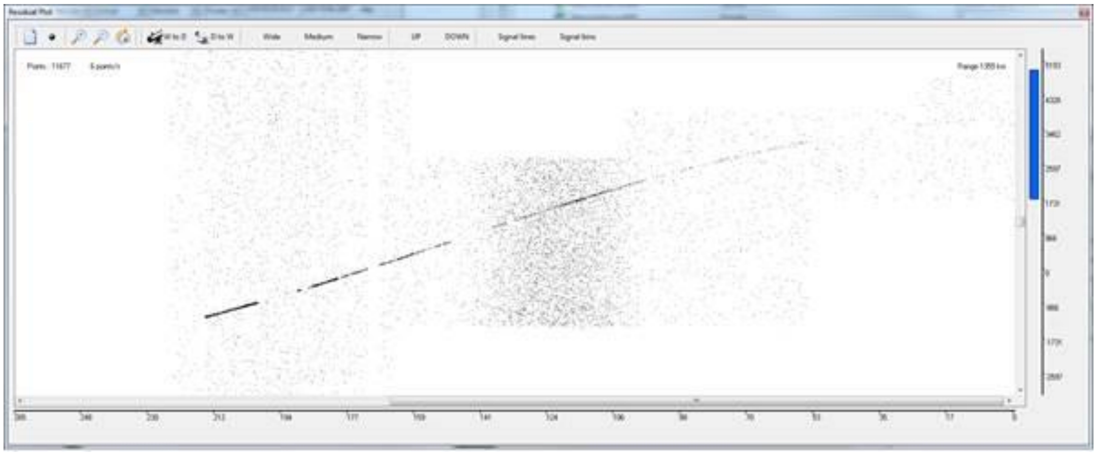

**Fig 6: First laser track for the Learmonth site from an un-cooperative target at 1,600km. (Nov 2016)**

## 4. PASSIVE TRACKING SENSORS

The laser tracking systems provide superb accuracy for tracking LEO satellites but as noted are range limited (like radars) to around 2,000-3,000 km depending on target size and composition. Beyond those ranges we rely largely on passive sensor detecting sun-illuminated objects in the dark sky (terminator conditions). In LEO the terminator lasts just a few hours after sunset and before sunrise. The length of terminator however, is determined by the target altitude and lasts essentially all night in deep space.

EOS scheduling algorithms optimize tracking time by visibility conditions (amongst a number of other factors) so will commence a night focused on LEO objects before shifting to higher and higher altitudes as the night progresses and the shift down again (depending on the priority of tasking) as the morning LEO terminator approaches.

As noted the two laser tracking telescopes (B1 and B2) are optimized for LEO laser tracking but are still quite capable systems for deep space passive tracking. The two 70 cm telescopes are wide field systems optimized for Deep Space and GEO tracking though a also capable of passive tracking even down to LEO altitudes. Astrometric (in-frame) corrections using known star positions allow the wide field systems to provide excellent pointing accuracy (1 – 2 arcsec rns) even without the ruggedized structure and high performance drive systems of the 1 m laser trackers. An example is shown in Fig. 7 of deep space tracking of co-located Optus C1 and D3.

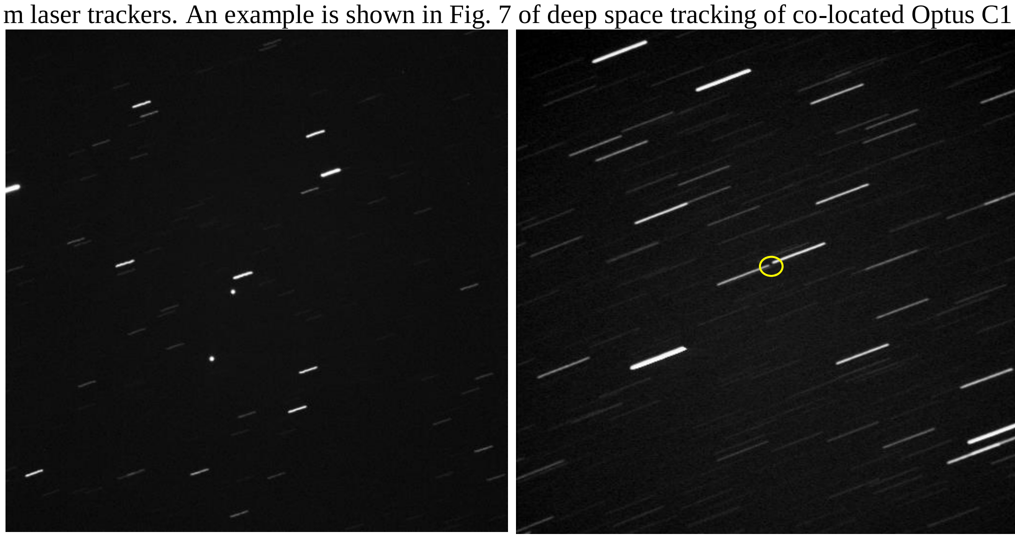

**Fig 7: Left Tracking Optics C1 & D3 in GEO. Right a faint target detected amongst star clutter**

A feature of these systems is the automated target detection capable of detecting multiple targets per frame despite extensive star clutter (fig 8).

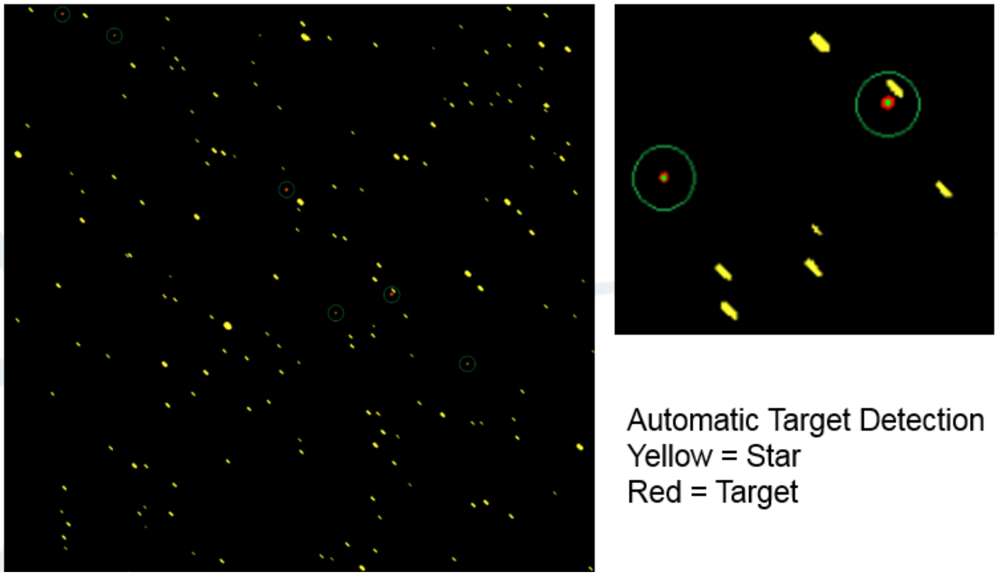


**Fig 8: Automated target detector has found 6 separate targets in the deep space field.**

During system commissioning, tests were conducted to determine the single station capacity by tasking the four telescopes with passive tracking with targets ranging from LEO to MEO, GEO and Deep Space. Results from two weeks of continuous tracking is shown below in Fig. 9, including weather outages. During the two weeks the system averaged 926 tracks per day (from 1,2480 requested tracks) with a 74% success rate. The definition of a track here is 30 s of data after acquisition.  The 2 week test series commenced during a new moon and continued through until full moon. For this particular set of tracks and scheduling there seemed to be little change in tracking success rates between new and full moon, though this is partly explained by the optimization of the scheduling algorithms. Bad weather at the start and end of the test period is clearly evident in the data.

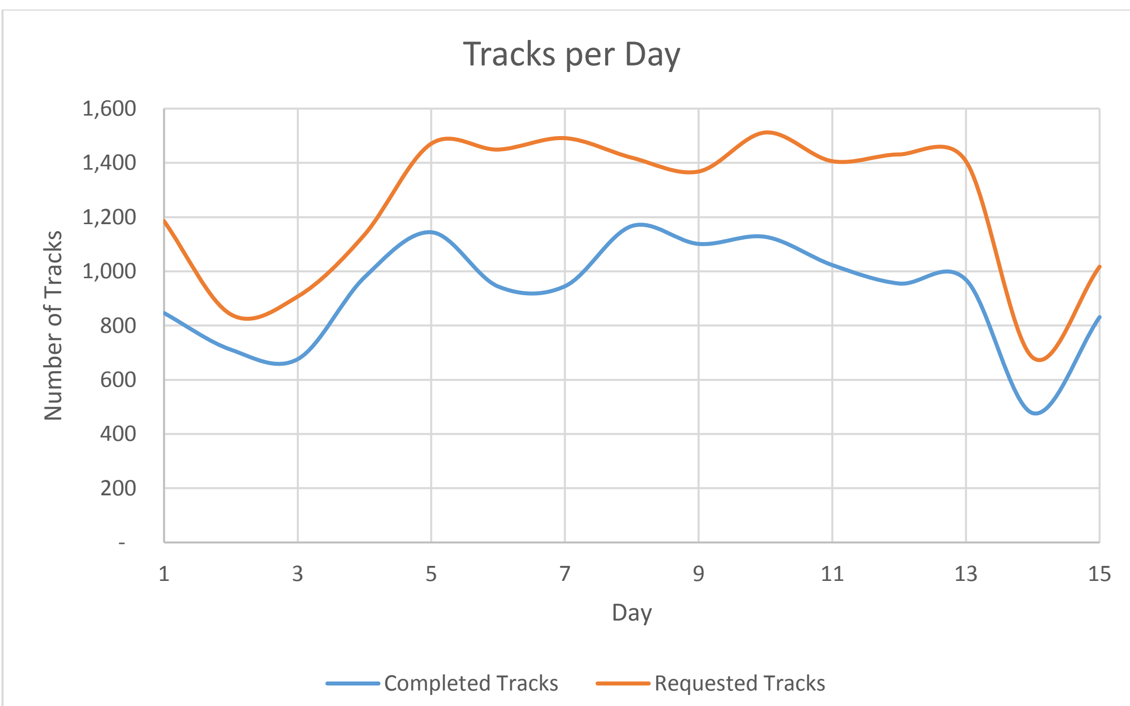


**Fig 9: Learmonth (Site B) daily track count for a 2 week period, including weather outages**

These test provided invaluable data about the capability and limitations of the systems. We are working now in improving the target acquisition and scheduling strategies

## 5. AUTOMATED AND REMOTE OPERATION

### 5.1 Automated Operation

The Learmonth SSA Observatory is designed for remote and autonomous operation. Through the test period described above there was no physical presence at the observatory during the entire period. Remote operation was limited to preparing the task lists and setting off each schedule at the start of an observing period and checking each morning that the station had indeed shut down as expected at the end of the night. All other operations, including data collection and cataloguing were performed autonomously by the Observatory Control System (OCS).

### 5.2 Observatory Control System

The OCS is highly flexible and has allowed EOS and its customers to conduct a large number of activities and experiments. It is truly multi-mission and can support the following activities:

- Astronomical photometric observations;
- Astrometric observations;
- Satellite and space debris tracking and observation with multiple cameras / fields of view;
- Satellite laser ranging (against cooperative targets);
- Debris laser ranging (against uncooperative targets);
- Variety of lasers – 1W class, 100W class, kW class; 100Hz – KHz rates;
- Variety of detectors – single cell, quad cell, 32x32 cell array APD;
- Variety of cameras – Andor, Princeton Instruments, Texas Instruments, Raptor Photonics, SBIG; CCD, EMCCD and thermal;
- Mono-static and bi-static satellite laser ranging;
- Tracking known targets;
- Discovery / acquisition of previously-unknown targets via optical detection and streak analysis;
- Full station automation including: scheduling, optical target search, detection, acquisition, tracking, guiding, ranging, signal detection, post-processing, data distribution;
- Laser ranging safety including thermal aircraft detection camera and aircraft transponder avoidance system.
- Intelligent and autonomous scheduling against multiple sensors.

The overall Observatory automation includes the following features:

- Station open / close in response to scheduled tasks / weather / power failure;
- Station start up / shut down in response to scheduled activity / inactivity;
- Downloading orbital elements;
- Scheduling of target passes;
- Data collection, post-processing, distribution;
- Continuous status monitoring / error recovery;
- Weather monitoring;
- Laser safety including system interlocks, site horizon, thermal detection of aircraft and aircraft transponder avoidance.

## 6. CONCLUSION

The Learmonth SSA Observatory is the second site (after Mt Stromlo near Canberra) in a planned network of SSA sites distributed across the Australian continent. The SSA site provides high accuracy active (laser) and passive optical tracking at ranges from LEO to Deep Space. The sites are capable of providing large numbers of tracks per day and are fully autonomous in operation. The planned capacity of the full network will be on the order of 100,000 tracks per week.

## 7. REFERENCES


1 Noda, H., Kunimori, H., Mizuno, T. et al. Earth Planets Space (2017) 69: 2. https://doi.org/10.1186/s40623-016-0589-8

2 Yue, G., W. Yanjie, C. Amy, D. Murray and G. Ben (2017). "High average power diode pumped solid state laser." Laser Physics Letters **14**(3): 035803