High-Altitude airborne platform characterisation of adaptive optic corrected ground based laser

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ABSTRACT

Adaptive optics can be used for more than astronomical imaging with large telescopes. The Research School of Astronomy and Astrophysics (RSAA) and the Space Environment Management Research Centre (SERC) at the Mount Stromlo Observatory in Canberra, Australia, have been developing adaptive optics (AO) for space environment management.

Turbulence in the atmosphere causes optical signals to become degraded during propagation, which reduces the effective aperture of your transmitting or receiving telescope. An AO system measures and corrects for the turbulence in the atmosphere, allowing for greater resolution of optical signals. AO can be used to correct a laser beam propagating from the ground into space, or high-altitude airborne platform. The AO system performance depends heavily on the chosen site and system design. In order to properly design and implement a cost-effective AO system to propagate a laser into orbit, we propose using high-altitude platforms to measure AO system performance directly as a precursor in-orbit measurements.

SERC plan on demonstrating remote manoeuvre of an orbiting object using photon pressure from an AO corrected high power ground based laser. The manoeuvre target will be a suitable piece of debris, or a dedicated satellite mission which is instrumented and tracked to measure the applied photon pressure and resulting orbit perturbation. High-altitude airborne platforms such as weather balloons or UAVs enable us to efficiently de-risk elements of this program by validating our numerical simulations of AO system performance with actual measurements. We are then able to confidently move towards in-orbit measurement of an AO corrected ground based laser, and remote manoeuvre with photon pressure. We present simulations along with experimental results for the development of array detectors which can be used to directly measure AO system performance.

INTRODUCTION

Adaptive optics (AO) is used in astronomy to correct atmospheric turbulence which distorts the image of a large aperture telescope, restoring the diffraction limit to the telescope regardless of atmospheric conditions. The Research School of Astronomy and Astrophysics (RSAA), Electro Optic Space Systems (EOS), and the Space Environment

Management Research Centre (SERC) at the Mount Stromlo Observatory in Canberra, Australia, have been developing adaptive optics (AO) for space environment management. We apply the same techniques used in astronomy to resolve smaller objects to rightly concentrate a laser beam projected from the ground into space.

Turbulence in the atmosphere causes optical signals to become degraded during propagation due to turbulent flow of layers of the atmosphere. This reduces the effective aperture of a telescope because the received optical wavefront is distorted by the turbulence. An AO system measures and corrects for the distortions caused by the atmosphere, allowing for greater resolution of optical signals by flattening the received optical wavefront. An AO system measures these distortions with a reference light source. In astronomical applications this is a guide star, which is a bright star near your target of interest. A wavefront sensor takes light from this guide star and measures the wavefront distortions at a high rate (typically between 300 and 2000 Hz). A layer of Sodium atoms in the atmosphere at 90 km altitude can be illuminated with a special guide star laser, which creates an artificial Laser Guide Star (LGS). A beacon such as a bright LED can be used as a beacon to create an artificial guide star on an object being tracked.

AO can also be used to correct a laser beam projected from a telescope, without conceptual modification. SERC plan on demonstrating remote manoeuvre of an orbiting object using photon pressure from an AO corrected high power ground based laser. The high power laser will impart momentum on the illuminated object with photon pressure, and the added momentum will perturb the orbit of the target to provide a remote manoeuvre. This demonstration will be on a specifically designed cubesat mission which is instrumented and tracked to measure the applied photon pressure and resulting orbit perturbation. Due to the complexity of such a task and the quantum of current funding SERC have devised a staged approach to efficiently de-risk elements of this program by validating our numerical simulations of AO system performance with actual measurements. We are then able to confidently move towards in-orbit measurement of an AO corrected ground based laser, and remote manoeuvre with photon pressure.

SERC are developing a high-altitude airborne platforms for weather balloons to measure the profile and flux of a laser beam projected from the EOS 1.8 m telescope at Mount Stromlo in Canberra, Australia. The platform will be flown several times to gather data on the platform systems, reliability, and AO system performance. This will then be used to inform the design of a specialised cubesat mission to measure photon flux in orbit in preparation for a remote manoeuvre demonstration.

PHOTON PRESSURE FOR REMOTE MANOEUVRE

Momentum is imparted when photons are absorbed or reflected from a surface proportionally to the incident flux. In order to remotely manoeuvre an object in orbit we must maximise the flux because the nature of achieving an orbit requires us to launch satellites with minimum area (to reduce atmospheric drag and increase lifespan), with a large mass (to maximise capability). Diffraction of light and atmospheric turbulence will spread the beam from even the largest telescope, limiting the flux from even the most powerful lasers in existence today. Off the shelf products can produce up to 100 kW of CW laser energy, but suffer from poor beam quality and large divergence, resulting in diminishing returns for higher laser power. Our approach is to combine lower power lasers (on the order of 10 kW) with higher beam quality, and utilise AO to increase the flux in orbit.

Orbit perturbations can be used to mitigate collisions with uncontrolled objects [1, 2, 3, 4, 5, 6] by using remote manoeuvre provided by photon pressure. With enough laser power, ground stations can potentially provide a significant fuel saving to operational satellites and extend their lifespan. While these remote manoeuvres are yet to be

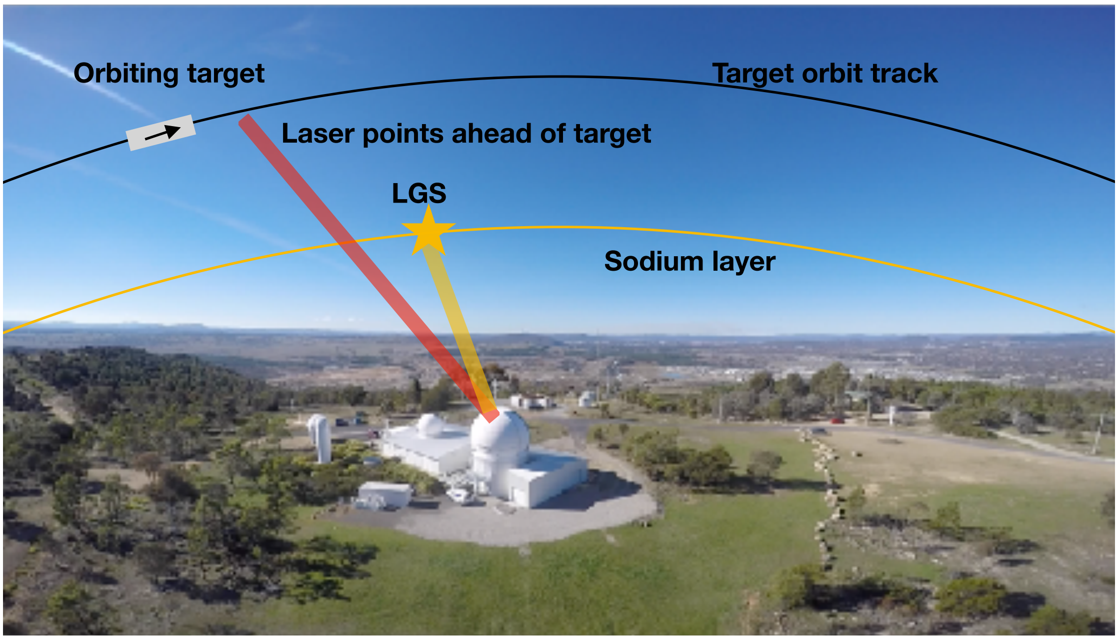

Figure 1: A laser guide star from the Sodium layer is used to measure atmospheric turbulence for the AO system. A laser is propagated ahead of the orbiting target, which is instrumented to measure flux in orbit.

demonstrated, technology is at a point where affordable components to achieve such are system are in existence.

EOS are developing a multi-kW CW laser for the photon pressure experiment, to be launched from their 1.8 m telescope at the Mount Stromlo Observatory in Canberra, Australia. We have developed a high performance AO system [7] to correct the upward propagating laser beam and increase the flux on a target with altitude between 650 and 1000 km. With up to 18 kW of CW laser power, AO, and a specially designed payload, we should be able to perturb a target by a measurable amount under ideal circumstances. The AO system (previously described in [7]) requires a guide star laser and an orbit which passes over the Mount Stromlo Observatory in order to take full advantage of the AO system.

A manoeuvre experiment is conducted by propagating a laser from the ground station to intercept the orbiting target at its altitude (Fig. 1). This requires pointing the laser ahead of the current satellite position to account for laser time of flight. A laser guide star is used to measure atmospheric turbulence for the AO system, and this is also positioned ahead of the laser propagation path, to account for time of flight from the Sodium layer. The AO system uses reflected sunlight from the target to maintain pointing on target. The target in orbit is instrumented to measure flux in orbit, and orbit perturbation is detected through precision laser ranging from the ground.

We plan on using a dedicated satellite mission to demonstrate our technique for remote manoeuvre. Due to the complexity of the mission and systems involved, this is likely to be a short lived or partnered mission payload on which we must achieve a number of goals, such as measuring laser flux in orbit, and photon pressure acceleration.

HIGH-ALTITUDE PLATFORM

In order to achieve this demonstration, we first employ a high-altitude airborne platform to verify our systems and techniques to efficiently utilise future satellite missions. We propose using a Helium filled weather balloon which will float at approximately 35 km altitude over the Mount Stromlo Observatory. This platform will be instrumented to image the beam profile projected by the telescope and AO system, and measure relative flux increase with and without the AO system enabled.

By using a low cost replicable system we are able to run multiple tests to affirm our measurements of system performance, and test key components of the satellite payload, without the expense of going to space. The majority of atmospheric turbulence is close to the ground, and the angular speed of the balloon in the upper atmosphere is expected to be quite close to that of a satellite in low Earth orbit.

The payload and balloon concept design is constrained by Australian regulations, which are less stringent on the 'Light Balloon' category, requiring the total system mass to be less than 4 kg. In order to meet this mass budget we must minimise the power consumption and battery capacity of the payload. Timing systems will be used to turn on large power loads such as radio telemetry and beacon light sources.

The payload is suspended below a Helium filled weather balloon (Fig. 2) with a release point between the balloon and descent parachute. A rigid ABS structure is used to mount and house flight electronics including batteries. This structure is used to connect the payload to the parachute and balloon, as well as secure the imaging screen below the payload. Foam insulation is secured to the ABS structure to keep the electronics within their operational temperature range.

A downward facing camera and short focal length lens are used to capture images from a semi-transparent screen suspended below the payload to capture images of the laser illuminating the screen. This allows direct measurement of the laser full-width at half maximum (FWHM), which can be used to measure AO system performance. A photodiode co-located with a high power beacon LED are located in the centre of the screen. The photodiode measures laser flux at high rate for post processing and correlation with recorded AO system telemetry. The LED beacon is used by the AO system wavefront sensor to measure wavefront distortion caused by atmospheric turbulence, and to precisely track the payload.

OPERATIONAL CONCEPT

The platform will be launched from a site which is predicted to result in a near-overhead flight (Fig. 3) of the payload at the maximum altitude (approximately 35 km). Timers based on the predicted track will be used to turn systems on and off, as well as release the payload for recovery before it is driven into unfavourable terrain or water. The balloon will be tracked with radio telemetry by the launch team until it is trackable from the Mount Stromlo Observatory. A tracking antenna will maintain a communication link with the payload, which includes GPS position information. This information will be used to generate a telescope track and enable optical acquisition by the 1.8 m telescope via the AO system, once the payload beacon is turned on by the timing system.

Once acquired by the AO system, the payload can be tracked and lased with and without the AO system engaged. The laser power required on the order of Watts, rather than the kW needed for remote manoeuvre. On-board processing of imaging and flux data greatly reduces the required downlink data rate, which reduces cost and weight of the system. Image FWHM, and peak intensity measured by the photodiode will be streamed to the ground station, allowing operators to fine-tune the AO system and check its performance in real time. The full data set will be available with recovery of each payload for further processing and analysis.

Termination of the flight will occur after a set time based on track predictions, or via radio command from the ground in case of unforeseen track deviations which may make the payload unrecoverable, or risk descending near a populated area. The payload will be tracked during descent by a recovery team. Data collected from recovered payloads will be analysed in conjunction with data recorded from the AO system during the

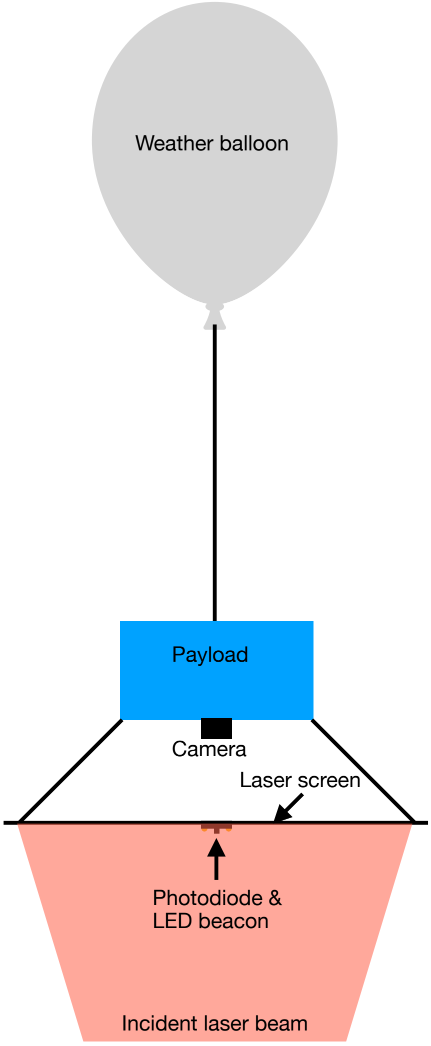

Figure 2: The payload is suspended below a Helium filled weather balloon. A downward facing camera images a laser screen which is illuminated by a laser beam propagated from the ground station. A photodiode positioned on the screen measures flux, and an LED beacon is used by the AO system to track the payload and measure atmospheric turbulence.

experiment.

CONCLUSION

We are developing a high-altitude airborne platform to test our high performance AO system and prototype a space-based sensor to measure laser flux in orbit. The platform is suspended below a Helium filled weather balloon and will be engaged as it over-flys the Mount Stromlo Observatory in Canberra, Australia at an altitude of 35 km. A 1.8 m telescope ground station equipped with AO and a laser will illuminate the payload, which is instrumented to image the incident laser beam as well as measure flux. These measurements will be correlated with telemetry from the AO system to test AO system as well as payload instrument performance. This information will be used to finalise the system design to launch a similar instrument into orbit for illumination from the ground by a high power laser to demonstrate remote manoeuvre with photon pressure.

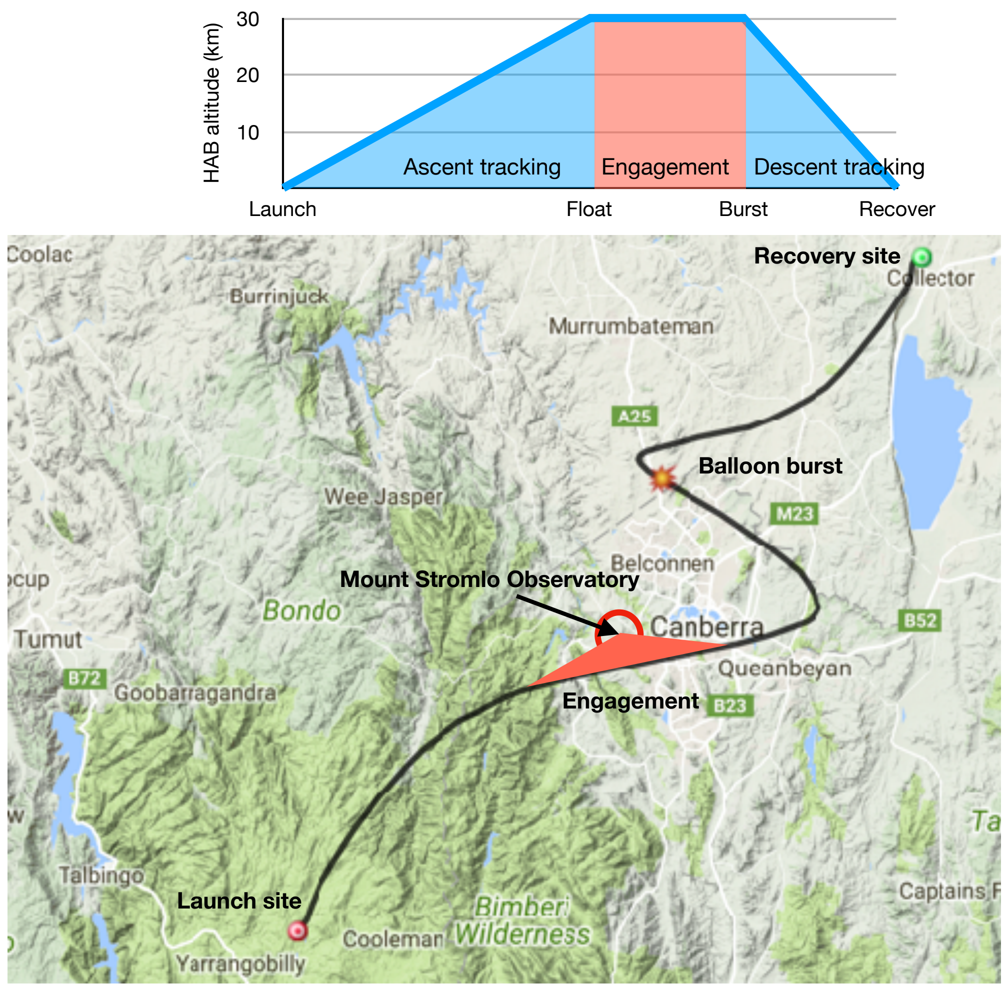

Figure 3: The balloon is launched from a site such that it passes close to the Mount Stromlo Observatory. Once overhead the payload is engaged with the AO corrected laser beam and data collected. The balloon is then burst and the payload recovered.

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References

[1] Y. Gao, C. Smith, and B. Greene, "Laser Tracking of Space Debris," in *European Space Surveillance Conference*, 2011.

[2] J.-C. Liou, "An active debris removal parametric study for LEO environment remediation," *Advances in Space Research* **47**, pp. 1865–1876, June 2011.

[3] J. Mason, J. Stupl, W. Marshall, and C. Levit, "Orbital debrisdebris collision avoidance," *Advances in Space Research* **48**, pp. 1643–1655, nov 2011.

[4] F. Bennet, C. D'Orgeville, Y. Gao, W. Gardhouse, N. Paulin, I. Price, F. Rigaut, I. Ritchie, C. Smith, K. Uhlendorf, and Y. Wang, "Adaptive optics for space debris tracking," in *SPIE 9148, Adaptive Optics Systems IV*, 2014.

[5] C. R. Phipps, K. L. Baker, S. B. Libby, D. a. Liedahl, S. S. Olivier, L. D. Pleasance, A. Rubenchik, J. E. Trebes, E. Victor George, B. Marcovici, J. P. Reilly, and M. T. Valley, “Removing orbital debris with lasers,” *Advances in Space Research* **49**, pp. 1283–1300, May 2012.

[6] B. Greene, C. Smith, and J. Bennett, “Debris Manoeuvre with Ground-Based Laser,” in *18th Annual Advanced Maui Optical and Space Surveillance Technologies (AMOS)*, 2017.

[7] F. Bennet, C. d’Orgeville, I. Price, F. Rigaut, I. Ritchie, and C. Smith, “Adaptive optics for satellite imaging and space debris ranging,” in *16th Annual Advanced Maui Optical and Space Surveillance Technologies (AMOS)*, 2015.