US Air Force Academy Fast-Tracking Telescope

Geoff Andersen, Derek Buzasi, James Dorman, Francis Chun and Brian Bailey
US Air Force Academy

ABSTRACT

The United States Air Force Academy is building a 2m-class ground-based optical telescope for experiments in space situational awareness. The new telescope will be a fast-slewing instrument suitable for both sidereal and low-Earth object tracking down to altitudes of 200km. The telescope will have a 20 arcminute field of view with instruments located at two possible Nasmyth locations. Construction of the new truss, mount and dome is due to begin in early 2008, with first light scheduled at the beginning of 2010.

1. INTRODUCTION

We are currently creating a new observatory at the United States Air Force Academy. The project was originally conceived with the primary mirror retrieved from the Space Based Laser initiative. The mirror is the central segment of the 4m diameter LAMP mirror built under the Zenith Star program. Our original task was to take this mirror and create a ground based facility capable of tracking and imaging low Earth and astronomical objects. In conjunction with the Laser and Optics Research Center at the Academy, we can leverage lasers with an extensive range of wavelengths, powers and temporal profiles. This will make it possible to conduct a wide range of experiments involving optical ranging, communications and characterization of satellites. Plans are also being considered to use the telescope to improve the capabilities of a pre-existing thermometric lidar as well as developing innovative lidars for atmospheric analysis. Future telescope research will also incorporate adaptive optics technologies being developed in the Department of Physics. The telescope will also greatly enhance the astronomical studies of cadets and faculty. Beyond our mission as a teaching facility for future Air Force officers, we also anticipate a flexibility in access of this telescope to other agencies. This includes availability as a test-bed for instruments as well as participation in time-critical projects where last-minute scheduling of other facilities may not be possible. In our presentation we will discuss the opportunities for other organizations to access time on this instrument, as well as suggesting joint projects with similar telescopes around the world.

2. THE TELESCOPE

For the purposes of reducing costs, we are offering two options for the primary mirror.

2.1 The GFE mirror

The mirror cell (government furnished equipment) consists of a glass mirror attached to a graphite composite reaction structure via 66 fine figure actuators and 3 piston phasing actuators. The actuators and graphite structure can be either retained or discarded as necessary to meet the construction requirement. The mirror itself is 17mm thick hexagonal segment of Ultra-Low Expansion (ULE) glass. The segment has a flat-to-flat diameter of 1.6m as shown in Fig. 2 and a mass of 77kg. Since the LAMP telescope was originally designed to function in a Mersenne configuration, the primary figure is parabolic.

As a ground-based telescope the FFAs can provide a minor amount of correction for gross gravitational sag. However, since the glass primary is too thin to provide enough internal stiffness to prevent bending under gravity, some inter-actuator deformation is expected. A finite element analysis of this bending for the mirror indicates that we can expect a root mean squared error of 0.23μm, or 0.3 arcsec seeing. While the ripple will not be a problem initially since site seeing conditions are significantly worse (typically 2-3 arcsec), we hope to remove this error using high-order adaptive optics in the future.

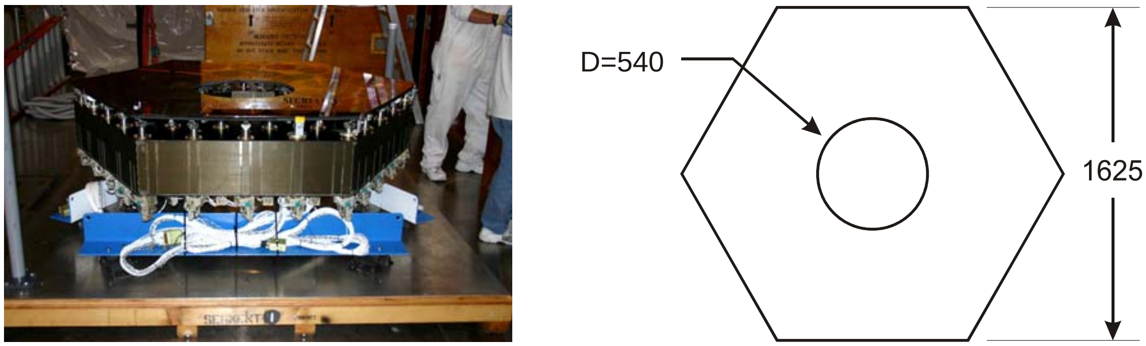

Fig. 2: An image of the government furnished hexagonal primary (left) along with critical dimensions (right).

2.2 Contractor supplied primary

It is understood that incorporating unknown technology and materials into a ground based system entails a great deal of risk for potential contractors. For this reason we have agreed to allow the contractor to supply a mirror separate to the GFE primary. If this option is exercised, then the minimum diameter of the contractor mirror is to be 2m. In this case, the primary optical properties and construction can be determined by the contractor subject to meeting the overall telescope performance specifications.

3. TELESCOPE DESIGN

3.1 Optical design

The telescope will have a convex secondary and have the following overall performance specifications

Minimum field of view	5 arcmin (diffraction limited)
	7 arcmin (0.2” spot size)
	20 arcmin (2” seeing)
Operating wavelengths	0.4-2.0 μm
Minimum plate scale	5 arcsec/mm
Total wavefront error budget	200nm r.m.s.

There is a great deal of freedom in the design and construction of the telescope optics so long as the above specifications are met. This covers many aspects from the thermalizing of telescope optics to the telescope dimensions and mechanical control. For example, the telescope primary can be constructed from a zero expansion glass or borosilicate glass that is actively cooled. The sole requirement is that the wavefront error budget is met and that the telescope focal plane is always fixed under a range of operating temperatures.

3.3 Truss and layout

The telescope will be constructed for instrument operation on one of two Nasmyth platforms. One of the Nasmyth foci will be for lidar and single object imaging, spectroscopy and photometry. Meanwhile the other focus will be derotated for wide-field/multiobject science and future adaptive optics. The platforms will support two 4’×6’ optical benches for mounting instruments, lasers and optics.

3.2 Mounting and tracking

The telescope will be mounted in an alt-az configuration and will be required to track objects in orbits as low as 200km. The mount is currently being designed with the following characteristics:

Azimuth range	±240°
Altitude range	2° below horizon to keyhole edge
Keyhole (zenith blind spot)	10° full cone angle about zenith (fast-track)
	1° full cone angle about zenith (sidereal)
Maximum blind pointing error	5 arcsec (0-70° from zenith)
Minimum slew rate	10 degrees/sec
Open loop fast-tracking rate	5 degrees/sec
Maximum rms error (fast-tracking)	0.3 arcsec
Maximum rms error (sidereal)	0.077 arcsec

Maximum jitter (0.1Hz and 10Hz)	2 arcsec r.m.s.

The requirement of pointing below the horizon is particularly notable. With our unique location we will be able to "see" other secure ground locations such as USSC (Cheyenne Mountain), USSC (Peterson AFB) and Shriever AFB. With this flexibility, we anticipate the possibility of future ground-to-ground experiments involving transmission of laser beams across large (20-30km) columns of highly turbulent air.

3.3 Location and facilities

The telescope will be located on campus at the US Air Force Academy in Colorado Springs, Colorado (39^o00'24" N, 104^o52'30 W) at an altitude of 2175m (7130ft). The Academy already has a small observatory with computer controlled 0.4m and 0.6m telescopes. For this telescope a new dome will be constructed along with extensions to existing observatory facilities. The telescope location was chosen primarily for accessibility to the cadets. On average the site can expect 280 days of cloud-free sky, low humidity and a mean nighttime temperature between -6 and 12°C. The observatory is located only 20km from Colorado Springs itself (population 500,000) and is thus subject to a large amount of light and aerosol pollution. The site is also on the leeward side of the Rocky Mountains which tends to produce moderate to high winds (~5-10 knots average) and poor seeing (2-3 arcsec).

3.4 Current status and schedule

The $5.1million firm fixed price contract for this project has just been released and it is anticipated that the award date will be at the end of 2007. Construction is due to begin by the end of the year with first light planned for the beginning of 2010.

4. RESEARCH

A 2m-class telescope would be an invaluable tool for many cadet and faculty research projects at the Academy as well as supporting other Air Force operations. The facility will be used for a number of projects in Space Situational Awareness (SSA) and basic research. In each of the project areas detailed below, cadet involvement would be highly encouraged and we anticipate outside collaborations and time available for other users.

1. <u>Astronomical observations</u>: The Academy already has a modest astronomical research effort [1-4] which would greatly benefit from a larger telescope. Current research projects include measuring light curves of supernovae, asteroids and stars as well as asteroseismology (high-resolution, time-resolved spectroscopy of bright sources). We are planning to make the telescope available for a larger range of astronomical research topics including planet detection, near Earth asteroid detection and characterization, galactic characterization and surveys. Since the Academy suffers from poor seeing and significant light and aerosol pollution, the telescope is not expected to be used for deep sky astronomy.
2. <u>Lidar</u>: The Academy's Laser and Optics Research Center (LORC) has developed a narrowband holographic spectrophotometer which has been incorporated into a working thermometric Raman/Rayleigh lidar [5]. The 25X increase in collecting area of this telescope will greatly improve resolution performance and provide rapid, absolute temperature profiles from ground to space: data critical for the Air Force in many areas ranging from weather forecasting to turbulence avoidance systems.
3. <u>Tracking/ranging/surveillance</u>: With the fast-tracking mount, a 2m lidar system could be modified for ranging off satellites [6, 7]. Data collected from these experiments would help us understand the complex relationship between solar activity and atmospheric drag on low-Earth satellites which in turn improves the tracking of objects in orbit. As well as ranging, we will conduct experiments in satellite illumination, optical communications, photometry, polarimetry and imagery. The Departments of Aeronautical Engineering and Physics have led a successful joint effort called FalconSat in which the cadets design, construct, launch and operate microsatellites. It is anticipated that future missions will utilize the new telescope for experiments relevant to real world SSA issues.
4. <u>Telescope system test-bed</u>: The LORC is currently developing novel high-power gas lasers [8], ultra-fast wavefront sensors [9] and MEMS-based deformable mirrors [10] which could all be used in next-generation, laser guide star adaptive optics. A telescope of this size is ideally suited for operational testing each of these systems and will ultimately be incorporated into the telescope for superior astronomical imaging and beam projection. The LORC has an exceptional range of high power lasers, both continuous and pulsed, at most wavelengths from near-UV to mid-IR which could be leveraged for any number of such experiments.

5. Holographic correction: The Academy has conducted many experiments [11, 12] involving the holographic correction of aberrated telescopes for various applications. We are currently investigating the possibility of extending our research to a 2m test using the telescope as either the corrected unit or as collimating source for similarly sized membrane mirror.
6. Teaching: As well as the obvious teaching and research opportunities for the cadets, this instrument gives the Academy the capability to leverage our expertise for the instruction of personnel from other organizations in the fields of low-Earth tracking imaging, communications and ranging.

5. CONCLUSION

The Academy is constructing a 2m-class telescope for operation as a Space Situational Awareness research and teaching facility. First light for the fast-tracking, ground-based telescope will be in 2010. With the aid of lasers already used in research at the Academy, many different projects are planned for this instrument.

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