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Review of USAF-Supported Astronomical Research: Letter Report

Committee on Review of USAF-Supported Astronomical Research, National Research Council

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July 6, 2004

Dr. Lyle H. Schwartz
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4015 Wilson Boulevard, Room 713
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Dear Dr. Schwartz:

This letter responds to your request that the National Research Council (NRC) review the results of the astronomy research program that uses the Advanced Electro-Optical System (AEOS) at the Air Force Maui Optical and Supercomputing (AMOS) site. The goal of this study was to review the scientific research currently under way at the USAF 3.67-meter telescope on Haleakala, Maui, and to provide the Air Force Office of Scientific Research (AFOSR) with an independent assessment of the quality and value of these efforts.

The charge specified the following tasks:

1. Evaluate the quality of the scientific research being conducted.

2. Evaluate the scientific productivity relative to the level of funding for this research.

3. Evaluate whether the research being conducted takes advantage of the unique aspects of this observatory, or can be done elsewhere.

The NRC convened the Committee on Review of USAF-Supported Astronomical Research,[1] which met at the Maui High Performance Computing Center on May 28-29, 2004,[2] to conduct the review. The committee received information from the AMOS staff, led by Dr. Paul Kervin, the AFOSR program manager Maj. David Byers, and the National Science Foundation (NSF) program manager Dr. Andrew Clegg. In addition, several of the principal investigators supported by this effort presented summaries of their work, as well as their experiences working with the AMOS facility.

This letter responds to the tasks in the charge and recommends ways in which the AEOS astronomical research program can be improved to better meet its goals. During the meeting, both the AFOSR and AMOS staff encouraged the committee to provide such

[1] A roster of the committee is attached.
[2] An agenda of the committee meeting is attached.

recommendations. It should be noted that this effort was conducted on a short timescale in order to accommodate AFOSR's decision-making process. Had there been more time, a more in-depth analysis (including comparisons with other NSF research programs) could have been conducted. Such a review could still be beneficial in helping make this program more productive.

The AMOS Telescope and AEOS

The Air Force's AMOS telescope is a 3.67-meter optical/near-infrared telescope sited on the 10,023-foot summit of Haleakala, on the island of Maui. The telescope is capable of rapid slewing and tracking, and it has a small number of site instruments built for its Air Force mission, including an optical CCD camera and a long-wavelength infrared camera. The centerpiece of the facility is AEOS, a state-of-the-art 941-actuator adaptive optics (AO) system that minimizes the effects of atmospheric turbulence on data gathered by the telescope.

Light gathered by the telescope is sent (via a series of mirrors) down two stories to a central room housing the AO bench. From this room, the light can be diverted into any one of eight coudé rooms, where instruments can be installed without affecting activities in the rest of the facility. Room Six is set aside for astronomical researchers supported by the joint AFOSR/NSF program. Astronomers can work in Room Six without needing or having access to sensitive or classified information, but foreign nationals must be accompanied at all times when they are in the AMOS facility.

The AEOS AO system can obtain good image correction at visible wavelengths of light, a capability that is not duplicated on any of today's large (>3-m-diameter) astronomical telescopes. Because of the unique capabilities of AEOS for high-resolution astronomical observations using visible wavelengths (in contrast to infrared AO systems available elsewhere), access to the facility is potentially of considerable interest to the astronomy community. In recognition of this potential, the AFOSR and NSF jointly fund a competitive research program aimed at construction of astronomical instrumentation for, and scientific observations with, the AMOS 3.67-meter telescope.

The committee was asked to assess whether the research conducted to date has made optimum use of the unique aspects of the AMOS facility. In the committee's view, the AMOS facility provides a number of unique capabilities, resulting not only from the design of its AO system, but also from the nature of the telescope itself, as well as the layout of the observatory. These include:

1. A high-actuator-count deformable mirror, suitable for visible AO (700-1000 nm),
2. A high-Strehl-ratio[3] near-infrared capability,
3. A rapid slewing mount with no dome interference,
4. Flexible, human scheduling/operation for rapid response to unique events,

[3] Strehl ratio — a measure of image quality. A Strehl ratio of unity describes an image taken with no optical aberrations or atmospheric distortions. For comparison, the Hubble Space Telescope often achieves Strehl ratios above 90 percent because of its position above the atmosphere.

5. Multiple coudé rooms for simultaneous setup of instruments,
6. The ability to change rapidly between instruments during a single observing session, and
7. Long-term stability associated with the AMOS facility's use as an operational Air Force system.

Overview of Astronomical Research Supported to Date Using AEOS

Several programs have concentrated on AO imaging of the atmospheres of planets and large satellites at visible or very-near-infrared wavelengths. Adaptive optics observations of Titan with AEOS have shown the existence of a region of methane "cirrus" clouds, placed limits on the frequency of discrete tropospheric clouds, allowed researchers to follow the changing hemispheric dichotomy in haze distribution, and provided additional information on surface albedo. These observations have given insight into the workings of Titan's atmosphere. A different effort has observed Jupiter's moon Io through the AO system but with specialized hardware that uses the broadband light to select and control shift-and-add processing of high-spectral-resolution measurements, potentially providing information on the potassium and sodium emission near Io. High-angular-resolution studies of the atmospheres of Mars, Jupiter, and Saturn have also been attempted. A stellar occultation by Titan was observed, although this observation proved to be too close to the magnitude limit of the system. In addition to these observationally oriented programs, the AO system was used to test a new class of imaging spectrometer designed to obtain "flash hyperspectral images" of time-varying objects such as asteroids. Two additional efforts have been approved to use the simultaneous infrared/visible capabilities of the telescope to study near-Earth asteroids, but are awaiting improvements to the relevant facility instrument.

More than 100 planets have now been discovered orbiting nearby stars, based on the use of indirect detection methods such as spectroscopy and transits at other facilities. The AFOSR/NSF research program has funded an ambitious instrumentation and observing project that will use the AEOS AO system to provide some of the first direct images of planets, brown dwarfs, and protoplanetary disks in orbit around bright nearby stars. The instrument consists of a new near-infrared camera coupled with a specially optimized coronagraph. The hardware has been completed and installed at the telescope and is in the process of being commissioned. The instrument's first on-sky results are very impressive: these are the highest-fidelity near-infrared images ever made from a large ground-based telescope. Based on measurements to date, planets should be detectable that are almost a million times fainter than their parent stars. Planet-detection observations with this new instrument will start in the summer of 2004.

To date, all searches for extrasolar planets have relied on the detection of their effect on the motion of their parent stars, or on the detection of a periodic diminution of the stellar intensity due to the transit of the planet across the stellar disk. The new AO coronagraphic technique being pursued with the AEOS would offer the possibility of eventually obtaining a spectrum of an extrasolar planet, which would provide invaluable information about its atmosphere, chemical composition, and other characteristics. This approach has not yet been attempted at any other ground-based telescope.

In the area of stellar astronomy, AEOS has been used to search for faint stellar companions near massive early-type stars. In this field the high-order AO system operating in the visible band provides sensitivity over a much larger range in magnitude difference than has been possible with either speckle or interferometric techniques. A large sample of O stars has been surveyed, and a number of new faint companions have been discovered. Many of these may be background field stars, but for those that are real binaries, follow-up observations will constrain the orbits and thus provide valuable constraints on stellar parameters.

The very high Strehl values obtainable in the infrared with the AEOS AO system will also enable searches for faint circumstellar disks around bright nearby stars. The coronagraph developed for extrasolar planet searches will be equipped with a spectropolarimetric capability to enable this work. Departures from spherical symmetry yield net polarization. Measuring polarization as a function of wavelength across a line profile enables moving from a small scattering volume to a high scattering volume. This approach provides a measure of the geometry as a function of radius.

Two studies involve observation of gamma-ray bursts and afterglows using a specially developed wide-field imaging capability for AEOS. The AEOS Burst Camera, a simple camera on one of the trunion ports, has a 6-arcmin field of view. This camera has only a single filter/grism position but has high throughput. The project is designed to rapidly respond to and study the first few hours of any afterglow, and has been used to study one afterglow to date. The other camera is a more extensive system, incorporating a filter wheel that can contain several wideband filters, a grism or two, and three linear polarizers (0, 60, 120 degrees) to provide photometry, spectrophotometry, and polarimetry of both the prompt emission and late-time afterglow of gamma-ray bursts (GRBs). It is currently in one of the coudé rooms but may be moved to a trunion position in the future.

Assessment of the Scientific Productivity of the AEOS Astronomy Research Program

The astronomical research program at the AMOS facility is young (observations began in 2001), and much of the initial investment has been in developing new scientific instruments. This circumstance makes a definitive evaluation of the quality of the research difficult, due to the low number of observations made thus far. The committee believes that many of the projects are promising, but there has not been sufficient time for that promise to be borne out.

The joint AFOSR/NSF program provides an annual pool of roughly $1 million to support research at the telescope.[4] The first grants for projects utilizing AEOS were awarded in

[4] The call for proposals can be found at: http://www.nsf.gov/pubs/2003/nsf03543/nsf03543.htm.

FY 2001. Since that time approximately 17 principal investigators have participated in the program. The committee found that in the case of this facility the limiting factor is not money, but available observing hours.

In the field of astronomy, the main measure of research productivity is the number of publications in peer-reviewed journals. By this measure the publication rate resulting from the AEOS astronomy research program has been disappointing. To date two astronomy papers have been published or submitted for publication in peer-reviewed journals, along with another six papers on instrument design and relevant imaging science. While the committee did not make a detailed assessment of the quality of these papers, it did appear that they addressed important scientific issues in their respective scientific subfields.

This publication rate is much lower than that in other NSF programs and is a cause for concern. In other situations the low rate of publication could be a symptom of poor scientific return on investment. However, in the case of the AEOS astronomy program, there have been several mitigating circumstances. The committee highlights the most important of these below.

Of particular relevance has been the initial underperformance of the AEOS instrumentation. In the first year of the program most of the funded projects emphasized astronomical observations using the AEOS AO system and its existing instruments. At that time the AO system had been in use for only a year or so and was operating at less than its design level. Several of the early investigators have decided that the results they obtained during that period are not of publishable quality, and others are trying to correct the problem by applying extensive image deconvolution methods to their data to reconstruct the point-spread function. In more recent years, the AEOS staff has vigorously addressed these AO performance issues. As of today the AO system is performing quite well: It typically achieves Strehl ratios of about 20 percent in the V band, rising to 55 percent or higher in the K band.[5] The committee is aware (from the presentations of various principal investigators) of several papers in draft form based on data obtained recently when the AO system was performing well, but these have not yet been published.

Limitations of other aspects of the available instruments have also created some problems. For example, the delayed commissioning of the AEOS radiometer system has hampered those efforts requiring simultaneous visible/infrared coverage. The lack of an atmospheric dispersion compensation system and of a field derotator has also restricted some potential investigations. Finally, the AO system initially used all of the available light at wavelengths short of 0.7 microns, prohibiting access to that band by the contributed instruments. This last restriction has now been reduced, however, as a result of modifications requested by the visiting astronomers — an example of the very good cooperation the AEOS staff has provided in trying to accommodate astronomers participating in this program.

[5] Lewis Roberts, The Boeing Company, presentation to the committee on May 28, 2004.

Unfortunately, the unusually bad weather during several of the past years has also been an obstacle to the science return. During the winter of 2001/2002 one synoptic program scheduled for 1 hour of observing on 56 different nights obtained useful data on only 7 nights.

A second potential cause of concern is the relatively low oversubscription rate for the AEOS astronomy research program. A high fraction of the proposals received in response to the solicitation were funded (and awarded telescope time), compared with other NSF astronomical sciences programs with which the committee is familiar. For example, in 2003 only seven proposals were received, and of those five were funded. Thus there has not yet been for AEOS the type of highly competitive selection process typically seen in the most scientifically productive NSF programs.

This lack of oversubscription is undoubtedly due in part to the relatively modest performance of the AO system in its early years. Word spreads rapidly, and PIs are understandably reluctant to propose studies when they are not assured of good instrumentation performance. Now that the AO system is working well, the committee believes that more investigators will be interested in submitting proposals.

The AEOS staff has identified several technical issues that, if addressed as planned, will enhance system performance. These include improving the tip-tilt system, improving telescope alignment, implementing wavefront sensor thresholding, and fixing bad actuators on the deformable mirror (or replacing the current mirror by its spare).

Another factor contributing to the shortage of proposals for AEOS is the fact that the AO system requires a very bright star in the field of view. Many astronomical observing programs of broad interest are not doable on the AEOS AO facility, because the desired fields of view do not contain the requisite bright stars. Thus, although the AEOS facility provides some truly unique capabilities, a large fraction of ground-based astronomical research cannot be conducted at this facility.

The committee believes that a third factor contributing to undersubscription for this program has been the lack of a diverse suite of astronomical instrumentation. This situation is improving, as the new and very capable instruments funded under the joint AFOSR/NSF program are now coming online.

A related issue is that the scientific breadth of the proposals submitted has also been somewhat less than what even the current instrumental capabilities of the system would support. This circumstance may be a result of the way the program has been managed within the Advanced Technology and Instrumentation (ATI) office at NSF, which encourages the development of new special-purpose instrumentation rather than the exploitation of the existing facility for broad-based astronomical research.

Unique Capabilities of the AMOS Facility

Some of the projects that have been funded to date have indeed been well matched to the unique capabilities of the telescope, particularly its visible AO system. Of the 17 funded projects, 14 use the AO system to varying degrees (those that do not are primarily focused on GRB follow-up). As discussed above, the initial results of several of these projects were limited by difficulties with the AO instrumentation during its initial year or two of observation, so those capabilities were not used to their fullest, but that situation should improve. However, because of recent advances in AO systems at other large telescopes, the parameter space in wavelength and Strehl ratio where AEOS does have a unique advantage has shrunk, and some projects initially begun there are now being continued at other facilities. The committee also believes that some of the other funded projects in the AFOSR/NSF program have only marginally taken advantage of the unique capabilities of AEOS and in an oversubscribed environment could have been directed elsewhere.

Potential new uses of AEOS that have not yet been proposed for the astronomy research program but that would further exploit its unique characteristics include:

1. Imaging of nearby bright sources in the vicinity of young stellar objects,
2. Target-of-opportunity observations of transient objects (near-Earth asteroids, novae, supernovae, X-ray transients, and so on),
3. Simultaneous satellite and ground-based observations of time-variable sources,
4. Synoptic observations of variable stars spaced over multiple nights, and
5. Simultaneous multiband observations of variable objects once the AEOS radiometer system becomes operational.

To summarize, while the committee believes that the unique aspects of the AMOS facility have been marginally exploited thus far, it sees promise for valuable research to be conducted in the future — even as the advantages of the AEOS system are reduced with time (e.g., due to the development of other AO systems).

Recommendations

As a result of its deliberations regarding the three questions raised in the charge, the committee arrived at a number of consensus recommendations:

1. Continuation of the AEOS astronomy research program.
As a result of its assessment, the committee regards the AMOS facility and AEOS on Haleakala as a valuable scientific resource for astronomical research, and it applauds the Air Force for making observing time and financial support available to the general astronomical community through the AFOSR/NSF grants program. From the testimony the committee received, the scientific and technical staff at the AMOS site have also provided invaluable assistance to the awardees of these grants in terms of performing the requested observations and facilitating the implementation of the PI-developed instrumentation. *The committee strongly supports the continuation of the AEOS*

astronomy research program over the next several years. However, as described below, there are a number of ways in which modifications to the administration of the program can enhance the scientific return.

2. Increased participation of the astronomical community in strategic planning for and continuing evaluation of the research program.

The committee believes that the scientific optimization of the observing time allocated to astronomical research requires a greater degree of strategic planning and oversight than have occurred to date with AEOS. The NSF-administered peer-review process is well suited to the evaluation of submitted proposals, but it does not naturally provide the forum for long-term planning that a facility of this size and capability requires. One potential course of action could be to form an astronomical science working group (ASWG). An ASWG would stimulate between the agency partners and with the community necessary conversations that have been missing in the first years of the program. An example of these discussions would include work with Air Force personnel to evaluate how various aspects of telescope and instrument operations affect astronomical observations. An ASWG would also provide a natural interface to the astronomical community at large. Finally, it could make recommendations to the NSF on revisions to the call for proposals, and could possibly participate in the proposal review process.

3. Reevaluation of the balance between development of new instrumentation and support for observational programs using existing instrumentation.

Within the NSF, the AEOS astronomy research program has been administered as part of the Advanced Technology and Instrumentation program. As such, the emphasis in recent competitions has been on the development of new instrumentation for implementation on the AEOS telescope, rather than on observational projects using existing instrumentation. This focus has led to the curious situation wherein a given principal investigator is effectively ineligible to compete for observing time to use his or her instrument once he/she has completed construction and commissioning of it. Although support for observing could be obtained from other NSF grants programs, the telescope time itself is awarded exclusively through the AEOS program. The committee believes that this bias toward the development of new instrumentation is not in the interest of maximizing the scientific return from the precious telescope time that has been made available. While the development of special-purpose advanced instrumentation should still be encouraged, purely observational programs should also be accommodated. If the program encouraged purely observational proposals in addition to instrumentation proposals, the problem of undersubscription would likely be eliminated. The ASWG discussed above could be helpful in determining the proper balance between these activities.

4. Provision for the development of facility instrumentation and equipment.

As currently constructed the AFOSR/NSF program primarily supports the development of special-purpose instrumentation for exciting but niche science investigations (such as optical follow-up to GRBs or direct detection of extrasolar planets around bright, nearby stars). While this effort addresses a real need, it is not necessarily the most important potential use of instrumentation development funding. The power of the AEOS facility for astronomical research would be greatly enhanced if several core pieces of facility equipment and instrumentation were developed. Examples include a field derotator for the coudé ports, atmospheric dispersion correction, mitigation of stray light for instruments mounted on the trunion, and so on. The committee believes that the AEOS astronomy program should provide a mechanism for some of the allotted funding to be made available to meet general needs like these—either via proposals from the community to the NSF or via direct funding from AFOSR. Recommendations on the priorities for facility instrument and equipment needs could come from the ASWG.

Summary

The committee considers the 3.67-m Air Force telescope on Haleakala an important resource for astronomical research and believes that the provision of both telescope time and funding to enable visiting astronomers to use this facility is of great benefit to the astronomical community. It applauds the AFOSR for initiating the AEOS astronomy research program and strongly recommends its continuation. In general, the instruments that have been developed thus far are promising. While the scientific return to date has been somewhat less than is typical for other NSF astronomy programs, the committee thinks that this situation can be ascribed largely to transient effects associated with the commissioning of the facility and will improve in the future. However, the AEOS astronomy research program can be made even more scientifically productive and can take better advantage of the unique features of the AMOS facility if some changes are made to the way in which it is administered. Several explicit recommendations in this regard are offered above.

The committee thanks its hosts at AMOS, AFOSR, and NSF for being helpful, open, and interactive during the course of this review. In particular, the committee thanks Dr. Joseph Janni for his invaluable aid in lining up presentations and helping the review run smoothly. The committee will follow the progress of the AFOSR/NSF program with interest as it develops in the future.

Sincerely,

/s/

Dr. Steven M. Kahn, *Chair*
Committee on Review of USAF-Supported Astronomical Research

Attachment 1

Committee on Review of USAF-Supported Astronomical Research

(Term expires August 1, 2004)

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Attachment 2

Committee Meeting Agenda

Maui High Performance Computing Center, Makai Conference Room
Kihei, Maui, Hawaii
May 28-29, 2004

Friday, May 28, 2004

CLOSED SESSION

8:30 am	Opening Thoughts Bias and Conflict of Interest Discussion	

OPEN SESSION

9:15 am	AEOS Research Program Introduction	Maj. David Byers, AFOSR
9:45 am	Proposal Solicitation and Evaluation Process	Dr. Andrew Clegg, NSF
10:15 am	*Break*	
10:30 am	High Definition Imaging of the Exospheres of Io and Europa	Dr. Michael Mendillo, Boston University
11:00 am	AMOS Telescope Mission and Unique Capabilities	Dr. Paul Kervin, MSSS Chief Scientist
11:30 am	Discussion	
12:00 pm	*Lunch*	
1:00 pm	AEOS System Detailed Overview	Dr. Lewis Roberts, Boeing Staff Scientist
1:45 pm	Polarimetric IR Circumstellar Imaging	Dr. Jeff Kuhn, University of Hawaii
2:30 pm	AEOS Observations of Titan, Monitoring Titan's Atmosphere	Dr. Antonin Bouchez, Keck Observatory
3:15 pm	*Break*	
3:30 pm	Computer Tomography Imaging Spectrometer with AO	Dr. Keith Hege, University of Arizona
4:15 pm	Diffraction-limited Coronagraph, AO Survey of Dwarf Stars in Double Star Systems	Dr. James Lloyd, Caltech
5:00 pm	Discussion	
5:30 pm	Adjourn for the Day	

Attachment 2

Saturday, May 29, 2004

CLOSED SESSION

8:30 am	Reconvene Discussion	

OPEN SESSION

9:00 am	Rapid Deep Observation of GRB Optical Counterparts	Dr. Donald Smith, University of Michigan
9:45 am	Faint Companion Search and Multiplicity Survey	Dr. Theo ten Brummelaar, Georgia State University
10:30 am	*Break*	
10:45 am	General Discussion and Responses to Questions	
12:15 pm	*Lunch*	

CLOSED SESSION

1:15 pm	Discussion and Letter Writing	
5:00 pm	Adjourn	