White Paper on Status of GSMT

January, 2009

SUMMARY

The US community needs access to the next generation of extremely large telescopes, a goal that can only be accomplished by structuring public private–partnerships with one or more telescope projects. In order to achieve this, the following actions and responsibilities can be envisioned:

- The community must examine a broad range of science use cases and identify and characterize the transformative science that can be accomplished.
- The community must be assured that it will have access to a "pyramid" or system of supporting facilities at a range of apertures and choice of instruments that can sustain the community and directly support ultimate use of a GSMT. Implementation of the ReSTAR program together with a successful response to the ALTAIR report will provide a valuable increase in access across a range of apertures and instrumentation needed by the community.
- The Decadal Survey should consider the merits of a Federally funded dedicated instrumentation program for GSMT that can support construction related costs and lead to an operations phase funding program.
- The NSF should consider ways to structure a long range budget that can allow the earliest possible commitment in terms of timing and amount of funding. It is recognized that this will entail (1) a sufficient level of confidence in a long range budget for the NSF consistent with the President's request (2) an internal policy on the part of NSF to structure an actual budget based directorate and divisional long range plan similar to that which exists for NASA.
- The full scope of the operations model and operations costs that constitute a viable public access facility should be developed and quantified. In addition, Federal contributions to operations should include programmatic participation by the National Observatory as well as any cash contributions.
- There must be a clear understanding of the readiness of the existing projects to accomplish their stated science objectives and the costs and benefits to the Government for participation in either or both of the construction and operations phases. To this end we believe that an independent non-advocate review should

be held prior to the Decadal Survey. Our present goal is to conduct independent reviews in April and May of 2009.

Top Level Goals

The 2000 Decadal Survey identified the Giant Segmented Mirror Telescope (GSMT) as the highest ground based priority. In order to carry out transformative science and remain competitive internationally, the US community needs access to a GSMT. The Thirty Meter Telescope (TMT) and Giant Magellan Telescope (GMT) constitute potential opportunities to achieve this goal. Sensitivity scales in the following way for the type of observations astronomers require (where D is aperture diameter, S is the Strehl ratio, and η is system throughput efficiency):

$\sim \eta D^2$ for seeing limited sensitivity
$\sim \eta S^2 D^4$ for background limited AO observations
$\sim \eta (S^2/1-S) D^4$ for high contrast, and
$\sim \eta D^6$ for very high contrast.

Thus, larger apertures in combination with adaptive optics (high Strehl ratios) gain an enormous advantage for cutting edge, transformative science.

The NSF has designated AURA/NOAO as the Program Manager for a national GSMT with the following goals:

- Provide access to extremely large telescopes during the JWST era. This access should provide a sufficient amount of observing time to meet community needs.
- Provide direct support for operations that will ensure the efficient and effective use of the observing time that will be available to community observers.
- Ensure that supporting facilities (the ensemble of telescopes comprising the US system) make it possible for investigators at all institutions to plan for, execute, and follow up their programs on extremely large telescopes.

Present Efforts

Within the US there are two predominantly privately funded Giant Segmented Mirror Telescope projects under development: the Thirty Meter Telescope (TMT) with an effective aperture of 30m and the Giant Magellan Telescope (GMT) with a collecting area equivalent to a circular aperture of 22m and an equivalent diffraction limited aperture of 24.5m. Both the TMT and GMT are at present designed as stand-alone, general purpose telescopes. Progress within each project is described in greater detail below.

Both projects at present include international participation at the partnership level. The Association of Canadian Universities for Research in Astronomy

has entered into an agreement to be a member of the TMT Observatory Corporation for the Detailed Design Phase of the TMT project, has contributed 25% of the design funds and plans to maintain that share in the construction and operating phases. Japan has also closely associated itself with TMT. The Australian National University[1] and a consortium called Astronomy Australia Limited (AAL) have joined the GMT project and Korea (KASI) has declared its intention to join and will shortly make a public announcement.

The ESO ELT (E-ELT) has converged on a 42m telescope design. ESO is planning to begin construction in 2010 with first light no later than 2018, in order to overlap JWST. ESO envisions a required European investment ~ 1000 M€ for construction, instrumentation, and initial operations to produce a working observatory before 2020. ESO does not now have the full funding to undertake this project at this stage; however, they are considering a variety of actions that will allow them to do so. A partnership with a non-European entity such as Japan limited to the E-ELT would also allow them to proceed now.

Technical progress for the Projects[2]

Giant Magellan Telescope

The GMT concept calls for a primary mirror made up of 7 circular segments, each of 8.4-meter diameter. The production of the 7 segments is the pacing item for completion of the project and, at an average of 3.5 yrs per mirror, can be accomplished in ten years with parallel processing. Each mirror must be identical to within a high level of tolerance (radius of curvature 1x10-6) If this critical path is maintained, GMT anticipates a construction start in September 2010 and operations to begin in September 2017. Peak construction funding will occur in 2012 at ~$100M.

In March 2008, the GMT Board notified AURA and the NSF in a letter and white paper that a Founders Agreement (an organic agreement formally establishing a Project Office) had been reached among the partners and that the GMT Board desired a public partnership at the 25% level.

Cost

[1] Presently both ANU and AAL are distinct partners, but they have expressed an intention of merging their interests in a single 10% share under AAL leadership at such time as Australian government funding is provided.

[2] Throughout this document, an effort has been made to characterize costs in a manner reflecting the statements of the projects themselves. These costs have not been independently reviewed and standardized on a common basis. Limited insight suggests that costs and assumptions may vary widely. Some differences include: assumptions regarding inflation rates; assumptions about FTE costs in the continental US, Hawaii, and Chile; the inclusion of instrument and AO development; contingency funds, etc. Thus, it is difficult to directly compare stated development of operations costs. Prior to consideration by the Decadal Survey, it may be necessary to carry out such an inter-comparison. This would logically be the responsibility of the NOAO.

Under the schedule described above, with a construction start around 2010, GMT will be completed in 2017 with partial science operations in late 2017 or early 2018. Based on the current level of design work, the total construction cost is estimated at $555 Million in 2004 dollars. Operating costs are anticipated to be $32 M/yr with contingency, consisting of $15 M in recurring costs and $14M in instrumentation and facility upgrades. GMT anticipates an operation staff of 120 FTEs of which about ¾ will be located in Chile. This represents ~6.5% of the capital cost, comparable to what the consortium believes has been achieved on other telescopes such as Magellan.

The GMT consortium is seeking a public role at the level of 25%, or about 80 nights. While not a formal proposal for NSF funding, the GMT Board has clearly signaled the interest of the current GMT partners in having public participation, ideally through a combination of capital contribution, operating cost contribution, and contributions to future instrument development at levels consistent with the nominal 25% public share. This is cited to be a capital contribution of $138M in FY04 dollars or $155M in FY07 dollars, and an annual operations contribution of $7.5M in FY04 dollars or $8.4M in FY07 Dollars.

The GMT Board has stressed that public participation in GMT need not exclude participation in other ELT projects, either as separate partnerships or as part of a coordinated US system of publicly funded ELT access. Finally, the GMT white paper encourages a system view of ELT's in combination with the current suite of observing facilities, especially those in the 6.5-10 meter class, with a view towards greater public participation in the existing private large telescopes.

Thirty Meter Telescope

The TMT concept is modeled on the Keck telescopes. The primary mirror consists of 492 hexagonal-shaped mirror segments with an equivalent filled area of 30 meters in diameter. The TMT project currently has 3 partners: Association of Canadian Universities for Research in Astronomy, Caltech, and the University of California.

Cost

The anticipated construction cost is $760M in 2006 dollars[3]. The operating costs are baselined at $25 M (2006 dollars) and 120 FTE. As is the case with GMT, this operating model represents a minimum science operations model. An additional annual instrumentation development budget of 20 M$ (2006) is desired. Included in that development budget is a small (11 FTE) team of scientists and engineers to oversee external development efforts.

[3] Letter of April, 2008. Full developmental costs cited to be just over $1B in real year dollars for a "technology driven schedule".

The operations costs including instrumentation are roughly 6% of capital investment per annum. TMT estimates that an additional 14 direct FTEs would be needed to support queue observing and an end-to-end data flow system with detailed data quality assurance and data product production. A full-service science archive would add to these costs as well. The total estimated additional cost per year is 3 – 5 M$ (2006) depending on exact service mix.

In an April 2008 letter to AURA and the NSF, the TMT Board suggested that a public partnership of around 30% would be compatible with its business plan. It also suggested that Federal support for two telescopes simultaneously would not be viable. (Other statements suggest that the range of possible public partnership could be at the 25-50% level.)

Activities of the GSMT Science Working Group

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The SWG defined as its current primary task as the compilation of a set of broad 'science use cases' in order to develop an overview of telescope performance, instrumentation, adaptive optics systems, operations modes, and archive and archive access tools that will be needed to fulfill the scientific aspirations of the US community. This will respond to the need to develop a "Design Reference Mission". This would:

- Capture, describe community-based science cases not yet included in GSMT SWG, GMT, or TMT science case documents
- Capture, describe community-based requirements for science operations (and technical capabilities where appropriate)
- Involve community-at-large as stakeholder in GSMT operations and instrumentation specification process
- Engage the community-at-large in envisioning scientific uses of a GSMT.

A workshop held in Chicago June 15-18 was intended to engage the entire community in thinking about how they might use a GSMT. As a result of this meeting, it became clear that there was limited value in attempting to create yet another science case for an extremely large telescope.

However, a better description of the capabilities desired in such a facility (with priorities) is needed. Therefore, NOAO intends to develop documentation:

- Briefly summarizing the science case for such a facility
- Science capabilities requirements on such a facility, primarily first generation (i.e., beyond first light) instrument suite and desired science operation services.

These must of course be matched to similar needs from the other partners in the facility.
- Estimates for the "community" fraction of science time on such a facility or facilities. It is not required that the access be concentrated on a single telescope.
- A description of the desired interface between the facility and the general community, including time allocation modes and user support.

Options for Federal Support

In general, there are three options for Federal Support.

- Construction—it is possible that the federal role can assume some portion of the overall construction costs. It is recognized that the present MREFC process constitutes a formidable barrier to accommodating two telescope projects simultaneously. The most plausible path consistent with the present MREFC process would involve the selection of a single project. However, in advance of the Decadal Survey it is premature to undertake such a down select. It is envisioned that the Decadal Survey will re-establish the relative priority of a GSMT and provide some guidance regarding the need for public access. Following the Decadal Survey, if the MREFC process were to take place at the maximum possible rate, construction funding would not materialize until 2014 or 2015, well after the bulk of the construction the two projects now envision. Thus, MREFC funding through the existing process does not match the timeline or needs of either project.
- Operations—the federal role can also take the form of partial support for operations. Under such a scenario, more than one telescope could conceivably be supported. However, it is not now known what level of support would be needed nor the impact if the support is divided among several telescopes. The form of support should not only consist of a cash contribution to the project (or projects) – there must be a substantive role for the national observatory. In addition, since an operations commitment would be a long term recurring cost, it is particularly important to scrutinize the operations models developed by the projects and to ensure a full understanding of the additional operations elements that might be needed to constitute a robust public observatory interface.
- Instrument support—AURA/NOAO has proposed a major expansion of the present TSIP program to support instrumentation for the two existing projects. This can follow the general policies developed for TSIP but would require funding on the order of $25M/yr to be successful. This program can transition to an operations support funding wedge at an appropriate point.

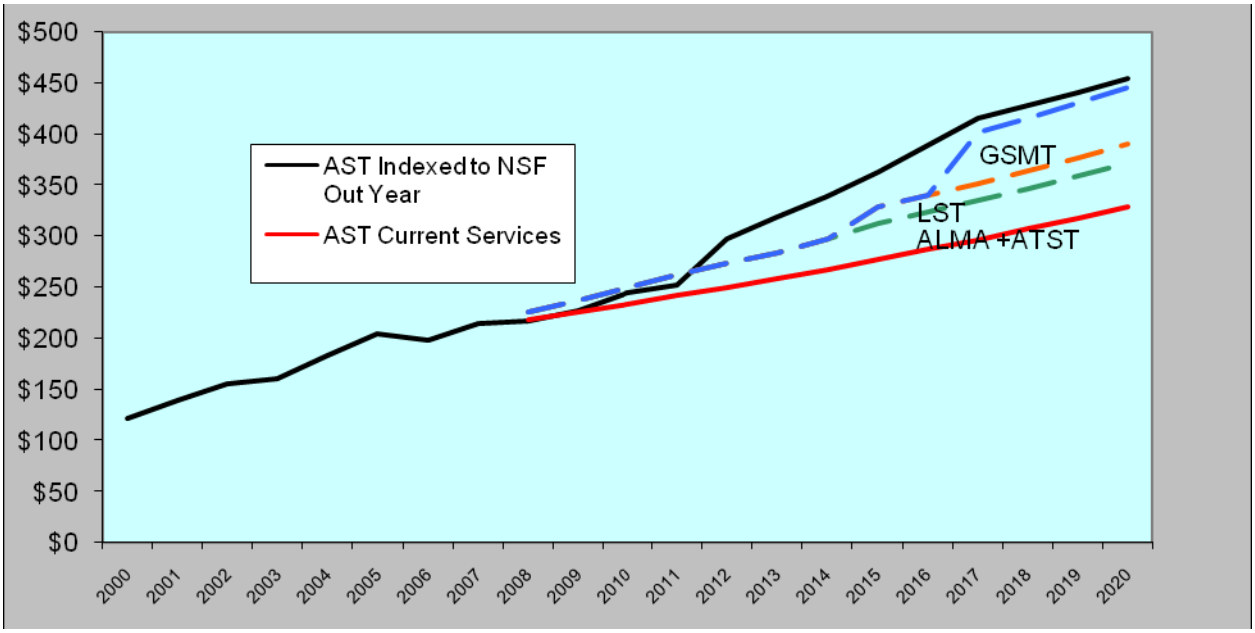
The Decadal Survey will provide an opportunity for broader community discussion of these options. Key to making the decisions will be a transparent and agreed upon scope for operations, and the federal funding needed to accomplish this, the actual viability of the projects themselves in terms of private and international funding, the shares the

projects are willing to offer, and the minimum level of public partnership that will allow them to remain viable.

Budget Outlook for GSMT

Prior progress reports have attempted to forecast the earliest plausible time frame at which a funding wedge could be achieved within the Astronomy Division to support an operations phase for an ELT. This is a central requirement regardless of whether or not construction funding is partially supported by the NSF. These past assessments have been based on the long range budget projected for the NSF under the framework of the American Competitiveness Initiative which would lead to a doubling of the NSF budget.

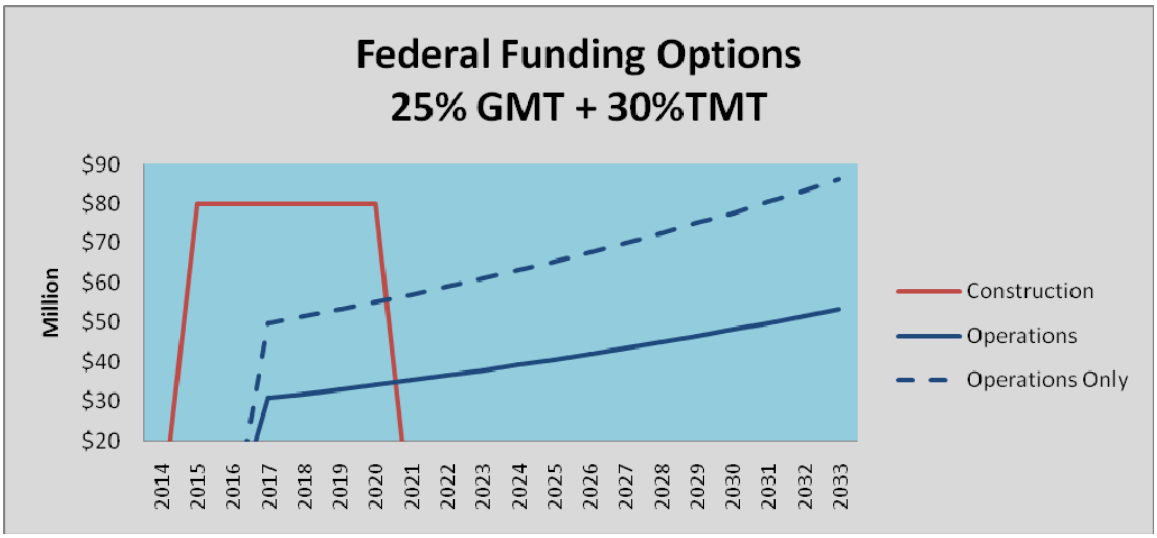
AURA's assessment has been based on an assumption that such a doubling will take place on a time scale matching the President's FY10 budget plan, that the astronomy division will achieve a proportional share of the overall NSF increase, that the base program within the astronomy division will grow but modest savings will be found through future Senior Reviews, and that the operations budgets for ALMA, ATST, and LSST are well characterized. If these assumptions are valid, the funding wedge for a GSMT of about $45-50M per year might be realized as shown in the following figure.



As stated earlier, in 2008 AURA received statements from both projects proposing, respectively, a 25% and 30% share in GMT and TMT. Both projects proposed that the funding associated with this share be some combination of construction and operations.

Using the stated construction and operations costs inflated to the years in which such funding would be required, it is possible to compare the nominal funding scenario with the funding wedge that would be available under the above optimum conditions.

Two cases are possible to characterize. First, that the NSF fund 25% and 30% of both construction projects, followed by a proportional share of both operating budgets. Second, that the Federal shares be achieved only through funding during the operations phase, which would require the NSF to fund 45-50% of these operating budgets. These two cases are shown in the following figure.



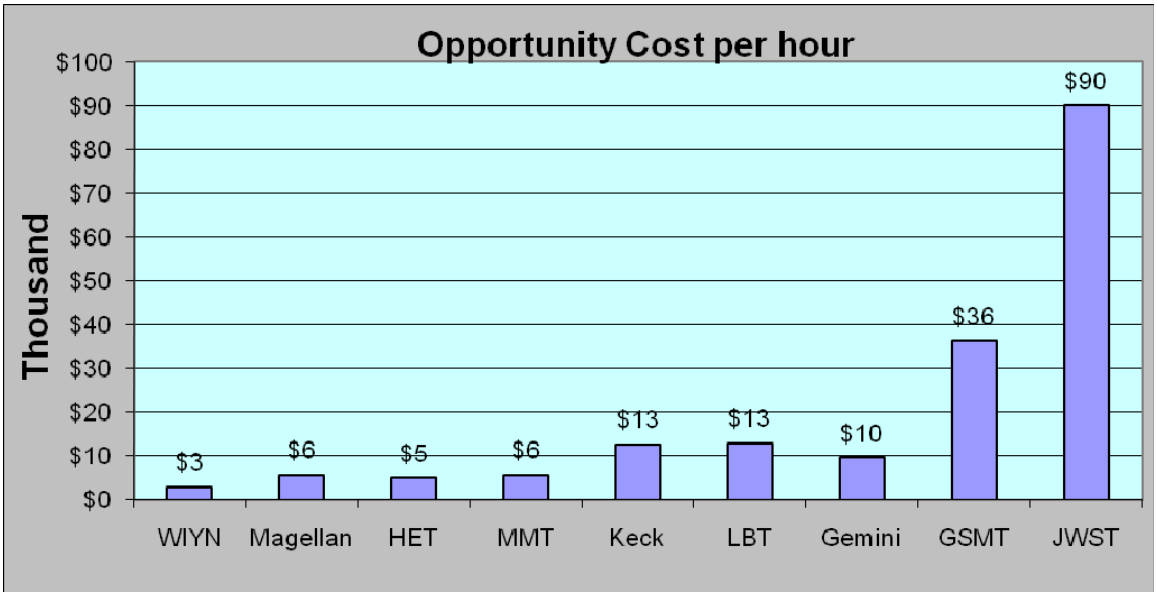
The blue curves represent funding within the astronomy division budget, the red curve represents MREFC funding. The solid set of red and blue curves represent the construction/operations scenario while the dashed line represents the operations only scenario. It is seen that for the construction/operations scenario, the operations funding would fit the optimal AST budget doubling projection. For the operations only scenario, the funding may fit, but it would consume nearly all of the available wedge and would more critically depend on achieving full funding for the astronomy division and a continued savings in the base astronomy program.

A major caveat to this plausibility analysis is that the simultaneous funding of two construction projects would be without precedent in the NSF and there would be a strong argument for some form of down select. However if the NSF role is achieved only through operations funding there is no policy impediment to funding two projects. Indeed access to two different telescopes with differing scientific strenghts would substantially benefit the "system" concept. That said, the practicality of funding the operations of two telescopes may depend on the actual funding determined to be available in the post-2014 time frame.

Comparative Value of an Investment in GSMT

What share of a GSMT might the above optimum case funding achieve, and how does this compare with the share TMT and GMT are willing to relinquish? More importantly what is the value of such a share compared to other existing telescopes.

For the proposed case in which the Federal share of TMT and GMT is, respectively 30% and 25%, and the stated costs for these facilities are taken at nominal value. The value per time unit in 2014 dollars can be compared to other potential access including TSIP telescopes, Gemini, and JWST.



Thus, an affordable investment in GSMT costs about a third JWST and more than three times Gemini. The community and NSF would need to make a judgment as to whether the productivity of such an investment is in proportion to these other benchmarks. Generally telescope productivity follows the trend in hourly costs and, in addition, proponents of the two projects as well as the GSMT SWG have clearly articulated science cases that are comparable to HST and JWST.

Comparing this hypothetical case with the two projects is not straightforward at this stage. It is crucial to understand better the actual operations costs if the public portion were operated in a manner acceptable to the community. That is, the public investment would include some portion of the operations scope stated by the projects themselves but would also include the cost of public queue observing, data archiving, etc. The portion of the operating cost borne by the NSF should not be a cash payment to the project(s) but

should be defined in terms of actual cost of the work carried out by NOAO as an operating partner. A major consequence of this approach is the possibility that NOAO, in providing common services, could examine the possibility of reducing the overall cost of a two telescope operations model by seeking economies of scale. Without a definition of these operations services and a clear knowledge of the operating sites and modes, this cannot be quantified at present.

Building the "Pyramid"

It became clear during the process of the Senior Review that the community would continue to rely on existing telescopes for the foreseeable future—at least the next ten years as an absolute minimum--and that a robust system of telescopes would need to exist in the future to carry out observations that would support use of extremely large telescopes. There are several elements that will form the basis for this "pyramid".
In December 2007, a report by the Committee for Renewing Small Telescopes for Astronomical Research (ReSTAR) identified a range of scientific problems that could be carried out on small and mid-size telescopes and the additional access that would be needed to fully exploit this science.

The report recommends that about twice the existing access would be needed, although the costs and process for achieving this is yet unclear. This will require establishing public access to additional private telescopes within the system, possibly building new telescopes, and developing a generation of high performance instruments for these telescopes. A phase 1 implementation plan proposal has been submitted to NSF by NOAO. The phase 1 proposal comes in at 12M for three years and concentrates on new 4m class spectrographs and system access at Palomar and the Discovery Channel Telescopes. About one half the proposed funding would go directly to non-NOAO partners in this plan.

A parallel community effort called ALTAIR will identify the access needs to 8 m class telescopes. This study intends to more closely tie use of small and mid size telescopes to the scientific use of larger aperture telescopes. Preliminary results suggest a strong need by the community for additional 8 m telescope access. If this is achieved through additional Gemini time, there will surely be a need to align Gemini operating modes and instrumentation more closely with US scientific needs.

Access to independent telescopes would be achieved through an increase in TSIP and a possible re-examination of the conditions under which time can be purchased (as opposed to time acquired through the funding of instrumentation), Approximately $25 M has been spent thus far on TSIP. The additional access to large telescopes gained by the community and scientific benefits have been widely acknowledged.

Beyond TSIP—an Instrumentation Program for GSMT

Building on the success of the TSIP program, AURA/NOAO has proposed the expansion of TSIP to address instrument development for GSMT projects. All present TSIP eligible independent observatories are partners in one of the two projects. Given that the present instrumentation portion of TSIP may be evolving to the saturation point, the time for this phase change may be soon. The expanded program will surely require a level of funding that can match actual instrument needs by the two projects. AURA/NOAO has estimated this to be in the range of $25 M/yr.

Although the process for the expanded program would need to be further developed, it could incorporate the following elements:

- The two projects would submit proposals that would be competitively reviewed. However an overarching need to roughly balance funding would also be considered
- Emphasis would be placed on achieving complementary capabilities rather than funding similar instruments
- Emphasis would be placed on workhorse instruments of optimum value to community participation.
- Recipients of funds could propose to return time to the community on existing telescopes operated by consortia members, or time on TMT and GMT themselves. Ideally a combination of these would be of most value to the community.

This expanded TSIP program would be in place at least through the development of first light instruments for the two projects. Thereafter, depending on an assessment carried out by AURA/NOAO, this funding wedge would be allocated to ongoing operations support.

AURA would examine changes to the payback formula that might better fit this new program. Specifically the 2 to 1 payback for nights to the community that has been in place may need to be reduced to some value less than 2 in order for a more equitable return to the NSF and the community for these larger investments.