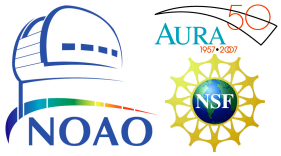


NOAO and the Ground-based O/IR System

A White Paper for the 2010 Decadal Survey
Dr. David Silva, NOAO Director
Dr. Robert Blum, NOAO Deputy Director

Executive Summary

The ground-based optical-infrared (O/IR) System envisioned by 2000 Decadal Survey report exists, is gaining momentum and is attracting Federal resources beyond the National Science Foundation. The NSF-funded Telescope System Instrumentation Program (TSIP) has been a major success, providing funding for new capabilities on existing facilities in return for access for the community-at-large. Other Federal agencies (NASA, DOE, DOD) have also provided funding for new System science capabilities. The National Optical Astronomy Observatory (NOAO)[1] has played a major role in the development of the System including significant technical contributions to the design, development and/or construction of consortia-led facility development projects (WIYN, SOAR, TMT, LSST, DES), administration of the TSIP program, provision of the US community interface to the International Gemini Observatory, and operations of key System capabilities on Kitt Peak in Arizona and Cerro Tololo in Chile. Despite growing international competition, the US can maintain world-class leadership in ground-based O/IR astronomy in the decades ahead through the System but only if sufficient funding is available.

1 Introduction

As envisioned by the 2000 Decadal Survey report, the US O/IR System is an emerging network of public and private ground-based observatories with telescopes in the 2- to 10-m aperture range allied for excellence in scientific research, education and public outreach. This network enables experimentation and exploration throughout the observable Universe. Indeed, the US O/IR System has played the fundamental role in the initial detection and characterization of the most important astrophysical topics of our time: dark matter, dark energy and exosolar planets. Current System science capabilities exploit the entire range of modern astronomical technology from (very) wide-field optical imaging to single (and soon multiple) conjugate laser guide star adaptive optics.

Development of the US O/IR System is on-going and touches on many activities within the purview of current Decadal Survey. These activities range from the modernization of instrumentation on mid-sized telescopes to enabling technology such as laser guide star adaptive optics development programs for present and

[1] NOAO is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation (NSF).

future facilities to the design and development of extremely large (20-m plus) telescopes and extremely large survey projects.

In this white paper for the 2010 Decadal Survey, the origins of the System concept and the current System facilities are briefly described. System development activities, past and present, are then summarized. Budget implications of current System aspirations are presented at the end. The intent of this white paper is to describe the current System without judgment or advocacy for any particular facility or project.

2 System origins

The O/IR System concept emerged from the 2000 Decadal Survey and has gained increased acceptance in the broader community over the five years, driven by the perceived success of the NSF-funded Telescope System Instrumentation Program (TSIP) and closer coordination and engagement between NOAO and a wide range of other US-led observatories. Fundamental to the System concept is the use of Federal money to fund new or improved science capabilities on facilities constructed and/or operated using non-Federal money in return for those facilities providing nights for open community access.

2.1 2000 Decadal Survey

During the 1990s, various calls were made for increased Federal investment in facilities built largely or entirely with non-Federal money. The 1995 McCray report *A Strategy for Ground-Based Optical and Infrared Astronomy* is perhaps the most prominent example. However, the current concept of a network of facilities that draws on Federal and non-Federal funding sources for the benefit of all did not emerge until the 2000 Decadal Survey. To quote from the Executive Summary of the McKee-Taylor report, *Astronomy and Astrophysics for the New Millennium*:

> U.S. ground-based optical and infrared facilities...should...be viewed by the National Science Foundation (NSF) and the astronomical community as a single integrated system drawing on both federal and nonfederal funding sources. Effective national organizations are essential to coordinate, and to ensure the success and efficiency of, these systems. Universities and independent observatories should work with the national organizations to ensure the success of these systems.[2]

The McKee-Taylor report also recommended the creation of a Telescope System Instrumentation Program (TSIP) and advocated that "…in exchange for TSIP funds, private observatories provide an opportunity to the entire astronomy community to apply for telescope observing time whose value (based on amortized investment and operations) would amount to 50 percent of the granted funds."

[2] Goals and objectives for the O/IR System and how the National Observatory fits within that system can be found elsewhere in the McKee-Taylor report and flow originally from the report of the OIR Ground-based Panel.

2.2 2002 TSIP begins

Actual TSIP funding began in 2002 and continues at 3 – 4 M$ per year, somewhat less than the 5 M$ per year advocated by the McKee-Taylor report. On behalf of NSF, NOAO administers TSIP. Since its inception, TSIP that has made 25 M$ in awards in exchange for 350 nights of community access time

Today, TSIP provides single and multi-year funding to develop new instrumentation, upgrade existing instruments, or otherwise enhance the scientific capability of the telescopes operated by the private (non-federally-funded) US observatories. TSIP also provides a "system access" mechanism for direct exchange of telescope time for use by the community in exchange for operations funding. Proposals are solicited annually and are competitively reviewed. The program is open to non-Federally funding observatories and affiliated institutions with telescopes of 3- to 10-m aperture range.

In exchange for TSIP funding, specific allocations of observing time are made available to the public community on the telescopes of funded observatories. The observing time purchased by TSIP on behalf of the community is assigned to proposers via the standard NOAO time allocation process.

Recently, the ALTAIR committee (see below) found that "TSIP is highly valued by the astronomical community, both because it provides open access to observing nights (and the instrumentation available) on non-federal facilities and because it funds instrument development on non-federal facilities. The ability to develop advanced instrumentation is critical for the US to remain at the forefront of astronomical progress" and recommended that "…NSF increase the funding, to $10M per year, for an NOAO-led TSIP or TSIP-like program in order to increase the open access time available on non-federal facilities."

2.3 System roadmap development: 2000 – 2006

NOAO sponsored three System roadmap development workshops between 2000 and 2006: Scottsdale-I (2000), Alexandria (2004), and Scottsdale-II (2006).[3] Each workshop had broad participation from the public and private observatory communities, and worked to connect emerging science problems with desired science capabilities within the System.

2.4 2006 Senior Review

With various motivations in mind, the NSF conducted a Senior Review of their astronomical facilities during 2005 – 2006. In their final report, *From the Ground Up: Balancing the NSF Astronomy Program,* the committee described a NSF Optical-Infrared Base program led by NOAO:

> The [NSF] Optical-Infrared Astronomy Base program should be led by the National Optical Astronomy Observatory. It should deliver community access to an optimized suite of high performance telescopes of all apertures through Gemini time allocation, management of the

[3] System presentations and workshop reports are available at http://www.noao.edu/system/

> Telescope System Instrumentation Program and operation of existing or possibly new telescopes at Cerro Tololo Inter-American Observatory in the south and Kitt Peak National Observatory or elsewhere in the north. The balance of investment within the Base Program should be determined by the comparative quality and promise of the proposed science. In addition, there should be ongoing support of technology development at independent observatories through the Adaptive Optics Development and the Advanced Technologies and Instrumentation Programs.

Since the release of the Senior Review report, NOAO has significantly re-oriented its base program to fulfill these and other high-level recommendations. In particular, at the request of NSF, AURA/NOAO withdrew from the Thirty Meter Telescope project as an official partner to refocus on its core System development mission in the 2- to 10-m range.

2.5 System roadmap development: after the Senior Review

As one response to the Senior Review recommendations and in preparation for the 2010 Decadal Survey, AURA and NOAO convened three community-based committees to survey the existing System and make recommendations for future System development.[4]

The **Renewing Small Telescopes for Astronomical Research (ReSTAR)** committee (chair: C. Pilachowski, Indiana U.) looked at the state of mid-sized facilities (2- to 5-m in aperture). It gave highest priority to ensuring safe, reliable, and efficient operations at existing telescopes, followed by the development of competitive instrumentation and associated data processing software. The committee recommended the incorporation of three or four new, or existing, 2- to 4-m class telescopes into the US O/IR System, and that specialized time domain facilities should also receive priority.[5]

The **Access To Large Telescopes for Astronomical Instruction and Research (ALTAIR**) committee (chair: L. Ramsey, Penn State U.) concluded that the Telescope System Instrumentation Program (TSIP) has been successful and well received by the community, providing powerful new instruments for large telescopes in return for increased access to independent observatories for the broader US community. The ALTAIR committee recommended the annual TSIP budget be increased to 10 M$. The ALTAIR committee also identified an increase in US participation in Gemini as the most straightforward way to increase the number of open-access nights in this aperture range. This recommendation was contingent on a realignment of Gemini instrumentation to better meet US scientific interests, among other concerns.[6]

---

[4] Tables of Content and Executive Summaries from the ReSTAR and ALTAIR reports have been submitted to the Astro2010 State of the Professional Study Groups, as has a white paper from the Future of NOAO committee.

[5] The ReSTAR final report is available on-line from http://www.noao.edu/system/restar.

[6] The ALTAIR final report is available on-line from http://www.noao.edu/system/altair.

The **Future of NOAO** committee (chair: T. Beers, Michigan State U.) reviewed the full scope of roles for NOAO including the elements of system development recommended by the Senior Review and the current interfaces with Gemini as well as potential future interfaces with the Large Synoptic Survey Telescope (LSST) and one or more GSMT facilities.[7]

3 Current System capabilities

3.1 National Optical Astronomy Observatory (NOAO)

NOAO is the US national research & development center for ground-based night time astronomy. The core mission of NOAO is to provide public access to qualified professional researchers via peer review to forefront scientific capabilities on telescopes operated by NOAO as well as other telescopes throughout the O/IR System. Today, these telescopes range in aperture size from 2- to 10-m. Over the next ten years, the O/IR System is expected to expand to encompass the Large Synoptic Survey Telescope (LSST) and one or more Giant Segmented Survey Telescopes (GSMT). In support of this mission, NOAO is engaged in various technology development programs and supports a nationally recognized Education and Public Outreach effort. NOAO is committed to broadening participation in the US science enterprise by inspiring young people to become explorers in science and research-based technology, and to reach out to groups and individuals who have been historically under-represented in physics, astronomy, and associated fields.

As advocated by the NSF Senior Review, NOAO has responsibility for developing and extending that System on behalf of NSF and the open-access community. Within that context, NOAO has several roles. It develops, operates and maintains key System facilities on Kitt Peak in Arizona and Cerro Tololo in Chile as well as facilitating US community access to the Gemini Observatory facilities in Hawaii and Chile. On behalf of NSF, NOAO manages TSIP to provide community access to non-Federally funded observatories in return for NSF investment in the science operations or instrumentation development activities of those facilities. NOAO plays active leadership roles in several consortia-led development projects, such as the Dark Energy Survey (DES) and the Large Synoptic Survey Telescope (LSST) project. Also on behalf of the NSF, NOAO enables various activities related to the design and development of the Giant Magellan Telescope and Thirty Meter Telescope, the US-led GSMT projects.

3.2 System facilities that provide community-access (3- to 10-m)

The table below lists the facilities that currently provide open access to the community-at-large through competitive peer review by the NOAO Time Allocation Committee (TAC). NOAO observing proposals allow users to apply for time at multiple facilities at once, making it easier for users to use a range of capabilities to attack the same scientific problem and easier for the TAC to understand the full

[7] *The Ground-Based O/IR National Observatory: A Roadmap to 2020*, a white paper from the Future of NOAO committee is available on-line from http://www.noao.edu/system/future09.

Facility	Aperture (m)	Open-Access Nights Per Year (2009)	Ratio	Access Funding
W.M. Keck Observatory Keck-I, Keck-II	10	28/730	4%	TSIP
Large Binocular Telescope	2 x 8.4	0[8]	0 (?)	TSIP
International Gemini Observatory Gemini-North, Gemini-South	8.2	200/730	28%	Gemini-base
Magellan Observatory Baade, Clay	6.5	17/730	2%	TSIP
MMT	6.5	29/365	8%	TSIP
Southern Observatory for Astrophysical Research (SOAR)	4.2	95/365	26%	NOAO-base
NOAO Mayall, Blanco	4	575/720	80%	NOAO-base
Wisconsin-Indiana-Yale-NOAO (WIYN) Observatory	3.5	100/365	27%	NOAO-base

Table Notes: open-access nights column shows available open-access nights for science operations in 2009 followed by total possible nights.

science program being proposed. Observing time allocated by NOAO is open to all, regardless of who they are, institutional affiliation, or geographical location. NSF funds these open access nights through three different budget lines: Gemini base, NOAO base, and TSIP.

An additional roughly 100 nights of Keck-I 10-m and Keck-II 10-m are funded by NASA and made available to the community through competitive peer review by the NASA Keck TAC. NASA has recently loosened subject area restrictions on NASA Keck time but still generally encourages that proposals be aligned with NASA space-based science programs.

NASA also funds the 3.0-m Infrared Telescope Facility (IRTF). About 250 nights per year are available through competitive peer review by the IRTF-based TAC. Half of these nights are reserved for solar system studies.

The following facilities with apertures between 3-m and 10-m currently provide no general community access:

Facility	Aperture
Hobby-Eberly Telescope (HET)	9.2-m
Palomar Hale	5-m
Advanced Electo-Optical System (AEOS)	3.7-m
Astrophysics Research Consortium (ARC)	3.5-m

Both HET (via TSIP) and AEOS (through a targeted NSF grant program) have provided open-access time in the past.

[8] TSIP access at LBT is pending completion of critical LBT instrument commissioning activities. When it begins, TSIP access will be 25 nights allocated over approximately three (3) years.

3.3 Limited US access to ESO facilities and Subaru Observatory

Although obviously outside the US O/IR System, access to the ESO Very Large Telescope and NAOJ Subaru Observatory has provided many US scientists with access to 8-m class facilities and helped build productive US-European and US-Japanese scientific collaborations.

Typically, US scientists can gain access to ESO facilities through collaborations with scientists from ESO member states, as summarized in the most recent ESO Call for Proposals[9]:

> (Sec 11.8) A Non-member State Proposal is a proposal where 2/3 or more of the proposers are not affiliated to ESO member state institutes independently of the nationality of the proposers and of the affiliation of the PI.
>
> (Sec 13.1) For non-member state proposals (Sect. 11.8) the following additional criteria will be taken into account: (1) the required telescope/instrumentation is not available at any other observatory accessible to the applicants; and (2) if an ESO member state proposal and a non-member state proposal are rated equally, preference will be given to the ESO member state proposal.

The equivalent Subaru Observatory policy is somewhat less restrictive, as described in the latest Subaru Call for Proposals:[10]

> Although Subaru Telescope is entirely funded by the Japanese government, we also invite proposals from the international community. (International proposals are defined as those submitted by non-Japanese principal investigators (PIs) belonging to non-Japanese institutions.) For the past semesters, about 10-20% of the available nights were allocated to such international proposals. In any case, non-Japanese researchers are encouraged to submit their proposals in collaboration with Japanese researchers.

4 Current System capability development projects

Over the next five (5) years, a significant number of exciting new instrument capabilities will appear on existing System facilities with open-access. The next table is a partial list.

Facility	Capability	Status[11]	Funding	Capability[12]
Keck 10-m	MOSFIRE	Cons	TSIP, private	Cryogenic multi-slit IR spectrometer
Keck 10-m	NGAO	D/D	TSIP, private	Multi-conjugate AO system
Gemini-S 8.2-m	MCAO	Cons	Gemini	Multi-conjugate AO system
Gemini-S 8.2-m	Flamingos2	Cons	Gemini	Cryogenic multi-slit IR spectrometer
Gemini-S 8.2-m	GSAOI	Ready	Gemini	High spatial res imager for MCAO
Gemini-N 8.2-m	GPI	D/D	Gemini	Extreme high-contrast AO imager
LBT 2x8-m	MODS 1,2	Cons	TSIP, OSU	Two optical multi-slit spectrometers
Magellan 6-m	AOM2	Cons	TSIP, Steward	Adaptive Secondary Mirror and optical and mid-IR cameras

[9] http://www.eso.org/sci/observing/proposals/CfP.pdf
[10] http://www.naoj.org/Observing/Proposals/Submit/call.html
[11] Cons=construction, D/D=design and development, Prop = proposed
[12] Res = resolution (either spectral or spatial, depending on context)

Facility	Capability	Status[11]	Funding	Capability[12]
Magellan 6-m	MMIRS	Cons	TSIP, SAO	Cryogenic multi-slit IR spectrometer
Mayall 4-m	OSMOS	Prop	ReSTAR	Med-res multi-mode opt spectrometer
Blanco 4-m	TripleSpec	Prop	ReSTAR	Med-res multi-mode near-IR spectrometer
WIYN 3.5-m	ODI	Cons	TSIP, WIYN	1^0 optical imager
Blanco 4-m	DECam	Cons	DOE, NOAO	2^0 optical imager
SOAR 4.1-m	SAM	Cons	NOAO	Ground layer AO system + imager
SOAR 4.1-m	STELES	D/D	Brazil	Optical echelle spectrometer
SOAR 4.1-m	SIFS	D/D	Brazil	Optical IFU behind GLAO system

The US community can also look forward to a number of new major facilities, as summarized in the next table.

Facility	Status
Las Cumbres Observatory Global Telescope Network (LCOGTN)	Under construction
Magdalena Ridge Observatory Interferometer (MROI)	Under construction
LBT Interferometer (LBTI)	Under construction
Discovery Channel 4.2-m	Under construction
Pan-STARRS	P1 operational
Large Synoptic Survey Telescope	Design/Development
Giant Magellan Telescope 24-m	Design/Development
Thirty Meter Telescope 30-m	Design/Development

5 System aspirations, budget challenges

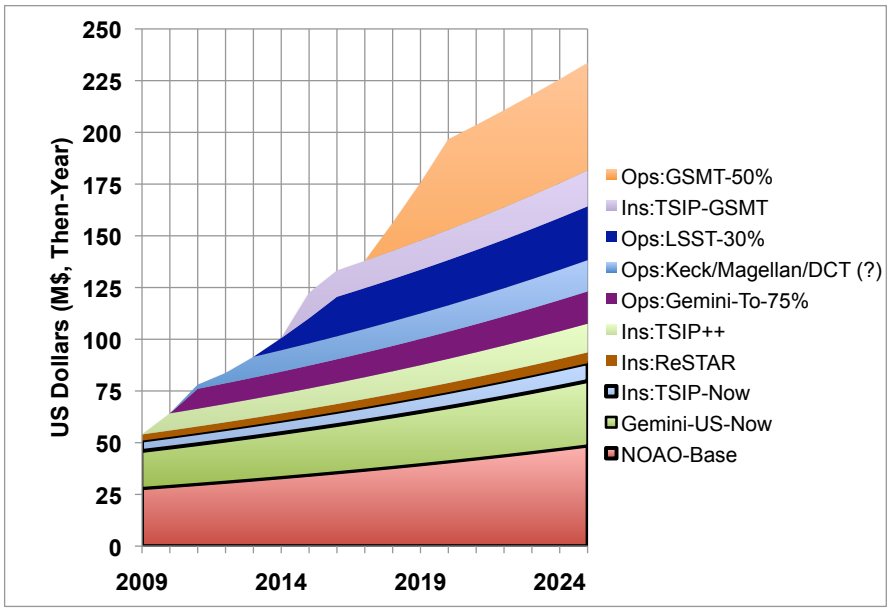
The development of the 6 – 10-m constellation of US-led observatories during the last 20 years was not only a magnificent scientific and technology tour de force, it was an amazing financial feat, drawing support from both public and private sources for construction, operations and post-construction capability development support. Let us assume for a moment that this feat can be repeated for construction funding of all the System development projects mentioned above and ask the question: *what financial commitments will be needed in 2025 to support these facilities?*

The following cartoon model is presented for discussion purposes only. It does not necessarily reflect official planning and/or commitments by NSF, AURA, NOAO or any of the projects/facilities described. *This is an aspiration-driven model, unconstrained by likely fiscal realities.*

The figure below shows a **cartoon model** for NSF-based operations and development support for the US O/IR System from present to 2025.

The following assumptions have been made:

- The NOAO base program continues at 28 M$ (2009) per year, the current US contribution to the Gemini base program continues at 18 M$ (2009) per year, and the current TSIP program continues at 4 M$ (2009) per year. All three programs are inflated by 3.5% per year.



- A program for 4-m class instrumentation, community access, and infrastructure improvement is created in response to ReSTAR recommendation. The program budget is 3 M$ (2009) per year plus inflation.

- Per the recommendation of the ALTAIR committee, TSIP funding is increased by 6 M$ (2009) per year to a total of 10 M$. This expanded TSIP program improves community open-access to 6- – 10-m facilities while making a significant contribution to their instrumentation programs. The additional money is named TSIP++ in the chart.
- The US Gemini share is increased from 50% to 75% in response to the ALTAIR finding that the US community-at-large needs more access to 8-m telescope time to remain scientifically engaged today and to prepare for the extremely large telescopes of tomorrow.
- A funding line of 10 M$ per year is created to allow NSF to acquire increased shares in Keck, Magellan, DCT, etc as opportunities arise. This is another path to increasing the amount of 8 – 10-m time available to the open-access community.
- The NSF funds a 30% share of LSST operations, estimated to cost 15 M$ (2009) but has a higher value in inflated then-year dollars. This contribution is the gateway for the community-at-large to participate in what is likely to be one of the highest-impact science projects of the early 21st century.
- A TSIP-like program is created for GSMT instrumentation development program with a cost of 10 M$ (2009) but has a higher value in inflated then-year dollars. To remain healthy, every facility needs a strong instrumentation program. GSMT will be no exception.

- The NSF chooses to become a 25% partner in both GMT and TMT for an equivalent 50% share of GSMT, the target goal set by the 2000 Decadal Survey. This share is funded over by annual payments over many years. *It is further assumed that the NSF makes no capital contribution to construction, so these annual payments are higher than just 25% of the then-year estimated annual operations costs.* This is in addition to the GSMT-TSIP program above. The operations contribution made here is the gateway for community open-access to GSMT.

There has been much hope that the NSF budget will eventually double in real-terms. Relative to this cartoon model, that means the NOAO+Gemini+TSIP funding increases from 51 M$ to 102 M$ (2009). If that number were inflated at 3.5% for 15 years, the inflated value in 2025 would be 171 M$. In short, merely doubling the NSF budget in real-terms is not enough to meet the estimated cost this aspiration-driven cartoon model.[13]

These are large numbers but must be consider in the international context. With the exception of LSST, Europe is essentially committed to an equivalent or better set of O/IR ground-based capabilities. A direct comparison between European operations and development investment to the combined operations and development investment from Federal, State, and private sources in the United States is not straightforward. But just the investment in the European Southern Observatory (ESO) alone for O/IR facility operations and development is of order 100 M€ per year. Looking beyond Europe, sustained investment from Japan continues as well, albeit at a lower level, and Korea has recently committed 90 M$ (2009) to the Giant Magellan Telescope project. It is also not improbable that over the next 10 years the US will face new scientific leadership challenges and opportunities originating within the BRIC countries (Brazil, Russia, India and China).

6 Final thoughts

US ground-based O/IR astronomy faces a clear and present leadership challenge on the international level. Failure to meet this challenge will result in the US becoming a minority partner in international consortia. The American high energy physics community has suffered a similar debacle. Coordinated and sustained investment in the US O/IR System with a view towards peer review and open-access presents the best path forward for the entire US community, public and private.

[13] As a comparison, consider another US national astronomy observatory with a current set of productive facilities and a major new world-class facility ramping into operations. The NRAO budget is likely to be in the 100 M$ range by 2013. That inflates to about 150 M$ by 2025 at 3.5% per year.