Sustaining Progress Toward The Decadal Survey Science Priorities Over the Next Decade
Submission to the NSF/AST Portfolio Review Committee by the
U.S. Ground-based O/IR System Roadmap Committee,
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Summary

The System Roadmap committee finds that the U.S. ground-based O/IR community is doing world-leading research aligned with the priorities recommended by the Decadal Surveys (NWNH, VVPS) using the existing O/IR system of federal and non-federal observatories and instruments. We urge the Portfolio Review Committee to identify the core capabilities for NSF to support, in whole or in part, to sustain this research effort into the next decade. We find that a vigorous instrumentation program within the ground-based O/IR community is central to sustaining our premier science program. The NSF, through various programs (e.g. MRI, ATI, TSIP, ReSTAR etc.), funding of observatory operations, and support (investigator grants) of researchers using the System, plays a critical role in the O/IR system, while leveraging the complementary contributions of DOE, NASA, SAO, universities, and non-federal research institutions. We recognize the need for NSF/AST to cut its expenditures, but recommend that cuts be made in a manner that maximizes the ability of the ground-based O/IR System, which serves a large fraction of the U.S. community, to continue to provide the core capabilities.

Community Survey

The Ground-based System Roadmap Committee was chartered by the director of NOAO to provide an annual assessment of the O/IR System as follow-on to the ReSTAR and ALTAIR one-time assessments of aspects of the System. We have representation from users of both federally funded and non-federally funded observatories, i.e. users of the entire U.S. System of ground-based O/IR observatories.

In November of 2011 we[1] undertook a survey of the astronomical community to inform our assessment of the current state of ground based O/IR observing capabilities and the community's plans for using existing facilities to pursue the science highlighted by the decadal surveys in their reports, NWNH and VVPS. We understand that the time-scales for realizing the NWNH highest priority new initiatives for ground based O/IR astronomy are 7 to 12 years away.[2] *A consequence of the time such projects require to mature is that the U.S. community must depend on existing facilities in order to make progress on the science opportunities highlighted by NWNH and VVPS, or risk not having a competitive community of researchers available to make use of LSST, GSMT, and other new major facilities once they are realized.* Our community survey expanded our knowledge beyond our own experiences and enables us to draw on the wisdom of the large ground-based O/IR community to inform our assessment of the current state of the U.S. System of Ground-based O/IR observing capabilities.

We received an unprecedented 1178 responses, including 962 from researchers based at U.S. or U.S. sponsored institutions. For comparison, the AAS has 6279 U.S. members (as of 1/30/2012, K. Marvel personal communication). The survey was distributed broadly and we received responses from across the country, type of institution, stage of career, and astronomical sub-discipline. The survey revealed[3] that the ground-based O/IR community is actively engaged in pursuing the science priorities highlighted by the decadal surveys. The top areas for research identified by respondents (who were free to indicate more than one area of interest) included *Time Domain Astronomy (45%), Galaxy and BH Evolution (45%),*

Star Formation and Main Sequence Evolution (31%), and Exoplanet Formation and Properties (23%). To attack the outstanding questions encompassed by these broad themes, and others cited by the decadal survey, the community is making use of the necessarily diverse imaging, spectroscopic, broad spectrum (near-UV through mid-IR) capabilities provided by the existing system of federally (NSF, NASA, DOE, and Smithsonian Institution) and non-federally supported facilities. The vast majority of researchers (more than 80%) heavily use numerous and diverse facilities because no single capability can provide the range of data required. They place a strong emphasis on continuing advancement in instrumentation to extend their research.

Current Ground-based O/IR Capabilities

The need for diverse observing capabilities with ever improving instrumentation does not come as a surprise, as this strong view of the community matches our extensive experience in using O/IR capabilities to pursue our astrophysical research. This view is also consistent with the methods and practices of the research groups producing some of the most recent highlights in our field (the discovery of the accelerating Universe, dark energy, which was recognized with the Nobel Prize for Physics; the study of the massive black hole in the Galactic Center, recognized with the 2012 Crafoord Prize; the discovery and characterization of extrasolar planets), which collectively have used telescopes ranging from 1m to 10m in aperture and techniques including all variants of imaging (wide-field, optical, near-IR, multiple epoch, queue scheduled and target of opportunity, synoptic, AO, and near-IR interferometry) and spectroscopy (optical, near-IR, low and high spectral resolution, multiplexed, IFU, multiple epoch, target of opportunity, synoptic, and AO).

The existing U.S. System of O/IR observing capabilities is in great demand for forefront research, including the Decadal Survey priorities. The System is an extensive federation of federally and non-federally supported facilities that together are providing the diverse set of capabilities and observing time required to undertake modern astrophysical research. As we learned from our survey, the vast majority of researchers use both open access and preferred access (through institutional affiliation) facilities. Most (more than 80%) respondents view both types of facilities as critical to their research. Seventy five percent of our survey respondents report that they will need on-going access (through the next decade at least) to an observing capability currently provided by a small and/or medium size telescope (aperture of less than 6.5m), while depending heavily on access to the largest aperture facilities as well. The growing focus on Time Domain Astronomy will benefit tremendously once LSST is on-line, but the time domain community indicates that enabling more Target-of-Opportunity and monitoring observations on existing facilities is critical to their research (15% and 29% of survey respondents indicated such modes of observing as required or of significant benefit to their research, 45% of the respondents indicated they work on time domain science, so 33 to 66% of the time domain community felt the availability of these observing modes needs to be supported).

Sustaining and Improving the Ground-based O/IR System

The great majority of respondents (73.8%) find the current U.S. ground-based O/IR system will be able to satisfy their pursuit of decadal survey science priorities for at least the next three years. The percentage that anticipates being satisfied for the next five years decreases to 52.8% and to 23.8% percent beyond five years. The most commonly identified need for the System is to improve the instrumentation available to the community. Additional potential improvements cited by respondents in the free response sections of the survey included massively multiplexed spectrographs (e.g. the proposed BigBOSS on the Mayall 4m) and more observing time with high-resolution optical and near-IR spectrographs on large aperture telescopes. When asked to assess the importance of on-going instrument development to the health of the ground-based O/IR System, 74% of respondents deemed such efforts as "critical" and an additional 23% said they were "important". While this might seem obvious, supporting on-going instrumentation development and deployment is a critical need of the U.S.

system that can only be met through collaboration of funding agencies and astronomical institutions, universities, and research labs. Although community input should be influential in the selection of new capabilities, community input should not unduly inhibit innovation or limit the development of state-of-the-art instrumentation.

The O/IR community also expressed particularly strong and growing interest in time domain astronomy (broadly defined as the study of any kind of variable, transient, or moving source), one of the areas of unusual discovery potential highlighted by NWNH. Nearly half of the respondents indicated that they plan to work in this field during the next decade. Exploiting the flood of transients that will be discovered by current and upcoming surveys will require not only a variety of telescope apertures and instruments, but also a mix of different modes of observing: classical, queue, remote, and robotic. While new spectroscopic capabilities, along with the ability to change instruments rapidly during the night, can improve the efficiency of time domain work *transient astronomy is already limited by the number of telescope hours available for follow-up observations*. Existing synoptic surveys (e.g. Pan-STARRS, PTF, and CSS) are already placing increasing demands on the System for their follow-up observations. Any significant reduction in the present size and capabilities of the ground-based O/IR system will only serve to further limit the community's ability to take advantage of the new scientific opportunities presented by the time domain.

NSF's Critical Role in the O/IR System

The NSF plays a critical role in sustaining the vitality of the user community and the quality of the capabilities that the U.S. community uses for their ground-based O/IR research. NSF funds the researchers directly, through the heavily over subscribed individual investigator grants program. NSF provides competitive access for a large community through its support of operations of facilities, through NOAO (including WIYN 3.5m and SOAR 4.2m), Gemini, TSIP (Keck I, Keck II, MMT, Magellan Clay, Magellan Baade), and ReSTAR (Palomar 5m). The most heavily used (and including the most productive; Crabtree 2011) U.S. facilities are those supported in some manner by the NSF that have an element of open or broad access (see Figure 1). The NSF has successfully leveraged a huge commitment of capital and talent in the U.S. ground based O/IR enterprise through a relatively modest annual investment of its own funds. Through its TSIP, MRI, and ATI programs, the NSF has funded (wholly or a major share of) forefront instruments on the premier telescopes of the U.S. system. These are available to all users of these facilities.

The U.S. astronomical community is actively pursuing decadal survey science priorities with existing ground based O/IR capabilities and will do so for the next decade, provided core capabilities remain available and we continue to improve instrumentation and observing modes. Improving instrumentation for existing capable facilities is cost effective when compared to the cost of developing new sites and telescopes to service comparable instrumentation.

Recommendation: Coherently Develop the O/IR System

We recommend that the NSF/AST and the Portfolio Review Committee attempt to optimize the science return from continued investment in ground-based O/IR observing capabilities by retaining the diversity of capabilities of core facilities currently being exploited and strategically improving a subset of the capabilities, likely in partnership with other U.S. government agencies, non-federal domestic partners, and international partners. This should allow some reduction in costs to NSF while minimizing the damage to the U.S. O/IR System.

Continued operation of the most heavily used "core facilities" (in decreasing aperture order, Keck I, Keck II, Gemini N, Gemini S, MMT, Magellan-B, Magellan-C, Mayall 4m, Blanco 4m, and SDSS 2.5m) is essential in order to provide the diverse capabilities required to pursue the decadal survey science priorities. We are not suggesting that NSF should be responsible for solely supporting the operations and ongoing

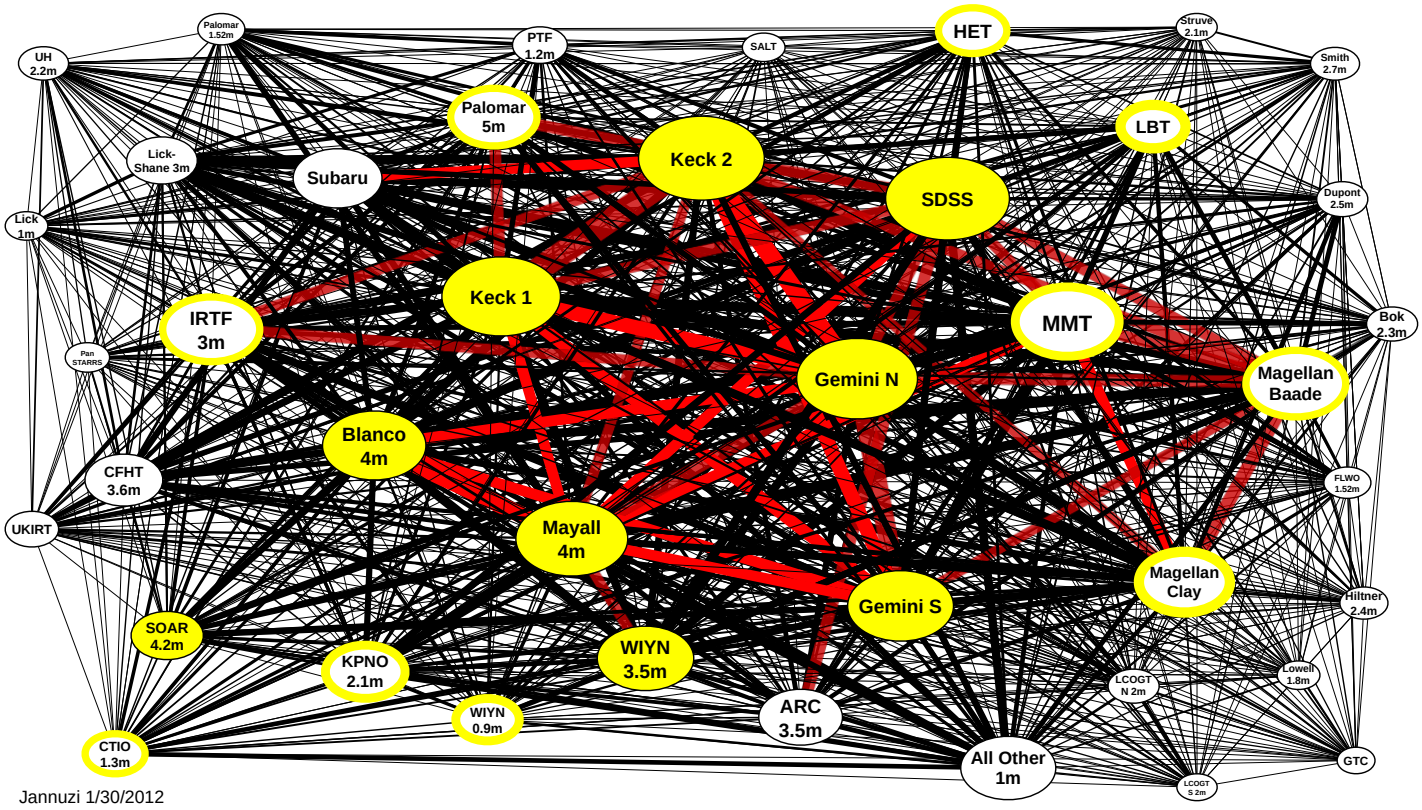

Figure 1: The U.S. has a diverse and capable set of ground based O/IR observing capabilities enabled through the combined efforts of the NSF, DOE, NASA, and non-Federal observatories and institutions. Shown are all the U.S. telescopes (these facilities are run by U.S. institutions, or have a U.S. partner, i.e. some fraction of the observing time for each of these facilities is allocated by a U.S. run institution) used by more than 3% of U.S. based respondents to our November 2011 survey of the astronomical community. This survey received responses from 1,178 individuals, 962 based at U.S. institutions. Shown are results from U.S. based respondents. Each telescope is shown as an ellipse whose area is proportional to the fraction of the respondents that reported using that telescope in the last three years. The thickness of lines between the telescope ellipses is proportional to the number of people that used both of the linked telescopes. The largest lines (representing more than 7% of respondents each) are in red to clearly show the strongest connections. While this manner of displaying the survey responses does not adequately show how many people used multiple telescopes, it does graphically demonstrate that the most frequently used telescopes (largest ellipses) are used by astronomers that are also using multiple other facilities. Those using the less frequently used telescopes are also heavy users of the most used facilities. As other portions of the community survey revealed, this is because a diverse combination of capabilities are required to pursue the Decadal Survey Science Priorities (e.g. programs needing both imaging and spectroscopy to study a large samples of objects). A table showing the data that were used to generate this figure and details regarding the telescopes shown (and those not shown because they were not used by more than 3% of the respondents) can be found at this link (**http://ast.noao.edu/about/committees/system-roadmap**). The most heavily used facilities (used by more than 20% of respondents), were W. M. Keck II 10.m (32.1%), SDSS 2.5m (31.1%), Gemini North 8m (29.6%), W. M. Keck I 10m (28.5%), NOAO/KPNO Mayall 4m (25.4%), Gemini South 8m (22.7%), MMT 6.5m (21.9%), NOAO/CTIO Blanco 4m (21.7%), and Magellan-Baade 6.5m (20.2). These core facilities have all received significant NSF funding (operations funding or funding for instrumentation, through the NSF MRI, ATI, TSIP, PREST, and ReSTAR programs) in the last decade. Past TSIP awards can be found at **http://ast.noao.edu/system/tsip/more-info/funding-summary**. Telescopes that have received, on average, more than $1M per year of support from the NSF for the last 10 years have their ellipses filled in yellow. Facilities that we are aware of having received NSF operations or other support from NSF/AST facilities, TSIP, ATI, MRI, PREST, and ReSTAR at a lower, but still significant, level are shown with a yellow boundary.

improvements of these facilities, but rather that the NSF should continue to partner with NASA, DOE, universities, and other partners to ensure the continued operation of these facilities as part of the U.S. System of ground-based O/IR observing capabilities. Facilities providing both open and preferential access to observing time in the U.S. System increasingly have to sell off time to foreign researchers in order to sustain operations. This situation needs to be addressed, but the selling of time or partnering of time is not intrinsically harmful. What should be maintained is the ability of the U.S. community to bring the full range of required capabilities to bear on the science priorities of the decadal surveys, making progress on these topics while training the generation of researchers that will eventually exploit LSST and GSMT.

Current observing capabilities will only meet the majority of the community's needs for the next 3 to 5 years (based on the responses to our survey[3]). Collectively the community will need to improve the System through the addition of new instrumentation and observing capabilities (e.g. increased ability for time domain follow-up, particularly spectroscopic follow-up with moderate sized apertures). A vigorous instrumentation program that engages the entire research community provides for the training of the next generation of instrumentalists. This is essential to sustaining a vital, world leading O/IR community.

The NSF should develop a strategic plan, with input from the community, on how it may assist in this community wide effort. As NWNH made clear, support is needed for midscale programs for ground-based O/IR astronomy. In spite of the recent decision by the National Science Board to recommend against the creation of a new NSF wide mid-scale initiative, we strongly encourage NSF/AST to continue to find ways, perhaps through partnerships like the NSF/DOE partnership that has enabled the Dark Energy Camera on the Blanco 4m telescope and its associated Dark Energy Survey, to enable such mid-scale, transformative capabilities.

The U.S. Ground-based Optical/near-IR System Roadmap Committee shares the decadal survey committees' excitement for the science opportunities that are available in the coming decade. We also acknowledge the difficult funding situation faced by all institutions, federal and non-federal, supporting astronomical research in our country. We recognize the difficult charge that has been given to the Portfolio Review Committee. We encourage the Portfolio Review Committee and NSF/AST to work with the entire community to develop options for NSF support of ground-based O/IR astronomy to maximize the scientific return from the entire U.S. System of O/IR observing capabilities. Such optimization will enable on-going instrumentation (e.g. through funding of programs like ReSTAR, TSIP, MRI, and eventually mid-scale initiatives) and continued operation of a diverse portfolio of facilities.

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[1] The U.S. Ground-based O/IR System Roadmap Committee is a standing advisory committee charged by NOAO to assess annually the state of the ground-based optical/near-IR system of observing facilities (i.e. all ground-based optical/IR telescopes operated by US institutions, including both federal and non-federal facilities) and to make recommendations regarding which capabilities are needed by the community on near and long term timescales. We are a successor to the past ALTAIR and ReSTAR Committees that performed valuable one-time assessments of the state of the U.S. ground-based system. The System Roadmap Committee has representation from the entire U.S. community that uses the system of ground-based federal and non-federal O/IR facilities. Our objective is to help the community and funding agencies that support us maximize the scientific return of the whole system.

[2] The earliest anticipated first light dates for LSST and either of the GSMT projects with U.S. institutional involvement are in 2018, with science operations beginning in 2020.

[3] A complete summary of the survey responses can be found at http://ast.noao.edu/about/committees/system-roadmap. The survey questions can be viewed at http://www.noao.edu/system-roadmap/communitysurvey/questions.html.