Final Report of the Committee
on
Access to Large Telescopes for Astronomical Instruction and Research (ALTAIR)[1]

Submitted March 9, 2009

Committee Members

Daniel Eisenstein, University of Arizona
Heidi Hammel, Space Science Institute
Lynne Hillenbrand, California Institute of Technology
Christopher Johns-Krull, Rice University
David Koo, University of California at Santa Cruz
Nancy Levenson, University of Kentucky
Tom Matheson, National Optical Astronomy Observatory
Andrew McWilliam, Carnegie Observatories
John Monnier, University of Michigan
Joan Najita, (vice-chair) National Optical Astronomy Observatory
Lisa Prato, Lowell Observatory
Larry Ramsey, (chair) Penn State University
Seth Redfield, University of Texas at Austin, Wesleyan University,
Tom Soifer, Spitzer Science Center

Liaisons and Observers

Tom Barnes, NSF observer
Michael Briley, NSF observer
Eileen Friel, NSF observer
Bob Blum, NOAO observer
Joe Jensen, Gemini liaison
Verne Smith, NOAO Gemini Science Center liaison
Peter Strittmatter, ACCORD liaison

[1]The ALTAIR committee was formed by Todd Boroson, interim director of the National Optical Astronomy Observatory (NOAO) in May 2008 in collaboration with the National Science Foundation. NOAO is operated by the Association of Universities for Research in Astronomy (AURA) under cooperative agreement with the National Science Foundation.

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I. Executive Summary

The ALTAIR committee was convened by NOAO in partial response to the NSF Senior Review, which directed NOAO to ensure that the US community's access to astronomical facilities remains balanced across all apertures. The ALTAIR committee was charged with assessing the current use of facilities in the 6.5- to10-m aperture range, describing the community needs for instrumentation and other capabilities on large telescopes between now and the end of the 2010-2020 decade, and developing guidelines for developing and expanding the US system of large telescopes. The committee gathered input from the community of O/IR telescope users through a survey, personal interactions of committee members with individuals, on-line resources, and opinions and information solicited from the non-federal observatory directors. The committee chose to set aside consideration of LSST, as this would be a future facility with a highly directed operations mode. Here we report our findings and recommendations based on the input we collected and our committee discussions.

1. Findings

Need for Observing Resources

We find that there is a large, engaged community of large telescope users that have been productive using federal and non-federal facilities for a broad range of astrophysical investigations. Demand for observing time on large telescopes currently exceeds the available time by a factor of 3-4 for proposers both with and without institutional access to non-federal facilities. To meet its scientific aspirations, the large telescope community requires access to a broad range of instrumentation that spans a range of wavelengths (optical to mid-infrared), spectral and angular resolutions, fields-of-view, and includes both "workhorse" (e.g., single-object high resolution spectrographs, multi-object spectrographs) and "advanced" (e.g., those that make use of sophisticated AO systems and/or high multiplex factors) instruments (Secs. III-V).

Need for a Large Telescope System

Among this suite of capabilities, there is significant demand for some that are unavailable from the federal facilities (i.e., Gemini) but are available on non-federal facilities. This synergy underscores the need for a system of large telescopes comprised of federal and non-federal facilities. Instruments for large telescopes are costly and only likely to become more so as they increase in capability and complexity. It is therefore impractical, as well as operationally inefficient, for all facilities to provide access to all capabilities. Providing access to a "system" of telescopes, each with their own more restrictive instrument complement, is an attractive way to address this issue (Sec. VI).

Need for Expanded System Access

Given the unmet demand for observing time, we find that there is a need to increase the effective observing time (more total nights and/or more efficient instrumentation) available to the US community on large telescopes. Only a fraction of the demand for "missing" federal capabilities can be met by the current Telescope System Instrumentation Program (TSIP) time that is available on non-federal facilities. 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 (Secs. VI, VIII).

Need for Changes at Gemini

Also critical to the expansion of the large telescope system is the need for greater alignment between the Gemini Observatory and US community needs. As the primary resource available to the large fraction of the US community that does not have institutional access to (the non-federal) large telescopes, the Gemini Observatory is a critical part of the large telescope system. Although Gemini is recognized for its infrared optimization, the access it affords to both hemispheres, as well as for providing some leading capabilities, there is nevertheless broad community dissatisfaction with the current Gemini Observatory. Major concerns are (1) the lack of alignment between the Gemini instrumentation suite and the needs of the US community and (2) the time burden on proposers at all stages of the process to end up with scientifically useful data. These difficulties appear to result from the very limited role that the US community has in setting scientific goals for Gemini (Sec. VII).

2. Recommendations

Based on the above findings, we have the following major recommendations.

Develop the Large Telescope System

We endorse the need for a system of large telescopes comprised of federal and non-federal facilities (Sec. VI). We recommend that NOAO take the lead in working with the US community to establish mechanisms for planning together the development of the entire U.S. system of large telescopes. Fundamental to this recommendation is that NOAO establish and maintain a transparent roadmap for the development of the large telescope system based on regular input from the US community, and that NOAO be an active advocate for the development of the large telescope system, using tools such as TSIP funding, input to the Gemini Board, and other methods (e.g., time purchases and trades) to achieve a balance of open access capabilities that is aligned with the research goals of the US community (Sec. V).

Increase Funding for TSIP

To develop and expand the large telescope system, we recommend 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. (The current TSIP budget is zero and has ranged between approximately $2-4M per year; Sec. VIII)

Increase the Alignment between Gemini and the US Community

We suggest NSF consult with NOAO and the US community to explore changes to (1) the current Gemini governance structure (the role of the Gemini Director, Board, and GSC in setting scientific goals for the Observatory) and (2) the selection process and composition of US representation on the Gemini Board and the GSC, and (3) create pathways by which US community input be provided effectively to the Board in order to achieve closer alignment between Gemini and the needs of the US community as soon as is feasible. The committee believes that changes of this kind will significantly increase the value to the US community from its current $17M/yr investment in Gemini (Sec VII).

Consider a Larger Share in Gemini in the Post 2012 Partnership

The Gemini partnership is being renegotiated, with a new agreement taking effect in 2012. We therefore also recommend that the NSF take advantage of this opportunity to increase US participation in the Gemini Observatory, but *only if* the above recommendation is effectively implemented, i.e., that Gemini becomes more responsive to the US community and evolves to a suite of instrumentation, operations modes, and other services that are well aligned with the needs of the US community (Sec. VII).

II. Defining the US System

The 2000 Astronomy and Astrophysics Survey Committee (McKee & Taylor 2000) argued for a new paradigm for establishing strategic priorities in U.S. ground-based optical/infrared (O/IR) astronomy, one that would take an inclusive perspective, creating a virtual "system" from the combination of public and private telescopes. The ground-based O/IR telescopes operated by private, state and federal agencies, and universities are an integral part of the research undertaken by the US astronomical community and represent the "system" that we are describing.

The system concept was endorsed by the 2006 NSF AST Senior Review, which directed NOAO to deliver community access to an optimized suite of high performance telescopes of all apertures. The NOAO portfolio including the Gemini Observatory, is the "open access component" of the system. (The complementary "institutional access component" is the suite of facilities that astronomers have access to by virtue of their institutional affiliation.) The most significant tool to implement this program is the Telescope System Instrumentation Program (TSIP) which is funded by NSF and administered by NOAO (http://www.noao.edu/system/tsip/).

While the system includes O/IR telescopes of all sizes, for this report we limit our discussion to the largest ground-based telescopes, those with apertures in the 6.5 to 10 m diameter class. Specifically, the system of large ground-based telescopes includes: the two Gemini telescopes (operated by AURA for an international consortium, with 50% share for the US national community), the two Keck Telescopes, the two Magellan telescopes, the Large Binocular Telescope, the MMT, and the Hobby Eberly Telescope. Collectively, these facilities are supported by federal agencies (NSF and NASA), state and private universities, private foundations and private philanthropy. The committee chose to set aside consideration of LSST, as this would be a future facility with a highly directed operations mode. The importance of a system viewpoint in considering the ground-based O/IR capabilities for US astronomy is in the recognition that the cost of modern instrumentation for telescopes of the 6.5-10 m class is typically $10 million or more for state of the art capability. The cost of data reduction software has become substantial, and archival access to ground-based data which can expand its utility well beyond the original purpose is also costly. Some measurement capabilities are general and widely desired, others are of a more specialized nature, and need not be available on all telescopes. It is then appropriate to consider how best to make available the less-than-common capabilities to the broad scientific community.

III. Current Use of 6.5-10 Meter Telescopes

1. Description of the suite of federal and non-federal 6.5- to 10-m telescopes

There are currently 11 telescopes in the 6.5- to 10-m aperture class to which segments of or the entire US astronomical community has access (Table 1). The two Gemini telescopes (the "federal" facilities) are accessible to all astronomers via the NOAO open-access proposal process. The other facilities (the "non-federal" facilities) are accessible to astronomers at partner institutions via their institutional affiliation. Additional nights on some non-federal facilities are accessible to the community through an open proposal process (e.g., NASA time on Keck or NOAO time on TSIP-funded facilities). Although mainly a foreign facility, Subaru is listed in the table as it is accessible to US astronomers (through institutional access or time trades) but generally requires collaborations with foreign scientists. The University of Hawaii has institutional access to the facilities located at its sites.

Table 1: 6.5 -10 meter telescopes to which some US astronomers have institutional access

Facility	Aperture	Hemisphere	Capital and/or Operating Partners
Gemini	8-m x 2	N & S	U.S., International, U. of Hawaii
Keck	10-m x 2	N	U. of California, Caltech, NASA, U. of Hawaii
Magellan	6.5-m x 2	S	Carnegie, U. of Arizona, Harvard, U. of Michigan, MIT
MMT	6.5-m	N	Smithsonian, U. of Arizona
HET	9.2-m	N	U. of Texas, Penn State, Stanford, International
LBT	8.4-m x 2	N	Arizona, Ohio State, Minnesota, Notre Dame, Virginia, International
GTC	10 -m	N	International, U. Florida
SALT	11-m	S	International, AMNH, Dartmouth, Carnegie Mellon, HET consortium, U. of North Carolina, Rutgers, U. Wisconsin
Subaru	8.2-m	N	International, Gemini time trades, U of Hawaii, Princeton

2. Nights Available and Over-subscription

Table 2 illustrates the demand for observing time on federal and non-federal facilities that are available through an open access proposal processes. For the non-NASA time, the number of requested and allocated nights come from NOAO Newsletter summary of requested vs. allocated nights for large telescope proposals during the 2004A to 2008B semesters. The NASA statistics are estimated from information given on the website referenced below.

Table 2: Public access time for the past 5 year observing semesters, 2004A-2008B. Note that Starting 2009 A NASA broadened the criteria for NASA Keck time access and made available 45 nights on 2009A and 35 nights in 2009B. The HET TSIP agreement expired in 2008.

Facility	Nights Requested	Nights Allocated	Average # of Nights/yr	Average over-subscription
Gemini N & S	3268	1015	203	3.2
Keck I & II	530	103	21	5.1
Magellan I & II	173	47	9.4	3.7
MMT	260	108	22	2.4
HET	110	67	13.4	1.6
ALL TSIP	*1073*	*325*	*65*	*3.3*
NASA Keck Access	N/A	336	67	2.5-3.0
Total Open Access		*1676*	*336*	

The table shows that proposers requested 3268 nights on Gemini and 1015 nights were allocated over 5 years, for an average oversubscription rate of 3.2. There are an average of ~200 nights allocated per year on the Gemini telescopes, and an average of ~65 nights allocated per year on the TSIP facilities to the broad U.S. community. Proposal pressure varies among the facilities by a factor of two, with Gemini defining the median level. The table also reports the 90 nights of time on the Keck I and II telescopes that is accessible to the community via an open access proposal process administered by NASA. NASA has recently broadened the proposal criteria to include a wider range of disciplines (http://nexsci.caltech.edu/missions/KeckSolicitation/gen-info.shtml). The committee notes the high value of this NASA administered time and hopes it will continue for the indefinite future. Of the open access time available to the entire US community, Gemini represents ~57%, the NASA Keck time represents ~25%, and NSF TSIP represents ~18%.

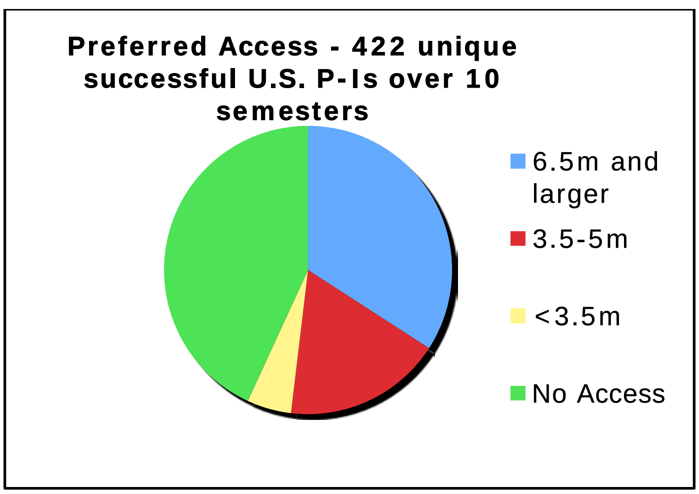


Figure 2: Extent to which PIs of successful NOAO proposals for large telescopes (Gemini and TSIP) have institutional access to telescopes of different apertures.

3. Gemini and TSIP User Communities

As described in Appendix D, the community that has proposed to use large telescopes through the NOAO proposal process (Gemini and TSIP facilities) is diverse, including proposers who are primarily from "large programs" (one of the 34 AURA member universities) as well as proposers from smaller (non-AURA) university programs, colleges, privately-funded research organizations (e.g., Carnegie Observatories), government laboratories (e.g., NOAO, Gemini, STScI), and industry (Figure 1, Appendix D). A large fraction of successful US proposers (~45%) have no institutional access to optical/infrared observing facilities, and approximately two-thirds have no institutional access to large telescopes (Figure 2, Appendix D).

4. Impact of facilities, Instruments, and Modes of Operation

A recent paper by Dennis Crabtree (SPIE, 7016, 40) uses refereed paper and citation counts to show that large telescopes in the U.S. system have a high impact, and that they share roughly the same impact trends with observatory age, plateauing in productivity after 7-8 years of operation. Among the 6.5-10m facilities included in the study (Keck, Magellan, Gemini), the median impact and distribution functions vary within a factor of two (Crabtree, Figures 6 and 7). Notably, the median impact of these facilities is similar within the same ranges to those of international facilities (Subaru, VLT) and of space-borne HST, even though the absolute numbers of papers may differ more significantly. Keck, VLT, and Gemini are noted as having the lowest percentage of low impact papers.

The large aperture telescopes are not equally effective in all areas, however. For example, the VLT and Gemini are effective in TOO (Target of Opportunity) science such as GRB, SN, and other transient objects, primarily through spectroscopic observations. Another example, The VLT is substantially ahead of Gemini due both to an earlier start and also to the larger number of foci, enabling data for almost any TOO request on any given night. Instrumentation advances such as iodine cells and laser guide star adaptive optics technology have given Keck the lead in other science areas such as planet and brown dwarf searches.

IV. Capability within the US System

1. Federal Facilities: Gemini Observatory

Among the large telescopes in the US, Gemini offers some relatively unique capabilities. The telescope is infrared optimized, providing a sensitivity advantage in the near- and mid-infrared. Gemini also operates primarily in queue observing mode. This allows rapid access to targets of opportunity, as well as the potential for more efficient use of telescope time as observing programs can be matched to the observing conditions at a given time (i.e., cloud cover, seeing, or water vapor). The twin telescopes provide access to both hemispheres, and multiple instruments are offered at each site. Some instruments offer unique capabilities, while others are less competitive than instruments at other facilities.

Gemini North

- GMOS-N: optical (400-1000nm) imaging, long-slit (R~400-4000) spectroscopy, multi-object (5x5 arcmin field of view) spectroscopy, and integral-field-unit (5x7 arcsec) spectroscopy. Nod & shuffle capability for spectroscopy (for better removal of night-sky emission lines). Optical spectrographs at other large telescopes are generally more sensitive or offer a greater multi-object capability.
- NIRI: near-infrared (1-5µm) imaging and long-slit spectroscopy (R~500-1500). Can be used with the adaptive optics system using either a natural guide star or the laser guide star. Competitive with comparable instruments at other large telescopes.
- Michelle: mid-infrared (7-26µm) imaging and long-slit spectroscopy (R~100-3000, R~10000-30000 echelle). Polarimetry capability for imaging. One of the best instruments in its class.
- NIFS: near-infrared (0.95-2.40µm) integral-field spectrograph (R~5000) over 3x3 arcsec field of view. Can be used with the adaptive optics system in conjunction with a natural or laser guide star.

Gemini South

- GMOS-S: Clone of GMOS North.
- T-ReCS: Mid-infrared (8-26µm) imaging and long-slit spectroscopy (R~100-1000). Typically provides diffraction-limited images at 10µ under natural seeing conditions. One of the best instruments in its class.
- Phoenix: near-infrared (1-5µm) echelle, single-order spectrograph (R~50000-80000). Phoenix is a visiting instrument whose future availability is to be determined. Phoenix is typically less competitive than NIRSPEC at Keck and CRIRES at the VLT.
- NICI: near-infrared (1-5µm) coronographic imager. Currently in operation.

The following are instruments to be available in the near term at Gemini:

Gemini North

- GNIRS: near-infrared (0.95-5.5µm) long-slit single-order (R~1700-18000) and cross-dispersed (R~1700, 0.9-2.5µm) spectrograph. This instrument was deployed at Gemini South, but an accident in 2007 severely damaged it. After repairs, it will be placed at Gemini North. Can be used with the adaptive optics system in conjunction with a natural or laser guide star. Competitive with comparable instruments at other large telescopes.

Gemini South

- FLAMINGOS-2: near-infrared (0.95-2.4μm) wide-field imager and multi-object spectrograph (*R*~1200-3000). Can be used with the multi-conjugate adaptive optics system in development for Gemini South. Potentially competitive with comparable instruments at other large telescopes.

Future planned Gemini instruments include a wide-field multi-object spectrograph (WFMOS) that would be used at the Subaru telescope, a high-contrast coronograph (GPI), multi-conjugate adaptive optics (MCAO) system for Gemini South, and a ground-layer adaptive optics system for Gemini North.

2. Non-Federal Facilities

Figures 5, 6 &7 are meant to summarize the instrument capabilities that are available currently or imminently in the U.S. suite of telescope facilities at optical, near-infrared, and mid-infrared wavelengths. The instruments include those listed at facility websites in June 2008 as reproduced in December 2008 at the NOAO web page that summarizes telescopes with some level of community access (http://www.noao.edu/science-capabilities.php). This snapshot is meant to be more illustrative than comprehensive. We recognize capabilities change continually.

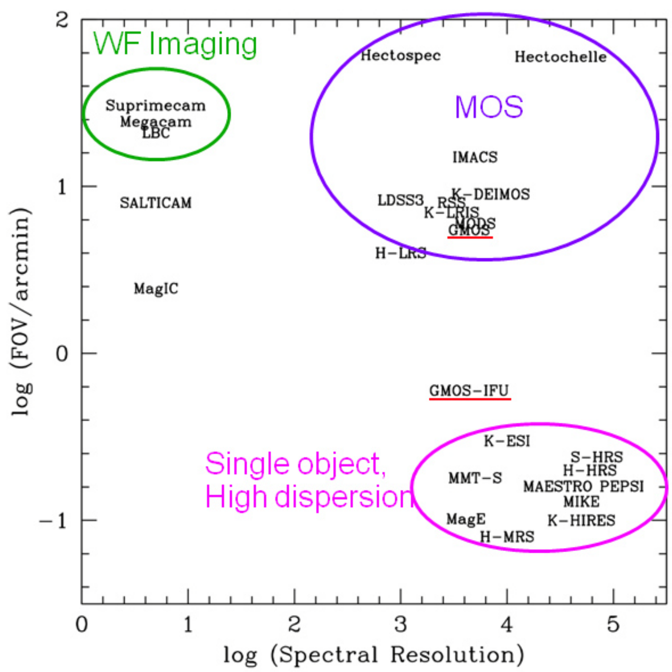


Figure 5. Optical instrument capabilities, for both imaging and spectroscopy, located on 6.5-m to 10-m telescopes in the U.S. system. The capabilities underlined in red are those available at Gemini. This figure is a snapshot in 2008 of the capabilities available and is meant to be illustrative and not comprehensive.

Many instruments provide a capability unavailable to the community through Gemini. These include spectroscopy at blue optical wavelengths (<400nm, with, e.g., LRIS at Keck) and multi-object spectroscopy over a large field (e.g., DEIMOS at Keck). High-resolution optical spectroscopy is in high demand; such instruments are only available on the non-federal facilities (e.g., HIRES and NIRSPEC at Keck, MIKE at Magellan, HRS on the HET and the multi-object Hectochelle at the MMT). Optical polarimetry and spectropolarimetry are not available at Gemini, but can be done elsewhere (e.g., LRIS at Keck). In addition, interferometry is offered at Keck (and soon at LBT.

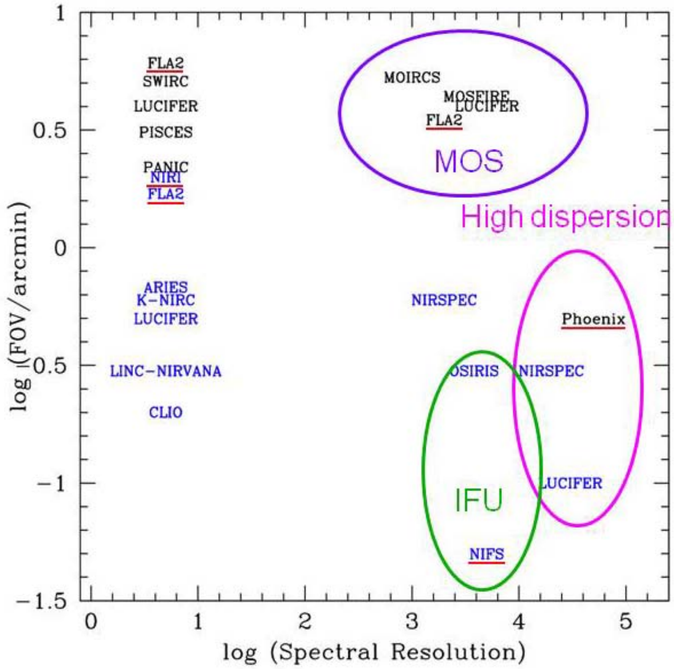


Figure 6. Near-infrared instrument capabilities, for both imaging and spectroscopy, located on 6.5-m to 10-m telescopes in the U.S. system. The capabilities underlined in red are those available on Gemini. This figure is a snapshot in 2008 of the capabilities available and is meant to be illustrative and not comprehensive.

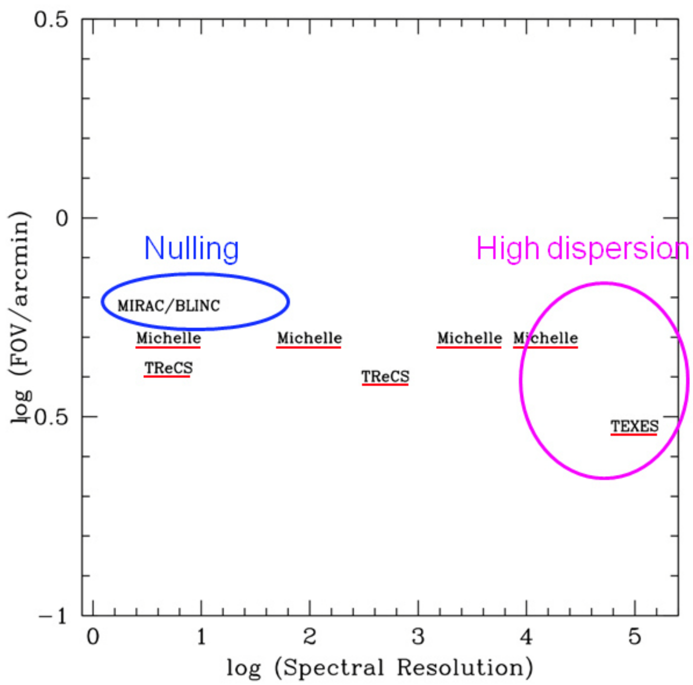


Figure 7. Mid-infrared instrument capabilities, for both imaging and spectroscopy, located on 6.5-m to 10-m telescopes in the U.S. system. The capabilities underlined in red are those available on Gemini. This figure is a snapshot in 2008 of the capabilities available and is meant to be illustrative and not comprehensive.

V. Input from the Broad US community

The committee was charged with gathering "input from the broad U.S. community in order to develop an understanding of the instrumental (and other) capabilities needed on ground-based O/IR telescopes of aperture between 6.5 and 10 meters, between now and the end of the 2010-2020 decade." In this section, we describe the process by which we gathered input from the US community and the main themes that emerged.

1. Community Input Process and Demographics

We assume "the broad US community" is that part of the US astronomical community that uses ground-based O/IR telescopes for their research in a dominant or supporting role. The input was gathered in several ways; using a survey designed by ALTAIR committee members, direct input from ACCORD and Gemini via representatives at our first meeting, follow up solicitation from all ACCORD directors via a direct e-mailing, and the contact committee members have in the community.

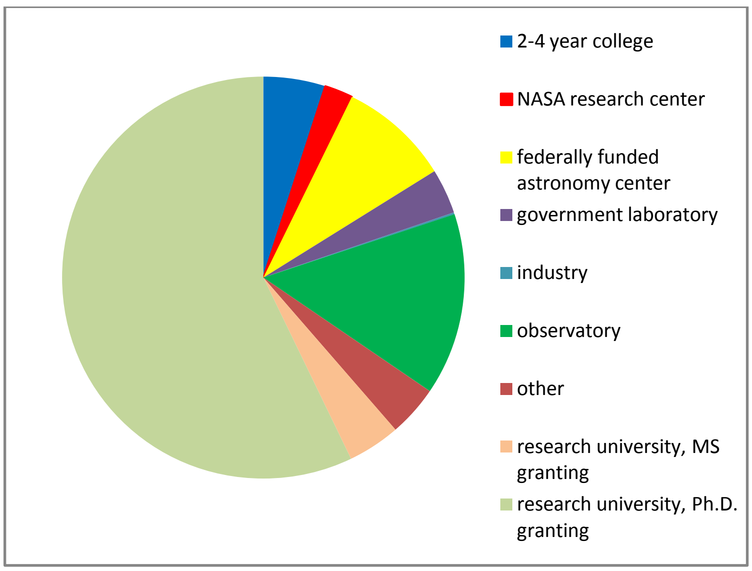


Figure 8: Demographics of survey responders

Of these, the ALTAIR survey figures most importantly (See Appendix C). It represents the most systematic, extensive and unbiased input. There were approximately 570 unique respondents from over 100 institutions, including colleges, universities, government laboratories, and federally funded astronomy centers. Figure 8 illustrates the institutional demographics of the survey respondents, which are roughly representative of the US large telescope community (see Appendix D). The respondents were primarily optical/IR observers and represent a broad range of science interests (Figure 9). Approximately 57% identify themselves as primarily optical observers, with 26% and 8% as primarily near-IR and mid-IR observers, respectively.

Approximately half of the respondents have access via their institutional affiliation to one or more large telescopes. More than 80% have experience using a large aperture telescope. More than 60% have proposed to use the Gemini telescopes as a PI or co-I. Approximately 44% have no access via their institutional affiliation to large telescopes. In the following, we summarize the survey results. Further details on the survey results are presented in Appendix C.

2. Observing Time and Observing Modes

The survey results regarding respondents' need for observing time is consistent with the NOAO large telescope oversubscription statistics (section II) and the input received from the ACCORD directors in indicating that the demand for large telescope time exceeds the available time by a factor of at least 3-4 for both open access and institutional access proposers. The true demand is likely larger, because proposal requests are probably limited by the expectations of proposers for what constitutes a "reasonable" request.

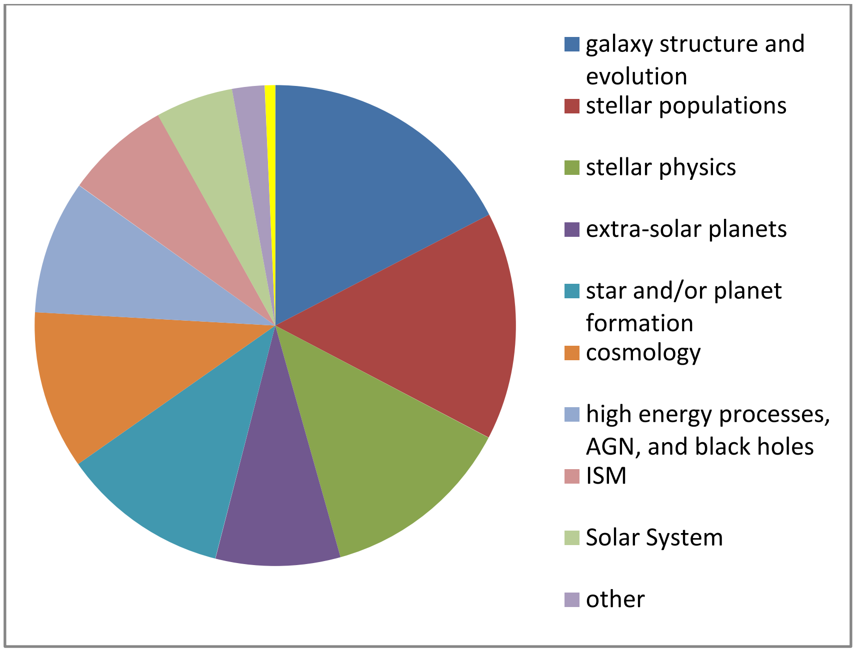


Figure 9: Research specializations of survey responders

As a related result, ALTAIR survey respondents generally felt that it is important for graduate students and post-docs to have experience observing with large telescopes and/or with the data from these facilities as part of their education and career development. The survey showed support for both small-scale and large-scale projects. Most respondents support 20% or more time for large projects even on the largest telescopes.

The survey revealed that both queue and classical scheduling are popular and valuable observing modes. However, under funding-limited conditions, respondents view queue scheduling to be less critical than improvements to instrumentation or an increased number of observing nights.

3. Instrumentation Needs

The survey highlighted mismatches between instrument capabilities that are or will be in high demand and those that are currently available in the open-access component of the large telescope system. The two tables below indicate respondents' anticipated need for specific instrumentation capabilities in the near term (the next 2-3 years) and on a longer time scale (the next 3-10 years). The percentages given in the tables indicate the fraction of all respondents that ranked a given capability either as their first priority (column 2) or as one of their top 3 priorities (column 3) in either time period. Note that these percentages reflect demand rather than being strongly science driven in the sense of being ordered by some objective measure of the quality of science.

Several capabilities that have high indicated demand are not well met by the current suite of capabilities in the open-access component of the large telescope system. The "missing" capabilities include optical (wide-field imaging, multi-object spectroscopy, high and low resolution single-object spectroscopy) and near-infrared (high resolution spectroscopy and low resolution multi-object spectroscopy) instrumentation that is both "workhorse" (high and low resolution single-object spectroscopy) and more specialized (wide-field, multi-object capabilities).

We note that the longer term need for optical multi-object spectroscopy and wide field imaging may be met with Gemini/WFMOS and LSST. Other missing high-demand capabilities currently exist in the non-federal component of the large telescope system (e.g., high resolution spectroscopy, wide-field imaging, multi-object spectroscopy; see Sec. III on "Current Use") and could be better accessed with increases to TSIP.

A significant reason for the mismatch between the instrument capabilities that are in high demand and those available in the open access system is that there is high demand for optical instrumentation, while Gemini, the major facility in the open access system (Sec. III), is IR-optimized and weak on optical instruments. Summing the top-three desired capabilities of the survey respondents, optical instrumentation comprises about 50-55% of the demand, near-IR 35-40%, and mid-IR 10%.

Table 3: High demand capabilities in next 2-3 years

Capability	% first choice	% Top three choice
Optical/Wide-field-imaging	16	33
Optical/Single-object-spectroscopy(R>15,000)	17	30
Optical/Multi-object-spectroscopy (R<15,000)	13	31
Optical/Single-object-spectroscopy (R<15,000)	8	22
Near-infrared/Single-object-spectroscopy(R>15000)	7	20

Table 4: High demand capabilities in next 3-10 years

Capability	% first choice	% Top three choice
Optical/Wide-field-imaging	14	27
Optical/Single-object-spectroscopy (R>15,000)	11	25
Optical/Multi-object-spectroscopy (R<15,000)	10	31
Optical/Single-object-spectroscopy (R<15,000)	6	18
Optical/Multi-object-spectroscopy (R>15,000)	6	18
Near-infrared/Single-object-spectroscopy (R>15000)	7	18
Near-infrared/Multi-object-spectroscopy (R<15000)	7	15

4. US Community Perception of Gemini

The Gemini instrumentation suite, discussed briefly above, also plays a role in the US community perception of Gemini. When asked to compare their experiences using Gemini and the non-federal facilities, some respondents commented favorably on the good seeing of Gemini as well as its infrared performance, queue scheduling, and the ability to accommodate targets of opportunity. However, there was also strong criticism from many respondents that Gemini instrumentation is uncompetitive with instrumentation available on other large telescopes and is not well aligned with the needs of a broad community of users.

The second most common concern was the large amount of time that a proposer must spend at all stages of the process to end up with science quality data. Respondents commented on the time burden of the Phase II process, concerns about data quality and observing efficiency, and the possibility of receiving little useful or no data for all the effort expended. Others expressed a strong desire to be more actively involved in collecting their own data through classical observing or a remote eavesdropping process. Overall, respondents remained fundamentally supportive of Gemini, but they found their experiences with Gemini frustrating and were disappointed that Gemini does not perform better.

5. Priorities for Federal Funding Increases

Accordingly, when asked to prioritize possible avenues by which the large telescope system could by enhanced with any increases in federal funding, the highest priority of respondents was for more open access time on non-federal facilities. The second priority for all responders (i.e. both with and without institutional access to large telescopes) was for increasing the US share in Gemini. The second priority for the more limited group of respondents with institutional access to large telescopes was for increased funding for instrumentation on non-federal facilities (e.g., via TSIP).

VI. Findings and Recommendations Regarding a System of Federal and Non-federal OIR Facilities

The information we gathered (Sec. II-V) and results of our committee discussions strongly support (1) the value of a large telescope system comprised of federal and non-federal facilities and (2) the need for an expansion of the current large telescope system in order to meet the needs of the US community now and in the coming decade. In this section, we summarize our findings that support this point of view and provide recommendations as to how such a system can be developed and maintained in terms of planning opportunities and funding tools. In subsequent sections, we discuss possible pathways for developing and improving the federal (i.e., Gemini; sec. VII) and non-federal (sec. VIII) elements of the large telescope system.

1. Findings

Need for a Large Telescope System

The ALTAIR survey clearly indicates that the community requires access to a broad range of instrumentation on large telescopes. At the same time, the cost of building instruments for large telescopes is high. It is unrealistic for any single facility to provide such a broad range of capabilities, e.g., spanning a range of wavelengths (the optical through MIR), spectral resolutions, fields-of-view, offering both seeing-limited and diffraction-limited performance, and including both "advanced" and "workhorse" types. "Advanced" instruments (LGSAO, MCAO, WFMOS, etc) are expected to produce breakthrough science but are particularly expensive and will be impractical to duplicate on many facilities. "Workhorse" instruments (e.g., low and high resolution spectrographs and imagers) remain highly valued.

Providing access to a range of facilities, each with their own more restrictive instrument complement, is an attractive way to address this issue. A large telescope system comprised of federal and non-federal facilities also addresses the current "missing" high-demand capabilities in the open access system. For example, the access to the additional capabilities on the non-federal facilities that is afforded by TSIP and the NASA open access time on Keck is highly valued by the community.

Maintaining and developing such a "system" of large telescopes will become increasingly important in the future in order to meet the scientific aspirations of the US community. It will be particularly critical as instrumentation becomes more complex (and costly), through the use of new technologies such as sophisticated AO systems or the enhanced multiplex of more conventional technologies such as wider field imaging or multi-object spectroscopy.

An effective large telescope system would facilitate the sharing or trading of resources among federal and non-federal facilities, as in the exchange of funding for time on other telescopes or through time trades between facilities. An efficient system would also optimize the suite of available capabilities through the coordinated use of federal and non-federal funding.

Needed Expansion of the Large Telescope System

Based on our review of the capabilities and current use of large telescopes (Sec. III and IV), as well as the input we received from the broad US community (Sec. V), we find that there is a large and engaged

US community that uses large telescopes for a broad range of astrophysical investigations. We also find that the demand for telescope time outstrips the available time by a factor of more than 3-4. As a result, only a fraction of excellent projects can be carried out in a timely manner. It is therefore critical to increase the effective observing time (more total nights and/or more efficient instrumentation) available to the US community on large telescopes.

Increasing the available observing time on large telescopes is also related to the strong sentiment expressed in the survey that it is critical for students and post-docs to have experience observing with large telescopes and/or the data from these facilities. Developing such a large community that is experienced in using the current generation of large telescopes will be crucial to take advantage of the unique opportunities offered by the next generation of 20-30 meter telescopes. The science cases described in Appendix B illustrate the variety and quality of science programs that could be carried out if significantly larger amounts of large telescope time were available.

Meeting these needs will require an expansion of the current large telescope system in terms of open access observing time and enhanced system instrumentation.

Developing the Large Telescope System

There is currently no formal mechanism for developing and maintaining a system of large telescopes that comprises of federal and non-federal facilities. A mechanism would include both *opportunities for planning* the development of the system (e.g., regular dialogue between the US community and the federal and non-federal observatories) and *tools for implementing* priorities (e.g., funding or time trades). Current planning opportunities meet some, but not all, of these needs:

- The US community needs for instrumentation on Gemini specifically have been discussed twice over the last 10 years at instrumentation planning workshops organized by the NGSC (or its equivalent) as part of the Gemini instrument planning process (Abingdon 1997; Aspen 2003).
- The US community needs for instrumentation in general on telescope apertures from small to large have been discussed at three previous System Planning workshops in October 2000, May 2004 and November 2006 (http://www.noao.edu/system/).

The primary funding tool for the development of the large telescope system, TSIP, is discussed in Section VIII.

2. Recommendations

NOAO as Steward of the (Non-NASA) Open Access System

We endorse the need for a large telescope system and recommend that NOAO take responsibility for the stewardship of the open access system (excluding the open access Keck time administered by NASA) and advocate for a balance of open access capabilities that matches the research goals of the US community. While Gemini and NOAO should work closely together to identify opportunities to develop the large telescope system, NOAO is the appropriate advocate for the US community interests in this endeavor. The Gemini Observatory reasonably must serve a variety of stake-holders' interests and should focus on maximizing the performance and competitiveness of the two Gemini telescopes.

Roadmap for the Large Telescope System

We recommend that NOAO regularly solicit broad community input regarding the value of current and future large telescope capabilities. As one mechanism, we recommend that NOAO organize regular meetings of the US community and representatives of the federal and non-federal facilities to discuss priorities for instrumentation, software, and other observing resources in a scientific context. US community members can also provide feedback via this venue on their experiences using federal and non-federal facilities.

Based on this input, we recommend that NOAO create and maintain a roadmap for the development of the open access system. The roadmap should indicate which capabilities are most desired and which are missing or overrepresented. As with any overview, this roadmap must not be taken too rigidly, as scientific breakthroughs will not necessarily correlate with plans and people's preferences are often too colored by past use rather than future opportunities.

The roadmap may (1) provide partial guidance to the selection of TSIP instrument proposals; (2) provide partial guidance to the development of the Gemini instrument suite; and (3) prove useful in making quick decisions to buy time on facilities should new opportunities suddenly become available.

Time Trades and Time Purchases

The access to the non-federal facilities that is afforded currently by TSIP is highly valued by the community and we endorse its continuation. We further recommend that the NOAO director be charged with attempting to negotiate time trades of US open access time within the Gemini and TSIP portfolio for observing time on non-federal facilities in order to balance access with US community science needs. We recommend that the NOAO director maintain active communication with the non-federal facilities (e.g., via ACCORD) in order to identify mutually beneficial time exchanges. We also recommend that NOAO work with the NSF to develop funding pathways (perhaps as an element of an expanded TSIP) that allow the NOAO Director to respond quickly to opportunities to buy time on highly valued facilities, including the possibility of a significant share and/or a significant number of nights, should new opportunities suddenly become available.

Balancing Demand with Potential for Astronomical Discovery

Much of the discussion thus far focuses primarily on resolving the unmet demand for particular instrumentation resources and less on the potential of these resources for astronomical discovery. Both are important for the health of the US astronomical enterprise. We therefore recommend that the potential for astronomical discovery be maintained as an important priority in allocating resources for the development of the large telescope system. It would be all too easy for a system management paradigm to seek out only the safest options, leaving the US open access community with broad access to yesterday's instruments. Similarly, it would be easy for a TSIP-like program to become overly focused on open access with insufficient attention to the development of transformative instrumentation. The roadmap discussed in recommendation 3 above should be able to accommodate emerging and transformative ideas.

VII. Findings and Recommendations for Gemini

The Gemini Observatory is a critical part of the suite of US telescopes in the 6.5 – 10 m aperture range. The Gemini telescopes are the primary resource available to the US community that does not have institutional access to (the non-federal) large telescopes. Gemini represents ~55% of the nights available to the ~ 45% of the large telescope community that does not have institutional access to large telescopes (section III). Clearly, the US astronomy community has a strong interest in Gemini being an efficient, effective observatory, and this should be expected since the US is a 50% partner.

1. Findings

US Community Perception of Gemini

Gemini is recognized as offering good image quality and low infrared background, as well as access to both hemispheres. It currently offers some leading capabilities (e.g., TEXES, T-ReCs) and additional leading capabilities are expected in the future (e.g., MCAO, GPI). However, the ALTAIR survey revealed broad dissatisfaction with the current Gemini Observatory. In particular, Gemini is viewed as not being closely aligned with the needs of the US community. This perception arises for several reasons.

Instrumentation is a Critical Factor in the Current Perception of Gemini

The instrumentation suite available at Gemini is not well aligned with the needs of a large fraction of the US community. High demand capabilities, such as optical and near-infrared, single object, high-resolution spectroscopy are either absent from Gemini or not offered by facility instruments. Wide field imaging and multi-object spectroscopy are also in high demand, and again Gemini is not well suited to this. Increasing the competitiveness of Gemini instrumentation is critical to making the Gemini Observatory more aligned with the needs of the US community. This can be accomplished in two ways:

1. Providing instruments that a significant fraction of the community requires, and/or
2. Outfitting Gemini with specialized instruments that are so unique and competitive that the non-federal facilities will seek time trades with Gemini. Such time trades can provide access to instrumentation not available at Gemini.

Currently the broad US community has the opportunity to comment on future Gemini instrumentation at international workshops held by Gemini every ~6 years (Sec. IV), most recently at Aspen in 2003. These workshops have a mixed record in providing instruments that are aligned with the needs of the US community. For example, the outcome of the Aspen process, thus far, is the construction of a niche instrument, GPI. Because of changes in the funding environment, “workhorse” instruments that were highly ranked at Aspen were planned and designed and later cancelled (e.g. the high resolution IR spectrograph HRNIRS). This outcome does not well serve the broad US community and suggests that it would be useful for Gemini to receive more frequent input from the US community regarding instrument priorities. The Aspen experience also suggests the need for a mechanism that can identify smaller scale instrumentation projects that can be developed quickly to respond to unmet US community needs. We note that two high-resolution optical spectrographs (MIKE and PFS) have been constructed by the Magellan consortium for < $5M each. Similarly efficient, simple, “work-horse” instruments could be developed for Gemini rapidly and inexpensively.

The Operational Mode at Gemini is seen as Burdensome to the US Community

A common frustration with Gemini is the large amount of time that a proposer must spend at all stages of the process to end up only sometimes with quality data. Currently, Gemini users must first prepare an observing proposal for peer review in a standard time allocation process. If approved in one of the Gemini science Bands (I-III), investigators must then prepare a Phase II observing proposal. In the survey question where users were asked to compare Gemini to non-federal facilities, the second leading complaint identified this Phase I/Phase II process as cumbersome or onerous, particularly given the fact that many programs, particularly in Band III, are not executed, not executed as specified, or not executed to completion.

While it is clear from the survey that the community does value many aspects of queue observing (because it relieves the time and financial burdens related to travel and/or provides the flexibility to match required observing conditions or timing requirements), queue scheduling was viewed as being less critical than improvements to instrumentation or an increased number of observing nights. A number of survey respondents also expressed the desire for more direct involvement with Gemini data taking, either through classical observing or real time remote observing. We note that Gemini has made recent attempts to promote alternate observing modes by lowering the time requirement for classical observing. Gemini is to be commended for this effort; however, the perception in the community is still that Gemini discourages modes other than queue observing.

The results of the ALTAIR survey, along with discussions of the ALTAIR committee, show that while the US community remains supportive of Gemini, there is widespread dissatisfaction with the current Gemini Observatory that goes beyond simple disappointment. The extent of the dissatisfaction suggests that US community support may erode significantly if Gemini does not become closer aligned with US community needs in the near term.

Reasons for the Lack of Alignment between Gemini and the US Community

Given the substantial US investment in Gemini, the current lack of alignment between Gemini and US community needs has led to significant frustration because there is currently no mechanism by which the science interests of the US community can strongly influence the goals and operational and instrumental priorities for the observatory. The committee considered the possible underlying reasons for this situation and identified the following possible explanations. The degree of community dissatisfaction with Gemini suggests that significant changes are needed to address several or perhaps all of the following:

a) *There is no direct path for communication between the US community and the Gemini Board*. The ALTAIR committee recognizes that Gemini is a partnership between 7 countries and that this adds complications to the governance. Nevertheless, the current structure does not facilitate, and may even impede, the needed exchange of information between the US community and the Gemini Board, the governing body of the Gemini Observatory. Conversely, the current structure may hinder communication from the observatory to the user communities which may result in perceptions such as that Gemini is not well disposed toward classical observing.
As background information, we can summarize the role of and relation between the various Gemini committees and the Gemini Board (see the diagram in Appendix E). The Gemini Board along with

the observatory director (who is approved by the Board) has the primary responsibility for setting budgetary constraints and providing broad oversight including adopting instrumentation priorities. The NSF (the US contractual agency in the Gemini partnership) selects and appoints the 4 US members of the Gemini Board; the Board has a total of 10 members. The Gemini Science Committee (GSC) advises the Gemini partnership on science requirements. GSC members are selected by the Gemini director; there are 13 total members, of which 4 are drawn from the US community. The NOAO Gemini Science Center (NGSC) is the gateway for US community access to Gemini. The US Gemini Science Advisory Committee (US Gemini SAC) is an NOAO-appointed community-based advisory council which consults with the NGSC on the US perspective on all matters that bear on the scientific quality and productivity of the Gemini Telescopes. While the NGSC is the primary US interface to Gemini, the NGSC has no direct authority over nor responsibility for the actions of the Gemini Observatory. Thus, despite the existence of these multiple entities, there is no direct pathway for US community opinion to reach the Gemini Board.

b) *Selection of US members of the Gemini Board and GSC*. There is very limited input from the US community (via their representatives such as NOAO) in the selection of US GSC and US Gemini Board members. Effective US representatives would be highly familiar with the US large telescope system and the role of Gemini in that system. They would also be advocates for the development of the US system.

c) *US representation on the Board*. The fraction of the US representation on the Gemini Board is less than percentage share of the US investment in Gemini. With limited representation, the broad US perspective is not always articulated effectively.

Role of Gemini in the Large Telescope System

Despite the current shortcomings of the Gemini Observatory, this committee believes Gemini is a valuable resource and can still meet more of the needs of the broad US astronomy community. If the concerns identified above can be addressed, acquiring an additional 10-25% share of Gemini could have a large positive impact on US community access to large aperture optical-IR telescope time and offer the advantages of continuity and stability that many astrophysical programs require. At the current rate of $17M/yr for the 50% US share in Gemini, acquiring an additional 10% share would cost $3.4M/yr and would be equivalent in cost to doubling the TSIP allocation which has varied greatly but planned at the is approximately $4M/yr level (see Sec. VIII.). The corresponding number of additional TSIP nights may not be available in the near future, according to the feedback received from the ACCORD directors. As a result, an additional investment in Gemini may be a critical pathway for increasing the open access time available on large telescopes. If the US were to increase its share of Gemini from 50% to 75%, for example, that would deliver about 50 additional nights per year on each of the two Gemini telescopes, or a total of 300 Gemini nights per year. This is approximately the same in cost as tripling the TSIP budget.

The original Gemini partnership will be renegotiated, with a new agreement taking effect in 2012. This will be an entirely new agreement, and the UK has already expressed interest in leaving the partnership. Therefore, it is quite possible that an additional share of time, and financial responsibility, is available at the Gemini telescopes. The US astronomy community has a clear need for more access to observing time on large telescopes (sec. V, VI). While current needs of the US open access community might be best met by an expanded TSIP (e.g., based on the ALTAIR survey, sec. V), the feasibility of the TSIP route depends on the non-federal observatories being willing to sell off additional time on their telescopes, either to fund new instrumentation or to pay for operating costs. Such agreements would need to be long term (~ 5 years) to allow for creative observing programs of multi-year duration. Without such a long-term agreement, there are likely to be fluctuations in open access to specific facilities from year to year. One way to guarantee additional open access time on large telescopes is to increase the US share in the Gemini Observatory as a result of the new partnership agreement that will take effect in 2012. Given that there is currently widespread dissatisfaction in the US community with Gemini, it will be important for Gemini to demonstrate progress addressing the concerns described above *before* the US invests substantially more in the observatory.

2. Recommendations

Instrumentation and Observing Modes

We recommend that NOAO work with the GSC and the Gemini Board to achieve closer alignment between the instrumentation offered by Gemini and the needs of the US community. While we recognize that Gemini is infrared-optimized and is therefore not easily adaptable to all instrument configurations, future instrument decisions should be carefully judged partially on the basis of what will make Gemini, both the observatory itself and the trades enabled by it, more aligned with the needs of the US community.

In the near term, we recommend that currently planned instrument upgrades and commissioning proceed as rapidly as possible. These include: 1.) Returning GNIRS on Gemini North, 2.) GMOS detector replacement at both Gemini North and South, 3.) Implementation of MCAO (which will be a truly unique ability), and 4.) Flamingos II commissioning on Gemini South. These upgrades, in addition to the availability of NICI on Gemini South, will make the observatory substantially more competitive and provide exciting potential to the US community.

We recommend that NOAO develop a mechanism for the US community to provide input on the progress of the Gemini instrumentation program more frequently (perhaps annually) than the time scale of the Gemini instrumentation workshops. This will provide valuable input to the Observatory when there are rapid shifts in funding and management. It will also keep the community informed about the changes to the instrument development process outside of the Aspen format.

We also recommend that NOAO work with the GSC and the Gemini Board to implement a mechanism for the rapid development and acquisition of smaller, cheaper instruments that fill high-demand “gaps” in the Gemini instrumentation suite. Visitor instruments may provide a valuable short-term solution in some cases.

We recommend that NOAO continue to work with the Gemini Observatory to provide more US observers with firsthand experience at the Gemini telescopes. The success of the Gemini Observatory as a major component of the US observing system depends in part on developing a knowledgeable, dedicated, and supportive user base within the US astronomy community. This process can be aided by users taking a more personal, vested interest in the observatory, and this in turn is often enhanced by actually visiting the observatory and being present when one's data is obtained. Such experiences can also help observers prepare better queue programs.

Role of the US in Setting Scientific Goals for Gemini

Recognizing that the current lack of alignment between Gemini and the needs of the US community likely stems from the very limited role that the US community plays in setting scientific goals for Gemini, we

- Suggest NSF consult with NOAO and the US community to evaluate the current Gemini governance structure (regarding the role of the Gemini Director, the Board, and the GSC in setting scientific goals for the Observatory), compare it to other observatories such as Keck, Magellan, etc., and implement a solution that will address the concerns described in Finding 4 above and ensure that Gemini becomes more aligned with the needs of the US community as soon as is feasible (i.e., even in advance of the 2012 transition, see below).
- Suggest NSF consult with NOAO and the US community to adjust the selection and composition of the US representation on the Gemini Board and GSC. Members of these bodies should be charged to understand and represent the diverse needs and aspirations of the US community. It would make sense for the US to be represented by a number of Board members that is more comparable (as a fraction) to the percentage share of the US investment in Gemini.
- Recommend that NOAO take leadership in working with the US community to determine a process for soliciting and representing US community opinion that will be communicated to the GSC and the Gemini Board.

2012 Transition

We advise the NSF to take advantage of the 2012 transition as a unique opportunity to negotiate a new Gemini partnership that gives the US community a direct role in setting scientific priorities for Gemini, i.e. instrument selection, operations modes, and other high level observatory priorities, to an extent that is appropriate for the US fractional share in Gemini. We also advise the NSF to put in place governance structures that ensure that the needs and priorities of the US scientific community are heard and that the Gemini Observatory is responsive to US community needs. Provided that the NOAO director working with the NSF determines that the existing concerns regarding Gemini are being addressed, then the ALTAIR committee recommends increasing the US share of Gemini up to a 75% share.

VIII. Findings and Recommendations for Access to Non-federal Facilities Using TSIP and Other Mechanisms

1. Background

The twin goals of the NSF-supported Telescope System Instrumentation Program (TSIP), as articulated in the 2000 Decadal Survey "Astronomy and Astrophysics in the New Millennium," are to promote the coordinated development of federal and non-federal facilities (i.e., to encourage the evolution of large telescope resources as a coherent system) and to increase the open access observing time on the non-federal facilities.

TSIP currently provides single- and multi-year funding (with a total program budget of approximately $4M/year) to develop new instrumentation, to upgrade existing instruments, or to otherwise enhance the scientific capabilities of large aperture telescopes operated by 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 approximately annually and are competitively reviewed. (Note: TSIP has awarded $24.5M in funding over the period 2002 – 2008 for an average of $3.5M/yr. The yearly funding level has varied over this period, with $4M/yr being typical for a given call for proposals and lower levels of funding or no funding in some years. In comparison, $5M/yr was the funding level recommended in the 2000 Decadal Survey.)

The program is open to non-federal observatories and affiliated institutions with telescopes of 3-10m aperture. The priorities for selecting instruments through this program come, in part, from the priorities established in previous NOAO system workshops (see http://www.noao.edu/system). In exchange for TSIP funding, specific allocations of observing time are made available to the open access community on the telescopes of funded observatories (approximately 50 nights/year currently). The observing time purchased by TSIP on behalf of the community is assigned to proposers via the standard NOAO proposal process.

2. Findings

TSIP is a Success

TSIP funding has been important in increasing open access to non-federal facilities and in significantly improving the observing capabilities of these facilities. Most US observatories have taken advantage of TSIP funding for instrument development (Table 2) and the program itself enjoys widespread support. TSIP is also valued by the astronomical community, enabling open access to a broader range of instrumentation than is available at Gemini, or any other single observatory, as well as increasing the total number of open access observing nights on large aperture telescopes. This finding is supported by the results of the ALTAIR survey (sec. V) as well as the documented oversubscription rates for TSIP time allocated by the NOAO TAC (Table 2). TSIP time fills a critical need for US astronomers who reported that their research interests (both near- and long-term) are not adequately served by Gemini resources alone.

Need for a Constant TSIP Funding Stream

The TSIP funding can fluctuate dramatically from year-to-year (from $0M/yr to $4M/yr), which severely limits the ability of the non-federal observatories to integrate TSIP into their long-term budget planning. As a specific example of the current dilemma, there was no call for TSIP proposals in 2008 and as of February 2009 it is as yet unclear whether there will be a call in 2009. Thus, the TSIP observing time available to the public can be intermittent and limited, acting as a barrier to the entry of new proposers. Short-term or variable access is detrimental to developing an expert user community of these facilities, particularly in the case of new or unusual instruments (e.g., laser guide star adaptive optics systems, integral field unit spectroscopy, interferometry). Short-term or variable access also discourages programs that require long-term monitoring (e.g., planet searches via radial velocities).

Needed Support for Technology Development and Advanced Instrumentation

This report documents compelling science cases demanding multi-object spectroscopy, large-format imaging cameras, and advanced adaptive optics systems (Appendix B). However the available instrumentation resources are currently lacking to accomplish even the highest priority programs within a reasonable time frame. Investing in instrument infrastructure is essential to maintaining an active instrumentation community that is capable of supplying innovative world-class instruments. Astronomical progress has largely been propelled by large improvements in technology. For US astronomy to remain at the forefront in the coming decades, we must aggressively invest in new technology and the groups capable of implementing it. TSIP is a significant contributor to this effort.

3. Recommendations

An Expanded TSIP with Increased Flexibility& Stable Funding

We recommend increased funding for an NOAO-led TSIP or TSIP-like program that has enhanced flexibility, from $4M/yr to $10M/yr, in order to increase the open access available time on non-federal facilities and to enhance the suite of instrumentation capabilities in the US large telescope system. Such a program would be able to

1) Fund instrumentation development or other infrastructure development (including operations, user support, and software development) in exchange for open access time.
2) Purchase nights on certain facilities.

Increased and stable funding will be needed to fund the development of (the increasingly expensive) forefront capabilities, both instruments and AO systems, and/or to purchase observing time (at an increased cost per night) on facilities where such capabilities are available. There would be an official proposal process, as there is now for TSIP. In its role as steward of the large telescope system, NOAO may also proactively solicit proposals from some observatories or explore alternative long-term agreements for funding or time trades to foster continued access to capabilities that are otherwise unavailable to the open access community or are in high demand.

Long-term Funding Agreements

We recommend that, as much as possible, TSIP be based on long-term funding agreements to effectively integrate non-federal observatories into a national system and to enable long term stable access by the US community to these facilities and broaden a skilled user base.

Use of Incentive Factors

We recommend additional flexibility in the current framework for defining the "incentive factors" that are used to calculate the open time access for a given TSIP funding level. The "incentive factors" currently differ for instrument development, user support activities, or straight time purchases. We recommend additional flexibility in setting the incentive factors, e.g., to recognize the complexity of the instrumentation suite that the funding provides access to, to enable a longer-term time purchase agreement, or in seeking access to high-priority capabilities.

TSIP Proposals and the Roadmap

In order to better optimize the US system of federal and non-federal facilities, we recommend that TSIP proposals specifically address how they would meet the needs expressed in the large telescope roadmap (sec. VI).

Developing Transformational Instrumentation

We recommend that NOAO work with ACCORD to explore how it might facilitate or coordinate efforts to build complex "transformational" instruments that are beyond the scope of individual institutions to develop even with TSIP resources. Such opportunities should involve full participation by all federal and non-federal observatories and should be consistent with the large telescope roadmap.

IX. Prioritized Recommendations

Recognizing that funding, time constraints will bear on the development of the large telescope system, we provide the following priorities for our recommendations. Recommendations made in earlier sections that are not listed below have a roughly equal, but lower, priority than the following.

1. Increased and Stable Funding for TSIP

We recommend increased funding, to $10M/yr, for an NOAO-led TSIP or TSIP-like program that has enhanced flexibility and stability, with the primary goal of increasing the available open access time on non-federal facilities. (The current TSIP budget is approximately $4M/yr.) TSIP is a success and we expect that increased TSIP funding will continue to be successful in meeting the community's needs. Such an enhanced program would (1) fund instrumentation development or other infrastructure development (including operations, user support, software development) in exchange for open access time and/or; (2) purchase open access nights on certain facilities (Sec. VIII).

2. Greater Alignment between Gemini and the US Community

We suggest that NSF consult with NOAO and the US community to explore possible changes to (1) the current Gemini governance structure (the role of the Gemini Director, Board, and GSC in setting scientific goals for the Observatory) and (2) the selection process and composition of US representation on the Board the GSC, and (3) create pathways by which US community input be provided effectively to the Board in order to achieve closer alignment between Gemini and the needs of the US community as soon as is feasible. The committee believes that changes of this kind will significantly increase the value to the US community from its current $17M/yr investment in Gemini (Sec VII).

3. 2012 Transition: Greater Alignment and a Possibly Larger Share in Gemini

In the longer term, the ALTAIR committee advises the NSF to negotiate a new Gemini partnership as part of the 2012 transition that gives the US expanded influence in decision making (regarding instrument selection, operations modes and high level observatory priorities) that is more directly proportional to the US financial contribution to the Gemini budget. We recommend acquiring a larger share of Gemini only if the Gemini Observatory becomes more responsive to the US community and evolves to a suite of instrumentation, operation modes, and other services that are well aligned with the needs of the US community. As the total time available to the community on large telescopes is a critical limitation now, acquiring a larger share of Gemini will be an important development path if the opportunities to expand access to non-federal facilities through TSIP are limited. If the NOAO director working with NSF determines the concerns above are being addressed, increasing the US share on Gemini to 75% should have a significant positive impact on US community access to large aperture optical-IR telescope time (Sec. VIII).

4. Developing the Large Telescope System

We recommend that NOAO take the lead in working with the US community and representatives of the non-federal facilities to establish mechanisms for planning together the development of the large telescope system. We recommend that NOAO establish and maintain a roadmap for the development of the large telescope system based on regular input from the US community, and that NOAO be an active advocate for the development of the large telescope system, using tools such as TSIP funding, input to the Gemini Board, and other methods (e.g., time purchases and trades) to achieve a balance of open access capabilities that is aligned with the research goals of the US community (Sec. V).

We also recommend that the NOAO Director work with the non-federal facilities (e.g., via ACCORD) to identify mutually beneficial time exchanges. In the longer term, international collaborations may be considered as a way to improve US access to a balanced system of capabilities. We also recommend that the "incentive factors" that are used to calculate the open time access for a given TSIP funding level be used flexibly to optimize the large telescope system. Higher incentive factors may be used in particular circumstances, for example to negotiate a longer-term agreement or to make available high-priority capabilities (Sec's. V, VIII).

5. Short-term Gemini Instrumentation Solutions

We recommend that NOAO work with the GSC and the Gemini Board to implement a mechanism for the rapid development and acquisition of modest cost effective instruments that meet near term high demand needs in the Gemini instrumentation suite. Visitor instruments may provide a valuable short-term solution in some cases (Sec. VII).

Appendix A: Committee Charge

1. Gather input from the broad U.S. community in order to develop an understanding of the instrumental (and other) capabilities needed on ground-based O/IR telescopes of aperture between 6.5 and 10 meters, between now and the end of the 2010-2020 decade. The list of capabilities should flow from community scientific aspirations and should represent all areas of astronomical research and wavelength and types of observation, though the committee should roughly prioritize and/or establish a time sequence.
2. Develop an understanding of the U.S. community's present use of the large telescopes within the system, the Gemini telescopes and those available through TSIP, including how the oversubscription rates, the number of astronomers who use them, the papers published, and the impact of those papers are related to the capabilities that are being provided. Both instrumental capabilities and aspects of operations (e.g., queue vs. classical) should be considered.
3. Within the context of the entire U.S. system, identify those capabilities which the Gemini telescopes are the best suited to provide – because of the amount of access that the community has or the particular characteristics of the telescopes or sites. Similarly, identify the optimum capabilities for non-federally-funded telescopes through which access might be provided to the broad community through programs like TSIP.
4. Provide a set of recommendations to guide the formulation of the U.S. position on Gemini, with particular attention to the expected transition in 2012 to a new international agreement. These recommendations should cover items such as number of nights the community needs on 6.5 to 10m telescopes, future instrumental capabilities, operations modes, access to archived data, and types of user support. The recommendations should also address processes for ensuring a strong link between Gemini capabilities and the interests of the U.S. community, taking into consideration the nature and constraints of the international partnership.
5. Provide a set of recommendations to guide federal activities aimed at expanding the system of large telescopes using TSIP or other mechanisms. These recommendations should cover the same areas as those for Gemini.

Appendix B: Science Cases

Telescopes in the 6-10 meter aperture range remain among the most productive science facilities. A metric developed by Madrid and Macchetto (arXiv: 0901.4552v1) using the 200 most cited papers in an given year most recently shows the VLT, Keck in the top 10 and Gemini and Subaru in the top 15 facilities which are dominate by space missions. In this section we give a cross section of the exciting science that the US community is pursuing and aspires to pursue with this class of telescope. It is meant to be illustrative and by no means comprehensive.

1. Solar System Science

Planetary science within our Solar System encompasses a vast range of topics: the formation history and atmospheric evolution of the giant planets; the locations of biologically hospitable conditions in the past/present/future; the structure and composition of the Asteroid and Kuiper Belts; etc. Many of these topics can only be addressed with large telescopes. We highlight just a few representative examples of Solar System science enabled by access to 6.5-10 m class telescopes.

Kuiper Belt Composition and Structure

The past decade has yielded incredible progress in unveiling both the complex dynamical structure of the outer solar system and the spectacular diversity of trans-neptunian objects (TNOs). The orbital elements of TNOs can be computed, adaptive optics (AO) imaging can reveal binary companions, permitting mass and density estimates, and from colors and low-resolution spectroscopy in the visible and near-IR, investigators can determine surface compositions, identify families of objects with common histories, and compute rotation rates. From such observations, a picture is emerging of early solar system history: a cold, quiescent disk of small planetesimals slowly accreted from frozen volatiles, as well as more thermally processed materials violently ejected outward from closer to the young Sun, until a cataclysmic sequence of events abruptly excited the orbits of bodies in the disk, eliminated most of them from the region, and left the present day Kuiper belt in its wake. The Nice model developed by A. Morbidelli, H. Levison, et al., suggests that the triggering event was a resonance crossing between Jupiter and Saturn that initiated the outward migration of Neptune; as Neptune plowed through the disk, it scattered objects into the inner solar system and out to the Oort Cloud.

Yet questions remain regarding the composition of TNOs, the nature of the protoplanetary disk they formed in, and their dynamical history. Because of their faint magnitudes and small angular sizes (and separations for binaries), 6.5-10 m telescopes are required to study all but the brightest few objects in the Kuiper Belt. Furthermore, these questions require the application of large apertures to large samples of objects. The more than 1500 known TNOs already translate to dozens of nights per year of large-telescope time. As the next-generation all-sky surveys (LSST, Pan-STARRS) come on line, the TNO discovery rate will increase dramatically and the demand for 6.5-10 m class telescope time to perform follow-up observations of surface composition, binarity, and other physical properties will similarly increase.

Titan's Methane Weather

Titan, Saturn's largest moon, is our solar system's only planetary moon with a substantial atmosphere, composed primarily of nitrogen with a few percent of methane. In analogy to water on Earth, Titan's atmosphere hosts a methane-based meteorology over its 30-yr seasonal cycle. Titan provides us with a unique laboratory in which to study a hydrological cycle on a planet other than Earth with a different condensable species (methane on Titan, water on Earth). Recent tantalizing images of Titan's surface from the Cassini Mission's Huygens Lander show a complex network of incised channels, shorelines, and damp streambeds, likely formed from liquid methane raining out of the atmosphere. Ground-based AO imaging shows evidence of frequent storm and cloud activity near the South Pole, but until recently never anywhere close to the latitude of the Huygens landing site.

A fundamental understanding of the dynamics of Titan's weather, including reflectivities, locations and altitudes of Titan's clouds, and a clear picture of how these attributes change with season, remains elusive. Ground-based large telescope AO observations are critical for two reasons. First, Cassini's expected lifetime is significantly shorter than Titan's 30-year seasonal cycle (imagine trying to understand Earth's weather using data covering only March to May!). Second, Titan flybys are limited to ~2 per month, and the geographic distribution of spatial coverage is often highly constrained. Ground-based observations can mitigate both the temporal and spatial limits of Cassini. Titan's small angular size requires imaging with AO on a large telescope. Because Titan is bright, however, the images can be obtained in a few minutes per night on a queue-scheduled large telescope. Such observations are crucial to understanding Titan's methane meteorological cycle.

Ice Giants

Extrasolar planet searches have matured to the point of detecting Neptune-sized bodies around other stars, yet many questions associated with the ice giants, Uranus and Neptune, in our own Solar System remain elusive. What are the natures and timescales of the mechanisms driving atmospheric circulation on an ice giant? By what process are large discrete atmospheric features formed and dissipated? How does seasonally-varying insolation affect the energy balance in an ice giant atmosphere? These questions have direct implications for the atmospheres of ice giants around other stars, and may be answerable for Uranus and Neptune in the coming decade.

High spatial resolution is required to effectively assess the dynamics and evolution of ice-giant atmospheres and ring systems. As with Titan, these bodies' small angular sizes require observations with 6.5-10-m class telescopes. Near-infrared images permit mapping of zonal winds as well as the study of the formation and evolution of atmospheric features. Imaging over many years and even decades is required for long-term climate change studies. The ring systems of Uranus and Neptune are known to be highly variable, but are accessible only to AO images on large aperture telescopes. As with Titan, Uranus and Neptune are bright, and require just minutes per night on a queue-scheduled large-aperture telescope for atmosphere studies; rings are fainter and require more dedicated observational strategies.

2. Stellar Astrophysics

Stellar astrophysics encompasses a large portion of astronomical research. Stellar birth, main sequence lifetime, and death fall under this rubric, and all stages of this evolution are radically distinct for the highest mass O stars compared with the lowest mass M stars. Substellar brown dwarfs follow yet another evolutionary path. While it is not possible to catalogue all areas of stellar astrophysics here, the following overview provides a sampling of a variety of studies in which 6.5 - 10 m are needed for significant progress. Two additional sections provide more detailed examples of cutting-edge research that requires large aperture facilities. This research will no doubt continue and likely increase over the next decade. Separate sections of this report discuss star formation and stellar populations (chemical abundances) and thus these subjects are not mentioned here.

Partial Overview

Parameters of extra-solar planet host stars
The accurate characterization of extra-solar planets depends on very accurate characterization of the stars they orbit. This is particularly true for transiting planets given the abundance of available information. Increasingly, these planets are being discovered around fainter stars, and large aperture telescopes are needed for the required follow-up work.

High mass stars and their environment
Much of the light seen from distant galaxies is dominated by their high mass stars. However, there is still a great deal about the birth, evolution, and demise of massive stars that remains unknown. This is in large part the result of the distance to most such stars and the corresponding field crowding that results. Foreground extinction is often a severe problem in such studies because of the environments in which they are found. The high spatial resolution at near- and mid-IR wavelengths afforded by AO-equipped 6.5 - 10 m telescopes is invaluable for this work.

Debris disk and exozodiacal dust studies
Studies of debris disks trace the evolution of planetary systems after the initial formation of these objects in gaseous, planet forming disks. Studies of such systems are critical for connecting primordial disks with the myriad of planetary systems being uncovered by radial velocity and other techniques. Debris disk observations require the high spatial and spectral resolution capabilities of large aperture, AO-equipped, ground-based telescopes.

Post main sequence mass loss
Mass loss in stars of all masses on the post-main sequence is responsible in part for determining their ultimate fate and for returning much nuclear processed material to the ISM for incorporation into future stellar generations. The mechanisms responsible for this mass loss are uncertain, as are the mechanisms responsible for shaping objects such as planetary nebulae. Again, the high angular resolution in the near- and mid-IR offered by 6.5 – 10 m AO-equipped telescopes is critical for making progress on these topics.

Stellar magnetism

Stellar magnetic fields are critical for understanding phenomena as diverse as the interaction of newly formed stars with their circumstellar disks, possible interactions of close orbiting extra-solar planets with their host stars, the influence of activity such as flaring on the habitability of exoplanets, and the shaping of planetary nebulae. Progress in these studies will largely depend on obtaining high signal-to-noise, high resolution optical and near-IR spectra on large samples of faint targets; work that again requires large-aperture, ground-based telescopes.

Brown Dwarfs

A key area of stellar astrophysics that has seen tremendous growth over the last 10 - 15 years, with the advent of 6.5 - 10 m telescopes, is the study of very low mass stars and brown dwarfs. Although these mid- to late-M, L, and T type objects are the most numerous in our galaxy, they are in many ways the least-well understood; because they are intrinsically faint, their census in the solar neighborhood is likely incomplete, as shown by the SUPERBLINK survey. Measuring basic parameters for these objects such as effective temperature, gravity, and particularly metallicity, remains problematic. Given the large numbers of these objects in the solar neighborhood, they are emerging as particularly attractive candidates for extra-solar planet research with the hope that some of them may harbor Earth mass planets in their habitable zones. Understanding these low mass, cool objects has become a high priority. However, progress in this area will require considerable theoretical work on the atmospheres of these objects, including the relevant opacities, cloud formation, and weather. These new models will demand an increasing array of observational comparisons that will require 6.5 - 10 m telescopes to obtain. Additionally, an entire new class of even cooler, fainter objects, the Y dwarfs, are highly sought after and their discovery and characterization will require photometric and spectroscopic observations at large aperture facilities.

Supernovae and Gamma Ray Bursts
The mechanism by which a high mass star ends its life in a supernova explosion can expose clues about the structure of the star at this point. One method is to use nebular-phase spectroscopy. From these spectra, one can derive the mass and distribution of synthesized elements, as well as the energy released by the explosion. This provides a direct probe of the physics of the explosion itself, as well as a picture of the stellar structure prior to explosion. Another method is spectropolarimetry. This again reveals the nature of the explosion (typically asymmetry). Both of these methods require large telescopes, even for relatively nearby supernovae, because of the resolution and signal-to-noise requirements. A more clear understanding of the explosion mechanism in all types of supernovae will lead directly back to the structure of the star and the fundamental stellar physics that govern stellar evolution. Gamma-ray bursts, especially the long-bursts associated with supernovae, represent even more extreme end-states of stars. In addition, their tremendous luminosity allows for a sampling of a young stellar population at a wide range of redshifts. Understanding the physical origin of the bursts, the environments from which they arise, and the clues they provide about high mass stellar populations are issues that require the use of large aperture telescopes.

3. Star Formation

The birth sites of stars are initially obscured in dense molecular gas; within <1 Myr the protostellar objects become visible, first via scattered light and increasingly directly as the circumstellar material evolves and disperses. Semi-pristine matter from the interstellar medium is accreted and processed, first through an envelope and later through a disk, which provides the raw material for potential planet formation. Establishing the detailed connections of such star plus proto-planetary systems, observed in their formation stages, to both our own solar system and to the hundreds of exoplanets now known, addresses a fundamental human goal to understand our own origins.

An unexpected outcome is the extreme diversity in the physical properties of planets found to orbit other stars. Comparison of these statistics with those emerging on debris disks, which may harbor yet-unseen planets and planetary systems, and yet further back to the star and planet formation stages is key to our understanding. An important part of the scenario is that stars typically do not form in isolation, but rather in multiples (binaries, triples, etc), small groups or associations, and dense clusters. Quantifying the statistical properties of young stellar populations then leads us to an understanding of the star formation environment most likely to have hosted our own proto-Sun. Both young stellar populations

and individual star/disk systems are quite active areas of research, engaging 25-30% of the community using large ground-based telescopes.
Although some investigations focus on individual objects of particular interest (e.g., FU Ori, T Tau, or Beta Pic, or AU Mic), many are surveys. Each survey area requires 10-30 nights over a few years for the assembly of good statistics on one or a few star forming regions, e.g., complete surveys for multiplicity at close separation via aperture masking, also at wider separations via coronography, complete samples for accretion rates, maybe some veiling variability monitoring, a good interferometric survey at *L*-band, *K*-band, and *H*-band. In sum, star formation research demands several hundred large aperture telescope nights with sensitive instrumention that can deliver the following: precise photometry; moderate resolution optical and near-infrared spectroscopy, with multiplexing; high dispersion spectrographs in optical, near-infrared, mid-infrared; moderate dispersion spectrographs in ultraviolet; spectropolarimetry; high spatial resolution (adaptive optics) imaging; long baseline interferometry and interferometric spectroscopy; coronography and short baseline (aperture masking) interferometry; integral field spectroscopy; astrometric studies (including monitoring); radial velocity studies (including monitoring). Partial overviews of two major areas of star formation science and the requisite instrumentation, and a more detailed example of an important research topic, gaseous circumstellar disks, are presented below.

<u>*Partial Overview: Young Stellar Clusters*</u>

Stellar and sub-stellar mass functions require precise photometry and moderate resolution spectroscopy with multiplexing; high spatial resolution is needed for young massive cluster environments such as those towards the Galactic center or outer Galaxy.

Cluster membership and dynamics requires astrometry with wide field adaptive optics as well as radial velocity and other high dispersion work, perhaps using multi-object or integral field spectrographs.

Stellar multiplicity requires adaptive optics imaging using coronographs or aperture masks, and/or radial velocities, with repeated observations to test for dynamical association.

Dynamical masses at young ages requires adaptive optics and/or interferometry and/or long term radial velocity monitoring.

Low-mass stellar/substellar atmospheres at low surface gravity require high-resolution spectroscopy.

<u>*Partial Overview: Circumstellar Disks and Planet Formation*</u>

Disk accretion and star/disk interaction requires high dispersion work in the optical and near-infrared including spectropolarimetry, low dispersion work at ultra-violet wavelengths.

Disk dynamics and dust/gas chemistry requires high dispersion work in the near- and mid-infrared, as well as interferometric spectroscopy.

Direct imaging of proto-planetary and debris disks requires high spatial resolution adaptive optics imaging or integral field spectroscopy, spectro-polarimetry, near-infrared and mid-infrared interferometry, nulling interferometry.

Planet Formation in Gaseous Disks

Taking just one of the many interesting questions concerning star and planet formation, we focus as an illustrative program on the chemistry and dynamics of circumstellar gas in the planet forming region of the disk, i.e., within ~5 AU of the central star. Numerous molecular (CO, H_2O, OH, C_2H_2, HCN, CH_4, H_2CO, NH_3, H_2, etc.) and atomic (OI, NeII, etc) transitions at near- and mid-infrared (IR) wavelengths provide powerful tools for ground-based studies of this region of the disk. Spectroscopy at high dispersion (R = 20,000-100,000) with high sensitivity and high angular resolution enables the study of the kinematics, temperatures, densities, and molecular abundances as a function of disk radius. These quantities are needed for detailed studies of issues such as (1) the lifetime of gaseous disks; (2) the synthesis of potential prebiotic molecules in disks; and (3) diagnosing disk structure induced by forming giant planets.

Telescopes with apertures 8-30m are required for this science. Significant advances require the sensitivity of instruments such as Keck/NIRSPEC in the near-IR and Gemini/TEXES in the mid-IR. The combination of high dispersion and high angular resolution (e.g., offered by VLT/CRIRES) provides unique insights since it enables the use of spectroastrometry in extracting both kinematic and spatial information (e.g., Pontoppidan et al. 2008). In order to spatially resolve the line-emitting regions, we can employ AO-corrected large-aperture interferometers with better than 1 AU spatial resolution for nearby star-forming regions. So far, only a few of the brightest disks have been observed and analyzed for both molecular synthesis and radial disk structure. A promising new diagnostic that may probe the lifetime of gaseous disks, and thereby constrain the giant planet formation timescale, is [NeII] 12.8μm; only a handful of [NeII] emitters have been studied at high spectral resolution to determine whether the emission arises in the disk and over what radii. Addressing the 3 issues listed above requires surveys of large samples (many 100s) of objects at high dispersion and high signal-to-noise. While the study of such large samples probably requires a ground-based 30-m class telescope, important path-finding work can be carried out with the current generation of large ground-based telescopes. Using such facilities to characterize spectral line diagnostics and study the brightest populations can easily consume 100 nights of observing.

4. Exoplanets

Long-Period Exoplanet Systems: Imaging

The development of extreme adaptive optics systems with coronagraphy for the imaging of exoplanets (e.g., the Gemini Planet Imager [GPI] and Spectro-Polarimetric High-contrast Exoplanet REsearch [SPHERE, by ESO]) will play a key role in the future of large aperture telescopes, providing optimal blocking of light from the central source to image faint companions close to their host stars. In order to succeed in detecting young, self-luminous exoplanets in orbit between 4 to 40 AU around nearby stars, these instruments must achieve contrast ratios of 10^7, with an inner working angle of $3\lambda/D$. To achieve the high quality adaptive optics correction of the wavefront, bright guide stars are needed (V=5-9 mag) which limits the most precise measurements to bright galactic objects. The recent widely publicized detection of a three-planet system around the A5V star HR 8799 spectacularly illustrates the power and potential of this technique.

In addition to exoplanets, these extreme AO systems will allow new studies of low surface brightness emission for circumstellar disks. Through dual channel polarimetry, capable of removing the unpolarized stellar light while allowing the scattered light from the disk to be detected, imaging of low-contrast disk features such as rings and arcs will provide tracers of unseen planets and the planet formation processes at work. These sensitive observations will furthermore detect circumstellar disk structure closer to the central stars and with higher angular resolution and contrast ratios than any previous studies.

The most scientifically rich stellar samples include young stars, A stars, adolescent FGK stars, a 2000 star volume limited sample, and an unbiased disk survey. Simulations suggest that more than 100 exoplanets will be detected by these surveys, enabling meaningful statistical analysis of exoplanet demographics of the long period systems not practically detectable using radial velocity monitoring. Furthermore, coronagraphy is not limited to low-activity main sequence stars, as are the high-precision radial velocity surveys, and so will permit the exploration of a completely new parameter space important for the development of planet formation theory and for the study of exoplanets around stars more massive than the Sun.

Short-Period Exoplanet Systems: Spectroscopy

The vast majority of exoplanets found to date have been detected with sensitive radial velocity (RV) surveys; this remains a key technique for the exploration of the short-period parameter space. Consistent progress has been made in improving instruments on large and small telescopes in order to detect lower and lower masses. Currently precisions of ~1 m/s are routine. Not only are RV surveys now sensitive to lower masses than ever, but they are also pushing exoplanet detection into diverse populations: higher mass, lower mass, and younger stars.

Searches for the lowest mass, even terrestrial mass, planets hold the most promise for the lowest mass stellar targets. Thus, M stars are key. While planets in the HZ around M stars are likely to be tidally locked, this is no longer viewed as fatal to life and indeed, vigorous arguments for the viability of life on M star planets is made in a comprehensive 2007 review titled "*A Reappraisal of The Habitability of Planets around M Dwarf Stars*" published in Astrobilogy, Vol. 7, by Tarter et al.

Although M stars are the most numerous and are easily identifiable in the Solar neighborhood, they are also the faintest and thus pose a particular observing challenge, well-met by 6.5-10 m facilities. The higher the signal-to-noise ratio, the more precise the RV measurements. In the quest to identify Earth-mass planets around other stars, high precision is tantamount. The youngest planets, presumably undergoing formation or recently formed in the circumstellar disks of T Tauri stars, also require large aperture telescopes because the closest star forming regions are at 120 pc or more. At these distances, even the FGK stars are relatively faint and thus current surveys are sensitive only to Jupiter mass or larger planets. The challenge of disentangling the legitimate RV signal from the star spot induced RV variability in young stars is best met by conducting surveys in the infrared with visible light followup spectroscopy, requiring the availability of large amounts of time on 6.5-10 m class telescopes with a high-resolution infrared spectrograph.

Long-term stability in planet searches enables the detection of longer-period systems. Thus not only is it desirable to use large aperture systems, but also it is crucial, in order to overlap the imaging and RV planet parameter space, to design surveys at these facilities that are sensitive to planets further from their parent stars over years and decades. Thus, significant 6.5-10 m time guaranteed on long time scales is needed.

Characterization of Exoplanet Atmopheres: Transit Photometry

Transiting (or near-transiting) extrasolar planets provide unique opportunities to measure physical properties of exoplanets and their atmospheres. The physical characteristics of an exoplanet atmosphere can be probed via: (1) resonance line absorption of starlight transmitted through the extended exoplanetary atmosphere during a transit, (2) reflected stellar light of a transiting or near-transiting exoplanet, (3) secondary eclipse measurements in the infrared. These observations provide fundamental measurements of exoplanetary atmospheres, including, albedo, chemical constituents, temperature and pressure profiles, and atmospheric dynamics and mixing. Disentangling signal from the host star and the exoplanet is a daunting task and requires access to large aperture telescopes with the appropriate instrumental capabilities. Indeed, attempts to measure exoplanetary atmospheres in these ways have been made from all major large-aperture telescopes. Although ground-based attempts at all three techniques have been made, no reflected light off an exoplanetary atmosphere has been detected, and secondary eclipse measurements in the infrared have only been successful from space.

These measurements are typically on the very edge of the capabilities of the current telescopes and instrumentation. Therefore large aperture telescopes, efficient instrumentation for which systematic noise sources are well-characterized and capacity for rapid readout observations of transient events (e.g., transits, secondary eclipses) are absolutely essential. Observations of many transits will be critical for precise, high signal-to-noise measurements of any temporal behavior. At this point, only a handful of bright exoplanet host stars are available for studies of this kind, but in the near-future, with the continued success of both ground-based and space-based transit searches, the number and diversity of targets will increase significantly. Optimal observing wavelengths range from the optical to the infrared. In some cases moderate resolution spectrographs (R=20,000) are important, but of paramount importance is the efficiency of the instrument, and the capacity for acquisition of observations at specific times or for specific intervals, relative to the exoplanetary orbit.

It appears that hot-Jupiters show diversity in their atmospheric properties. For example, some exoplanetary atmospheres contain a thermal inversion layer (e.g., HD209458b), while others do not (e.g., HD189733b). Therefore, a large-scale effort to do comparative exoplanetology, will be critical for understanding the atmospheric properties of hot exoplanets. In addition, any advances that can be made from the ground, on characterizing the atmospheres of hot-Jupiters, will lay the foundation for similar future work on Earth-sized extrasolar planetary atmospheres (and the relationship between atmospheric properties and habitability.

5. The Interstellar Medium at High Spectral Resolution

The interstellar medium (ISM) is one of the basic constituents of galaxies and one of the essential components of the life-cycle of stars. Therefore, studies of the ISM connect to many fundamental areas of astrophysics. The morphology, density, and temperature of the ISM control star formation, the dynamics of the ISM provides information on the stellar winds of both early- and late-type stars, the ionization of the ISM provides information on the radiation field, and the chemical abundances and enrichment of the ISM provide information about the death of stars and supernovae.

Observationally, ISM studies reduce to the determination of the location and three-dimensional morphology of the ISM and the sensitive measurement of any number of physical properties (e.g., density, temperature, turbulence, kinematics, shock structure, dust content and composition, molecular and atomic abundances). The structures that are studied include shells, bubbles (that often spill into the galactic halo), planetary nebulae, supernova remnants, star-forming regions, etc. These structures are basic constituents of all galaxies, can be observed along the line of sight toward bright but distant targets (e.g., quasars and gamma ray bursts), and tell us something fundamental about how galaxies evolve, how galaxies control internal feedback on processes such as star formation, and how galaxies modulate the infall and outflow of ISM material with their immediate environments.

High resolution spectrographs on large aperture telescopes open up new ISM environments, including the Milky Way halo, nearby galaxies, and even high redshift interstellar media, while at the same time providing more detailed access to Galactic ISM environments. Currently, Galactic ISM environments, such as the local ISM, the canonical nearby low-mass star-forming clouds, Galactic bubbles, shells, and fountains, and many high-mass star-forming regions, are being studied in detail using high dispersion and high spatial resolution optical and infrared spectroscopy. A critical breakthrough in studying these environments was the accessibility of multiple sight lines and multiple diagnostics. More distant environments, such as the halo, ISM of nearby galaxies, and circumstellar material surrounding supernovae (SNe) and gamma ray bursts (GRBs), suffer from a severely limited number of accessible sight lines, which prevent anything beyond a simplistic generalization of the ISM properties. The ISM is, by definition, an extended object. While many programs focus on the extended structure along the line of sight, there is much to be gained by high spatial resolution and multiplexing (e.g., multi-object spectrographs or integral-field units [IFUs]), such as in studies of small-scale structure in galactic environments, disk/stellar outflows, and circumstellar structures of stars, SNe, and GRBs. Future observations with high-resolution spectrographs, with multi-object or IFU capabilities, or high spatial resolution, on large aperture telescopes, will enable us to produce rich data cubes of absorption line measurements through the ISM environments of our own Galaxy, that will have a strong synergy with existing and future IR databases (e.g., Spitzer, Herschel) and radio emission data cubes (21 cm, CO, ALMA), and be able to probe ISM environments of the halo and nearby galaxies.

High resolving power (R~100,000 - 300,000) is typically required for this work. In order to measure basic morphological and physical properties from ISM absorption lines, multiple individual components need to be resolved. Cold Na I ISM absorption has been observed with intrinsic FWHM~0.6 km/s (Meyer et al. 2006). To fully resolve such a narrow component is beyond most astrophysical spectrographs, but currently the standard high resolution platforms fall in the R=120,000 to 250,000 range (HST, VLT, AAT, HET, etc). In addition, high spectral resolution is required to resolve multiple transitions within molecular bands. Observations taken with a resolving power <100,000 significantly limit the scientific output. The blending of multiple Doppler-shifted ISM environments results in erroneous measurements of basic physical properties. Some applications, notably toward the most distant and faintest targets, are willing to sacrifice spectral resolution (i.e., operate near R~50,000) for gains in throughput and broader spectral range.

Numerous ions are available in the optical. The strongest transitions include Ca II (3933 A) and Na I (5890 A), and would be the highest priority. Other lines include K I (7699 A), Ti II (3300 A). In addition, several molecules are available (CN, CH, CH+). In the infrared, numerous important molecular transitions are accessible (e.g., CO, H3+). Essentially, there are lines of interest from the atmospheric cutoff near 3000 A, into the near-infrared beyond 3 micron, and therefore full coverage across these wavelength regions is desirable.

6. Stellar Populations

Stellar population studies with current and future large telescopes include Galactic archaeology, an approach that exploits the fossil record of element abundance ratios contained in the long-lived stars which constitute the major components of the Galaxy (i.e. thin and thick disks, halo, bulge, and bar). These chemical abundance ratios probe the history of the star formation rate (SFR), formation timescale, initial mass function (IMF), mixing, and the importance of gas inflows and outflows. Detailed study of the Galaxy is important for understanding the evolution of extra-galactic systems, which cannot be studied in as much detail.

The Milky Way and Close Neighbors

Accreted galactic fragments within the Milky Way, identified by kinematic and chemical properties, shed light on the hierarchical structure formation scenario for the Galaxy. However, to understand this paradigm it is necessary to have a library of the chemical signatures of the potential accreted fragments. In this regard galactic archaeology of nearby low mass systems (Magellanic Clouds, Local Group dwarf spheroidals, and irregular galaxies) not only helps to define the role of accretion, but also probes galaxy evolution and chemical evolution as a function of galactic environment and stellar nucleosynthesis yields.

Low signal-to-noise (S/N), low resolution, multi-object, Ca-triplet spectroscopic studies of red giant stars in the outskirts of M31 have recently been pursued by several groups. The measured properties of kinematics, metallicity, and crude estimates of the [□/Fe] ratios, have enabled an understanding of the structure and evolution of M31's bulge and halo, including the role of accretion. Similar studies of M33 and all other galaxies out the most distant parts of the Local Group will be important for understanding evolution of the Milky Way in the context of general galaxy evolution. By combining low S/N spectra, obtained with efficient multi-object spectrographs, high S/N composite spectra for the most distant populations in the Local Group may be obtained, to determine the detailed chemical composition of the ensemble.

A handful of globular clusters (GCs) in the Milky Way and the LMC show evidence for multiple main sequence turnoffs. For the old GCs of the Milky Way it is believed that sub-populations with different He abundances are the cause, whilst the young LMC GCs are proposed to contain sub-populations with slightly different ages. Investigation of this phenomenon is important for understanding the formation of GCs.

Extra-Galactic Populations

Of particular interest is the chemical composition of stars in the newly discovered low-luminosity galaxies, with both low- and high-resolution spectroscopy. Some of these stars are chemically peculiar. This might be explained with a very low SFR plus stochastic sampling of the supernova IMF, or an unusual enhancement of population III material, or it may be related to the high fraction of dark matter in these galaxies. These galaxies may also be an important source of the extreme metal-poor (EMP) stars seen in the Galactic halo. The exploration of low-luminosity galaxies is just beginning; their unusual properties may tell us much about galaxy evolution, and with LSST many more will be discovered. The composition of EMP stars probe the earliest phase of chemical evolution. Some EMP stars are dominated in certain elements by individual supernovae (SN), and provide direct measurement of SN nucleosynthesis yields. Certain systematic EMP element ratio trends (e.g. [Co/Cr] versus [Fe/H]) may be a fossil record of population III. Current progress in understanding what these stars can tell us about the beginning of chemical and galaxy evolution and supernova physics is limited by the small number known EMP stars, but new surveys (e.g., SEGUE, SDSS, Pan-STARRS and LSST) will find more.

A new technique of detailed abundance analysis for GCs in their integrated light offers the potential to perform galactic archaeology well outside the Local Group. It will not be possible to obtain this level of detailed composition information for *individual* red giant stars outside the Local Group even with 30m-class telescopes. Potential targets include the closest giant elliptical galaxy, Cen A, which is important because a census of all galaxy types must be studied for a complete picture of chemical evolution. Abundance studies of individual supergiant stars in galaxies outside the Local Group are useful for tracing the composition of the current gas only, and not galactic evolutionary history.

Crowded Field Populations

Stellar populations science with multi-conjugate adaptive optics (MCAO) includes photometry of crowded regions in the near-infrared, and feeding near-IR spectrographs, such as Flamingos II on Gemini. Imaging and spectroscopy of the Galactic center region, and its HII regions, are planned to detect intermediate mass stars to determine the IMF and an approximate age. MCAO observations of the star-forming region in Orion will enable measurement of the IMF. Deep MCAO imaging of the cores of nearby open clusters, GCs and young super stellar clusters (e.g. in 30 Dor and NGC 3603) will allow the IMF to be measured down to the limit of H burning (brown dwarf regime) as a function of metallicity. Other stellar population MCAO projects include the study of stellar populations in nearby starburst galaxies, the brightest AGB stars out to the Virgo cluster of galaxies, a search for remnants of the merger history from resolved stars in the outskirts of Cen A, and the properties of extra-galactic GCs.

Summary

Ultimately, detailed chemical abundance studies of all the above areas will result in a single picture of galaxy evolution, chemical evolution, and stellar nucleosynthesis yields. The main obstacle to pursuing many of the above projects on federal telescopes is the lack of, current or planned competitive high-resolution optical, UV and IR spectrographs. High spectral resolution (R~30,000 to 100,000) is required for optimal detection of the weak, abundance-sensitive lines, to isolate lines from blends, and for proper continuum definition (for metal-rich stars). The UV region is important for EMP stars, which have very few lines in the optical, while the NIR region is important for CNO abundances, and the composition of M stars in metal-rich populations. For many of the listed projects multi-object spectroscopy could, in principle, provide enormous efficiency gains. In this regard the planned WFMOS spectrograph would be of some use: for projects on the Galactic thin disk and bulge, and global studies of large Local Group galaxies. However, for the Galactic halo, the low luminosity Local Group galaxies, GC studies, and sub-regions of large Local Group galaxies, WFMOS is very poorly suited, due to mismatch in fiber and target densities and/or target field size. Far less than optimal use of WFMOS would be obtained for Galactic thick disk studies and GC integrated-light abundance work.

7. Galaxy Structure and Evolution

Explorations of the nature and evolution of distant galaxies were primary science drivers for the construction of large optical/near-IR telescopes and, based on the fraction of accepted proposals in this area and increasing publications by new astronomers, continue to be a significant portion of the science done on these facilities today. Discoveries of evolution over the last dozen years with these telescopes have been many, diverse, and important and include: stellar mass buildup, dusty and non-dusty star formation activity, blue-red color bimodality, merger rate, supermassive black hole growth, chemical abundances, kinematics, clustering and environment, and morphologies. These discoveries have usually been the result of combining deep multi-band imaging and spectroscopic data as well as joining data sets from other major telescopes, especially HST, Spitzer, Chandra, and VLA.

Galaxies are, however, a very rich, complex, challenging, time-evolving, and diverse set of targets that involve many physical mechanisms and processes that have yet to be well-understood or characterized. Many fundamental questions have yet to be answered: When did the first galaxies form? What is their role in ionizing the IGM? What is the inflow and outflow of cool gas and how has this changed with time? What is the relationship among a zoo of distant galaxy types already identified: Lyman Break Galaxies, Lyman alpha emission line galaxies, sub-mm bright galaxies, radio and X-ray bright galaxies, distant red galaxies, galaxies found in *BzK* diagrams, GRB galaxies, and many others? How and when did bulges, thick and thin disks, bars, etc. form and evolve? What is the influence of minor and major mergers? What about the dependence on dark halo masses or their environments such as clusters and groups? How did galaxies get quenched or transition from the "blue cloud" to "green valley" to "red sequence" in their evolution of the color-mass/luminosity diagram? What is the co-evolution among black holes and bulge formation?

As we have learned from SDSS, samples of many 10,000's or even larger are sometimes critical to yield statistically useful measures of galaxy properties and their relationships. Thus, despite the explosion in the quantity and quality of data and of theoretical simulations, these still open questions illustrate that astronomers are scratching only the surface with answers needing to await the next generation of research.   Improvements will be enabled not only by the vastly increased capabilities in multiplexing and areal coverage, anticipated to yield 10 to 100 times larger samples, or in higher spatial and spectral resolution information, but also by new facilities and capabilities such as with JWST and ALMA and, perhaps, LSST over the next decade, followed by ELTs and the SKA.

As one concrete example of the enormous capacity for higher efficiency, more capabilities, and many more nights on 6.5-10m class telescopes in faint galaxy research, let us estimate the resources needed to “merely” follow up the few small regions (representing 1/1000 of 1% of the sky) that have already received investments of the deepest multi-wavelength data (X-ray to radio) for the study of distant galaxies and AGN's, namely, the two GOODS fields (300 sq. arcmin), EGS (600 sq. arcmin), and the ultra deep survey region of COSMOS (120 sq. arcmin). This 1000 square arcmin area has well over 100,000 galaxies, of which only a few 1000 have even the barest of *optical* spectroscopy and mainly at depths needed for just redshifts. With deeper data in the optical and especially spectra in the near-infrared, we can hope to reach higher redshifts, less luminous galaxies, stellar population measures of age and chemical abundance and star formation histories, and kinematics. With wider and larger samples, we can hope to beat "cosmic variance", explore the co-moving evolution of subclasses of galaxies and active galaxies, or their dependence over a range of environments.

Higher multiplexing capabilities (through IFU or multi-object spectrographs) are critical to afford the very long exposures needed to reach the fainter targets. Pushing to the near IR, especially for spectroscopy, is essential to explore the information-rich, rest-frame optical of the high redshift galaxies and to diminish the effects of dust. Higher spatial resolution at the adaptive optics scale (< 0.1 arcsec) for near-IR imaging enables separate measures of the luminosities and colors (stellar populations) of bulges, bars, tidal/merger features, thick disks, and aggregating subunits of young galaxies. Multi-IFU or multi-slit AO spectroscopy will be needed to study star formation rates, metallicities, and kinematics on subcomponent scales.

How many nights are needed using these new capabilities? For near-IR MOS, at say 50 targets with one-night exposures to cover 10,000 galaxies in one of the *JHK* windows (targets chosen by photometric redshifts), 200 nights are needed without losses due to weather. For MCAO, near-IR imaging at one-night (preferably more) exposures for each of two filters (say *H* and *K*) per coverage of 5 square arcmin translates to another 400 nights without including losses due to weather. For multi-IFU (say 5) AO (MOAO) spectroscopy of one night exposures for a tiny subsample of only 1000 targets requires another 200 nights. Assuming these intensive follow-up studies (roughly a total of 1000 nights when weather is included) will be roughly 1/3 of all programs in the galaxy structure and evolution category, then roughly 3000 nights of 6.5m-10m class telescopes would be easily consumed, i.e., the equivalent of 15 years of the entire US time on Gemini!

8. Active Galactic Nuclei and Star Formation in Evolving Galaxies

Supermassive black holes may be ubiquitous in the nuclei of large galaxies, and the empirical relationship between the black hole and stellar bulge masses demonstrates that the interplay of black hole accretion and star formation are fundamental to the evolution of galaxies. Here we show the necessity of observations with large telescopes to make progress in three related areas: the problem of IR-luminous galaxies, black hole growth in the early universe, and describing the immediate AGN environment. These topics are merely representative examples, not a comprehensive list of AGN and galaxy science with large telescopes. Fundamentally, accounting for black hole growth and star formation as galaxies evolve requires the high sensitivity and high angular resolution that large telescopes afford.

IR-luminous galaxies

Over the last decade, surveys undertaken with MIPS on Spitzer, SCUBA on JCMT, and many other platforms have made it clear that much of the star formation and AGN luminosity in the distant universe is occurring in extremely dusty galaxies that are hidden from view at optical wavelengths. The galaxies hosting this activity are highly luminous, with emergent luminosities of 10^{12} –10^{14} L_{sun}, comparable to the luminosities of quasars. Their peak space density appears to occur at $z \sim 2$, with high comoving densities of such systems extending out to at least $z = 4$. The high redshift limit for these systems is defined by the search techniques, rather than by any physical processes.

While these systems are comparatively bright at their discovery wavelengths (i.e., a few to 10 mJy at submm wavelengths, 0.1–10 mJy at 24μm from Spitzer), by their very nature such galaxies are extremely faint in the optical and near-IR. Understanding the characteristics of these galaxies, their power sources, and their place in the overall evolutionary history of galaxies requires substantial investments in large (6.5–10m class) telescope time. These systems are simply too faint to allow meaningful observations on smaller telescopes.

The identification process is difficult, requiring deep images at optical and/or near infrared wavelengths. This is most efficiently done with 6.5–10m imaging. The follow-on spectroscopy at optical and near infrared wavelengths that is necessary to establish properties as basic as redshifts, as well as spectral classifications, require many hours of 6.5–10m telescope time. Probing other properties, e.g. morphology and dynamics, requires sub-kpc spatial resolution. This angular resolution and sensitivity is afforded only by adaptive optics fed imagery and spectroscopy on 8-10m telescopes.

Tens of such galaxies have been observed to date. To address the deeper questions posed by these heavily dust enshrouded systems requires studies of hundreds to thousands of such systems, which requires hundreds of nights of 8-10 m class telescopes with current instrumentation.

Black Hole Formation and Growth

Observations of AGN at high redshift provide input for models of galaxy formation. Determinations of black hole mass estimates are particularly important for understanding galaxy formation. For the central black holes of quasars with masses greater than 10^9 M_{sun}, either black hole growth must have proceeded rapidly at the earliest times, or the seed black holes in galactic nuclei must have had large initial masses. In addition to enabling mass estimates, spectroscopy of active galaxies also reveals the immediate relationship between star formation and accretion. Current results indicate that star formation, too, proceeded rapidly in the early universe, resulting in chemically enriched galaxies at early epochs.

As in the case of the IR-luminous galaxies, the problem of AGN identification is particularly severe when space-based infrared or X-ray data provide the initial selection of candidate AGN because these objects are extremely weak in the optical and near-IR. However, the leverage of the most extreme examples best yields black hole masses and AGN luminosity functions. Current results show strong evolution in redshift with luminosity dependence. Observations of both the high redshift cases that sample the high mass/high luminosity end and the intrinsically faint low mass/low luminosity sources are experimentally challenging: large telescopes are essential to continued progress. Moreover, further dynamical measurements of the black hole masses, which define the black hole mass/stellar bulge mass relationship, are now feasible out to $z = 0.1$. These rely directly on diffraction-limited adaptive optics with integral field spectroscopy available at 6.5-10 m class facilities.

The Immediate AGN environment

The presence of an optically and geometrically thick torus of gas and dust around AGN generally accounts for a variety of observational characteristics in the context of unified theories, but the exact properties of this torus and its role in introducing selection effects that alter the cosmic census of black holes remain uncertain. Because the dust intercepts and reprocesses the intrinsic AGN power to emerge predominantly in the mid-infrared, measurements at these wavelengths (7–25 μm) are critical. Moreover, current work shows that the torus is characteristically small (20 pc), so diffraction limited measurements on large telescopes are essential to separate the immediate AGN environment from surrounding stellar contamination. While the near-infrared emission represents a smaller fraction of the reprocessed luminosity than the mid infrared emission, it plays a useful role in the determination of the physical properties of the torus and viewing geometry, provided the measurements are obtained on comparable physical scales, such as those that are feasible with adaptive optics.

9. Cosmology

Dark energy, dark matter, and cosmology are leading topics in modern astrophysics and one of the principle drivers for large optical telescopes. The study of these topics requires ambitious work with either very large samples or very precise measurements, or both. But the rewards are high, as astronomy provides an opportunity to study physical laws that are beyond the scale of terrestrial laboratories.

Dark Energy

High-redshift supernovae Ia have been the leading route to the cosmological distance-redshift relation. Spectroscopy to determine the redshift and type of the SNe has required major allocations of 8-meter class telescope time. Current work is approaching the systematic limit of current photometry. However, it is likely that future imaging surveys (PanSTARRS, Dark Energy Survey, and LSST) will reduce these errors and keep the need for spectroscopic followup vigorous. It also appears that SNe will remain the dominant dark energy method at $z<0.5$, as cosmic variance limits the other major probes. Searching for evolution in the Ia population is therefore critical, and 8-m spectroscopy is a major ingredient.

Weak lensing is a rapidly growing field that will have major impacts on the study of dark energy, structure formation, and galaxy evolution. Most of the imaging to date has been on smaller telescopes (with some from Subaru and VLT), but the need for deep data over most of the sky is one of the key drivers for LSST. Moreover, to extract the best information from weak lensing requires photometric redshifts, which in turn require spectroscopic validation. Validating the samples at the depth of dozens of object per square arcminute is a challenging project. The estimates for required survey sizes in the literature are likely to be too optimistic (i.e., too small).

Cluster counting will continue to be pursued, particularly with the SZ surveys and deep imaging from DES and LSST. Systematic errors are crucial here, and this will require detailed study of a representative sample of clusters. That implies significant narrow-field spectroscopy as well as deep weak lensing maps. Higher redshift clusters are particularly interesting but will require extensive validation with IR imaging and spectroscopy.

Large galaxy redshift surveys offer multiple probes of dark energy. Baryon acoustic oscillations provide a standard ruler, traceable from the microwave background and largely insensitive to low-redshift astrophysics. This offers a robust route to measuring the angular diameter distance and the Hubble parameter as a function of redshift, likely to precisions better than 1%. The non-oscillatory portion of the galaxy power spectrum could also produce distance estimates if galaxy bias could be accurately modeled. The large-scale infall measured by redshift distortions provides a direct measure of the growth of structure. Cross-correlation of redshift surveys with weak lensing maps offers a number of important opportunities to characterize galaxy masses and measure the large-scale amplitude of the matter power spectrum. All of these applications are volume starved. Surveys at the level of $(Gpc/h)^3$ are the metric of the field; this drives one to thousands of square degrees at $z\sim1$ and many hundreds at higher redshift.

Pursuit of direct measures of the Hubble constant will continue to be an important topic. Cross-checking direct measures against the CMB-based inferences from the acoustic oscillations is an important check of our cosmological assumptions about the dark sector. Moreover, precision measurements of H_o are important for dark energy constraints at low redshifts.

It is likely that other methods for measuring dark energy will mature and will put demands on 8-meter class telescopes. Examples include: measurements of type II SNe; follow-up of standard sirens from LISA; follow-up of high-redshift objects such as radio jets and gamma-ray bursts; follow-up of strong lenses.

Dark Matter

In the study of dark matter, the focus has been on smaller scales. This can be probed with mass modeling of low-surface brightness galaxies, which requires large numbers of high-precision (<5 km/s) velocities of individual stars. Surveys of dwarf galaxies around more distant galaxies puts a premium on reaching low surface brightnesses. Small scales are also reached in the study of the Lyman-alpha forest, which favors high-resolution spectroscopy in the blue. Finally, strong gravitational lensing can probe dark matter properties; this requires the discovery of clean systems with deep imaging and characterization thereof with multi-object narrow-field spectroscopy.

Other Cosmological Applications

The study of ``fundamental'' cosmology goes well beyond dark matter and dark energy. Studies of cosmological perturbations as detailed above allow us to look for deviations from a power-law initial spectrum, deviations from Gaussianity, minor admixtures of isocurvature perturbations, and primordial gravitational waves, which push our view into the first second of the history of the Universe. These will rely on the combination of CMB data with data from redshift surveys, weak lensing, and cluster counts. Searches for variations in the fundamental constants (fine structure constant, electron-to-proton mass ratio, etc.) will require very high-resolution spectroscopy (and exquisite wavelength calibration) on the largest telescopes. It should be expected that other interesting tests will be developed. Many will be applied to survey data taken for other purposes, but some will benefit from directed time on 8-meter class telescopes.

It is also the case that the large homogeneous data sets compiled for cosmological questions tend to be highly useful for the study of major astrophysical research areas such as the evolution of galaxies, clusters, black holes, and the intracluster and intergalactic media. (Probes of the intracluster and intergalactic media include gamma-ray bursts and quasars; the burst will fade, though, enabling a more thorough study of the structure that produces absorption features in the spectra of the burst afterglow.) This leveraging opportunity can be improved with care in the experimental design as well as funding of researchers intent on using the data sets for these purposes.

10. Acknowledgements

In addition to committee members, we would like to acknowledge the many short contributions by ALTAIR survey participants that supplied the background and ideas for this brief. We also appreciate contributions by, W. Grundy, I. de Pater and H. Roe for their extended contributions to the solar system science.

Appendix C: Altair Survey

Goals and Method: The survey was designed to probe the needs of the US ground-based O/IR community for resources (observing time, observing modes, instruments, telescopes) at the 6.5- to 10-m aperture range, both now and into the next decade.

A draft of the survey was written by committee members Lisa Prato, David Koo, Seth Redfield, and Joan Najita. It was reviewed by the entire ALTAIR committee and revised based on their input.

The first 7 questions of the survey explored the demographics of the respondents (the kind of institution they are affiliated with, their science research areas, their observing wavelengths, functional responsibilities, etc.). The remaining questions focused on the needs of respondents for observing time, instruments, observing modes, and other observing resources, both now and in the future. Respondents were invited to respond to either the short version of the survey (the first 20, mostly non-essay questions) or the longer version (5 additional, mostly essay questions). The latter essay questions allowed respondents to elaborate on their views on the Gemini telescopes, the impact of new observing resources (ALMA, etc.) on their future research program, the appropriate scope of large collaborations, and anticipated future science, and priorities for the allocation of additional federal funding, all in the context of large telescopes.

The survey was advertised to a broad community in the 2008 July 15 issue of the NOAO electronic newsletter, *Currents*. It was also advertised by e-mail in a targeted way to Gemini proposers (PIs and co-Is) from the last 3 years. The Keck Director Taft Armandroff also advertised the survey to the Keck community via e-mail and through the Keck electronic newsletter.

The survey was conducted via an on-line web form (archived at http://www.noao.edu/cgi-bin/altair/survey.pl). Respondents were encouraged to respond by 2008 August 15, so that the results could be reviewed at the September meeting of the ALTAIR committee. Survey responses were accepted up to approximately 2008 September 15. The data were ingested into a database for analysis.

1. Re-survey

A review of the results accumulated by 2008 August 7 revealed a problem with the way the database software ingested the responses to question #14 on instrumentation. The problem stemmed from the fact that the software did not anticipate that people would assign the same rank to multiple capabilities in the same time period, despite instructions to the contrary. This flaw made it difficult to interpret the results.

As a result, we modified the survey form on 2008 August 11 so that the instructions and format made it clearer that the goal was to create a single ranked list. The form was also changed so that it would not allow multiple capabilities to be ranked equally. We further re-surveyed on question #14 everyone who had already responded and provided contact information (approximately 170 of the approximately 320 responses received at that point). Of the 170 people contacted, approximately 110 responded.

2. Results: Demographics

We received responses from approximately 570 individuals. The high response rate, despite the limited advertising effort, indicates that there is a significant, energized US community of large telescope observers. The science research areas of the respondents span a broad range, including solar system, extra-solar planets, stars, galaxies, and cosmology. We received responses from graduate students, post-docs, faculty/staff, and administrators. The respondents represent more than 104 distinct institutions, as determined from non-mandatory institutional affiliation information provided by respondents. These institutions include 2-4 year colleges, universities, observatories, government laboratories, federally funded research centers, and industry.

Approximately 44% of respondents (253/570) have no access via their institutional affiliation to 6.5- to 10-m facilities. The remainder, have institutional access to one or more facilities. More than 80% of respondents (468/570) have experience using 6.5- to 10-m telescopes. Below we tabulate the responses to the demographic questions.

Number of respondents: 570

Q1. I am primarily (check all that applies):

A theorist	41
An instrument builder	61
An observer	544
Other	24

Q2. My research involves observations made at the following wavelengths (*indicate as many as are relevant and in priority order, 1-8 with 1 being the highest*)*:*

	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
UV	17	64	78	54	20	21	15	2
X-ray	18	26	42	55	38	18	19	1
Gamma-ray	1	3	6	4	9	8	12	46
Longer wavelength radio	9	19	27	36	41	30	22	9
Mid-infrared	43	70	106	49	33	15	7	1
Near-infrared	149	230	86	31	11	4	0	0
Optical	328	121	62	15	9	1	0	0
Submillimeter/millimeter	5	12	28	59	34	26	20	14

Q3. My science research areas are (check all that applies):

ISM	100
Solar System	74
Cosmology	151
Extra-solar planets	119
Galaxy structure and evolution	247
High energy, AGN, and black holes	128
Other	31
Solar physics	10
Star and/or planet formation	160
Stellar physics	184
Stellar populations	218

Q4. My home institution is:

In the United States (or considered to be US-based)	528
Not in the US (or not US-based)	42

Q5. The institution I am affiliated with is a (check all that apply):

2-4 year college	33
NASA research center	15
Federally funded astronomy center	59
Government laboratory	24
Industry	1
Observatory	97
Other	27
Research university, MS granting	28
Research university, Ph.D. granting	379

Q6. I am currently:

A postdoc	105
A student	69
Administrator	8
Faculty or staff with primarily research responsibilities	182
Faculty or staff with significant service or functional responsibilities	89
Faculty or staff with significant teaching responsibilities	106
Other	11

Q7. I have access through my institution to the following 6.5 to 10-m facilities (check all that apply; do not include access via time trades with other observatories or open access time, e.g. through the NOAO or NASA Keck proposal process):

None of the above	253
GTC	14
Gemini	23
HET	51
Keck	103
LBT	55
MMT	62
Magellan	95
Other	14
SALT	31
Subaru	21
VLT	23

The results reported above include a correction for those respondents who could be identified as incorrectly claiming institutional access to Gemini, as determined from their institutional affiliation (if provided) or other identifying information.

Q8. Do you use optical/IR 6.5 to 10-m telescopes?

No, I do not have a need for such facilities	12
No, high oversubscription rates dissuade me	52
Yes, I anticipate using such telescopes in the next few years	300
Yes, I have used a 6.5 to 10-m telescope	468

3. Results: Observing Programs

Q9. Number of Nights Proposed and Received
If you have observed with 6.5 to 10-m telescopes in the last 5 years, approximately how many nights in total have you proposed for and received in the last 5 years?

Number of respondents: 447

Results for all respondents:

	< 5	**5-10**	**10-20**	**20-50**	**> 50**
Number of nights proposed	89	102	119	94	38
Number of nights received	153	104	88	61	25

Results for respondents with institutional access to facilities (287) as a fraction:

	< 5	**5-10**	**10-20**	**20-50**	**> 50**
Number of nights proposed	0.17	0.19	0.28	0.24	0.12
Number of nights received	0.28	0.22	0.24	0.19	0.08

Results for respondents without institutional access to facilities (160) as a fraction:

	< 5	**5-10**	**10-20**	**20-50**	**> 50**
Number of nights proposed	0.26	0.30	0.25	0.16	0.03
Number of nights received	0.50	0.28	0.14	0.05	0.03

Interpretation: The results for all respondents indicate that their ambitions are much greater than the resources that are available to meet their needs. (The distribution of desired number of nights peaks at 10-20 while the distribution of allocated number of nights peaks at <5.) The distribution of nights allocated to respondents with institutional access to facilities is roughly equal across the bins (<5, 5-10, 10-20, and >20). The distribution of nights allocated to respondents without institutional access to facilities is much more sharply peaked at <5 nights. This group is much less able to carry out programs requiring a large number of nights.

Q10. Paths for Access to Large Telescopes
What paths do you use for access to 6.5 to 10-m telescopes? (Indicate as many as apply and rank order these 1-6, with 1 indicating your primary access path.)

Number of respondents: 540

	#1	**#2**	**#3**	**#4**	**#5**	**#6**
Institutional access to facilities	203	38	21	4	6	0
Access to facilities via a collaborator	93	127	70	24	5	1
Open access to Gemini via the NOAO proposal process	122	119	48	19	4	0
Open access to non-federal facilities	31	47	51	26	7	0
Other open access time	76	69	35	17	6	0
Other	10	5	1	3	1	5

Interpretation: Both open access paths and access via one's institution or via a collaborator are common paths by which people use large telescopes.

Q11. Interest in Applying for Gemini Time (Part 1)
Have you applied for time on the Gemini telescopes as PI or co-I?

Number of respondents: 568

No	214
Yes	354

Interpretatation: A significant fraction of the large telescope community has or has had some interest in the Gemini telescopes.

Q12. Interest in Applying for Gemini Time (Part 2)
If you have not applied for time on the Gemini telescopes, or you do not plan to apply again, why is that?

Number of respondents: 296

There were 36 people who checked "Other" and provided an explanation in the associated text box. Whereas the check box allowed the respondent to select only one response from a list of options, the text box allows respondents to select more than one response from the list. They could also express additional thoughts that were not in the list.

Method: We tabulated the number of times various ideas were expressed in the written comments. The ideas that duplicated the options from the list were added to the tabulated values for those options.

Results:

Gemini does not have the instruments I need (77+7)	84
Gemini is too highly oversubscribed / TAC process is flawed (32+12)	44
I am interested in principle but have not yet applied (86+5)	91
I have access to other 6.5- to 10-m telescopes (47+3)	50
My science does not require 8-m telescopes (13+1)	14

Additional thoughts expressed by respondents:

Keck is a lot better / Gemini utterly dissatisfying	4
Visitor instruments not supported	2
Queue not reliable / is a disaster / produced flawed observations	3
Data quality inadequate	3
Classical observing not accommodated	1
I had an accepted program but got no data	1
Gemini process (phase I, phase II) is onerous	2
I've heard negative things about Gemini	1

Q13. Need for Access to Hemispheres
How important is access to specific hemispheres to your science programs?

Number of respondents: 570

I can do my science from either hemisphere.	186
My science programs require access to both hemispheres.	327
My science programs require access to the northern hemisphere.	38
My science programs require access to the southern hemisphere.	17

Respondents were invited to comment on their selection. The responses identified considerations such as the hemisphere-dependence of precursor observations and astronomical targets, as well as the need for access to both hemispheres in order to study sufficient numbers of rare objects.

Method: We tabulated the number of times a specific reason was given for access to one or both hemispheres in the written comments.

Reason	Hemisphere	Details
Complementary Capabilities	North (10)	Existing surveys such as SDSS or deep fields (7)
		Access to complementary facilities (e.g., WIYN, VLA) with which to carry out preliminary or complementary observations (3)
	South (10)	Existing surveys such as RAVE or deep fields (5)
		Access to complementary facilities (e.g., LCO, ALMA, South Pole Telescope, LSST) with which to carry out preliminary or complementary observations (5)
	Both (2)	Existing surveys (2)
Targets	North (3)	M31
	South (18)	Galactic center or bulge, Magellanic clouds, young stars or star forming regions, nearby dwarf galaxies, nearest globular clusters, Pluto and low dec KBOs
	Both (31)	Distribution of astronomical targets such as the Galactic plane or ecliptic (15) or need for larger samples of rare objects (16).
Site Characteristics	North (1)	Access to a high altitude, low water vapor site (MKO).

Q14. Instrumentation (including Re-survey Results)

As discussed above, after we noticed that there was a problem with the way the software that ingested the survey results treated question 14, we modified the survey form on 2008 August 11 so that people could not provide the same ranking for multiple capabilities. We received approximately 260 responses to the ALTAIR survey after the survey form was modified. We also carried out a re-survey solely on question 14 of everyone who responded before 2008 August 11 and who had also provided contact information (name or e-mail address). Approximately 110 people responded to the re-survey. The results for this question therefore reflect the priorities of approximately 370 respondents, a smaller number than responded to the entire survey.

The results are reported in matrix format. For each capability, we list the number of times it was chosen as a first, second, third priority, etc.

Q14a. What instrument capabilities will be important for your research in the next 2-3 years?

Please indicate as many as you require **currently** (in the next 2 -3 years) and over the **longer term** (2010 onward, in the era of ALMA, NVO, JWST, LSST, etc.). Rank order these with 1 being the highest rank. For each time period, create a single rank-ordered list from the entire suite of optical, NIR, and MIR capabilities below. **Do not** provide separate rankings for each wavelength region. **Do not** assign the same rank to multiple instrument capabilities.

Number of respondents: 365

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
MIR/High contrast DL imaging	7	4	3	9	6	1	3	4	2	2
MIR/IFU imaging and spectroscopy	0	5	1	3	1	2	3	1	1	0
MIR/Imaging	3	7	6	8	8	11	5	4	4	2
MIR/Interferometry	1	2	3	0	1	3	2	2	3	1
MIR/Other	1	0	0	0	0	0	1	1	0	0
MIR/Polarimetry or spectropolarimetry	0	2	4	1	2	5	0	3	0	0
MIR/Single-object spec. (R < 15000)	5	5	8	13	4	5	4	7	1	2
MIR/Single-object spec. (R > 15000)	4	1	11	2	6	4	2	1	1	1
Near-infrared/Diffraction-limited imaging	16	18	20	22	10	6	13	6	5	1
Near-infrared/High contrast DL imaging	10	7	5	7	8	3	2	3	0	2
NIR/IFU imaging and spectroscopy	7	11	10	14	15	8	5	2	4	5
NIR/Interferometry (including nulling)	3	5	3	1	4	3	5	1	1	0
NIR/Multi-object spectroscopy (R < 15000)	11	23	10	18	11	7	4	6	3	3
NIR/Multi-object spectroscopy (R > 15000)	4	4	7	15	6	6	3	0	0	0
NIR/Other	5	2	5	2	4	0	1	1	0	0
NIR/Polarimetry or spectropolarimetry	0	1	7	4	4	3	4	1	2	4
NIR/Seeing-limited imaging	5	20	30	17	10	12	6	6	2	1
NIR/Single-object spectroscopy (R < 15000)	14	27	14	22	16	13	8	3	5	4
NIR/Single-object spectroscopy (R > 15000)	25	23	26	8	13	8	4	3	1	0
Optical/IFU imaging and spectroscopy	15	9	12	8	14	10	7	3	7	2
Optical/Multi-object spec. (R < 15000)	46	38	29	20	5	8	3	0	0	1
Optical/Multi-object spec. (R > 15000)	13	27	17	13	9	2	2	1	0	0
Optical/Other	5	7	5	2	1	0	0	0	1	0
Optical/Polarimetry or spectropolarimetry	5	3	6	4	7	2	1	4	1	3
Optical/Single-object spec. (R < 15000)	31	29	20	19	13	7	2	5	1	3
Optical/Single-object spec. (R > 15000)	61	30	17	15	6	2	8	4	3	0
Optical/Wide-field imaging	59	31	31	15	12	8	6	0	4	1

Q14b. What instrument capabilities will be important for your research in longer term?

Number of respondents: 329

	#1	#2	#3	#4	#5	#6	#7	#8	#9	#10
MIR/High contrast DL imaging	5	7	4	8	6	5	3	2	4	2
MIR/IFU imaging and spectroscopy	2	4	5	3	4	3	5	3	2	1
MIR/Imaging	1	7	6	5	9	5	7	5	5	3
MIR/Interferometry	1	0	2	1	4	4	2	1	3	2
MIR/Other	0	0	0	0	1	0	0	1	1	0
MIR/Polarimetry or spectropolarimetry	1	4	5	1	2	2	0	4	0	0
MIR/Single-object spec. (R < 15000)	8	4	8	8	6	3	2	4	3	4
MIR/Single-object spec. (R > 15000)	3	3	8	6	7	3	0	4	1	2
NIR/Diffraction-limited imaging	16	21	16	23	7	14	9	5	3	2

NIR/High contrast DL imaging	11	11	8	6	7	6	0	2	1	2
NIR/IFU imaging and spectroscopy	7	14	11	21	13	12	8	2	3	2
NIR/Interferometry (including nulling)	5	5	4	2	3	3	5	3	2	1
NIR/Multi-object spectroscopy (R < 15000)	22	18	9	18	13	6	5	7	2	1
NIR/Multi-object spectroscopy (R > 15000)	12	6	14	16	5	5	4	1	0	1
NIR/Other	4	4	5	1	3	0	1	0	0	0
NIR/Polarimetry or spectropolarimetry	1	3	3	4	5	4	5	3	1	3
NIR/Seeing-limited imaging	1	15	26	15	12	9	10	5	1	1
NIR/Single-object spectroscopy (R < 15000)	12	20	9	19	13	13	6	7	3	2
NIR/Single-object spectroscopy (R > 15000)	23	15	20	8	11	6	5	3	4	0
Optical/IFU imaging and spectroscopy	14	12	11	9	9	11	5	1	7	3
Optical/Multi-object spec. (R < 15000)	34	32	36	16	6	5	3	1	0	0
Optical/Multi-object spec. (R > 15000)	20	26	13	12	12	0	1	2	0	0
Optical/Other	9	6	4	5	1	0	1	0	0	0
Optical/Polarimetry or spectropolarimetry	6	1	6	4	5	4	4	1	2	4
Optical/Single-object spec. (R < 15000)	19	24	17	15	13	7	4	4	2	4
Optical/Single-object spec. (R > 15000)	37	25	19	15	9	2	3	3	2	0
Optical/Wide-field imaging	45	23	20	15	18	7	7	2	3	2

High-resolution (optical and NIR) spectroscopy is highly prioritized, as are optical capabilities such as wide-field imaging, multi-object spectroscopy, and low-resolution single-object spectroscopy, both in the near term and longer term. These instrument priorities indicate demand rather than being strongly science driven in the sense of being ordered by some objective measure of the quality of science it enables.

Q16. Interest in Future Gemini Instruments
Gemini is planning the following future instruments: an extreme-AO, high contrast imager and coronagraph (GPI), a wide-field R=1000-40,000 multi-object spectrograph (WFMOS), and a ground-layer adaptive optics system (GLAO). Brief descriptions of these capabilities are available at the links provided. Which of these capabilities are likely to be important for your future research? (Check all that apply.)

Number of respondents: 554

GLAO	197
GPI	124
I don't know enough to decide	45
None of the above	86
WFMOS	293

Q17 Operational Modes
What operational modes are important for your observing programs? (*Please rank all that apply, with 1 being the highest rank.*)

Results for all respondents: 553

	#1	#2	#3	#4	#5	#6
Archival use of public datasets	31	41	56	72	41	23
Classical scheduling	165	104	80	38	18	7
Classical with remote observing	104	154	78	41	10	2
Interrupt access	21	21	26	16	19	28
Other	3	1	3	2	0	1
Queue scheduling	178	105	80	57	15	3
Service observing	47	91	89	46	33	6

Results for those with institutional access to facilities: 324

	#1	#2	#3	#4	#5	#6
Archival use of public datasets	13	21	33	35	27	13
Classical scheduling	103	60	39	24	9	2
Classical with remote observing	47	94	46	22	5	2
Interrupt access	15	9	17	7	11	15
Other	1	1	1	1	0	0
Queue scheduling	110	63	41	35	4	0
Service observing	32	49	54	23	17	3

Results for respondents without access to facilities: 229

	#1	#2	#3	#4	#5	#6
Archival use of public datasets	18	20	23	37	14	10
Classical scheduling	62	44	41	14	9	5
Classical with remote observing	57	60	32	19	5	0
Interrupt access	6	12	9	9	8	13
Other	2	0	2	1	0	1
Queue scheduling	68	42	39	22	11	3
Service observing	15	42	35	23	16	3

Interpretation: Both queue and classical are important observing modes.

Q18. Value of Additional Resources
Additional resources such as data reduction pipelines, data archives, and queue observing can add scientific value and convenience to ground-based observational programs. But they also add significant cost. In a resource-limited environment, these costs are balanced against other budget items, such as the funding that is available for instrumentation or the number of nights available for observing. Given these considerations, what priority would you assign to the following?

Results for all respondents: 557

	Critical	Useful	Unimportant
Data reduction pipelines	228	288	41
Data archives	246	263	41
Queue observing	107	333	108
Improvements to instrumentation	271	246	21
Increased number of nights for observing	245	265	35

Interpretation: Looking at the distribution of rankings in each row, queue is regarded as the least critical. Instrumentation is the most critical.

Results for respondents with institutional access to facilities: 325

	Critical	Useful	Unimportant
Data reduction pipelines	152	157	16
Data archives	136	160	26
Queue observing	70	190	62
Improvements to instrumentation	155	148	12
Increased number of nights for observing	117	169	30

Interpretation: Looking at the distribution of rankings in each row, queue is regarded as the least critical. Instrumentation and pipelines are the most critical.

Results for respondents without institutional access to facilities: 232

	Critical	Useful	Unimportant
Data reduction pipelines	76	131	25
Data archives	110	103	15
Queue observing	37	143	46
Improvements to instrumentation	116	98	9
Increased number of nights for observing	128	96	5

Interpretation: Looking at the distribution of rankings in each row, queue is regarded as the least critical. The number of observing nights is the most critical.

Overall: Queue is thought to be the least critical by all groups. Instrumentation is regarded as critical by all groups. For respondents that do not have institutional access to facilities, an increased number of observing nights is very critical. For respondents that do have institutional access to facilities, pipelines are as important as instrumentation.

From the comments: 144 respondents elaborated on their priorities in the comment box provided. There was a considerable range of opinion on the value of queue observing, pipelines, and archives.

Common themes include the following:

1) While many acknowledged that queue observing can be valuable in principle, it was debated where this is in fact the case for Gemini. Drawbacks (both scientific and organizational) of any queue were noted. It was clear that queue observing does not meet all needs. Comments argued that

classical observing is also needed, particularly to carry out complex observations, to train observers to carry out such observations, and to engage the community with observatory staff and vice versa.

2) Pipelines and/or data reduction tools are important for some, but not for others. Many (13) stated that pipelines are important for complex instruments such as IFUs. It was clear from the comments that the term "pipeline" meant different things to different respondents in terms of complexity and completeness. As a result, it is difficult to gauge the support for a specific kind of pipeline capability without knowing what kind of pipeline a given respondent had in mind in prioritizing this capability. Future surveys should be more specific on this issue in order to get a useful answer.

3) The term "archives" was also unclear. What is being archived? (Raw data or reduced data? How well is the data reduced?) Archives were sometimes endorsed in a philosophical way ("The same data should never be taken twice!"), without indicating whether the respondent would actually make use of archived data. As a result, it is difficult to know what kind of archive a given respondent had in mind in prioritizing this capability. Future surveys should be more specific on this issue in order to get a useful answer. It would also be good to ask in such a future survey whether an individual is likely to use an archive (of a specified kind) in their own research.

4) There was general acknowledgement that new/competitive instruments are important or essential.

5) Observing nights were also thought to be critical, especially for the US community. One clear truism that was articulated: without observing time and instruments, there is no need for queues, pipelines, or archives.

Q19. Valued Aspects of Queue Observing
If queue observing is important, what aspects of it do you value? (Check all that apply.)

Number of respondents: 516

Results for all respondents: 516

Ability to observe targets of opportunity	118
Ability to specify the cadence and frequency of observations	185
Convenience	258
I don't need queue observing	83
Match to observing conditions	291
Other	36

Additional reasons given in comment box provided for "Other":

Small or widely varying RA range	7
Small data sets / observe less than one night	8
Large data sets	1
Getting data is guaranteed (won't be weathered out)	8
Convenience / saves time or travel cost	5
Queue observers more experienced	1

Good for complex AO observations	1
Uniformity of data	1
Efficiency	3
For optimal astrometric & photometric calibration	1
Phase coverage of binaries	1
Specifying star time of transits	1
Can use lots of bad seeing time	1
Long exposures	1

Additional information: 398 respondents chose one or more among “TOO”, “Cadence or frequency” or “Match to Conditions”, i.e., they included at least one science-based reason why they value queue observing. The majority of “Other” responses articulated scientific reasons why they value queue observing. Approximately 118 respondents did not select a science-based reason for valuing queue observing; i.e., they selected “Convenience” or “I don’t need queue observing”.

Q20. Value for Students and Postdocs
How important is it for students and postdocs to have experience observing with 6.5 to 10m telescopes and/or to have access to the data from these facilities?

Number of respondents: 567

Very important	339
Important	190
Unimportant	13
No opinion	21

Interpretation: There is general agreement that having experience with large telescopes, either through observational experience or through the use of data from these facilities, is important for students and postdocs. In that sense, access to large telescopes and/or the data from these facilities is an important aspect of graduate education and/or career development.

From the comments: Some people commented that having access to the data from large telescopes was much more important than the actual observing experience. Others said that both the data and the observing experience were important. Some said that students should learn to observe on smaller telescopes. One respondent commented that the experience of meeting other astronomers when observing at a large telescope was very valuable for students.

4. Additional Questions for the Longer Survey

Q21. Gemini and Other Facilities
If you have used both Gemini and other non-federal facilities, how does Gemini compare with these facilities?

Number of respondents: 152

Format: Respondents were invited to provide their responses in a text box.

Method: The nature of the comments was tabulated as to whether they expressed positive or negative comments regarding Gemini and the reasons given. The comments of each respondent were counted as "1" if they expressed only positive or only negative comments. If respondents had both positive and negative comments, their comments counted as "1" each for positive and negative.

Total number of positive comments: 58
Total number of negative comments: 99

Most of the comments were negative in tone. At some level this might be expected in that people may be more inclined to document complaints than satisfaction. Many positive comments were generic ("Gemini is fine."), lukewarm or at least far from effusive, with perhaps 1 or maybe 2 reasons provided for that viewpoint. In contrast, many of the negative comments sounded angry or highly critical, and often numerous reasons were given. Rightly or wrongly, a lot of people appear to be critical of Gemini.

Positive reasons given:

Cost	Cheaper than the VLT	1
Instrumentation	Desirable (include. AO, IFU, TEXES)	6
Performance	Good seeing or DIQ	6
	IR performance	4
	Pointing	1
Proposal process		1
Observing modes	Queue scheduling	9
	Time domain science / ToO	3
	More flexible in classical mode than VLT	1
	Rapid instrument switching	1
Other resources	Good documentation	1
	Archiving	2
	Data reduction packages, pipelines	4
Services	User support	7

Negative reasons given:

Cost	Less cost effective	3
Instrumentation	Instrumentation inferior / not the right kind / less robust	47
	More spectroscopic capability needed	4
	Instrument not well documented	1
Access	Not enough nights available / proposal rejected	7
Performance	Less capable / low science return	5
	Smaller aperture	1
	Smaller FOV	1
Efficiency	Phase I/II cumbersome, time consuming, onerous	35
	Observing prep onerous (MOS, etc)	3
	Observing efficiency low (slewing, etc)	6
	Performance/efficiency poor in marginal conditions	2

	No/little data received for an accepted program	7
	Program completion	3
	Probability of getting useful data low	2
Observing modes	Queue observer, efficiency or DQ problem	6
	Prefer / want classical	4
	Remote participation in queue (offsets Phase II labor)	2
	Limited flexibility and spontaneity allowed	3
	Difficulty observing solar system objects	2
	Calibration problematic / inadequate	1
Other Resources	Pipelines inferior / cumbersome	3
	Software	1
Community Interaction	Feedback process lacking	1
	Disconnected from user community and vice versa	2

Interpretation: The good news is that only a few of the negative comments focus on something that cannot be altered (e.g., aperture size). So Gemini is not fundamentally inadequate for people's needs. People want the process of getting good data to be simpler and to place a smaller time burden on the proposer; for observing to be more efficient; for Gemini to have better and more capable instruments; and to offer a wider range of observing modes.

Q22. Impact of ALMA, NVO, LSST, JWST etc.
How will the major new facilities and programs planned for the next decade (e.g. ALMA, NVO, LSST, JWST, etc.) impact your science programs?

Number of respondents: 215

The responses, provided in essay format, are not easily summarized here.

Q23. Time for Large Collaborations
What fraction of time on a public facility do you think is appropriate for large-scale, large-collaboration programs?

Number of respondents: 230

Method: Responses were provided in essay format. The desired fractions of time were tabulated where specific values were provided. These values were often qualified as requiring that any allocation be scientifically justified; that allocations consider the impact of the resulting oversubscription on smaller, PI-class programs; that the data and/or data products from large programs be made publicly available. While some respondents felt uncomfortable responding to such an unqualified question, many suggested a fraction of 20-30%.

Solely merit based; no quotas	10
< 10%	8
10-20%	44
20-30%	96
30-50%	27
>50%	19

Q24. Priorities for Increased Federal Funding
Would increased federal funding at the 6.5 to 10-m aperture class for observing time, instrumentation, and/or facilities enable a significant enhancement to your research? If so, what level and kind of investment would you advocate? (Indicate all that apply and indicate priority order, with 1 being the highest.)

Total number of respondents: 299

Results for all respondents:

	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Build a special purpose telescope	41	29	21	14	9	14	1	0
Build a new telescope(s)	30	29	21	15	20	11	2	0
Instrumentation for Gemini	37	51	45	23	8	5	0	0
Instrument. for non-federal telescopes	42	39	39	18	21	6	0	0
Increase US share in Gemini	45	46	31	24	4	2	0	0
More open access time on non-federal facilities	90	59	36	19	4	0	0	0
None of the above	3	0	0	0	0	0	0	0
Other	8	4	1	2	1	0	0	0

Respondents with institutional access to facilities: 176

	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Build a special purpose telescope	26	21	14	8	3	5	0	0
Build a new telescope(s)	16	12	11	8	12	5	1	0
Instrumentation for Gemini	23	27	28	11	4	1	0	0
Instrument. for non-federal telescopes	37	27	19	10	3	3	0	0
Increase US share in Gemini	22	23	18	11	3	1	0	0
More open access time on non-federal facilities	45	37	18	8	2	0	0	0
None of the above	3	0	0	0	0	0	0	0
Other	2	1	1	1	0	0	0	0

Respondents without institutional access to facilities: 123

	#1	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**	**#8**
Build a special purpose telescope	15	8	7	6	6	9	1	0
Build a new telescope(s)	14	17	10	7	8	6	1	0
Instrumentation for Gemini	14	24	17	12	4	4	0	0
Instrument. for non-federal telescopes	5	12	20	8	18	3	0	0
Increase US share in Gemini	23	23	13	13	1	1	0	0
More open access time on non-federal facilities	45	22	18	11	2	0	0	0

None of the above	0	0	0	0	0	0	0	0
Other	6	3	0	1	1	0	0	0

Interpretation: More people answered this question than any other additional question in the long version of the survey. This indicates that for the great majority of respondents, increased funding would enable a significant enhancement to their research.

Among both respondents with and without institutional access to facilities, the most popular choice was for more open access time on non-federal facilities. As a first choice, it was more desired by a 2:1 margin over increasing the US share in Gemini. For respondents without institutional access to facilities, these two choices were clearly the most popular as first choices, reflecting the high value placed by this group on an increased number of nights for observing (Q18).

For respondents with institutional access to facilities, the second most popular first choice (following increased open access time on non-federal facilities) was improved instrumentation for non-federal telescopes. This was followed by building a special purpose telescope, which received a similar number of first choice votes as the two choices involving Gemini (an increased share or improved instrumentation).

These results complement the information we gathered through the online poll in NOAO's electronic newsletter *Currents.* When we previously asked the US community whether they favored acquiring more observing time and/or a larger share in Gemini, the 62 respondents were in favor by a large margin (5:1). However, the results of the ALTAIR survey indicate that, when compared against other options for the use of additional federal funding, acquiring a larger share in Gemini appears to be less desired than acquiring more observing nights on non-federal facilities.

We were not explicit in asking respondents to evaluate the value of increased influence over Gemini planning and operations that might come with an increased US share. However this did come up in the text comments that we received.

Q24. Priorities for Increased Federal Funding: Essay Responses

Respondents were invited to elaborate on their priorities in essay form. Here are some common themes from among the 140 text responses.

Observing Time:
The US community needs more observing time/performance on large telescopes. (>17 responses)

International Context:
We need to improve the US system of large telescopes to remain competitive with other countries. (6)

Role of Non-federal Facilities:
Access to non-federal facilities can increase the diversity of instruments available to the community. (> 10)

But we need to acquire enough nights (15-20%) that people can become expert in using the facilities. (1)

We also need commitment to adequate user support. (2)

Role of Gemini:
Gemini does not provide good value compared to other facilities. (5)

We need well chosen, capable instruments for Gemini. (3)

We need workhorse (not “niche”) instruments for Gemini. (7)

There's something (very) wrong at Gemini. (7)

I would advocate for a larger US share or funding for Gemini instrumentation if the US has more control of Gemini and/or so that things would be done differently/better at Gemini / be more responsive to the needs of the US community. (13)

If the US can't improve Gemini, we should minimize our share in it and buy into non-federal facilities. (1)

“If only Keck were a national observatory, including its smooth operations and excellent.instrumentation on what, compared to Gemini, would probably be seen as a shoestring budget.” (1)

“I think that if the Gemini operational set-up is a given, you might as well not bother. What should be done is to replace the operational model at Gemini with the one used at Keck. You want a hands-on, free-form observing experience that encourages creativity and spontaneity. That is why the science impact from Keck is much greater than that from Gemini. Not because Caltech and UC astronomers are better, as they themselves have rather self-servingly suggested, but because the way the telescope is run is simply more conducive to productive, exploratory observations that capitalize on the moment.” (1)

Interpretation: The community wants increased access to large telescopes that are capably instrumented and can compete with resources available internationally. There is the strong sense that things are going wrong at Gemini that it's not worth investing further in Gemini until its problems are solved. Facilities like Keck are regarded as a useful model for improvement or as an alternative for investment.

Tabulated Responses to Q24, Option 6
Would increased federal funding at the 6.5- to 10-m aperture class for observing time, instrumentation, and/or facilities enable a significant enhancement to your research? If so, what level and kind of investment would you advocate? (Indicate all that apply in priority order, with 1 being the highest.)

Option 6: Build a special purpose 8-m class O/IR telescope optimized for **_________** (e.g., spectroscopic surveys, LSST follow up, etc.)

Method: We tabulated the number of times the following terms appeared in the list of responses. A single response like “wide-field multi-object spectroscopy” would be counted as 1 each for “wide-field”, "MOS", and "spectroscopy". The column headings "#1" etc indicate the rank that the respondent gave to this capability.

Words used/implied	**#1**	**#2**	**#3**	**#4**	**#5**	**#6**	**#7**
Spectroscopy	22	11	7	4	5	2	1
Spec. survey	11	6	5	3	4	2	1
Spec. wide-field	8	1		1	2	1	
Spec. faint/deep	2	1					
Spec. MOS	6	2	1			1	
Spec. high res	5	1	1	1			
Spec. blue/UV	1		1				
Spec. IR	2	2	2		2		
Spec. for LSST followup	2	1		1			
Spec. AO		1	1				
Spec. precision Doppler	2	1					
LSST followup	8	3	4	1			1
LSST itself	1	1					
Imaging	6	3	1				1
Im. survey	2	1	2		1		1
Im. IR	3	1	1		1		
Im. AO	1	1					
Im. Blue/NUV			1				
Synoptic programs	1	1					
Queue/service		1	1				
Interferometry	1	1		1			
Solar system					1		

Interpretation: Among those who responded, 8-m spectroscopic capability is highly desired. Some fraction of the survey, wide-field, faint/deep, MOS, and high resolution spectroscopy needs could be met by a capability like WFMOS. Another frequent request is for LSST follow up generically (imaging or spectroscopy or something else not specified). This may motivate a narrow-field, high throughput spectroscopy, and imaging facility optimized for LSST follow up. (Note that these popular choices were included in the examples in the question itself.)

5. Institutional Affiliation of Respondents

AMNH
Applied Physics Laboratory
Arecibo Observatory
Australian National University
Brigham Young University
Caltech
Carnegie Institution of Washington
Carnegie Observatories
Centro de Astrofisica da Universidade de Porto
CIDA-Venezuela
Clemson University
Cornell University
Dickinson College
ESA-STSCI
Eureka Scientific
Everett Community College, University of Washington
Fermilab
Gemini Observatory
Georgia State University

GSFC
Harvard-Smithsonian Center for Astrophysics
Herzberg Institute of Astrophysics
Hofstra University
IA UNAM
Indiana University
Infrared Processing and Analysis Center
Institute for Astronomy, Universtity of Hawaii
Japan Aerospace eXploration Agency
Johns Hopkins University
JPL
Las Cumbres Observatory
LLNL
Lowell Observatory
McDonald Observatory
Michigan State University
National Science Foundation
New Mexico State University
New York University
NOAO
Northern Arizona University
Northwestern University
Observatorio Nacional, Rio de Janeiro
Ohio University
Pennsylvania State University
Planetary Science Institute
Princeton
Rice University
Rochester Institute of Technology
Rutgers University
San Francisco State University
SETI Institute
Smith College
Southwest Research Institute
Space Science Institute
Spitzer science center
Stanford
Steward Observatory
STScI
Swarthmore Colllege
Tennessee State University
Texas A&M University
The Ohio State University, Dept. of Astronomy
U de Chile
U Virginia and NRAO
UC Berkeley
UC Davis
UC Santa Cruz
UChicago/KICP
UCLA
UCO/Lick
UCSD
Univ. of Central Florida
Universidade de Sao Paulo
University of Alberta
University of Arizona
University of California, Irvine
University of California, Santa Barbara
University of Central Arkansas
University of Colorado
University of Delaware
University of Florida
University of Georgia
University of Hawaii
University of Heidelberg, Landessternwarte
University of Idaho
University of Illinois
University of Kansas
University of Maryland at College Park
University of Michigan
University of Minnesota
University of Pittsburgh
University of Texas at Austin
University of Toronto
University of Virginia
University of Washington, Seattle
University of Wisconsin
US Naval Observatory
USRA/MSFC
Vanderbilt University
Vatican Observatory
W.M. Keck Observatory
Wesleyan University
Yale
Youngstown State University

Appendix D: The Large Telescope User Community in the US

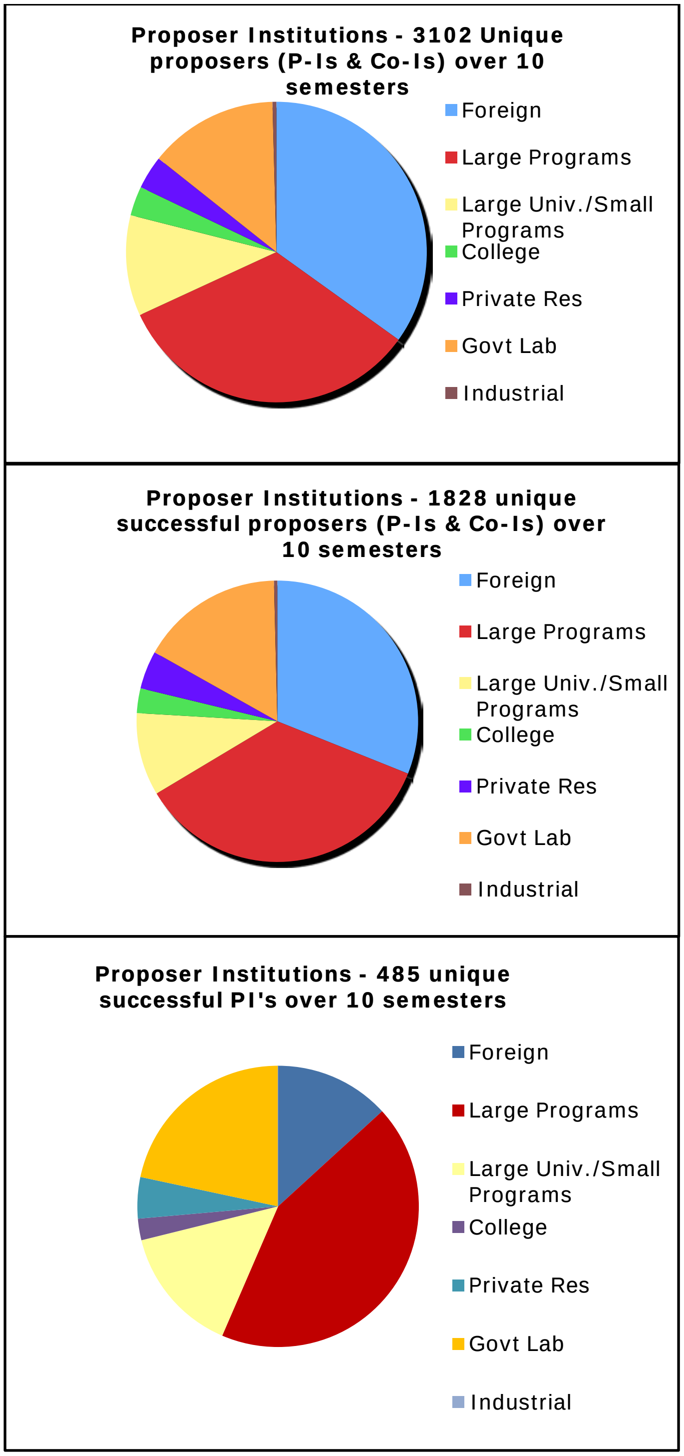


Figure D-1: Type of institutional affiliation of proposers for all large telescopes (Gemini and TSIP) through the NOAO proposal process, for (*a*) all PIs and Co-Is; (*b*) all successful PIs and Co-Is, (*c*) successful PIs only.

In the following, we relate the ALTAIR survey demographics with those of the entire US astronomical community. The Gemini and TSIP user communities and the survey demographics were described briefly in the report (Sec. III and V respectively). Further details on the survey results are presented in Appendix C.

1. AAS Community

Since we are placing significant weight on the survey results it is appropriate to ask who is the US community and is the survey reflective of that community. The entire US astronomical community as reflected by AAS membership includes about 6500 members who work in colleges and universities of every size and level, observatories, government labs and even from their homes as individuals.

2. Gemini and TSIP User Communities

The following figures provide a statistical overview of the community that has proposed to use large telescopes through the NOAO proposal process. Figures D-1 and D-2 show the statistics for proposers to all large (6.5- to 10-m) telescopes, both Gemini and TSIP. Figure D-1 shows the type of institutional affiliation for all P-Is and Co-Is (top panel), successful P-Is and Co-Is (middle panel), and successful PIs (bottom panel). Figure D-2 shows the extent to which successful U.S. PIs have preferred access (via their institutional affiliation) to large, medium, or small telescopes. Figures D-3 and D-4 show the same information for proposers for TSIP facilities only (facilities other than Gemini). Because of the much larger number of proposers for time on the Gemini telescopes, the distributions for Gemini only are similar to those for Gemini and TSIP combined. In Figures D-1 through D-4, the data shown are for the 2003B-2008A semesters.

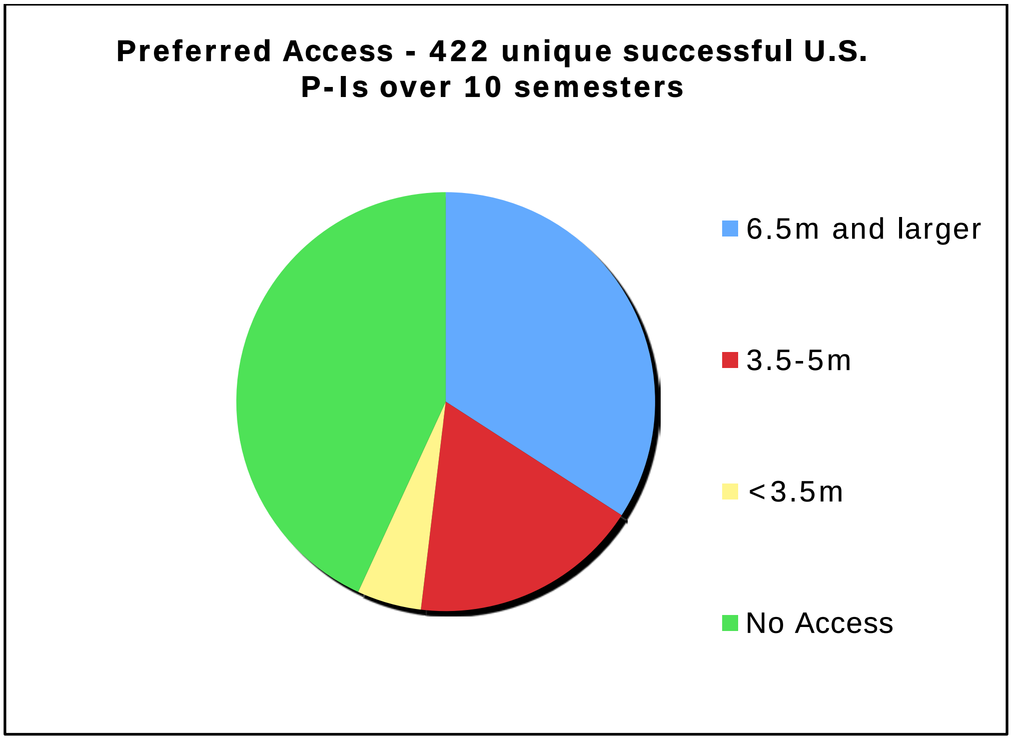


Figure D-2: Extent to which PIs of successful NOAO proposals for large telescopes (Gemini and TSIP) have institutional access to telescopes of different apertures.

In these figures, "large programs" are AURA member universities (currently there are 34 such U.S. astronomy Ph.D.-granting institutions). A "large university/small program" is a large state or private university that is not an AURA member (e.g., University of Alabama, Arizona State University, Northwestern, University of Massachusetts, Columbia). The group "college" indicates all other colleges and universities (e.g., Dartmouth, Pomona, Agnes Scott College, Tufts). The last two groups are a mix of Ph.D., M.S., and B.S./B.A. programs. "Private research" indicates privately funded, nonprofit, research organizations (e.g., Carnegie, Lowell, AMNH, IAS). The group "government lab" represents federally funded research and development centers (e.g., NOAO, Gemini, Livermore, STScI). "Industrial" indicates for profit corporations (e.g., Raytheon, Lucent, Aerospace Corp.) Note that since most proposers from Harvard/SAO gave their affiliation as "CfA", it was difficult to distinguish affiliation with Harvard (a "large program") or the SAO (a combination of "private research" and FFRDC); in practice these were all counted as Harvard (i.e., in large program).

The figures for Gemini+TSIP show that the NOAO large telescope community is diverse. Although the proposing community includes a significant foreign component (Figure D-1, top and middle panels), the majority of such proposers appear to be co-Is (Figure D-1, bottom panel). As shown in Figure D-2, a large fraction of proposers (~45%) have no institutional access to optical/infrared observing facilities, and approximately two-thirds have no institutional access to large telescopes.

Foreign PIs and Co-Is make up a smaller fraction of proposers for TSIP time (Figure D-3). PIs from large programs and universities account for a larger fraction of successful TSIP proposals (Figure D-3, bottom panel) than they do for successful Gemini and TSIP proposals combined (Figure D-1, bottom panel). Of these successful TSIP only PIs, ~40% have no institutional access to facilities, and ~75% have no institutional access to large telescopes (Figure D-4). PI's from institutions with institutional access to large telescopes propose to Gemini and TSIP generally in order to gain access to different instrumental capabilities, though some do so because they desire more nights than they can obtain through their own institutional TACs.

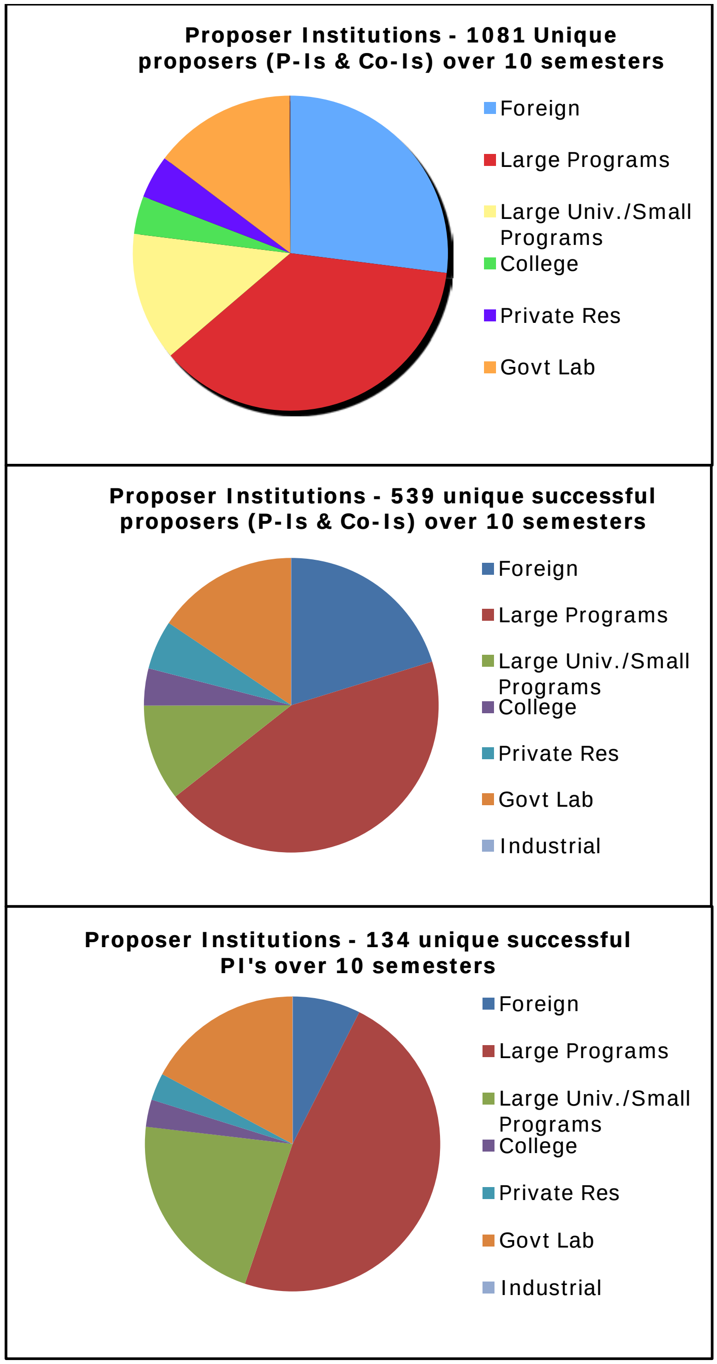


Figure D-3: Type of institutional affiliation of proposers for all large telescopes (TSIP only) through the NOAO proposal process, for (*a*) all PIs and Co-Is; (*b*) all successful PIs and Co-Is, (*c*) successful PIs only.

Figure 8 in Section V of the report body illustrates the institutional demographics of the survey respondents. To explore whether the survey reflects the US community that uses 6.5-10 meter O/IR telescopes we compare the survey demographics with recent NOAO user statistics (Figure D-1). Direct comparison between Figures D-1 & 8 is complicated by the different characterization of programs and open foreign access to US telescopes. However, lumping together large universities and government laboratories and NASA centers, there is considerable overlap. Also note that Figure D-1 under-represents astronomers with institutional access to non-federal facilities. These users will be almost entirely members of large programs, hosted at either academic or research institutions. With the important exception of some active researchers at 4-year colleges and MS granting institutions, the typical 6.5 -10 meter telescope user is an active researcher in a university with a PhD program in Astronomy or Physics or a private or government research center. Based on AIP statistics (http://www.aip.org/statistics/trends/reports/physrost.pdf), there are 40 programs that grant a PhD in Astronomy; these programs accounted for about 525 PhDs between 2003 and 2007. A slight majority of these PhD's came from the ~16 programs that had preferred access to a non-federal facility. It should be noted that the AIP list does not include important programs that are part of Physics departments; for example MIT, Johns Hopkins and several UC campuses.

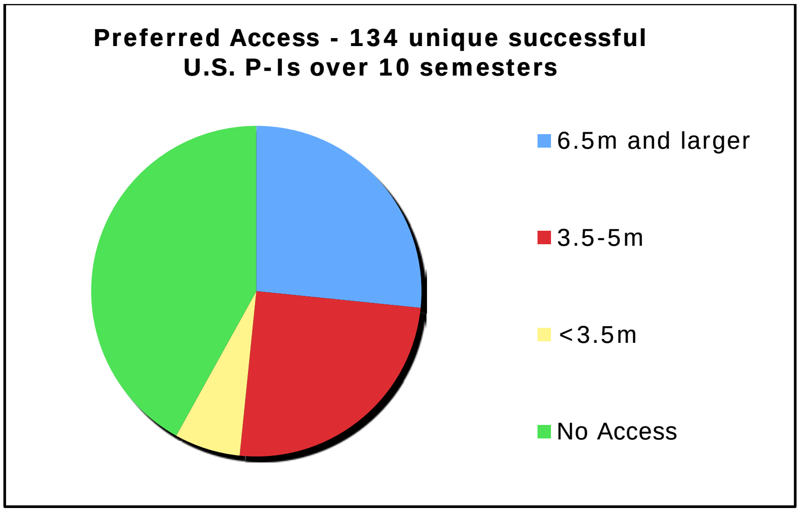
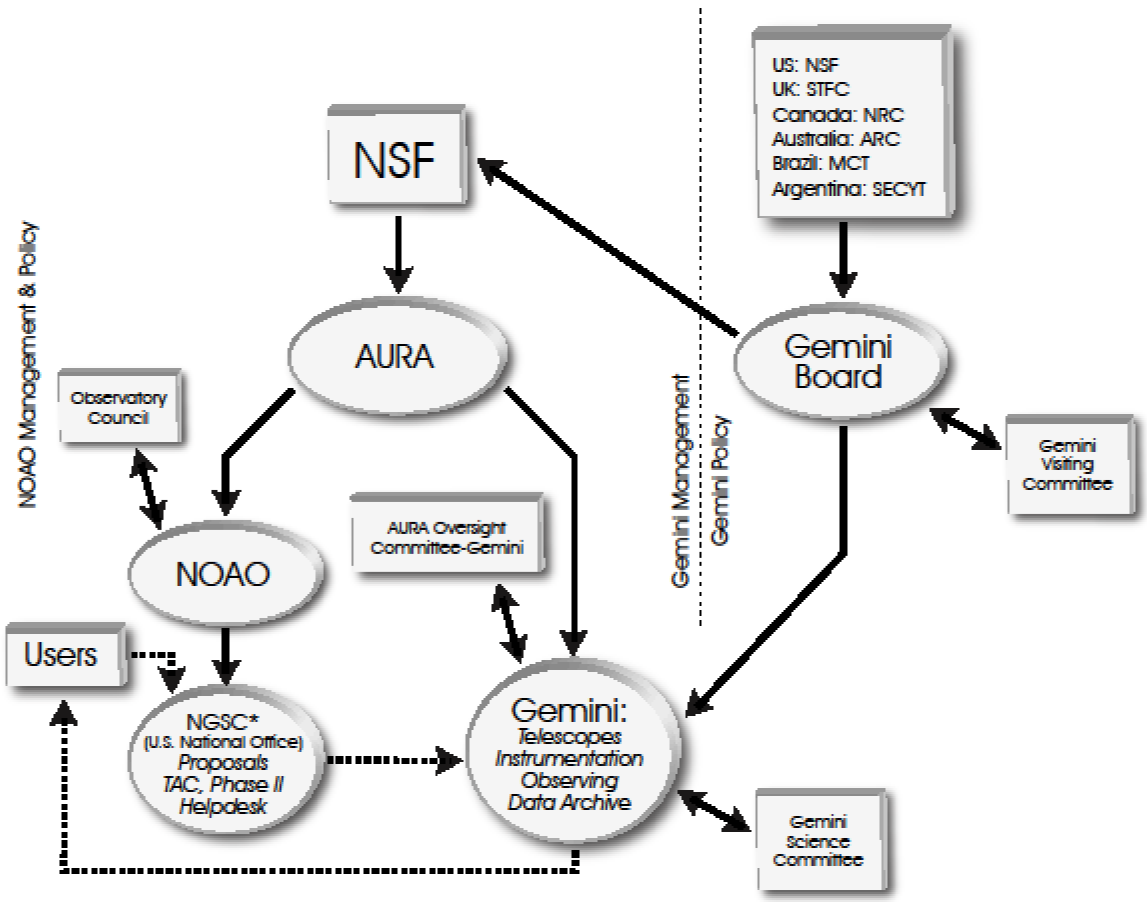


Figure D-4: Extent to which PIs of successful NOAO proposals for large telescopes (TSIP only) have institutional access to telescopes of different apertures.

As noted in the report (in Sec. V), of the approximately 570 survey responders >90% identify themselves as observers with the rest split between instrument builders and theorists. 57% identify themselves primarily as optical observers and 26% and 8% as near-IR and mid-IR observers, respectively. The second wavelength focus of these observers were predominantly near- and mid-IR for the optical observers and vice versa. The distribution over the nine fields surveyed and displayed in Figure 9, while not even, was representative.

Appendix E: Gemini Management & Policy Organization Chart



*Each partner country has a national office.