Optimizing the U.S. Ground-Based Optical and Infrared Astronomy System

Committee on A Strategy to Optimize the U.S. Optical and Infrared System in the Era of the Large Synoptic Survey Telescope (LSST)

Board on Physics and Astronomy
Division on Engineering and Physical Sciences

NATIONAL RESEARCH COUNCIL
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Statement of Task

In order to position the **observational, instrumentation, data management,** and **support capabilities** of the U.S. optical and infrared astronomy (O/IR) system to best **address the science objectives** identified in the 2010 report entitled New Worlds, New Horizons in Astronomy and Astrophysics and Vision and Voyages for Planetary Sciences in the Decade 2013-2022 and to help achieve the best science return from the National Science Foundation investment in O/IR astronomy over the next 10-15 years, the National Research Council will convene a committee to write a short report that will **recommend and prioritize adjustments to the U.S. ground-based O/IR system**.

The committee will consider **needs and strategies for several interrelated components** of the system: existing and planned focal plane **instrumentation**; focal plane instrumentation and **technology development**; and **data** management, processing, mining, and archiving. The committee may make recommendations or offer comments on organizational structure, program balance, and funding, with discussion of the evidentiary bases, as appropriate.

Interpretation of Task

- Adhered to NWNH, VVPS, PRC priorities
- LSST one of the central components of the study, but all ground-based nighttime OIR elements considered
- No budget, but aimed for realistic, implementable recommendations
- Based our decisions on science drivers
- Considered community input (White Papers, presentations)
- We were invited to comment on SOAR (and MSIP if desired)
- Considered telescope apertures >2 m for completeness but mentioned others

Committee’s Guiding Principles

- An integrated OIR System can achieve the best science when it engages a broad population of astronomers to pursue a diversity of science and scientific approaches.

- Federal investment in LSST follow-up capabilities and in community-prioritized instrumentation across the OIR System will help to maximize scientific output.

- Federal support to sustain technology, instrumentation, and software development, and expertise in these fields, is necessary to optimize future science returns.

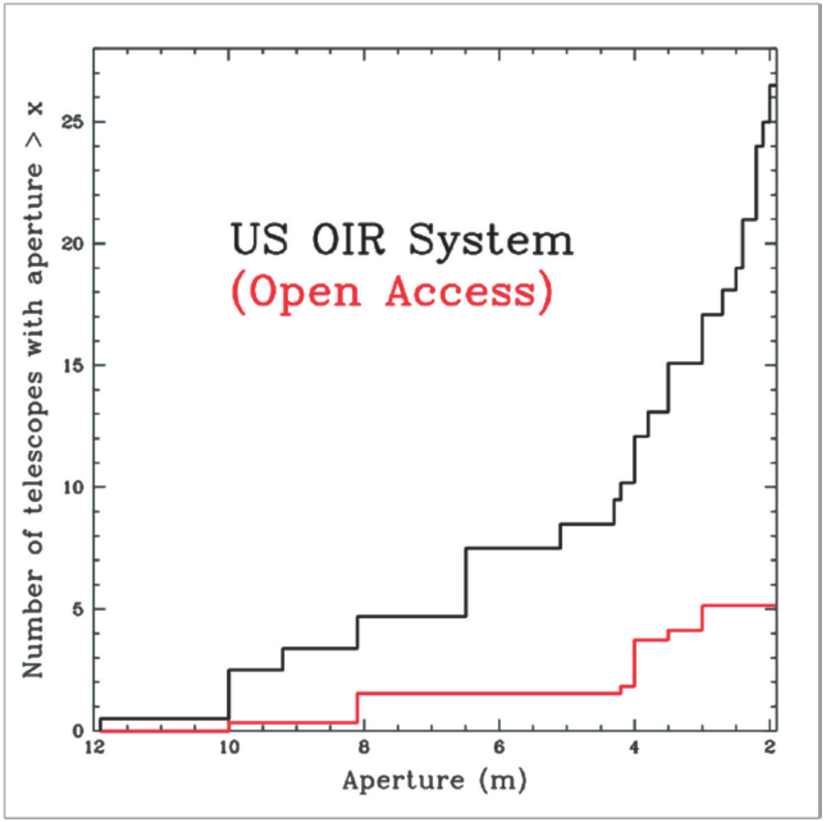
Summary of Recommendations

- Telescope and data access exchange program
- Ongoing community planning process
- Near-term critical instrument needs
- Coordination for best return on LSST data
- Investment in GSMTs
- Critical instrument technologies
- Training networks

Subjects of high level conclusions

- Data archives and accessibility
- DECam, DESI
- MSIP structure
- International discussions on exchanges

The current US OIR System suite



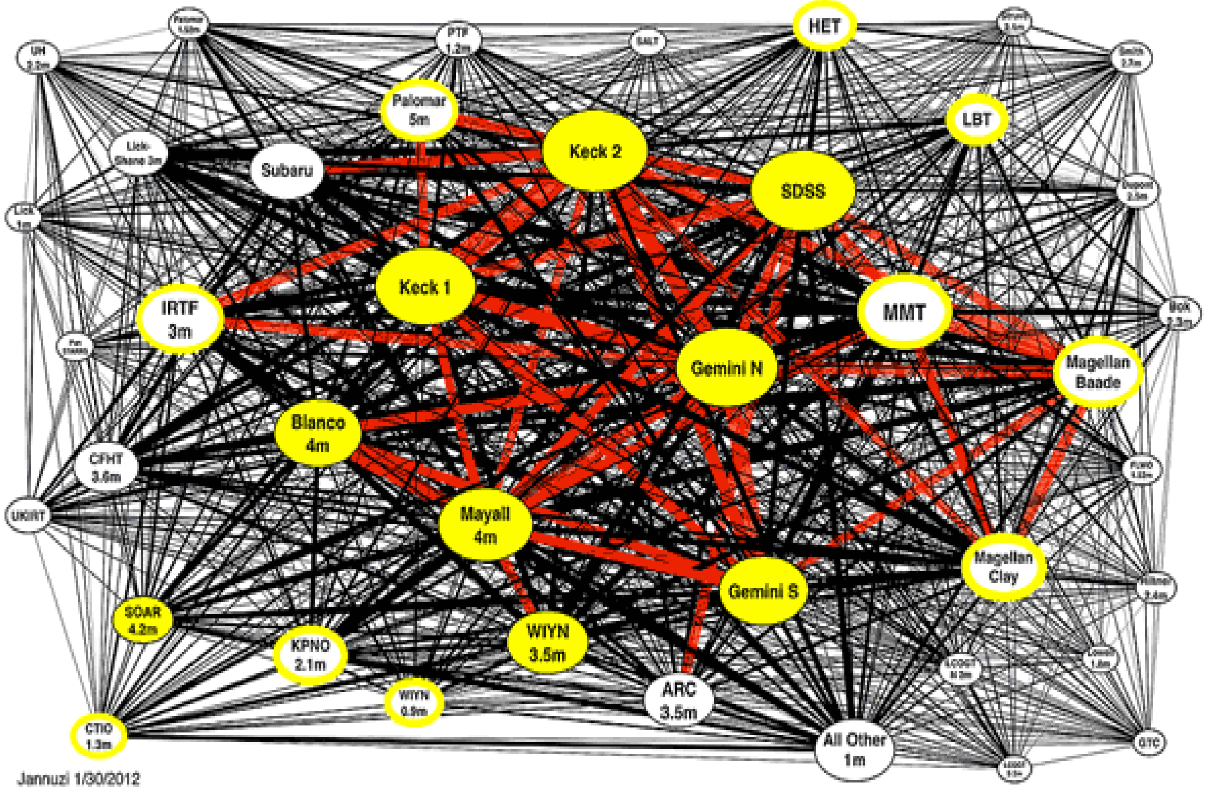
- For U.S. telescopes > 2m, 76% of time is private (open access for 19% 6-12m, 33% 3.5-5m, 8% 2-3m)
- Private facilities don't have all the resources they need, and are open to the idea of sharing

TABLE 3.1 Telescopes Considered by the Committee

	Observatory/Site	Aperture	U.S. Fraction	Open Fraction
Large Telescopes (6-12 meters)				
Large Binocular Telescope (LBT)	Mt. Graham, AZ	11.8*	0.50	0.00
Keck 1	Mauna Kea, HI	10.0	1.00	0.17
Keck 2	Mauna Kea, HI	10.0	1.00	0.17
Hobby Eberly Telescope (HET)	McDonald Observatory, TX	9.2	0.89	0.00
South African Large Telescope	South African Astronomical Observatory, Sutherland, S.Africa	9.2	0.40	0.00
Subaru	Mauna Kea, HI	8.3	0.10	0.00
Gemini N (Gillette)	Mauna Kea, HI	8.1	0.69	0.60
Gemini S	Cerro Pachon, Chile	8.1	0.59	0.60
Magellan (Baade)	Las Campanas, Chile	6.5	0.90	0.00
Magellan (Clay)	Las Campanas, Chile	6.5	0.90	0.00
MMT	Mt. Hopkins, AZ	6.5	1.00	0.00
	Effective fractional number of telescopes		**7.99**	**1.54**
Medium Telescopes (3.5-5 meters)				
Hale Telescope	Palomar Observatory, CA	5.1	1.00	0.00
Discovery Channel Telescope	Happy Jack, AZ	4.3	1.00	0.00
SOAR	Cerro Pachon, Chile	4.2	0.70	0.30
Blanco Telescope	Cerro Tololo, Chile	4.0	0.90	0.90**
Mayall Telescope	Kitt Peak, AZ	4.0	1.00	1.00
UKIRT	Mauna Kea, HI	3.8	1.00	0.00
CFHT	Mauna Kea, HI	3.6	0.20	0.00
ARC 3.5m	Apache Point, NM	3.5	1.00	0.00
WIYN	Kitt Peak, AZ	3.5	1.00	0.40
	Effective fractional number of telescopes		**7.80**	2.60
Small Telescopes (2-3 meters)				
Shane	Lick Obser., Mt. Hamilton, CA	3.0	1.00	0.00
IRTF	Mauna Kea, HI	3.0	1.00	1.00
Harlan Smith	McDonald Observatory, TX	2.7	1.00	0.00
DuPont	Las Campanas, Chile	2.5	0.90	0.00
Sloan Foundation (SDSS)	Apache Point, NM	2.5	1.00	0.00+
Hiltner	Kitt Peak, AZ	2.4	1.00	0.00
WIRO	Jelm Mtn, WY	2.2	1.00	0.00
Bok	Kitt Peak, AZ	2.2	1.00	0.00
UH 88-inch	Mauna Kea, HI	2.2	1.00	0.00
Otto Struve	McDonald Observatory, TX	2.1	1.00	0.00
KPNO 2.1m	Kitt Peak, AZ	2.1	1.00	0.00
LCOGT	Haleakala, HI	2.0	0.75	0.00
LCOGT	Siding Spring, Australia	2.0	0.75	0.00
	Effective fractional number of telescopes		**12.40**	1.00

* LBT is two coupled 8.4-meter telescopes with the equivalent area of a single 11.8-meter telescope.
** This is for pre- and post-DES.
+ Sloan is a survey instrument; all Sloan Digital Sky Survey (SDSS) I-III data are now public.

The best science often requires multiple capabilities



- Even astronomers with private access don't have all the capabilities they need
- The 9000 nights of telescope time to US astronomers generates 2000 papers from 1500 astronomers

CONCLUSION: Interest from and telescope usage by a large, diverse, and active community of high-quality researchers is correlated with high-impact scientific output.

Prioritized: Recommendation 1

- The NSF should direct NOAO to administer a new **telescope time exchange** with participating observatories of the U.S. OIR System. Observatory representatives would **barter facilities, swap instruments, or engage in limited term partnerships for telescope time or data access** on behalf of their respective constituencies, as appropriate, and **NSF would barter telescope time or data access or engage in limited term partnerships to carry out proposals competed through a System-wide time allocation committee**.

Notes:

- A telescope time exchange would enable more decadal goals to be met by broadening the suite of capabilities available to U.S. astronomers and fostering complementarity
- NSF participation in an exchange would help restore lost public access due to divestment
- NSF investment would be for U.S. PIs, through a peer-review competitive TAC
- Any interested observatory (any size facility) could offer a minimum and maximum amount of time (or data); cost or barter to be negotiated
- A multi-year arrangement between NSF and observatories would be best if possible
- NOAO is the logical body to negotiate access and manage time allocation on behalf of NSF
- NSF investment of even $1-2M would be a good start (=40 nights 8m, much more on smaller)

Recommendation 2

- The NSF should **direct NOAO** to administer an **ongoing community-wide planning process** to identify the critical OIR System capabilities needed in the near term to realize the decadal science priorities. NOAO could facilitate the meeting of a System organizing committee, chosen to represent all segments of the community, which would produce the prioritized plan. **NSF would then solicit, review, and select proposals to meet those capabilities, within available funding**.

Notes:

- This Committee report provides recommendations for short-term needed capabilities, but a U.S. OIR System planning process would be useful to identify and develop highest priority new peer-reviewed capabilities to address science needs **on an ongoing basis**
- **Periodic System workshops** (facilitated by NOAO) and the coordination of science needs and new capabilities must include an invitation for participation for all segments of the community
- The process would need to be **empowered** by NSF and **endorsed** collectively by all stakeholders
- This roadmap would only account for a fraction of System activities, and would not impede other separate creative proposals and efforts
- Peer-reviewed selection is required at each stage in which **proposals are competed**
- Organizations providing significant resources to the System must be included in program oversight
- Development and implementation **will require funding as available**, groups to carry out the technical work, and telescopes on which to deploy new instruments

Critical Instrument Needs

Table 4.1: Key instrument needs in the Era of LSST

Instrument	**Examples of applications**
Wide-field, highly multiplexed moderate resolution spectroscopy on 4- to 10-meter telescopes	Studies of individual interesting objects, compact stellar remnants, galaxy assembly fossil record, cosmic structure formation, first stars, cosmic acceleration, redshift distributions, Milky Way chemical and dynamic evolution
High throughput, moderate resolution single object spectrograph (and spectropolarimeter) on 6- to 30-meter telescopes	Transients (LSST follow-up), quasars, planetary atmospheres, individual objects (solar system objects, stars, binaries, galaxies)
Multi-conjugate AO on 6- to 30-meter telescopes	Circumstellar disks and protoplanetary, supernova progenitors, galaxy assembly, cosmic structures, black holes, first stars, planetary systems
IFU optical, NIR spectroscopy with AO	Protoplanetary disks, stars, high redshift galaxies
High resolution optical, NIR imaging with AO	Solar system objects, planetary atmospheres, protoplanetary disks, stars, high redshift galaxies
AO coronagraphy	exoplanets, protoplanetary disks
Extreme precision radial velocity (Doppler) spectroscopy	Exoplanet detection
Small and medium aperture (1- to 5-meter) telescopes with low-resolution spectrographs and spectropolarimeters, and broadband and narrowband imaging from U band to 5 microns. Global arrays best; need rapid response	Bright transients, nearby galaxies, stars, Solar system objects

- These are critical for a diversity of studies in NWNH and VVPS
- Small, medium, and large aperture telescopes serve a range of science endeavors

Recommendation 3

- The NSF should support the development of a **wide-field, highly multiplexed spectroscopic capability** on a medium or large aperture telescope in the Southern Hemisphere to enable a wide variety of science, including follow-up spectroscopy of LSST targets. Examples of enabled science are studies of cosmology, galaxy evolution, quasars, and the Milky Way.

Notes:

- This capability is called out in **4 of 5 science frontier panels** in NWNH.
- It is important on 4m (e.g., DESI-like) and larger telescopes, especially in the Southern Hemisphere for greatest overlap with LSST
- There is no wide-field highly multiplexed spectroscope on medium or large aperture U.S. telescopes **in the Southern Hemisphere**
- The committee envisioned that Gemini-S would be appropriate for this spectroscope
- The instrument details are TBD; WPs suggest ~ 1^{o}, a few thousand targets

Related High Level Conclusions

- If the **DESI** project proceeds as planned, then **upon completion of its survey from the KPNO Mayall 4-meter**, the NSF and the DOE could partner to **move DESI to the CTIO Blanco 4-meter** (if technically feasible) early in the era of LSST operations in order to enable southern wide-field spectroscopic surveys.

- **If DESI were moved** to the Blanco 4-meter, decadal science priorities in the LSST era could benefit from **installing DECam on the Mayall 4-meter** and using it to carry out wide and deep multi-band imaging surveys in the north.

Notes:

- A **range of science** could be accomplished in support of LSST and other goals with DESI on Blanco
- Moving DECam to Mayall would of course be based on the premise that Mayall was still operational beyond DESI
- PRC called for divestment of the Mayall but notes that it is well suited for wide-field Northern Hemisphere imaging, but that its instrumentation is inferior to DECam
- If made available to the community, DECam on the Mayall would **offset the loss of public nights** to Northern Hemisphere facilities

Follow-up Science in the LSST era

Follow-up needs: generally, a **high throughput moderate resolution spectrograph** on 4m to 30m telescopes, with rapid response capability

Transient events: LSST will detect changes in position or flux for **2 million** objects per night and produce alerts

- **Days to weeks** – asteroids, comets, AGNs, stars – need a policy for handling
- **Hours to a day** – novae, SNe, microlensing detections – need human decision, quick response
- **Minutes or less** – GRBs, SN shock breakout, gravity wave – need non-human response, policy, rapid turnaround

→ Need **EVENT BROKERS** to aggregate information and filter into manageable diverse science themes and generate follow-up requests

CONCLUSION: Plans for coordination and communication of transient events are currently inadequate.

CONCLUSION: Coordination is required to maximize the scientific yield from transients in the LSST era. There is a need for dedicated telescopes and instruments, a system of telescopes, and software to respond efficiently to transients.

Recommendations 4a-4d

(a) The NSF should help to support the **development of event brokers**, which should use standard formats and protocols, to maximize LSST transient survey follow-up work.

(b) The NSF should work with its partners in Gemini to ensure that Gemini-South is well positioned for faint object spectroscopy early in the era of LSST operations, for example by supporting the construction of a rapidly configurable **high-throughput moderate-resolution spectrograph** with broad wavelength coverage.

(c) The NSF should ensure via a robustly organized U.S. OIR System that a **fraction of the U.S. OIR System observing time be allocated for rapid, faint transient observations** prioritized by an LSST event broker system so that high-priority events can be efficiently and rapidly targeted.

(d) The NSF should **direct its managing organizations to enhance coordination** among the federal components of medium to large aperture telescopes in the Southern Hemisphere, including **Gemini-South, Blanco, SOAR, and LSST,** to optimize LSST follow-up for a range of studies.

Notes:

-- The above recs are coupled in that they all pertain **to maximizing the science return from LSST**.

-- (a) and (c) pertain to transient events; (a) is **ongoing by several groups** but needs support; (c) is not a set-aside from federal observatories but a **coordination process** that may include private facilities too

-- (d) is most important for **rapid response** to transient events but is also important for non-time-critical follow-up to LSST. SOAR has rapid response, could play a role for moderate-brightness transients; also Gemini

-- The high throughput moderate resolution spectrograph in (b) could be, for example, the Gen4#3 (generation 4) instrument if so selected by the Gemini organization

Recommendation 5

- The NSF should plan for **an investment in one or both GSMTs** in order to capitalize on these observatories' exceptional scientific capabilities for the broader astronomical community in the LSST era, for example through **shared operations costs, instrument development, or limited term partnership in telescope or data access or science projects**.

Notes:

- GSMTs are highlighted both in VVPS and in NWNH as key to future goals across a broad range of science topics
- NWNH recommended a 25% share in one GSMT as a goal, through construction funds or ops (VVPS supported NWNH recs but had no specific rec on GSMTs)
- GMT and TMT both appear to be moving towards construction, without federal construction money
- Both projects welcome partnerships in any of a variety of forms
- Investing in them, at a level at or below the equivalent of a 25% share in one, would enable more decadal science by engaging more of the community

Recommendation 6

- The NSF should continue to invest in the **development** of critical instrument technologies, including **detectors, adaptive/active optics and precision radial velocity measurements**. NSF should also use existing instrument and research programs to support small-scale exploratory programs that have the potential to develop **transformative technologies**.

Notes:

- There is a widespread sense that the U.S. is falling behind other countries in technology development
- Robust AO capabilities are needed for NWNH and VVPS science goals across a range of wavelengths, spectral resolutions, and cadences
- Optimize use of current and next generation large apertures relies on the continued development of AO technologies
- Exoplanet detection requires precision radial velocity instruments (to 10 cm/s) and high-contrast coronographs
- Continued investment in detector technology is critical

Recommendation 7

- The NSF should **support a coordinated suite of** schools, workshops, and **training networks** run by experts to train the future generation of astronomers and maintain instrumentation, software, and data analysis expertise. Some of this training might best be **planned as a sequence**, with later topics building on earlier ones. NSF should use existing instrument and research programs to **support training to build instruments**.

Notes:

- Specialized training in general observing, instrumentation, software, and data analysis is **essential**
- A training network**, taught as a sequence**, would help develop a cohort of experts
- This was recommended to build up Level 3 expertise for LSST
- Generating higher-level algorithms and data products for science beyond the primary mission of LSST are not part of the LSST Project's scope, but are important for extracting the maximum science; **training networks could build up this expertise**
- **Continued support of student training** through small instrumentation projects is important; there is inadequate funding in the ATI and MRI lines

Other High Level Conclusions

- Consistent with NWNH recommendations and federal mandates, a **data archive** that is publicly accessible and well curated would be a commendable **central goal** for every major survey from a public or private facility.

- Making effective use of petabyte-scale databases ("**big data**") requires new skills, and the astronomical community working in this area needs to continue to **develop algorithms and procedures for data processing and analysis** to take advantage of the next generation of datasets.

- The scientific return from **large surveys** (both ground- and space-based) would be maximized if their **data and catalogs were made widely available using standard protocols**, with appropriate data products made available for copying or downloading when possible. Because of the volumes of data involved, the centers serving the data would be most useful if appropriate public computing cycles and storage were available to users to take data-intensive analysis to the data instead of requiring redundant copies of the data on local computing resources.

High Level Conclusions (cont.)

- **MSIP** is not structured in a way that supports strategic decisions, nor is its funding pool large enough that strategic decisions could be easily integrated into its funding process.

Notes:

  - Public-private partnerships difficult within current structure.
  - MSIP selection not structured in a way that is aimed explicitly at strategic goals.
  - Funding pool not large enough – but with **sufficient** funding, MSIP could allocate a portion for decadal goals (prioritized by a System plan; other wavelength planning could occur too, as suggested by AANM), and a portion for all suggestions.

- Creation and operation of the Telescope Time Exchange, OIR System strategic planning, and implementation of the plan, might be most effective if carried out as an **integrated program**. NOAO has successfully conducted activities like these in the past, and would be the logical choice to undertake this program, representing NSF interests.

Notes: Ongoing planning and telescope time exchange, if both run by NOAO, would be part of the same integrated System process

- NOAO could play a potentially beneficial role as a facilitator of discussions between the U.S. OIR System and other countries' observatories in order to pursue possible **international telescope time exchanges**.

Notes: Other countries have indicated their willingness to coordinate and collaborate. In some situations it could be easier for them to negotiate with a federal rather than a private entity.

  - Growing sense that Europe and Asia are surpassing U.S. pre-eminence in ground-based OIR