ReSTAR Meeting Summary

Renewing Small Telescopes for Astronomical Research

October 2007 - Chicago

The ReSTAR committee met on October 15-16 at the Chicago O'Hare Hilton Hotel to continue its discussions concerning the future of small and moderate aperture telescopes through the next 10 years, particularly in the pre- and post-LSST and Pan-STARRS era. In attendance were Michael Briley (University of Wisconsin Oshkosh), Jennifer Johnson (Ohio State), Robert Joseph (University of Hawaii), Steven Kawaler (Iowa State), Lucas Macri (NOAO), Caty Pilachowski (Indiana University), Michele Thornley (Bucknell University). Attending by telecon were Charles Bailyn (Yale University), Chris Clemens, (University of North Carolina), Randy Phelps (National Science Foundation), and Deidre Hunter (Lowell Observatory). Tom Barnes attended representing the National Science Foundation. Steve Ridgway (NOAO) and Rachel Akeson (Michelson Science Center) attended portions of the meeting to inform the ReSTAR Committee about developments in interferometry. Todd Boroson, Mia Hartmann, and David Sprayberry attended on behalf of NOAO, and Ron Probst and Jay Elias attended by telecon from NOAO. Suzanne Hawley (ARC Observatory Director) and George Jacoby (WIYN Observatory Director) participated in portions of the meeting as representatives of the group of private observatory directors. Not able to attend were John Salzer (Connecticut Wesleyan University) and David Weintraub (Vanderbilt University)

The goals of the meeting were to move from our science discussions in July to the beginning of a blueprint defining the broad capabilities needed in a national system of small and mid-size telescopes. Science discussions led to the need to understand costs of facilities and instrumentation and of operational modes not yet a part of the system, but needed by the community both to carry out the science that should be done on telescopes in this size range and to fulfill the broader needs of the community for education, training, innovation, and support of other major facilities including ALMA, JWST, GSMT, and LST.

Capabilities Needed

Based on discussions from our July meeting of science to be done on small and mid-sized telescopes the capabilities needed most are summarized in the following table. The committee drew several conclusions from this summary.

- Both wide field and high spatial resolution imaging, in both the optical and the near-infrared wavelength regions, will remain essential instrumental capabilities that should be included in the system to carry out high-priority science programs in several fields.
- Both optical and infrared spectroscopy spanning a range of resolutions from $10^3 < R < 10^5$ will be needed to carry out high-priority science programs in several fields.

Field	Science Goal	Telescope	Instrument	Mode	Comment
Solar System	Solar System, misc	4m	Optical Imaging	C/R/Q, Synoptic	high spatial resolution
Solar System	Solar System, KBO, comets	4m	Optical Imaging	C/R/Q, Synoptic	wide field, broad band & narrow band
Exoplanets	microlensing & followup	dedicated	Optical Imaging		wide field
Exoplanets	transit followup	1-2m	Optical Imaging	time domain	quick response, high speed
Exoplanets	transit searches	dedicated	Optical imaging		
Stellar Astrophysics	Monitor Variables	1-2m	Optical Imaging		Small FOV
ISM + SFR	SFR	1-2 m	Optical Imaging		wide field - 0.5-1 degree
Compact Objects, Accretion	Photometric monitoring	10 x 2-3m	Optical Imaging		narrow field, wide and narrow passbands
Compact Objects, Accretion	High speed photometry	1 x >= 3m	Optical Imaging	time domain	narrow field
Structure & Evol Galaxies		4m	Optical Imaging		narrow band, narrow field
Structure & Evol Galaxies		4m	Optical Imaging		wide field, broad band
Cosmology, etc.	LSST optical followup, SN etc	2-3m	Optical Imaging	ToO, synoptic	wide field, narrow band
Cosmology, etc.	Epoch of reionization, Ly-alpha; photometric redshifts at z=6	4m	NIR Imaging	C/R/Q	wide field, many filters needed for photometric redshifts
Solar System	Solar System, misc	4m	NIR Imaging	C/R/Q, Synoptic	high spatial resolution
Solar System	Solar System, misc	4m	NIR imaging	C/R/Q, Synoptic	
ISM + SFR	SFR	1-2m	NIR Imaging	time domain	wide field - 0.5-1 degree
Compact Objects, Accretion	Photometric monitoring	10 x 2-3m	NIR Imaging	time domain	narrow field, wide and narrow band

Structure & Evol Galaxies		2.5-4m	NIR imaging		JHK
Cosmology, etc.	Cepheids in nearby galaxies	4-m	NIR imaging	synoptic	broad band, wide field
ISM + SFR	Spitzer Warm followup	4m	NIR imaging	C/R/Q	wide field, broad and narrow band, incl L
Solar System	Solar System, misc	4m	Optical Spectroscopy, low	C/R/Q, Synoptic	R<1000 to 100000
Stellar Astrophysics	MW Fossil Record	4-m	Optical Spectroscopy, low		
Stellar Astrophysics	Monitor Variables	2-3m	Optical Spectroscopy, low	Time Domain	
Stellar Astrophysics	Identify Stellar Types	2m	Optical Spectroscopy, low	C/R/Q	
Cosmology, etc.	SN followup	4m	Optical Spectrosxopy, low	time domain	R<1000, single slit
Compact Objects, Accretion	Spectroscopic monitoring	above	Optical Spectroscopy, medium	time domain	medium resolution, single object
Structure & Evol Galaxies		4m	Optical Spectroscopy, medium		1000 - 10000
Structure & Evol Galaxies		4m	Optical Spectroscopy, medium		10000 - 50000
Solar system	Solar System	4m	Optical Spectroscopy, high		100000
Exoplanets	detection; host, exoplanet properties	4-m	Optical Spectroscopy, high		
Stellar Astrophysics	MW Fossil Record	4-m	Optical Spectroscopy, high		
Stellar Astrophysics	Abundances	1-4 m	Optical Spectroscopy, high		R=100,000, blue very helpful
Stellar Astrophysics	Planet Hosts	1-4m	Optical Spectroscopy, high	C/R/Q	wide wavelength coverage
ISM + SFR	ISM	4-m	Optical Spectroscopy, high	C/R/Q	R-100000 - 1000000, narrow wavelength, blue
Solar System	Solar System	4-m	NIR Spectroscopy	C/R/Q, Synoptic	R<1000
Solar System	Solar System	4-m	NIR Spectroscopy	C/R/Q, Synoptic	R<20000

Solar System	Solar System	4m	NIR Spectroscopy	C/R/Q, Synoptic	R>20000
Exoplanets	detection; host, exoplanet properties	4m	NIR Spectroscopy	Q, time domain	R=60000
Stellar Astrophysics	Abundances	1-4m	NIR Spectroscopy	C/R/Q	R=50000
Stellar Astrophysics	MW Fossil Record	4m	NIR Spectroscopy	C/R/Q	wide wavelength coverage
ISM + SFR	molecular spectroscopy	4m	NIR spectroscopy	C/R/Q	R=100000, narrow wavelength
Structure & Evol Galaxies	em line spectroscopy, pops, kinematics, SF evolution, extinction maps	3-4m	NIR spectroscopy		<200000
Cosmology, etc.	Cluster velocity dispersions, redshift surveys	4-6m	Optical MOS	C/R/Q	high throughput, wide field; AO helpful but not essential
ISM + SFR	SFR	3-4M	Optical MOS	time domain	0.5-1 degree
ISM + SFR	SFR	3-4 M	NIR MOS	time domain	
Cosmology, etc.	denspak	4m	IFU Spectroscopy	C/R/Q	single galaxies
Solar System	Solar System	4m	Mid-IR imaging	C/R/Q, Synoptic	
Structure & Evol Galaxies	dust features	4m	Mid-IR spectroscopy		R~1000
Solar System	Solar System	4m	Mid-IR spectroscopy	C/R/Q, Synoptic	
Solar System	Solar System	4m	Polarimetry	C/R/Q, Synoptic	
Stellar Astrophysics	Stellar Properties	1-4m	many techniques		spectropol, low high res spec, dome domain imaging & spec
Stellar Astrophysics	Calibration	1-2m	misc	C/R/Q	

- Additional instrumental capabilities including optical multi-object spectroscopy over large (> 0.5 degree) fields of view, optical and IR multi-object spectroscopy over limited fields of view with integral field units, and mid-IR imaging and low or moderate dispersion spectroscopy will also be needed for science programs spanning several fields.
- Other capabilities needed for a more limited range of scientific applications include polarimetry and spectropolarimetry.
- Most scientific programs to be carried out on small and mid-size telescopes will benefit from apertures in the range 3-4 meters, although some can be done on smaller telescopes.

The exception to the need for apertures in the 3-4 meter range is programs in the area of time domain science, where smaller telescopes may be advantageous. Some events saturate on telescopes with larger apertures. The competitive nature of access to larger facilities also makes scheduling time domain observations problematic. Starting with relatively small apertures will allow for the development of methodology and demand for time domain observations.

The committee noted that much of the science to be done on small and mid-size telescopes is often essential for effective use of larger facilities. However, research on small and mid-size telescopes isn't necessarily directly motivated by the science done on larger facilities or in direct support of those observations, and observers using small and mid-size telescopes don't think of themselves as providing support for big-glass science. Advocacy for small and mid-size is important in its own right.

The committee emphasized the importance of the connection between the science and the specific capabilities that should be provided through the system of small and mid-size telescopes. The management of the system should be dynamic, and changes to the capabilities offered should be driven by oversubscription rates.

Nevertheless, the system should include some mechanism for access to really small telescopes for some science programs. An example is the determination of parallaxes for Cepheids observed with HST, where apertures in the range of 0.4-0.6 meters is needed. Science on most of the telescopes in this aperture range today is dominated by time domain observations.

The Las Cumbres Observatory is a good example of a network of telescopes being developed for time domain observations. LSO is interested in providing community access to their facilities, and are engaged in a dialog with NOAO about how such access might be provided. LCO does not yet offer a spectroscopic capability, and the contribution by NOAO of spectrographs for LCO 2-m telescopes may be a mechanism to obtain community access to the network.

Costs for New Facilities, Instruments, and Capabilities

David Sprayberry of NOAO provided very rough cost estimates for instruments, facilities, and operational models that the committee identified as important for the system. Sprayberry stresses that these are very rough order of magnitude estimates. The estimates are based on varying standards for costs, specifically what are deliverables in terms of documentation, software, interface controls, commissioning, integration and test, and the level of complexity and robustness of an instrument or facility ("facility-ness").

The main cost drivers for instruments are field of view and "facility-ness." Operations drivers include reconfiguration time, expendables, and maintenance costs. For telescopes, location is the most significant cost driver. Full life-cycle costs should be included.

Spectrographs

- The MIKE spectrograph at Magellan cost about $1M (Rebecca Bernstein, private communication) but scientist salaries not included, nor overhead or benefits, and some capital items off budget. The true cost is probably closer to $2M. The costs for documentation, software, the data reduction pipeline, and integration and testing are also not included.
- The cost of the High Resolution Spectrograph on HET was $2.7M.
- For a new echelle on a 4-m telescope, the cost would probably fall between $2.5 - $3M.
- The Goodman spectrograph for SOAR is a Nasmyth, low and medium resolution, 5'x5' FOV spectrograph with a slit mask option. The cost is approximately $2.1M (Chris Clemens). All capital costs are documented in some detail, as is all labor, including students and faculty, totalling $1.5M. A clone of the Goodman spectrograph would cost about $600K. That cost does not include integration, testing, commissioning, data reduction software, or documentation. The cost would be greater if the design were modified for a Cassegrain focus. Commissioning costs are hidden in staffing costs at the observatory, but the cost of the fully burdened operations budget is significant. UNC will continue to support the Goodman spectrograph for at least 12 months. The instrument team needs to be sustained for years beyond commissioning.

The cost of a near-IR echelle spectrograph (R~50,000) for a 4-m telescope can be estimated from the cost of Phoenix, although it was built some years ago. Alternatively, Hinkle, Joyce, Jaffe, and Tokunaga have proposed a dual-beam spectrograph that would cover the 1-2m and 2.5-5m regimes simultaneously. A dual-beam design doubles the cost for detectors but reduces mechanical moving parts and provides efficient operations. The design includes an on-slit acquisition and guide camera.

Estimated cost:

- $2M for purchased parts
- $2-3M for labor - design, build, test

- $0.5-1M for data pipeline

Total: $4-5M

The NEWFIRM Wide Field NIR Imager:
The cost for the wide-field (28'), near-IR imager NEWFIRM provides a case study. This facility instrument is challenging because of the large FOV, fast readout, fast optical system with large and difficult, tightly integrated software, and because it is well tested and documented

Costs include:
$4.3M payroll - NOAO
$0.65M - MD data reduction pipeline
$1.5M detectors
$1.1M other capital (lenses, dewar, motors)
TOTAL $6.9M, including all costs and benefits, but not institutional overhead

The cost to clone another NEWFIRM now would be about $4.75M. This is based on $2.7M in non-recurring engineering costs and $2M for four detectors. The design would only work for the Mayall or Blanco 4-m telescopes.

To provide a full degree FOV on a 4-m would require four times the NEWFIRM FOV. A 4x4 mosaic of 1-2 micron detectors on Mayall or Blanco would provide 48/53 arcmin FOV without reimaging (easier optics, not larger than focal plane) but includes a corrector. The plate scale would depend on pixel size (18 or 20 microns), but would be roughly 0.4" per pixel. Finer sampling would require reimaging, which would drive up cost and size. A larger instrument would not fit in the prime focus envelope.

The cost of detector for such an imager would be around $6.4M, and the total cost would be in the range of ~$10M. It might be more cost effective to use more nights with a smaller FOV than to build an instrument with this large FOV.

<u>Estimating the Cost of Telescopes</u> -

- Scaling laws don't work - Even standard, off-the-shelf, commercial telescope costs are changing
- Site is a critical driver (infrastructure, transportation, staffing)
- Annual operations costs are very roughly 10% of construction (unlike instruments)

<u>Southern IRTF clone</u>. - 3-m telescope comparable to the IRTF in the north will cost about $25M for telescope and dome construction, not including instruments or site infrastructure or permission.

What might the science drivers be for a southern IRTF clone? Gemini south is already IR optimized. What might make IRTF competitive in the south might be a higher altitude than Gemini, and greater friendliness to visitor instruments. Cerro Pachon, where Gemini is located, isn't particularly high altitude, but the site is very dry. However, because of the altitude, telluric features are pressure broadened. A higher altitude site might provide a significant gain in performance for some observations. Potential higher altitude sites include Tolanchar (undeveloped, ~4500m, dry, good seeing, part of AURA reserve) and Chajnantor (development planned, ~5600m; Cornell/Caltech submillimeter telescope). Site costs could easily equal or exceed telescope costs. Operations costs and instruments would also be needed.

"Baby" LSST
Since the bright limit for LSST will be roughly 18th, and many transient events are brighter than that limit, a smaller aperture, wide-field imaging telescope slaved to the cadence of LSST would be useful for covering the sky to follow bright transients. A cost model based on a simple scaling of LSST MREFC proposal for a facility co-located with LSST would be about ~$3M for a 1-m telescope and ~$6M for a 2-m telescope.

The cost of a camera would also be significant. A 1-1.5 gigapixel camera may be sufficient, rather than a 3.2 gigapixel camera. In that case, the cost of the camera would be similar to the Dark Energy Camera or the WIYN ODI camera ($7-10M). Much of the infrastructure for the site, operations, and the data pipeline could be shared with LSST (software, pipeline, etc.), especially if the telescope were co-located with LSST. Costs might be comparable to Pan-STARRS in the north.

Time Domain System of 2-m Telescopes
The cost of telescopes in a global network of 2-m telescopes for spectroscopy operated for time domain science would be about $8-10M each. Spectrographs similar to the Goodman spectrograph built for SOAR would be $0.6-1.1M each. Small field (5' FOV) NIR imaging cameras would cost about $0.7-1.2M each. The total cost per telescope with instruments in the network $10-15M per copy. Costs for site development could be as much as 100% of the telescope cost, and would be less for developed sites.

Operations costs are harder to estimate. Intensive scheduling, queue, service, TOO modes require highly capable staff. Robotic telescopes may be an option, but maintenance will still be expensive. It may be better to build a global network from the ground up than to acquire and upgrade a mix of older facilities with different initial states and non-standard optical configurations.

Science Subcommittees
The Science sub-committees constituted in July provided short progress reports.

Stellar Physics (Jennifer Johnson) - The science case for stellar physics focuses mostly on bright targets. Fainter targets include white dwarfs and L and T dwarfs. Understanding how much community-access time is needed for these observations is difficult, as is the fraction of such time that might be used for stellar physics on non-federal facilities.

Exoplanets (Mike Briley) - The report of the Exoplanet Task Force is not yet public, but will be soon. That report should offer useful guidance on the role of small and mid-size telescopes in exoplanet research. The amount of time needed by the community for high dispersion spectroscopy of stars with planets is also unknown, since this may be an area in which much work will be done using non-federal facilities.

Nearby Galaxies (Deidre Hunter): The subcommittee has identified one overarching question (what are the processes that drive galaxy evolution?) and five questions that drive specific research.

- How do external and internal forces shape galaxies along the Hubble sequence?
- What leads to nuclear activity?
- What are the star formation histories, enrichment histories, and star formation drivers along the Hubble sequence?
- What are the star formation and growth processes in outer stellar disks?
- How does the structure and mass distribution of galaxies change over time?

The subcommittee is still grappling with how to decide on the emphasis between nearby and distant galaxies. Investigations of higher redshift galaxies may need further discussion.

Cosmology - (John Salzer, presented by Bob Joseph): The cosmology sub-committee requests advice and guidance from the full committee. Their science focus includes the following:

- Cosmic explosions - the light curves of supernovae and gamma ray bursts can be monitored with 2-4 m telescopes.
- Deep Surveys for distant galaxies - narrow band imaging near quasars is needed using wide field imagers like NEWFIRM.
- Large scale structure - new redshift surveys will be needed, as well as additional specialized spectroscopic surveys (which may need telescopes bigger than 4m).
- Velocity independent distance indicators are needed to investigate peculiar velocities imposed on the Hubble flow to map dark matter.
- Will small and mid-size telescopes make important contributions to weak lensing - or will planned surveys already fulfill this need up until LSST?
- Observations of galaxy clusters, even relatively nearby systems like Virgo and Coma, are needed to probe cluster environments. 2-4 meter class telescopes with imaging spectroscopy are needed
- Dark matter studies on small and large scales will be important especially velocity dispersion studies and strong lensing for dark matter in clusters.

Solar System (Deidre Hunter) - Efforts to find a representative from planetary science to serve on ReSTAR were not successful. Instead, we will ask the DPS to convene a group to review Deidre's original summary of planetary science, and advise us further on what capabilities are most important for planetary science.

Compact Objects (Charles Bailyn) - Charles was not available to participate.

Star Formation (Randy Phelps/David Weintraub) - Randy noted that much of the science in this area requires 4-m class telescopes, and that mid-IR observations are important.

Instruments like MIRSI on IRTF are important for star formation. Science topics in star formation include:

- distribution of stellar masses
- star-disk interaction
- stellar outflows
- evolution of circumstellar disks - how transformed into planets
- debris disks
- clustered vs. distributed star formation.

A Blueprint of the System - apertures, telescope nights, instruments, modes

The committee identified several specific issues for discussion and priorities for a public access system of small and mid-size telescopes.

- The system should also include infrastructure support and support for data pipelines, not just instrumentation
- The balance between providing many nights of public access and the quality of services provided needs to be defined. The committee feels that telescopes contributing to the system should work to a high standard.
- Public access means that time is available through merit review and is not dependent on developing collaborations to gain access.
- A minimum set of deliverables processed through a pipeline should be included in the agreements through which non-federal facilities participate in the system.
- Software should be available and documented so that observers can reduce data and data formats should be standardized such that observers can software of choice for data reductions.
- The productivity of VLT may be due in part to user and data support of those facilities. We should consider what services users of the system will need to make effective and productive use of public-access facilities.
- Archives are exceptionally useful, and providing usable archives of data may be a higher priority than data pipelines.

Approaches to the Question, "How many nights?"

The committee considered several approaches to the question "How many nights are needed in the public-access system of small and mid-size telescopes?" Approaches included demographic estimates based on AIP and AAS statistics, estimates based on science initiatives appropriate to small and mid-size telescopes, estimates based on proposal pressure on current facilities, and estimates based on a comparison of public and private access levels

Demographic Estimates

The ReSTAR committee understands that a system defined strictly by user need and not by competitive science is not tenable. However, demographics do provide an estimate of the number of telescope nights needed in a public access system under the assumption that competitive peer review provides an effective filter to assure that the science is significant and important in the broad context of astronomy and astrophysics.

The committee considered first the number of dissertations each year that utilize public-access facilities. Roughly 150 Ph.D. degrees are awarded each year in astronomy and astrophysics. If half of those use OIR ground-based data, and half utilize non-federal facilities, then roughly 35-40 dissertations each year would utilize public-access facilities. In fact, NOAO supports roughly 50 proposals each year from different, individual dissertation students who request time at KPNO, CTIO, Gemini, or through TSIP. Student programs require about 10 nights per year per student. A typical student requires two years of dissertation observations. Thus, supporting dissertation observations requires at least 500 nights per year of telescope access. Roughly two equivalent telescopes are devoted full-time to the support of Ph.D. dissertations.

Of the 400 proposals received per semester from all investigators, roughly half receive telescopes time (400 programs per year). NOAO awards about 1600 nights per year of telescope time. Over 2000 unique, individual users (PIs and CoIs) were awarded time on facilities available through NOAO during the period 2000-2005.

Of the roughly 6000 US members of the American Astronomical Society, approximately 2500 are OIR ground-based observers. This is consistent with the number of NOAO users over a 5 year period. Allowing for an oversubscription factor of two, providing 10 telescopes nights per year to half of 2500 U.S. observers would require 12,500 nights. Increasing the oversubscription factor and allowing for significant access to non-federal facilities, roughly 5000 telescope nights per year (roughly 12+ equivalent telescopes) might be a reasonable goal for a public-access system. NOAO now has available 5.5 equivalent telescopes. This number would effectively need to be doubled. The availability of data archives could reduce the demand for telescope nights, especially if data were reduced via a pipeline.

Of the 28 telescopes larger than 2-m, 80% are private. Only 6 more telescopes would be needed to match 12,500 nights needed for all observers, with an oversubscription factor of two. However, providing modern, competitive instrumentation, data pipelines, and archives is probably more cost effective than building new telescopes. Improving telescope efficiency through pre-prepared observing templates for observing programs, with review by support astronomers to check that calibrations etc. are done might be a cost-effective approach to improving productivity even on small and mid-size telescopes.

Science Driven Estimates

The primary argument for the number of telescope nights included in a public access system must, of course, be based on science, as emphasized by the Senior Review. The difficulty comes in trying to define a number of nights. The numbers of nights needed for specific programs can be defined fairly easily, but the problem comes from understanding the number and scope of programs that might be recommended by competitive peer review.

An example of a science program that might be carried out on small and mid-size telescopes is the followup of exoplanets discovered by the Kepler mission. Kepler will find roughly 1000 planets in 3 years. Some will be followed up using private telescopes, but perhaps 100 per year will need access to publicly available facilities for followup.

Another example is followup to the Tycho mission. Of the 2 million stars in that mission, only 3500 have been analyzed at high resolution. How much time on small and mid-size telescopes will be needed to carry out the science that will result from Tycho?

The use to which the community will put new resources may also not be predictable. For example, CSHELL on IRTF was built for studying comets, but has been very popular for stellar astronomy.

We could, to obtain a basic estimate, estimate the number of planets that will be found, number of KBO's likely to be discovered, the number of supernovae to be discovered, and a few other cases and determine the number of telescope nights needed for just these programs. This will surely be an underestimate of the true need.

Proposal Driven Estimates

NOAO receives 800 proposals per year, and awards time to half. This number is likely to change with new investment in a system of public access facilities, particularly if modern instrumentation is a part of the new system. Lack of opportunity limits what people propose for. Providing a new, state of the art instrument on the KPNO 2-m telescope will likely increase its oversubscription rate from the current factor of 0.9 to more than 2. Under-subscription rates on most small telescopes are likely due to limited and aging instrumentation rather than to a lack of scientific value. In the range of 1-2 meter telescopes, what's needed is not more facilities but better instruments. The Canada France Hawaii Telescope continues to be heavily oversubscribed because of the constant renewal of its instruments. Improving instrumentation makes more sense than increasing number of nights, except in the area of exploitation of the time domain. Efficient RC spectrographs will also increase oversubscription on NOAO's 4-m telescopes even though this is not a new capability.

Comparing Public and Private Access

The committee looked at the level of access available to astronomers with access to non-federal facilities, and asked if users of public-access facilities should have a comparable level of access as users of non-federal facilities. The goal, again, is to get an independent estimate of the number of telescope nights needed in a public access system.

Given that 80% of the 28 U.S. telescopes larger than 2 meters are non-federal, doubling the number of public-access nights (now only 1600) will still not bring public access to the level available users of non-federal facilities.

The committee reviewed Trimble and Ceja's (Astron. Nachr. / AN, 328, 983, 2007) recent data on the productivity and impact of astronomical facilities, which provides paper production and citation data by aperture. Both public and private facilities show a range of productivity and citation rates.

A common method for gaining access to non-federal facilities is through collaboration with those who have access. This approach was felt to be insufficient for the community because it is not merit based. The committee was also concerned that confinement of certain capabilities to non-federal facilities is not good for the health of the discipline. Capabilities needed for highly competitive science programs but which are not available on national facilities could offered through public access to non-federal facilities.
In particular, uniqueness should not be a defining characteristic for instrumentation on national facilities. Key capabilities in high demand for a range of science programs should be available on national facilities.

Principles of the System - What are the principles around which the system is built?

The ReSTAR committee identified the following principles that should characterize the new system of public access to small and mid-size telescopes.

Principles

- Access should be based on scientific merit through peer review.
- Access should be driven by the science and not by entitlement.
- The capabilities most in demand must be available on public access telescopes
- Capabilities in demand by relatively small numbers of users or for a limited scientific application may be best deployed on non-federal facilities.
- The public access system of small and mid-size telescopes should emphasize reliability, standardization, and quality of data. Resources will be needed for non-federal facilities to achieve these standards.
- Archives and pipelines are an important component of a public access system.
- Competitive instruments are important at all apertures.
- Procedures for assuring continued support for dissertations already underway on public facilities should be assured
- Ongoing oversight of the system will be needed. The system must be allowed to evolve in a dynamic way.
- The needs of the system should be considered in allocation of NSF funds to non-federal facilities for participation in the system.

Comparison to the TSIP and URO Programs

Two models for NSF support of non-federal facilities are in use at this time, the Telescope System Instrumentation Program and the University Radio Observatory program. The goal of TSIP is to make telescope time on large, non-federal facilities available to the community in return for NSF funds for instrumentation and for operations support. The URO program makes operations funding available for radio astronomy facilities operated by universities in return for community access. Neither program is necessarily optimal for a new system of national access to small and mid-size telescopes.

A hybrid solution is probably called for to establish a new system of community access. Arrangements for each non-federal observatory that participates in the system will likely be different, involving a mixture of access, new instruments, and operations support, and will likely be brokered by NOAO. The system will need to be sustained over a relatively long time so that the access available to the community remains stable. The system will also need to evolve as the science and scientific priorities shift over time. A proposal for support of the system will probably need to be submitted to the NSF, and a group convened regularly to review the effectiveness of the system and the needs of the community.

The participation of non-federal observatories should be evaluated using well-defined criteria (for example, an exposure time calculator should be available for instruments available to the community, reduction software should compile on standard platforms, a "point and click" GUI should be available for users, documentation on FITS headers should be available, an up-to-date users manual should available on line, etc.).

Investigator funding

The committee considered whether funding for investigators should be an important part of the system. Funding might include funds for travel, publication, or data reduction and analysis. The cost for NOAO to provide support for observers currently using facilities available through NOAO can be estimated. To pay all page charges for all papers resulting from NOAO observations would cost $0.7M. Covering all travel costs at the level of one observer per run would add $0.4M. Currently, about $0.05M per year goes to students to support dissertation observations

The cost of covering page charges and travel for one investigator per run is comparable to the cost of building a clone of the Goodman spectrograph per year. A full-up observing queue for one telescope is also about $1M. The committee felt that new instrumentation is a higher priority and is more cost effective than providing travel and publications costs for observers. Likewise, it be more cost effective to make investments to enable remote observing or service observing than to fund observers' travel.

Observing Modes

The committee turned to a discussion of the balance of observing modes - classical, queue, and service observing. Gemini originally planned to split observing time evenly between classical observing and service observing, but the community overwhelmingly preferred queue observing. Gemini is now scheduled with queue observing more than 90% of the time. Queue is also particularly appropriate for time domain observations.

The availability of classically scheduled observing time is particularly important for training students, or for observations that are experimental and need to be tweaked.

The cost of queue observing depends on the level of service. If the community is able to enter observational requirements into the queue, then a full-time queue can be operated by 2.4 FTE of observers and two people to manage the queue. The Hobby-Eberly Telescope uses four people to staff their queue, and four telescope operators. The cost of queue observing is probably less on small telescopes with limited instrumentation, since complexity comes from selecting from among several instruments at any given moment. Remote observing is less expensive than queue observing, but is less efficient since alternate programs can't be carried out when conditions aren't right for the primary program.

The committee recommends increasing opportunities for both remote observing and queue observing. Additional special opportunities should be built into queue observing, including TOO programs and "snapshot" programs. The WIYN 2-hour queue allowed observers to obtain limited or test observations. The queue should also include programs that can be carried out when conditions are less than optimal. It is especially important that queue observing protocols lead to the completion of most programs initiated during a semester. The experience of the WIYN Queue, for example, suggests that observers are dissatisfied and the science suffers when only portions of their approved programs are completed.

What is the right balance of survey and large programs?

The question of the right balance between classical programs and large or survey programs is hard to answer in the abstract. The trend is more and more toward surveys and large programs, and astronomers early in their careers are becoming comfortable with significant fractions of available observing time devoted to large programs and surveys.

NOAO survey programs are limited to 20% of observing time, the NOAO tries to limit the fraction of time allocated to surveys and large programs in any calendar phase (e.g. not more that 20% of March/April dark time). Surveys are required to return to the community uniform data products through the NOAO archive and investigators must describe in their proposals how the work will be managed. A survey fraction of 20% can be problematic, however, when a substantial share of telescope time is committed to partnerships.

NRAO is moving toward a limit of 50% of time on their facilities allocated to large programs and surveys. Proprietary time periods will be set at one year, and it will be considered a competitive advantage to shorten proprietary periods. NRAO may also help with funding or support if investigators provide additional data products to the archive. Investigators have to provide a data reduction and release plan.

The community has expressed great interest in using NEWFIRM for surveys. NEWFIRM will be shared between the northern and southern hemispheres.

The role of non-federal observatories in carrying out surveys was also discussed. Arrangements for public access time on non-federal telescopes should continue over a long enough period of time that surveys can be carried out. The participation of non-federal observatories in the system should be designed to enhance collaboration of community members in major surveys carried out on those facilities. It may also be appropriate for non-federal observatories to provide access to survey products in return for public operations support.

Adaptive Optics - What is the role of AO on small/mid-size telescopes?

ACCORD has undertaken to rewrite the adaptive optics roadmap, and the NSF is considering changing the mechanisms for supporting AO development. It is an appropriate time to consider the role that adaptive optics should play on telescopes in a public access system. The roadmapping activity will be overseen by Julian Christou at NSF.

In a programmatic sense, is it worth making major investments in AO for small and mid-size telescopes compared to the gains to be made? The limiting brightness for natural guide stars is independent of telescope aperture at around 12th magnitude, and the price for laser beacons is coming down within reach. AO is almost always worth the cost for larger telescopes, but the question remains open on 1-5 meter class telescopes.

An AO system with a laser beacon is being built for the SOAR telescope. The budget for AO on SOAR is $3.7M for a laser guide star system. The SOAR AO system will provide ground layer correction to work into visible wavelengths for moderate field, deep imaging. The goal is to fit in capability between Blanco and Gemini.

AO systems for 4-m class telescopes are less complicated than for larger telescopes and require fewer elements. Turnkey natural guide star systems are available for 2-3m class telescopes.

Simple tip-tilt systems do well on small telescopes. For example, the gain on WIYN using the WIYN Tip-Tile Module is 0.1" to 0.15". The gain from no correction to tip-tilt to full AO needs to be investigated for 4-m telescopes. Applications for IR spectroscopy and with IFUs may gain the most, but costs may lead to the conclusion that investigators may be better off making observations requiring full AO on 8-m class telescopes.

The ReSTAR committee requests the guidance of AO roadmap group on the utility and cost effectiveness of AO on 2-4 meter class telescopes, particularly for use with IFU spectroscopy and IR spectroscopy.

Interferometry

Rachel Akeson and Steve Ridgway came to our meeting to discuss the role of interferometry on small and mid-size telescopes in the context of a new system of public access telescopes. Interferometry is a capability that the community has no access to at this time, but advances in interferometry now allow application of the technique to a variety of interesting scientific programs.

Akeson reviewed the major points of the report that the interferometry community prepared for our consideration. The report was distributed prior to the meeting.

- Review of facilities, basic parameters, optical to 10 microns, baselines 30-300 meters
    - Spatial resolutions of 1 mas in optical to 25 mas in mid ir
    - spectral resolution 30,000 in optical
- Science research areas include
    - Fundamental stellar physics - basic driver, masses, radii, rotation, oscillations, binary interactions
    - Stellar atmospheres, deep convection, limb darkening, multicomponent atmospheres
    - Dust formation and mass loss
    - Young stars and planetary systems
    - AGN size of BAL of accretion disk

Ridgway described the demand for access to interferometers.

- Oversubscription for facilities
    - Keck schedules 95 nights per year via NASA, with oversubscription factors of 2-4
    - VLT oversubscription factors are about 3
    - CHARA is scheduled for 360 nights per year, with competition within the consortium
- Collaborators - other groups buy in to university facilities
- Exponential increase in publications has occurred in recent years.
- Breakthrough results - any time new objects are observed, they find that new measurements lead to unexpected results in conflict with models
- Radio interferometry - optical interferometry is following the same publication curve that radio interferometry followed previously.
- The IAU has established a new commission for interferometry (Commission 54)
- Centers for interferometric studies are being established, with more than half in Europe.

Last year's workshop on the future of interferometry recommended that NOAO and NSF should facilitate broad community access to interferometers.

Akeson described the current status of interferometers in the U.S.

- Long term NASA support for KI is unlikely.
- PTI and ISI may shut down as other arrays become available.
- MROI is still under development.
- CHARA and NPOI are operational, but with limited operations budgets, and their full science potential remains unrealized

She also noted parallels with millimeter interferometry

- Millimeter interferometry started with university facilities that led to CARMA and ALMA

- However, budget levels are different, CHARA and NPOI have budgets of $0.5-0.8M per year, while OVRO and BIMA have budgets of $1-2M per year

Funding models for interferometry need further discussion. It may be possible to create URO-like system, or to modify the TSIP programs to accommodate interferometry. Interferometers are funded by different agencies, including NASA, NSF, and the DOD, with some state funding, as well.

The last Decadal Survey recommended $100M for development of interferometry.

Providing community access to interferometry also depends on building a user community beyond the current facility users. Observing might be by queue/service observing, which would have a modest impact on staffing of existing interferometers.

Draft Recommendations

The committee reviewed and discussed a set of draft recommendations, distributed separately.

Concerning facilities recommendations, the committee found that the science case for a southern clone of IRTF may not be compelling. Gemini is already optimized for IR, so many of the science goals can be fulfilled there. If a higher site is selected, the costs will go way up, but a higher site may enable science that cannot be done at Gemini. A southern IRTF should be reconsidered in five years when new sites or facilities have been developed at higher altitude.

More information is needed to establish a science case for a "baby LSST" clone. Any recommendation would also need to factor in the contribution of Pan-STARRS in the north and justify, on the basis of science, why a facility might be needed in the south. A 2-m class LSST clone would provide data when transient events are too bright for LSST to observe. Is such a facility interesting enough to justify the expense? How often will transients occur that will saturate LSST? The need for an LSST companion in the south can be assessed after Pan-STARRS has been in operation for a year?

Process for Drafting the Report

Subcommittee reports on science themes for small and mid-size telescopes to be included in the report should be available in draft form early in November. Where appropriate, science themes should tie into ALMA, Spitzer, JWST, LSST, and GSMT. The science themes should clearly define what instrumental and operational capabilities are needed to achieve the science goals.

The DPS will be asked to revise and expand the science theme for planetary science.

The report, incorporating the science themes will be available in draft form in late November. Our goal is to circulate the draft report to selected groups for comments, which will be discussed at our December meeting. Comments will be requested from the NOAO Users Committee via the Chair, the group of non-federal observatory directors, selected members of the Senior Review, and other groups as appropriate.

NOAO has arranged a Town Meeting at the Austin meeting of the AAS on January 10. The Town Hall discussion will begin a major effort to educate users of facilities of all sizes about the value of small and mid-size telescopes and about the synergy that results from observations over the range of all apertures. We must remember that although ReSTAR received input from many members of the community, we still heard from only 5% of the astronomers NOAO is serving.

Beyond the Town Hall will be the need to convince the next Decadal Survey that a balanced program is the best hope for the health of the field, and that a system of public and non-federal facilities will best meet the needs of the community.

We should also consider how the new system will be overseen to assure that it continues to evolve as the scientific needs evolve. The next decade will see the construction and early operations of ALMA, JWST, GSMT, and LST, as well as the true blossoming of the NVO. All of these will have profound effects on our field, and the system of small and mid-size telescopes will need to change as our field changes.

The NOAO scientific staff working groups on the system are looking at implementation issues, including several facilities that have approached NOAO about participation in the system, at interferometry, and at time domain facilities.

Finally, we may wish to consider holding a community workshop next summer to help realize our recommendations and consider how to implement new instruments and new facilities as part of a system of small and mid-size telescopes.