

The Time Domain – A Bigger Change Than You Think

Todd Boroson

As I write this, the Renewing Small Telescopes for Astronomical Research (ReSTAR) committee has been meeting in Washington, DC for the last two days. Their discussions about the facility needs of the community—using input from the many contributions to the ReSTAR Web site—have impressed upon me the difficulty of coming up with a reliable estimate for what the community wants.

How do you know that the input is representative? How do you factor in a reasonable oversubscription rate? How do you adjust for the difference between what people say they will do and what they will actually have time to do? However, these are merely concerns of a quantitative nature. The more interesting questions are those that are qualitative and have to do with the evolution of fields and of capabilities, and how our interests will change as a result. Among these, the '800-pound gorilla' is the time domain.

The door has just been cracked on the time domain, with little bits from projects like the Sloan Digital Sky Survey, MACHO and SuperMACHO, and the Palomar-Quest Survey. Researchers study dozens or even hundreds of variable or transient objects, and explore statistical properties of larger samples. But now we are gearing up for projects that will produce many orders of

magnitude more discoveries, and will require significant new facilities—operated in significantly different ways—to make effective use of those projects.

The Panoramic Survey Telescope and Rapid Response System (Pan-STARRS-1) will soon begin to show us how bad a mess we are in, and by the middle of the next decade, the Large Synoptic Survey Telescope (LSST) will have fundamentally changed the way we view the sky. The need to follow up on short-lived transients, the challenge of putting together programs that provide the appropriate sampling of extrasolar planet transits, cataclysmic variable orbits, reverberation effects in active nuclei, or supernova light curves, will not be satisfied by telling the Time Allocation Committee, "I know I'll have objects whenever my observations are scheduled."

The time domain follow-up network of facilities must be created. It will include 1-meter, 2-meter, and 4-meter telescopes (and maybe larger ones) with optical and infrared imagers and spectrographs. But time will be allocated and observations will be made in a different way.

Your 12,000 spectra of 600 targets will be preprogrammed to give you just the phase coverage you need. You will be allocated 150 target-of-opportunity (TOO) interrupts over

the semester given a certain set of transient characteristics from an LSST "filter" that you have defined. Perhaps 30 percent of the time will be reserved for unanticipated events, requiring some sort of quick-response peer review. And, in between the time domain observations, the telescope will slew to the nearest object from a non-time-critical program and obtain that observation.

We already do this to some extent. We schedule TOO interrupts on our classically operated telescopes. We schedule a series of fractional nights to monitor some object with a known period. The huge quantitative change, however, will drive a huge qualitative change.

Of course, the current projects we do, and our normal observing modes, will not disappear. And bits of the time domain system—VOEvent, the Panchromatic Robotic Optical Monitoring and Polarimetry Telescopes (PROMPT), the Las Cumbres Observatory Global Telescope network, the robotic P60 telescope—are already starting to appear. But the time domain represents such a huge discovery space, and an opportunity to explore a new dimension of the Universe, that it will be an unforgivable waste of the resources that are going into those discoveries if we do not prepare ourselves to systematically follow-up on them.

Update on ReSTAR

The Renewing Small Telescopes for Astronomical Research (ReSTAR) committee concluded a very successful solicitation of community input on the specific and quantitative needs for capabilities on small telescopes. Over 160 individuals ranked capabilities and contributed their ideas through the committee Web site (www.noao.edu/system/restar) in time for their meeting at the end of July. The input was summarized statistically and all the comments were read and discussed by the committee. Their next meeting will be October 15-16 in Chicago.

Announcement of Opportunity for Participation in Large Synoptic Survey Telescope Science Collaborations

Michael Strauss (Princeton University) & the LSST Science Advisory Committee

The science goals of the Large Synoptic Survey Telescope (LSST), a dedicated 8.4-meter wide-field telescope to be placed on Cerro Pachón in the Chilean Andes, have been discussed in numerous forums and meetings. Now it is time for more detailed investigations of the science questions that LSST will address. A call for proposals is being prepared (targeted for release in December) to offer formal participation in the planning and execution of science activities with the LSST, for researchers in the US astronomical and elementary particle physics communities.

The LSST will obtain repeated images of ~20,000 square degrees in six pass bands (u,g,r,i,z,Y) during a ten-year survey of the southern-hemisphere sky. Individual visits by LSST to each 10 square-degree field will reach $r = 24.7$ (5σ for point sources) in a pair of 15-second exposures, and each field will be imaged ~1,600 times, spread over the six bands, with co-added aggregate images reaching $r \sim 27.6$ AB mag.

The current project plan calls for telescope commissioning to begin in 2014. Survey operations are expected to begin in 2015. This survey will enable a vast range of investigations that can exploit the depth, sky coverage, and time-domain sampling provided by the LSST data. The design of the telescope and operations is driven by four core science goals:

- Investigating the Nature of Dark Energy and Dark Matter
- Taking an Inventory of the Solar System
- Exploring the Transient Optical Sky
- Mapping the Milky Way

Detailed descriptions of the core project goals and design criteria can be found in the LSST Science Requirements Document at www.lsst.org/Science/docs/SRD.pdf. Previous discussions of the science drivers for the project can be found at various sites, including www.lsst.org/Science/community_input.shtml, www.lsst.org/Science/science_goals.shtml, and most recently, www.lsst.org/Meetings/AAS/2007/AAS209.shtml.

The LSST vision is built on the notion that a survey that primarily addresses the four core goals above will also be useful for a wide range of other scientific investigations. LSST will go deeper and will cover a wider range of wavelength than any other steradian-class sky survey, and its extensive time domain coverage over such a large solid angle will be unprecedented. It is in this context that the LSST Board of Directors and LSST Project Director, Tony Tyson, have established a series of Science Collaborations in broadly defined scientific areas in which LSST will provide opportunities for scientific investigation. The collaborations have been initially seeded by members from the LSST partner institutions. The chairs of the seed collaborations have been appointed for a period of two years; future leadership of the col-



This image from the Deep Lens Survey (DLS) provides a sense of LSST imaging data. The DLS image shows roughly ten times as many galaxies per unit area as images from the Sloan Digital Sky Survey, and LSST data will actually go deeper than the DLS. LSST images will also have better resolution, and each will cover 50,000 times the area of a DLS image, in five different optical bands.

Image credit: Deep Lens Survey/University of California-Davis/NOAO

laborations will be chosen by the full complement of their respective members, in consultation with the chair of the LSST Science Advisory Committee and the LSST director.

In addition, new collaborations, or even competing collaborations, may be formed (see more below). The collaborations are organized by science area, with the explicit understanding in the project that there will be many areas in which different groups have overlapping interests. The tasks of the Science Collaborations are to:

- develop and document in more detail the science opportunities provided by the LSST
- provide input to aspects of the LSST design that remain under discussion such as the planned cadence, software and database design, filter design, etc.
- develop a roadmap and participate in precursor studies, calibrations, algorithm development, etc., that may be required in

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Participation in LSST Science Collaborations continued

advance of first light, so that it is possible to take full advantage of LSST early in its operational phase

- participate actively in the commissioning of the telescope, instrument, and data system by using the early data to do science, and thus determine the data quality, identify any systematic effects, etc., and recommend ways to address any problems that are identified.

Prospective applicants can get a sense of the science goals of the existing collaborations from posters presented at the January 2007 American Astronomical Society meeting, which can be found at www.lsst.org/Meetings/AAS/2007/AAS209.shtml.

With this pending announcement, we are alerting members of the broader US astronomical and particle physics communities that we will soon invite them to apply to join one of the existing collaborations, or to propose and constitute a new collaboration, either in one of the existing areas or in a new area.

Receipt and review of applications will be organized by NOAO and the Stanford Linear Accelerator Center/Kavli Institute for Particle Astrophysics and Cosmology (SLAC/KIPAC) on behalf of the LSST Corporation. The review will involve individuals representing both the astronomical and particle physics communities. Recommendations from the review process will be forwarded to the LSST director for approval. Membership in the Science Collaborations is open to individuals from both the astronomy and physics communities, so applications submitted through either NOAO or SLAC will be given full and equal consideration.

The Science Collaborations will work closely with the LSST project as it builds the telescope, camera, and software, and the collaborations will be expected to play a substantial role in the scientific commissioning of the project. The chairs of each Science Collaboration comprise the LSST Science Advisory Committee (SAC), which is chaired by Michael Strauss (Princeton). The SAC reports to LSST System Scientist Zeljko Ivezic (University of Washington) and to LSST Project Director Tony Tyson (University of California-Davis).

It should be emphasized that because the LSST data taken during the operations phase will be made public immediately, there is no requirement that an individual be a member of a Science Collaboration in order to use these data. However, in practice, the Science Collaborations will be closer to the instrument, software, and data-taking process, and therefore will better understand its characteristics than people from the general community just starting to work with the data after commissioning is completed. Moreover, the collaborations will be able to influence the LSST in decisions on cadence and software, as described above, and members of the Science Collaborations will be welcome to attend relevant LSST technical meetings.

The LSST project does not plan to explicitly fund the science operations, since the NSF major facilities and research equipment program, to which LSST has applied for construction funds for the telescope facility, cannot be used to fund research.

Therefore, project support for the Science Collaborations will be limited to funds for phone conferences and support for science com-


missioning activities required to complete the construction phase. The Science Collaborations will be encouraged to submit proposals to the NSF, DOE, or other funding sources to support precursor work and science projects to be carried out with data from the LSST operations phase.

The proposal and selection process is presently being structured and initiated. Expect to see a detailed announcement on the NOAO, SLAC, and LSST main web pages (www.nao.edu, www.slac.stanford.edu, and www.lsst.org) with application forms and discussion of the specifics by which proposals will be judged. You will be asked to include a description of the science program that you would like to pursue, a description of your expected contribution to the Science Collaboration of your choice, and a list of recent publications and/or experience relevant to the work of the Collaboration.

Membership in a Science Collaboration represents a serious commitment of time and energy. Thus, if you apply for membership in more than one Science Collaboration, you should submit separate applications and justify your time commitment to each. Finally, the initial Science Collaborations listed do not attempt to cover all possible science to be done with LSST; if you are interested in defining another Science Collaboration, you will be asked to describe why you think such a group is necessary, and to suggest other members in it.

The current Science Collaborations and their initial chairs are:

- Supernovae: Michael Wood-Vasey (Harvard-Smithsonian Center for Astrophysics)
- Weak lensing: David Wittman (UC-Davis) and Bhuvnesh Jain (University of Pennsylvania), co-chairs
- Stellar Populations/Variable Stars: Abi Saha (NOAO)
- Active Galactic Nuclei: Niel Brandt (Pennsylvania State University)
- Solar System: Steve Chesley (Jet Propulsion Laboratory)
- Galaxies: Harry Ferguson (Space Telescope Science Institute)
- Transients: Shri Kulkarni (Caltech)
- Large-scale structure/baryon oscillations: Andrew Hamilton (University of Colorado)
- Milky Way structure: Connie Rockosi (University of California-Santa Cruz)
- Strong lensing: Phil Marshall (University of California-Santa Barbara)

Please send any questions to lsstcollabqueries@noao.edu. We will begin posting answers soon to frequently asked questions at www.naoa.edu/lsst/collab_faqs/. 

Workshop on Ground-Based Optical Interferometry

Stephen Ridgway



The CHARA Array on Mount Wilson, showing telescopes E1 and E2 (separation 75 meters) and the vacuum light pipe. Other telescope separations range from 34 to over 300 meters. NOAO participated in the CHARA Array project in several ways. Under contract with Georgia State University, NOAO carried out design of the telescopes, design of custom optical mounts and subsystems, and design and fabrication of major parts of the vacuum beam transport system. It also provided components for the first-light beam combiner and data system.

(Photo credit: S. Ridgway and NOAO/AURA/NSF)

Since the Bahcall Committee gave a high priority to technology development for optical interferometry in the decadal survey of 1990, prototype experiments have led the way to the first generation of user facilities. As optical interferometry now comes of age (with approximately 100 science papers published in the last two years), it is becoming clear that high spatial resolution is sparking a revolution in stellar physics. At the same time, filled-aperture technology is approaching its limits with an Extremely Large Telescope (ELT), yet still falling short of fully relieving confusion in crowded regions. We are still very far from resolving main structure in compact and/or distant sources.

The 2005 report of the community-based Optical/Infrared Long Range Planning Committee, “Strategies for Evolution of US Optical/Infrared Facilities” (www.noao.edu/dir/lrplan/strategies-final.pdf), included a recommendation for further study of a next-generation infrared interferometer featuring sub-milliarcsecond resolution and faint-target capability.

Given this recommendation and the looming start of the next decadal survey, it is timely to look beyond the unique capabilities of today’s optical and near-infrared arrays, and consider what science opportunities may be enabled by the performance of future arrays. In order to shape and inform discussions of the future of interferometry for long-range planning at NOAO, a community workshop was convened in Tucson in mid-November 2006.

This international workshop was sponsored and supported by AURA, NOAO, the NOAO New Initiatives Office, and the Georgia State University Center for High Angular Resolution Astronomy (CHARA).

Fifty scientists participated, including both experienced users of interferometry and experts in scientific areas to which interferometry might contribute in the future.

The workshop was oriented around four themes:

- science opportunities with a next-generation optical array
- array concepts
- candidate sites
- current arrays and future technologies—toward a roadmap to the future.

During the workshop and in the following weeks, the participants developed a consensus of findings and recommendations. The participants’ major conclusions are:

1. Optical interferometry offers a unique and powerful resource for astrophysics.
2. Two significant opportunities exist:
 - a. Very-high angular resolution studies of compact sources. The highest-priority science objective is the detailed study of circumstellar material related to star and planet formation. A second high-priority objective is the study of energetic and interacting systems, including active galactic nuclei (AGNs), relativistic stellar systems, and binary systems with mass transfer.
 - b. High angular resolution observations over extended fields with high sensitivity. The highest priority science objectives in this area include deep imagery and photometry of stellar fields in distant galaxies that are confusion limited with ELTs.
3. The scope of a next-generation facility requires national coordination at a minimum; international collaboration may be essential.

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CTIO Partnerships continued


4. Vigorous programs with current generation interferometer arrays will clarify and assure the scientific motivation and technical foundation for significant future projects.

Two promising concepts have been identified. High angular resolution within a wide field can be achieved with a compact array of large apertures (as in the Large Binocular Telescope). Very-high angular resolution within a narrow field is possible with a classical array consisting of a sparse distribution of moderate apertures.

The workshop also prepared a lengthy series of recommendations to NOAO, NSF, and the interferometry science community. The first recommendation to NOAO, which seems particularly timely in light of report of the NSF Senior Review, is to “support or otherwise facilitate broad community access to existing US optical interferometer facilities under competitive, peer-reviewed guest observer programs.” Additional recommendations to NOAO concerned primarily technology, concept and program development.

The recommendations to NSF emphasized funding for facilities, and bringing existing interferometry facilities further into mainstream astronomy, including the optical/infrared system and access to competitive funding opportunities for instrumentation and technology.

Workshop recommendations to the interferometry community focused on improvement of imaging capabilities and sensitivity, and on scientific program development and implementation, particularly including better communication of the opportunities offered by current capabilities to scientists who may wish to exploit them.

A synopsis of the workshop sessions and the detailed recommendations on science opportunities, technical rationale, and the roadmaps, can be found at www.noao.edu/meetings/interferometry/Workshop-report.pdf, and further input is welcomed. 

GSMT Program Office News

Jay Elias & Steve Strom

The revised role of the Giant Segmented Mirror Telescope Science Working Group (GSMT SWG) was outlined in the June 2007 NOAO-NSO *Newsletter*. Since then, the SWG has resumed its activities with a modified membership (listed at www.gsmt.noao.edu). The SWG will continue to be chaired by Rolf-Peter Kudritzki (University of Hawaii), with Steve Strom (NOAO) as vice-chair.

Initial activities for the coming year include completion of the studies underway from last year, and a “hand-off” meeting between past and present members of the working group. Links to published reports from the SWG can be found on the GSMT Program Office Web site listed above.

AURA wishes to express its gratitude to the departing SWG members for their past efforts, and to thank new and continuing members for their willingness to continue to work in support of community access to extremely large-aperture telescopes.