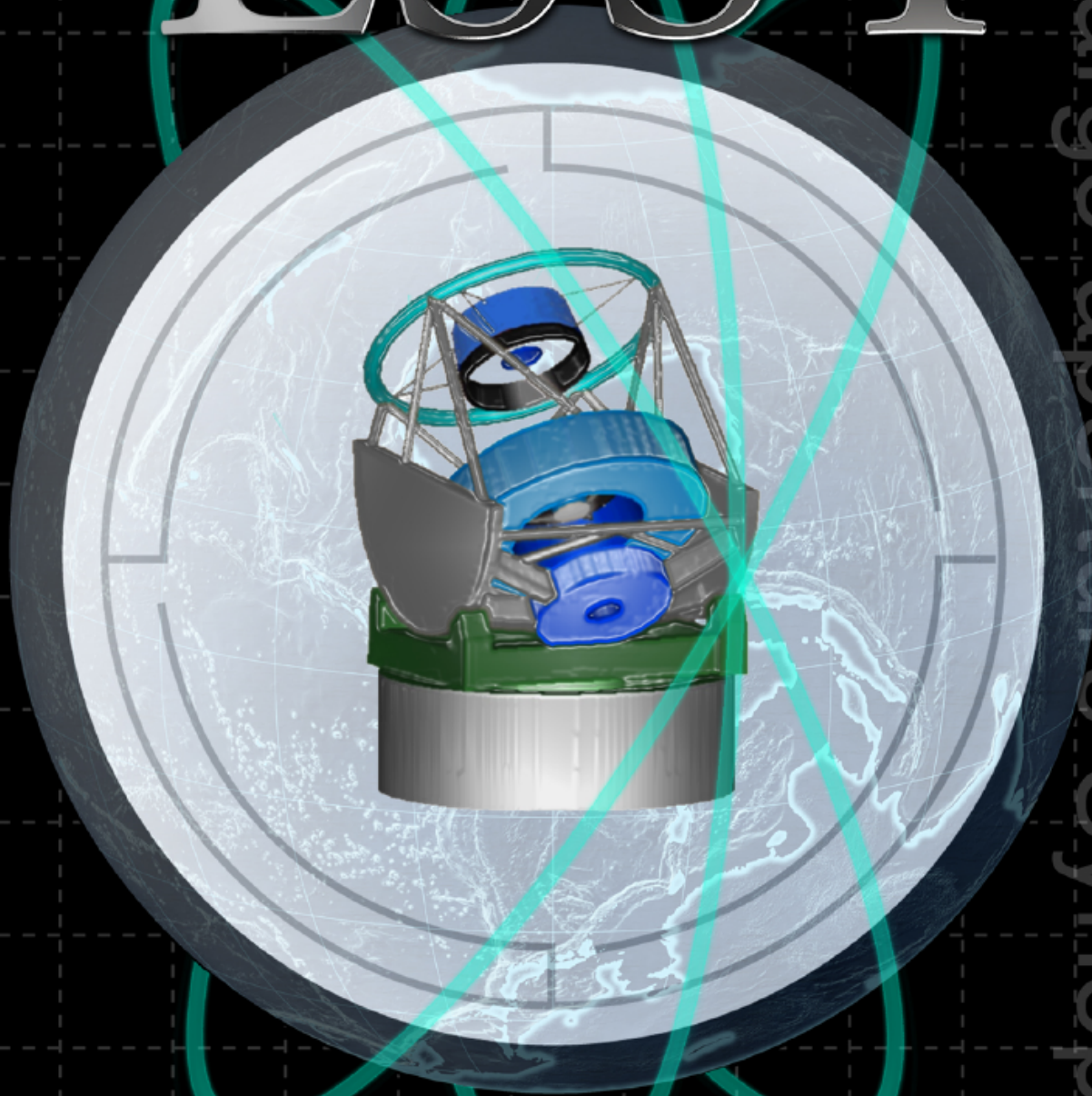


Science With

LSST



Large-aperture Synoptic Survey Telescope

WORKSHOP REPORT

Science with the Large-aperture Synoptic Survey Telescope

A Community Workshop

Tucson, Arizona

November 17-18, 2000

Organizing Committee

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Science with LSST Workshop

Table of Contents

Introduction..... 3

Technical Presentations..... 4

 Evolution of Telescope Design.....4

 Instrument Concept/Detector Issues..... 4

 Operations Mode Concept/Performance Issues for Data System..... 5

 Other Relevant Projects with Similar Goals..... 5

 Photometry Issues..... 6

 Astrometry Issues..... 6

Reports of the Breakout Groups..... 7

 Moving Objects..... 7

 Variable/Transient Objects..... 8

 Images of the Whole Sky..... 8

 Very Deep Images..... 9

Summary/Synthesis of Requirements.....9

Conclusions.....11

Appendix A: Workshop Participants.....13

Appendix B: Workshop Agenda.....14

Appendix C: Presentation Viewgraphs.....15

INTRODUCTION

One of the ground-based O/IR initiatives of the Astronomy and Astrophysics Survey Committee (AASC) report, *Astronomy and Astrophysics in the New Millennium*, is the Large-aperture Synoptic Survey Telescope (LSST). This 6.5-m-class telescope facility will “open a new frontier in addressing time-variable phenomena in astronomy.” It will combine an innovative telescope design, a state-of-the-art optical imager, and an extremely ambitious data management and distribution system to attack a number of problems simultaneously. Areas in which LSST will have a dramatic impact range from the discovery of potentially hazardous asteroids, through a census of the outer solar system, understanding the stellar composition of the Milky Way and neighboring galaxies, and extending to mapping dark matter and pinning down the parameters that describe the origin and evolution of the universe.

As described in the AASC report, LSST will be operated in a manner different from existing telescopes. Rather than time being assigned to individuals or groups to carry out specific programs, LSST will observe a pre-programmed series of fields, effectively imaging the entire visible sky every four nights. The intent will be to address a number of different scientific areas through a single integrated data set, and the data will be made available to the entire astronomical community as it is obtained. This tight coupling between the science drivers and the performance and operation of this facility demands a detailed and quantitative understanding of the requirements of each potential science program.

In order to develop that understanding of the science drivers and their requirements, and the flowdown to performance of the facility and operations strategy, the workshop on “Science with LSST” was held November 17-19, 2000 at NOAO in Tucson. In attendance were 55 participants from 22 different institutions or organizations. The attendees are listed in Appendix A.

The workshop began with a number of presentations to provide technical background for the science discussions. These were followed by four presentations on the science that LSST could potentially carry out, divided into areas: (1) moving objects, (2) variable or transient objects, (3) images of the whole sky, and (4) very deep images. Breakout groups formed to discuss each of these areas: detailing the science, defining observational programs, and discussing the requirements for the entire LSST system to carry out these programs. The groups were asked to structure their reports back to the full session by addressing the following list of areas in which requirements might be specified:

- Photometric precision: requirement and goal
 - What limiting magnitude or limiting surface brightness, in what band and in what exposure time?*
 - How much of the coverage must be in photometric conditions?*
 - What are the strategies for this program under non-photometric conditions?*
 - What are the limits for uniformity of detectivity and over what field?*
- Near-IR option: is near-IR coverage critical or desirable for the project?
- Areal coverage: requirement and goal for survey area and time to cover “unit area”, if applicable, and total survey area
- Cadence: requirement and goal for time sampling interval. The requirement is the maximum acceptable time interval to repeat the observation that will achieve the scientific goal. How does the effectiveness of the survey roll off between the optimum and minimum acceptable sampling rate?
- Angular resolution: requirement and goal for delivered image quality and pixel sampling

- Astrometric accuracy: requirement and goal (coupled to cadence and distortion)
- Limits on field distortion for photometry, object matching, image stacking
- Astigmatism, stability of astigmatism, and stability of field distortion
- Post processing : what information must be generated on what timescale and with how must it be distributed? How much image data must be spinning for real-time analysis?
- Follow-up observations: which observational programs require additional observations (spectroscopy, multiple wavelengths)? On what timescale are they required? Will these observational capabilities exist and be accessible?

Following the breakout group meetings, the full workshop met again, heard and discussed reports from the four groups, and compiled a list of issues for further study. The complete agenda of the workshop is given in Appendix B.

Technical Presentations

The technical background presentations are summarized below. The full set of viewgraphs presented are included in Appendix C.

Evolution of Telescope Design (Roger Angel)

The Paul-Baker three-mirror design allows seeing-limited image quality over a 3 degree field of view. For a primary diameter of 8.4 m and f/1.25 focal ratio, a 3.4 m convex secondary and a 4.4 m concave tertiary are needed. The central obscuration of this design is more than 30%, giving an effective aperture of 6.9 m. Chromatic aberration is a consequence of a filter and/or a dewar window, and must be compensated, perhaps with an additional lens inside the dewar. The image quality achieved is 80% encircled energy inside 0.33 arcseconds diameter at all field angles (up to 1.5 degrees). The focal plane has a radius of curvature of ten meters. Alignment would be maintained by laser metrology, with measurements and corrections carried out during the time that the shutter is closed between exposures. This design is detailed in Angel, Lesser, Sarlot, and Dunham (2000, ASP Conf. Ser. 195). See also <http://lssto.org/design.html> and <http://athene.as.arizona.edu:8000/caao/publications/angel/angel3d.pdf>

Instrument Concept/Detector Issues (Brian McLeod/Michael Lesser)

The concept for this instrument is a “mosaic” of approximately 1300 1K X 1K CCDs with 10 μ m pixels (0.25 arcsec/pixel), covering a 55 cm diameter focal surface. The small size is required because of the curvature of the focal plane and numbers of bright stars. In order to achieve the desired five second readout time, each of the 1300 devices must be read out at 200 kpix/sec, resulting in a total data rate of 500 Mb/sec. Operating at a rate of a new exposure every 30 seconds will result in 5 Tb per night from this instrument. The detectors themselves should have the highest possible DQE. It may be possible to operate this camera relatively warm (-20C) and to employ a dewar filled with low conductivity gas, eliminating a 14-ton load on the window of a vacuum dewar and simplifying shutter/filter design.

The requirement to maximize the fill factor in such a large mosaic has important impacts for both signal routing and thermal management. Four-side buttable devices will be needed, and Chip-on-Board technology should be explored. Signal routing off the chips will also be an issue. Other detector considerations will include minimizing the blooming of bright objects and the low full-well and relatively poorer MTF of small pixel devices. Detectors other than CCDs (e.g., CMOS devices) are currently not

competitive, but their development should be monitored. The feasibility of fabricating the CCDs for this instrument is high, since the devices themselves are small. It is estimated that 11 lots (equivalent to that required for typical current space missions) would be needed.

Operations Mode Concept/Performance Issues for Data System (Christopher Stubbs/Douglas Tody)

The highest-level pipeline strategy is relatively straightforward. Upon readout, images are corrected for instrumental signature “on the fly.” Image differencing allows all objects that have changed brightness or position to be detected. Several thousand such objects are expected to be detected each night of operation.

Hardware — data processing speed and storage capacity — of sufficient capability is anticipated to be available. Network bandwidth may force a major part of the data processing to be done in close proximity to the telescope.

The data management areas that are expected to be difficult include:

Robust automatic detection, discrimination, and classification of changing objects

Calibration of detection efficiency

Data dissemination

“System-wide” coordinated follow up

Stacking of images

Database mining algorithms

Mechanisms for appropriate community participation

Questions/concerns that must be addressed:

Will it be necessary to change filters (implications for data reduction/flat fielding)?

Will it be necessary to take multiple consecutive exposures in order to reject cosmic rays?

Other Relevant Projects with Similar Goals (Todd Boroson)

A number of similar, but less ambitious, O/IR survey facilities are under development. VST is the VLT Survey Telescope, a 2.5 m telescope with a 16K X 16K CCD array, covering 1 degree square. It is being built on Cerro Paranal by the ESO consortium and is expected to be in operation by the end of 2001. VISTA is a 4m telescope with both optical (20K X 23K, 2.25 square degrees) and near-IR (9 2K X 2K HgCdTe, 1.2 square degrees with 4 pointings) cameras. It is being built on Cerro Paranal by the UK and is expected to be in operation by 2004.

Several NEO surveys are under way, on 1 m-class telescopes with imagers of varying size. These typically reach to magnitudes of 19 – 21, and are attempting to catalog a large fraction of the NEOs having diameters of one km or more. LSST will have a value of $D^2\Omega$, that is more than an order of magnitude greater than VISTA, and two orders of magnitude greater than other existing survey capabilities.

Potential LSST-precursor experiments were discussed. The goal of such a project would be to provide a testbed for the development of software for data processing and management, and to explore operations techniques including the ability to follow-up with time-critical observations. Alan Dressler presented a concept for a simple imager that would cover a six square degree field on the 1.0 m Swope Telescope, and that could survey the visible sky down to a limiting magnitude of $V=21.5$ (7σ) in five nights. George Jacoby presented a plan for a one degree field of view imager using orthogonal-transfer (OT) CCDs on the WIYN telescope. This could potentially go as deep as LSST (using the “tip-tilt” compensation of the OT CCDs) and could use substantially narrower bandpass filters. Tony Tyson presented a status report on the Deep Lens Survey Project on the NOAO 4-m telescopes. This is a LSST precursor, both in terms of the pipeline processing of data (including automated transient detection) and database mining tool development.

Photometry Issues (Steve Kent)

This presentation, based on experience with the Sloan Digital Sky Survey (SDSS), focused on requirements and solutions for achieving accurate photometry. SDSS has routinely achieved 2% rms accuracy in the g', r', and i' bands; 3% rms accuracy in the u' and z' bands. It is important to simultaneously consider realistic requirements, metrics, and a test plan early on in the project. Two possible calibration schemes are: (1) to establish a few standard star calibration patches and observe these one or more times per night, or (2) to set up a grid of standard stars over the sky and calibrate *in situ*.

Concerns for accurate photometry include:

- Flattening the data: the sky will vary temporally and spatially; variable vignetting, geometric distortions, and scattered light (including ghost images) add to the problem. Baffling must be done properly.
- Filter uniformity and variation in bandpass with temperature are additional problems affecting accuracy.
- PSFs will vary over the field due to optics and will vary over time due to seeing and defocus. Understanding how to correct — and whether to perform — photometry through apertures or by PSF-fitting will be critical.
- Atmospheric extinction will vary spatially and temporally. SDSS routinely sees 3% p-p variations of this type.

Useful ancillary equipment might be (1) a 10 μm cloud camera, (2) a monochromator and calibrated light source, and (3) a small telescope that could monitor extinction.

Astrometry Issues (David Monet)

It was pointed out that (as a byproduct of other observations) LSST could produce a parallax catalog that would fill a significant gap in our knowledge of the nearby universe. If the astrometric accuracy is good enough (a few milliarcsecs per observation), then short-arc parallaxes can be measured for stars closer than 10 pc in about four months. An additional targeted survey of brighter stars could provide a tie between LSST-measured positions and the Inertial Coordinate Reference System (ICRS).

Previous experience is that such accuracy can be achieved with small field of view instruments, but that larger field of view instruments have been limited to several tens of mas accuracy.

Why is this important? Current and planned astrometric surveys with this kind of precision are limited to much brighter stars. An all-sky parallax survey to $m=23$ would surpass even the goals (at the faint end) of planned space astrometry missions such as FAME or GAIA. Anticipated science return from this work would include a complete inventory of the solar neighborhood to 50 pc, improved distances to open clusters, and a much improved linkage between optical and radio reference frames. Studies should be undertaken to develop robust techniques for achieving this kind of astrometric accuracy from LSST.

Reports of the Breakout Groups

The potential LSST science was divided into four “types”:

1. Moving objects (Ted Bowell; Robert Millis)
2. Transient and variable objects (Nick Suntzeff; Christopher Smith)
3. Whole-sky imaging (Ed Olzewski; Dennis Zaritsky)
4. Ultra-deep imaging over limited fields (Tony Tyson)

The breakout groups formed around each of the four types of investigations that LSST could undertake. The groups were asked to formulate in each area one or more projects appropriate to LSST, and using the observations that would be needed to carry out these projects, to report the required performance in various areas of the LSST system. These areas range from optical and mechanical performance of the telescope, through conditions at the site, to requirements for how the telescope would be scheduled and what ancillary data would be available (see list in previous section).

The reports of the four breakout groups are summarized below. The viewgraphs presented in the final discussion session are given in Appendix C. The specific performance requirements and goals identified by each group are given in the table following the reports.

Moving Objects (Ted Bowell/Bob Millis)

This area comprises studies of the smaller objects in the solar system, including asteroids of various types, comets, and possibly earth-orbital space debris. Four principal types of objects were discussed.

1. One of the principal justifications for LSST, and one of the principal drivers for its required capabilities and operations modes, is the goal of discovering and determining orbits for a large fraction of the potentially hazardous asteroids. These Near-Earth Objects (NEOs) include asteroids with diameters greater than 300 meters in earth-crossing orbits. There are thought to be approximately 10,000 objects down to this size, above which any ocean impact would cause global devastation on all coastal margins.
2. Over the past few years, the discovery of Kuiper Belt Objects (KBOs; or trans-neptunian objects [TNOs]) has been accelerated by the advent of wide-field imagers on 4 m telescopes. By discovering a large number of these, the LSST could help address a number of fundamental questions about the formation of the solar system, including its extent and its dynamical history. Studies of the physical and chemical nature of KBOs discovered by LSST would also add to our knowledge of the primordial solar system.
3. The discovery of a large number of comets and Centaur asteroids would help establish the relation between these populations and the Kuiper Belt.

4. A systematic effort to discover main belt asteroids would provide basic information about these objects, and would allow new size regimes to be studied systematically.

In addition, the relevance of these observations to the discovery of (earth-orbital) space debris was noted.

The most stringent requirement for the NEO observations is the balance among the exposure time, the limiting magnitude, and the cadence. The constraints include a short enough exposure time to “freeze” the objects with the largest non-sidereal motion and short enough intervals between some exposures to match such objects unambiguously. Fields must be repeated over long enough intervals to detect the objects moving most slowly, and must sample orbits of objects of all apparent speeds appropriately. This breakout group devised an observing strategy that combined four unequally spaced nights per month on a given field with multiple exposures (2 or 3) of that field on each of these nights.

The NEO search would result in the discovery of thousands of KBOs as well. However, in order to determine the true distribution of these objects, both over size and distance, it would be necessary to supplement these observations with a more spatially limited survey to fainter magnitudes. The group suggested that a series of observations that targeted 10 fields (about 7 square degrees each) four times per year for two years to a depth of $m=27$ would achieve the desired results.

In general, the moving object searches do not require a particular bandpass; the objects have approximately solar colors.

Variable/Transient Objects (Nick Suntzeff/Christopher Smith)

A large number of different types of transients and variables were identified, including QSOs and other AGN, Supernovae, GRBs, microlens events, variable stars of many types, extrasolar planet transits, and stellar flares. In addition, it was argued that this regime is a major “discovery space” to be opened up by LSST. These searches will turn up previously unknown objects.

This group desired that data be taken in two modes. In the “all-sky” mode, the entire visible sky would be imaged over periods up to about seven days. Uneven spacing between exposures would reduce aliasing. The limiting magnitude would be around $m=24$. Observations during one pass over the sky would be made in a single band, but a multi-band database would serve as a comparison. In the “deep” mode, certain fields would be targeted for longer exposures, giving limiting magnitudes around $m=26$. The distribution of intervals between exposures would run from hours to days. Multiple bands would be observed on a given field on a single night.

In both modes, the following parameters were desired:

- Split exposures for cosmic ray rejection
- Changing objects found and alerts issued within minutes
- Relative photometric accuracy better than .005 magnitudes (driven by extrasolar planet transits)
- Stable image quality
- A site with a large fraction of clear skies (marginal preference for site in southern hemisphere)

Images of the Whole Sky (Ed Olszewski/Dennis Zaritsky)

This regime encompasses the broadest community use for the LSST dataset. The whole-sky images, built up over time to substantial depth, will provide critical support and ancillary information for a huge number of studies over a large range of wavelengths. The LSST data, in this mode, will be the successor to the Sloan survey, going several magnitudes fainter, with greater astrometric precision and with time domain information. Such general purpose applications argue for the maximum wavelength coverage (U through Z, and possibly J) and roughly equal depth in all bandpasses. This very wide wavelength coverage may require two detector arrays.

In addition to general descriptions of samples of objects such as faint galaxies, QSOs, and hot and cool stars, several specific science programs were identified. These included the determination of the halo white dwarf luminosity function, the measurement of photometric parameters of giant stars in galaxies in the Local Group, and studies of turnoff stars halfway to M31. These sorts of projects will provide the drivers for the data mining algorithms that are being developed in concert with the beginnings of the National Virtual Observatory.

Programs that aim to define complete samples over the whole sky require dithered exposures to fill in gaps between detectors in the focal plane. They require a high degree of photometric stability. Furthermore, the seeing and image quality will be critical for pushing as far as possible into the galactic plane.

Very Deep Images (Tony Tyson)

The scientific thrust of projects in this regime focused on cosmology using the technique of weak lensing, the statistical measurement of the effect of intervening mass concentrations on the observed ellipticities of background galaxies. A survey covering ten 100 square degree regions will produce a very narrow error ellipsoid in Ω_m vs. Ω_Λ space complementary to other probes such as CMB anisotropy and supernovae. In addition, such a survey would be expected to find thousands of high redshift supernovae, providing additional constraints on cosmological parameters. Five-band photometry is used to infer photometric redshifts for the lensed galaxies, enabling full 3-D mass reconstruction over a significant range of lookback time. This will be a sharp test of the equation of state of dark energy.

Ultra-deep wide-field imaging, built from many exposures over time, is uniquely capable of discovering faint, optical transients and following them, as well as uncovering faint KBOs. The desired observational strategy is to mix fields and filters resulting in sampling of a given field with a logarithmic distribution of intervals between visits. The goal is to achieve the following 10σ limits in each bandpass:

Band	Limit (Mag)	Band	Limit (Mag)
B	28.2	I	26.7
V	27.8	Z	25.6
R	27.5		

Photometric accuracy at about the 0.1 magnitude level is required. The most stringent requirement may be on image quality and PSF stability. Poor image quality, which tends to circularize images, weakens the effect that is being measured, although 0.5 arcseconds FWHM is adequate. Optical aberrations, such as astigmatism, coma, and trefoil, which create false intrinsic ellipticity, must also be minimized.

Summary/Synthesis of Requirements

The following table lists, for each of the four types of science, a number of the performance requirements or desires for various aspects of the LSST system.

Observing Technique	Moving Objects	Transient/variable objects	Whole-sky imaging	Ultra-deep imaging
<i>Science</i>	<ol style="list-style-type: none"> 1. NEO's: find >90% of objects w/ $D > 300\text{m}$ 2. Census, orbits, and physical nature of KBOs 3. Comets and centaurs – link to KB 4. Main belt; space debris 	<p>Large # of topics (SNe, GRBs, grav. Lens monitoring, QSO discovery, planet transits, etc.) separate into</p> <ol style="list-style-type: none"> 1. All-sky projects 2. Deep-mode projects 	<p>Represents use by broadest community – general support for studies at other wavelengths.</p> <p>Sample science:</p> <ol style="list-style-type: none"> 1. Giants as tracers in MW, M31, LG 2. MSTO to 200 kpc 3. 10^5 clusters of galaxies to $z=1.4$ 	<p>Supernovae and 3-D mass tomography and time-development of cosmic structure; test of the equation of state of dark energy; ten 100 square degree fields;</p> <p>Will also find very faint optical transients and moving objects.</p>
<i>Limiting Mag</i>	<p>At least 24th for 20 sec exp. 7-10 sigma</p> <p>Exposure time limited by non-sidereal motion of fastest moving objects</p>	<p>1. 24th (concern about saturation limit); want relative accuracy of 0.005 mag for planet transits</p>	<p>~26th, high degree of photometric stability, equal depth in all filters</p>	<p>10 sigma detections in B thru R at 28, I=26.7, $z=25.6$; phot. Acc = 0.1 absolute</p>
<i>Filters</i>	<p>Broadband VR ideal; can tolerate diff. Filters</p>	<ol style="list-style-type: none"> 1. 1 band OK 2. Multiple bands/night 	<p>U through z, with possible case for J to do high redshift work</p>	<p>B, V, R, I, z</p>
<i>Astrometry</i>	<p>100 milliarcsec or better</p>	<p>Nominal</p>	<p>Nominal</p>	<p>Nominal</p>
<i>Cadence</i>	<ol style="list-style-type: none"> 1. 4 unequally spaced nights/month; 3 visits one night, 2 visits other nights 2. same as 1. Plus very deep area-limited (10 fields) survey to 27th: 2 hrs/field, 4 times/year, 2 years. 	<ol style="list-style-type: none"> 1. <7 day spacings, unequally spaced, CR splits 2. spacings from hours to days 	<p>Want dithered exposures to eliminate gaps, CR splits</p>	<p>Log (t) sampling; few exposures/3 degree field, then move to new field.. multi-field/filter night; some fields: multi-filter/night; want dithered exposures for sampling, CR removal</p>
<i>Image quality</i>	<p>No requirement; whatever necessary to meet depth req.</p>	<p>Stability most important</p>	<p>Good IQ critical for crowded fields</p>	<p>IQ ~ 0.5 arcsec, need PSF stability and minimal astigmatism</p>
<i>Post-processing/follow-up</i>	<p>Prompt, but not instant detection; a few objects will require prompt follow-up elsewhere</p>	<p>Need data delivered in minutes; all data archived</p>	<p>Need ongoing access to all data</p>	<p>All data reduced and on-line; want small auxilliary telescope to monitor sky emission over same field</p>
<i>Site</i>	<p>Clear sky, adequate seeing to ensure limiting magnitude, some pref for North</p>	<p>Clear skies priority; small preference for south</p>	<p>Arguments for both north and south</p>	

In addition to these requirements, the astrometry presentation noted that LSST data hold the promise of producing a catalog of parallaxes (at the one milliarcsec precision level) far more complete and to fainter limits than any other ground or space-based project. This previously unappreciated application has important implications for a number of scientific areas including properties of stars in the solar neighborhood, better distances to clusters, the ability to tie together the optical and radio reference frames, and providing critical information for Origins-related space-based observations (with TPF).

General conclusions:

LSST can address a broad range of important scientific questions by operating in two modes that are interwoven. Some fraction of time (likely 50% or more) will be spent imaging the entire sky repeatedly to a modest depth (24th magnitude in 20-30 second exposures) with a complex series of intervals and filters. These exposures will also serve to generate a deep multicolor image of the entire sky that will form the principal database that the broadest segment of the community will want. The rest of the time will be used to obtain a much deeper image of a set of smaller fields in several bandpasses. These exposures will also be taken with a well-defined set of intervals to enable searches for much fainter variable objects.

The desirability of an LSST-precursor experiment was acknowledged. Since both the data rate and data volume represent two order of magnitude increases over the most relevant ground-based survey facilities, it is imperative that (a) lessons learned from projects such as SDSS and 2MASS are remembered, and (b) new approaches be tested with efforts where less is at stake. Ideas proposed and discussed included using a planned 1-degree FOV imager for the WIYN telescope and using the LCO 1.0-m Swope telescope (3 degree FOV) for such an experiment. The ongoing Deep Lens Survey was also noted.

LSST issues identified by breakout groups or in discussion:

- The NEO observing strategy needs further thought and more sophisticated modeling. The desired sequences are based on experience with undersampled images and fields of view that do not allow coverage of the entire sky with frequent visits.
- Techniques for finding variable or moving objects in crowded fields should be explored. There were claims that frame-differencing was best, but this would depend on PSF stability.
- There is no consensus on how to ensure that one can do photometry (even relative) at the <0.01 magnitude level. This is required for extrasolar planet transits, but is desirable for other programs also.
- The whole subject of extrasolar planet detection by transits was discussed. It was acknowledged that modeling is needed to understand what the best approach should be (see asto-ph #0101024 for a recent study of this).
- Detector issues identified include (a) how to achieve good sensitivity over the broadest wavelength range (U-z), (b) how to minimize fringing in the red, and (c) how to raise the level at which saturation is seen as high as possible.
- Filter issues identified include (a) how to manufacture filters with uniform optical properties on very large, curved substrates, and (b) what process would be used for changing filters (i.e., is this something that could be done quickly, or would it be a daytime operation?).
- It was noted that little is known about the spatial or temporal variations of sky brightness in the far red, though there is much anecdotal evidence that these will be limiting systematic factors in short exposures.

- Several individuals proposed that LSST have one or more auxiliary telescopes to perform calibration observations of various types simultaneously. Specific applications mentioned include monitoring sky brightness and structure, and measuring extinction.
- The whole concept for follow-up observations must be developed. The two most obvious requirements are (a) for more precise orbit determinations of NEOs, where the sequence of LSST revisits shows that the object will pass close to the earth, but supplemental observations are needed for a precise determination, and (b) for transient objects such as SNe or microlensing events, where the LSST discovery is meant to serve as a trigger for closely spaced observations or observations of some different type. Note that in many cases, the LSST will follow-up its own discoveries.
- The question of whether LSST should work in TDI mode was considered. The advantages would be improved flat-fielding and reduced overhead time. The difficulties would be limitations in the observing strategy and the necessity to build a telescope/camera system in which objects move along columns of the detector.

APPENDIX A

Workshop Participants

Roger Angel	University of Arizona
Taft Armandroff	NOAO
Tim Axelrod	Mt. Stromlo Observatory
Gary Bernstein	University of Michigan
Richard Binzel	MIT
Todd Boroson	NOAO
Ted Bowell	Lowell Observatory
Dick Bredthauer	Semiconductor Technology Associates
Chuck Claver	NOAO
Roc Cutri	Caltech/IPAC
Lindsey Davis	NOAO
Dave DeYoung	NOAO
Alan Dressler	Observatories of the Carnegie Institution of Washington
Eileen Friel	NSF/AST
Richard Green	NOAO
Alan Harris	Jet Propulsion Laboratory
Doug Isbell	NOAO
George Jacoby	NOAO/WIYN
Buell Jannuzi	NOAO
Nick Kaiser	University of Hawaii
Steve Kent	Fermi National Accelerator Laboratory
Jeremy Kepner	MIT Lincoln Laboratories
Jeff Larsen	University of Arizona
Tod Lauer	NOAO
Mike Lesser	University of Arizona
Steve Levine	U.S. Naval Observatory
Jim Liebert	University of Arizona
Robert Lupton	Princeton University
Brian McLeod	Harvard-Smithsonian Center for Astrophysics
Bob McMillan	University of Arizona
Ken Mighell	NOAO
Bob Millis	Lowell Observatory
Dave Monet	U.S. Naval Observatory
Ed Olszewski	University of Arizona
Earl O'Neil	University of Arizona
Jeff Pier	U.S. Naval Observatory
Rob Pike	Lucent/Bell Labs
Phil Pinto	University of Arizona
Connie Rockosi	University of Chicago
Luc Simard	University of Arizona
Chris Smith	NOAO
Bill Stephens	Scientific Imaging Technologies, Inc.
Chris Stoughton	Fermi National Accelerator Laboratory
Peter Strittmatter	University of Arizona
Steve Strom	NOAO
Chris Stubbs	University of Washington
Nick Suntzeff	NOAO
Doug Tody	NOAO
Tony Tyson	Lucent/Bell Labs
Frank Valdes	NOAO
Jenni Virtanen	Lowell Observatory
Dave Wittman	Lucent/Bell Labs
Sidney Wolff	NOAO
Dennis Zaritsky	University of Arizona

APPENDIX B

Science with LSST
Tucson, AZ -- November 17-18, 2000

AGENDA

Friday, November 17, 2000

- 9:00 Welcome, Introduction
- 9:10 Evolution of Telescope Design [Roger Angel]
- 9:40 Instrument Concept/Detector Issues [Brian McLeod/Mike Lesser]
- 10:10 Operations Mode Concept/ Performance Issues for Data System Hardware and Software [Chris Stubbs/Doug Tody]
- 10:40 Break
- 11:00 Other Relevant Projects: VISTA, VST, LSST - Precursor Ideas [Todd Boroson]
- 11:30 Moving Objects: NEOs, TNOs [Ted Bowell]
- 12:00 Transient and Variable Objects: SNe, Microlensing Events, GRBs, Extrasolar Planet Transits, Variable Stars, AGNs [Nick Suntzeff]
- 12:30 Lunch
- 1:30 Co-added Deep Images over Entire Sky: Stellar Pop Studies (e.g., halo white dwarfs), Support to Other Wavelengths [Ed Olzsewski]
- 2:00 Very Deep Images over Limited Areas: Weak Lensing [Tony Tyson]
- 2:30 Photometry Issues [Steve Kent]
- 3:00 Astrometry Issues [Dave Monet]
- 3:30 Instruction to Breakout Groups
- 3:40 Breakout Groups Meet
1) Moving Objects; 2) Transient/Variable Objects; 3) Whole-Sky Deep Images; 4) Very Deep Images
- Consider: requirements on site, telescope, instrument, operations mode, data analysis, photometry, astrometry. Also discuss outreach, data distribution, synergy with other areas.
- 5:00 Adjourn
- 6:30 Dinner

Saturday, November 18, 2000

- 9:00 - 10:00 Breakout Groups Meet/Write Reports
- 10:00 Breakout Groups Report/Discussion
- 12:00 Lunch/Adjourn

APPENDIX C

Presentation Viewgraphs

1. Evolution of Telescope Design – *Roger Angel*
2. Instrument Concept – *Brian McLeod*
3. Detector Issues – *Michael Lesser*
4. Operations Mode Concept – *Christopher Stubbs*
5. Performance Issues for Data System Hardware and Software – *Doug Tody*
6. Other Relevant Projects -- *Todd Boroson*
7. SSST: Small Synoptic Survey Telescope – *Alan Dressler*
8. WIYN One Degree Imager – *George Jacoby*
9. Photometry Issues – *Steve Kent*
10. Astrometry Issues – *David Monet*
11. Moving Objects – *Ed Bowell, Bob Millis*
12. Transient/Variable Objects – *Nick Suntzeff/Chris Smith*
13. Whole-Sky Deep Images – *Ed Olszewski/Dennis Zaritsky*
14. Very Deep Images – *Tony Tyson*