WHY GALAXIES CARE ABOUT AGB STARS
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The Impact of LSST on Asymptotic Giant Branch Star Research

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Abstract. The Large Synoptic Survey Telescope (LSST) is currently by far the most ambitious proposed ground-based optical survey. With initial funding from the US National Science Foundation, Department of Energy laboratories and private sponsors, the design and development efforts are well underway at many institutions, including top universities and leading national laboratories. The main science themes that drive the LSST system design are Dark Energy and Matter, Solar System Inventory, Transient Optical Sky, and Milky Way Mapping. The LSST system, with its 8.4-m telescope and 3,200 Megapixel camera, will be sited at Cerro Pachon in northern Chile, with first light scheduled for 2013. In a continuous observing campaign, LSST will cover the entire available sky every three nights in two photometric bands to a depth of $V \approx 25$ per visit (using two 15-second exposures), with exquisitely accurate astrometry and photometry. During the proposed survey lifetime of 10 years, each sky location would be observed about 1000 times, with the total exposure time of 8 hours distributed over six broad photometric bandpasses ($ugrizY$). I describe how these data will impact AGB star research and speculate how the system could be further optimized by utilizing narrow-band TiO and CN filters.

1. The Large Synoptic Survey Telescope

Three recent committees comissioned by the US National Academy of Sciences[1] concluded that a dedicated wide-field imaging telescope with an effective aperture of 6–8 meters is a high priority for US planetary science, astronomy, and physics over the next decade. The LSST system (Tyson 2002) includes such a telescope and is designed to obtain sequential images covering the entire visible sky every few nights. Detailed simulations that include measured weather statistics and a variety of other factors that affect observations predict that each sky location can be visited about 100 times per year, with two 15-second exposures per visit.

The range of scientific investigations which would be enabled by such a dramatic improvement in survey capability is extremely broad. The main science themes that drive the LSST system design are the following:

1. **Constraining Dark Energy and Dark Matter** using a variety of probes and techniques whose synergy will fudamentally test our cosmological assumptions and gravity theories

[1] Astronomy and Astrophysics in the New Millennium, NAS 2001; Connecting Quarks with the Cosmos: Eleven Science Questions for the New Century, NAS 2003; New Frontiers in the Solar System: An Integrated Exploration Strategy, NAS 2003.

2. **Taking an Inventory of the Solar System** and extending the boundaries of our reach in distance and detectable size of potentially hazardous asteroids

3. **Exploring the Transient Optical Sky** by characterizing known classes of object and discovering new ones

4. **Mapping the Milky Way** all the way to its edge with high-fidelity.

1.1. The LSST Reference Design

The LSST reference design[2], with an 8.4-m diameter primary mirror, standard filters, and current detector performance, reaches a depth equivalent to $V \approx 25$ in 30 seconds[3] over its entire 10 square degree field. The key figure of merit for a large survey telescope is the étendue – the product of the collecting area of its primary mirror and the field of view ($A\Omega$). The solid angle of sky that can be surveyed to a limiting depth per unit time is proportional to the étendue. LSST will provide an order of magnitude larger étendue than any existing facility, and at least a factor 5 larger étendue than any other planned or proposed facility. A unique consequence of this very high étendue is that many different science programs can utilize a common observing strategy, yielding a single common database. One can think of this as *massively parallel astrophysics*: rather than devoting a distinct set of observations to each area of science, a single universal set of observations feeds all science investigations in parallel.

This large étendue is achieved in a novel three-mirror design (modified Paul-Baker) with a very fast f/1.2 beam, together with a 3200 megapixel camera with state-of-the-art detectors. The baseline designs for telescope and camera are shown in Figures 1–2, and the main system parameters are summarized in Table 1.

The LSST survey will open a movie-like window on objects that change brightness, or move, on timescales ranging from 10 seconds to 10 years. The survey will have a data rate of about 30 TB/night (more than one complete Sloan Digital Sky Survey per night), and will collect over 60 PB of data during its lifetime, resulting in an incredibly rich and extensive public archive that will be a treasure-trove for breakthroughs in many areas of astronomy. In the next section I describe how this archive will impact AGB star research and speculate how the LSST system could be further enhanced by utilizing narrow-band TiO and CN filters.

2. The Impact of LSST on AGB Star Research

The LSST survey will yield continuous, overlapping images of 20,000 square degrees of sky in six broad-band filters covering the wavelength range 320 – 1050 nm. Each sky location will be observed about 1000 times (total exposure

[2]More details about the LSST system are available at http://www.lsst.org.

[3]An LSST exposure time calculator has been developed and is publicly available at http://tau.physics.ucdavis.edu/etc/servlets/LsstEtc.html.

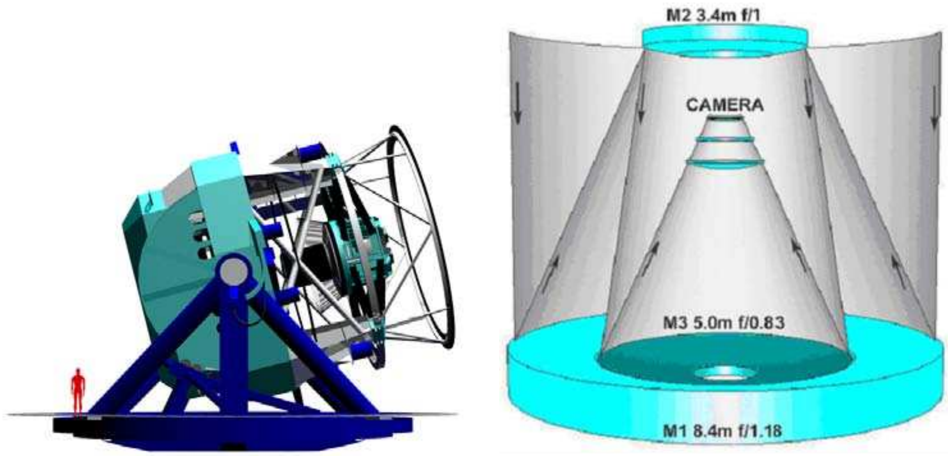

Figure 1. The *left* panel shows the baseline design for the LSST telescope, current as of April 2006. The telescope will have an 8.4-meter primary mirror and a 10-square-degree field of view. The *right* panel shows the LSST baseline optical design with its unique monolithic mirror: the primary and tertiary mirrors are coplanar and their surfaces will be polished into a single substrate.

time of 8 hours) over the survey lifetime of 10 years. These data can be used for finding AGB stars by several methods:

1. **Optical identifications of IR counterparts**. If, for example, the dust-enshrouded C star IRC+10216 were 40 kpc away, it would have i=27, z=25 and Y=23 (based on SDSS observations), which is brighter than LSST faint limits in these bands. Therefore, even stars with exceedingly thick dust shells and barely detected by IRAS will be detectable in the i, z, and Y bands by LSST throughout the Galaxy.

2. **Search for spatially–resolved envelopes**. As demonstrated by SDSS observations of IRC+10216, LSST will be able to detect and *resolve* an IRC+10216–like envelope at a distance of 15 kpc!

Table 1. The LSST Baseline Design and Survey Parameters

Quantity	Baseline Design Specification
Optical/mount configuration	3-mirror modified Paul-Baker; alt-azimuth
Final f-ratio, aperture	f/1.25, 8.4 m
Field of view area, étendue	9.6 deg^2, 318 m^{2}deg^2
Plate scale, pixel count	50.9 μm/arcsec ($0''.2$ pix), 3.2 Gigapix
Wavelength coverage, filters	320 – 1050 nm, *ugrizY*
Single visit depths (5σ)	u: 23.9, g: 25.0, r: 24.7, i: 24.0, z: 23.3, Y: 22.1
Mean number of visits	u: 70, g: 100, r: 230, i: 230, z: 200, Y: 200
Final (coadded) depths (5σ)	u: 26.3, g: 27.5, r: 27.7, i: 27.0, z: 26.2, Y: 24.9

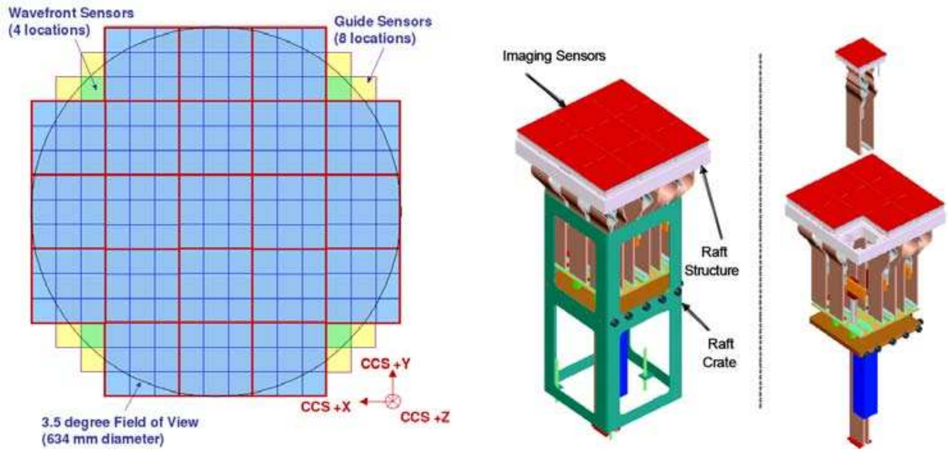

Figure 2. The *left* panel shows the LSST focal plane. Each square represents one 4096×4096–pixel sensor. Nine sensors are assembled together in a raft. There are 189 science sensors, each with 16.8 Mpix, for the total pixel count of 3.2 Gpix. The LSST raft module with integrated front-end electronics and thermal connections is shown in the *right* panel.

3. **Color selection**. The extremely red colors of dusty AGB stars are very distinctive; color-selected LSST samples will be able to trace structure throughout the Local Group and beyond.

4. **Variability**. Large optical amplitudes and ∼1000 observations over 10 years will be a powerful detection method for AGB stars (e.g. LSST will detect over one hundred million variable stars).

It is evident that LSST, although driven by different science goals, will be a powerful machine for discovering and characterizing AGB stars. This ability could be further enhanced by utilizing narrow-band filters.

2.1. Specialized narrow-band filters

The current LSST baseline design includes six broad-band filters. The system throughput as a function of wavelength for these bandpasses is shown in Figure 3. The ability of LSST to characterize AGB stars (e.g. C vs. O type classification) could be further enhanced by adding narrow-band filters. For example, the so-called TiO (7780 Å) and CN (8120 Å) filters introduced by Wing (1971) have been successfully used by a number of groups (Cook, Aaronson & Norris 1986; Kerschbaum et al. 2004; Battinelli & Demers 2005, and references therein) for identification and characterization of late-type stars in external Local Group galaxies.

The LSST Scientific Requirements Document allows for about 10% of the observing time (300 nights) to be allocated to specialized programs. If only 2 nights (<0.1% of the total observing time) were allocated to a narrow-band survey, it would be possible to cover about 10,000 deg^2 of sky in each band. Such a time allocation would match the cost of procuring the filters to the cost of the LSST system itself (about 150,000 USD per filter and per observing night).

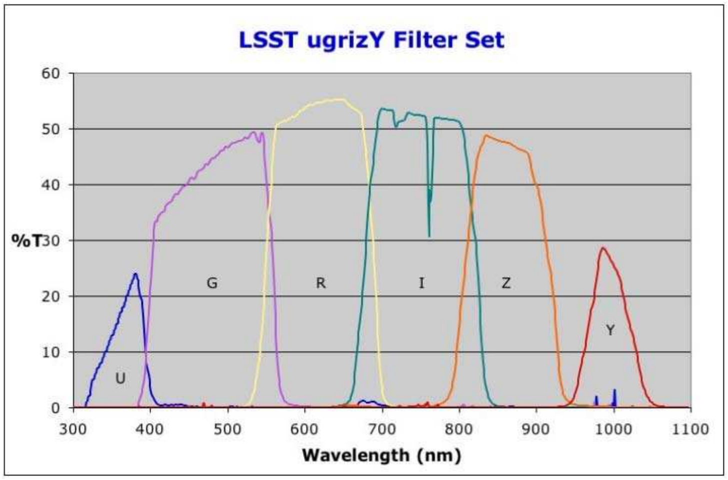

Figure 3. The current design of the LSST bandpasses. The y-axis shows the overall system throughput. The bandpasses are similar to those employed by the Sloan Digital Sky Survey, with the addition of the Y band.

Assuming 100 Å wide filters, the faint limits would be at about apparent magnitudes 22 – 22.5. This is about 0.5–1 mag shallower than e.g. a recent study of And II by Kerschbaum et al. (2004), but the surveyed area would be over 1,000,000 times larger! Furthermore, it is noteworthy that the deep and exceedingly accurate broad-band photometry will come for "free," and will include many epochs which can be used to reject foreground Galactic M dwarfs by variability. The same data would enable efficient calibration of the narrow-band survey.

This program may represent an exciting opportunity for the AGB star community. In order to execute such a program, this community may wish to organize a working group which would have three main goals: fundraising for the filter procurement, securing an allocation of observing time from the LSST Collaboration, and the timely analysis of narrow-band survey data.

Acknowledgments. I acknowledge my numerous LSST collaborators for their efforts in the design and development of the LSST system, including the figures used in this contribution. I am thankful to Jill Knapp for inspiration that in part motivated this work.

References

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Discussion

Jørgensen: It is a wonderful intention of the LSST project to make the data quickly and publicly available. Do you think this intention is likely to become reality when the actual data starts flowing (as opposed to what seemingly happens now to the Pan-STARRS project)?

Ivezić: Pan-STARRS and LSST have different funding schemes. From its very inception, LSST maintained the view that all data and data products should be publicly available as soon as practically possible. As long as the major funding sources remain NSF and DoE, it is unlikely that this policy will change.

Wing: Aren't there limits to the physical size of filters that employ thin films, and if so, would it be feasible to use smaller interference filters to survey selected regions such as the Magellanic Clouds?

Ivezić: Although LSST filters will be quite large (0.76 m diameter), they can be made. Indeed Pan-STARRS has already procured somewhat smaller filters (0.5 m diameter).

Demers: What is the pixel size of your LSST camera?

Ivezić: $0.''2$

Željko Ivezić with the money in his back ...