Large Synoptic Survey Telescope

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Exploring the Transient and Variable Universe

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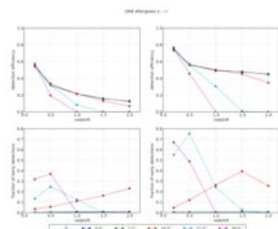
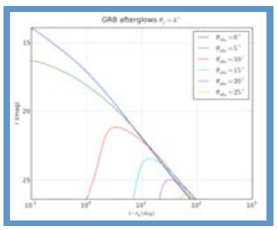
LSST will open new opportunities to explore the variable and transient sky. The combination of all-sky coverage, consistent long-term monitoring, and flexible criteria for event identification will allow LSST to probe a large unexplored region of parameter space and discover new types of transients. LSST data will shed new light on a wide variety of astrophysical objects and events, from the familiar ground of classical variables in our Galaxy to exotic explosive cosmological transients. For example, LSST's breadth and depth will capture new samples of rare variables that inform our understanding of stellar evolution, such as AM CVn systems and both eruptive young and evolved stars. In addition, a vast diversity of new transients will be observed by LSST each night. LSST will generate "alerts" within 60 seconds of detecting a new transient, permitting the community to follow up unusual events in greater detail. With an estimated 10^5 such alerts per night, effective classification will be required to identify the most interesting objects. LSST will be the instrument of choice for finding very rare and faint transients, as well as probing the distant Universe for the most luminous events. LSST will make localization for LIGO events possible, identify counterparts to GRBs and X-ray flashes, and discover new supernovae. Finally, LSST will expand the observational frontier of optical transients by probing new areas of parameter space that were not previously accessible. Many types of transient events are expected on theoretical grounds to inhabit this space, but have not yet been observed. Through observations of both new and known transient and variable objects, we can begin to understand their underlying fundamental physical processes, their commonalities, and differences.

Orphan GRB Afterglows

Gamma-ray bursts (GRBs) are the most relativistic (known) explosions in the Universe and are associated with the birth of rapidly spinning stellar black holes. Long duration GRBs are believed to result from the deaths of certain types of massive stars (Woolsey & Bloom 2006). The explosion is deduced to be conical ("jetted") with opening angles ranging from less than a degree to a steradian. The appearance of the explosion depends on the location of the observer.



Right: Summary of LSST's ability to detect GRB afterglows-- off-axis orphan afterglows in particular.



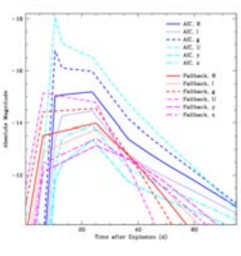
Above: model predictions of the forward shock emission from a GRB jet propagating into the circumstellar medium.

Statistics of off-axis afterglows, when compared to GRBs, will yield the so-called "beaming fraction," and more importantly, the true rate of GRBs. The total number of afterglows brighter than R ~ 24 visible per sky at any given instant is predicted to be ~1,000, and rapidly decreases for less sensitive surveys (Totani & Panaitescu 2002). With an average afterglow spending 1-2 months above that threshold, we find that **monitoring 10,000 deg^2 every ~3 days with LSST will discover 1,000 off-axis afterglows per year.**

LSST will speed up the discovery rate of the supernovae associated with GRBs by at least a factor of 10 relative to GRB missions.

Exotic Transients

We have also begun full-fledged theory efforts to model transients beyond the well-studied supernovae and GRBs. These include phenomena such as fallback supernovae, accretion induced collapse, stellar mergers, enshrouded supernovae and helium flashes or ".Ia supernovae". These outbursts provide insight into stellar evolution and supernovae and some are much better probes of neutrino and gravitational wave physics than typical supernovae and GRBs. **Theory can provide insight into distinguishing these different outbursts from each other.** Already surveys such as the Palomar Transient Factory have discovered some interesting objects that may be explained by these "new" transients: e.g. 2005cz, 2005E (Kawabata et al. 2009, Perets et al. 2009).

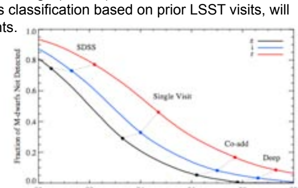


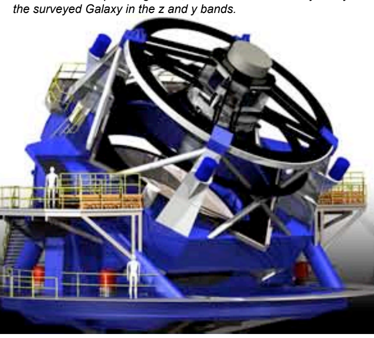
Above right: r,i,g,u,y,z band light-curves for two modeled outbursts: an accretion induced collapse and a fallback supernova (Fryer et al. 2009). Our accretion-induced collapse models tend to have much brighter u-band magnitudes than other outbursts and this may be a way to distinguish accretion-induced collapse models from other outbursts.

Transient Events on Variable Objects: M Dwarf Flares

Flares on foreground M dwarfs may be a source of confusion for transients, as stars that are below the detection limit in quiescence may be visible during flare events. The total number of M-dwarfs in a given field depends on its size and location in the Galaxy. For a 3'x3' field at l=90, b=60, there are tens of thousands of M-dwarfs, many of which will be undetected in the z band co-added image (z=26.5). However, additional sensitivity to very red objects provided by the Y band, as well as classification based on prior LSST visits, will help to discriminate between recurrent flares and "true" transients.

Right: The fraction of M dwarfs along a typical LSST line-of-sight that are not detected during quiescence in r, i and z (star counts are from the Galfast model of Juric (2009). The dashed lines indicate the approximate survey limits for SDSS, LSST single visit, co-added visits, and deep-drilling fields. In the deep drilling fields, LSST will detect nearly every M dwarf in the surveyed Galaxy in the z and y bands.





A flare will appear as a u band optical transient (appearing in an image when it is not detected in quiescence) if it meets the following criterion:

Δu > (uquiet-zquiet) + (zobs - zlimit) + (zlimit - ulimit)

How often a flare of a particular magnitude (Δu) occurs and will be seen as a transient depends on the flare frequency distribution and is the subject of current work by Eric Hilton and collaborators.

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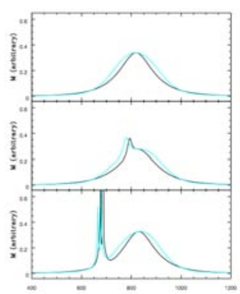
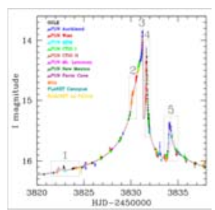
Gravitational Microlensing

For high mass lenses, the deviations from baseline last long enough and evolve slowly enough that LSST can track the event and provide good model fits. In these cases, data collected by **LSST alone can identify the correct models.**

Right: Model lensing light curves for high-mass lenses (black holes with M = 14 $M_\odot$ and DL = 200 pc). Cyan curves include parallax effects due to the motion of the Earth around the Sun; black curves do not. Top: The lens is an isolated black hole. Middle and Bottom: The lens has a white-dwarf companion with orbital period appropriate for the end of mass transfer. The orbital phase at the time of peak is the distinguishing feature between the middle and bottom panels.





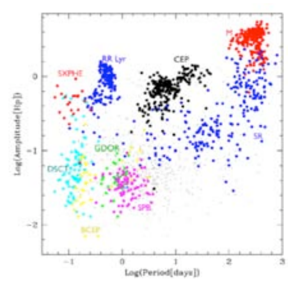
For short-duration events or for some planet lenses, **LSST can discover events and spark alerts** to allow more frequent monitoring.

Left: This figure (derived from Gaudi et al., Science, 319:927, 2008) demonstrates a microlensing light curve which LSST could 'alert' on but follow-up networks are required to extract the science (two exoplanet system discovery). OGLE alerted on this event at the first point in the light curve and identified the event as anomalous at the 4th point.

Alerts and Classification

Accurate classification is essential for transient/variable separation and prioritization of follow-up efforts.

In even simple metrics (e.g. amplitude, period, color, phase offset between harmonics) broad classes of variables can be distinguished using LSST data alone. For example, lightcurves of pulsating variables provide two fundamental metrics: the pulsation period and the light curve amplitude. At right we show the period-amplitude diagram for different classes of pulsating variables (adapted from Eyer & Mowlavi 2008): δ Scutis (DSCT), SX PHe (SXPHE), γ Dor (GDOR), β Cepheid (BCEP), Cepheids (CEP), RR Lyraes (RRL), semi-regular variables (SR), slowly pulsating B stars (SPB), and M dwarfs (M). These different classes are easily separable from one another in period-amplitude space.



For new classes of transients and variables, such as the exotic events discussed at left, we expect these traditional metric spaces to also have diagnostic power, even as more complex metrics are developed.

Summary

- **LSST data will be capable of both discovery *and* characterization of known and new transient types**
- **Classification, including cross referencing with catalogues and previous LSST observations to distinguish between outbursting variables and true transients, will be crucial to prioritize follow-up observations**
- **Extensive preliminary observations and theoretical work are underway to quantify survey expectations and provide figures of merit for transient and variable objects**

References

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