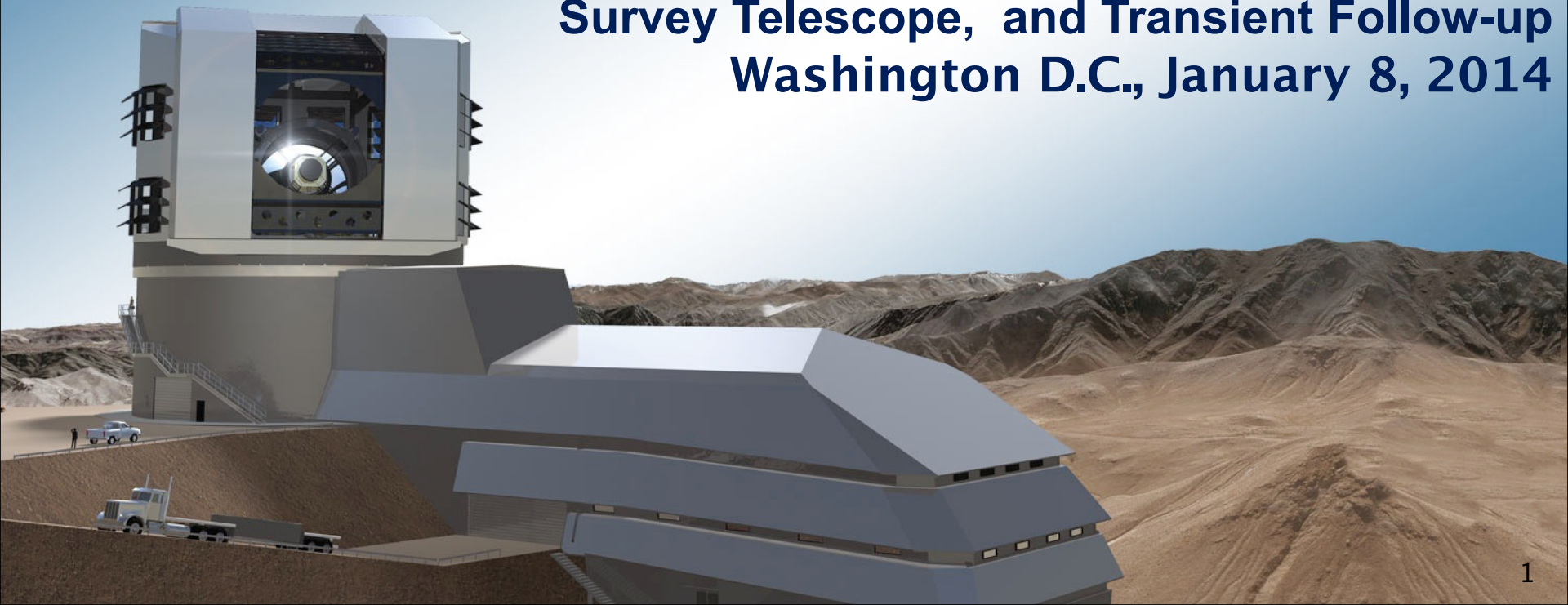
Opportunities and challenges for time-domain astronomy with LSST

Željko Ivezić
University of Washington

The 223rd AAS Meeting
Special Session on "Time-domain astronomy, the Large Synoptic Survey Telescope, and Transient Follow-up
Washington D.C., January 8, 2014



Outline

1) Terminology: what are not "true transients" (at least not in this presentation)

- LSST will report all sources detected in difference images (within 60 seconds)

- this data stream of alerts will thus include moving objects, variable stars, quasars, SNe, and "true transients"

- "true transients" will include, roughly speaking, "everything else"

2) Brief introduction to time-domain with LSST

3) Opportunities and challenges

Time Domain:

"objects changing in time"

1) **positions:**

a) fast: asteroids, comets

b) slow: stellar proper motions

2) **brightness:** cosmic explosions, variable stars (or periodic vs. irregular, etc.) and everything else

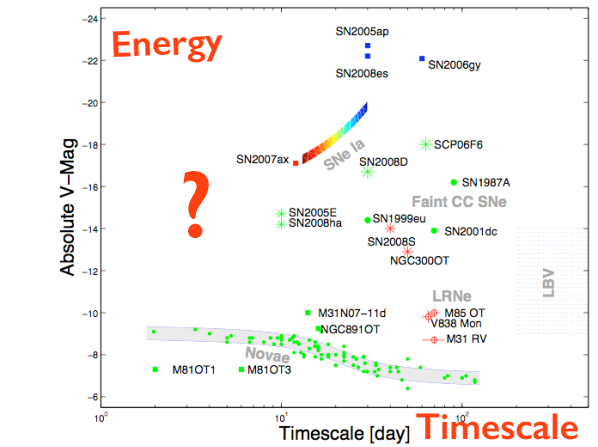
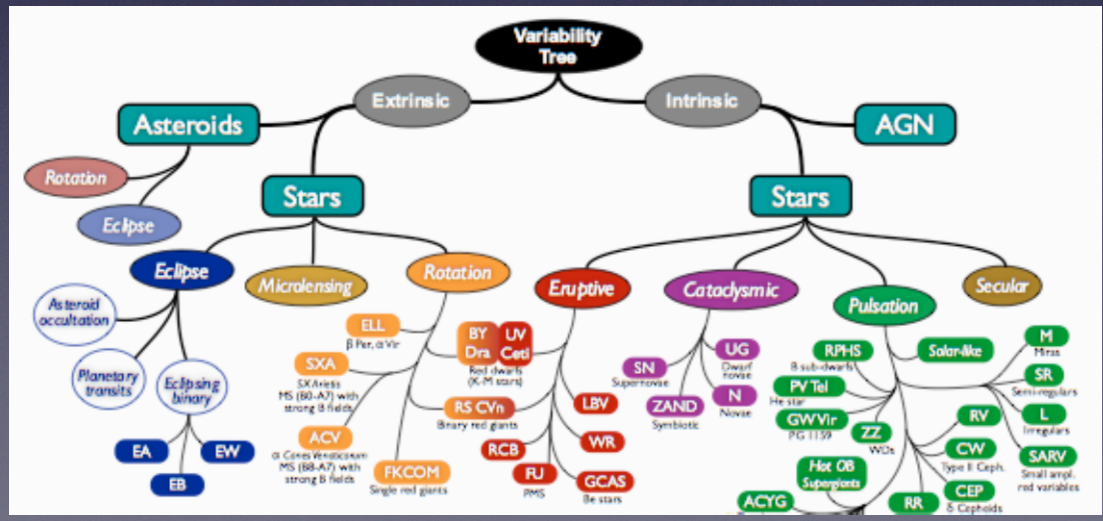


FIG. 29.— The phase space of cosmic explosive and eruptive transients as represented by their absolute V band peak brightness and the event timescale (adapted from Kulkarni et al. 2007).

Kulkarni et al. 2007



Eyer & Mowlavi 2007

What is a "true transient"?

Justice Potter Stewart: "I know it when I see it."

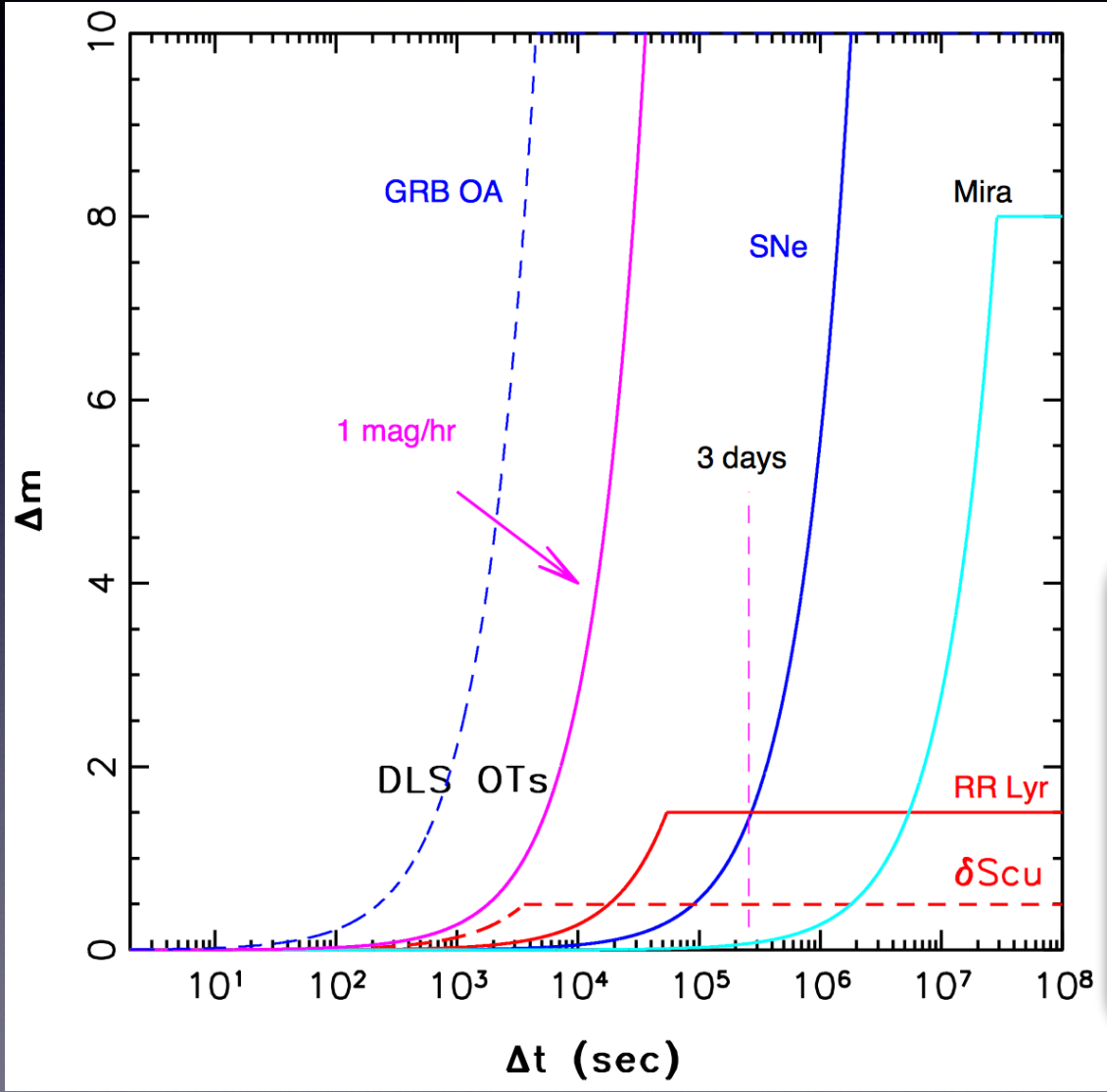
1) If we define it as a non-recurrent source (after being "on" for some time), then we are coupling survey properties into it (e.g. a faint quasar).

2) The same is true for a definition based on duration (e.g. faint SNe, comets).

3) One possibility that works well in practice is to assert that "true transients" are those that can reach photometric variability of at least 1 mag/hr.

What is a "true transient"?

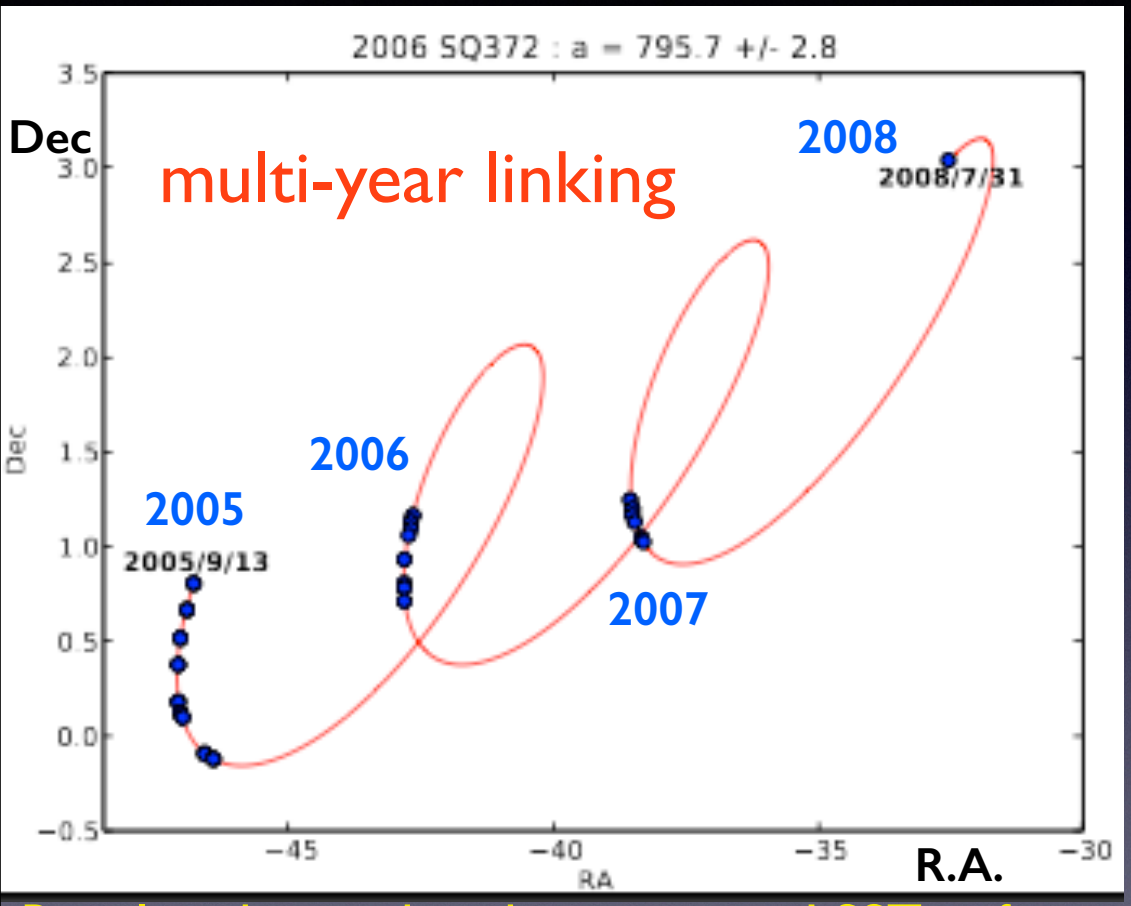
"True transients" are those that can reach photometric variability of at least 1 mag/hr.



This definition rejects most common variable stars (an M dwarf burst might qualify), and also rejects SNe.

It is most certainly not a perfect definition but it does select transients where LSST latency of only 60 sec will represent major new science opportunities

Exploring beyond Kuiper belt with SDSS Stripe 82



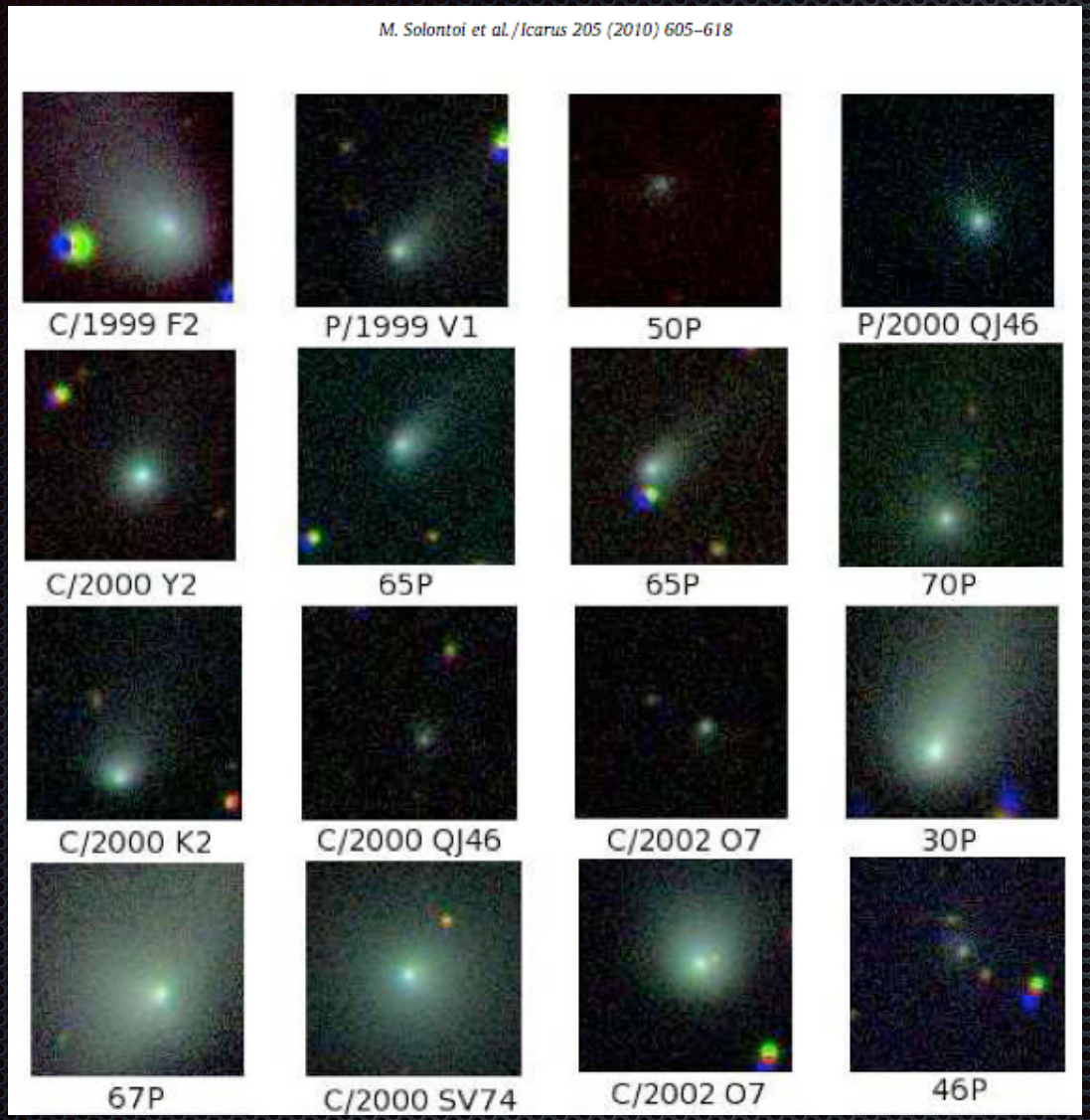
Becker et al. (2008)

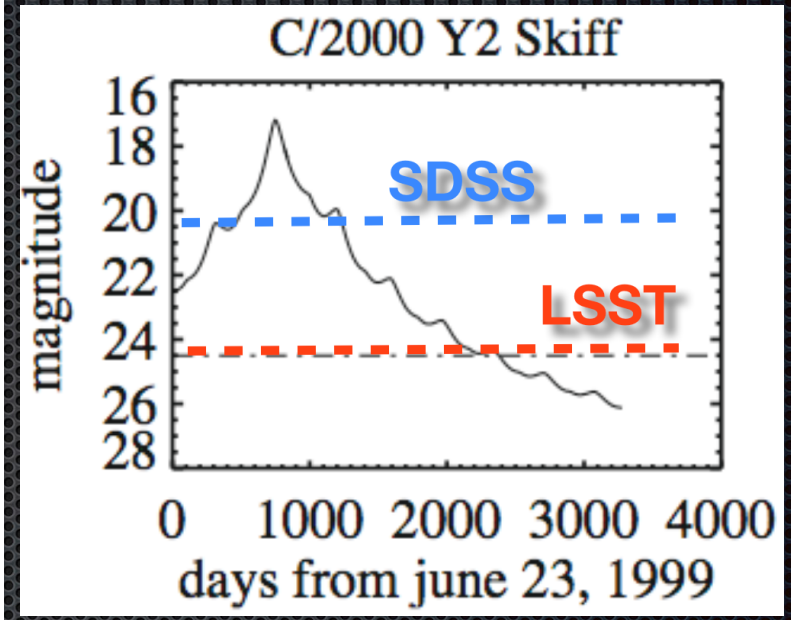
- based on SDSS stripe 82 scans
- discovered 2 (out of 6 known) Neptunian Trojans
- discovered ~50 TNOs
- 2006 SQ 372: the most interesting object with a semi-major axis of ~800 AU!!!
- simulations strongly suggest that this objects was recently scattered into inner Solar System from the Oort cloud

Results obtained with prototype LSST software (built on Pan-STARRS' MOPS code)

! essentially a "transient" source but not a "true transient"

SDSS comets (Solontoi et al. 2010; n~20)



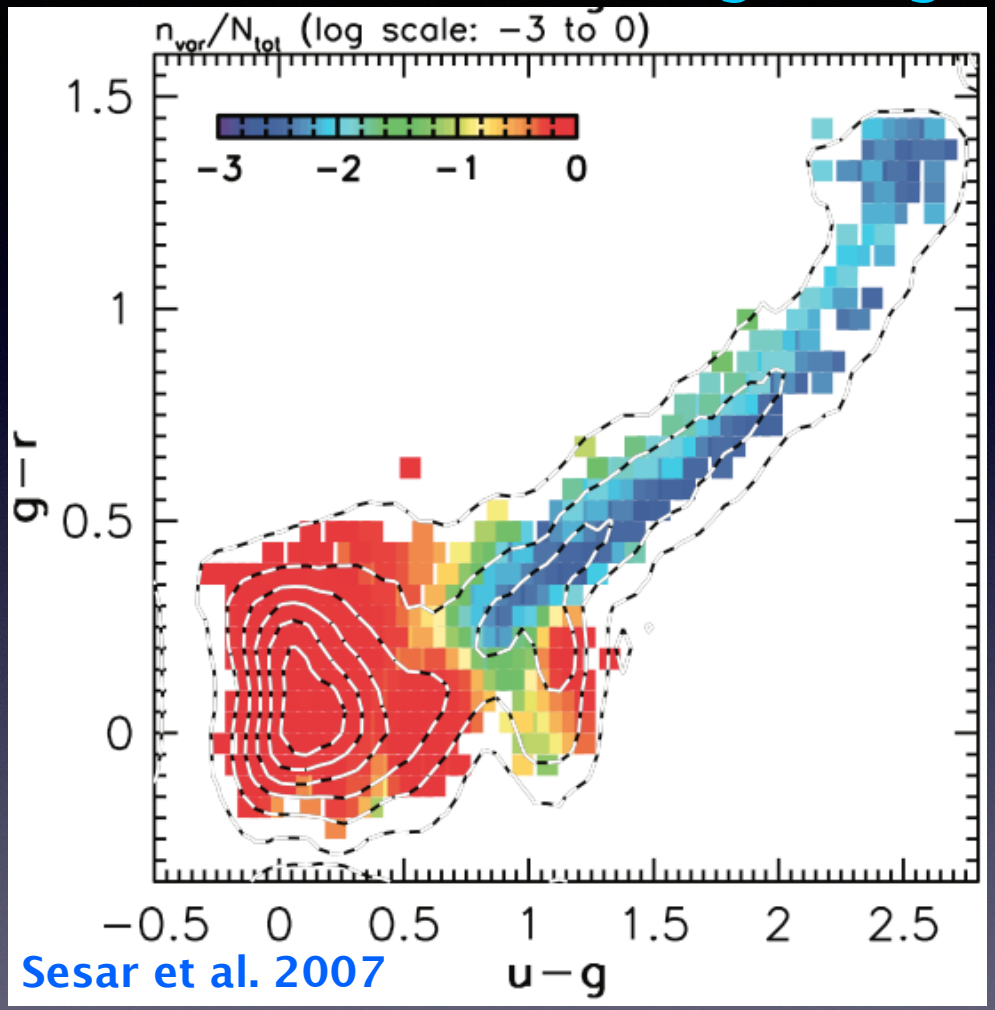


Comets will "last" longer with LSST than with SDSS

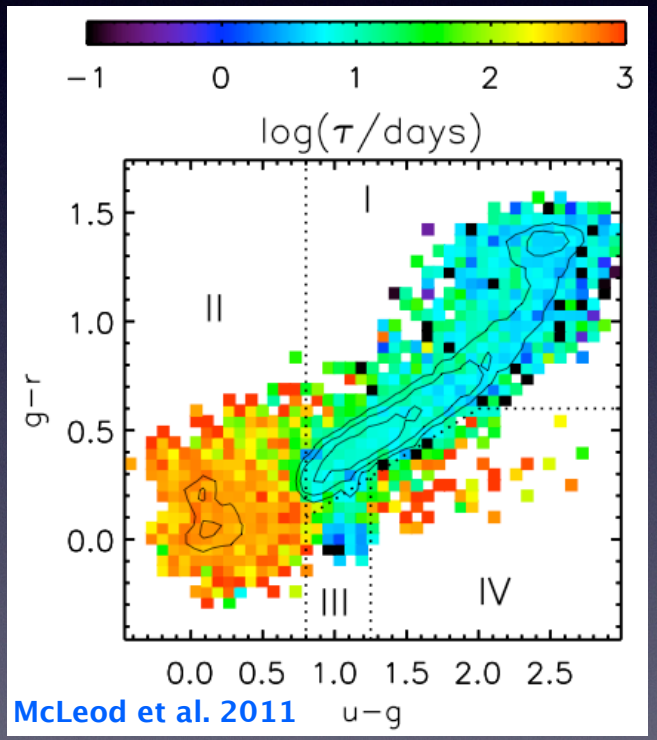
! **essentially "transient" sources but not "true transients"**

The fraction of photomet. variable objects

SDSS, with rms>0.05 mag and g<20.5



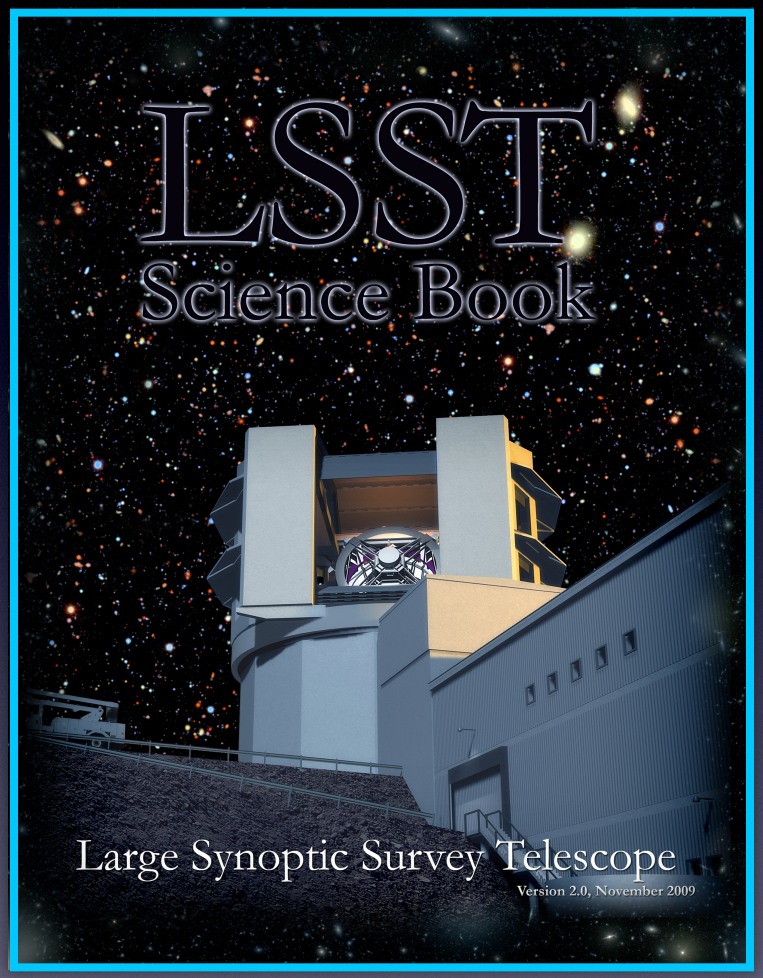
The sample is dominated by quasars, RR Lyrae and eclipsing binaries.



This science would be achieved even if 60 sec would be 60 mins

Quasars are easily distinguished from stars by their long time scales. !

More information about LSST:



LSST Science Book: describes scientific capabilities of the survey in detail. Available at:

http://www.lsst.org/lsst/scibook

Chapter 8 on **"The Transient and Variable Universe"**

A shorter paper: arXiv:0805.2366

Basic idea behind LSST: A uniform sky survey.

- ~90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about 2.5 million 3.2 Gpix images (visits), enabling **measurements for 40 billion objects**

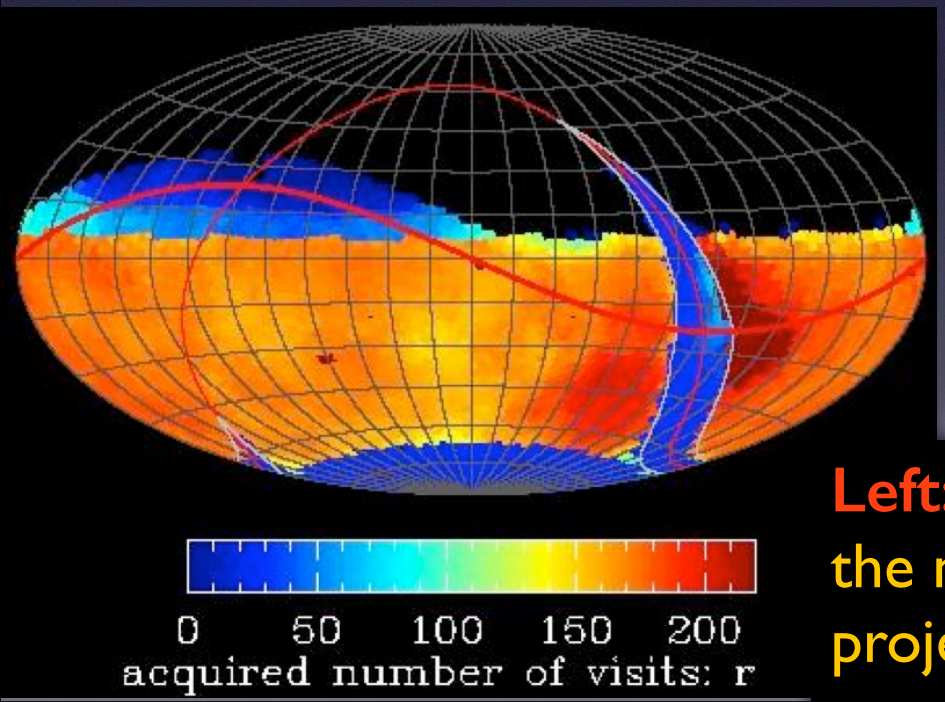
Visit: basic unit for data taking; baseline assumes a total exposure time per visit of 30 sec, split into two back-to-back exposures of 15 sec each

LSST in one sentence:
An optical/near-IR survey of half the sky in ugrizy bands to r~27.5 (36 nJy) based on ~825 visits over a 10-year period: **deep wide fast.**

LSST will collect about 2.5 million visits. Each visit results in a 3.2 Gpix image of 9.6 sq.deg.

Basic idea behind LSST: A uniform sky survey.

- ~90% of time will be spent on a uniform survey: every 3-4 nights, the whole observable sky will be scanned twice per night
- after 10 years, half of the sky will be imaged about 1000 times (in 6 bandpasses, ugrizy): a digital color movie of the sky
- ~100 PB of data: about 2.5 million 3.2 Gpix images (visits), enabling **measurements for 40 billion objects**

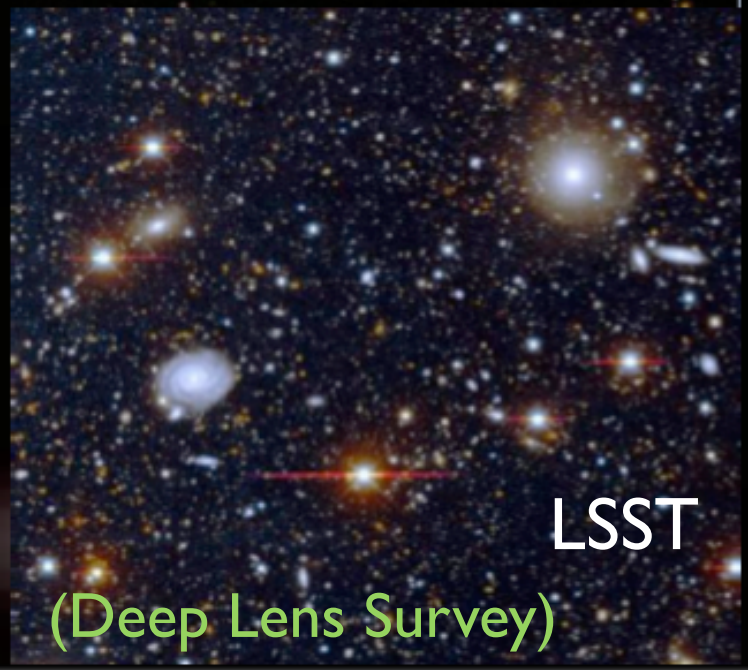


Current baseline cadence
Not set in stone - LSST project and the community are revisiting optimization of LSST deployment (first workshop in June at NOAO)

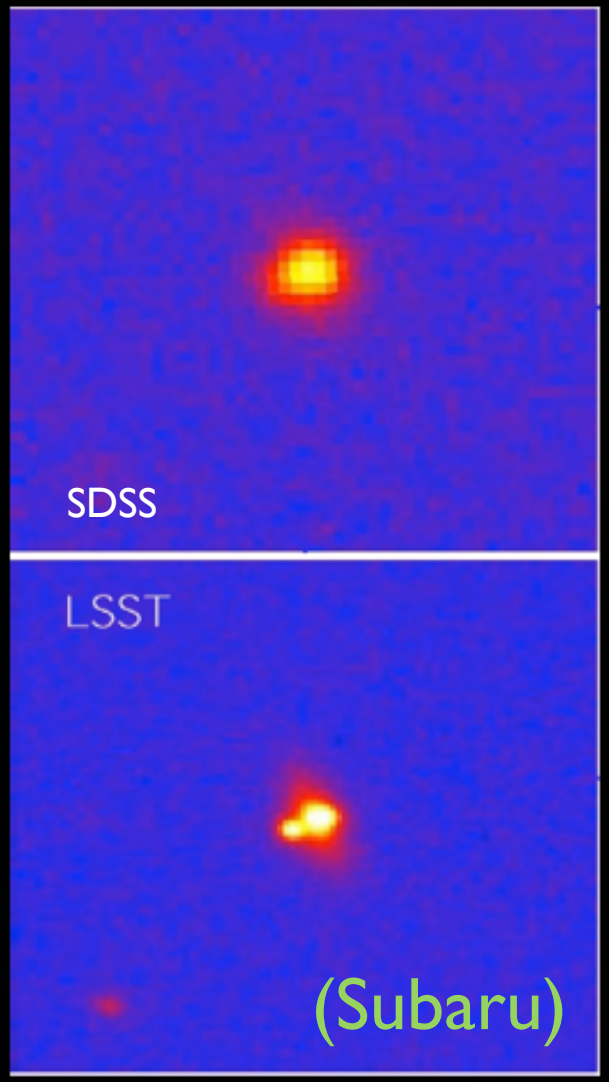
Left: a 10-year simulation of LSST survey: the number of visits in the r band (Aitoff projection of eq. coordinates)

SDSS-LSST comparison: LSST=d(SDSS)/dt, LSST=SuperSDSS

3x3 arcmin, gri

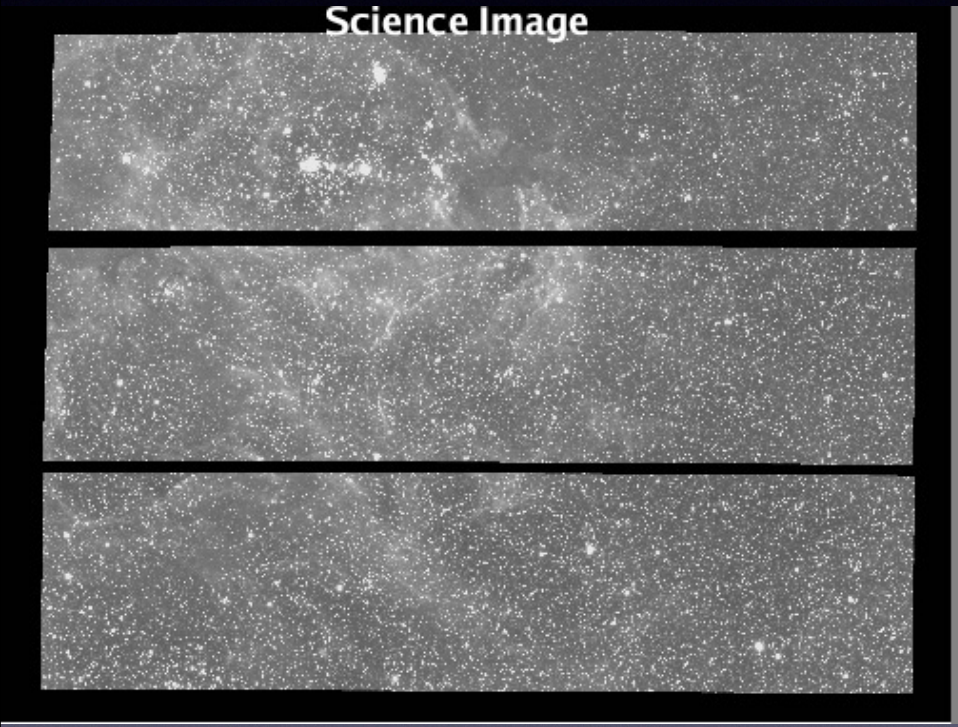


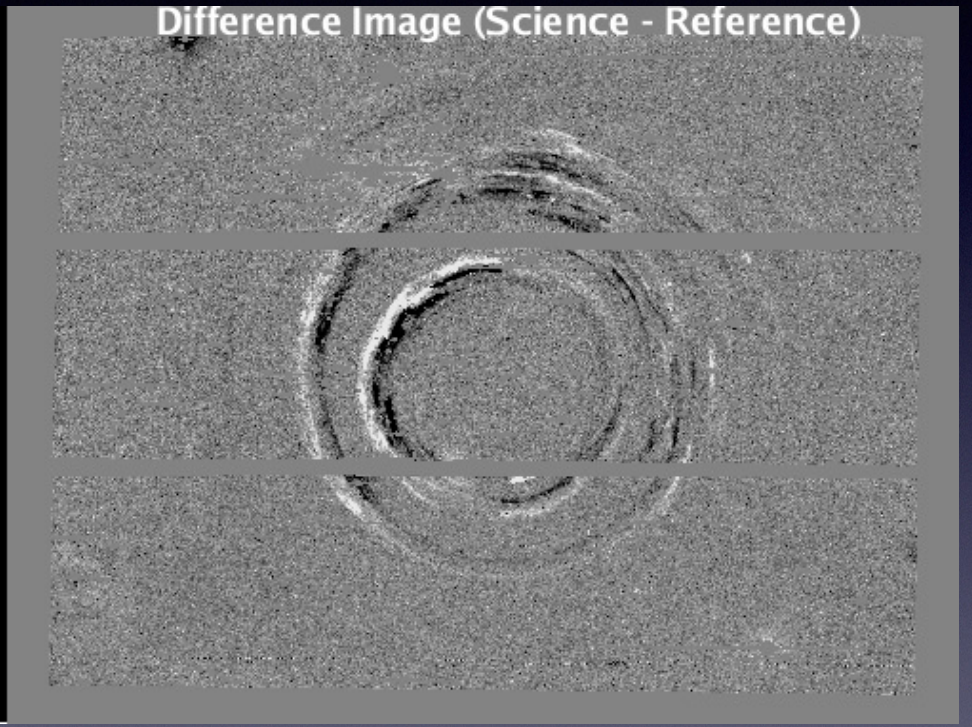
20x20 arcsec; lensed SDSS quasar
(SDSS J1332+0347, Morokuma et al. 2007)



LSST will extend time-volume space a thousand times over current surveys (new classes of object?)

Not only point sources - echo of a supernova explosion:





Becker et al.

As many variable stars from LSST, as all stars from SDSS!

Data stream of alerts within 60 seconds

However, the above is left for “Level 3” (i.e. not done by LSST)

Three main classes of LSST data products:

Level 1 data products are generated continuously **every observing night**, including alerts for objects that have changed flux or position, that will be released within 60 seconds (and will include measurements of positions and fluxes, as well as images).

Primary purpose: rapid followup!

Level 2 data products will be made available as **annual Data Releases** and will include images and catalogs with measurements of positions, fluxes, and shapes, as well as variability information such as orbital parameters for moving objects and light curve parametrization.

Based on about 1000 observations of each position, $\alpha(t)$, $\delta(t)$, u(t), g(t), r(t), i(t), z(y), y(t) (and their uncertainties) for 40 billion objects!

Three main classes of LSST data products:

Level 3 data products will be **created by science teams** external to the project using suitable Applications Programming Interfaces (APIs) that will be provided by the LSST Data Management System. The Data Management System will also provide user-dedicated processing capability and user-dedicated storage. The key aspect of these capabilities is that they will reside “next to” the LSST data, avoiding the latency associated with downloads.

Back to "Transients"

Level 1 data products are generated continuously **every observing night**, including alerts for objects that have changed flux or position, that will be released within 60 seconds

1) These detections in difference images (science images with respect to deep coadded templates) are called DIASources in LSST documentation.

2) It is very unfortunate that sometimes they are also called "transients", although they also include variable stars, quasars, and asteroids.

3) It is estimated that LSST will report of the order 10 million DIASources per night (this varies by a factor of a few with sky position); this is equivalent to ~10,000 DIASources every ~40 seconds

Level 1 Requirements

Contents

Throughput

Filtering

The fast release of data on likely optical transients will include measurements of position, flux, size and shape, using appropriate weighting functions, for all the objects detected above transSNR signal-to-noise ratio in difference images (design specification: 5). The data stream will also include prior variability information and data from the same night, if available. The prior variability information will at the very least include low-order light-curve moments and probability that the object is variable, and ideally the full light curves in all available bands.

Specification: The system should be capable of reporting such data for at least transN candidate transients per field of view and visit (Table 29).

Quantity	Design Spec	Minimum Spec	Stretch Goal
transN	10^4	10^3	10^5

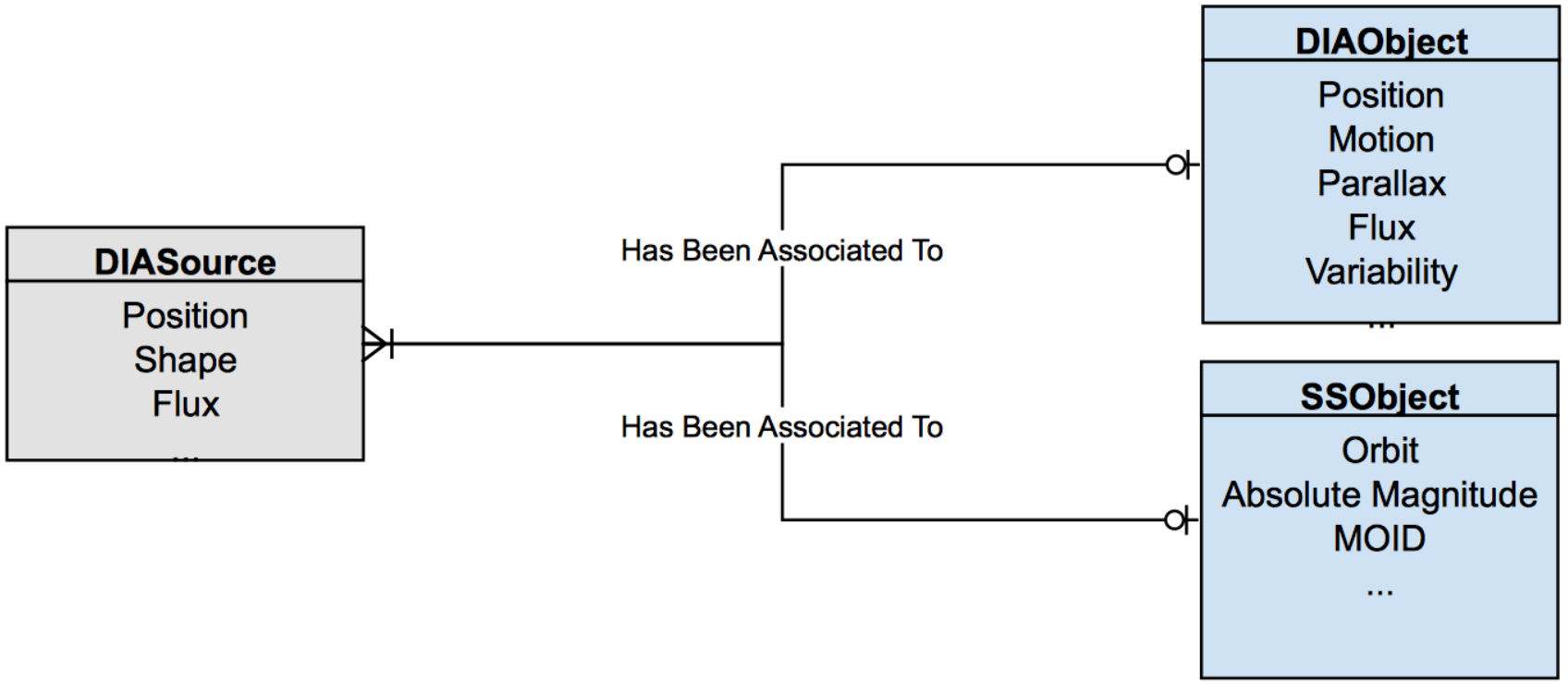
Table 29: The minimum number of candidate transients per field of view that the system can report in real time.

The users will have an option of a query-like pre-filtering of this data stream in order to select likely candidates for specific transient type. Users may also query the LSST science database at any time for additional information that may be useful, such as the properties of static objects that are positionally close to the candidate transients. Several pre-defined filters optimized for traditionally popular transients, such as supernovae and microlensed sources, will also be available, as well as the ability to add new pre-defined filters as the survey continues.

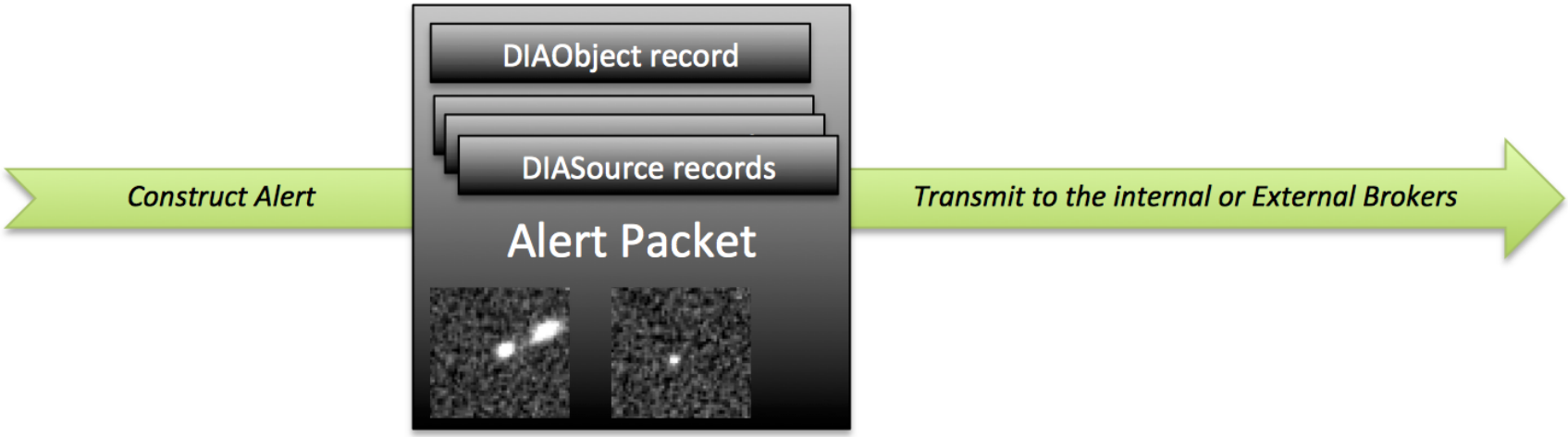
Level 1 Catalogs

Level 1 processing will populate the Level 1 database tables, including:

- `DIASource`: table of sources detected on difference images
- `DIAObject`: objects and their characteristics, inferred from DIASource detection
- `SSObject`: the catalog of orbits of objects in the Solar System



Level 1 Alert Packets



An alert packet is constructed that includes all previous DIASource measurements, all information contained in the DIAObject record, image cut-outs, and all metadata necessary to query the Level 1 database for a copy of this alert.

- LSST plans to use a community-accepted standard (baseline: VOEvent) as the format for alert transmission
- The packet will be transmitted to VOEvent Brokers
- LSST expects the community to provide sophisticated brokers with classification engines, cross-match capabilities to other catalogs, etc.
- LSST will provide a default, limited, broker

Level 1 Alert Packets

Each alert include the following:

- Alert and database ID: IDs uniquely identifying this alert.
- The DIASource record that triggered the alert
- The entire DIAObject (or SSObject) record
- All previous DIASource records
- 30x30 pixel cut-out of the difference image (FITS)
- 30x30 pixel cut-out of the template image (FITS)

The goal is to transmit nearly everything LSST knows about any given event, enabling downstream classification and decision making *without* the need to call back into LSST databases (thus introducing extra latency)

Contributions to DIASource counts

Given a stream of ~10,000 DIASources every ~40 seconds (per 10 sq. deg. field),

1) Asteroids will dominate on the Ecliptic, and become insignificant more than 30 deg. from it.

2) Variable stars (~1 % of all stars) will dominate in the Galactic plane, and will always be significant (about 400 per field at the Galactic pole)

3) Quasars will contribute up to 500 per field (but likely several times lower)

4) SNe will contribute up to about 100 per field

Counts of new DIASources

Steve Ridgway at Hot-wiring the Transient Universe 3:

The discovery rates will drop fast, by about a factor of 100 after 2 years: discoveries (new DIASources) will become dominated by cataclysmic variable stars and quasars.

1) It will be much easier to select "true transients" after about 2 years of surveying (significantly fewer false positives)

2) Algorithms and tools need to be developed with this fact in mind, and on relevant time scales (e.g. filtering, with all the testing and fine tuning)

3) Time-domain community experience will help greatly!

Counts of "true transients"

Every 40 seconds: of the order 10 with r<23 (a wild guess) selected from a few thousand new DIAsources early in the survey, to a few dozen later in the survey.

1) Very uncertain (even when not including "unknown unknowns") due to very faint flux limit and cadence variations; perhaps 10,000 per night (with uncertainty of no less than a factor of 2, and possibly as large as 10)

2) Two key components for successful time-domain science programs driven by LSST are
   a) robust filtering, and
   b) rapid followup

3) Feedback from ongoing surveys will be important for optimizing tools and system deployment

Summary

1) Sources detected in difference images (DIASources) will be measured and reported in 60 sec (baseline: as a VOEvent stream). Users will be able to filter this stream (of the order 10 million DIAsources per night, including variable stars, SNe, asteroids, and "everything else").

2) LSST will deliver a toolbox, and this will be done on a fixed schedule and budget. The more we can gain from other surveys and groups outside the formal project boundaries, the better this toolbox will be, for everyone. LSST Project invites community members with relevant expertise to help optimize the project-led development.

3) The critical period for "making everything work" is prior to first light (say, two years earlier, which is 2017), and thus we have only about 4 years!

LSST will provide ingredients but YOU will need to cook the science soup!