TMT in the era of LSST

aam at astro.caltech.edu (Caltech)
Co-chair LSST Transients and Variable Stars Science Collaboration
TMT Science Forum
Jun 24th, 2015
Probing faint transients & variables

Single
- $u$: 23.9
- $g$: 25.0
- $r$: 24.7
- $i$: 24.0
- $z$: 23.3
- $y$: 22.1

Stacked
- $u$: 26.3
- $g$: 27.5
- $r$: 27.7
- $i$: 27.0
- $z$: 26.2
- $y$: 24.9

$\sim 0.01$ mag precision photometry
### Summary of high level requirements

<table>
<thead>
<tr>
<th>Survey Property</th>
<th>Performance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Main Survey Area</td>
<td>18000 sq. deg.</td>
</tr>
<tr>
<td>Total visits per sky patch</td>
<td>825</td>
</tr>
<tr>
<td>Filter set</td>
<td>6 filters (ugrizy) from 320 to 1050nm</td>
</tr>
<tr>
<td>Single visit</td>
<td>2 x 15 second exposures</td>
</tr>
<tr>
<td>Single Visit Limiting Magnitude</td>
<td>$u = 23.9; g = 25.0; r = 24.7; i = 24.0; z = 23.3; y = 22.1$</td>
</tr>
<tr>
<td>Photometric calibration</td>
<td>&lt; 2% absolute, &lt; 0.5% repeatability &amp; colors</td>
</tr>
<tr>
<td>Median delivered image quality</td>
<td>~ 0.7 arcsec. FWHM</td>
</tr>
<tr>
<td>Transient processing latency</td>
<td>&lt; 60 sec after last visit exposure</td>
</tr>
<tr>
<td>Data release</td>
<td>Full reprocessing of survey data annually</td>
</tr>
</tbody>
</table>
LSST data volume and scientific yields

- Two 6.4-gigabyte images (one visit) every 39 seconds (15TB per night)
- ~1000 visits each night, ~300 nights a year
- Up to 450 calibration exposures per day

Can detect >10 million real time events per night, for 10 years
Changes detected, transmitted, within 60 seconds of the observation

Observe ~38 billion objects (24B galaxies, 14B stars)
Collect ~5 trillion observations (“sources”) and ~32 trillion measurements (“forced sources”) in a 20 PB catalog

User databases and workspaces (“mydb”)
Making the LSST software available to end-users
Feeding the data back to the community
Hierarchical steps of survey complexity

1. single band, single program, static science
2. multi-bandpass data: ugrizy
3. time domain

...not all sky regions were created equal!
Galactic plane
LMC/SMC
northern Ecliptic
south Galactic pole
deep drilling (and other special) fields

It’s likely that these regions will need a modified cadence, but not clear yet how exactly (depends on fast-evolving science drivers and the system performance)
Transients and Variable Stars Science Collaboration  
Co-chairs: Ashish Mahabal, Lucianne Walkowicz

Classification/Characterization  
Distance Scale  
Multiwavelength Characterization/Counterparts  
Cosmological  
Fast Transients  
Galactic  
Gravitational Waves  
Interacting Binaries  
Magnetically Active Stars  
Microlensing Subgroup  
Non-degenerate Eruptive Variables  
Pulsating Variables  
Supernovae Subgroup  
Tidal Disruption Events  
Transiting Planets

Developing roadmaps (~100 members)  
roadmaps based on aims, simulations, data and lessons from other surveys  
[testing co-add pipeline for CRTS images]
### Variability on huge range of timescales

<table>
<thead>
<tr>
<th>Class</th>
<th>Timescale</th>
<th>Amplitude (Δmags)</th>
</tr>
</thead>
<tbody>
<tr>
<td>WD Pulsations</td>
<td>4-10 min</td>
<td>0.01 - 0.1</td>
</tr>
<tr>
<td>AM CVn (orbital period)</td>
<td>10-65 min</td>
<td>0.1 - 1</td>
</tr>
<tr>
<td>WD spin (int. polars)</td>
<td>20-60 min</td>
<td>0.02 - 0.4</td>
</tr>
<tr>
<td>AM CVn outbursts</td>
<td>1-5 days</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Dwarf Novae outburst</td>
<td>4 days - 30 years</td>
<td>2 - 8</td>
</tr>
<tr>
<td>Symbiotic (outburst)</td>
<td>weeks-months</td>
<td>1 - 3</td>
</tr>
<tr>
<td>Novae-like high/low</td>
<td>days-years</td>
<td>2 - 5</td>
</tr>
<tr>
<td>Recurrent Novae</td>
<td>10-20 year</td>
<td>6 - 11</td>
</tr>
<tr>
<td>Novae</td>
<td>$10^3$-$10^4$ yr</td>
<td>7 - 15</td>
</tr>
</tbody>
</table>
# Expected Rate of Transients

<table>
<thead>
<tr>
<th>Class</th>
<th>Mag</th>
<th>t (days)</th>
<th>Universal Rate</th>
<th>LSST Rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Luminous SNe</td>
<td>$-19...-23$</td>
<td>50 - 400</td>
<td>$10^{-7}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>20000</td>
</tr>
<tr>
<td>Orphan Afterglows SHB</td>
<td>$-14...-18$</td>
<td>5 - 15</td>
<td>$3 \times 10^{-7}...-9$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>$\sim10 - 100$</td>
</tr>
<tr>
<td>Orphan Afterglows LSB</td>
<td>$-22...-26$</td>
<td>2 - 15</td>
<td>$3 \times 10^{-10}...-11$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>1000</td>
</tr>
<tr>
<td>On-axis GRB afterglows</td>
<td>$...-37$</td>
<td>1 - 15</td>
<td>$10^{-11}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>$\sim50$</td>
</tr>
<tr>
<td>Tidal Disruption Flares</td>
<td>$-15...-19$</td>
<td>30 - 350</td>
<td>$10^{-6}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>6000</td>
</tr>
<tr>
<td>Luminous Red Novae</td>
<td>$-9...-13$</td>
<td>20 - 60</td>
<td>$10^{-13}$ yr$^{-1}$ Lsun$^{-1}$</td>
<td>80 - 3400</td>
</tr>
<tr>
<td>Fallback SNe</td>
<td>$-4...-21$</td>
<td>0.5 - 2</td>
<td>$&lt;5 \times 10^{-6}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>$&lt; 800$</td>
</tr>
<tr>
<td>SNe Ia</td>
<td>$-17...-19.5$</td>
<td>30 - 70</td>
<td>$3 \times 10^{-5}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>200000</td>
</tr>
<tr>
<td>SNe II</td>
<td>$-15...-20$</td>
<td>20 - 300</td>
<td>$(3.8) \times 10^{-5}$ Mpc$^{-3}$ yr$^{-1}$</td>
<td>100000</td>
</tr>
</tbody>
</table>

Table adapted from Rau et al. 2009 by Lucianne Walkowicz
Number of transients and variables

$10^6 - 10^7$ per night (that's 1000/minute!)

Most of them of a typical/known nature

Characterizing them to get to the rare ones is important

iPhone app
“Transient Events”
The tapering down

- Ridgeway et al., arXiv: 1409.3265
Cadence “conservation laws”

How can we optimize the deployment parameters: exposure time per visit, $t_{vis}$, single-visit depth, $m_5$, the mean revisit time, $t_{revisit}$, and the number of visits, $N_{vis}$?

While each of these four parameters has its own drivers, they are not independent (scaled to nominal LSST):

$$m_5 = 24.7 + 1.25 \times \log(t_{vis} / 30 \text{ sec})$$

$$t_{revisit} = 3 \text{ days} \times (t_{vis} / 30 \text{ sec})$$

$$N_{vis} = 1000 \times (30 \text{ sec} / t_{vis}) \times (T / 10 \text{ years})$$

How to allocate the total observing time per position of ~7 hours to ugrizy, and how do we split allocations into individual visits?
2014, 2015 cadence meetings

**Sensitivity** (visit? coadd?) by filter (especially u and g), needed for several (many? all?) variable types

**Phased uniformity** (periodic variables): for a given period how uniformly would the lightcurve be sampled?*

**Window function** (per filter/all filters) FWHM, ...
statistics of **revisit time histogram** (per filter/all filters) e.g. min/max/median/5th & 95th percentiles

**Hour angle distribution** (to check aliasing), at a given sky position, maximum difference, rms ...

20-22 Aug 2015
Bremerton
Optimization more than in Tzolk’in

Victory points == science

Large number of variables and each player wants to win.
Optimizing is (generally) a zero-sum game

Easy to make the survey “greatest” in one science

Optimization means compromise

BUT, the sum of parts is GREATER than the whole i.e. compromise does NOT mean sacrifice
   In other words, the players are NOT playing AGAINST each other

   It’s the best middle ground we are seeking

LSST is its own follow-up machine in a proactive way.
By coming up with a good cadence we can minimize the follow-up needed.
And you can help. And get the science you love done in the process.
Semantic Tree of Astronomical Variables and Transients
Domain Specific Knowledge

Galaxy proximity, Galactic latitude etc.

Data Science

Machine Learning

Efficient algorithms and optimization

Computer Science

Mathematics and Statistics

Abstractions and summaries
From Python’s scikit-learn
Many features - not all are independent

Adam Miller

15 Jan 2015

Ashish Mahabal
Feature selection strategies

- Fast Relief Algorithm (wt and t)
- Fisher Discriminant Ratio
- Correlation based Feature Selection
- Fast Correlation Based Filter
- Multi Class Feature Selection

ZTF (2016): an order of magnitude faster than PTF.

<table>
<thead>
<tr>
<th></th>
<th>PTF</th>
<th>ZTF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Active Area</td>
<td>7.26 deg$^2$</td>
<td>47 deg$^2$</td>
</tr>
<tr>
<td>Readout Time</td>
<td>36 sec</td>
<td>10 sec</td>
</tr>
<tr>
<td>Exposure Time</td>
<td>60 sec</td>
<td>30 sec</td>
</tr>
<tr>
<td>Relative Areal Survey Rate</td>
<td>1x</td>
<td>14.7x</td>
</tr>
<tr>
<td>Relative Volumetric Survey Rate</td>
<td>1x</td>
<td>12.3x</td>
</tr>
</tbody>
</table>

3800 deg$^2$/hour
⇒ 3π survey in 8 hours,
> 250 observations/field/year

New ZTF camera:
16 6k x 6k e2v CCDs

Kulkarni/Prince/Bellm/Kasliwal

Existing PTF camera
MOSAIC 12k

15 Jan 2015
Ashish Mahabal
CRTS-II

- Same telescopes
- Bigger cameras and FOVs:
  - MLS 1.5m, 1.2 → 5 sq. deg
  - CSS 0.7m, 8.2 → 19 sq. deg

Upgrades funded and underway.
Probing faint transients & variables

~0.01 mag precision photometry
Enter TMT

- What fraction of time will be ToO?
- Capabilities of the instruments ...
- Demands of observers (only bright transients?)
- LSST/(A-)LIGO/other fractions?
- All object types (that can be done only by TMT) are fair game [Paula Szkody’s talk on specific types]