Transients and Variable Stars: Followup in the Era of LSST

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Princeton University
Co-chair, LSST Transients & Variable Stars Science Collaboration
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Suzanne Hawley • UW
Arne Rau • MPI
Eric Agol • UW
Arne Henden • AAVSO
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Marcel Agueros • Columbia
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Mercedes Richards • Penn State
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Abi Saha • NOAO
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Howard Bond • STScI
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Zoltan Haiman • Columbia
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Edward Schmidt • U Nebraska
Rolf Chini • U Catolica del Norte
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Mark Claire • U East Anglia
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Avi Shporer • Caltech
Kem Cook • Independent
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Przemyslaw Wozniak • Los Alamos
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### LSST Transients & Variable Stars

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- Chris Fryer • U of A
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- Robert Williams • STScI
- Suvi Gezari • U Maryland
- Przemyslaw Wozniak • Los Alamos

**Note:** Not all simultaneously in outburst.

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**Thursday, September 12, 2013**
**LSST Data Products**

**Application Layer** -
Generates open, accessible data products with fully documented quality

<table>
<thead>
<tr>
<th>Processing Cadence</th>
<th>Image Category (files)</th>
<th>Catalog Category (database)</th>
<th>Alert Category (database)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nightly</td>
<td>Raw science image</td>
<td>Source catalog (from difference images)</td>
<td>Transient alert</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td></td>
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<td>Orbit catalog</td>
<td>Data quality analysis</td>
</tr>
<tr>
<td></td>
<td>Noise image</td>
<td>Source catalog (from calibrated science images)</td>
<td>Alert statistics &amp; summaries</td>
</tr>
<tr>
<td></td>
<td>Sky image</td>
<td>Object catalog (optimally measured properties)</td>
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</tr>
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</tr>
<tr>
<td>Data Release</td>
<td>Stacked science image</td>
<td></td>
<td></td>
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<tr>
<td>(Annual)</td>
<td>Template image</td>
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<tr>
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The known transient & variable sky

Figure by Mansi Kasliwal
Fast/faint transient sky still unknown

- Filled: Well observed
- Vertical Stripe: Rare
- Horizontal Stripe: Not yet detected
- Unfilled: Theoretical

Near-term facilities will begin to populate this space at bright end

adapted from Rau et al 2008
LSST étendue compared with other surveys
What does breadth/depth/width really give you?

- Characterization
- Known
- Rare
- Common
- Unknown
- Outlier Detection
- Clustering

Thursday, September 12, 2013
Even known variables & transients have surprises

Dwarf nova in the Kepler field
Even known variables & transients have surprises

Eccentric pulsating A star binary
## 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>~10 - 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>~50</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>
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<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*
## 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>
Questions/goals/projects within the Transients & Variable Star collaboration

Theoretical research on transients and variables, with eye towards follow-up observation strategy

Study of transients & variables in multiwaveband context, both to crossmatch w/ extant data & for future co-observing

What should the content of an alert be?

Precursor surveys, especially extending characterization/classification to new regimes
Understanding cadence choices for transient/variable identification

Provided multiband lightcurve templates to simulation team

Interest in making the OpSim a user-facing tool

Hsaio supernova template
Simulating the variable sky

<table>
<thead>
<tr>
<th>Variability Name</th>
<th>Responsible Party</th>
<th>Delivered</th>
<th>Implemented</th>
<th>Validated</th>
<th>Assigned</th>
<th>Typical LC</th>
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</thead>
<tbody>
<tr>
<td>RRLy</td>
<td>Andy Becker (acbecker at gmail.com)</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>![Typical LC image]</td>
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<tr>
<td>exotic SNe</td>
<td>Przemek Wozniak</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Typical LC image]</td>
</tr>
<tr>
<td>AM CVn</td>
<td>Josh Bloom</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Amcvn.png]</td>
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<tr>
<td>Mira stars</td>
<td>Stephen Ridgeway</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Mira.png]</td>
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<td>Kilanova</td>
<td>Daniel Holz</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Kilanova.png]</td>
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<td>AGN</td>
<td>Simon Krughoff</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
<td>![Image:Agn var.png]</td>
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<td>M flares</td>
<td>Eric Hilton</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Mflares.png]</td>
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<td>Cepheids</td>
<td>Joseph Richards</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Cepheid.png]</td>
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<tr>
<td>Classical Novae</td>
<td>Knox Long</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Novae.png]</td>
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<td>Micro Lensing</td>
<td>Rosanne DiStefano</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>No</td>
<td>![Image:Microlens.png]</td>
</tr>
</tbody>
</table>
“Follow up” means different things to different people

What is the latency of the required follow up?

60 sec makes rapid followup possible, but when is it necessary?

What is the intent?

Discrimination, detailed characterization?

What is the scope?

# of objects, magnitude range, sky coverage, cadence
Spectroscopic resources are limited

Figure adapted from Adam Myers
Co-observing:
Contemporaneous observations of common fields

Multiple wavebands provide SED constraints
  e.g. radio (SKA), GW (LIGO), X-ray (LOFT, eROSITA), IR (Euclid)

Multiple potential contexts:
  Main survey, ToO, Deep Drilling Fields

**Logistical issues require forethought**

Programmatic: Target Updates
Data access/information sharing
Large scale collaboration/communication
Enabling unique science opportunities: joining the EM/GW Skies

LSST well-matched to localization of aLIGO events (e.g. talk by S. Nissanke)
Probing faint transients & variables

~0.01 mag precision photometry
Bright-end synergy with variables/transients from other efforts

Gaia variability at Launch+65m is close to LSST commissioning

Well-characterized sources provide a starting point for understanding LSST

How can we fold in available ancillary information? Perhaps provide some crossmatching with alerts?
Importance of context, characterization & classification

Prioritization is crucial!

Huge number of alerts for limited follow up resources

- Bright events - 4m class
- Faint 22-24 events - 10-30m

Must rely on rapid filtering of events, including using ancillary data
Characterization, classification act on multiple timescales

Roles of the classifier

Nightly products:
real-time classification, cross reference with contextual data

Aggregate products:
Classifier that acts on larger dataset

Filter actionable items from 30 Tb of data
Level 3 = YOU

Alert packets provide basic characterization, with goal of enabling alert triage - classification is not provided

Need to both improve on current classification, and to extend existing efforts to fainter regime

There is interest, but relatively little coordinated effort to create these tools (so far)
"It would be criminally negligent if our community squandered [this] opportunity."

- Rob Kennicutt
Rich opportunities, but significant challenges...

...now is the time to start strategizing!
Thanks!