Transients: Gotta catch ‘em all

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Sky Maps of a few (optical) surveys

- CRTS
- PTF
- Gaia
- LSST
Survey properties

• Coverage area (all sky, observable sky, deep fields)
• Number of times (Gaia, LSST, CRTS)
• Spacing of observations (CRTS)
• Filters (white-light, multi-band)
• Depth (overlap, possible follow-up) - also co-added
• Etandue
What is a transient?

One that has a **large brightness change** (delta-magnitude) within a short timespan (small delta-time)
Only a small fraction are rare - find/characterize them early

CRTS 10+ year status

<table>
<thead>
<tr>
<th>Telescope</th>
<th>All OTs</th>
<th>Supernovae</th>
<th>Cataclysmic Variables</th>
<th>Blazars</th>
<th>Asteroids/Flares</th>
<th>CV or SN</th>
<th>AGN</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>CSS</td>
<td>5353</td>
<td>1669</td>
<td>964</td>
<td>265</td>
<td>366</td>
<td>562</td>
<td>640</td>
<td>977</td>
</tr>
<tr>
<td>MLS</td>
<td>5879</td>
<td>886</td>
<td>119</td>
<td>109</td>
<td>299</td>
<td>890</td>
<td>2787</td>
<td>1004</td>
</tr>
<tr>
<td>SSS</td>
<td>700</td>
<td>105</td>
<td>256</td>
<td>18</td>
<td>13</td>
<td>109</td>
<td>33</td>
<td>171</td>
</tr>
<tr>
<td>SNhunt</td>
<td>197</td>
<td>197</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Total</td>
<td>12129</td>
<td>2857</td>
<td>1339</td>
<td>392</td>
<td>678</td>
<td>1561</td>
<td>3460</td>
<td>2152</td>
</tr>
</tbody>
</table>

Current Status: Few tens of transients per night
Future (LSST): $10^6 - 10^7$ per night; $10^4$ per minute
That is why we need automatic classification algorithms
AGN Variability - different perspectives
Depending on cadence different time-scales are available

CRTS
4000 days

Kepler
100 days
## 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>

Slide from Lucianne Walkowicz
We only knew about three classes (denoted by gray bands). In the past six years, systematic searches, or pair instability explosions?), Ia explosions (helium detonations in ultra-compact white dwarf binaries), or Ca pollution events. Therefore, prior to the ambitious search for an electromagnetic counterpart to a gravitational wave signal, it would only be prudent to build this complete inventory of transients in the local Universe. In the past six years, systematic searches, or pair instability explosions?), Ia explosions (helium detonations in ultra-compact white dwarf binaries), or Ca pollution events.

The framework for cosmic explosions in the year 2011 (Kasliwal 2011). Note that until 2005 (Fig. 1), we only knew about three classes (denoted by gray bands). In the past six years, systematic searches, or pair instability explosions?), Ia explosions (helium detonations in ultra-compact white dwarf binaries), or Ca pollution events. Therefore, prior to the ambitious search for an electromagnetic counterpart to a gravitational wave signal, it would only be prudent to build this complete inventory of transients in the local Universe. In the past six years, systematic searches, or pair instability explosions?), Ia explosions (helium detonations in ultra-compact white dwarf binaries), or Ca pollution events.
Despite the heterogeneity, gaps, heteroscedasticity
Characterize/Classify as much with as little data as possible

Credit: L. Eyer & N. Mowlavi (03/2009) (updated 04/2013)
<table>
<thead>
<tr>
<th>Rarity</th>
<th>Pokémon Images</th>
</tr>
</thead>
<tbody>
<tr>
<td>Everywhere:</td>
<td></td>
</tr>
<tr>
<td>Virtually Everywhere:</td>
<td></td>
</tr>
<tr>
<td>Very Common:</td>
<td></td>
</tr>
<tr>
<td>Common:</td>
<td></td>
</tr>
<tr>
<td>Uncommon:</td>
<td></td>
</tr>
<tr>
<td>Ununcommon:</td>
<td></td>
</tr>
<tr>
<td>Rare:</td>
<td></td>
</tr>
<tr>
<td>Very Rare:</td>
<td></td>
</tr>
<tr>
<td>Special:</td>
<td></td>
</tr>
<tr>
<td>Epic:</td>
<td></td>
</tr>
<tr>
<td>Myths:</td>
<td></td>
</tr>
<tr>
<td>Still Not Convinced: It Exists</td>
<td></td>
</tr>
</tbody>
</table>

Transients can be typed by rarity. Flaring M-dwarfs are everywhere. These form our priors.

TDEs are rare. EM counterparts to NS-NS/BH. EM C to BH-BH.

organizedmesses.com
Classification by type also possible

Various Galactic types (nearer plane of the Galaxy), Supernovae (near other galaxies), Blazars etc. (extra-Galactic)

These form part of our ancillary information
Trouble is, this is what we see

CSS090429:135125-075714
Flare star

CSS090429:101546+033311
Dwarf Nova

CSS090426:074240+544425
Blazar, 2EG J0744+5438

Different phenomena look the same!
Example CRTS Transients

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Flare star

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Dwarf Nova

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Different phenomena look the same!
# 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>$10^{-7} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>20000</td>
</tr>
<tr>
<td>Orphan Afterglows SHB</td>
<td>-14...-18</td>
<td>5 - 15</td>
<td>$3 \times 10^{-7...-9} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>~10 - 100</td>
</tr>
<tr>
<td>Orphan Afterglows LSB</td>
<td>-22...-26</td>
<td>2 - 15</td>
<td>$3 \times 10^{-10...-11} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>1000</td>
</tr>
<tr>
<td>On-axis GRB afterglows</td>
<td>...-37</td>
<td>1 - 15</td>
<td>$10^{-11} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>~50</td>
</tr>
<tr>
<td>Tidal Disruption Flares</td>
<td>-15...-19</td>
<td>30 - 350</td>
<td>$10^{-6} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>6000</td>
</tr>
<tr>
<td>Luminous Red Novae</td>
<td>-9...-13</td>
<td>20 - 60</td>
<td>$10^{-13} \text{ yr}^{-1} \text{ Lsun}^{-1}$</td>
<td>80 - 3400</td>
</tr>
<tr>
<td>Fallback SNe</td>
<td>-4...-21</td>
<td>0.5 - 2</td>
<td>$&lt;5 \times 10^{-6} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>&lt; 800</td>
</tr>
<tr>
<td>SNe Ia</td>
<td>-17...-19.5</td>
<td>30 - 70</td>
<td>$3 \times 10^{-5} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>200000</td>
</tr>
<tr>
<td>SNe II</td>
<td>-15...-20</td>
<td>20 - 300</td>
<td>$(3.8) \times 10^{-5} \text{ Mpc}^{-3} \text{ yr}^{-1}$</td>
<td>100000</td>
</tr>
</tbody>
</table>

Table adapted from Rau et al. 2009 by Lucianne Walkowicz
The tapering down in LSST

- Recomputation of features
- Updating priors

- Ridgeway et al., arXiv: 1409.3265
Individual objects to ensembles

500 Million Light Curves with $\sim 10^{11}$ data points

RR Lyrae

W Uma

Eclipsing

Flare star (UV Ceti)

CV

Blazar

CRTS PIs Djorgovski, Drake
Life-cycle of an event

- Solar System
- LSST History
- Other catalogs
- Ancillary data

0.1 rare alerts/image

NOAO’s proposed broker Antares

Saha et al 1409.0056
Using Discriminating Features for Brokering

You can not step into the same river twice.
Binary Broker(s)

- Using features to tell classes apart - one class at a time
- Speed required
- Rarity determination crucial

Objects LC → Broker → \( X \) → \( !X \)
Binary Broker(s)

- Using features to tell classes apart - one class at a time
- Speed required
- Rarity determination crucial
A variety of parameters - choose judiciously

Discovery; Contextual; Follow-up; Prior Classification …

**Whole curve measures**
- Median magnitude (mag); mean of absolute differences of successive observed magnitude; the maximum difference magnitudes

**Fitted curve measures**
- Scaled total variation scaled by number of days of observation; range of fitted curve; maximum derivative in the fitted curve

**Residual from fit measures**
- The maximum studentized residual; SD of residuals; skewness of residuals; Shapiro-Wilk statistic of residuals

**Cluster measures**
- Fit the means within the groups (up to 4 measurements); and then take the logged SD of the residuals from this fit; the max absolute residuals from this fit; total variation of curve based on group means scaled by range of observation

Think why/when TMT will allow TOOs
Metaclassification - combining diverse classifiers optimally

As varied classifiers are used for parts of the classification tree combing their outputs in an optimal way becomes crucial

Mahabal, Donalek
Automating the Optimal Follow-Up (scheduling future observations)

What type of follow-up data has the greatest potential to discriminate among the competing models (event classes)?

Request follow-up observations from the optimal available facility

Collaboration with M. Turmon, Thomas Fuchs (JPL)
Follow-up: LCOGT/MSIP

- MSIP award buys public time at LCOGT (1300 1-m hours, 200 2-m hours per semester for 7 semesters)
- Opportunity to build the time-domain system now

Session at next AAS (Jan 2017)

Also one about SAMSI
LSST Cadences

minion.1016 — The New Baseline Cadence.
minion.1012 — Only Universal Cadence, with pairs of visits.
minion.1020 — A Pan-STARRS-like observing strategy.
minion.1013 — Only Universal Cadence, no visit pairs.
kraken.1043 — Baseline Cadence, but with no visit pairs.
enigma.1281 — NEO test: triplets of visits.
enigma.1282 — NEO test: quads of visits.
kraken.1052 — Baseline Cadence, but with 33% shorter exposure time.
kraken.1053 — Baseline Cadence, but 100% longer exposure time.
kraken.1045 — Baseline Cadence, but with doubled u-band exposure time.
kraken.1059 — Baseline Cadence, but with doubled u-band exp. time.
minion.1022 — Only Universal Cadence, with relaxed airmass limit.
minion.1017 — Only Universal Cadence, with stringent airmass limit.
astro_lsst.01.1004 — Extend Universal Cadence to the Galactic Plane.
ops2.1102 — “Swiss Cheese” rolling cadence, version 1.
enigma.1260 — “Swiss Cheese” rolling cadence, version 2.
enigma.1261 — “Swiss Cheese” rolling cadence, version 3.
Metric Analysis Facility

LSST MAF analysis - adapted by ZTF too
LSST TVS activities

SNe and CVs

Cadence determination whitepaper

Transients Chapter
Bellm, Bianco
SMOTE and Sampling with replacement used to take care of unbalancedness.
Feature Correlations
Semi-supervised learning

- Features for known set of classes - clusters
- For unknown objects find best matching clusters
- Effect of non-uniformity
- Sparse datasets and streaming

Comparison with archives
Comparison with Antares Touchstones
A lot more using archives

• Next talk by Matthew Graham
Data Challenge

- Past: supernovae only (real + duplicates)
  - Kessler et al. arXiv:1008.1024
  - First six data points
- Proposed: as many types as possible
  - Lightcurves
    - Real preferred if enough uniformity
  - Ancillary information
- Inputs/data/ideas welcome
Summary of challenges

- Characterize/Classify as much with as little data as possible
- Only a small fraction are rare - find/characterize them early
- A variety of parameters - choose judiciously
- Real-time computation is required - find ways to make that happen
- Metaclassification - combining diverse classifiers optimally
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These challenges involve:
• Making sense of unparalleled volumes of structured and unstructured data in real-time, and
• Teaching machines how humans think by understanding pattern recognition when handling diverse types of data sources
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Better tools to make sense of very sparse data and Streamlined workflows