The Palomar Transient Factory (PTF) Survey & Discovery of Small Mission-Accessible NEAs

Adam Waszczak
Graduate Student
Division of Geological & Planetary Sciences
California Institute of Technology
The Palomar Transient Factory (PTF)

48-inch (1.2-m) “Oschin” robotic wide-field imaging [r-band]

- exposure time: 60s
- field-of-view: 7.3 deg² / 11 CCDs
- limiting mag: $r \approx 20.5$
- resolution: 1.0 arcsec/pixel
- typical seeing: 2.0 arcsec FWHM
The Palomar Transient Factory (PTF)

48-inch (1.2-m) “Oschin”
robotic wide-field imaging
[r-band]

- exposure time: 60s
- field-of-view: 7.3 deg² / 11 CCDs
- limiting mag: \( r \approx 20.5 \)
- resolution: 1.0 arcsec/pixel
- typical seeing: 2.0 arcsec FWHM
The Palomar Transient Factory (PTF)

48-inch (1.2-m) “Oschin” robotic wide-field imaging [r-band]

60-inch (1.5-m) robotic imaging follow-up [ugriz-bands & SED machine]
The Palomar Transient Factory (PTF)

60-inch (1.5-m) robotic imaging follow-up
[ugriz-bands & SED machine]

200-inch (5.2-m) “Hale” spectroscopic follow-up [DBSP]

48-inch (1.2-m) “Oschin” robotic wide-field imaging
[r-band]
PTF is a world leader in the discovery and spectroscopic follow-up of extragalactic transients (e.g., supernovae).
PTF detections of asteroids in general

In past year, PTF submitted over 500,000 observations to the Minor Planet Center.

PTF is credited with more than 4,000 asteroid discoveries, including 8 NEAs (in < 1km range).

Above: PTF discovery images of a ~200m-sized NEA (2013 HN11)
(Angular Rate) \times (Exposure Time) = \text{Asteroid Streak Length}

Main-belt asteroids, Trojans & most large NEAs

Small, very close NEAs
A Novel Approach: Synthetic Tracking

Conventional Streaked Exposure

Synthetic Tracking (~700 coadded images)

Asteroid

Background Star

A typical main-belt asteroid (2013 BS45) and false positive detections are shown in the context of a detection probability framework.

- Original image
- Subtracted image
- Object pixel map
- $N$ data points $\{x_N\}$ in 3 dimensions

$M$ computed features $\{f_M\} = f(x_N)$

Output probability of real vs. bogus detection $P = P(f_M)$
Initial PTF discoveries of new streaking NEAs

March 2013 discovery

August 2013 discovery

March 2013 discovery
Small Near-Earth Asteroids in PTF: Simulation Results

These plots show the predicted observational circumstances of known small (< 10-meter) NEOs potentially viewable from Palomar.
Streak-detection “Figure of Merit” for surveys

\[ F_{oM} \equiv \Omega \ 10^{0.8(m_{lim}-20.0)} \left( \frac{\theta_{PSF}}{\tau \times \tau_{tot}} \right) \]

Table 1: Comparison of Streak FoM for Telescopes

<table>
<thead>
<tr>
<th>Telescope</th>
<th>(\Omega)</th>
<th>(m_{lim})</th>
<th>(\theta_{PSF})</th>
<th>(\tau)</th>
<th>(\tau_{tot})</th>
<th>FoM</th>
</tr>
</thead>
<tbody>
<tr>
<td>ZTF (optimized)</td>
<td>47</td>
<td>19.8</td>
<td>2</td>
<td>0.2</td>
<td>0.45</td>
<td>857</td>
</tr>
<tr>
<td>ZTF (nominal)</td>
<td>47</td>
<td>20.4</td>
<td>2</td>
<td>0.5</td>
<td>0.75</td>
<td>523</td>
</tr>
<tr>
<td>PS1 or 2</td>
<td>7</td>
<td>21.8</td>
<td>1.1</td>
<td>0.5</td>
<td>1</td>
<td>424</td>
</tr>
<tr>
<td>Atlas</td>
<td>60</td>
<td>19.7</td>
<td>2.6</td>
<td>0.5</td>
<td>0.6</td>
<td>295</td>
</tr>
<tr>
<td>BlackGEM</td>
<td>22.0</td>
<td>20.7</td>
<td>1.0</td>
<td>1.0</td>
<td>1.2</td>
<td>57</td>
</tr>
<tr>
<td>PTF</td>
<td>7.25</td>
<td>20.8</td>
<td>2</td>
<td>1</td>
<td>1.5</td>
<td>42</td>
</tr>
<tr>
<td>CRTS-II</td>
<td>19.0</td>
<td>19.5</td>
<td>2.5</td>
<td>0.5</td>
<td>0.75</td>
<td>31</td>
</tr>
</tbody>
</table>
2016: The Zwicky Transient Facility (ZTF)

ZTF will survey 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 deg²</td>
<td>47 deg²</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 deg²/hour
⇒ 3π survey in 8 hours,
> 250 observations/field/year

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

Existing PTF camera
MOSAIC 12k