

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



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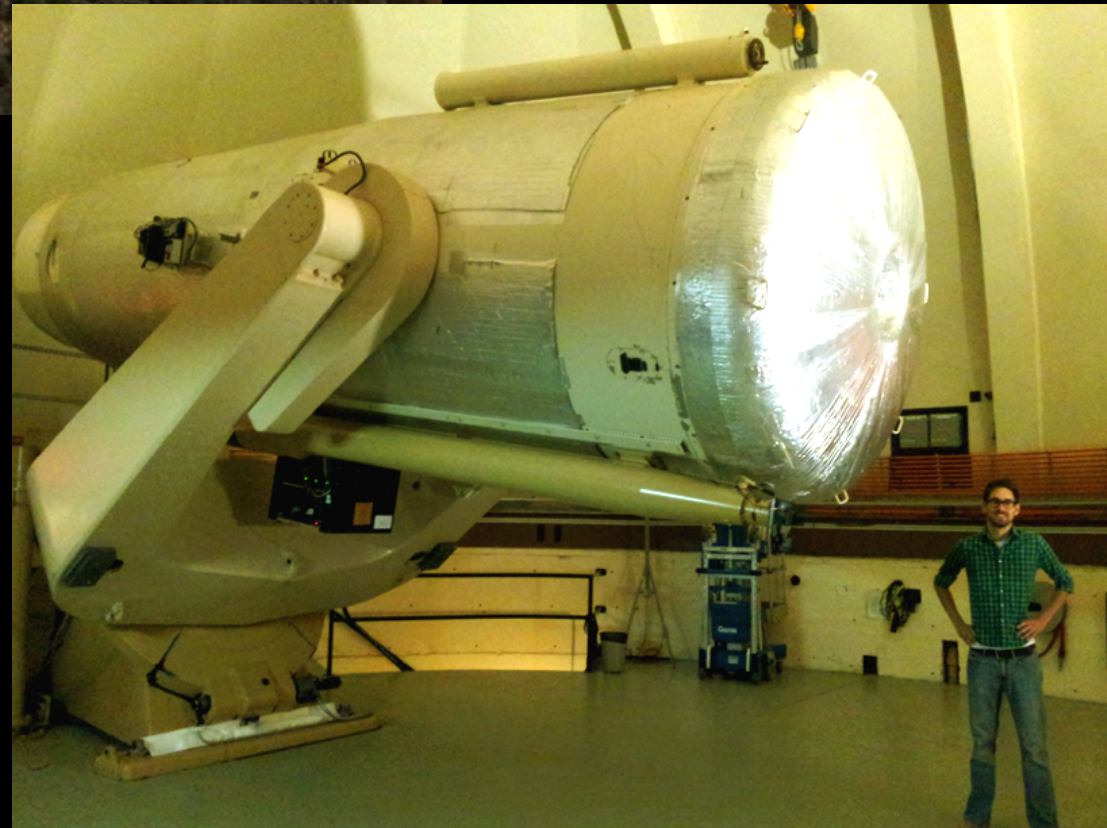
California Institute of Technology

# The Palomar Transient Factory (PTF)



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

- exposure time: 60s
- field-of-view:  $7.3 \text{ deg}^2$  / 11 CCDs
- limiting mag:  $r \approx 20.5$
- resolution: 1.0 arcsec/pixel
- typical seeing: 2.0 arcsec FWHM



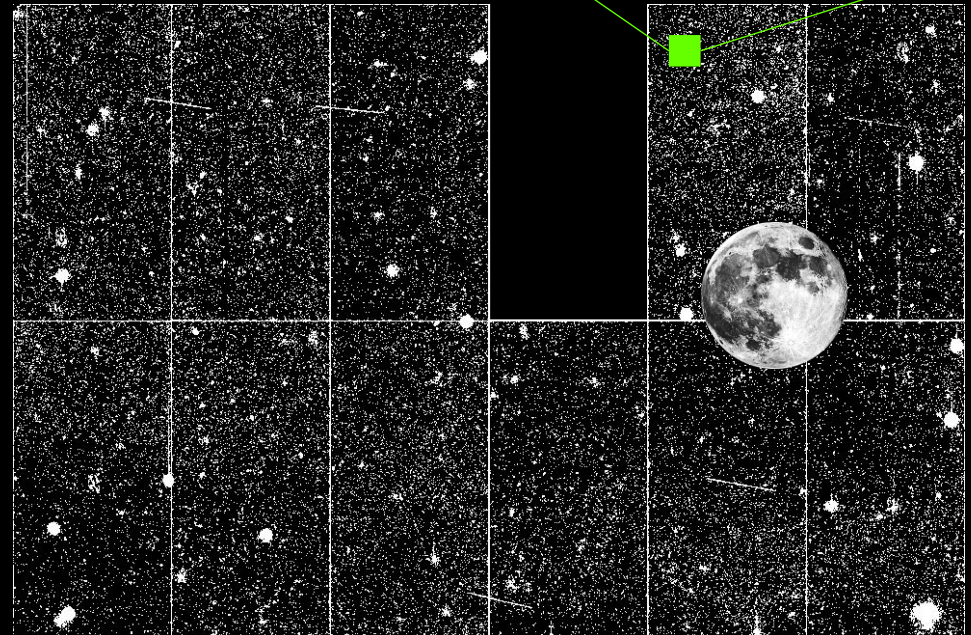
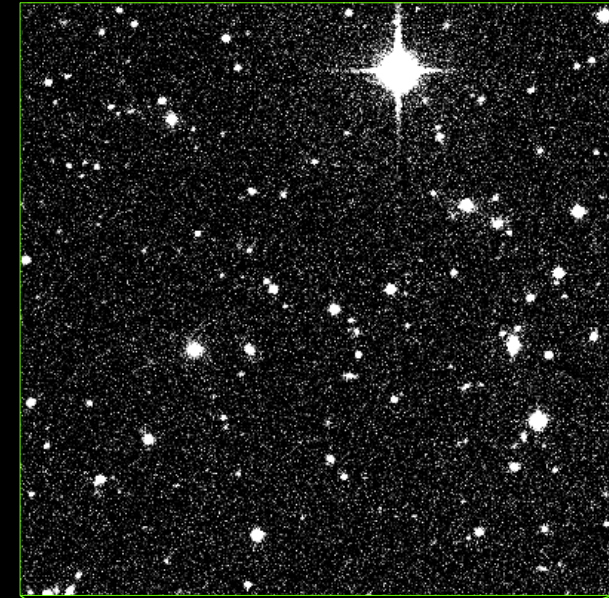


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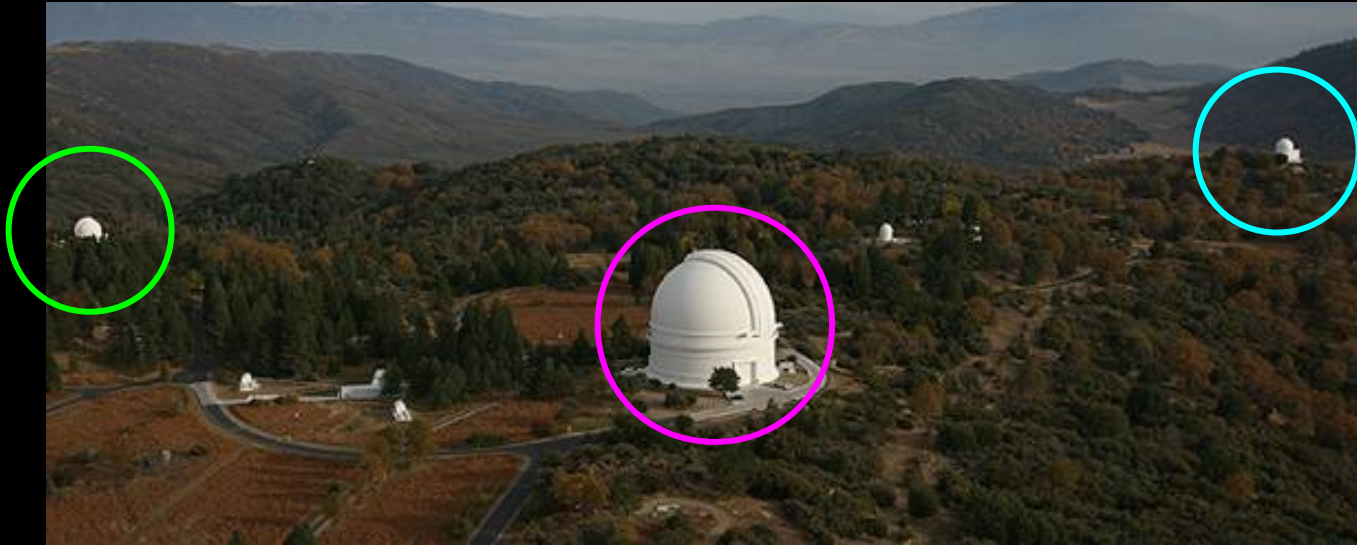


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60-inch (1.5-m)  
robotic imaging  
follow-up  
[*ugriz*-bands &  
SED machine]



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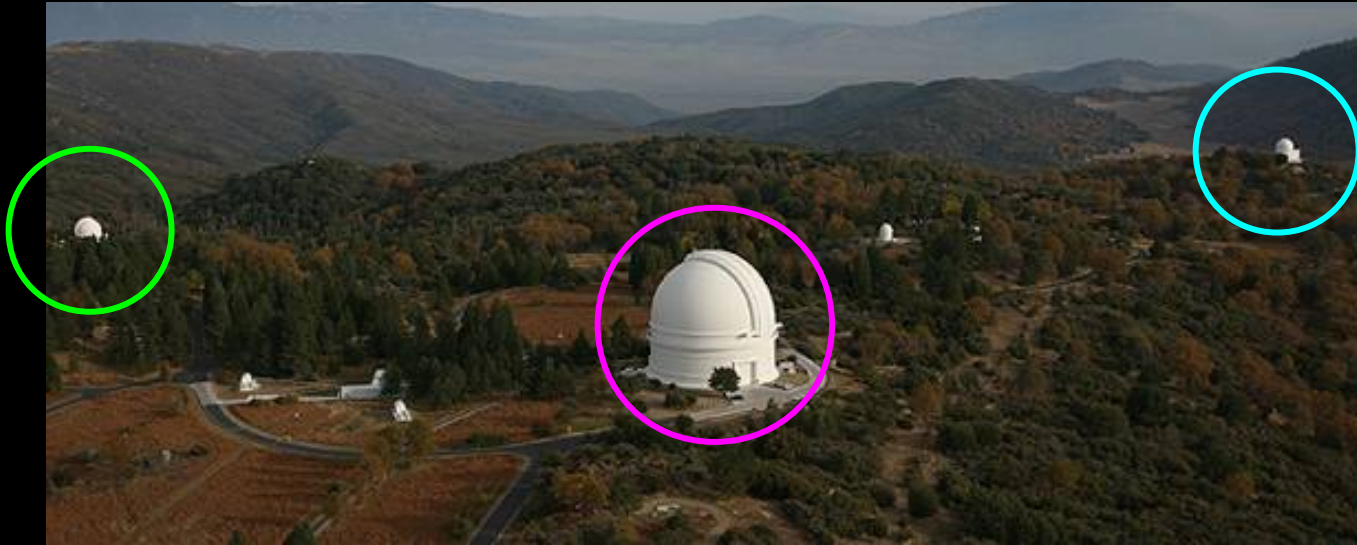


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200-inch (5.2-m) “Hale”  
spectroscopic follow-up [DBSP]

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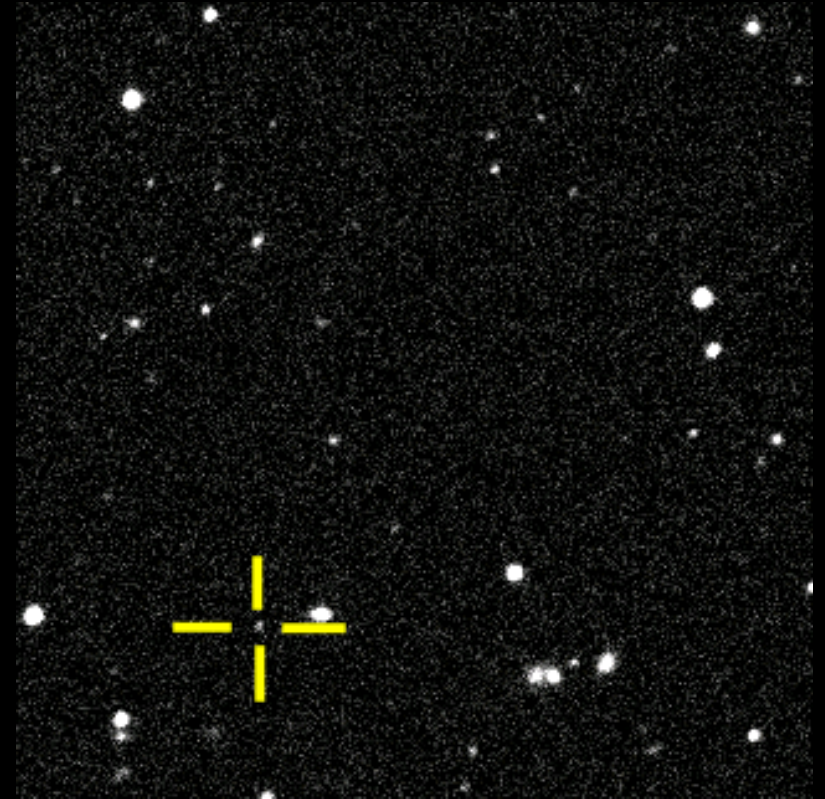
PTF is a world leader in the discovery and spectroscopic follow-up of extragalactic transients (e.g., supernovae).



# PTF detections of asteroids in general

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

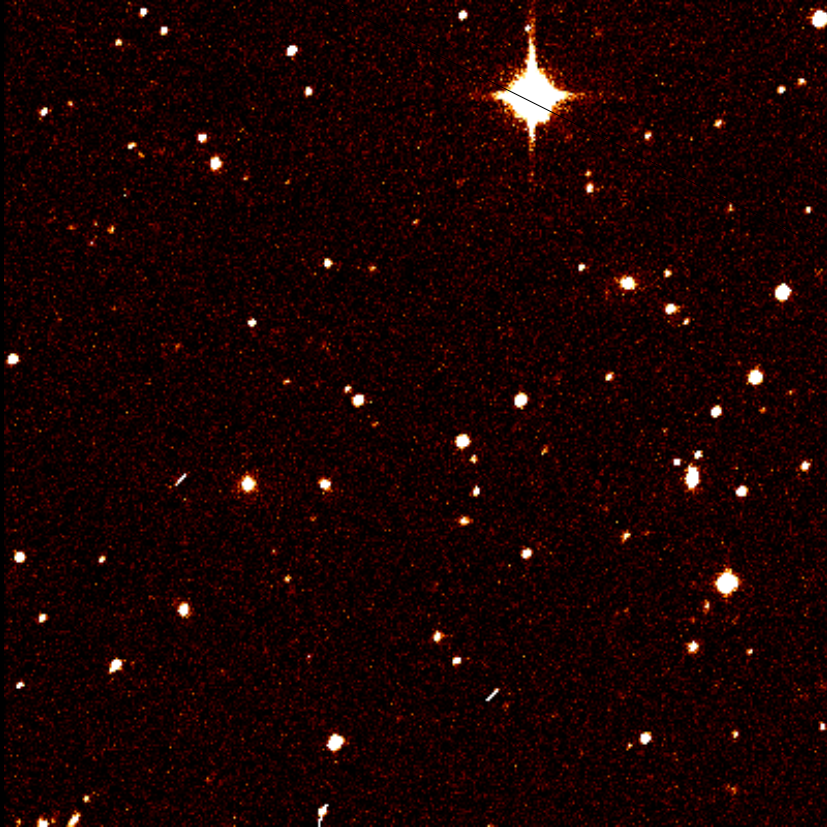
PTF is credited with more than **4,000 asteroid discoveries**, including 8 NEAs (in  $< 1\text{km}$  range).



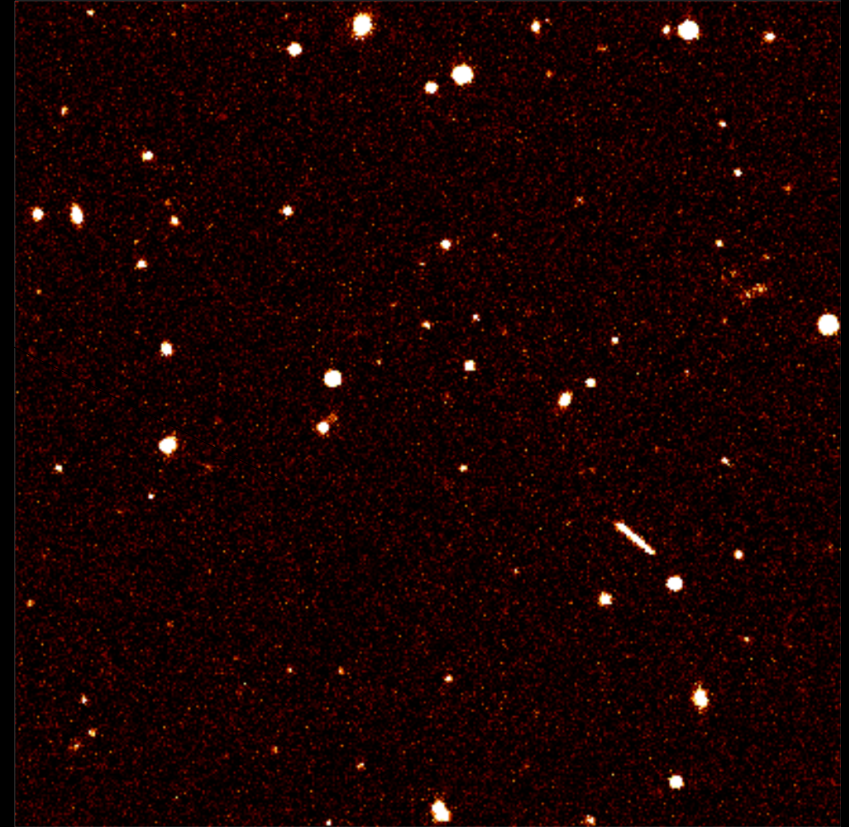
*Above: PTF discovery images of a ~200m-sized NEA (2013 HN11)*



$$\frac{(\text{Angular Rate}) \times (\text{Exposure Time})}{\text{Image Pixel Size}} = \text{Asteroid Streak Length}$$



Main-belt asteroids, Trojans  
& most large NEAs

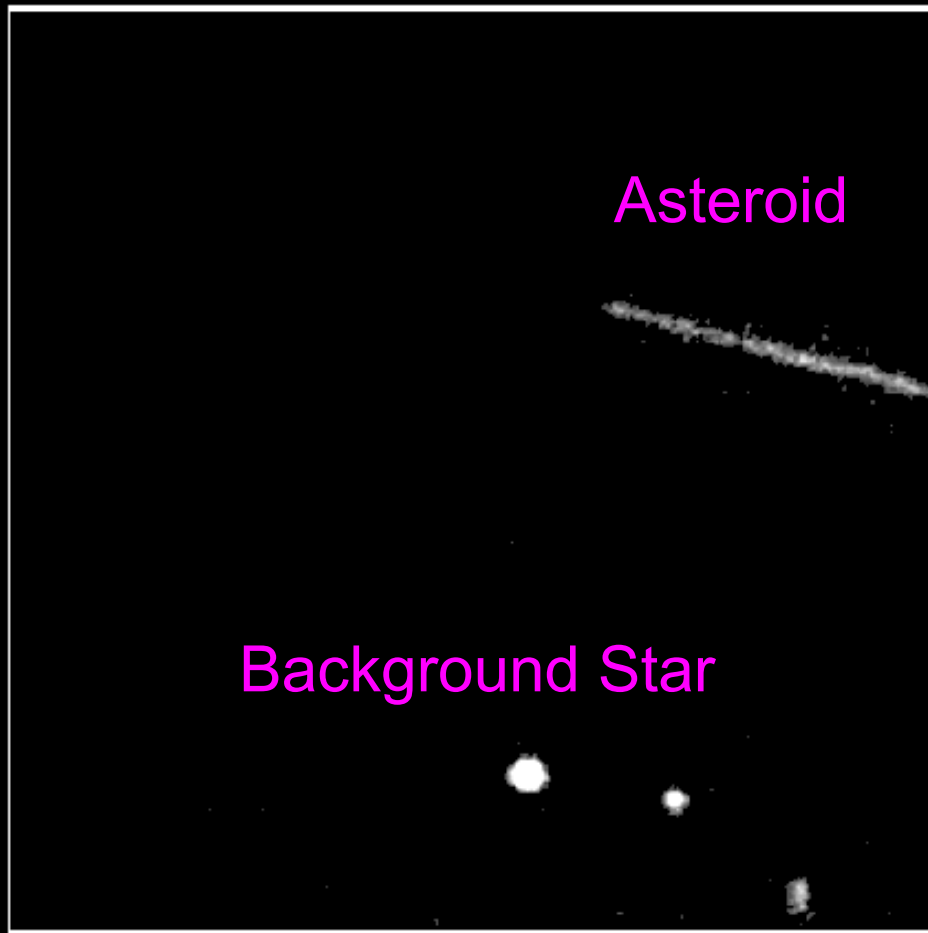


Small, very close NEAs

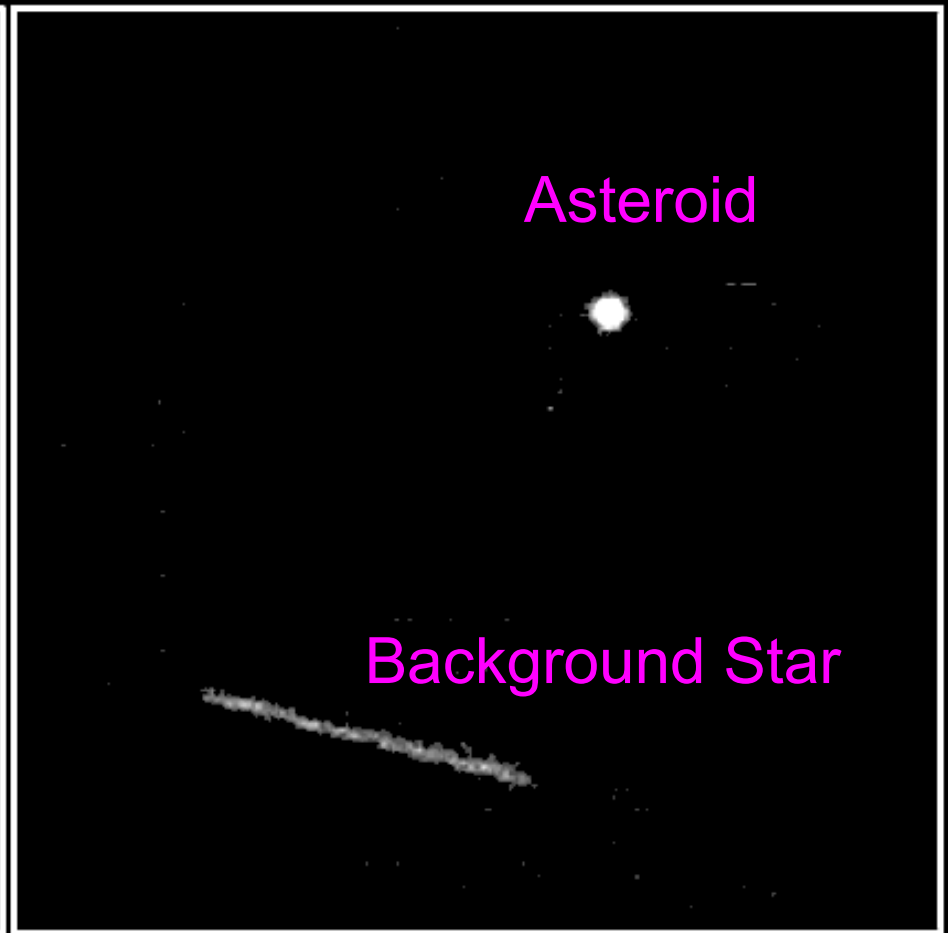


# A Novel Approach: Synthetic Tracking

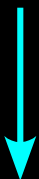
Conventional Streaked  
Exposure



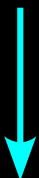
Synthetic Tracking  
(~700 coadded images)



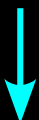
original image



subtracted image



object pixel map



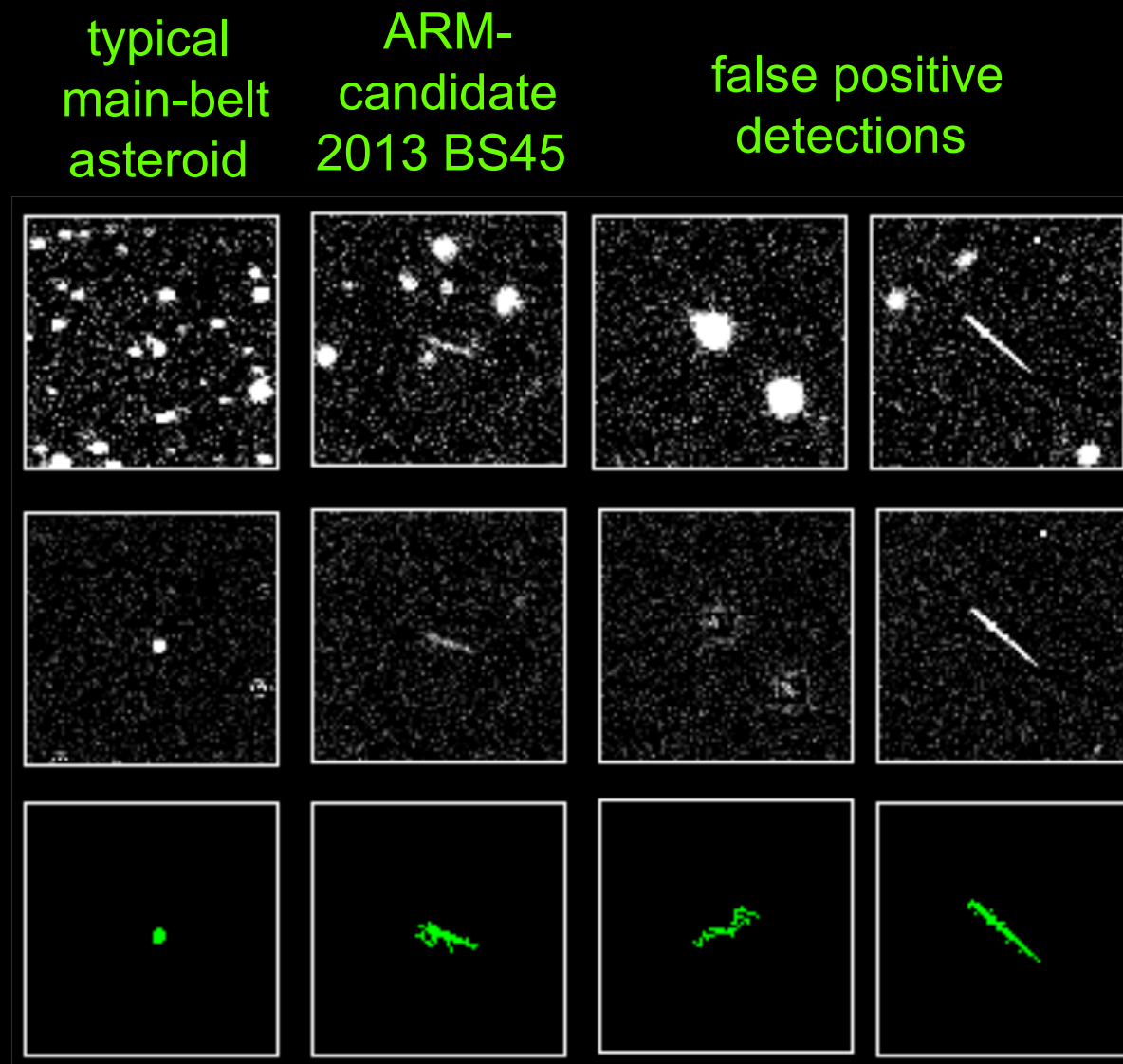
$N$  data points  $\{x_N\}$   
in 3 dimensions



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

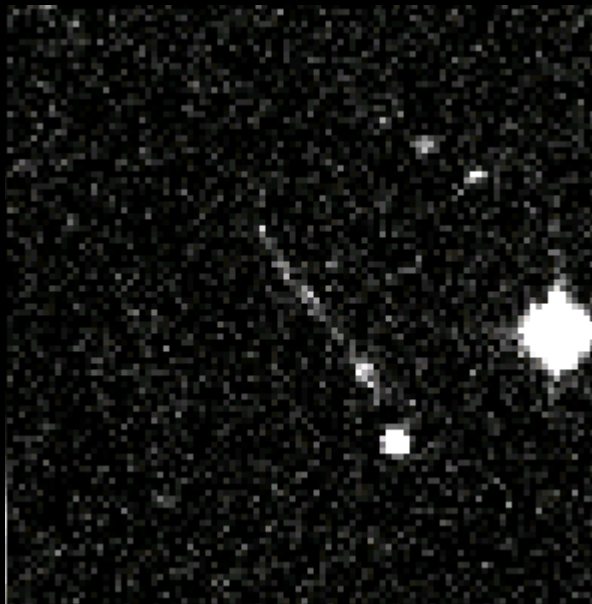


Output probability of  
real vs. bogus detection  
 $P = P(f_M)$





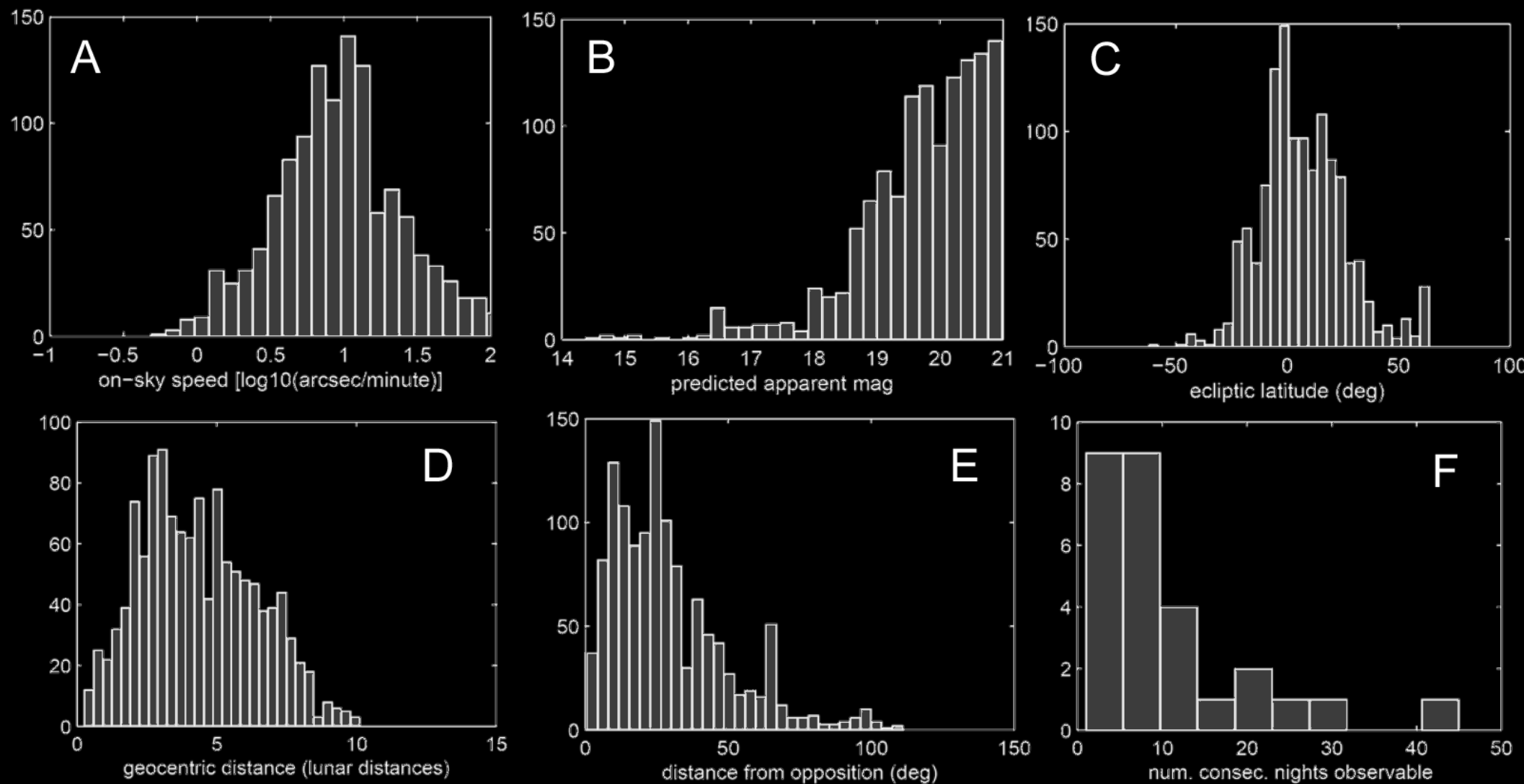
# Initial PTF discoveries of new streaking NEAs



March 2013  
discovery

August 2013  
discovery

# 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

$$FoM \equiv \Omega \, 10^{0.8(m_{lim} - 20.0)} \left( \frac{\theta_{PSF}}{\tau \times \tau_{tot}} \right)$$

Table 1: Comparison of Streak FoM for Telescopes

| Telescope       | $\Omega$<br>(deg <sup>2</sup> ) | $m_{lim}$ | $\theta_{PSF}$<br>(arcsec) | $\tau$<br>(min) | $\tau_{tot}$<br>(min) | FoM |
|-----------------|---------------------------------|-----------|----------------------------|-----------------|-----------------------|-----|
| ZTF (optimized) | 47                              | 19.8      | 2                          | 0.2             | 0.45                  | 857 |
| ZTF (nominal)   | 47                              | 20.4      | 2                          | 0.5             | 0.75                  | 523 |
| PS1 or 2        | 7                               | 21.8      | 1.1                        | 0.5             | 1.                    | 424 |
| Atlas           | 60                              | 19.7      | 2.6                        | 0.5             | 0.6                   | 295 |
| BlackGEM        | 22.0                            | 20.7      | 1.0                        | 1.0             | 1.2                   | 57  |
| PTF             | 7.25                            | 20.8      | 2                          | 1               | 1.5                   | 42  |
| CRTS-II         | 19.                             | 19.5      | 2.5                        | 0.5             | 0.75                  | 31  |

# 2016: The Zwicky Transient Facility (ZTF)

ZTF will survey an order of magnitude faster than PTF.

|                                 | PTF                   | ZTF                 |
|---------------------------------|-----------------------|---------------------|
| Active Area                     | 7.26 deg <sup>2</sup> | 47 deg <sup>2</sup> |
| Readout Time                    | 36 sec                | 10 sec              |
| Exposure Time                   | 60 sec                | 30 sec              |
| Relative Areal Survey Rate      | 1x                    | <b>14.7x</b>        |
| Relative Volumetric Survey Rate | 1x                    | <b>12.3x</b>        |

3800 deg<sup>2</sup>/hour

⇒ 3π survey in 8 hours,  
> 250 observations/field/year

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

Existing PTF camera  
MOSAIC 12k

