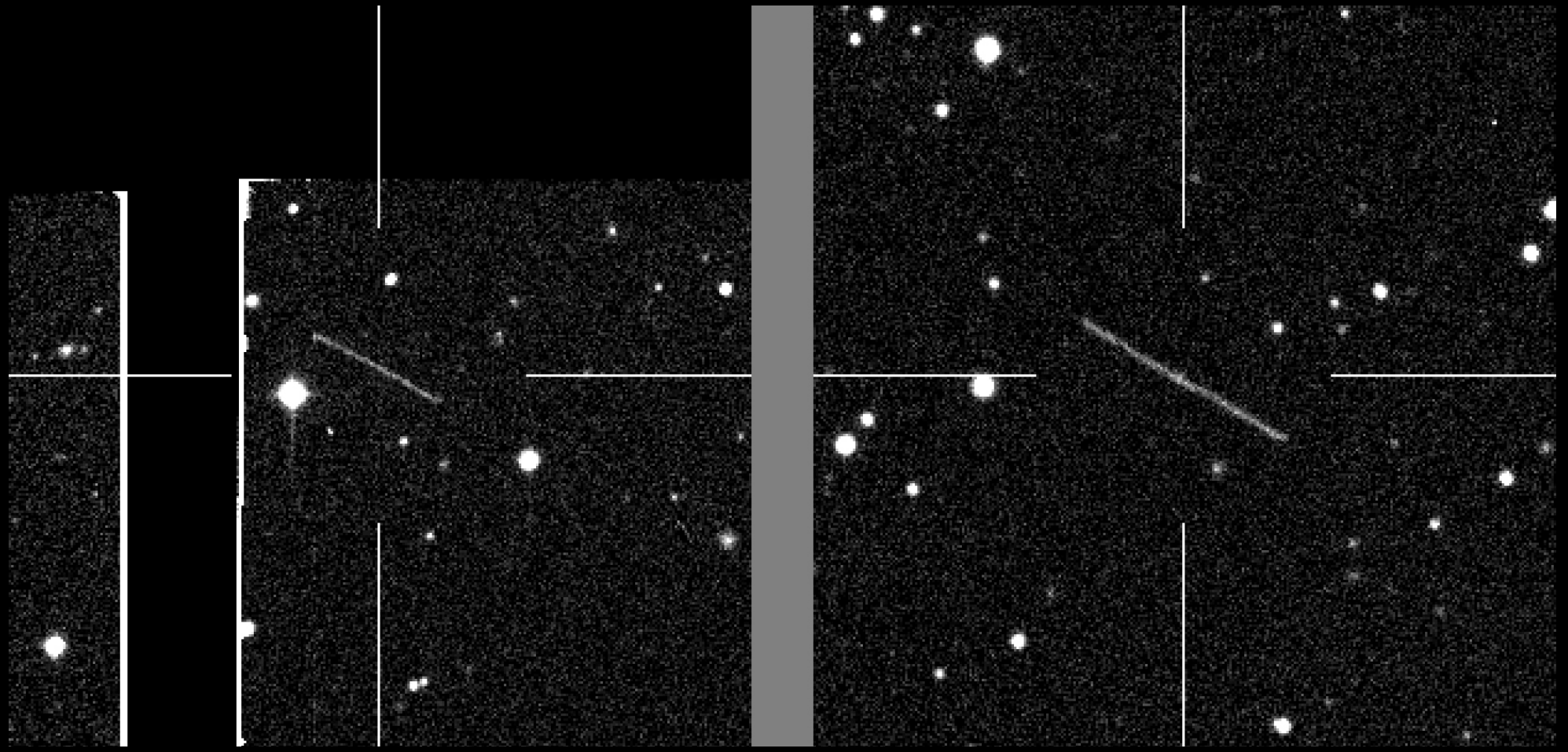
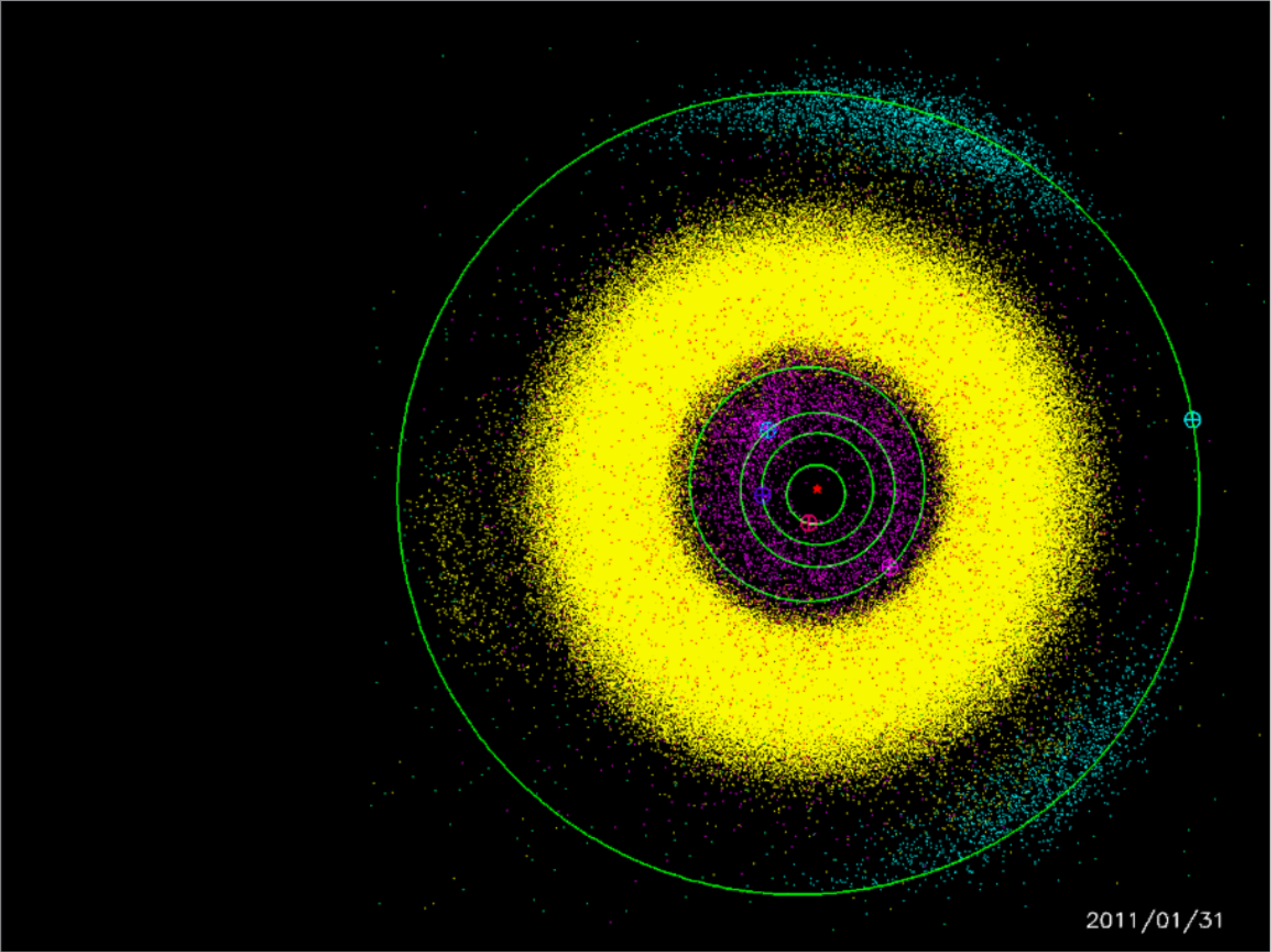
Near-Earth Asteroids in PTF



Adam Waszczak, Tom Prince, Russ Laher, Jason Surace,
George Helou, Frank Masci, Brian Bue, Umaa Rebbapragada
+ the streak scanning team


2011/01/31

Main-Belt Asteroids

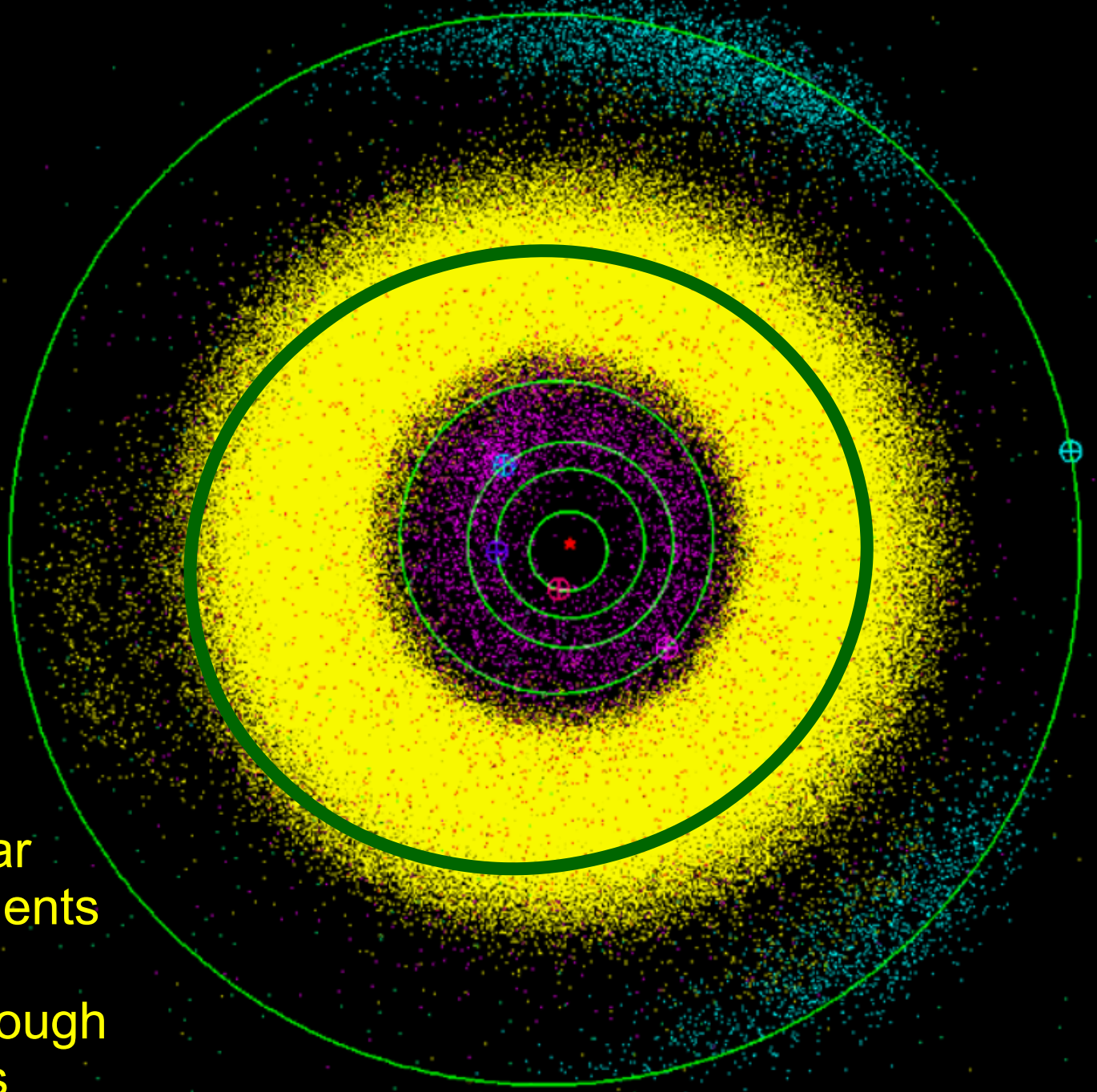
≈99.99% of all the moving objects detectable by PTF

Number per sq. deg ≈25–(deg. from opp.)

≈10^6 rocks bigger than ~few km (>90% known)

In 60-sec exposure, slow enough to appear as point-source transients

Over ~1 hour, fast enough to move tens of pixels



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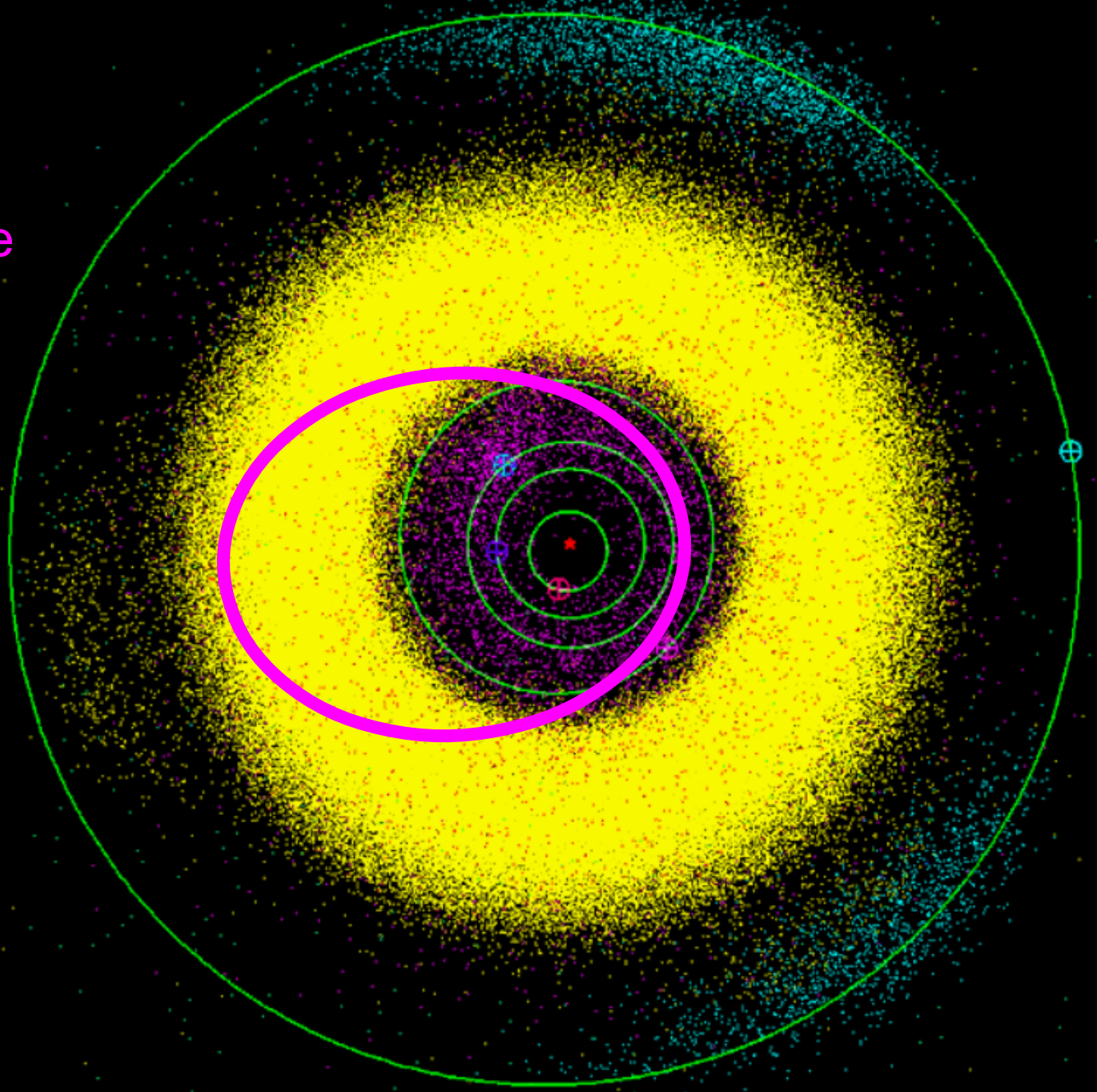
Near-Earth Asteroids

Unstable orbits
⇒ NEAs are very rare

Size matters:

if > ~500m, then
easily detected
far from Sun



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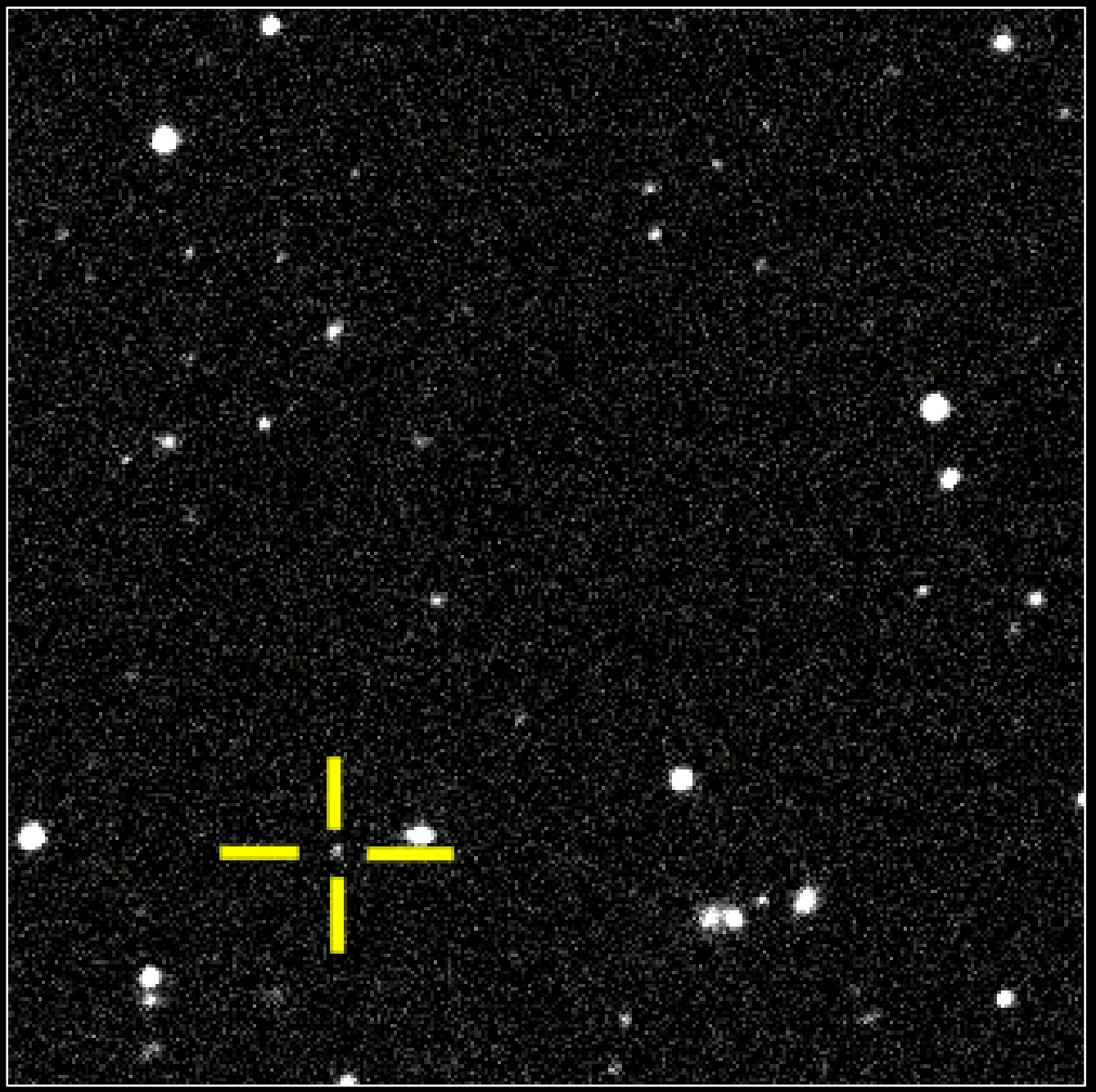

"slow"-moving NEA discovered by PTF

Near-Earth Asteroids

Unstable orbits
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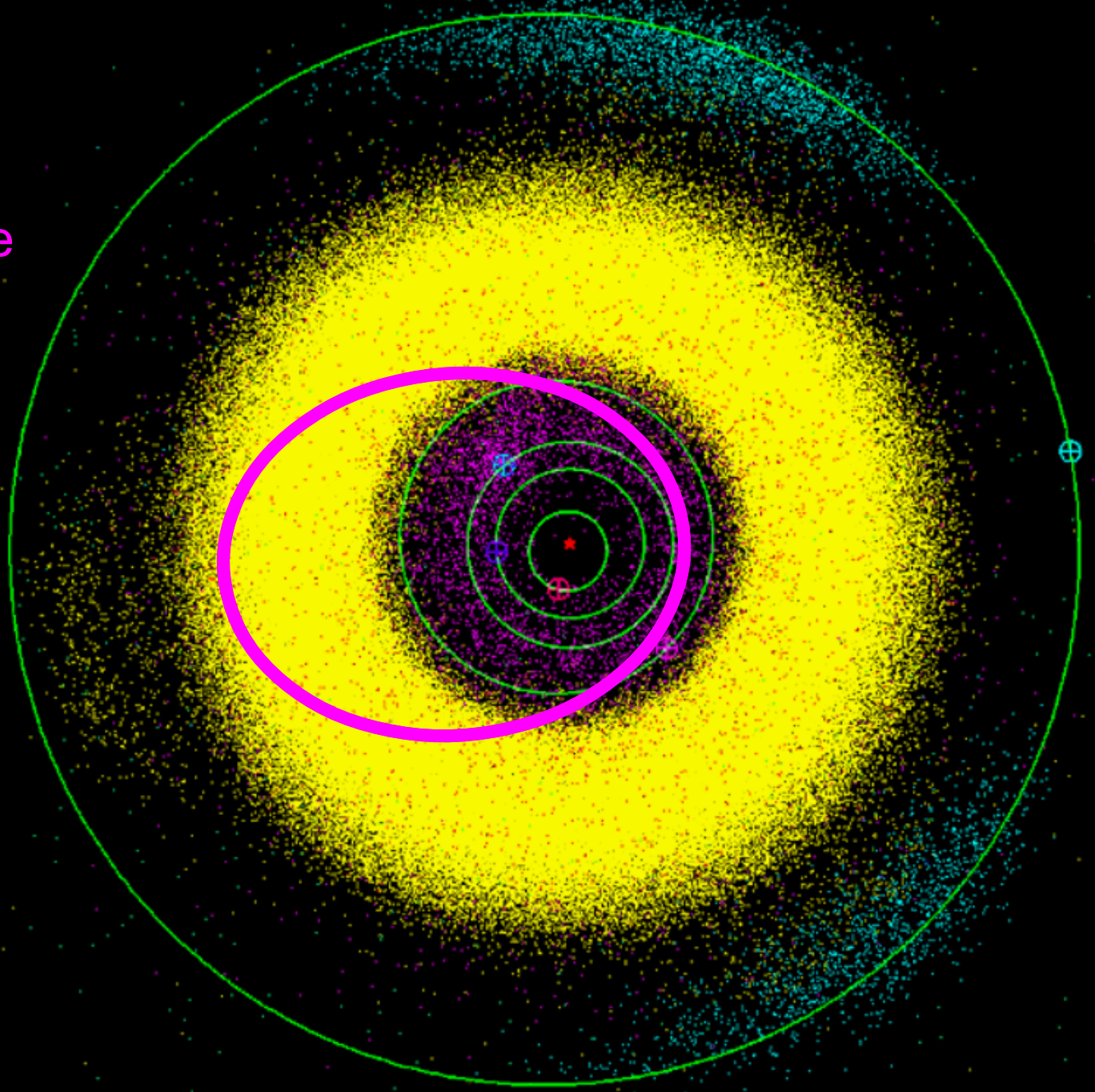
Size matters:

if < ~150m, then
(a) need big aperture
OR
(b) detect them when very close to Earth

Potentially large Δv with respect to Earth & large parallax
⇒ “streakers”



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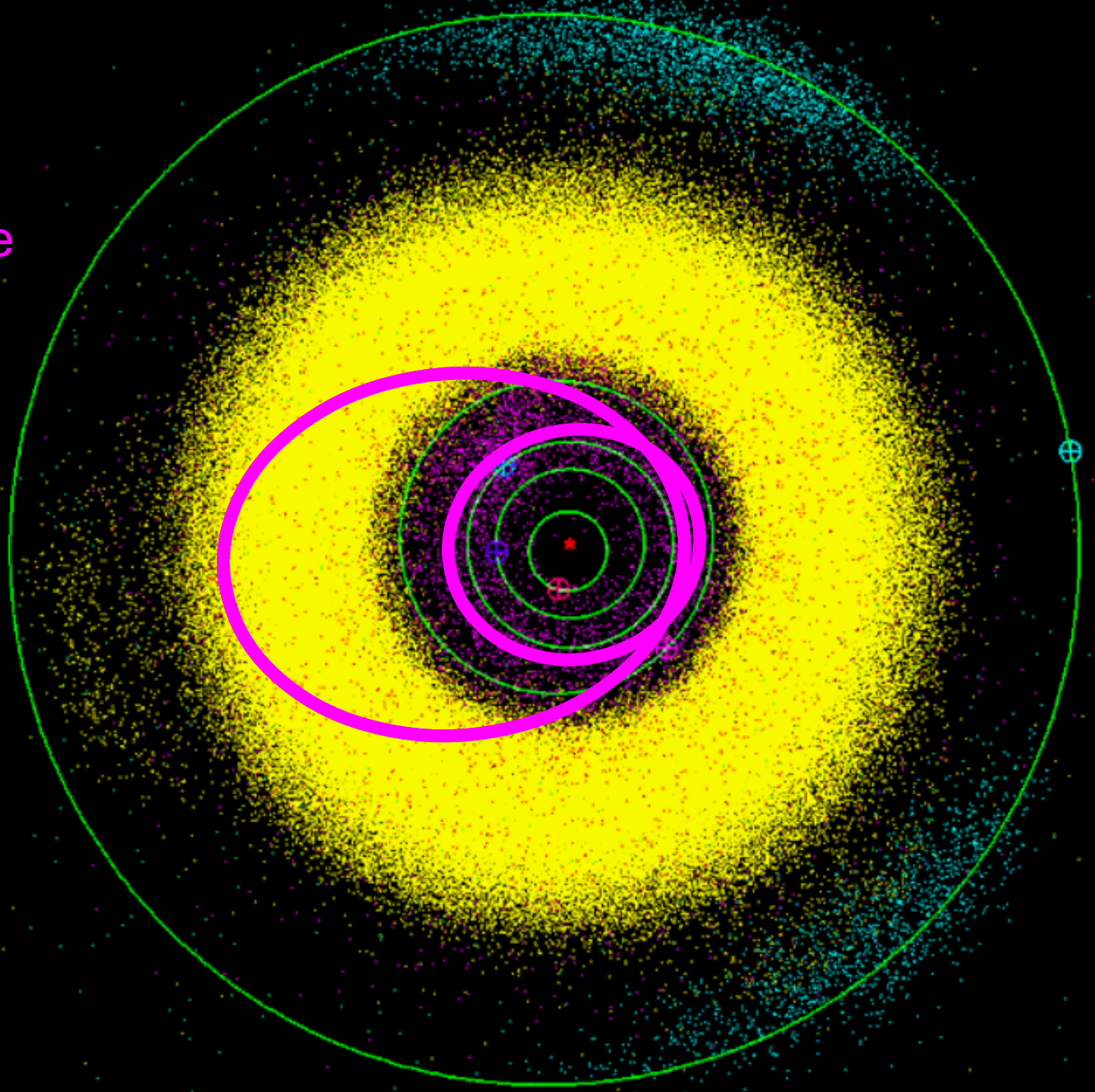
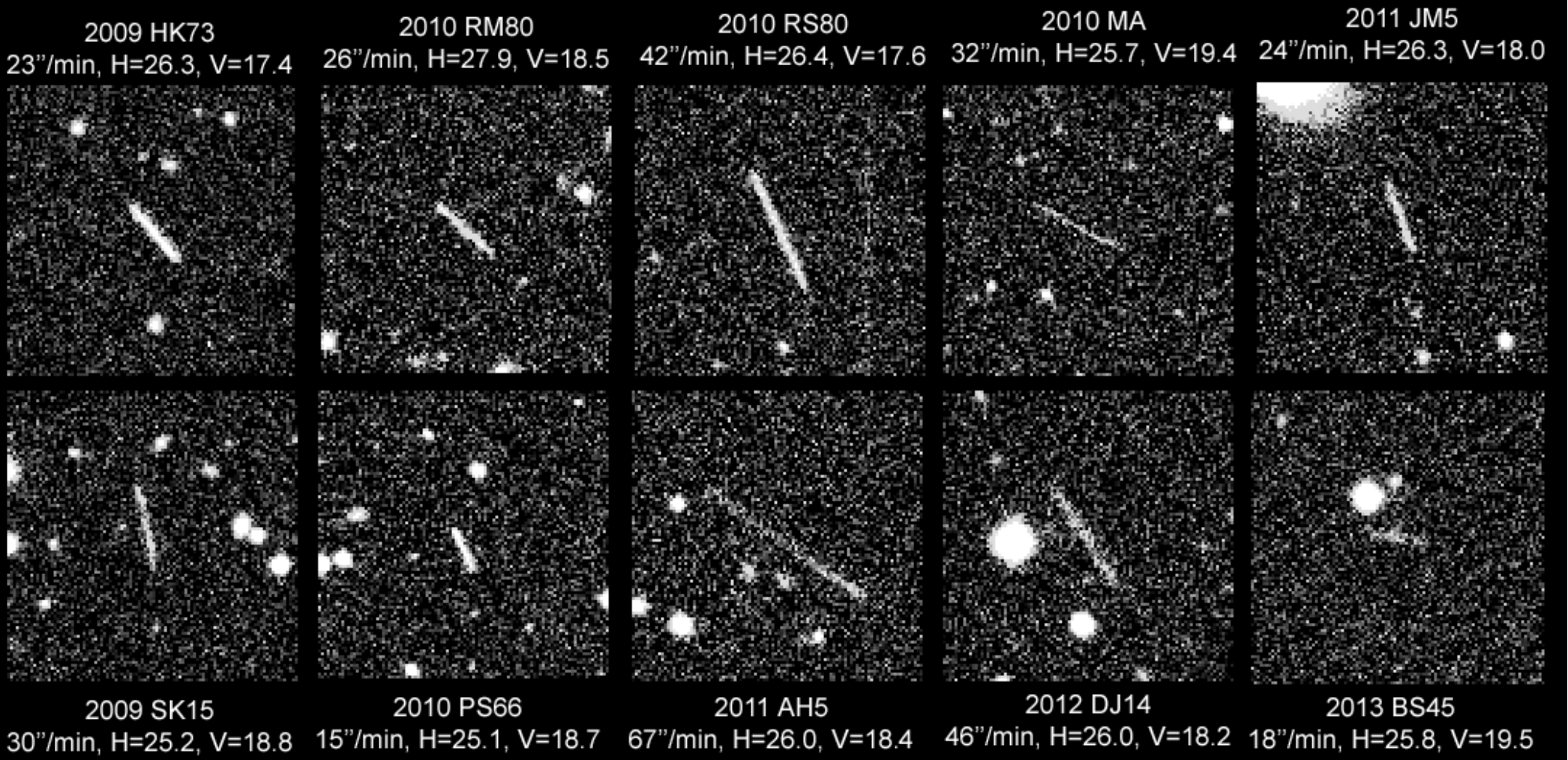
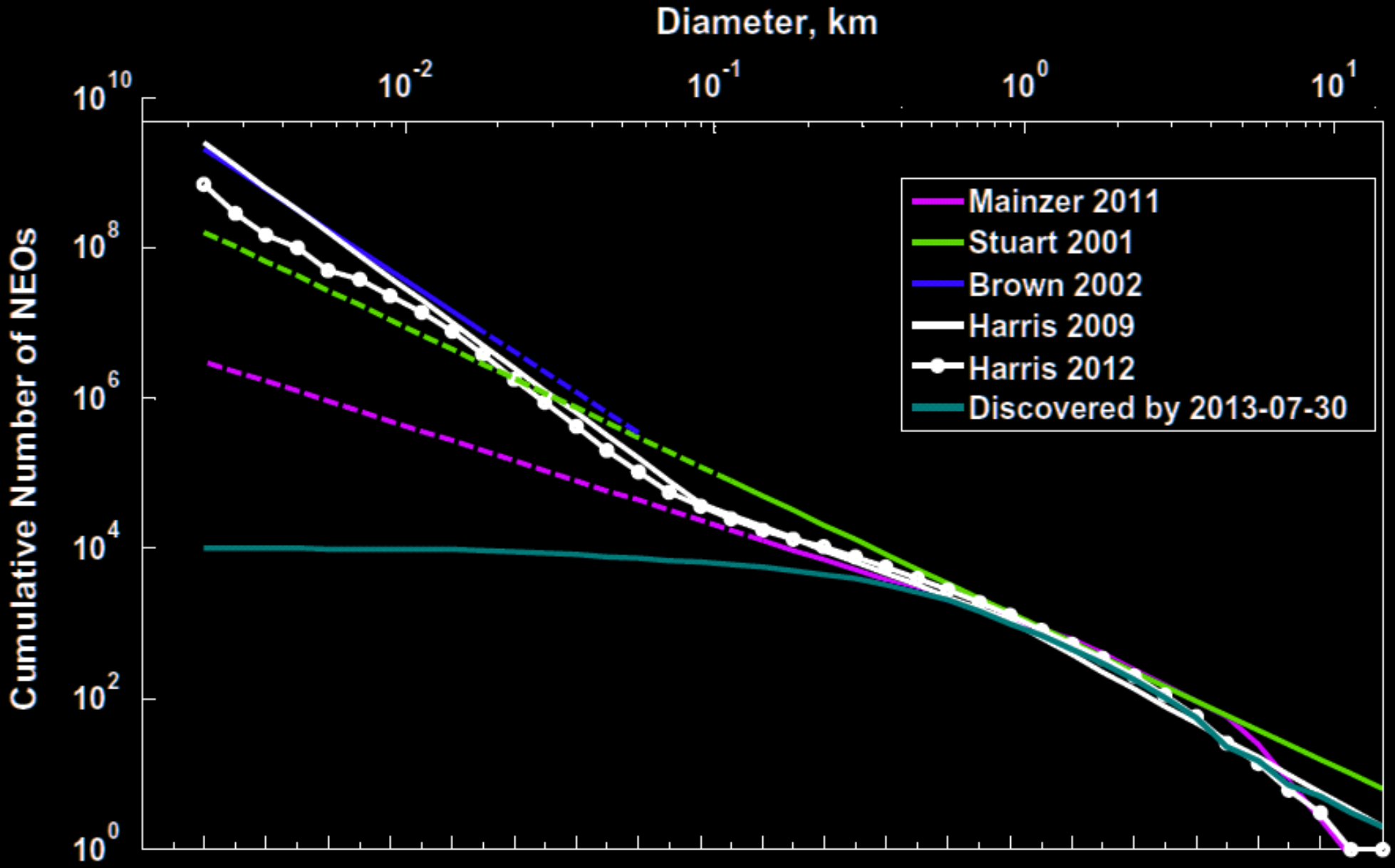
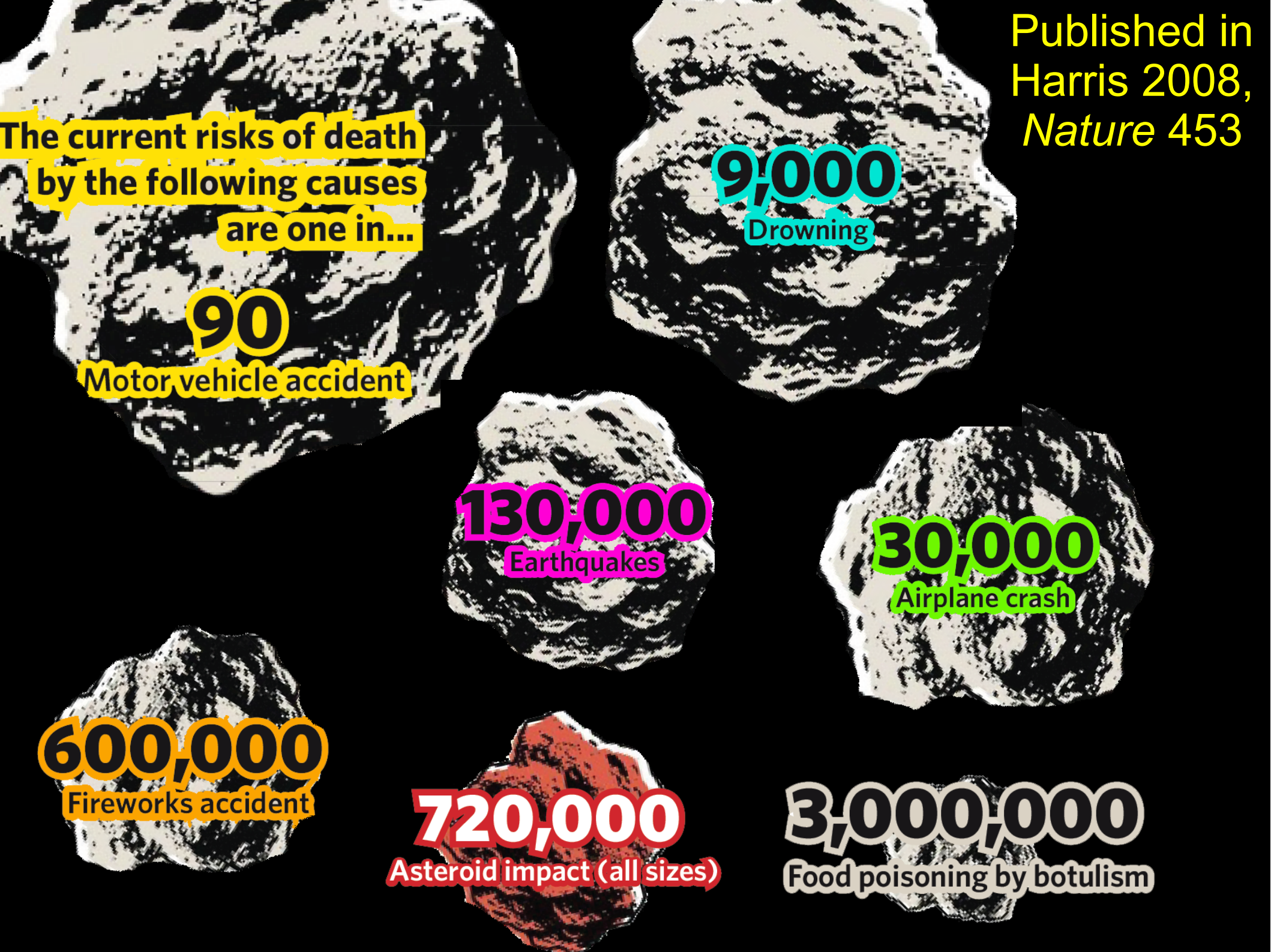


Streaking Near-Earth Asteroids in PTF



Near-Earth Asteroid Population Models

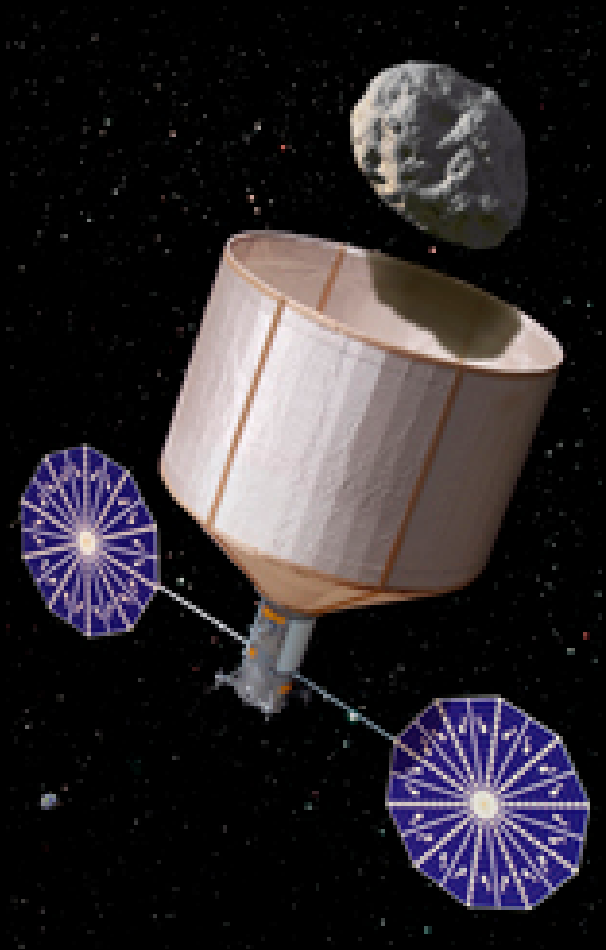



The current risks of death by the following causes are one in...
90
Motor vehicle accident
9,000
Drowning
130,000
Earthquakes
30,000
Airplane crash
600,000
Fireworks accident
720,000
Asteroid impact (all sizes)
3,000,000
Food poisoning by botulism
Published in Harris 2008, *Nature* 453

Near-Earth Asteroids "In the News"

Chelyabinsk Airburst (2013)

Space Missions Targets & Resources



Keck INSTITUTE FOR SPACE STUDIES
CALIFORNIA INSTITUTE OF TECHNOLOGY
JET PROPULSION LABORATORY

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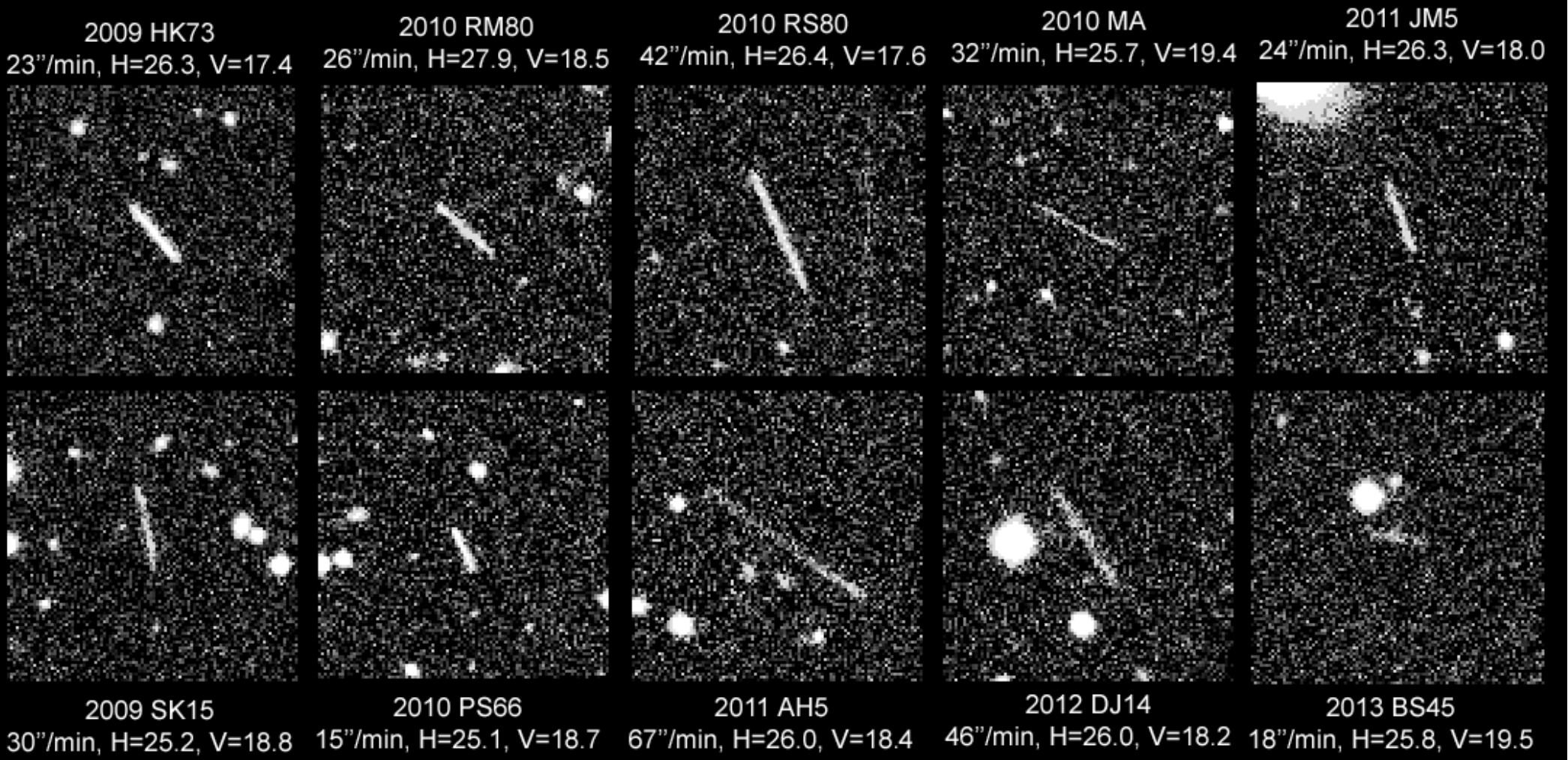

Streakers ≠ Short-Notice Impactors!

The Catalina Sky Survey has found two asteroids which impacted within hours of discovery

2008 TC3

2014 AA

These are not significantly streaked!

Near-Earth Asteroids

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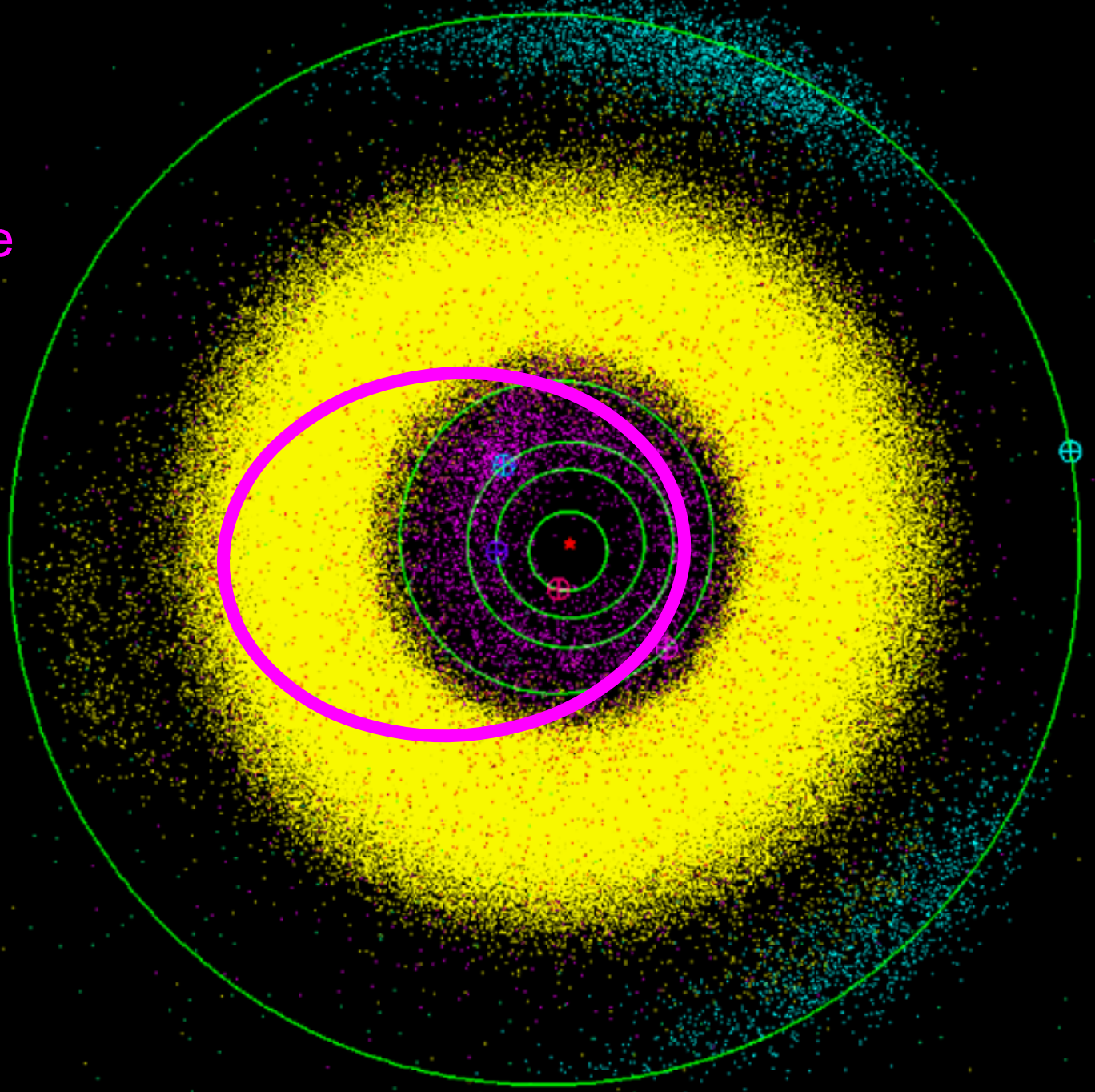
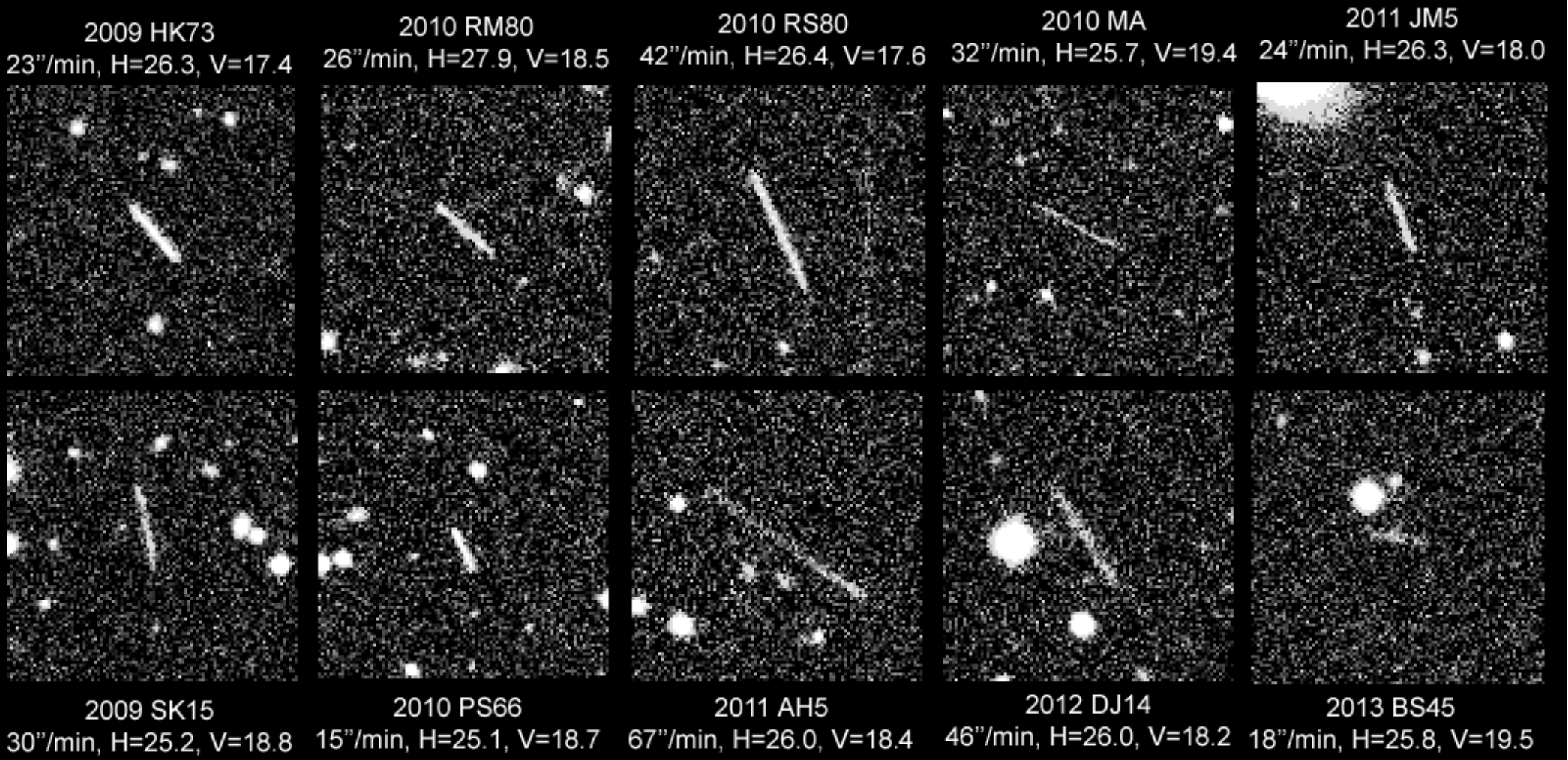
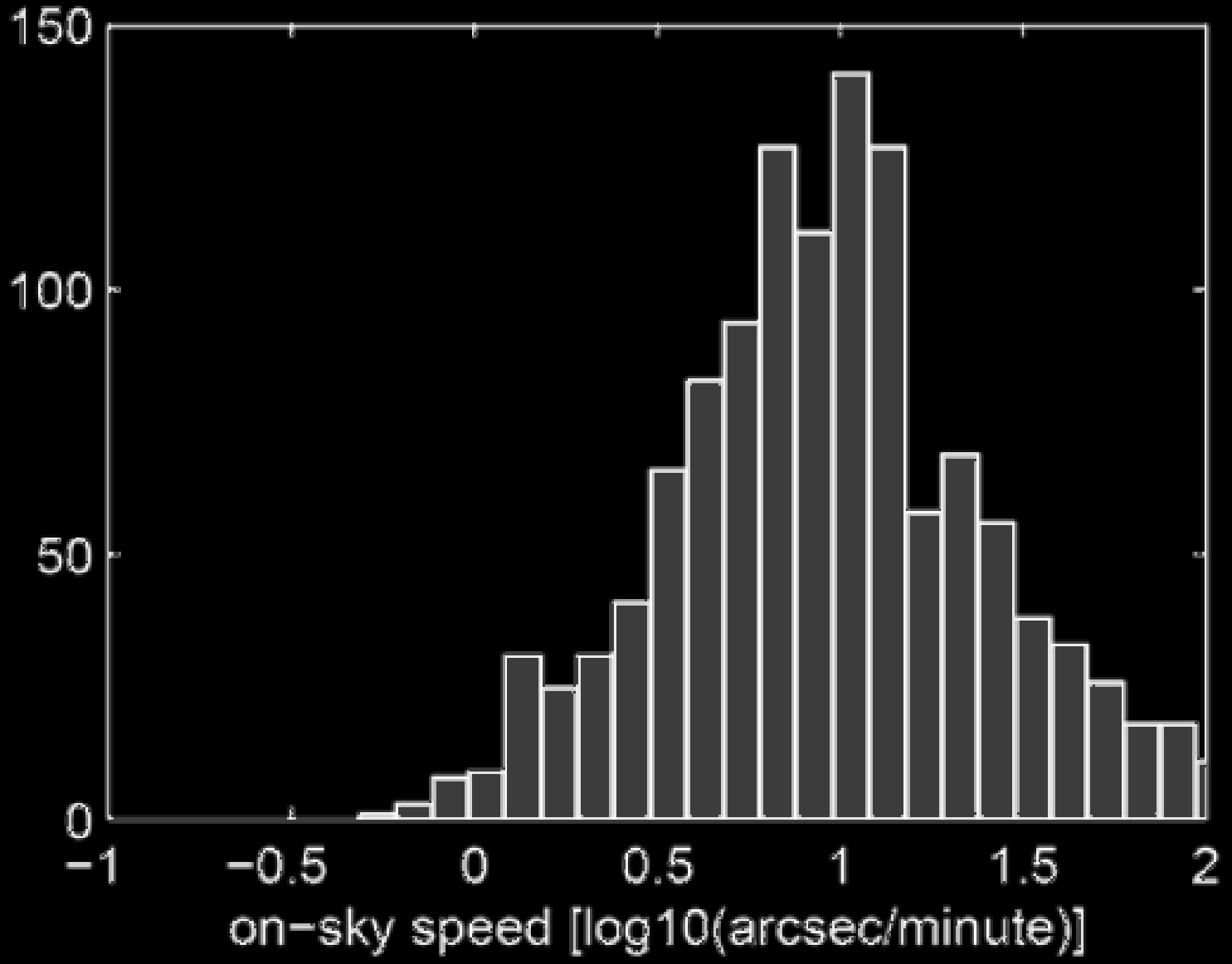


Streaking Near-Earth Asteroids in PTF



“Simulations” of observational circumstances of known streakers in PTF



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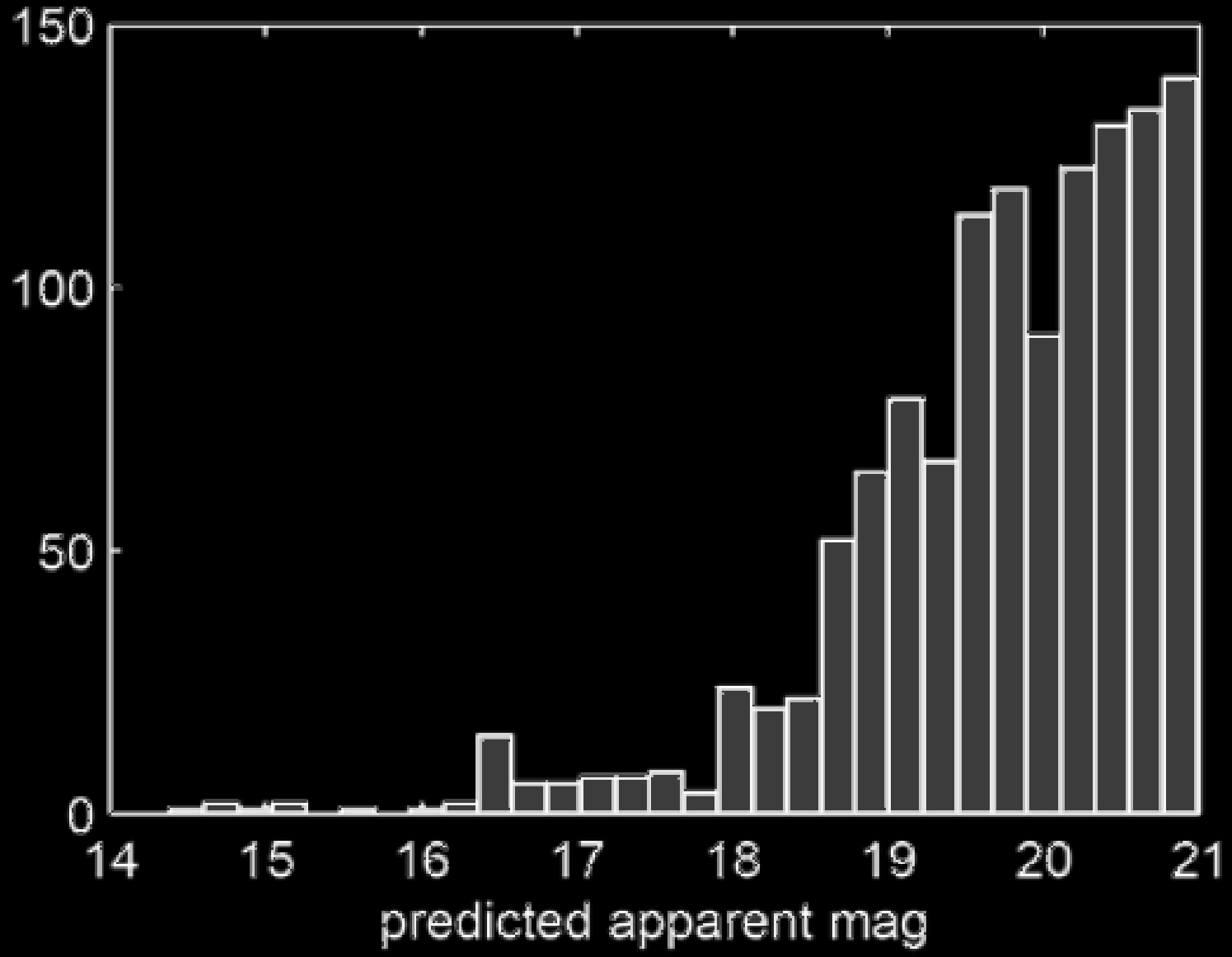

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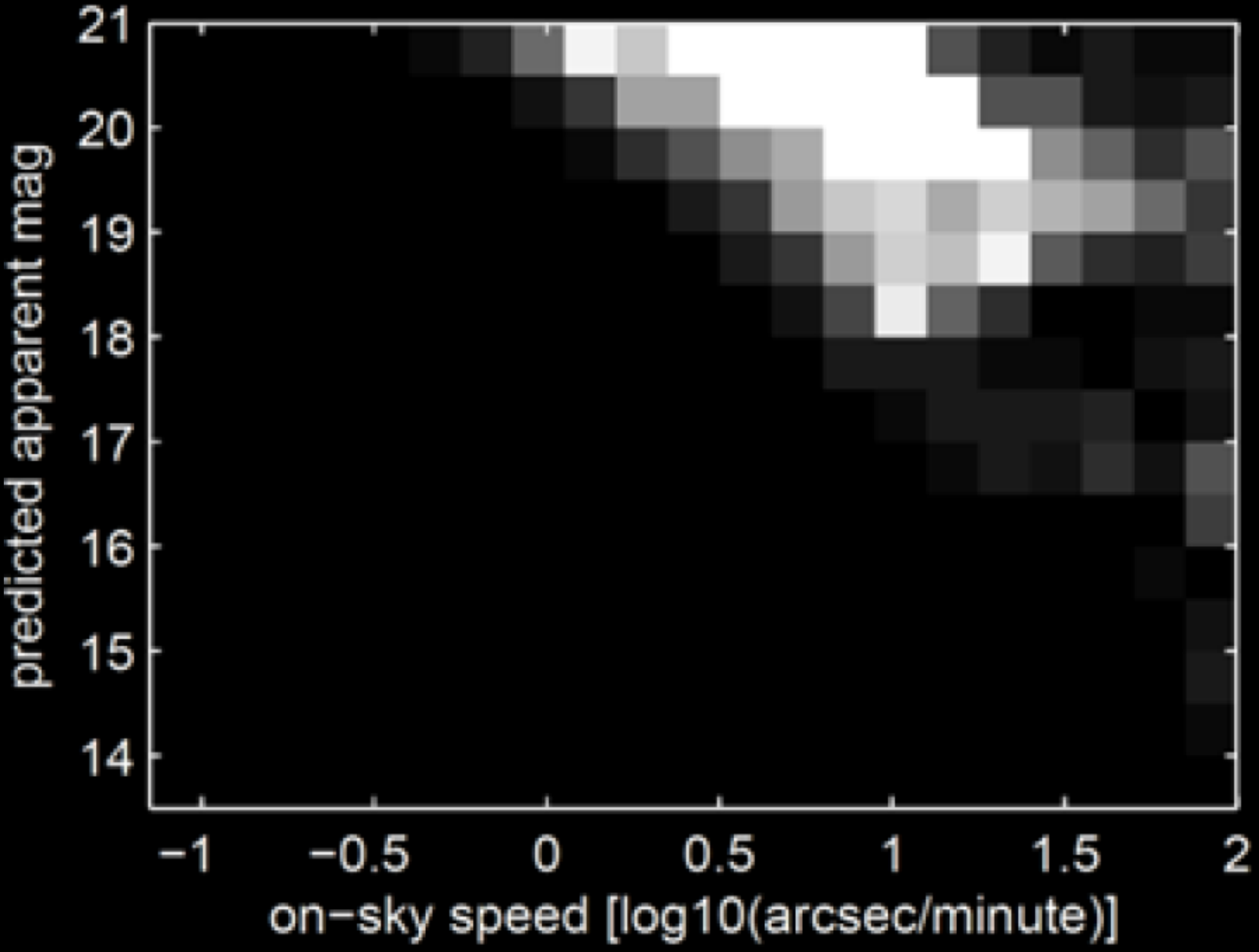

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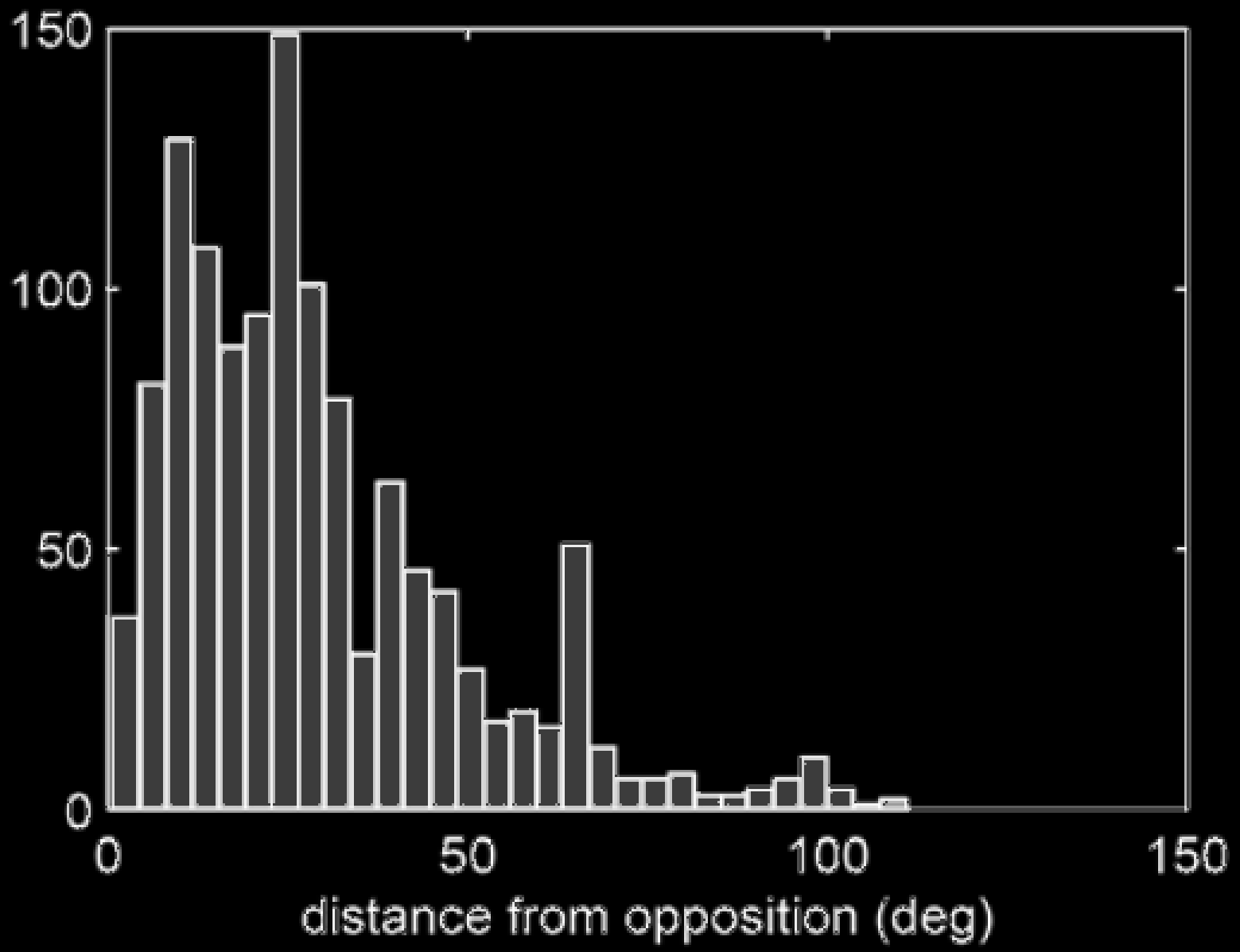

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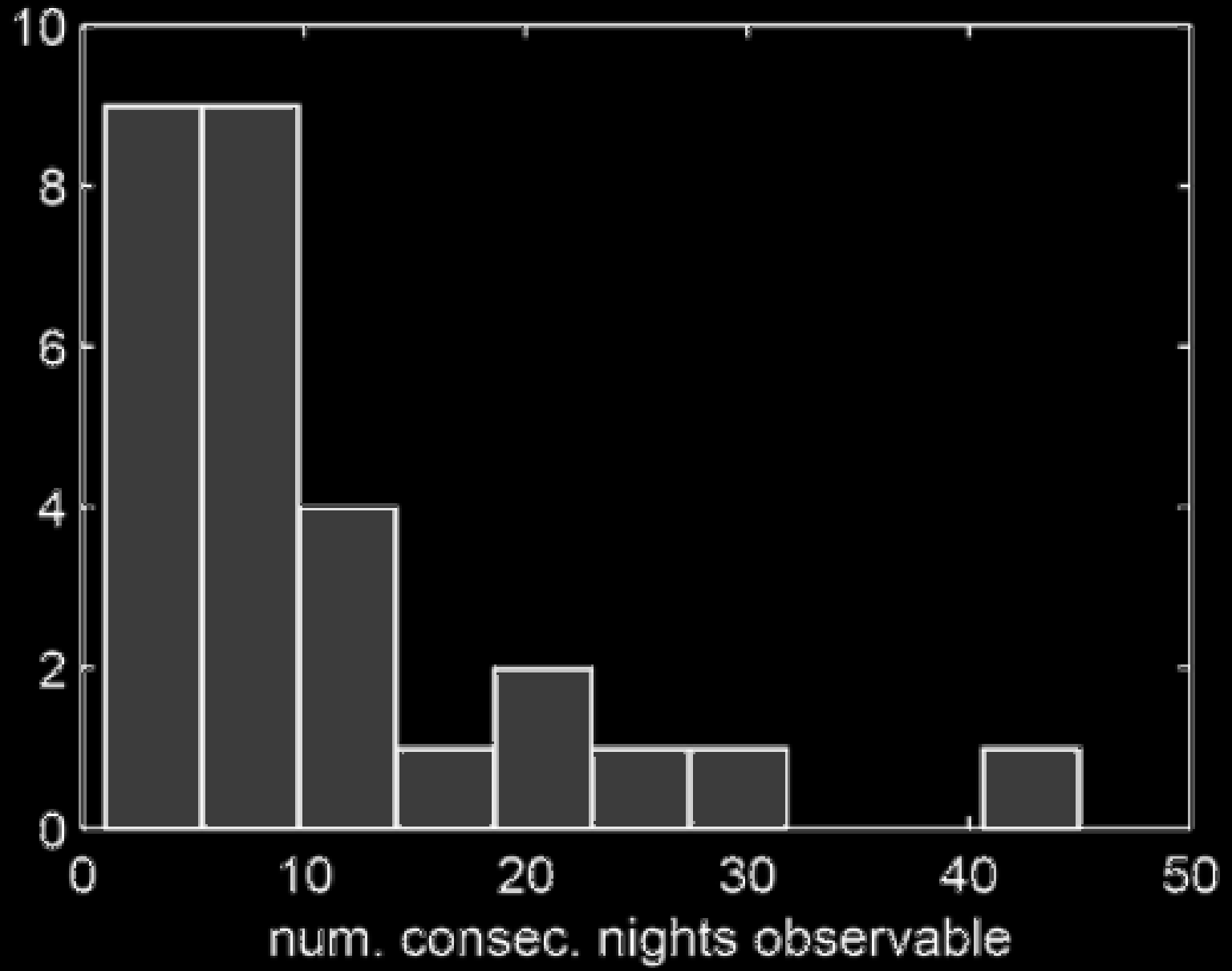
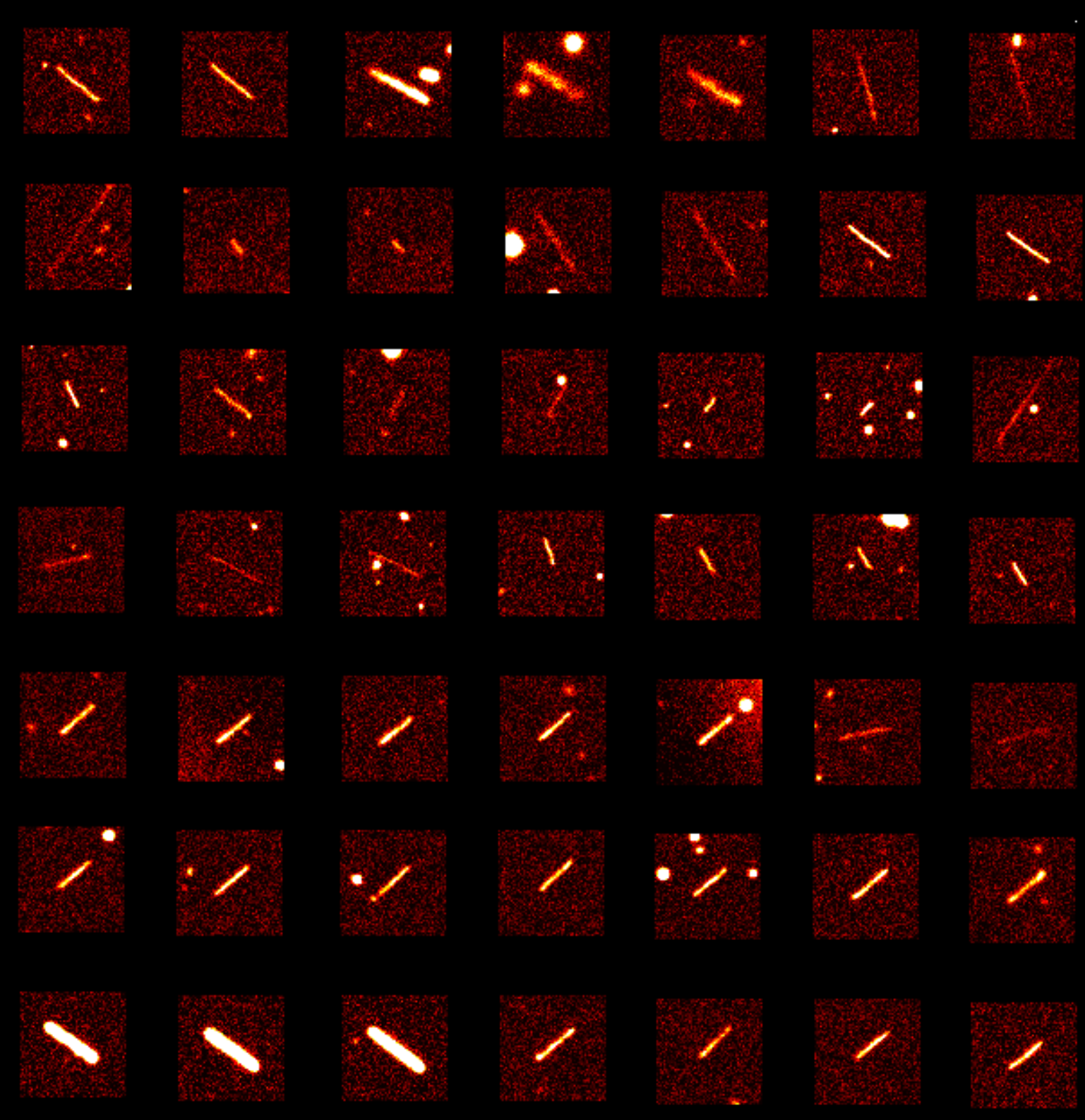




~250 known detections of ~50 unique objects in 4 yrs of PTF/iPTF

Synthetic Streaks

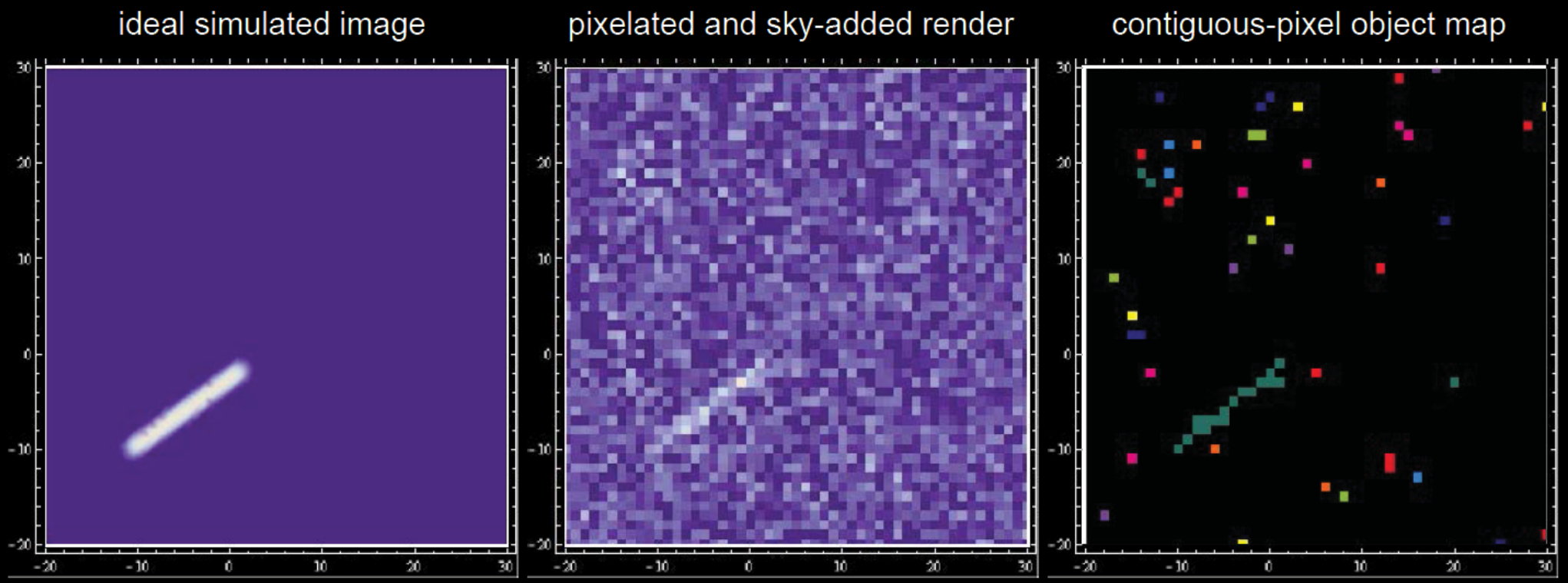


Figure 1: Illustration of the various stages of the streak simulation and detection process.

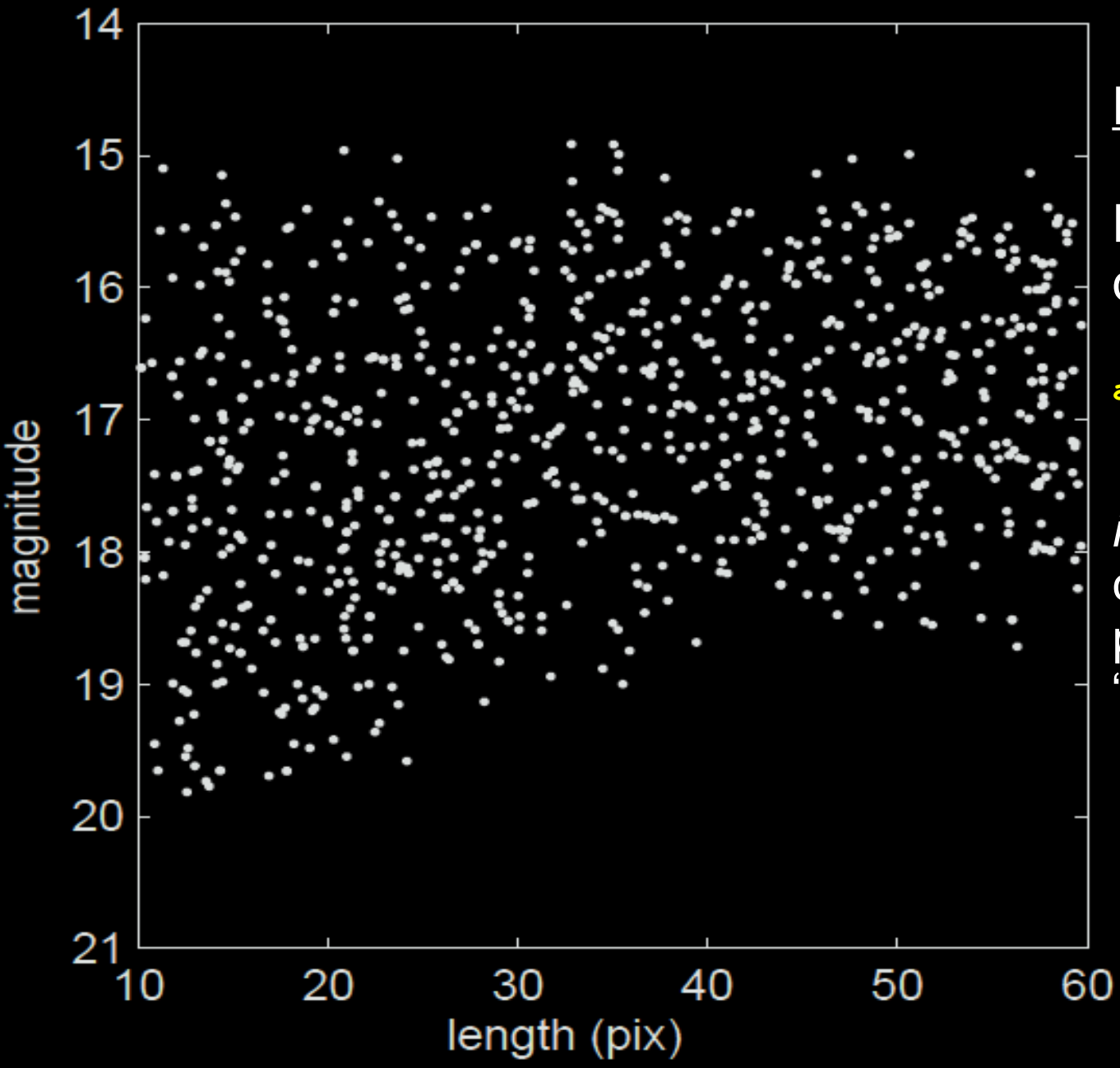
Detecting Streaks with **`findStreaks`**

(original software by Russ Laher)

plus PTFIDE (by Frank Masci)

PTFIDE removes stationary sources, then **`findStreaks`** identifies “objects” as blobs of pixels (replaces role of SExtractor)

Detection Capabilities from Synthetic Streaks



Notes:

Plot only shows “positive detections” defined as:

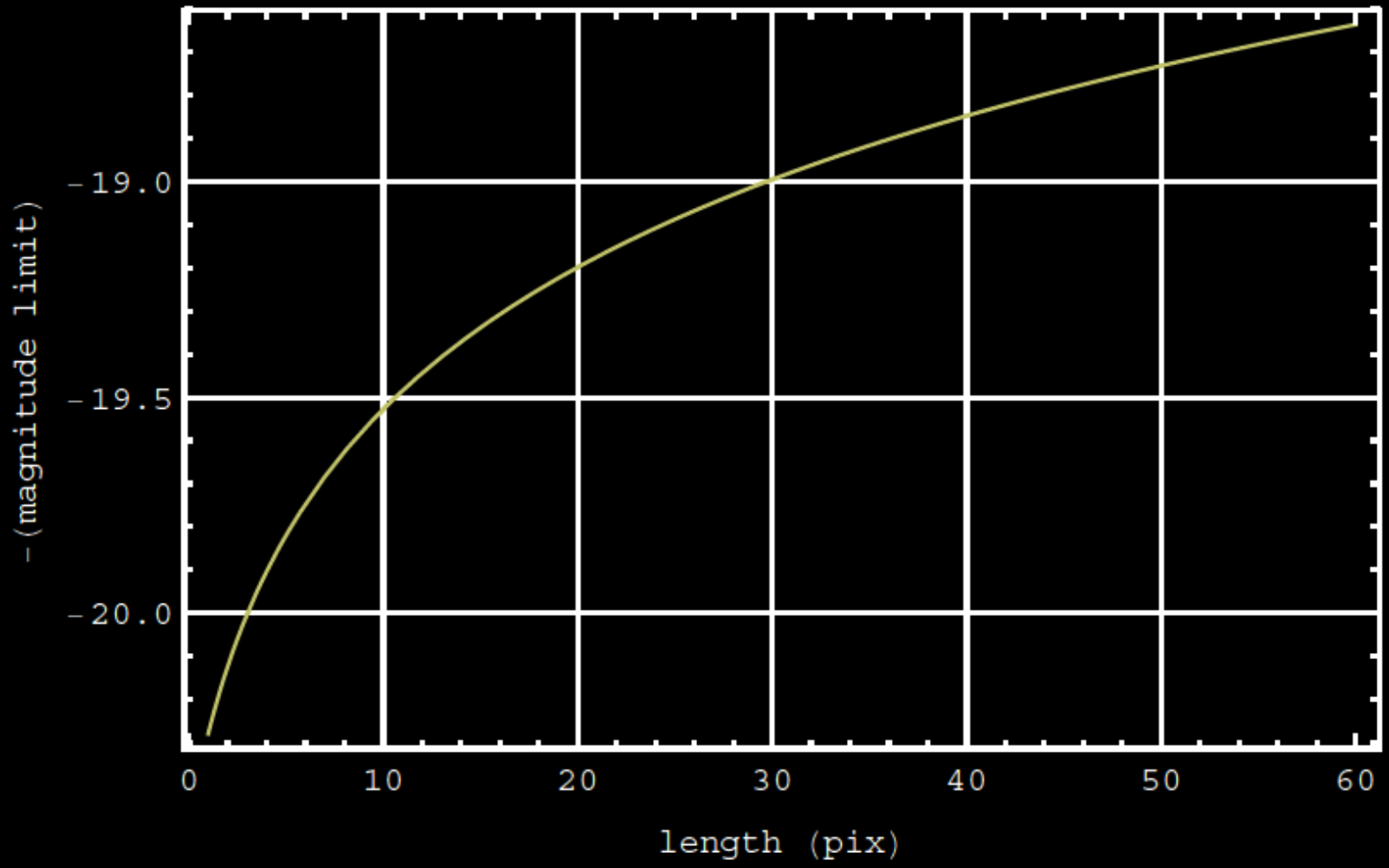
```
abs(measured_length -
        true_length) < 2*FWHM
```

i.e., no machine classification entailed in this plot's particular definition of “positive detection”

Ab initio detection-capability scalings by Tom Prince

$$SNR \sim \frac{F/(4\pi D_{strk}^2)}{\sqrt{B}} \times \sqrt{\tau_{PSF}} \quad (\text{for } \tau_{PSF}/\tau >> 1, \text{ i.e. streak})$$

$$\Delta m_{lim} = 5 \log_{10} (D_{pnt}/D_{strk}) = 1.25 \log_{10} \left(\frac{1}{1 + \tau/\tau_{PSF}} \right)$$



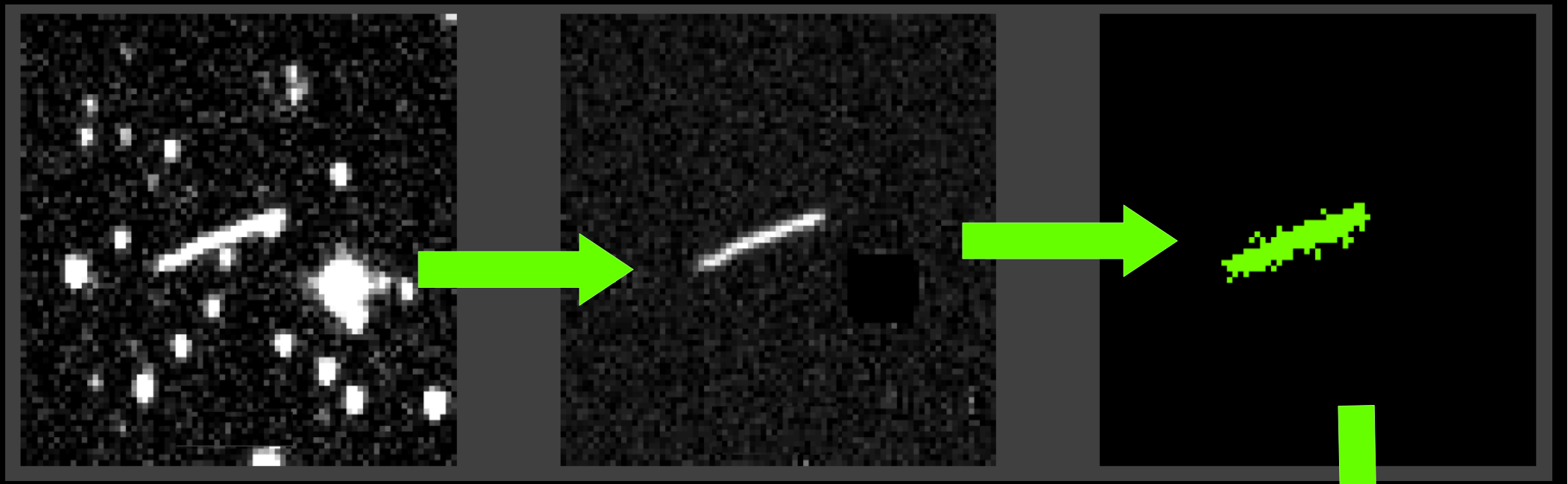
Streak-detection "Figure of Merit" for surveys (by Tom Prince)

$$FoM \equiv \Omega \; 10^{0.8(m_{lim}-20.6)} \left(\frac{\theta_{PSF}}{\tau v_{ast\perp} \times \tau_{tot}} \right)$$

Table 1: Comparison of Figure-of-Merit for Detection of Small Fast-Moving Asteroids

Telescope	Ω (deg^2)	m_{lim}	θ_{PSF} (arcsec)	τ (min)	τ_{tot} (min)	D_{strk} (lunar)	FoM (H=28.5, $v_\perp$=2 km/s)
ZTF (optimized)	47	19.8	2	0.25	0.42	6.1	425 (300)
ZTF (nominal)	47	20.4	2	0.5	0.75	6.6	304 (210)
PS1 or 2	7	21.8	1.1	0.5	1.	12.8	242
ATLAS	60	19.7	2.6	0.5	0.6	4.7	177
BlackGEM	22.0	20.7	1.0	1.0	1.2	5.4	43
CRTS-II	19.	19.5	2.5	0.5	0.75	3.7	21
PTF	7.25	20.2	2	1	1.5	5.0	10 (7)
P200-CMOS	0.22	22.4	-NA-	-NA-	0.5	22.4	88 (22)

Machine-learned classification of streak candidates



(x,y,flux) data per pixel

~15 morphological “features”:

- number of pixels, x-y correlation,...
- length, width, orientation,...
- flux median, spread in flux
- topological parameters (perimeter, etc...)

Python-based Random-Forest classifier (scikit-learn)

first version: ~80% completeness with ~1% contamination

Image stamp generation of high-scoring streak candidates

Human vetting with marshal webpage

The IPAC Real-time Pipeline

since early 2013

1. Real-time version of the IPAC frame-level processing pipeline (Jason Surace, Russ Laher, et al.)

2. Image Subtraction (PTFIDE: Frank Masci)

3. Streak detection (findStreaks: Russ Laher)

4. homebrew-MOPS moving-object detection (Adam Waszczak)
...soon to be upgraded to PTFMOPS (Frank Masci)

in past year

5. Streak real/bogus classifier: (Brian Bue, Umaa Rebbapragada et al.)

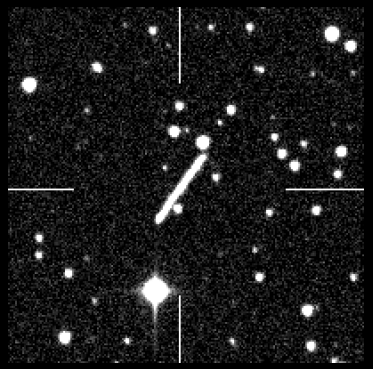
6. Solar System Marshal scanning webpage (Adam Waszczak & scanners!)

7. Email-based automated same-night P48 ToO system (Tom Barlow)

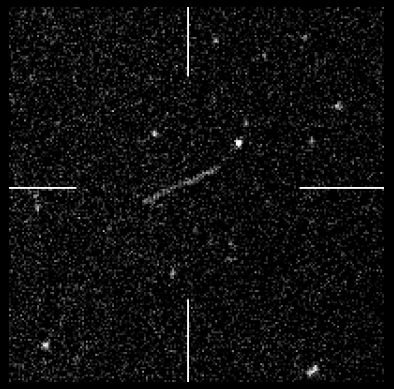
8. Discovery alerts distributed by the Minor Planet Center (based at Harvard)

9. Rapid follow-up by observers worldwide

May-June 2014:
Classifier Integration & Commissioning

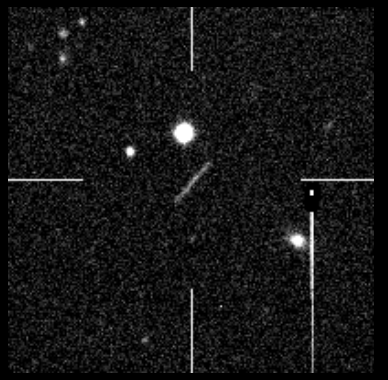


PTF8i6

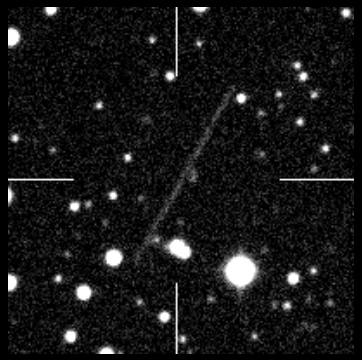


PTF7i3

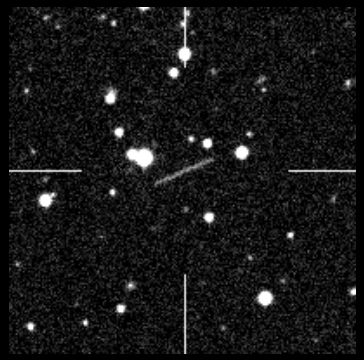
PTF6i4



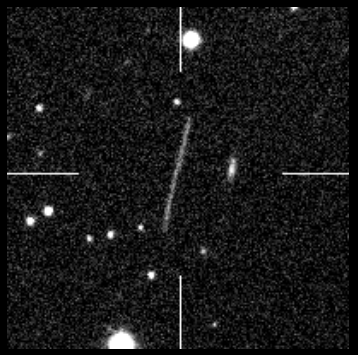
PTF7i1



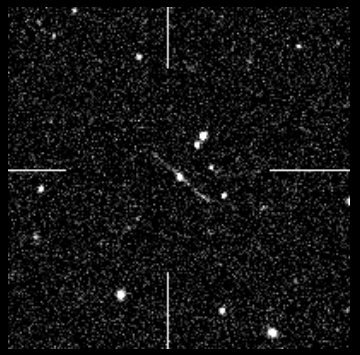
PTF7i2



PTF9i2



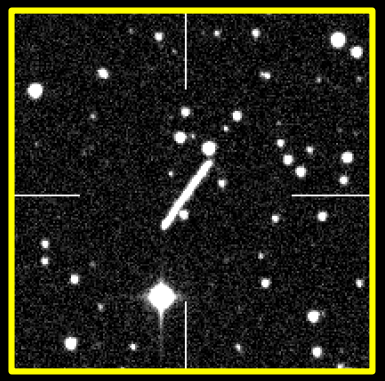
PTF6i2



PTF8i5

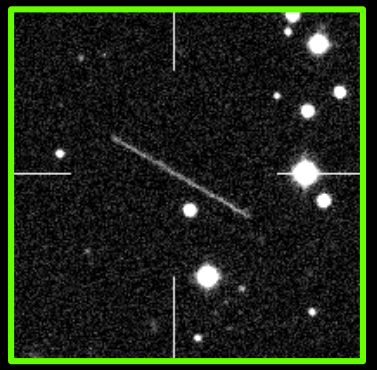
Artificial Satellites

Real Confirmed NEAs



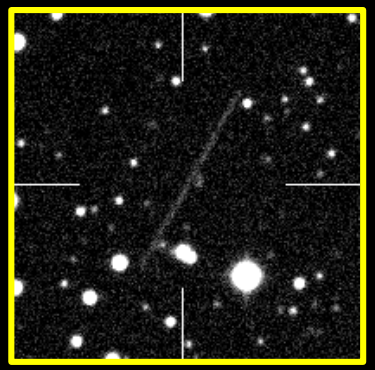
PTF8i6

PTF7i3

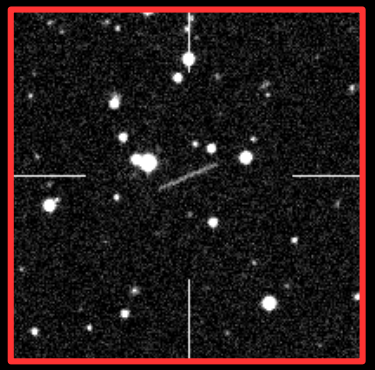


PTF6i4

PTF7i1



PTF7i2



PTF9i2

PTF6i2

PTF8i5

Lost/Unconfirmed Objects

Overview of the PTF Solar System Marshal

PTF Solar System Marshal

Updated: 2014-08-21 13:17 UT (Thu 06:17 AM Pacific)

Known NEAs Observable Tonight | Current PTF discoveries on the NEOCP | Past PTF discoveries on the NEOCP
Nightly Efficiency of homebrewMOPS | List of all PTF solar system discoveries

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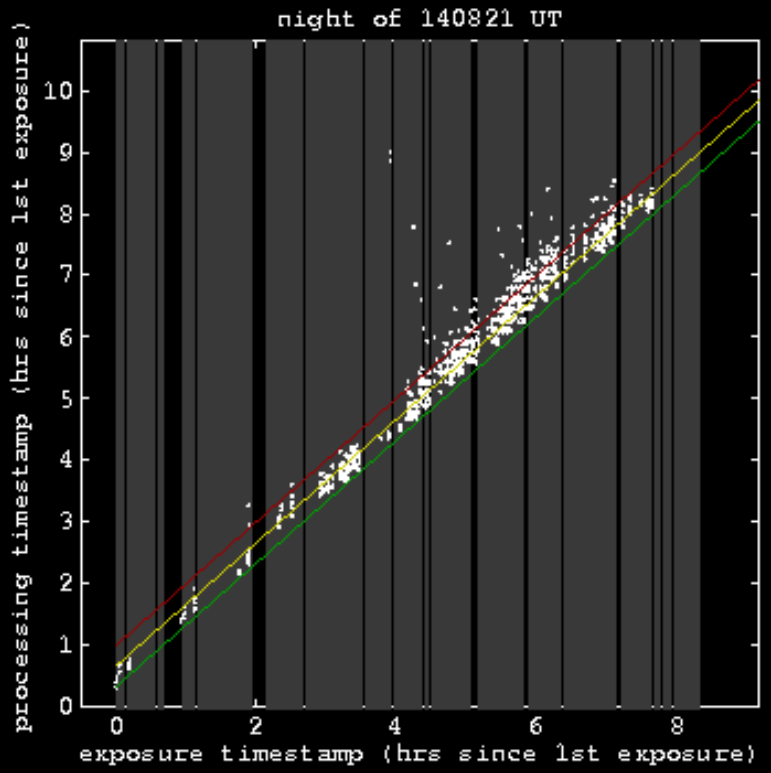
IPAC Real-time Processing Status

(about this plot)



Read the Scanning Guide

Tonight's Streak Candidates

(UT 2014-08-21)

Newest candidates are 80 minutes old

29 candidates with p > 0.7

593 candidates with p > 0.5

View examples of real asteroid streaks

Current Palomar All-Sky View

ptf.caltech.edu/marshals/asteroids/

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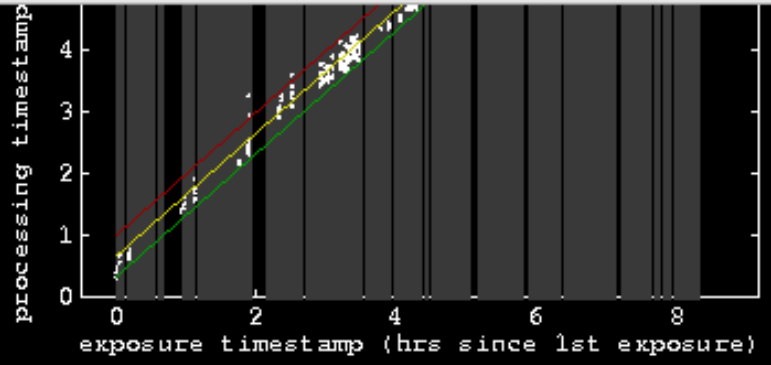

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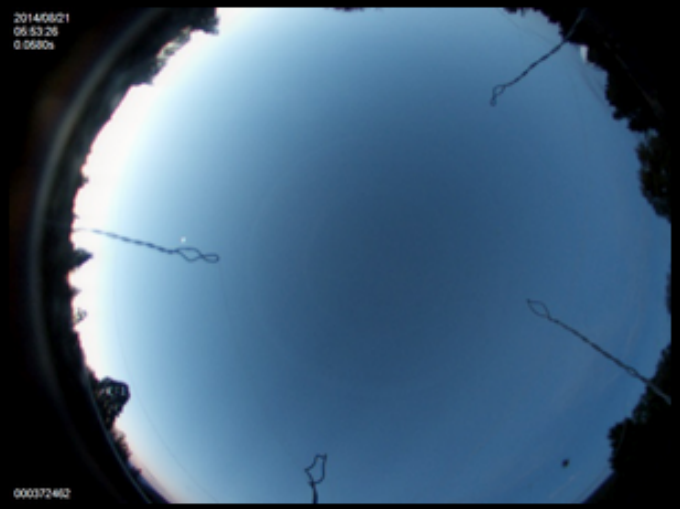
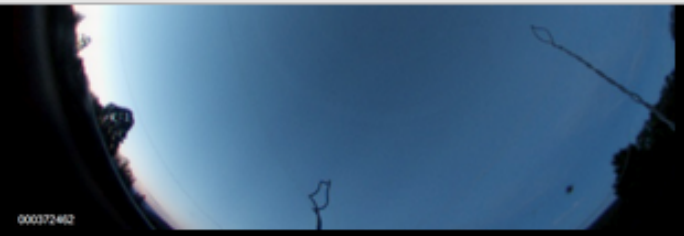


Current Palomar Weather

Timestamp:	2014-08-21 13:17:20 UTC
Outside Temp.:	16.5 Deg. C
Inside Temp.:	16.0 Deg. C
Primary Mirror Temp.:	16.2 Deg. C
Inside Dew Point:	7.5 Deg. C
Raining?	No
Wind Direction:	109 Degrees
Wind Speed:	4 M.P.H.

Current Sky Coverage for 140821 UT

(about this plot)



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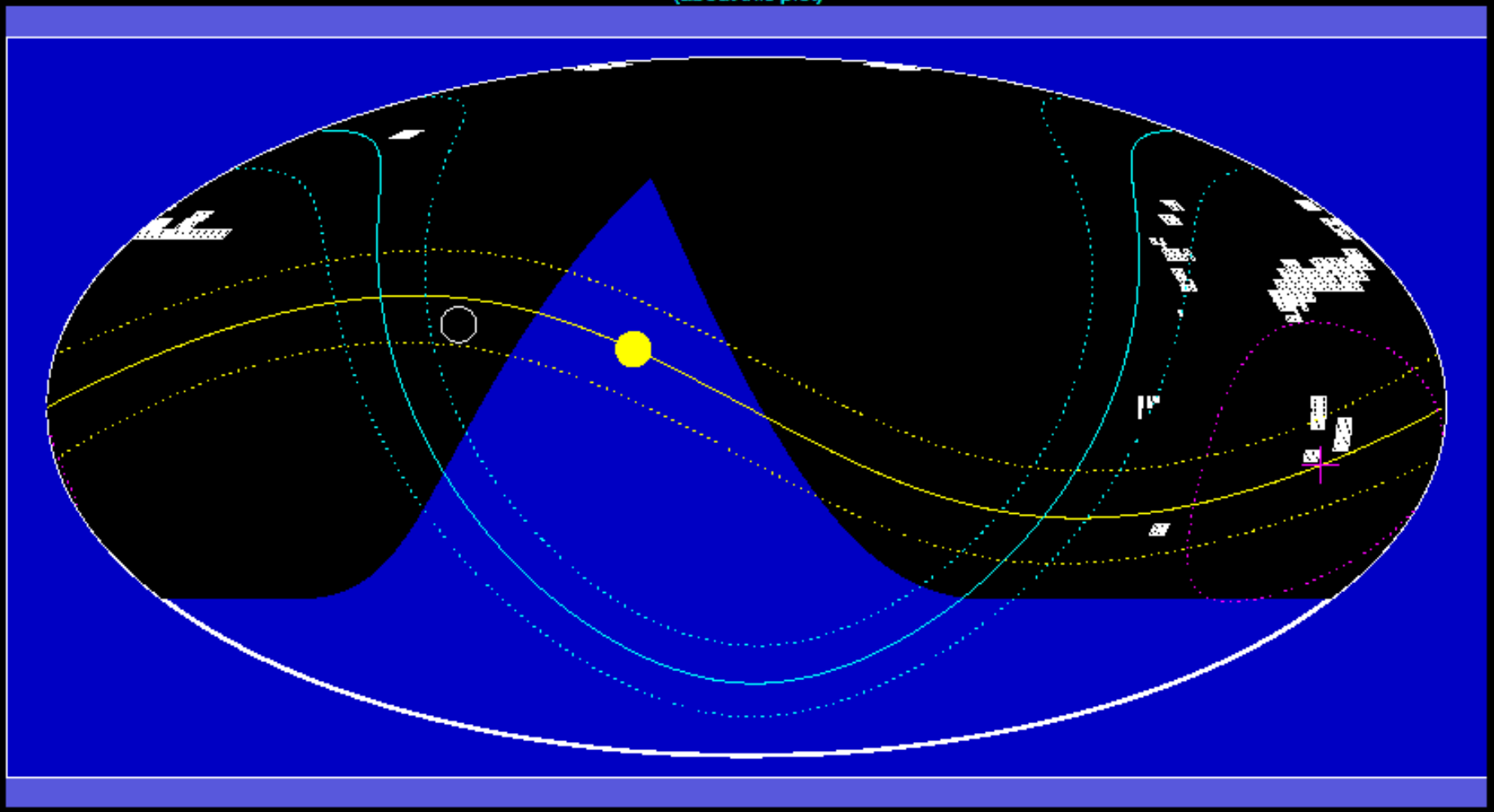

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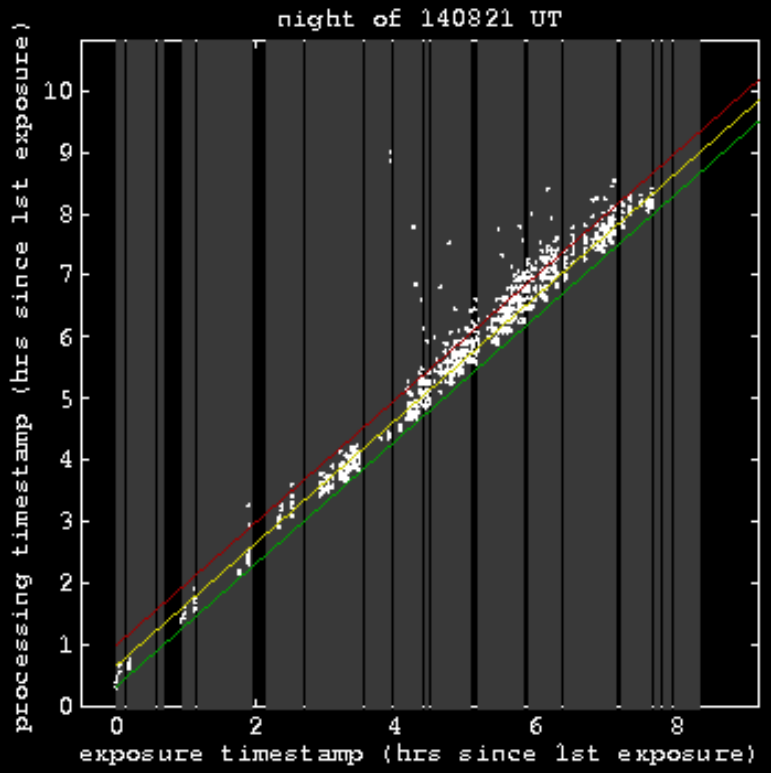

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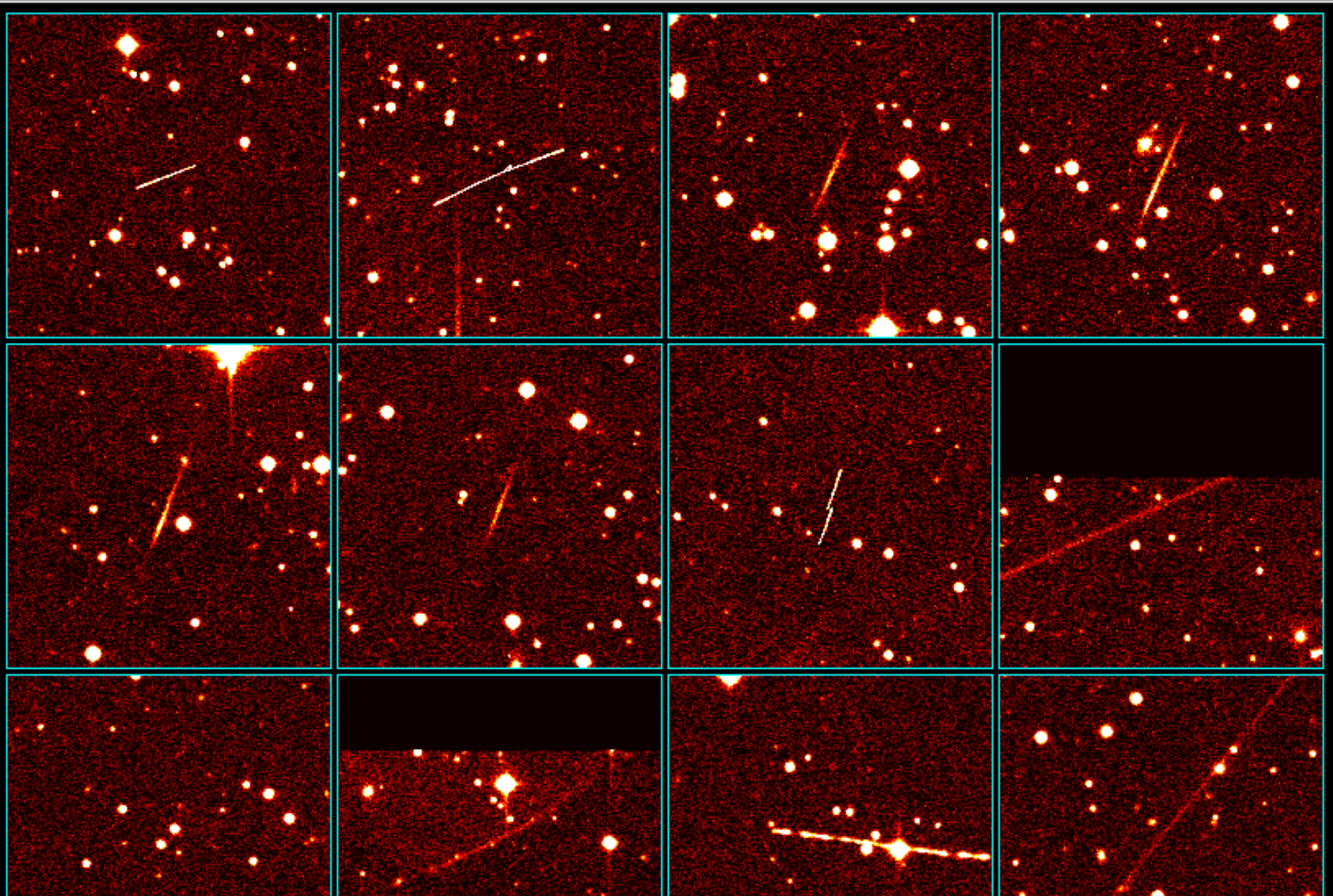
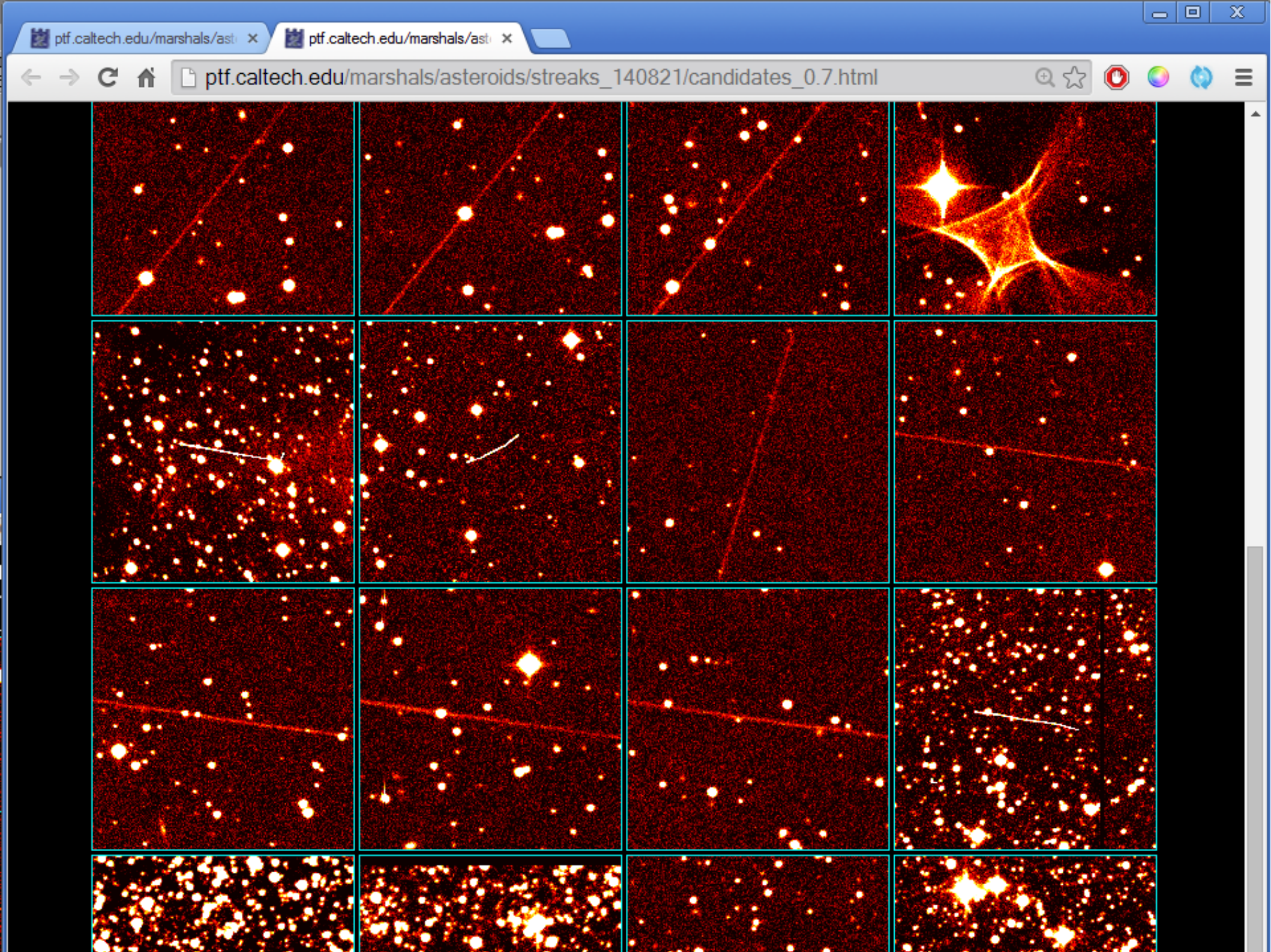
ptf.caltech.edu/marshals/ast × ptf.caltech.edu/marshals/ast ×

ptf.caltech.edu/marshals/asteroids/streaks_140821/candidates_0.7.html

PTF streak candidates (p > 0.7) for 2014-08-21

Updated: 2014-08-21 12:40 UT (Thu 05:40 AM Pacific) Latest image: 62 minutes old 29 candidates total




ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/asteroids/streaks_140821/candidates_0.7.html

ptf.caltech.edu/marshals/asteroids/streaks_140821/PTF2014_08_21.30702_20_25_45.2

MPC observation line (80-character string):

```
     PTFxxx * C2014 08 21.30702 20 25 45.23 +33 28 05.9          15.6 r      I41
```

realBogus score: 0.71

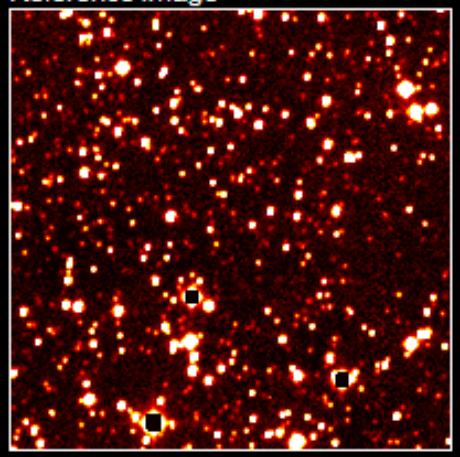
Generate single-observation ToO map

Next available PTFxxx codes for labeling MPC-submitted discoveries

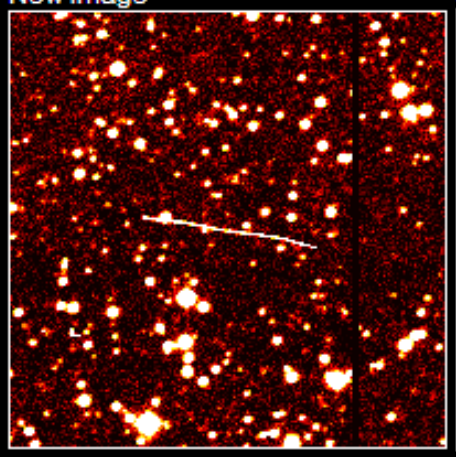
Updated: 2014-08-21 18:34 UT
(Thu 11:34 AM Pacific)

PTF1j1
PTF1j2
PTF1j3
PTF1j4
PTF1j5

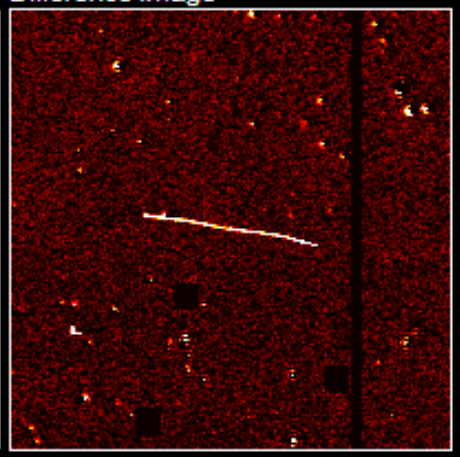
Reference Image

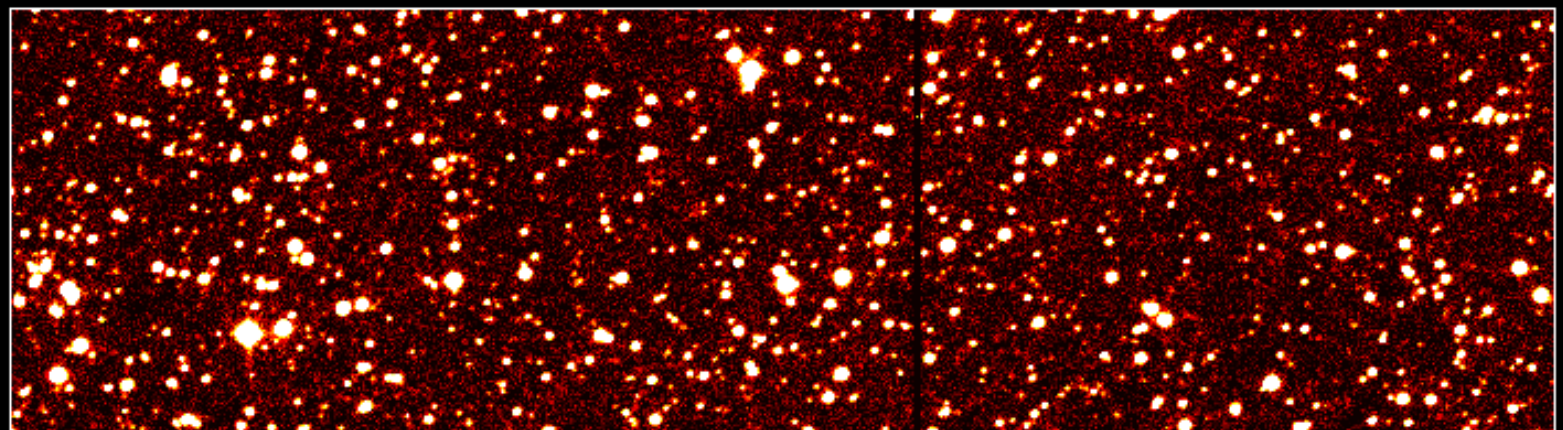


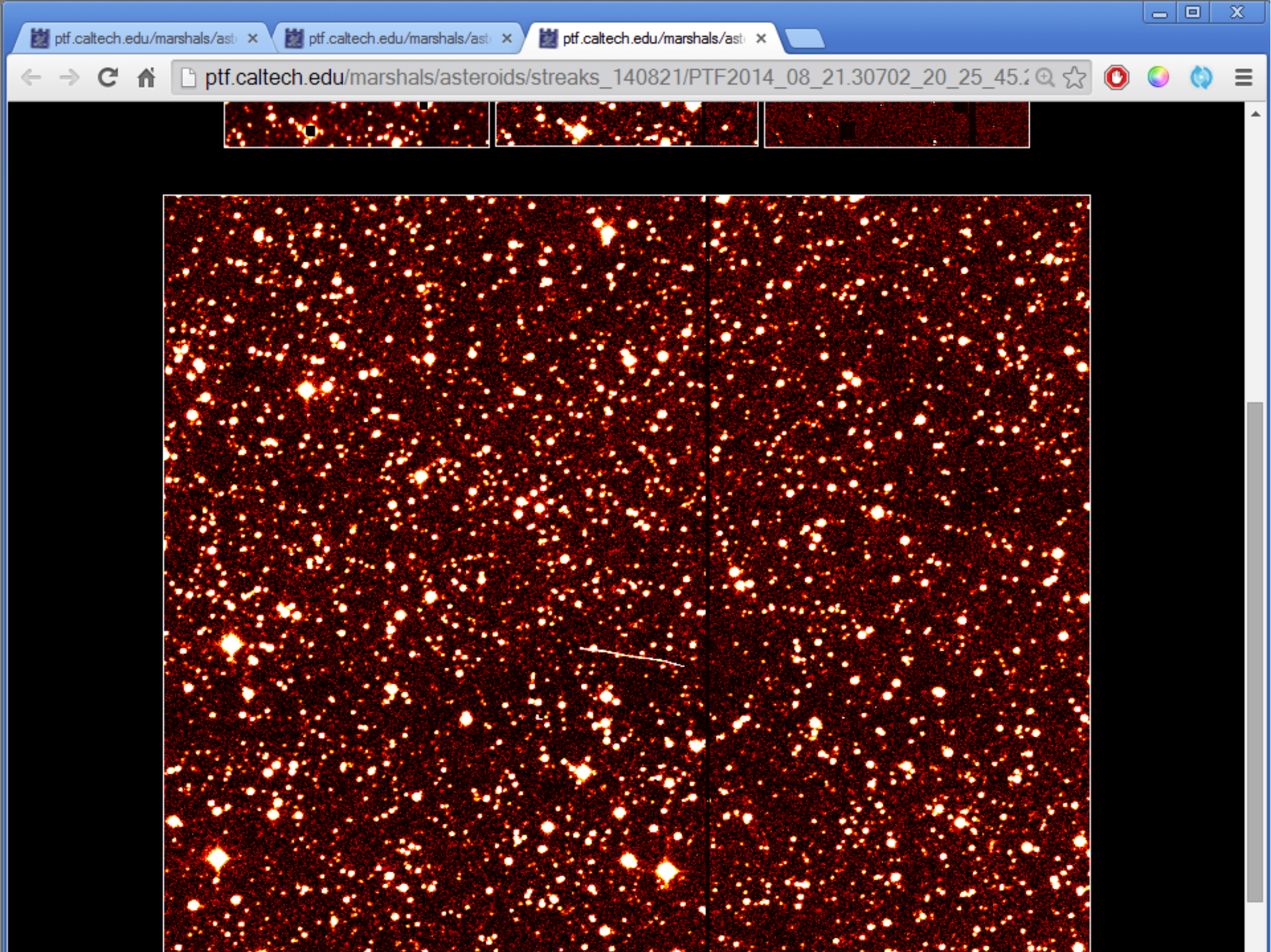
New Image

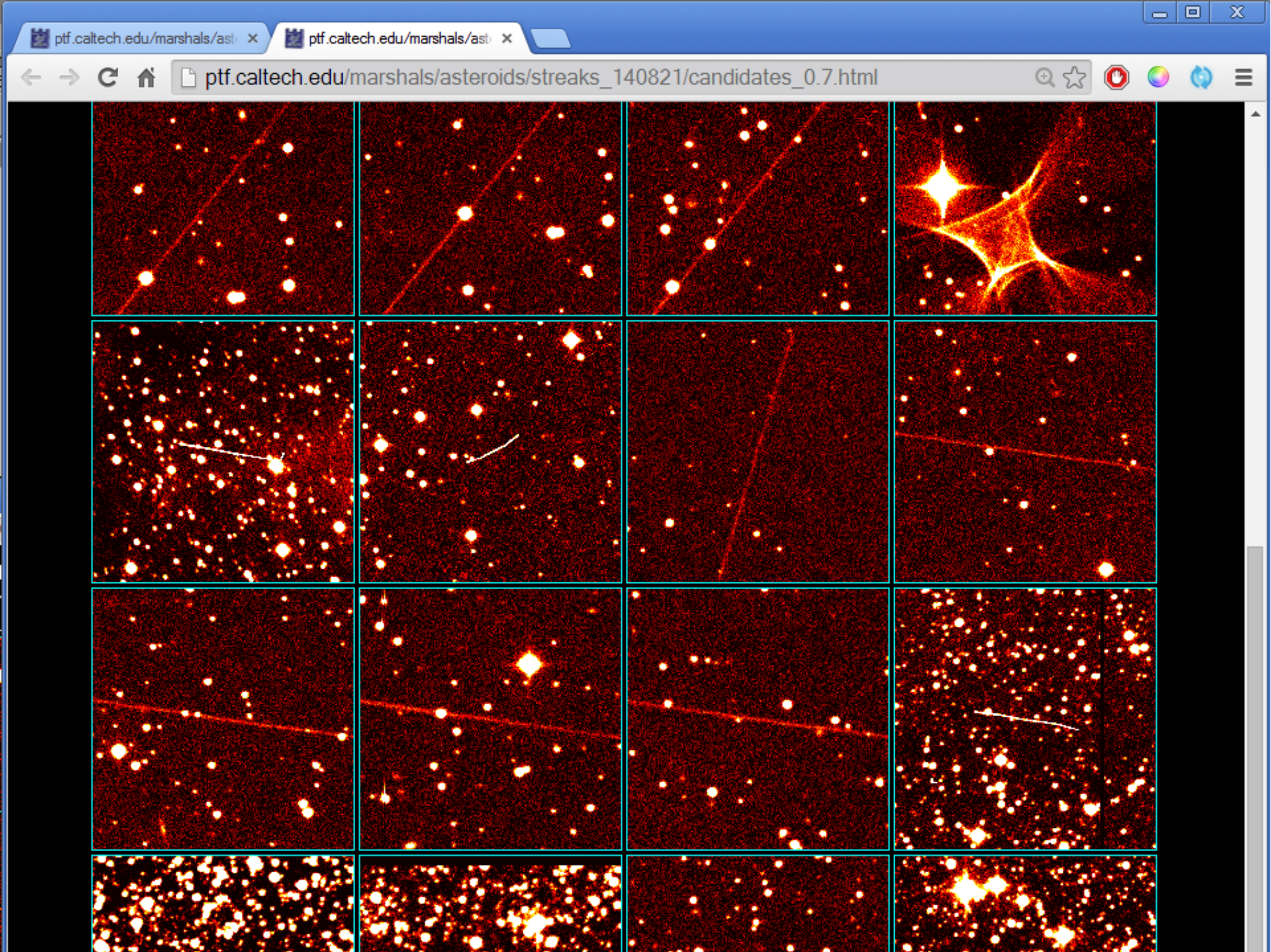


Difference Image






ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/asteroids/streaks_140821/PTF2014_08_21.30702_20_25_45.2


ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/asteroids/streaks_140821/candidates_0.7.html

ptf.caltech.edu/marshals/ast

ptf.caltech.edu/marshals/ast

ptf.caltech.edu/marshals/ast

ptf.caltech.edu/marshals/asteroids/streaks_140821/PTF2014_08_21.31172_21_36_03.

MPC observation line (80-character string):

```
     PTFxxx * C2014 08 21.31172 21 36 03.31 +23 20 51.3          16.6 r      I41
```

realBogus score: 0.73

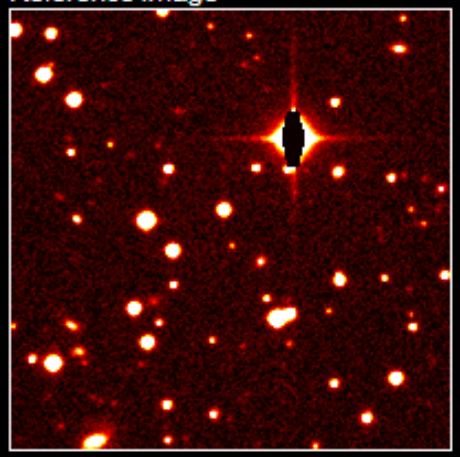
Generate single-observation ToO map

Next available PTFxxx codes for labeling MPC-submitted discoveries

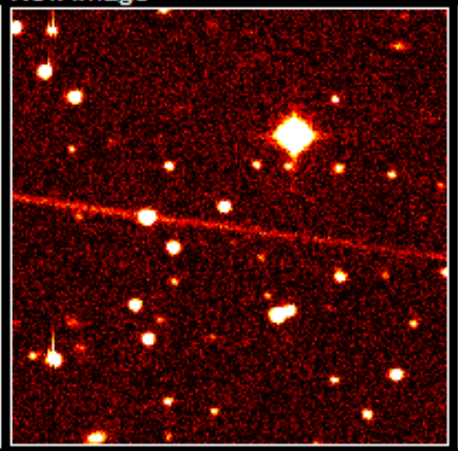
Updated: 2014-08-21 18:44 UT
(Thu 11:44 AM Pacific)

PTF1j1
PTF1j2
PTF1j3
PTF1j4
PTF1j5

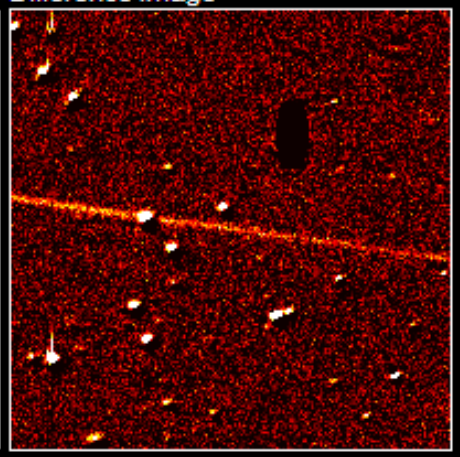
Reference Image

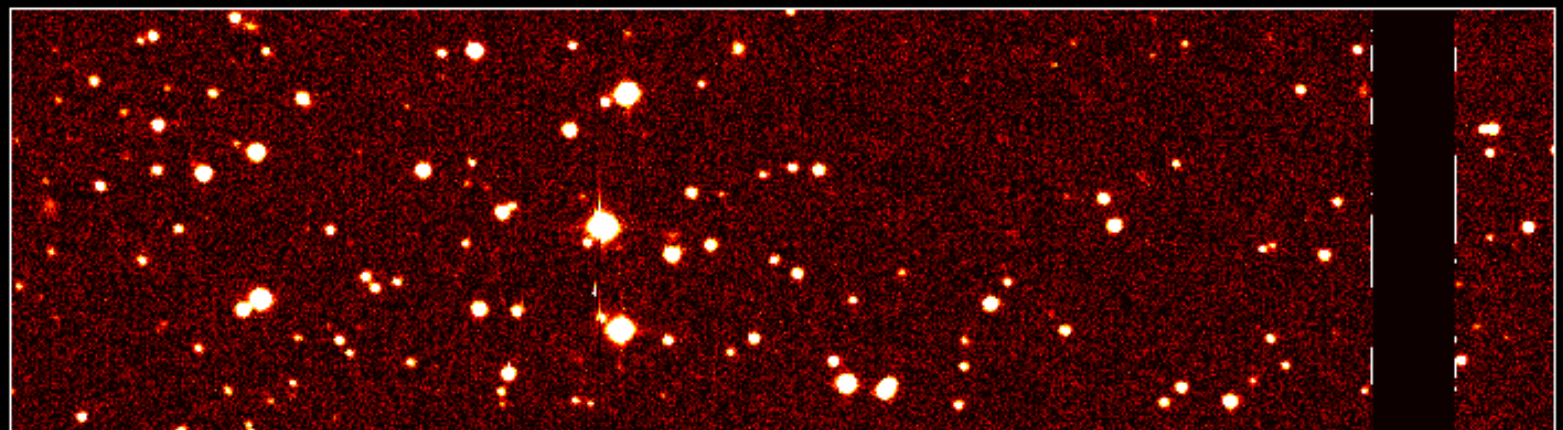


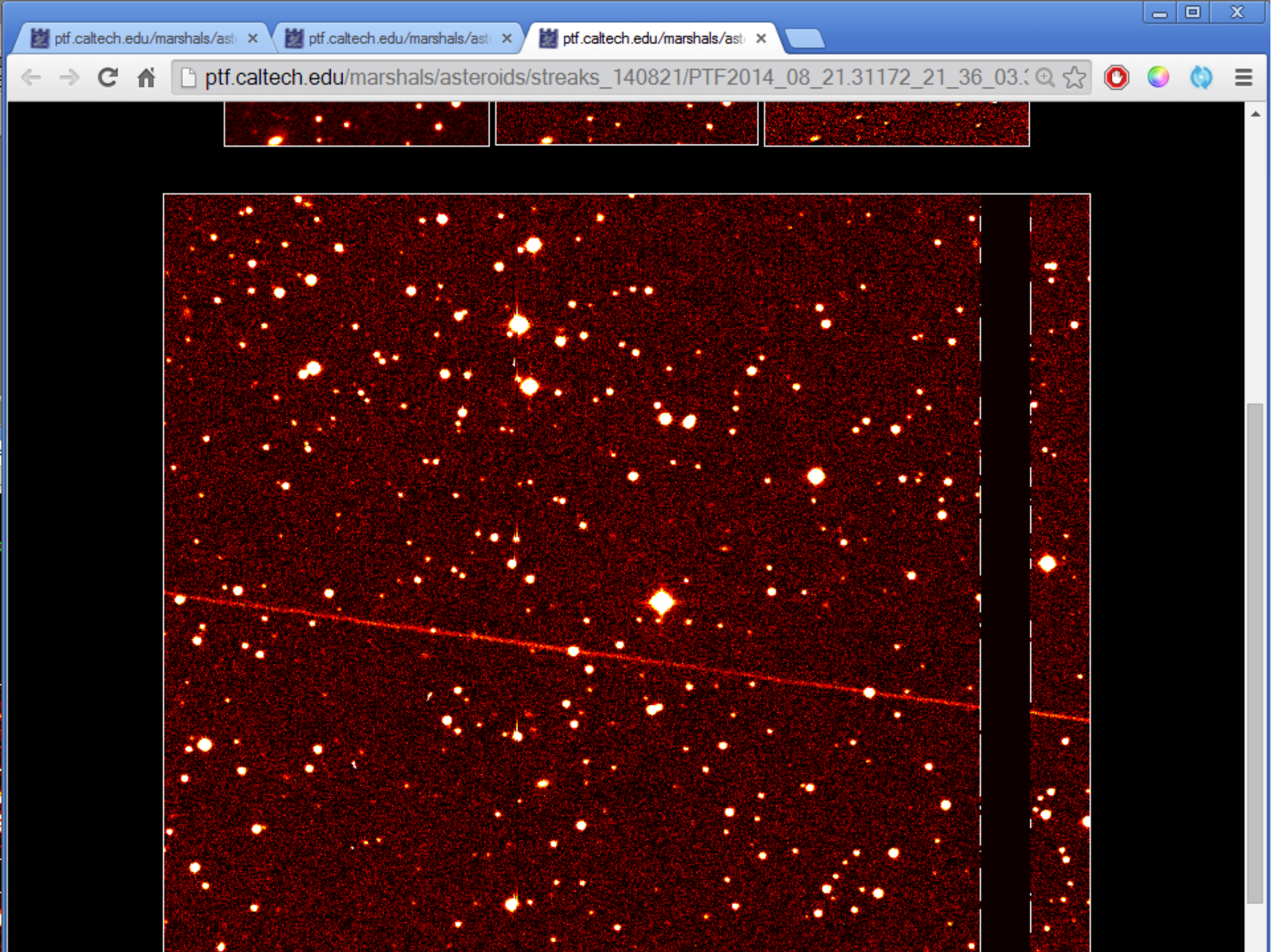
New Image



Difference Image





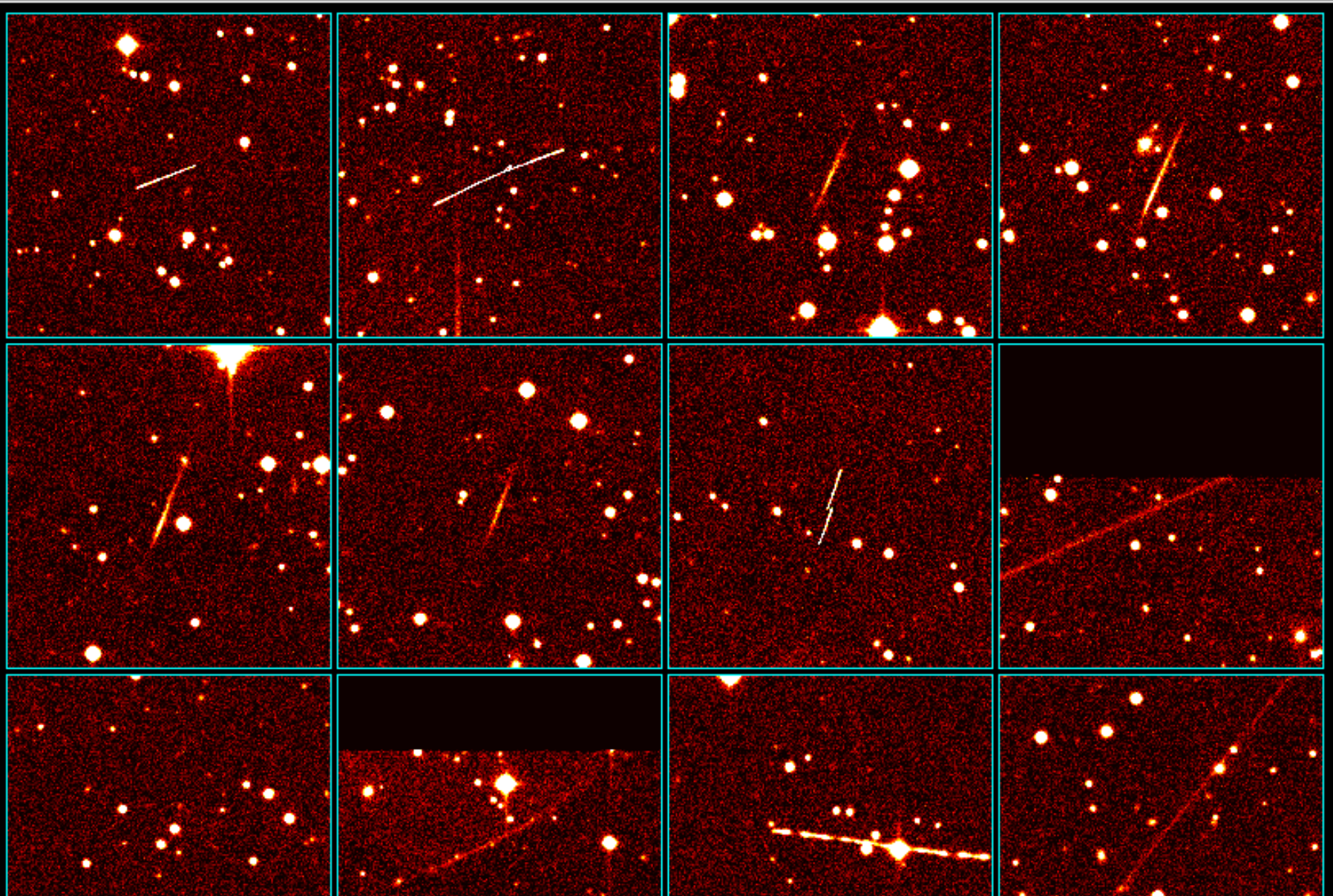

ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/asteroids/streaks_140821/PTF2014_08_21.31172_21_36_03.

ptf.caltech.edu/marshals/ast × ptf.caltech.edu/marshals/ast ×

ptf.caltech.edu/marshals/asteroids/streaks_140821/candidates_0.7.html

PTF streak candidates (p > 0.7) for 2014-08-21

Updated: 2014-08-21 12:40 UT (Thu 05:40 AM Pacific) Latest image: 62 minutes old 29 candidates total



MPC observation line (80-character string):

```
     PTFxxx * C2014 08 21.43198 23 47 06.38 +40 04 19.3          17.0 r      I41
```

realBogus score: 0.71

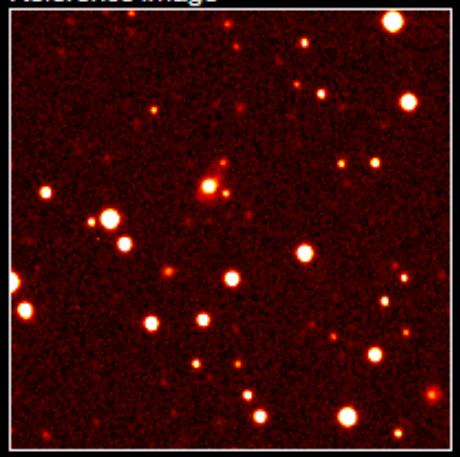
Generate single-observation ToO map

Next available PTFxxx codes for labeling MPC-submitted discoveries

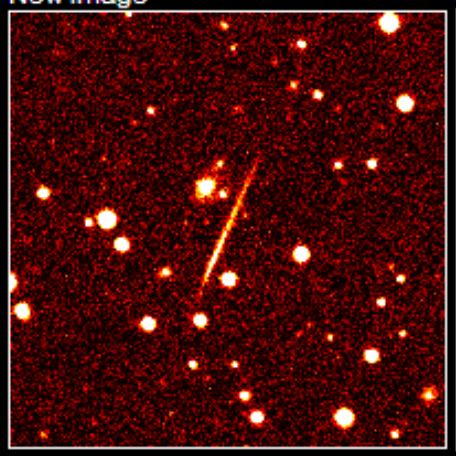
Updated: 2014-08-21 18:44 UT
(Thu 11:44 AM Pacific)

PTF1j1
PTF1j2
PTF1j3
PTF1j4
PTF1j5

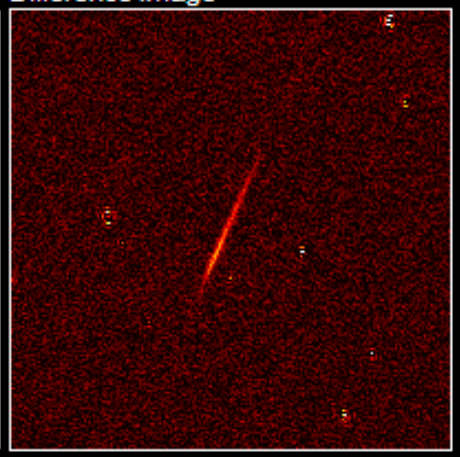
Reference Image

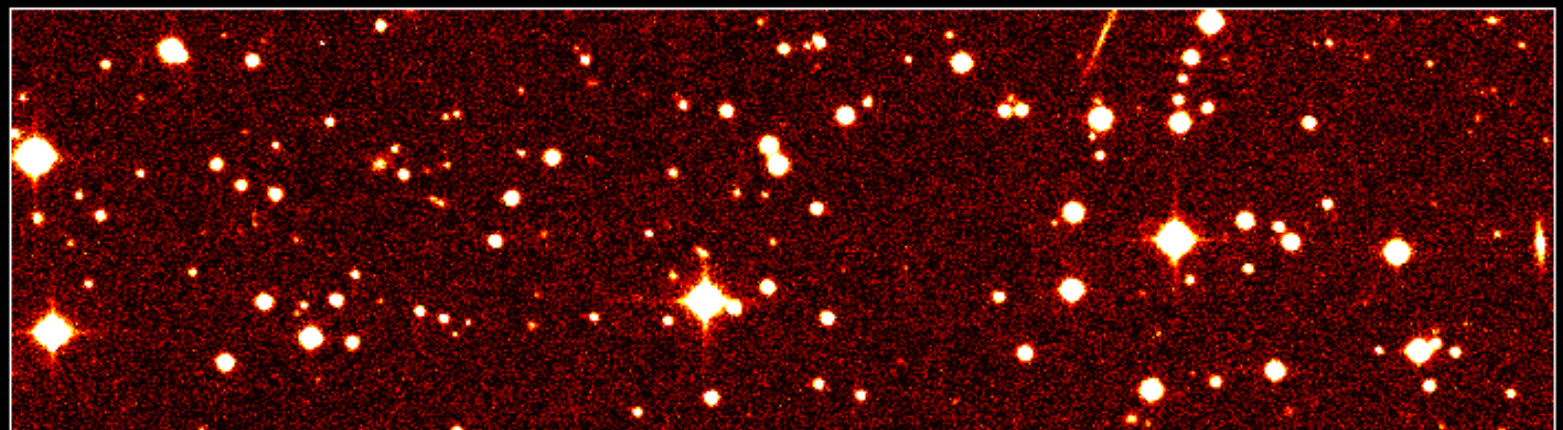


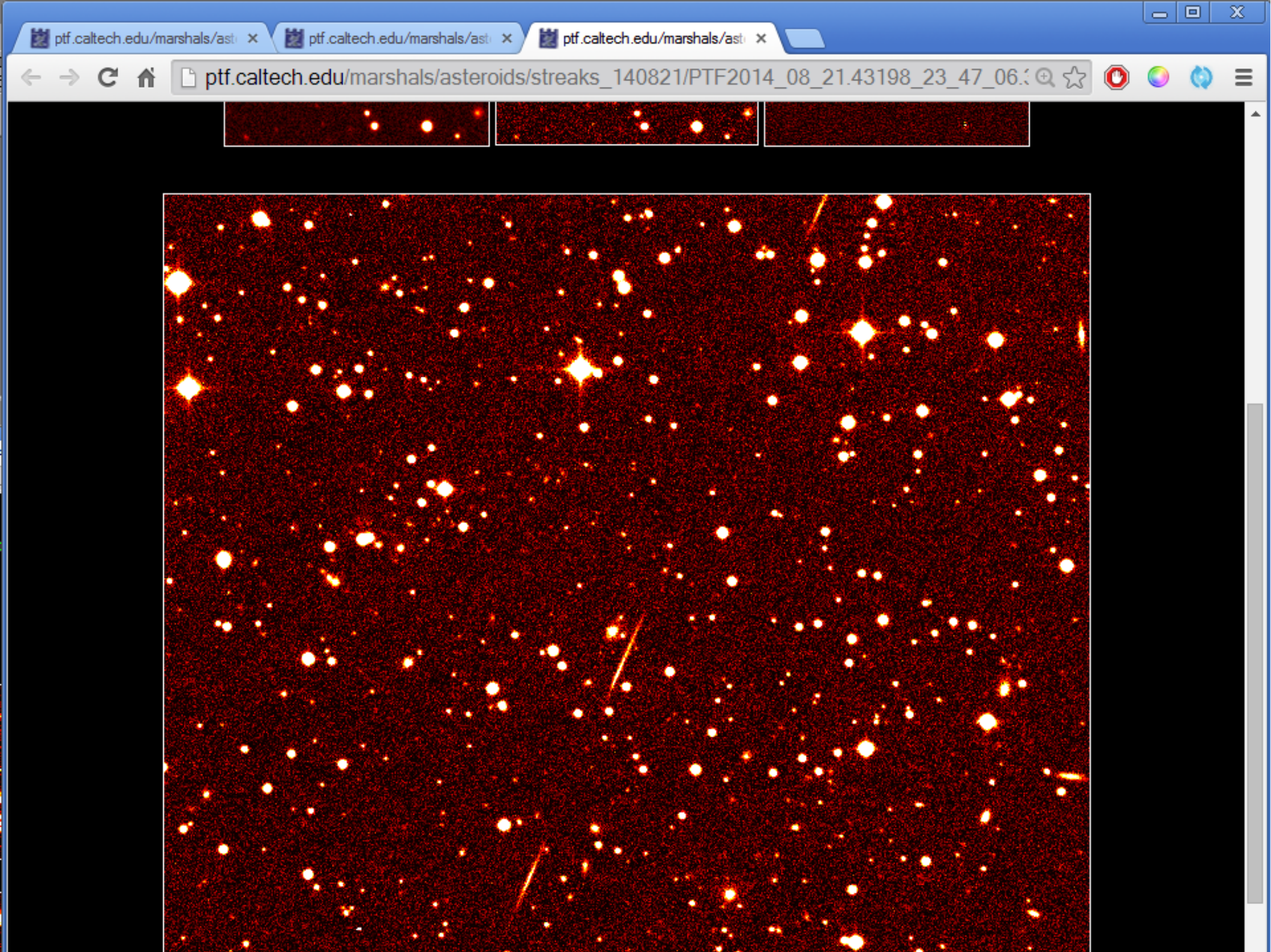
New Image



Difference Image






ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/ast
ptf.caltech.edu/marshals/asteroids/streaks_140821/PTF2014_08_21.43198_23_47_06.

PTF Solar System Marshal

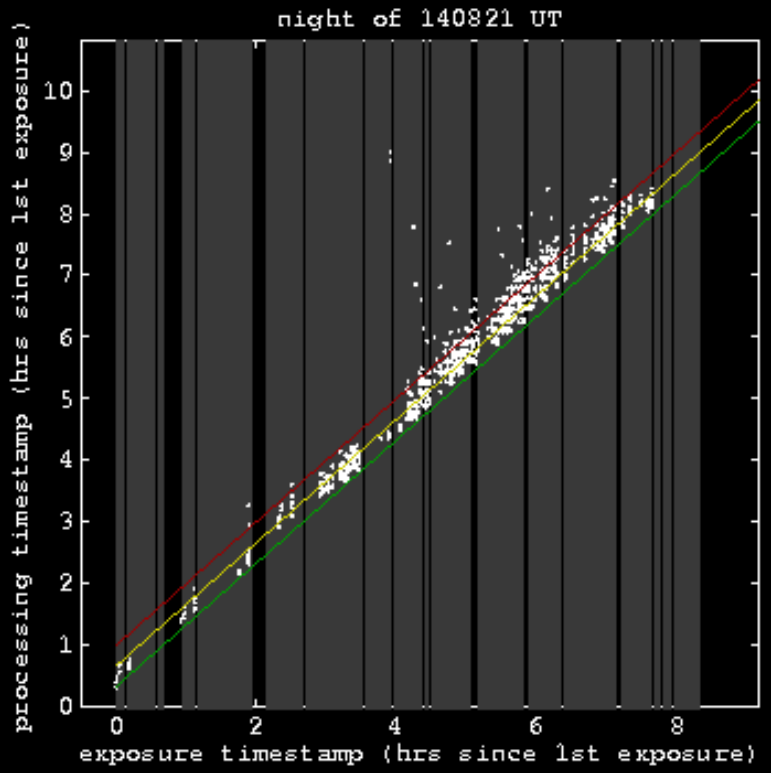
Updated: 2014-08-21 13:17 UT (Thu 06:17 AM Pacific)

Known NEAs Observable Tonight | Current PTF discoveries on the NEOCP | Past PTF discoveries on the NEOCP
Nightly Efficiency of homebrewMOPS | List of all PTF solar system discoveries

Join the iptfasteroids@astro.caltech.edu Mailing List

IPAC Real-time Processing Status

(about this plot)



Read the Scanning Guide

Tonight's Streak Candidates

(UT 2014-08-21)

Newest candidates are 80 minutes old

29 candidates with p > 0.7

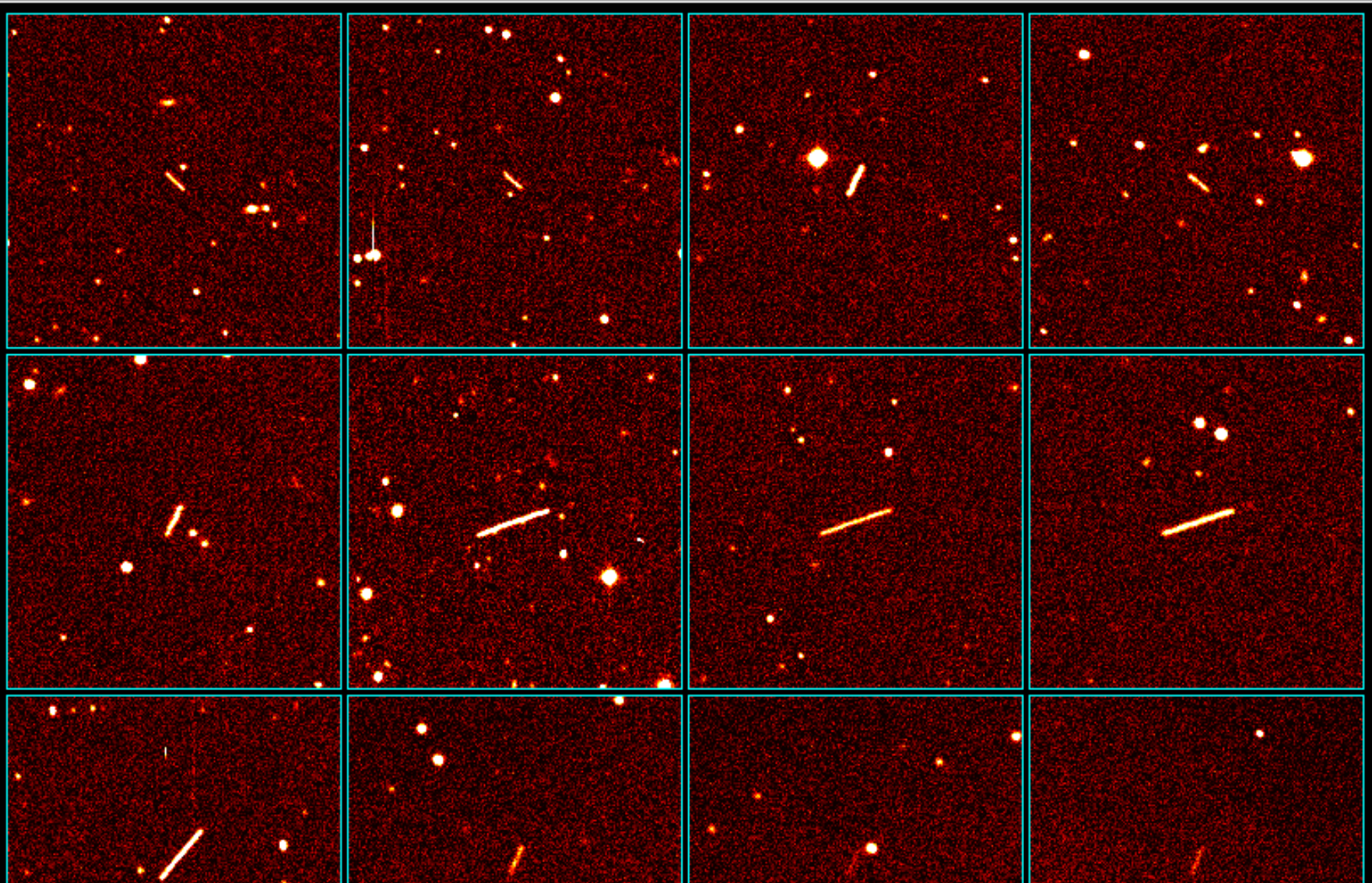
593 candidates with p > 0.5

View examples of real asteroid streaks

Current Palomar All-Sky View

Real PTF streaking asteroid detection examples

Included here are all known streaking asteroid detections in PTF, from March 2009 through February 2014. All of these were successfully detected by the streak detector, though not necessarily with a high real/bogus probability. In all cases the real streak is located at the center of the image. In some cases there are additional real-looking streaks nearby in the image, these are synthetic streaks that were injected randomly in the course of a detection efficiency test that we performed.

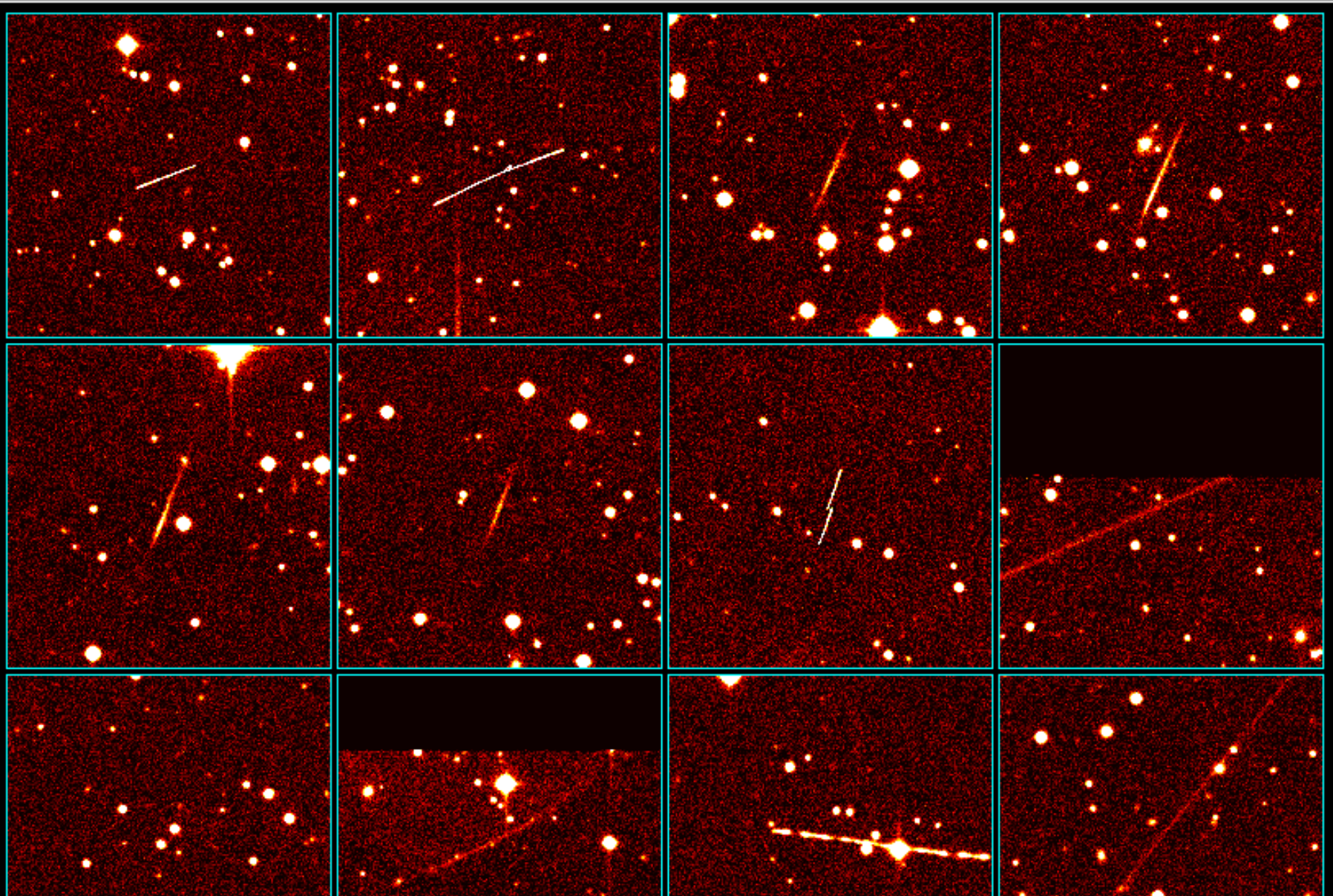


ptf.caltech.edu/marshals/ast × ptf.caltech.edu/marshals/ast ×

ptf.caltech.edu/marshals/asteroids/streaks_140821/candidates_0.7.html

PTF streak candidates (p > 0.7) for 2014-08-21

Updated: 2014-08-21 12:40 UT (Thu 05:40 AM Pacific) Latest image: 62 minutes old 29 candidates total



MPC observation line (80-character string):

```
     PTFxxx * C2014 08 21.47506 00 49 29.43 +37 53 50.3          17.0 r      I41
```

realBogus score: 0.78

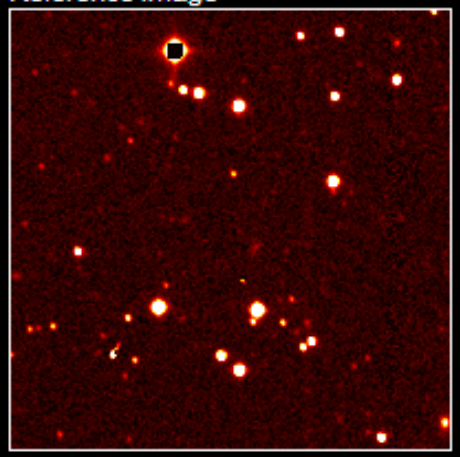
Generate single-observation ToO map

Next available PTFxxx codes for labeling MPC-submitted discoveries

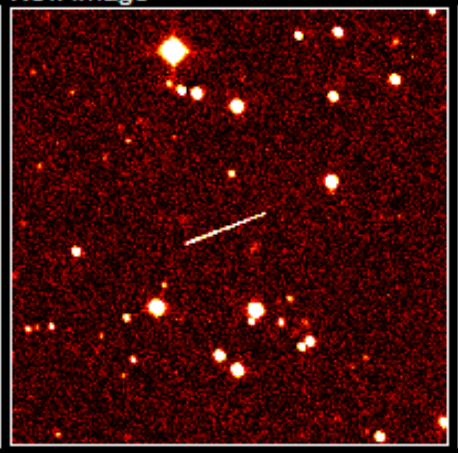
Updated: 2014-08-24 23:59 UT
(Sun 04:59 PM Pacific)

PTF1j1
PTF1j2
PTF1j3
PTF1j4
PTF1j5

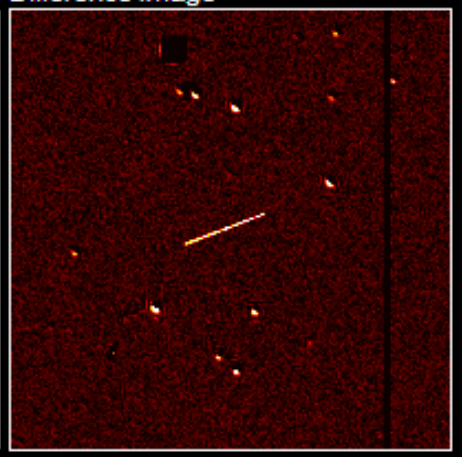
Reference Image

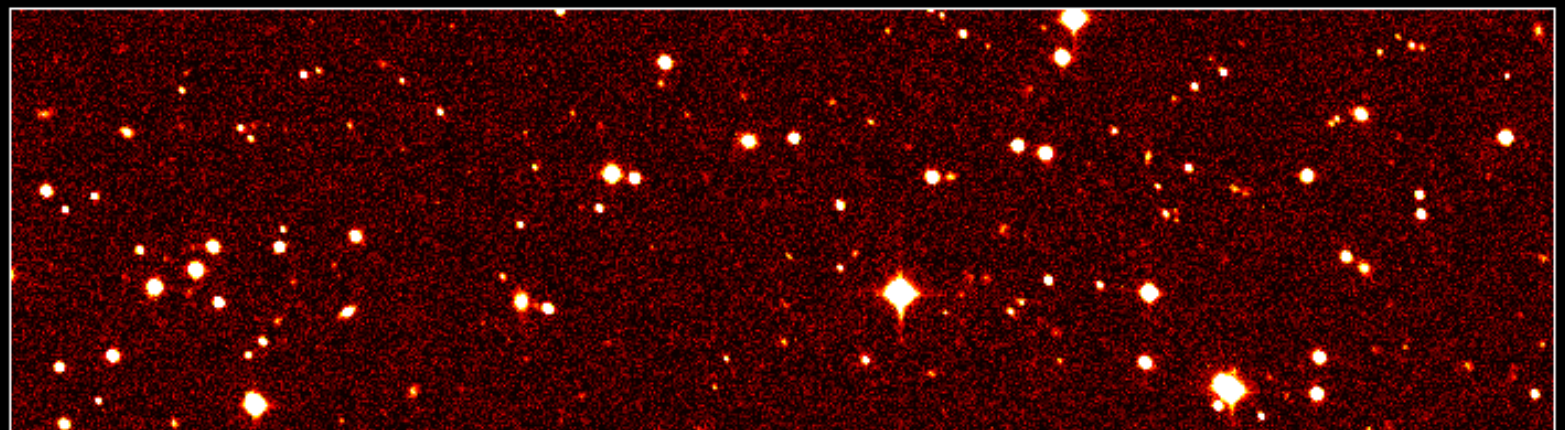


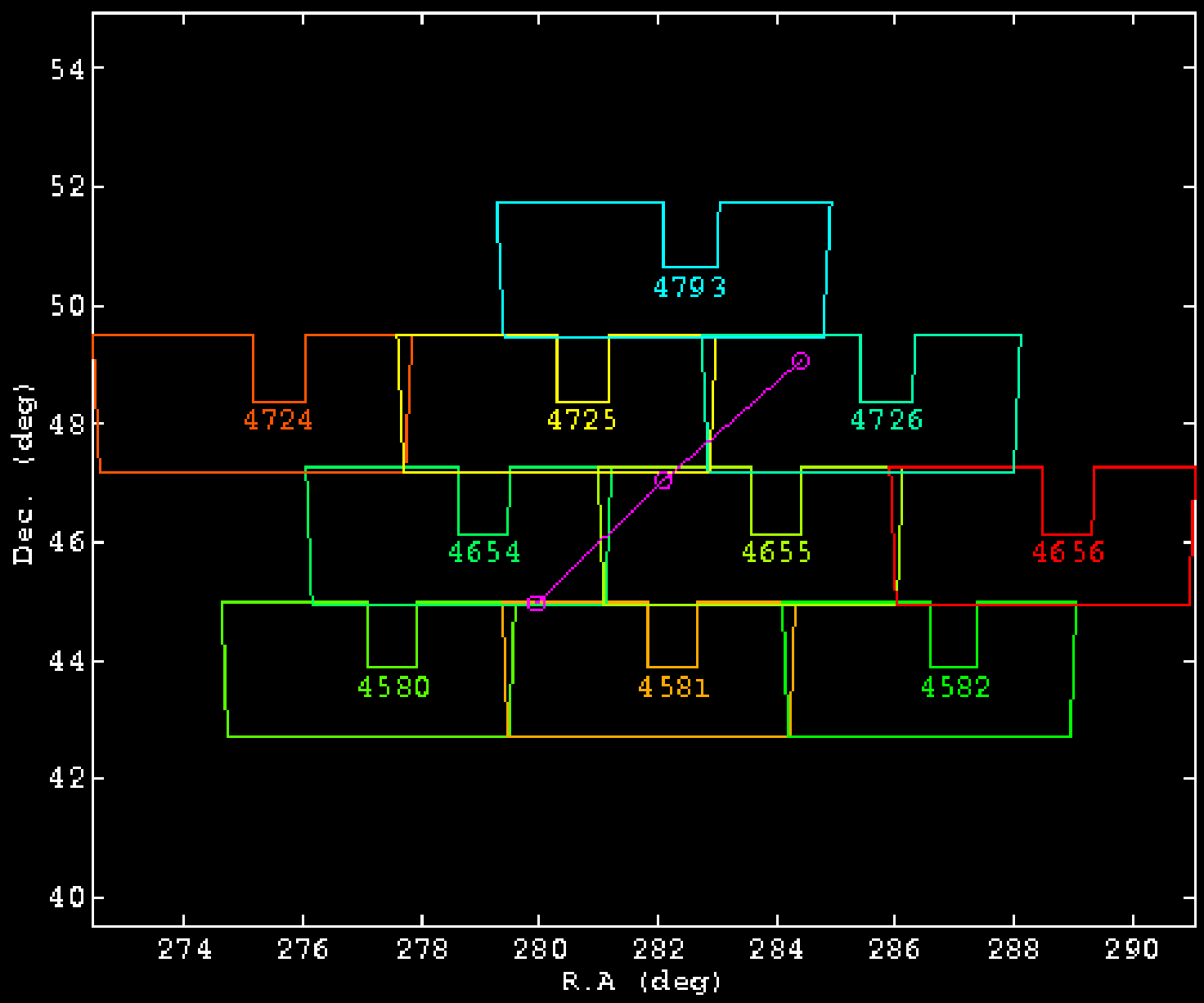
New Image

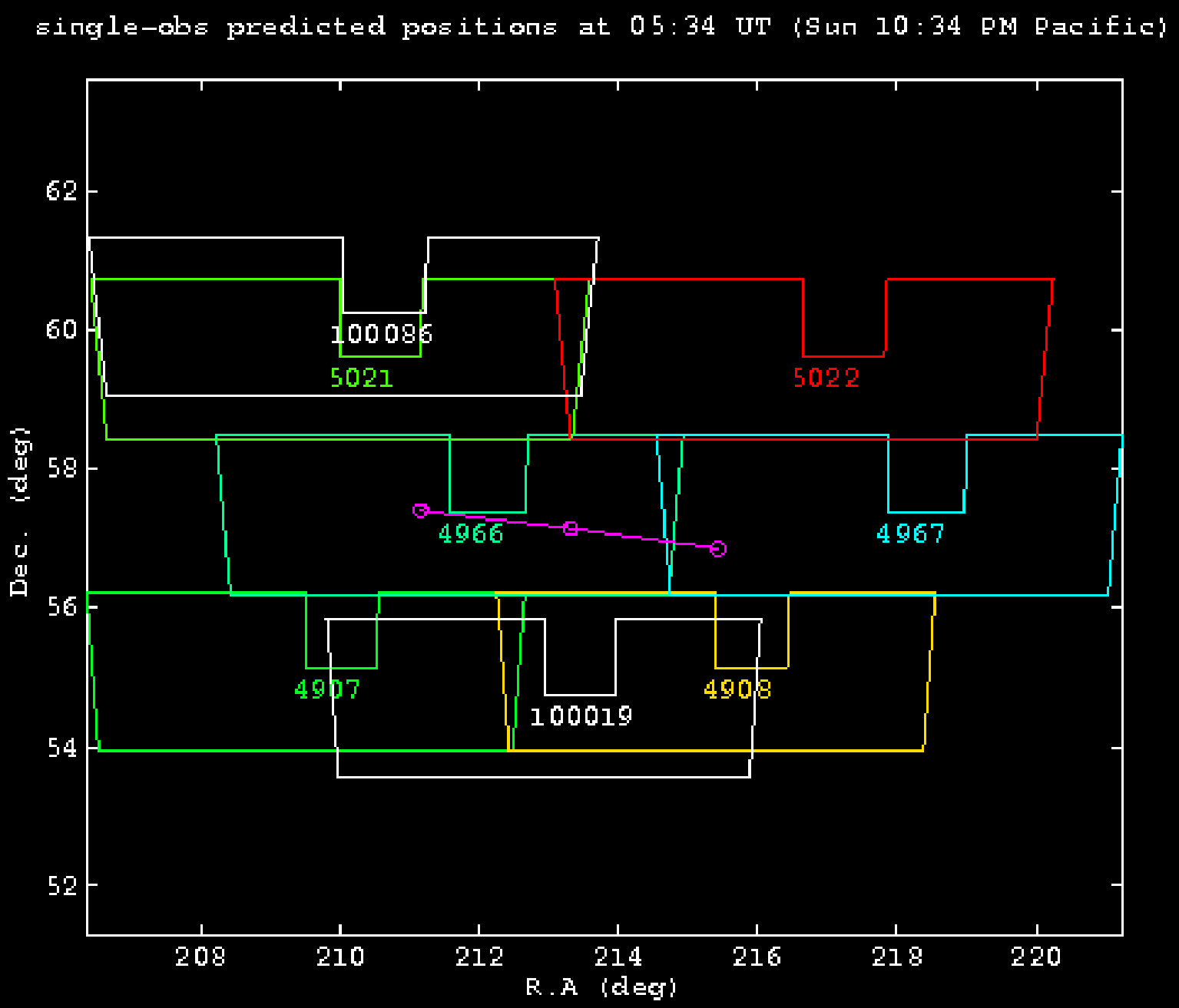


Difference Image






single-obs predicted positions at 13:52 UT (Thu 06:52 AM Pacific)
Dec. (deg)
R.A (deg)
54
52
50
48
46
44
42
40
274
276
278
280
282
284
286
288
290
4793
4724
4725
4726
4654
4655
4656
4580
4581
4582


single-obs predicted positions at 05:34 UT (Sun 10:34 PM Pacific)
62
60
58
56
54
52
Dec. (deg)
208
210
212
214
216
218
220
R.A (deg)
100086
5021
5022
4966
4967
4907
100019
4908

Coming soon:

- Larger fraction of NEA-optimized survey time
- ToO-interface for streak scanners
- Updated version of machine classifier (larger training set & integration of more morphological features)
- Integration Frank's PTFMOPS and inclusion of slower-moving objects into scanning marshal
- Hosting of asteroid lightcurves, like the Galactic Marshal (project with NCU group)