National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology

NEO Search with Small Synthetic Tracking Telescopes

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JPL/Caltech

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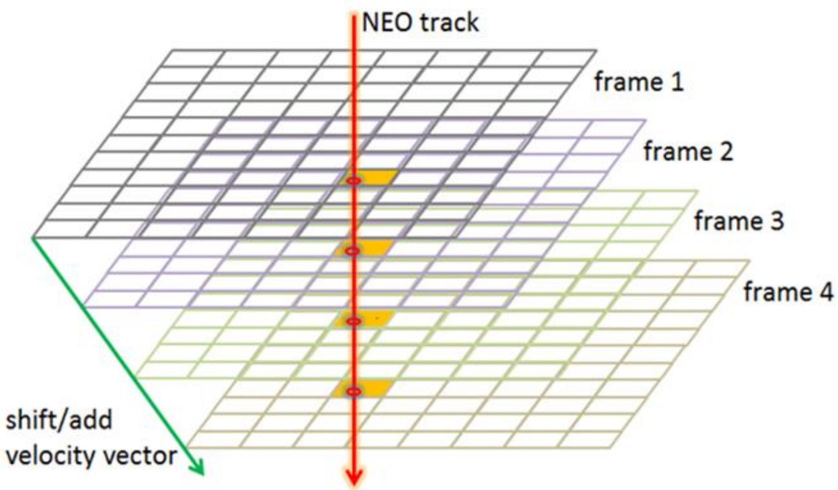
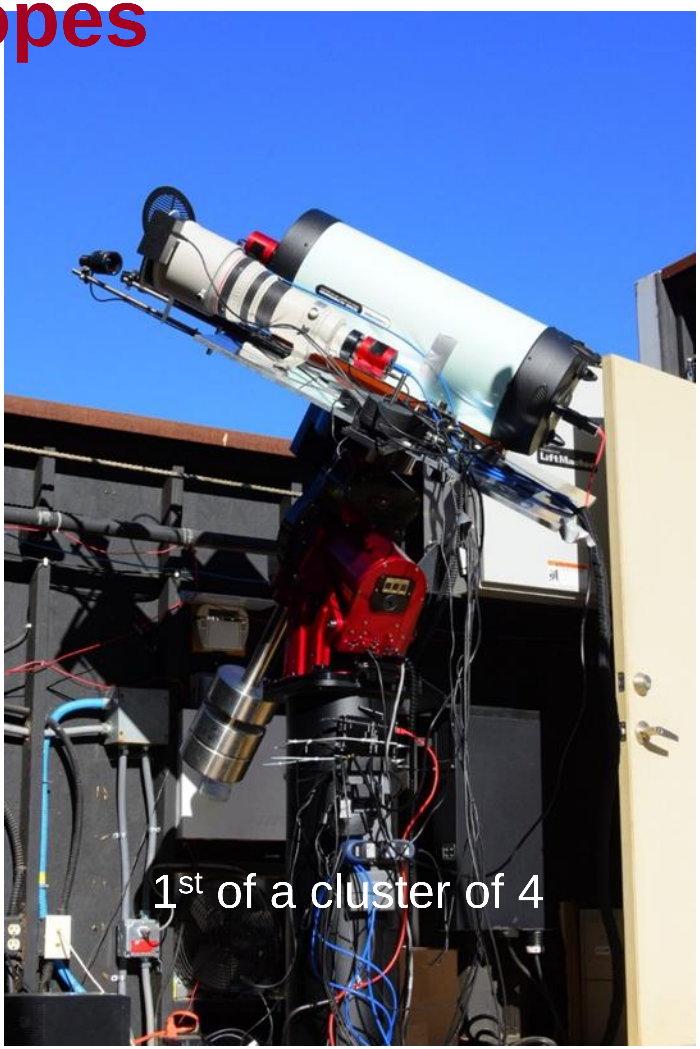
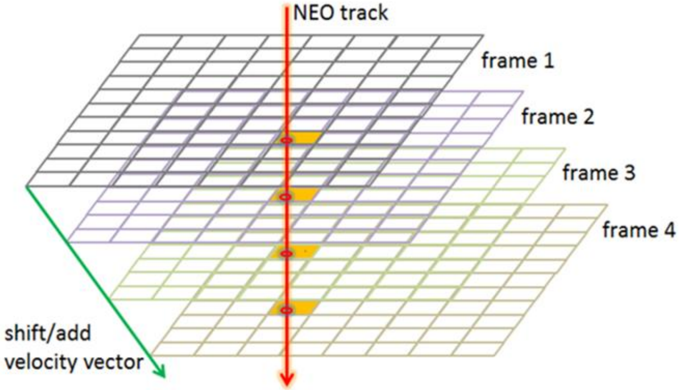


Current Discovery Rate ~2000? NEOs/year



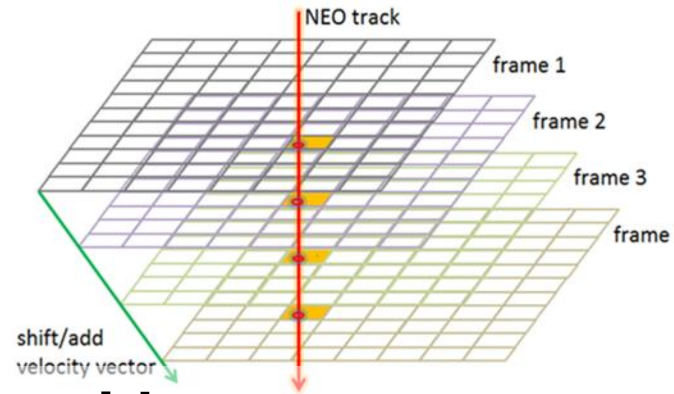
Outline

- What is synthetic tracking?
- Operational Parameters (Sensitivity)
- NEO Search simulation (Granvik pop)

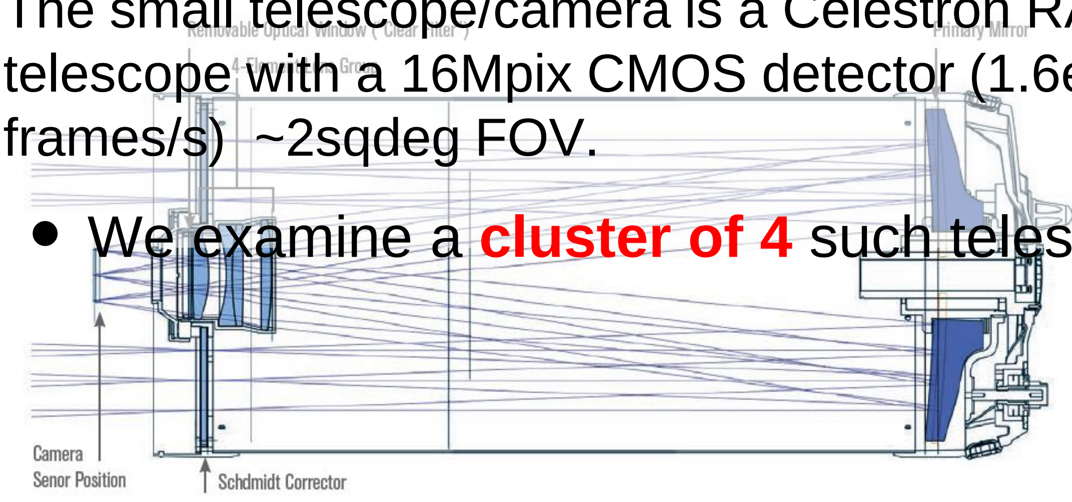


- Faster moving objects, 2017U1 interstellar asteroid(s) and earth orbiting objects.
- Low cost syn-tracking telescopes and amateur astronomers.

Synthetic Tracking
(detection of moving objects)

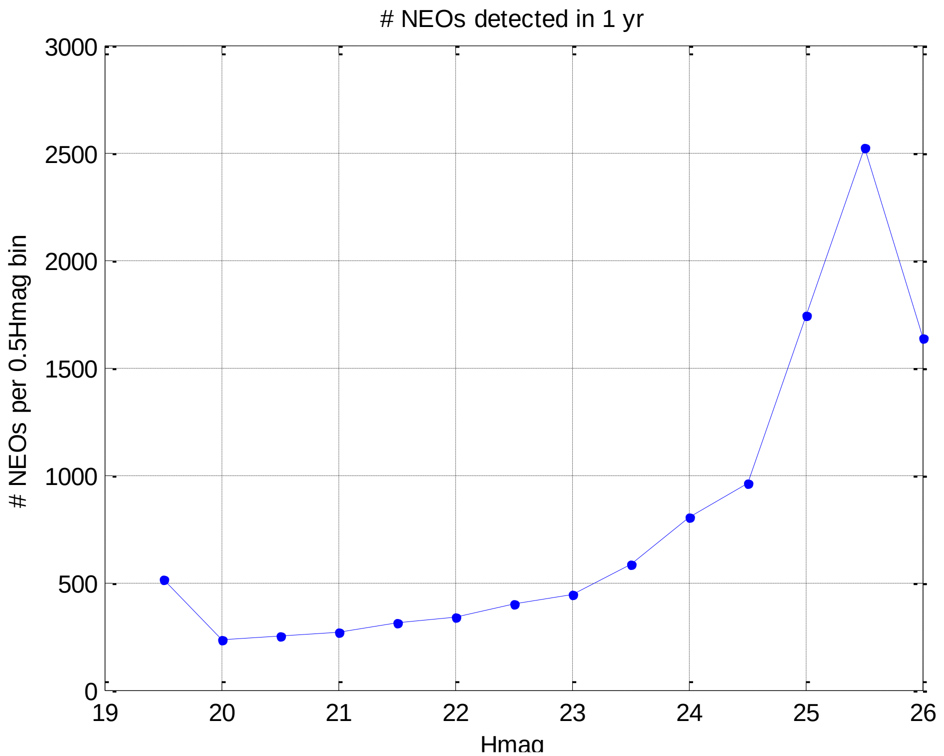


- **Synthetic tracking (NEOs) uses multiple short exposures (vs 1 long one) with sCMOS cameras.**
- **The data cube is analyzed with a multi-vector shift/add algorithm (in a GPU). With 2500~10,000 velocities. (no loss of sensitivity from streaked images)**
- The small telescope/camera is a Celestron RASA f/2.22 28cm dia telescope with a 16Mpix CMOS detector (1.6e read noise up to 10 frames/s) ~2sqdeg FOV.
  - We examine a **cluster of 4** such telescopes for NEO search



NEO Search Simulation

- Start with Granvik NEO population model
- Simulate 1 yr operation (ignoring Sun, Moon etc) 11,000 NEOs/yr
  - Cluster of 4 telescopes with total 8 sqdeg FOV
- Ground based telescope(s) **~1650 /yr**
  - 8hrs vs 24 hrs
  - 60% due to Moon
  - 80% from weather



Limiting mag	21.1mag	21.7m sky
1 exposure	5~10s	
Total Integ	450 s	
Sky	<60deg	Anti-Sun
Tel Dia/Pix	28cm	1.27 asec
#pix/FOV area	16Mpix	2.0 sqdeg

Low Cost SynTracking Telescopes Amateur Astronomers?

- Each of the 4 telescope/cameras, a Celestron RASA (11 inch) telescope and camera costs < $5,000.
  - A cluster of 4 and a PC/GPU could be assembled for ~ $40K
- The most ambitious amateur, who's contacted us is Alain Maury, who operates a small telescope farm in the Atacama Desert. (spaceobs.com)
  - 4 Celestron telescopes & cameras purchased
- When both sites are fully operational ~2900 NEOs/yr

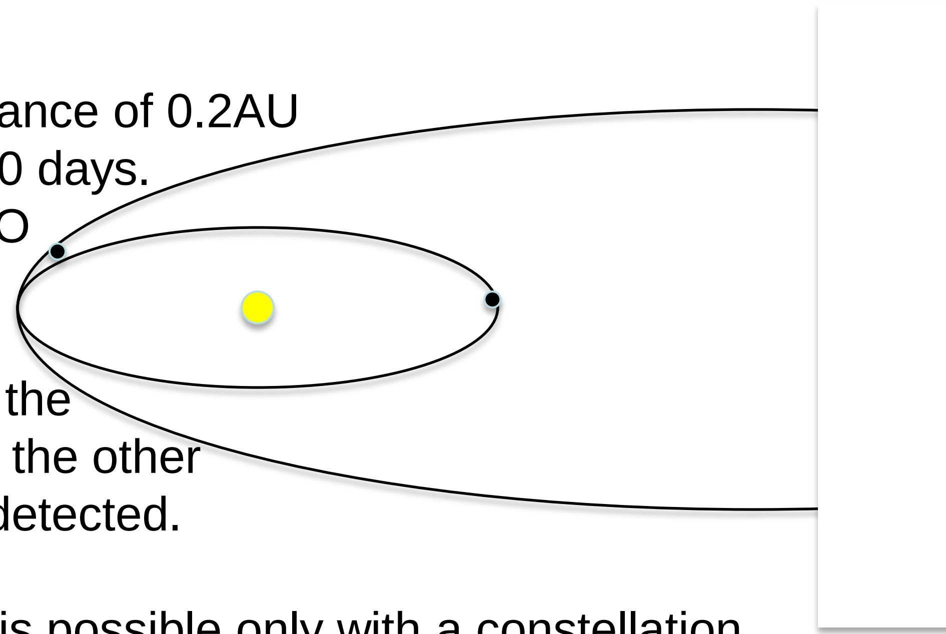
Interstellar Asteroids (and faster objects)

- The first interstellar asteroid was discovered with Panstarrs in 11/2017. At its closest approach A/2017U1 was ~0.2 AU from the Earth. At its ~brightest, 19mag @ 0.2 AU from Earth, moving at ~7.5deg/day ~ 0.3 arcsec/sec
  - For objects moving at this speed Syn tracking would be ~10X more sensitive (vs 30s CCD). (seeing objects with 2.5Hmag fainter)
  - 50~80X more objects (if their size distribution is similar to our NEOs)
- Other faster objects are Earth orbiting objects. (Geo 15as/s)
- The advantage of SynTracking for these objects is huge.
  - The USAF operates a global network of telescopes for SSA (GEODSS network)
  - USAF plans to deploy SynTracking to the GEODSS network over the next ~3 years.

Finding 90% of H=22mag (or 23mag) NEOs And the Saturation Effect

- A number simulations have been conducted on different instruments/facilities/misssion to attempt to find 90% of H=22mag NEOs. They all take > 10 years.
- Can adding more observatories, on the ground and in earth orbit find 90% of H=22mag NEOs is < 10yrs? **NO**

Assume we can detect a NEO at a distance of 0.2AU
At 10km/s it will be detectable for 30~40 days.
Saturation occurs when the sum of NEO
Covers ~20,000sqdeg in << 30 days.

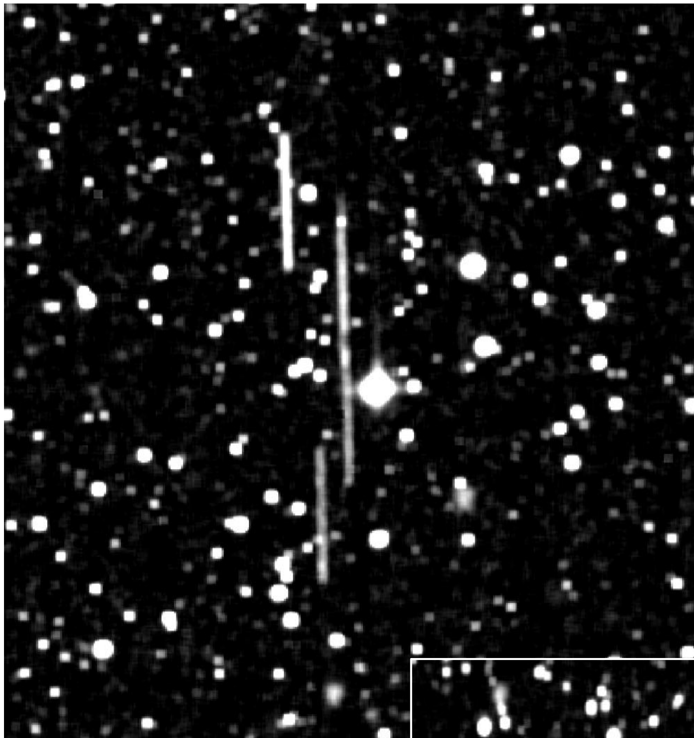


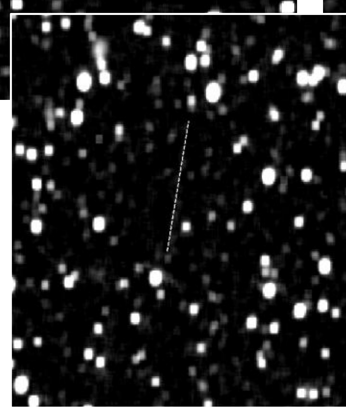
47% of NEOs have period > 3yrs but if the
NEO comes within 1 AU of the Sun, on the other
side from where Earth is. It will not be detected.

A search for 90% of NEOs in << 10yrs is possible only with a constellation of observatories in Solar orbit.

Backup Sample Data

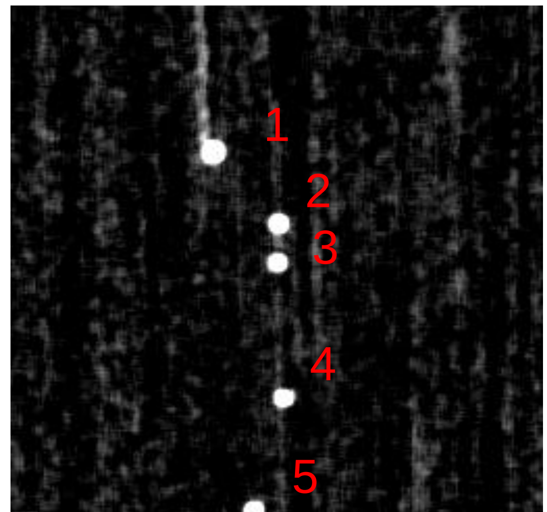
Zero Velocity Image (6 satellites)

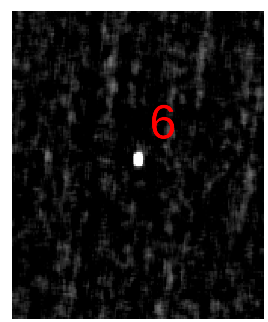




0 DN 500 DN

Synthetically Tracked Images
(Static Stars Removed)





0 DN 150 DN

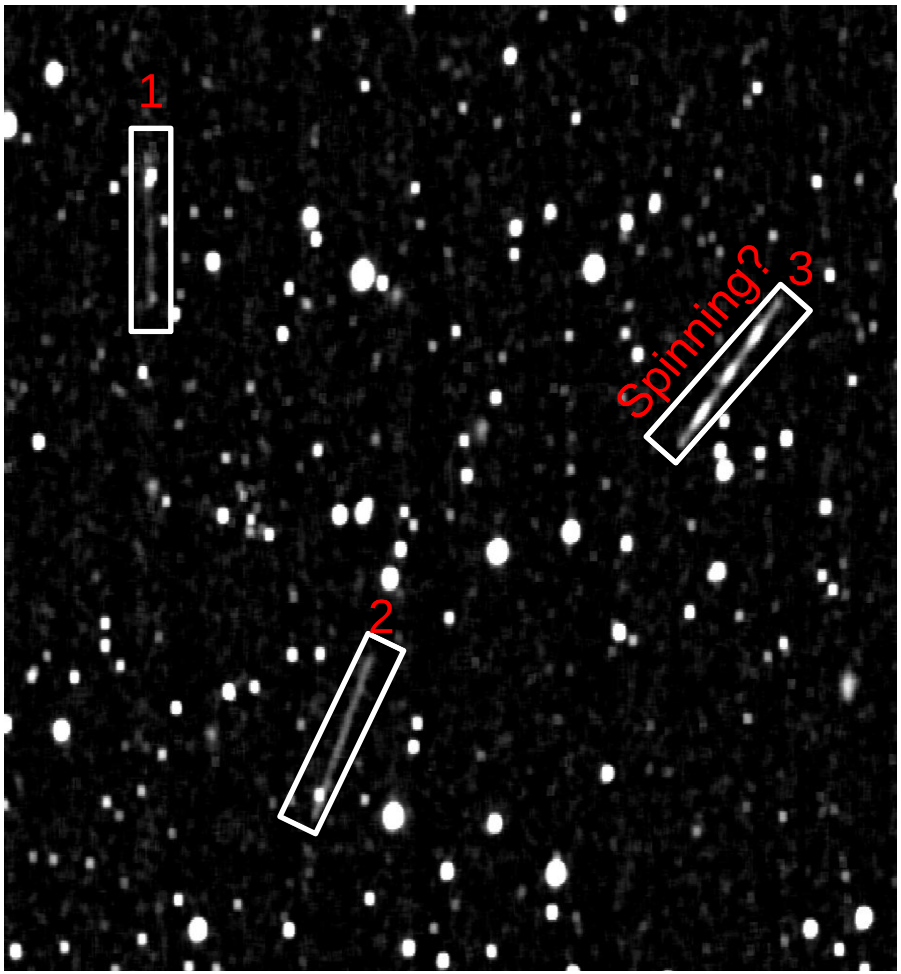
0.7 e/dn

Obj	Peak Intensity	Velocity
1	7258 DN	2.57 pix/s
2	3326 DN	2.59 pix/s
3	2704 DN	2.57 pix/s
4	1194 DN	2.57 pix/s
5	3597 DN	2.57 pix/s
6	453 DN	2.58 pix/s

Object 6 has a flux of ~11 phot/sec on the detector (143mm Dia Lens)

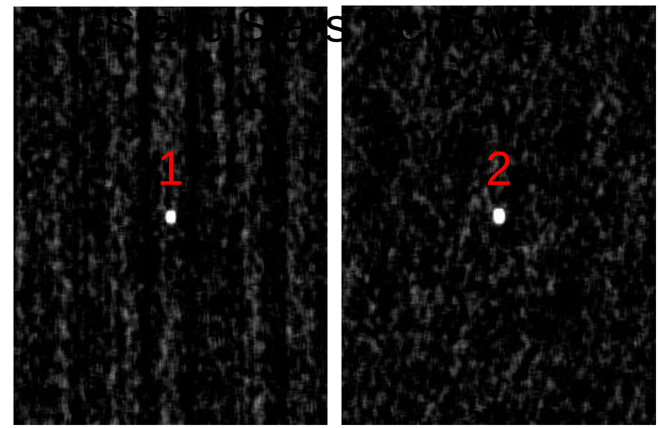
Zero Velocity Image (3 satellites)

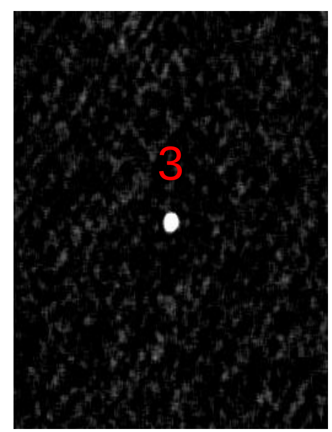
Motion in the vertical direction in these images => satelllite in a 0 deg inclination orbi



0 DN 500 DN

Synthetically Tracked Images





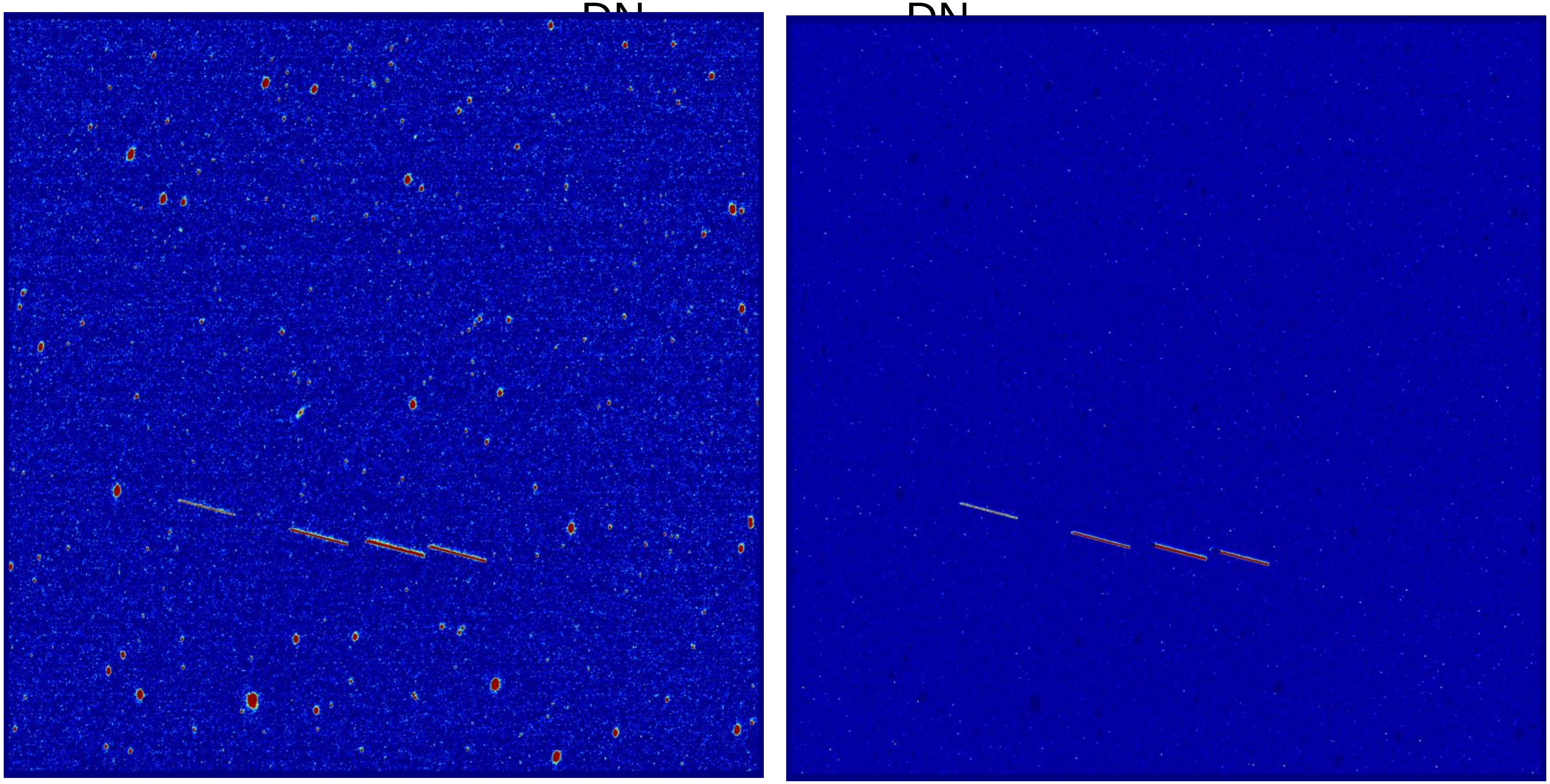
0 DN 150 DN

Obj	Peak Intensity	Velocity
1	902 DN	2.59 pix/s
2	2022 DN	2.86 pix/s
3	4687 DN	3.19 pix/s

Sky Removed

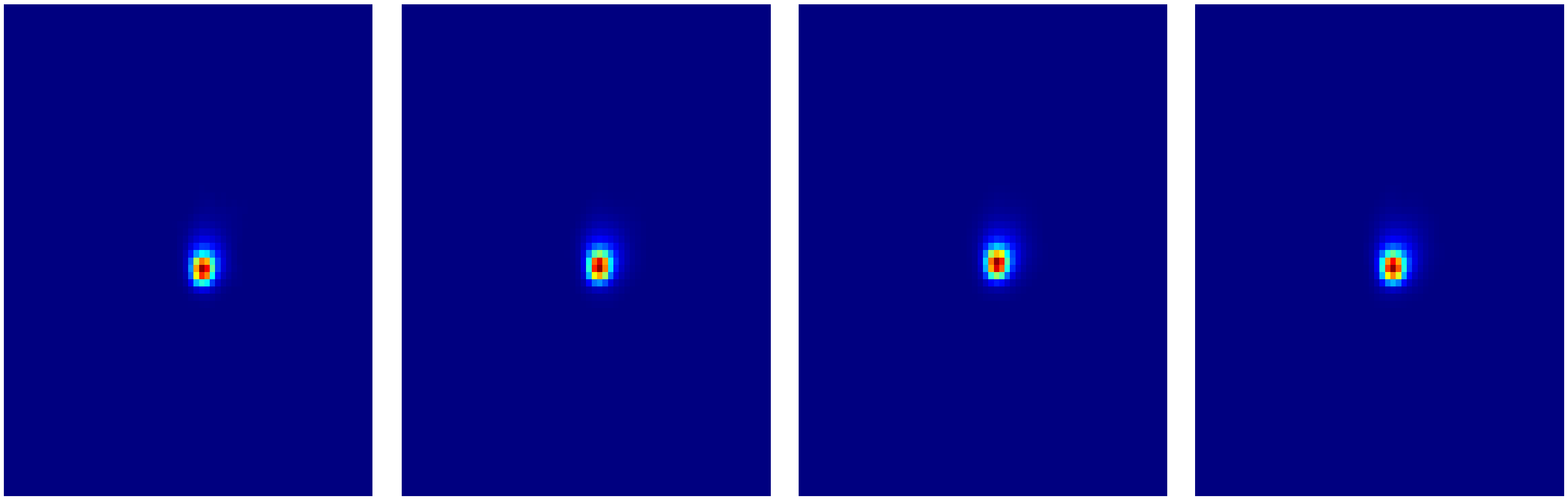
Stars, Sky, & Bias Drift Removed

Image Mean	~0
Image StDev	7.629 DN



We're continuing to make progress at getting the spatial noise very close to the ave
In this example we're able (after star removal) to get the spatial background down t

4 Satellites – Images after PSF Fit



0 DN  Brightest Pix

PSF Fit

Vx [pix/frame]	Vy [pix/frame]	X	Y	Brightest Pixel
0.7336784	0.1448973	455.968262	757.78656	4510
0.73329103	0.144445136	799.6616	825.3721	9371
0.733404	0.1445774	1033.90344	852.029968	14637