A TESS Search for Distant Planets

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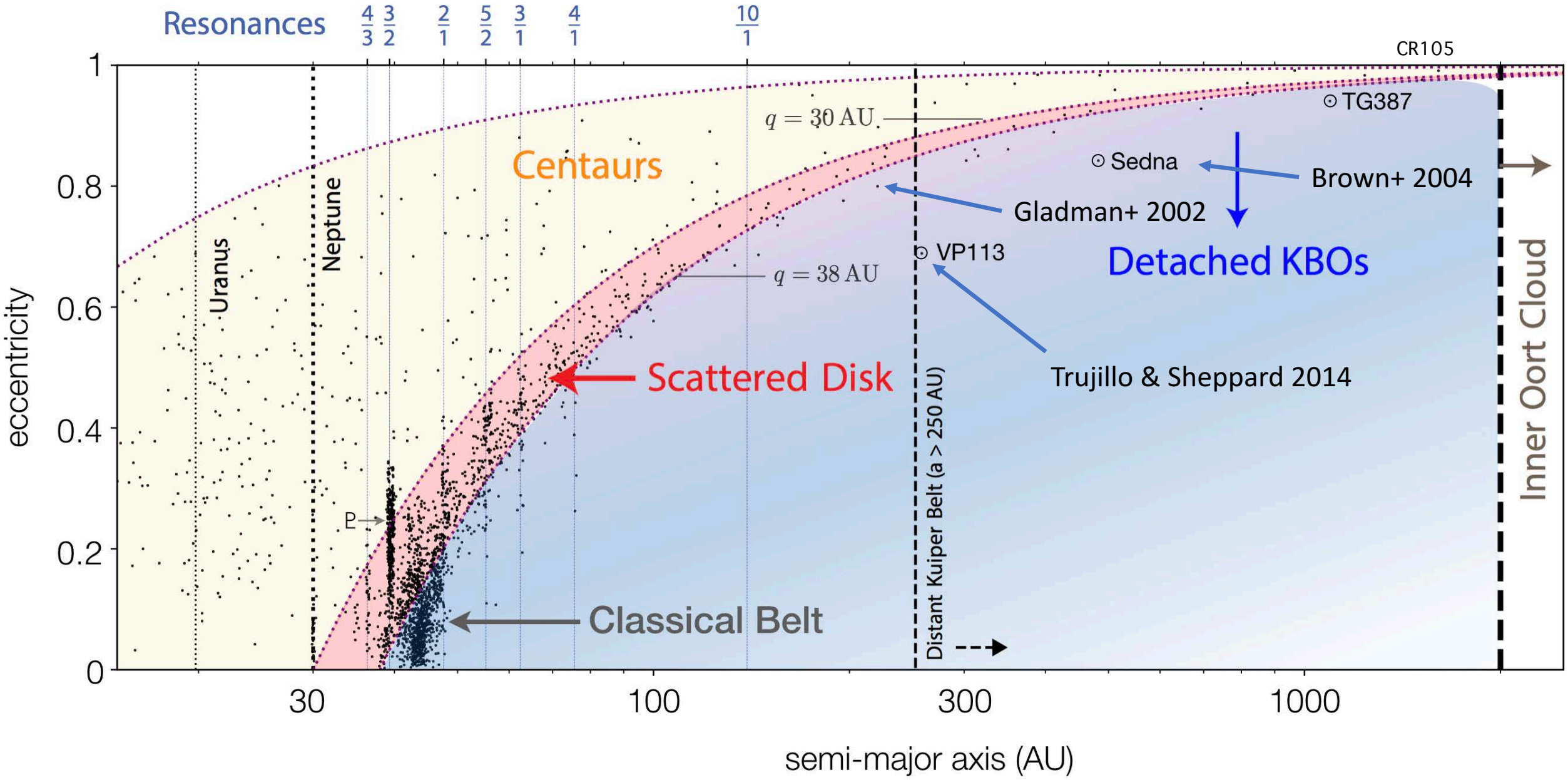
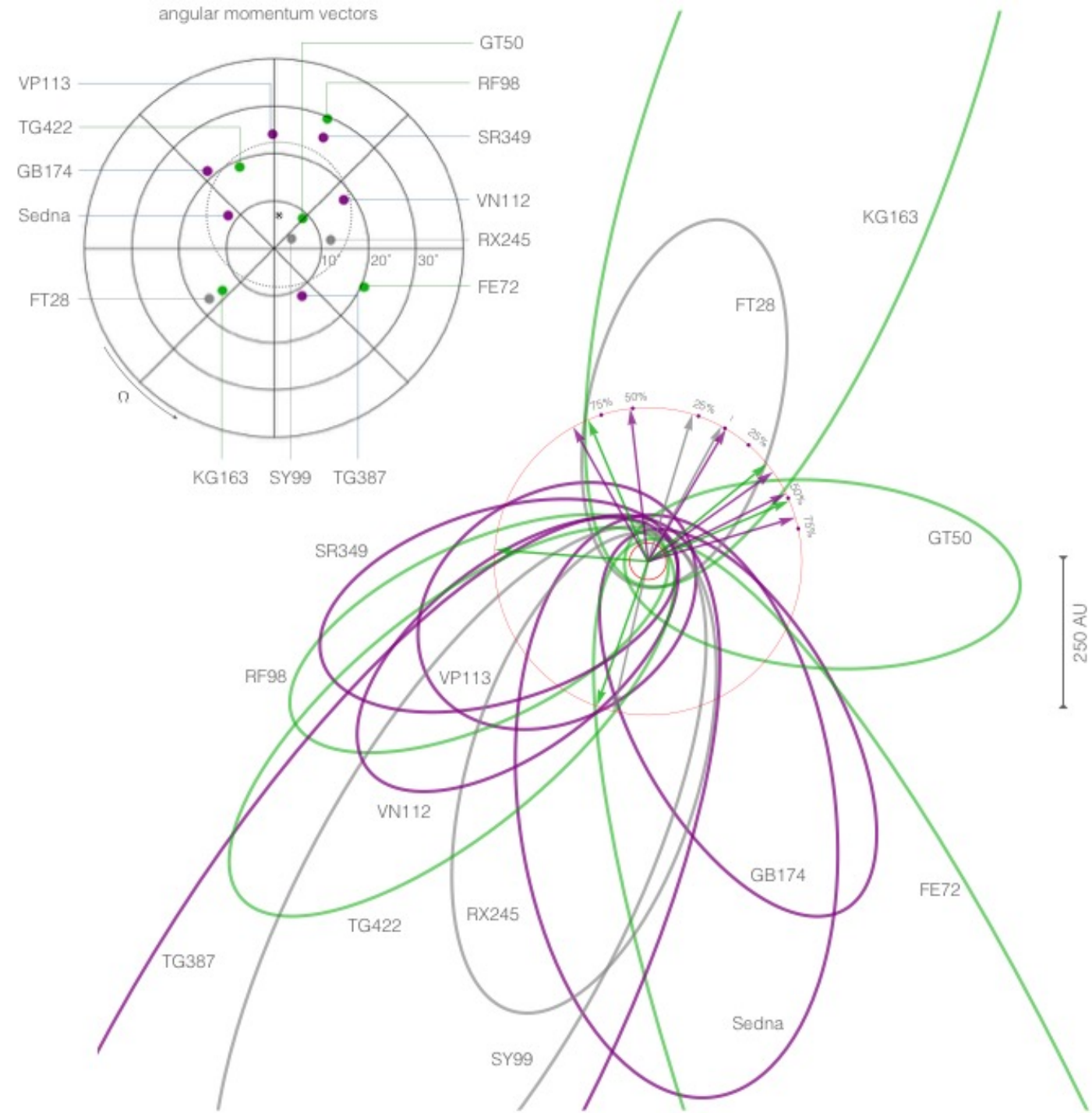
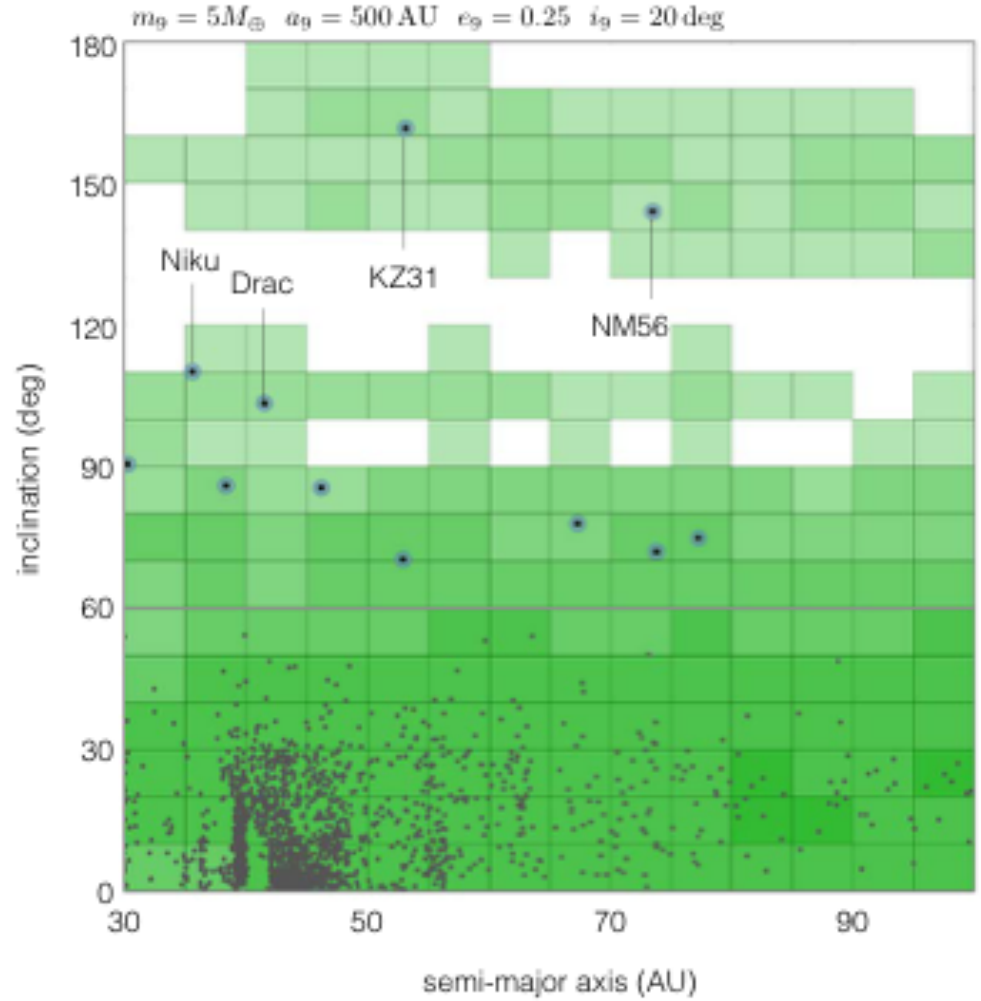
Special thanks:

- Andras Pal
- Deb Woods

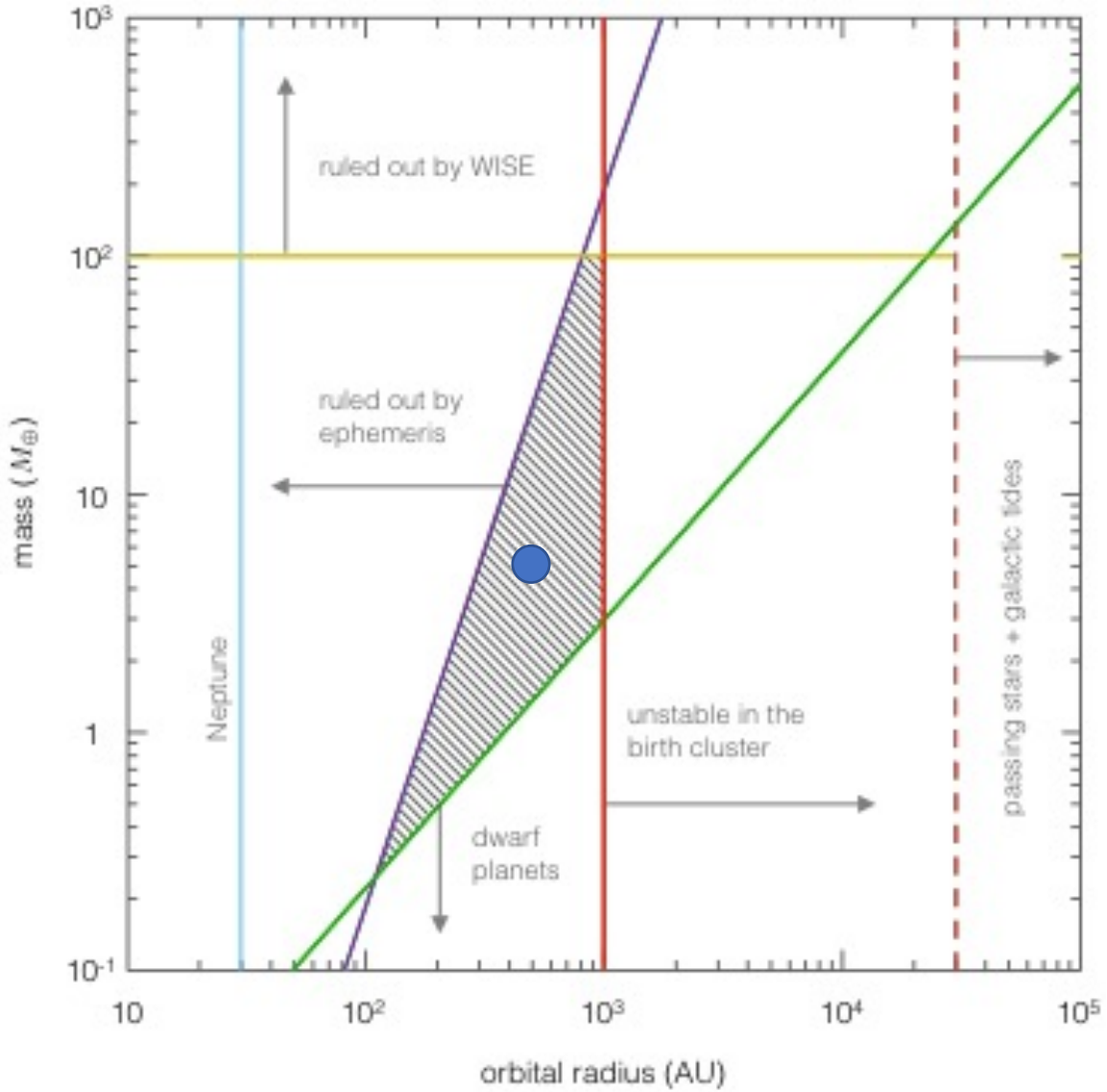


Batygin+ 2019 'The Planet 9 Hypothesis'





Batygin+ 2019



Batygin+ 2019

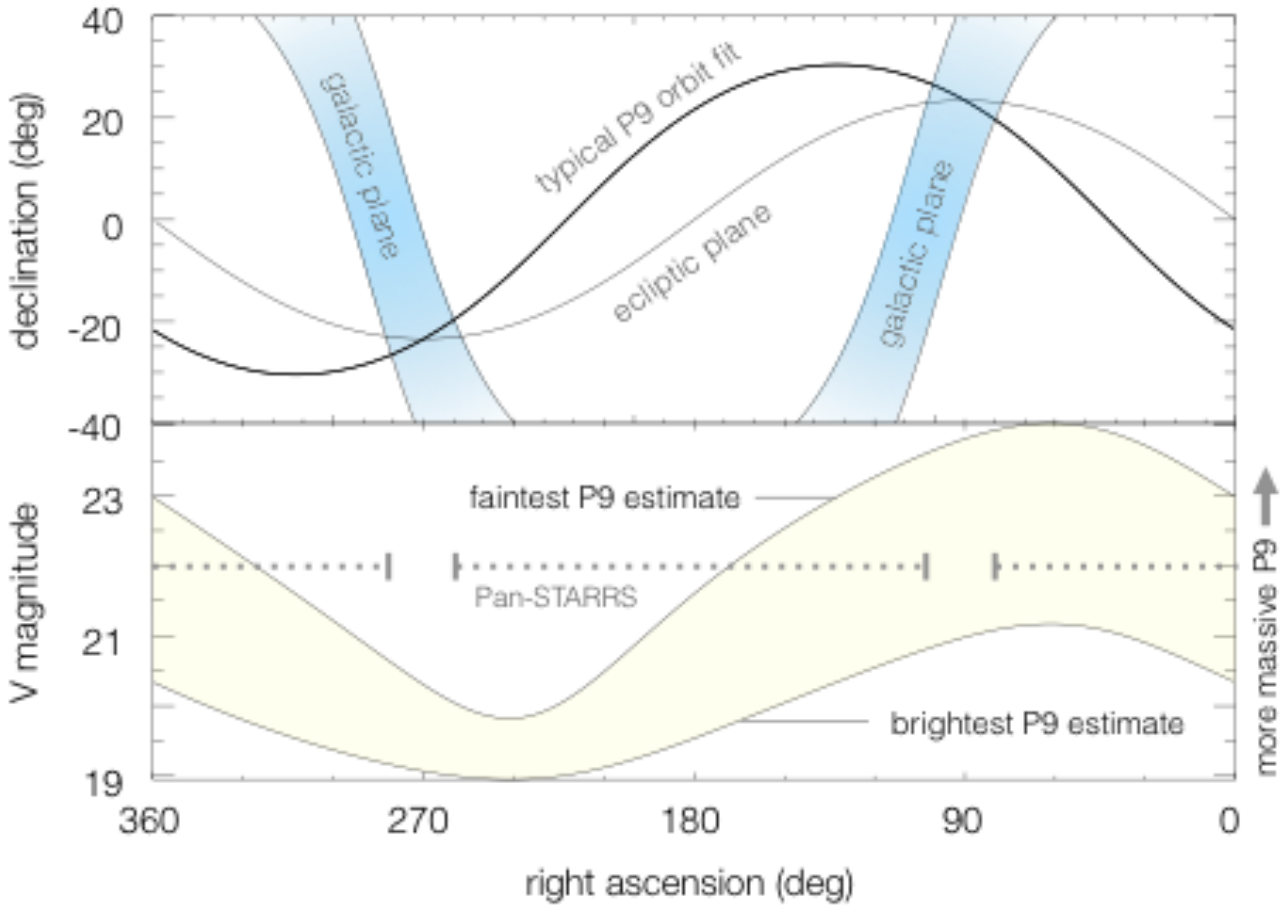
M ~ 5-10 M_{earth}

a ~ 400-800 AU

e ~ 0.2-0.5

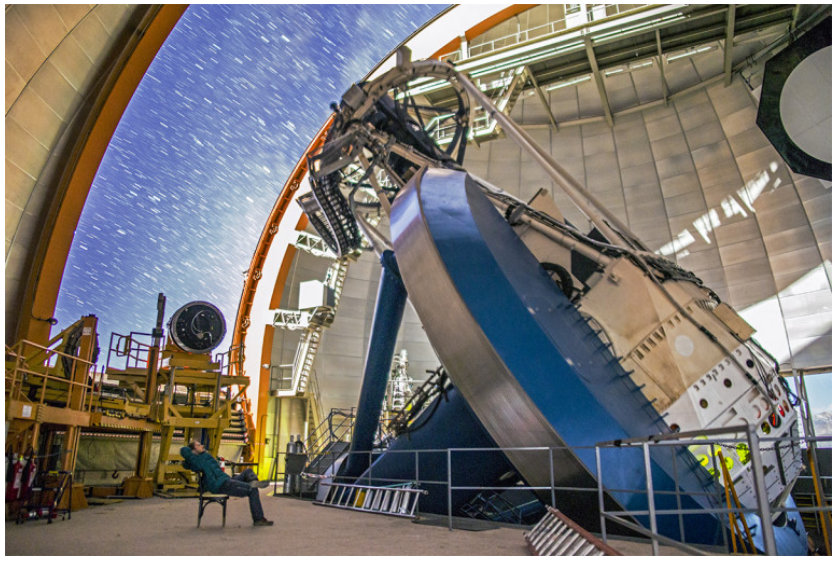
i ~ 15-25 deg

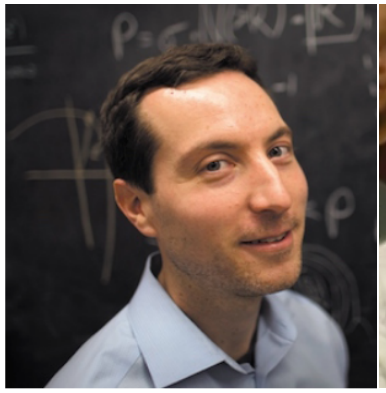
Specific range of orbital orientations



Juliette Becker

David Gerdes



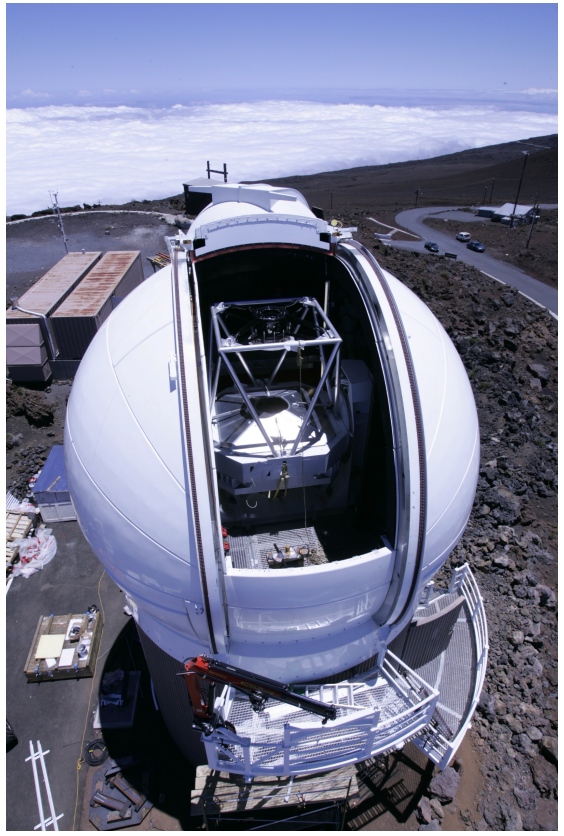


Scott Sheppard

Chad Trujillo

Matt Holman

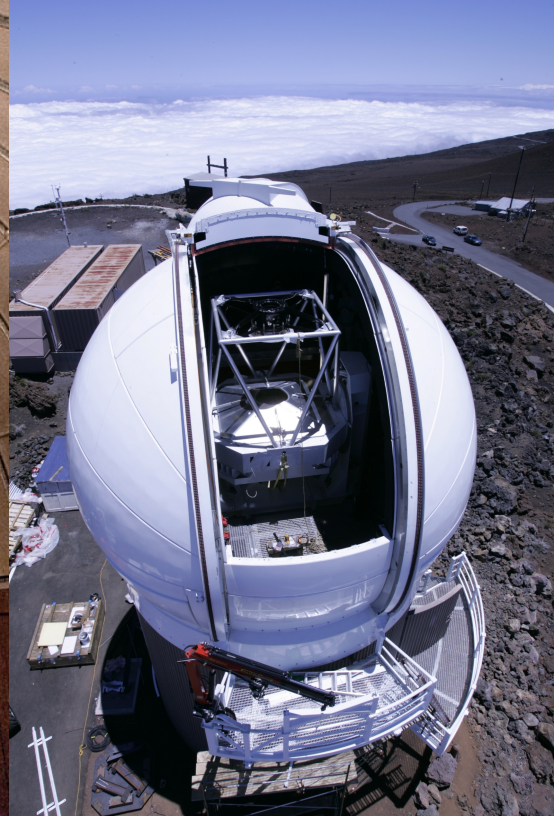
Matt Payne



Mike Brown

Konstantin Batygin

Catalina Sky Survey



Pan-STARRS

ZTF

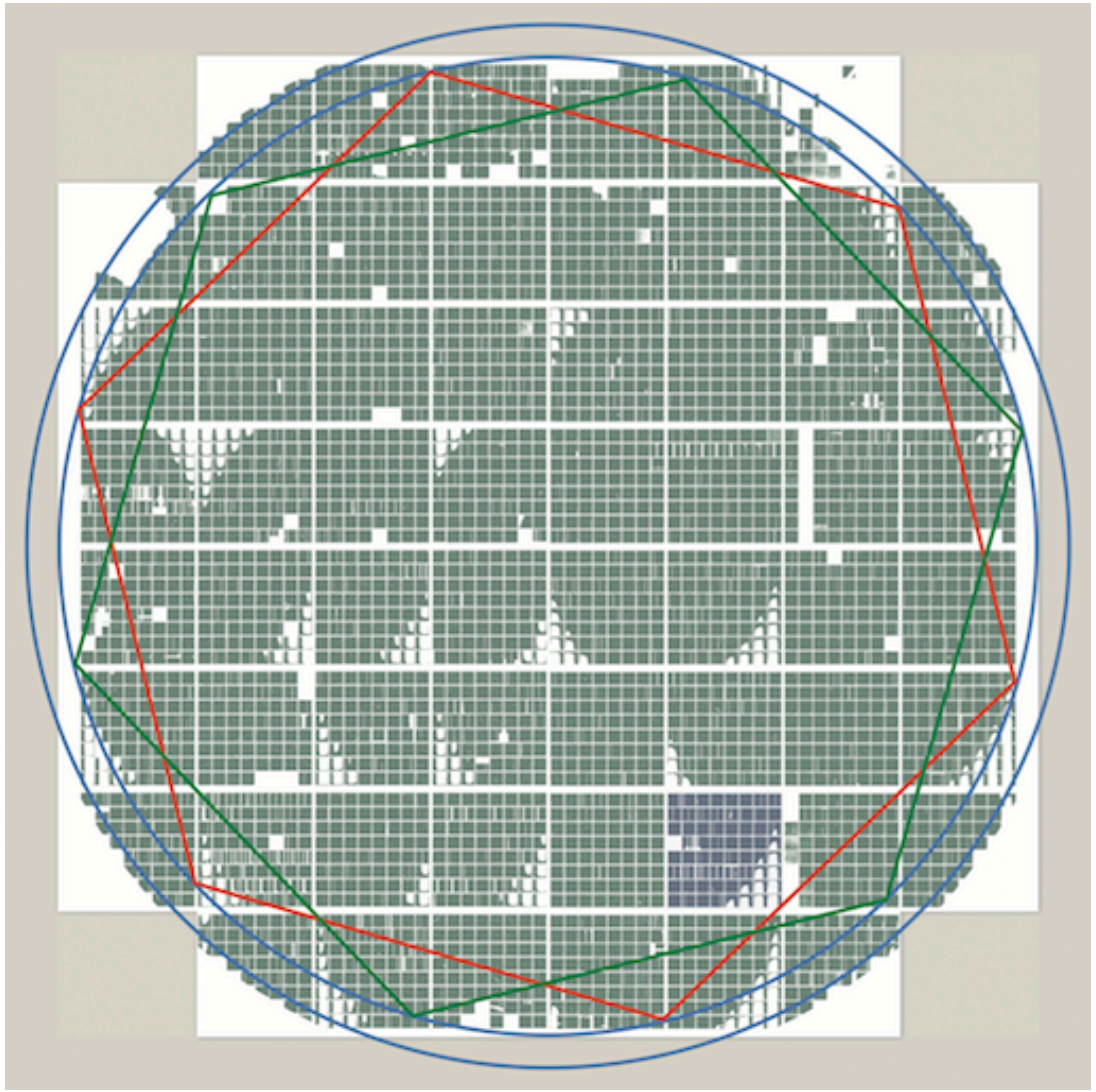
Fields of View: 7-47 deg^2

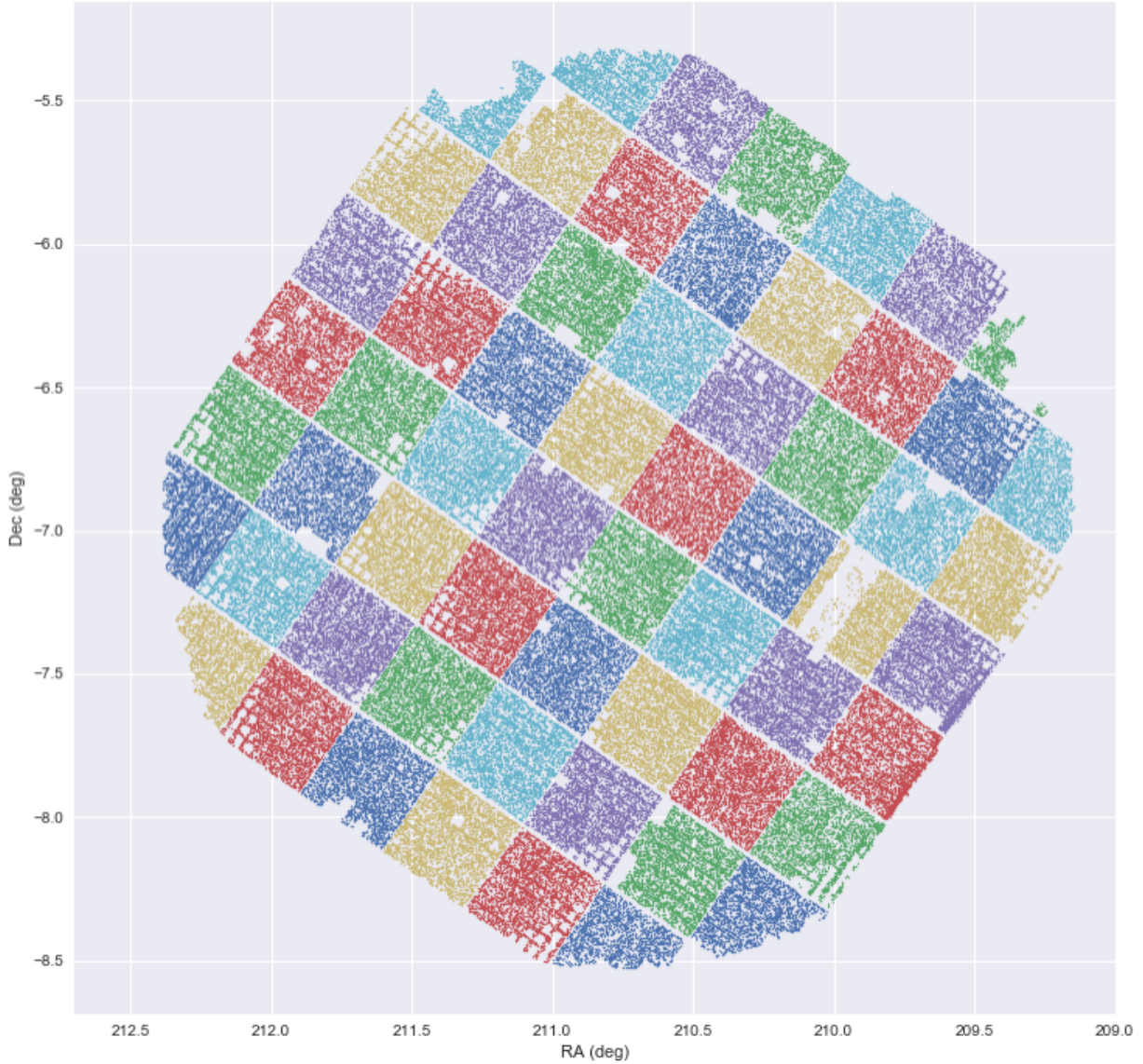
500-1000 exposures per night, for more than a decade

Limiting magnitudes of ~20-22

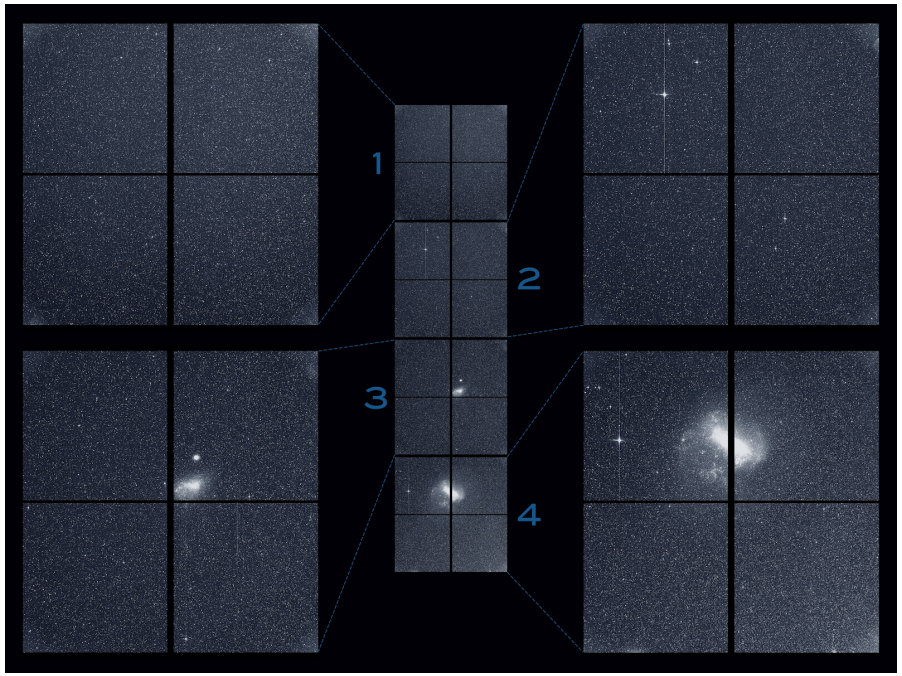
Millions of high quality exposures

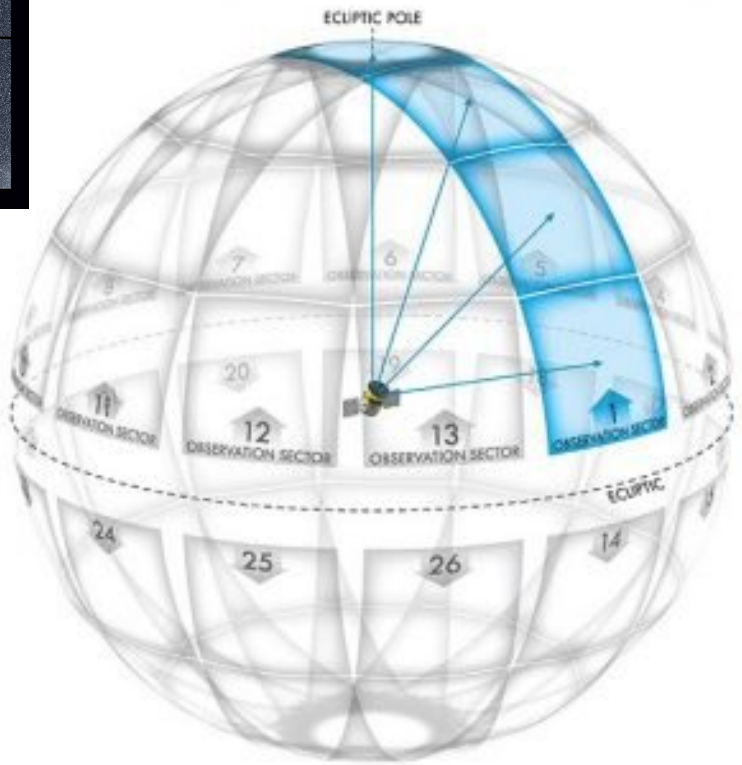
Every spot in the northern sky has already been imaged hundreds of times!

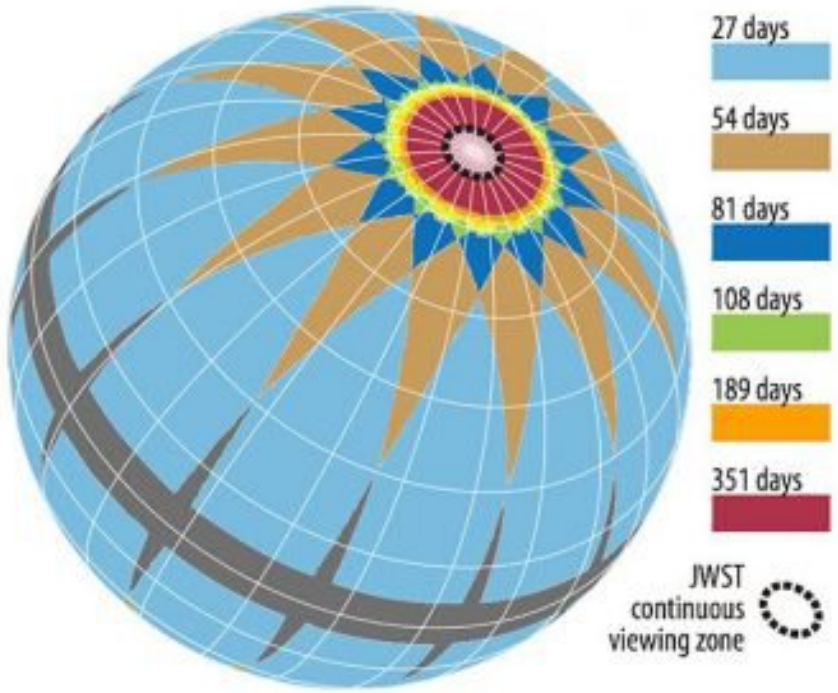


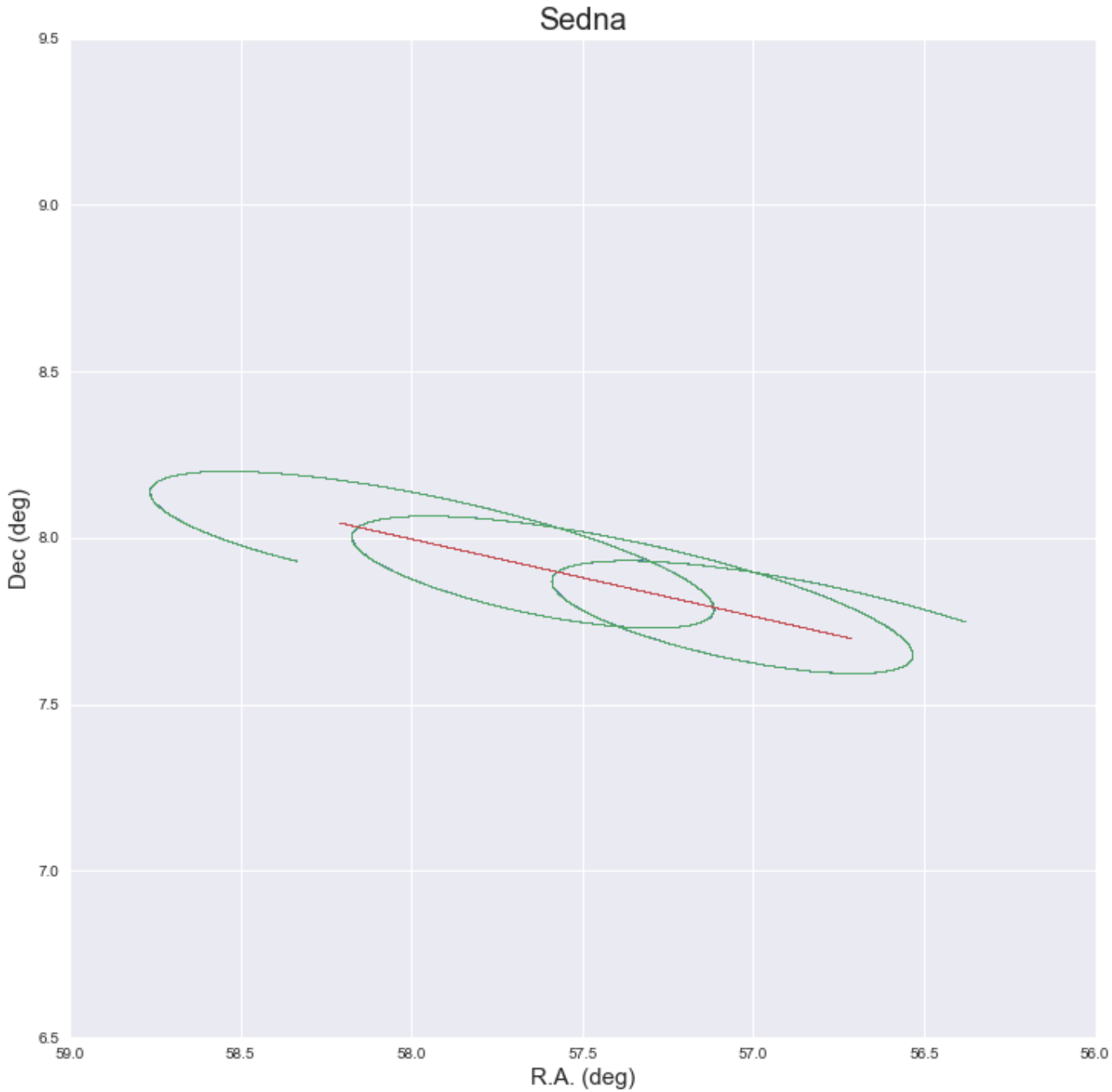


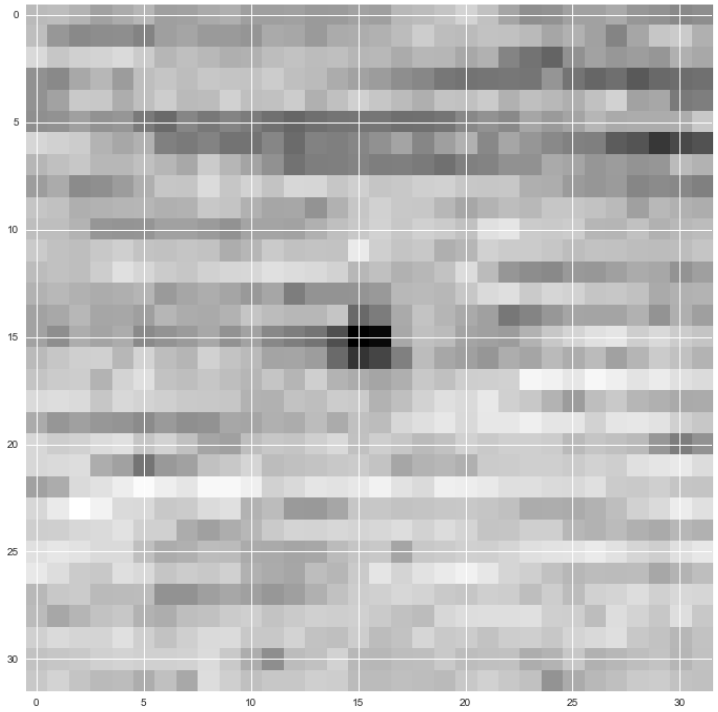
Pan-STARRS Gigapixel Camera-1


1
2
3
4

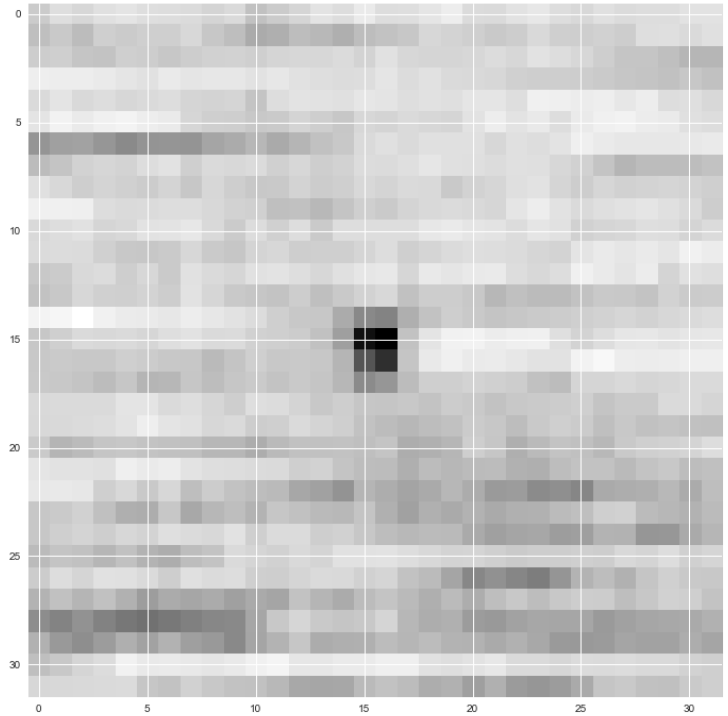

ECLIPTIC POLE
11
OBSERVATION SECTOR
12
OBSERVATION SECTOR
13
OBSERVATION SECTOR
ECLIPTIC
24
25
26
14


27 days
54 days
81 days
108 days
189 days
351 days
JWST
continuous
viewing zone

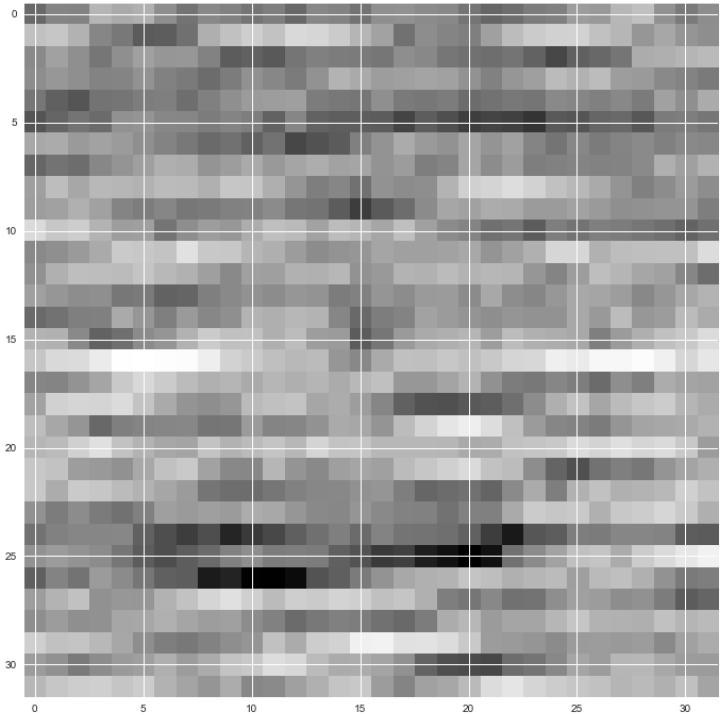

Sedna
9.5
9.0
8.5
8.0
7.5
7.0
6.5
Dec (deg)
59.0
58.5
58.0
57.5
57.0
56.5
56.0
R.A. (deg)



Sedna
V ~21



2015 BP519 ‘Caju’
V ~ 22



2007 TG422
V ~ 23

Thanks to Andras Pal!

Shift-and-Stack or Digital Tracking

Faint TNOs with CFHT	Gladman+	2001
Faint Moons of Neptune with CTIO 4-m	Holman+	2004
Extremely Faint TNOs with HST/ACS	Bernstein+	2004

Ingredients

- Search difference images.
- Use a good basis to try all possible orbits (Bernstein+ 2000, Holman+ 2018).
- Watch for where the signal pops out.
- Use a grid spacing that ensures completeness.
- Use synthetic sources to measure detection efficiency.
- Scramble time stamps to measure false positive rate.

Summary

- An all-sky survey to ~23rd magnitude for distant moving objects using the TESS FFIs is possible.
- It could be the most complete and most uniform such survey to date.
- The necessary tools and techniques have already been developed and demonstrated.

Thank you

Several lines of evidence indicate that additional planets in the outer solar system remain to be discovered. I am highlighting just a few.

'Planet 9 Hypothesis' Batygin et al (2019)

<u>Long-term perturbations</u>

Drop-off in number of TNOs beyond about 48 AU

Clustering of Extreme TNOs

Detachment of Perihelia (2000 CR105 and Sedna)

Trujillo & Sheppard (2014) 2012 VP113 5 Me, a=210, e~0 specific hypothesis

Inclined & Retrograde Orbits (Niku, Caju)

Warp in the orbital plane of TNOs (Volk & Malhotra 2017, Mars-mass at 60 AU)

<u>Short-term perturbations</u> to find the object

Pluto astrometry

Cassini ranging

Why use TESS, given all these other imaging resources?

--Uniform spatial coverage

--Continuous time coverage

--Very stable pointing and PSF

Nearly the entire sky

And, we can reach competitive depths

But it requires a different approach…

A tale of two communities: exoplanets and outer solar system.

These communities share very similar origin stories, stories that begin at nearly the same time. Like many origin stories, the early characters spent years alone in the wilderness. Unexpected events completely change the plot line. New characters arrive. Vibrant communities emerge. And along the way, our perspective changes. These two communities share much more than you might realize. And there is a ragged band of nomads that wander back and forth between them.

Of course, one of these communities is assembled here, telling its story.

In 1992, after many years of unsuccessful searches, Dave Jewitt and Jane Luu discover 1992 QB1, the first Kuiper belt object. They looked because…

1995 51 Peg (Queloz & Mayor)
2002 HD209458

Search

Vetting

Follow-up

Characterization

Deep studies of individual objects (physical and dynamical properties)

Survey de-biasing for population studies

Formation, physical processes, etc

Mission planning

Exploration

And our datasets are beginning to overlap

Solar System Examples:

NEOWISE	Mainzer+ 2018
CFEPS	Kavelaars+ 2016
OSSOS	Bannister+ 2016, Lawler+ 2018
LSST	Jones+ 2018