A TESS Search for Distant Planets

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Special thanks:
- Andras Pal
- Deb Woods
Batygin 2019 ‘The Planet 9 Hypothesis’

Resonances

Centaurs

Scattered Disk

Classical Belt

Detached KBOs

Uranus

Neptune

P

q = 30 AU

q = 38 AU

VP113

Gladman+ 2002

Sedna

Brown+ 2004

CR105

TG387

Trujillo & Sheppard 2014

Distant Kuiper Belt (a > 250 AU)

Inner Oort Cloud
Batygin + 2019

\[ M \sim 5-10 \, M_{\text{earth}} \]
\[ a \sim 400-800 \, \text{AU} \]
\[ e \sim 0.2-0.5 \]
\[ i \sim 15-25 \, \text{deg} \]

Specific range of orbital orientations
Catalina Sky Survey

Fields of View: 7-47 deg²
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!
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 \( \sim 23^{\text{rd}} \) 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)

**Long-term perturbations**
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)

**Short-term perturbations** 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