The case for a deep search for Earth's Trojan asteroids

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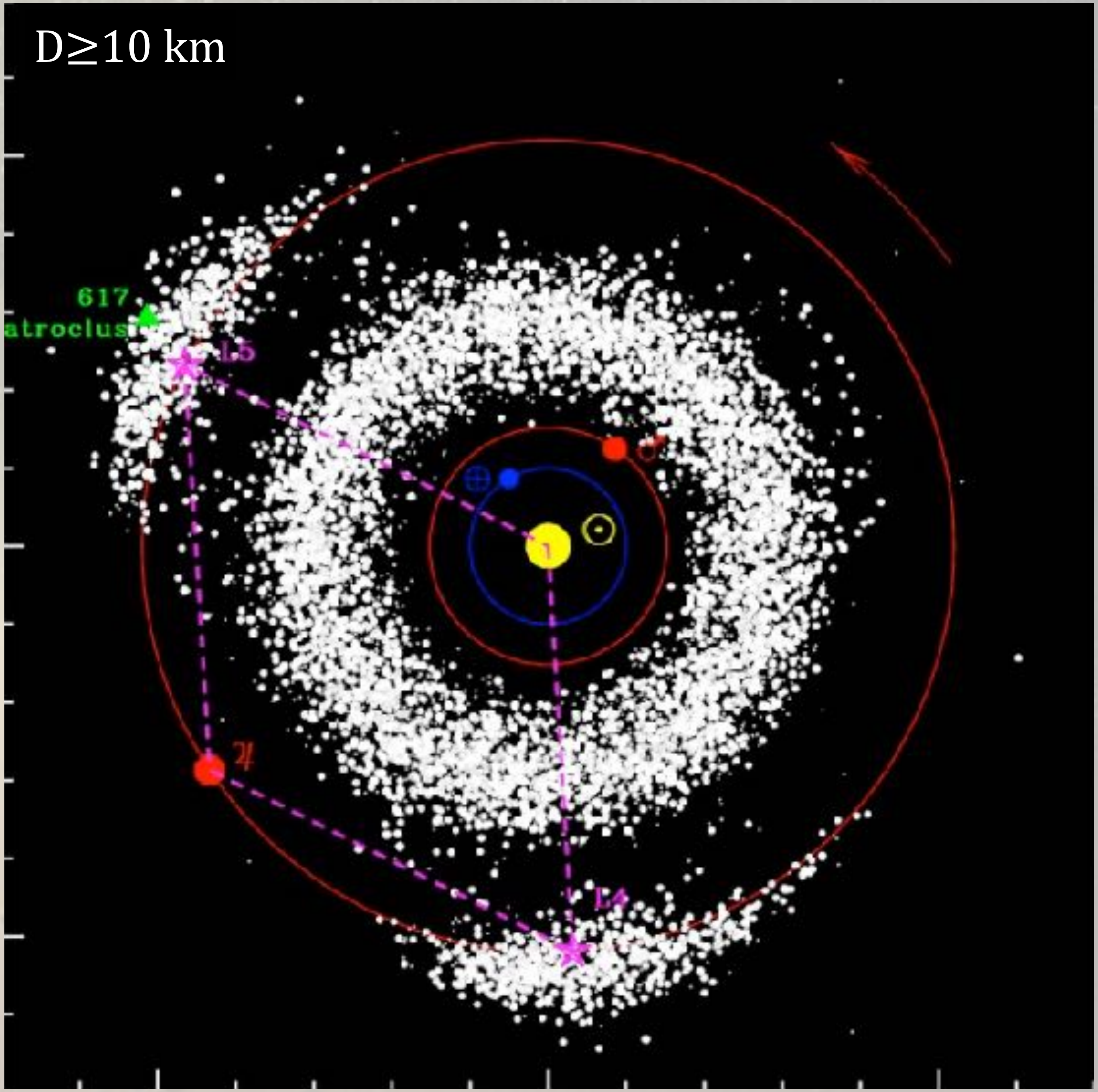
What are Earth Trojan asteroids?

Minor planets can share the orbit of a planet if they remain near the triangular Lagrange points, L4 and L5

Significant populations known for Jupiter, Neptune and Mars

What about Earth's Trojans?



snapshot of the locations of main belt and Jupiter Trojan asteroids

Why care about Earth Trojans?

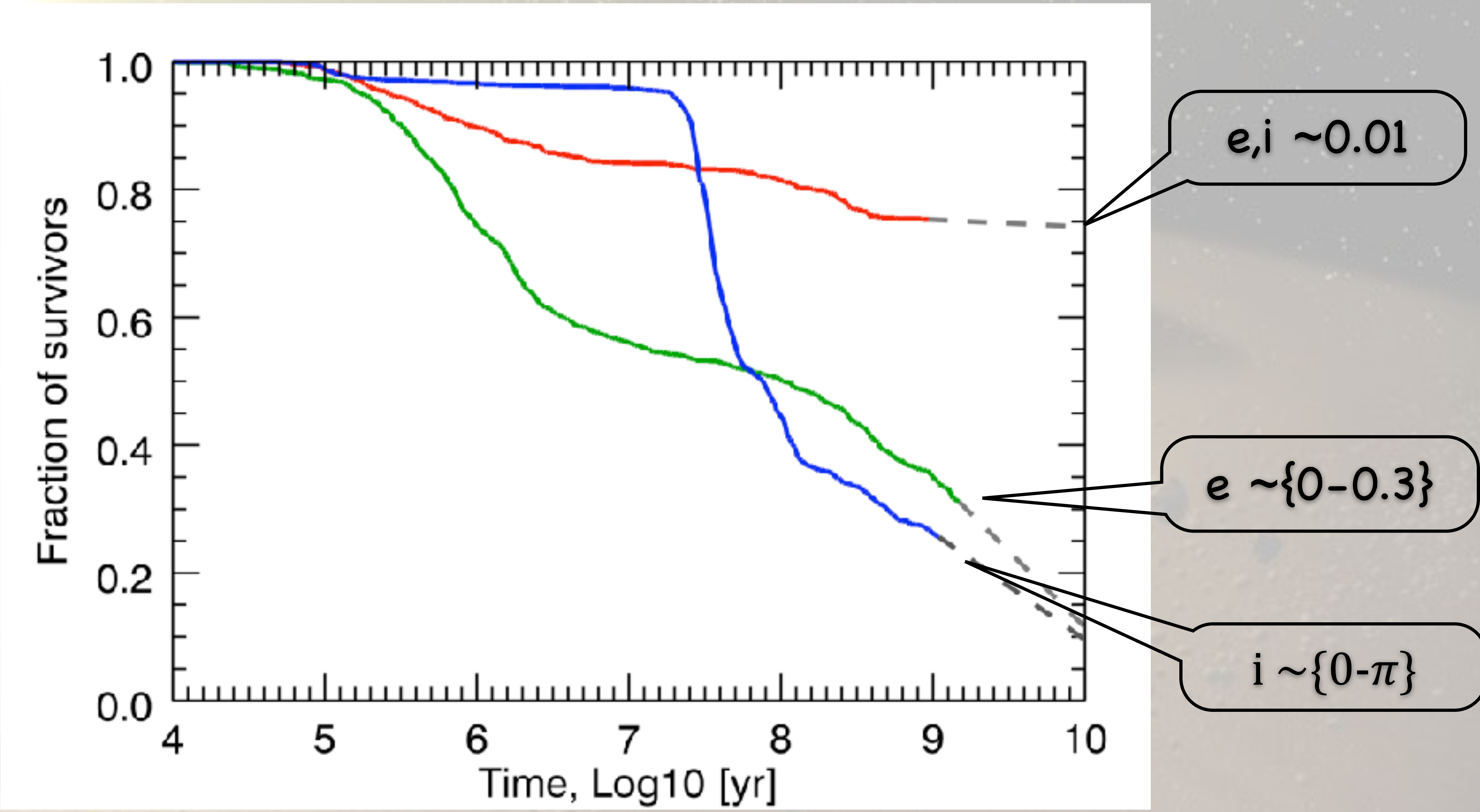
- A gap in our inventory of near-Earth asteroids
  - L4/L5 hard to observe from Earth due to challenging illumination geometry at dawn/dusk
- Clues to Earth's formation and dynamical history
  - an ET population could be remnants of Earth's primordial building blocks
- Attractive targets for space exploration
  - low delta-V

Why care about Earth Trojans?

<email from Prof. Paul Davies (ASU) today>

A recently discovered group of **nearby co-orbital objects** is an attractive location for extraterrestrial intelligence (ETI) to locate for observing Earth. Near-Earth objects provide an ideal way to watching our world from a secure natural object that provides resources an ETI might need: materials, a firm anchor, concealment. These co-orbital objects have been little studied by astronomy and not at all by SETI or planetary radar observations. I describe the objects found thus far and propose both passive and active observations of them by optical and radio listening, radar imaging and launching probes. We might also broadcast to them.

Earth Trojans
long term stability under planetary perturbations?



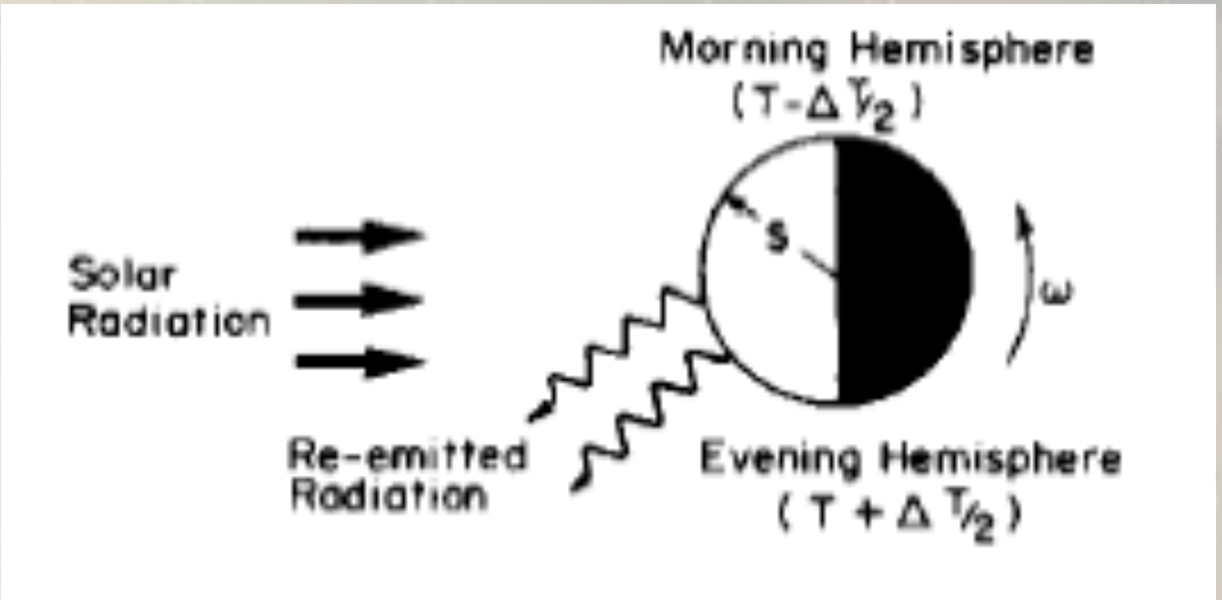
JeongAhn & Malhotra, 2011 (unpublished)

Earth Trojans

long term stability under planetary perturbations

+

solar radiation forces?



Burns et al., 1979

Yarkovsky effect:

D $\lesssim$300 m may not survive to the present day

-Zhou et al., 2018

Earth Trojans
Population estimates: theoretical

- Tabachnik & Evans (2000): ~260 objects of D > 1 km
  - scaled to Jupiter Trojan population

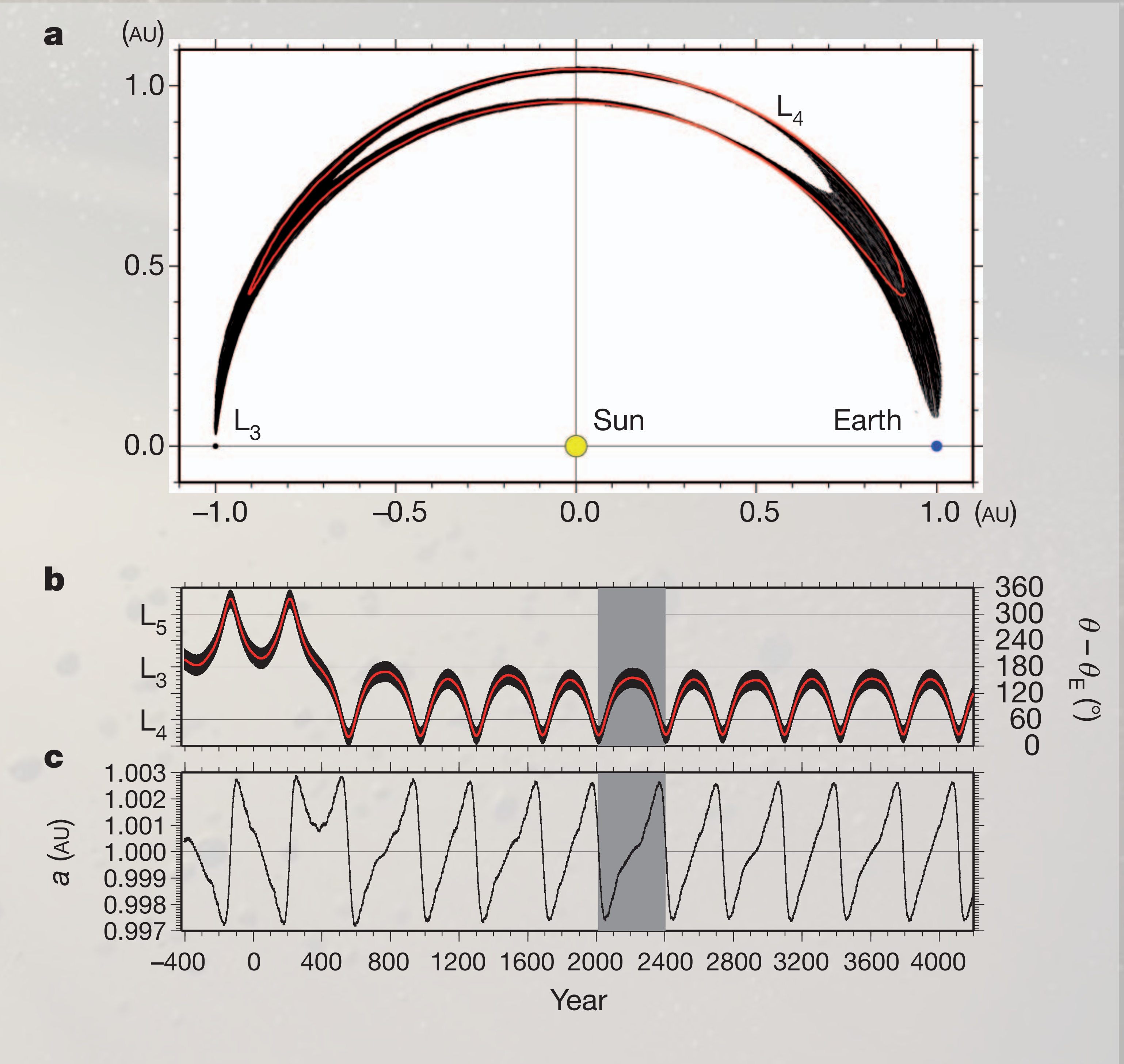
- Morais & Morbidelli (2002): 16±3 objects of D > 160 m
  - numerical sims of NEOs temporarily captured as Trojans

Earth Trojans
Population estimates: Observations

- Whiteley & Tholen (1998): < 3 per sq. deg for R < 22.8
  - surveyed 0.35 sq deg near L4, L5

Earth Trojans
Observations

- Connors et al. (2011) discovered the first ET in WISE archival data: 2010 TK7
  - H=20.6 (D~300 m for A=0.1)
  - inc=20.9 deg
  - ecc=0.191
    - unstable

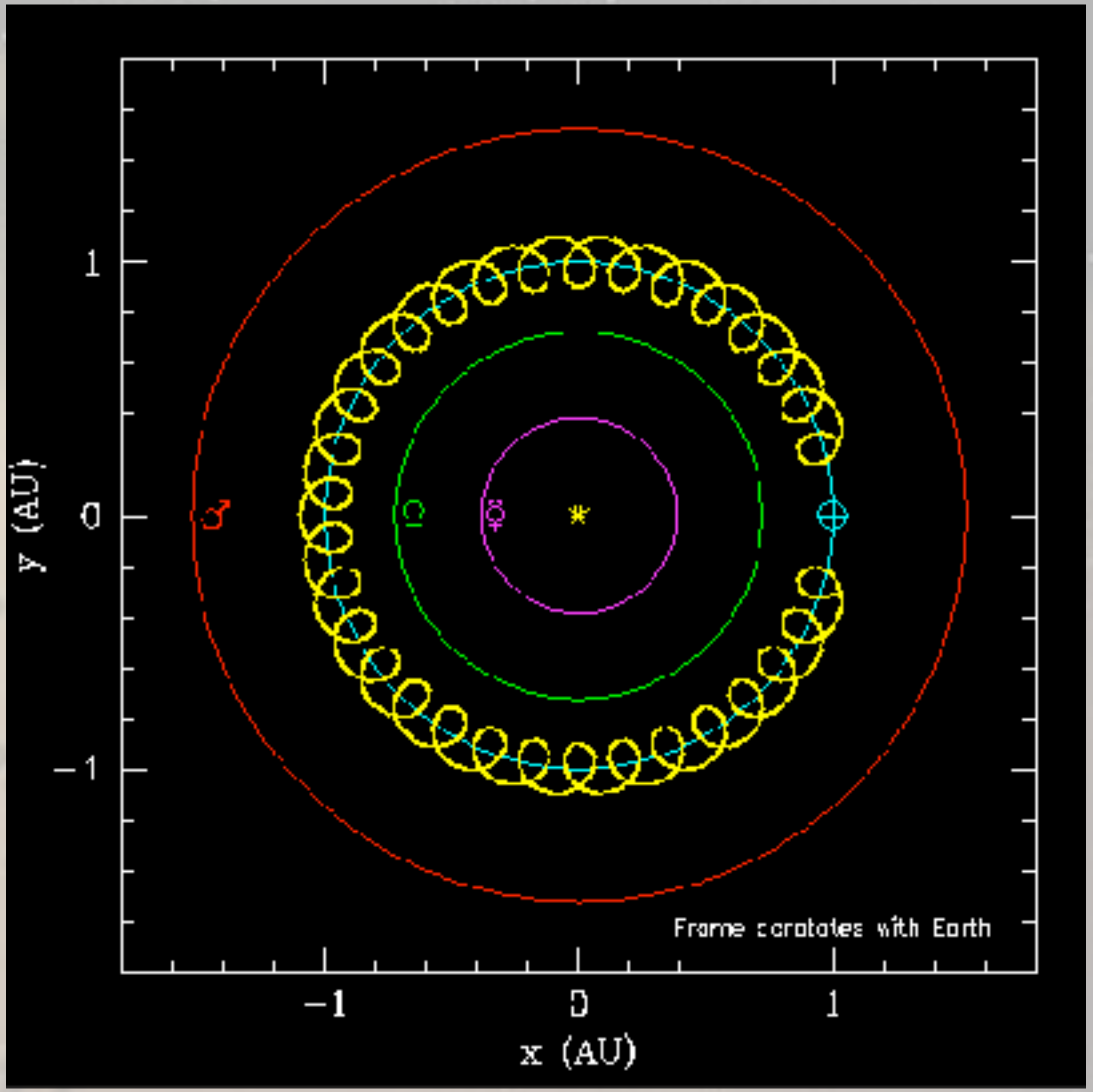


Earth Trojans
Observations

Three other 'Earth co-orbitals' are known

- 3753 Cruithne discovered in 1986, identified as co-orbital by Wiegert et al. (1997)
  - H = 15.2 (D~5 km)
  - inc = 19.8 deg
  - ecc = 0.515
    - unstable

image: Paul Weigert



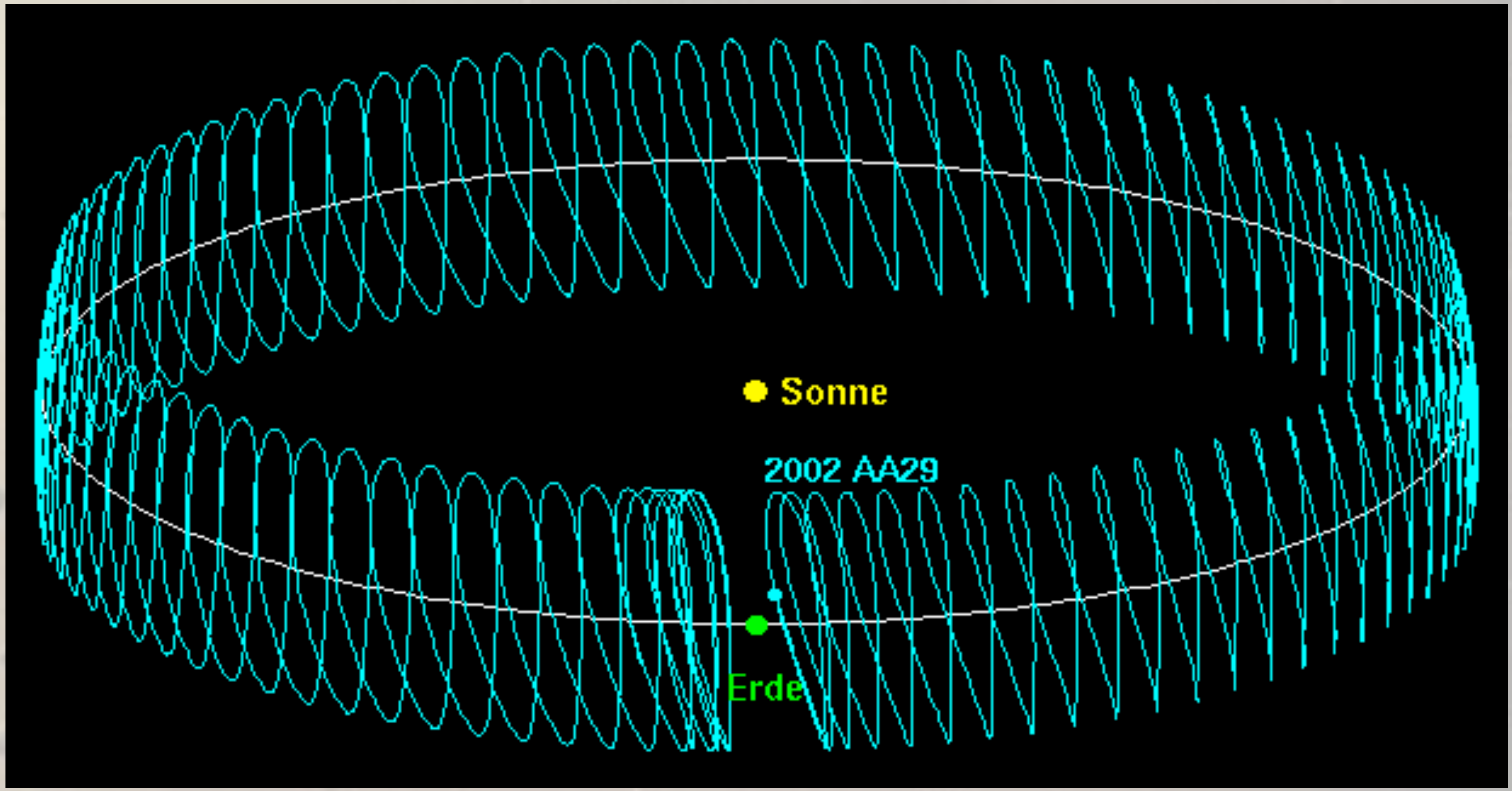
http://en.wikipedia.org/wiki/3753_Cruithne

Earth Trojans
Observations

Three other 'Earth co-orbitals' are known

- 2002 AA29 discovered by LINEAR
  - H = 24.08 (D~60m)
  - horseshoe-like orbit
  - inc=10.7 deg
  - ecc=0.012

image: JPL



Earth Trojans
Observations

Three other ‘Earth co-orbitals’ are known

- 2003 YN107 discovered by LINEAR
  - H = 26.3 (D~20m)
  - horseshoe-like orbit
  - inc=4.3 deg
  - ecc=0.014

Earth Trojans
Observations

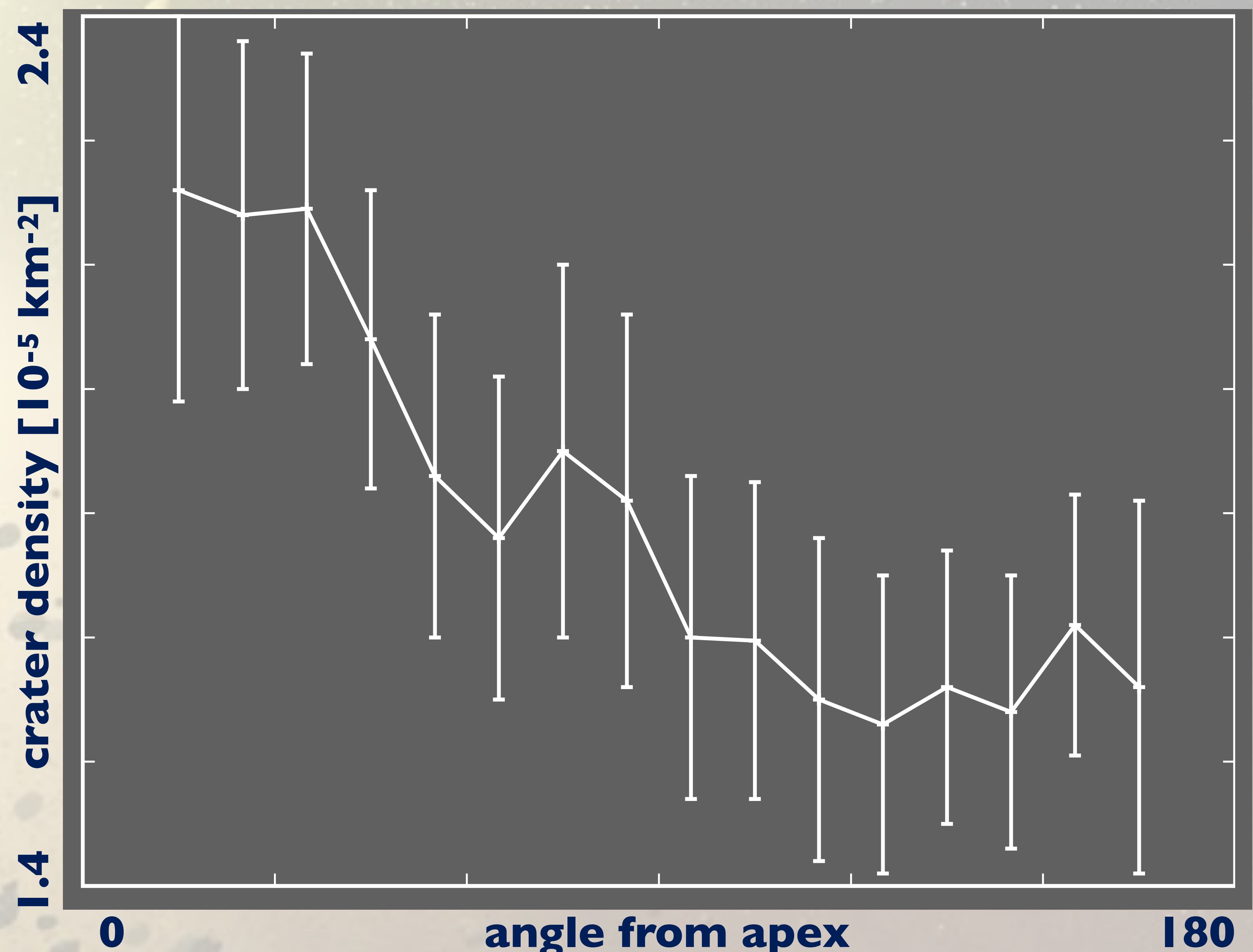
Three other 'Earth co-orbitals' are known

- 2003 YN107 discovered by LINEAR
  - H = 26.3 (D~20m)
  - horseshoe-like orbit
  - inc=4.3 deg
  - ecc=0.014

These three could be temporarily captured NEOs or could be ETs that leaked out.

Indirect evidence of ETs?

Lunar rayed craters longitudinal distribution, D>5 km



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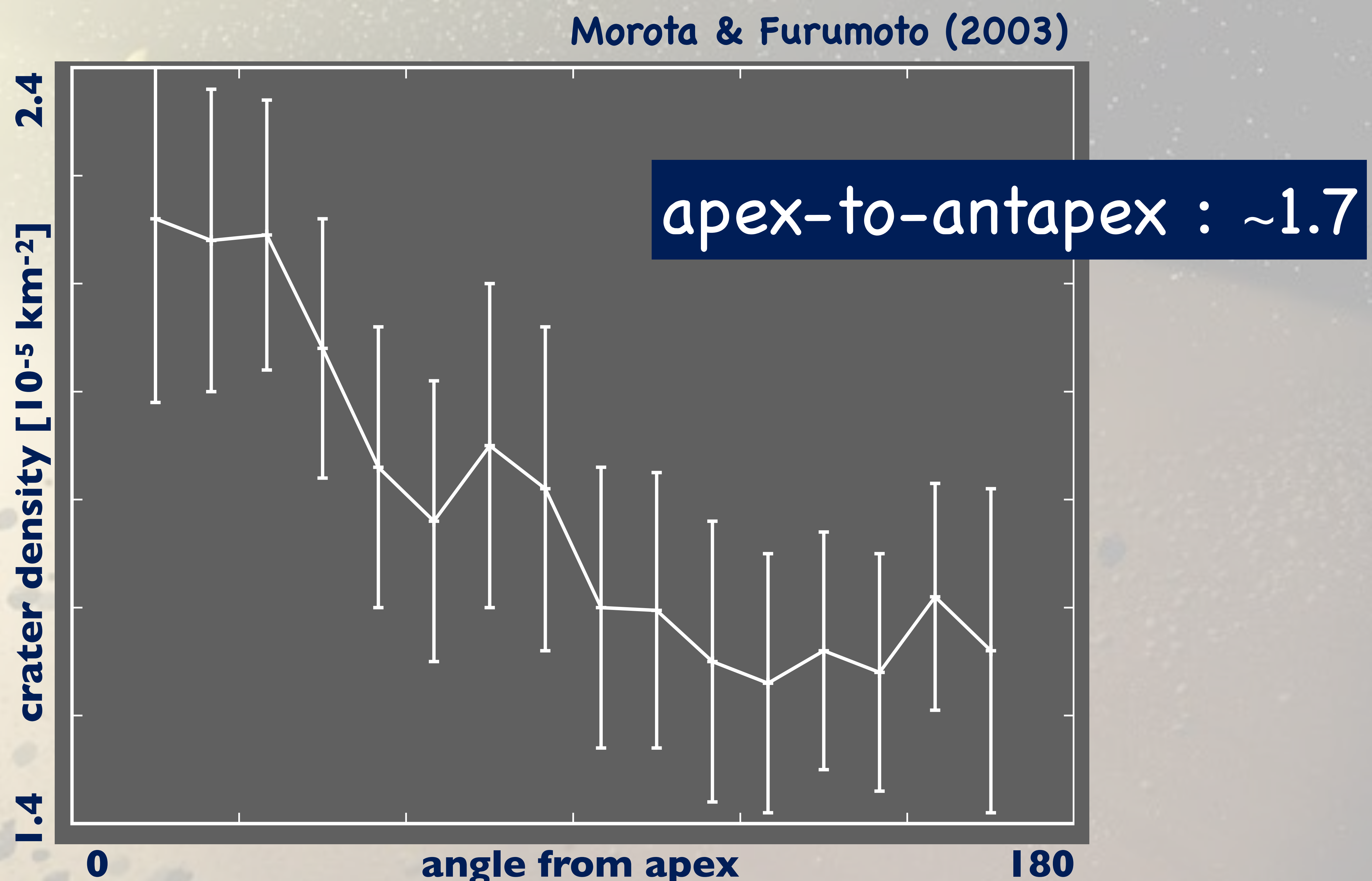
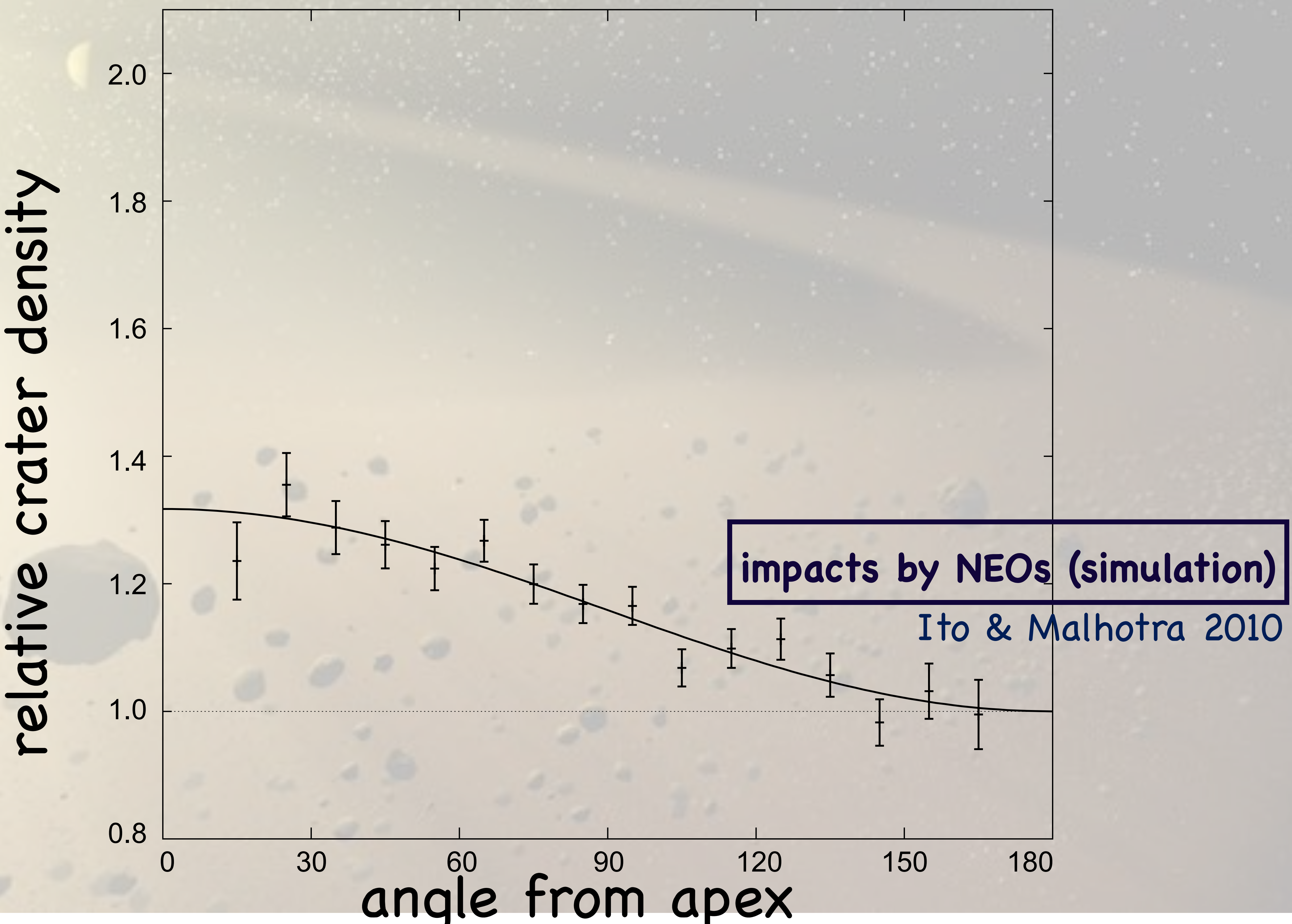
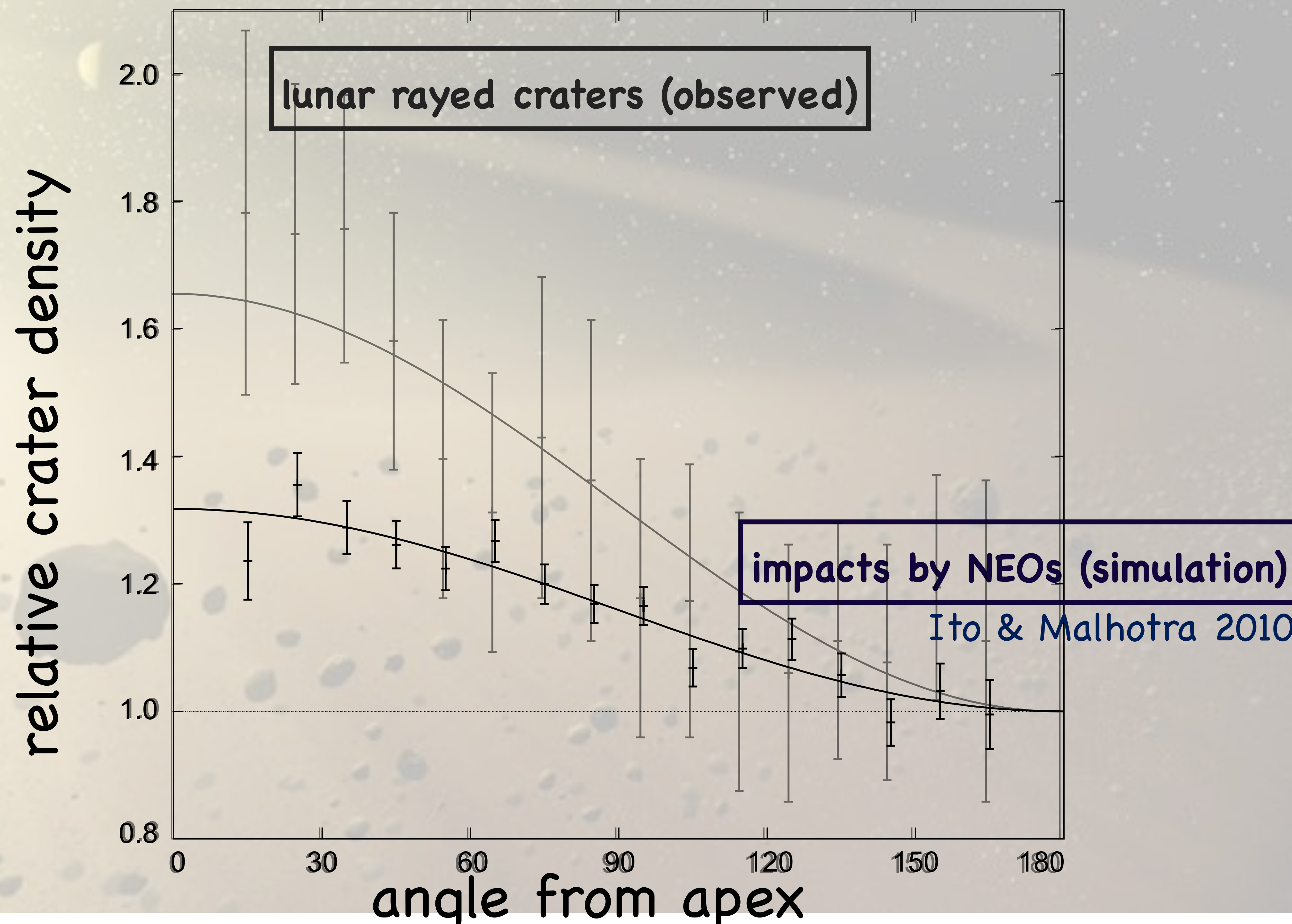


NEO impacts on the Moon: longitudinal distribution (simulation)



NEO impacts on the Moon: longitudinal distribution (simulation)

compared with lunar rayed craters (observed; ≲ 1 gyr old)



NEO impacts on the Moon: longitudinal distribution compared with lunar rayed craters

- Numerical simulations confirm asymmetric distribution of impacts by NEOs on the Moon

- Apex-to-antapex ratio is 1.32±0.01 (simulated)

  compare with 1.65±0.16 (observed)

  Gallant et al (2009) found ratio 1.28±0.01 (simulated)

- ETs could explain the discrepancy

Indirect evidence of ETs?

- Lunar impact flash monitoring at MSFC (2006-)
  - apex-to-antapex ratio ~1.45
- Apollo seismic monitoring
  - apex-to-antapex ratio ~1.8

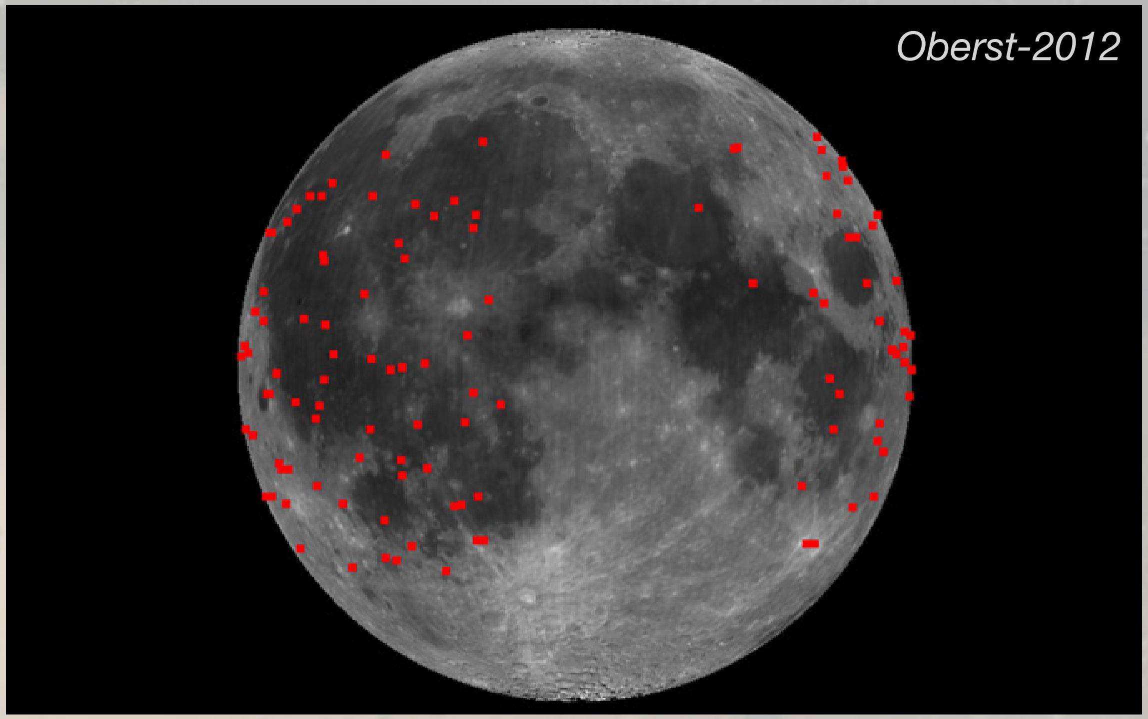
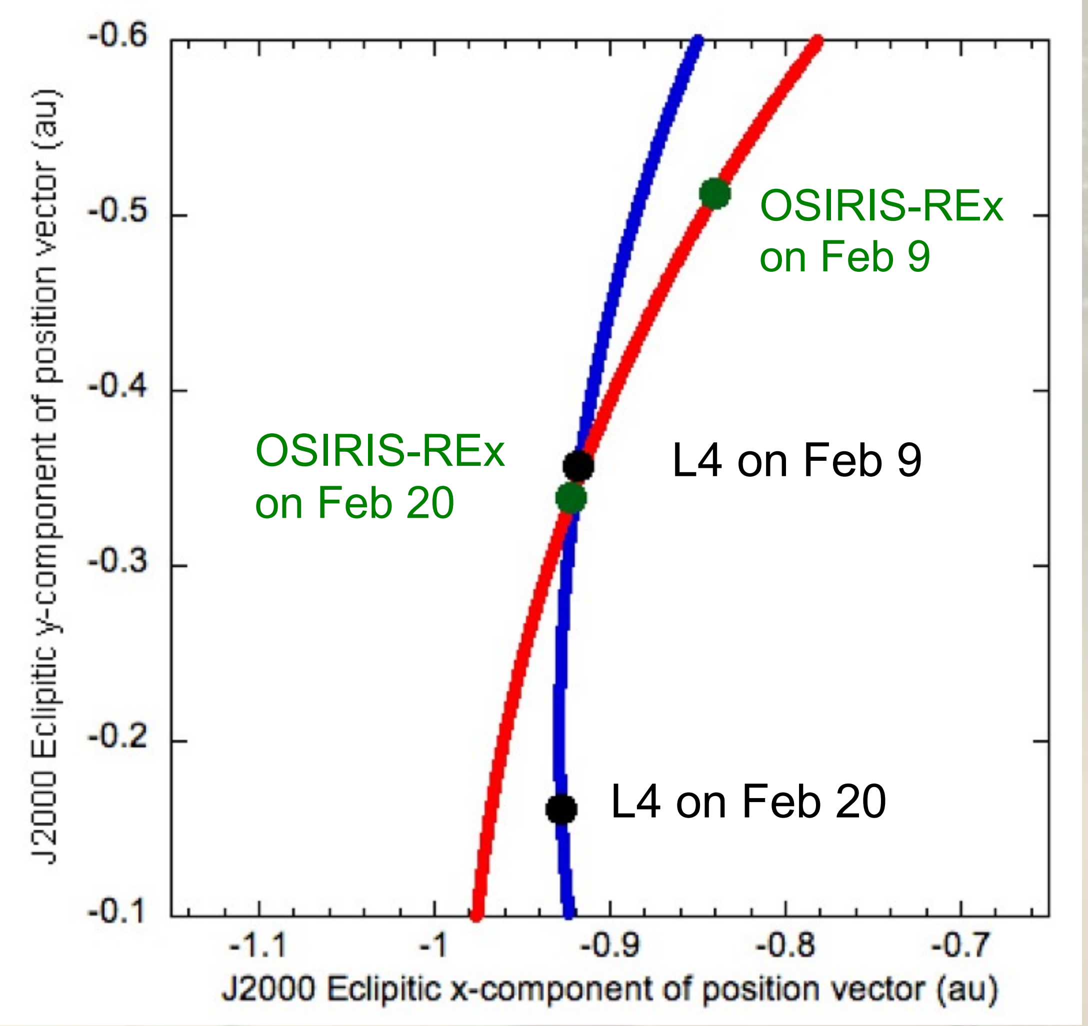
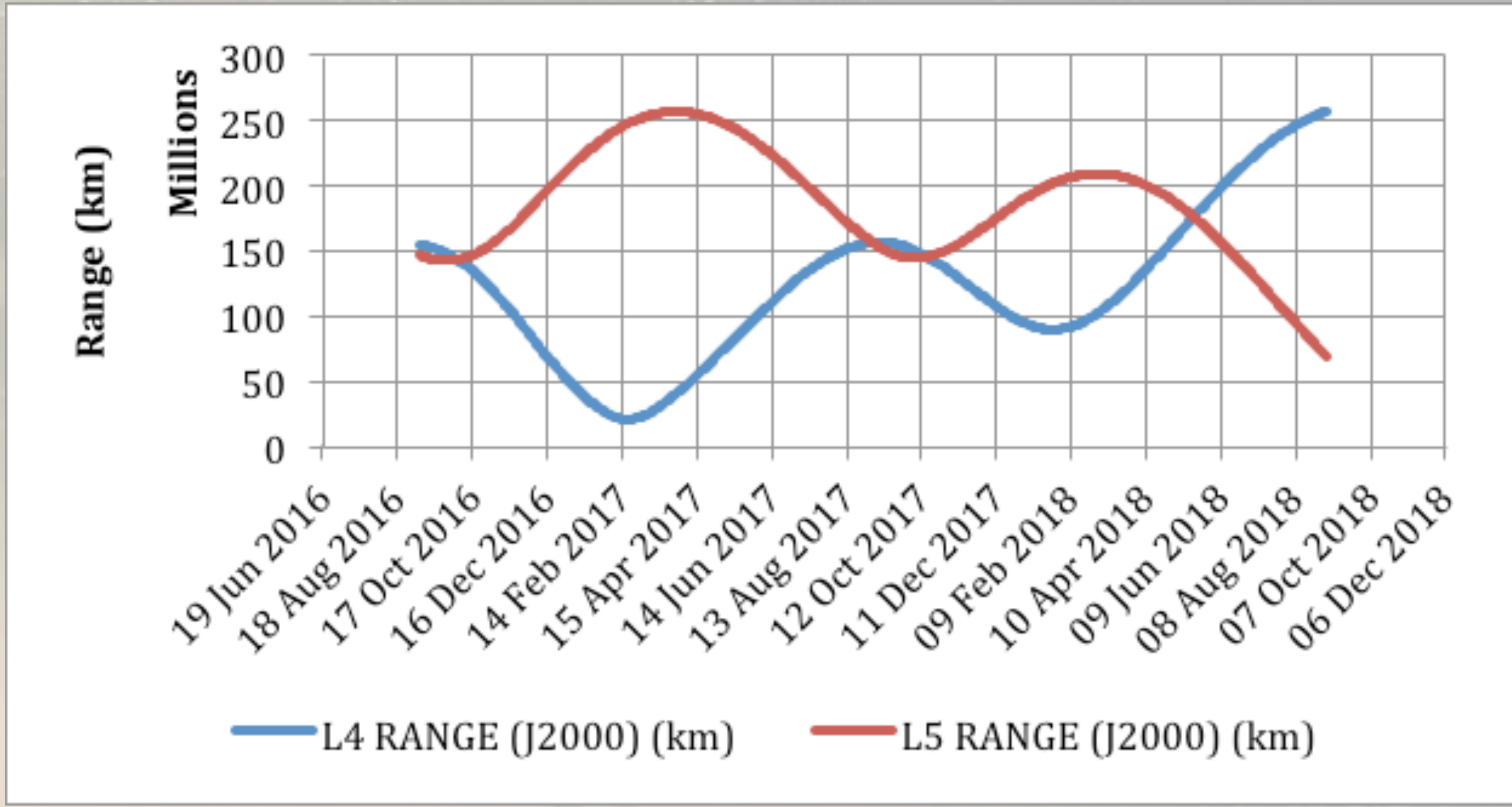


Fig. 8. Distribution of 108 impacts observed June 2006–June 2009. Flux asymmetry is 1.45:1. Fluxes are 1.55×10^{-7} in the western hemisphere (left) and 1.07×10^{-7} in the eastern hemisphere (impacts/km^2/hr).

ET search with OSIRIS-REx





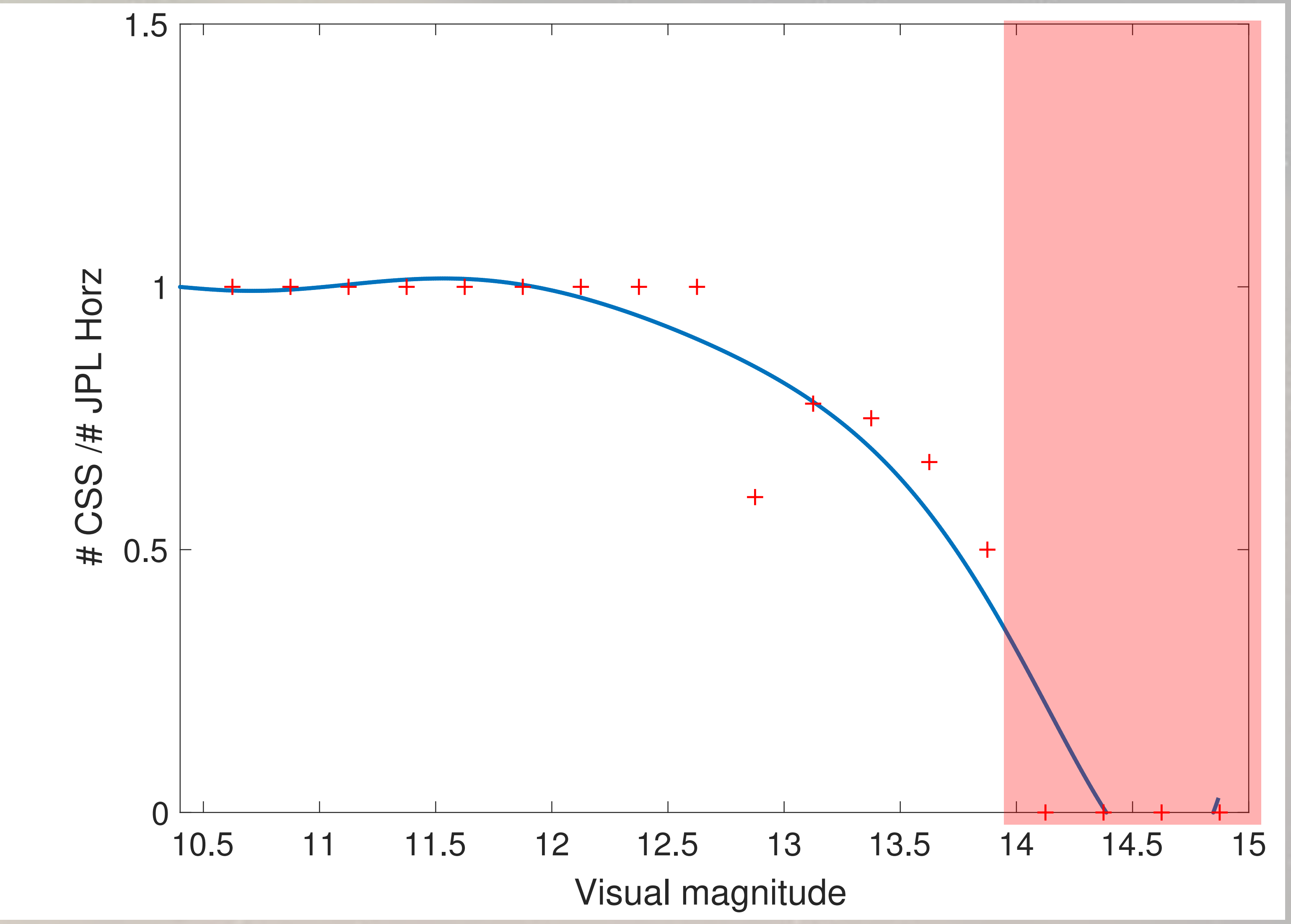
In Feb 2017: spacecraft cruised within 20 million kilometers of L4

ET search with OSIRIS-REx: Results

17 MBAs detected with a customized pipeline developed by Catalina Sky Survey (CSS) team

Comparison

Known MBAs
in the surveyed region
(JPL Horizons customized query)



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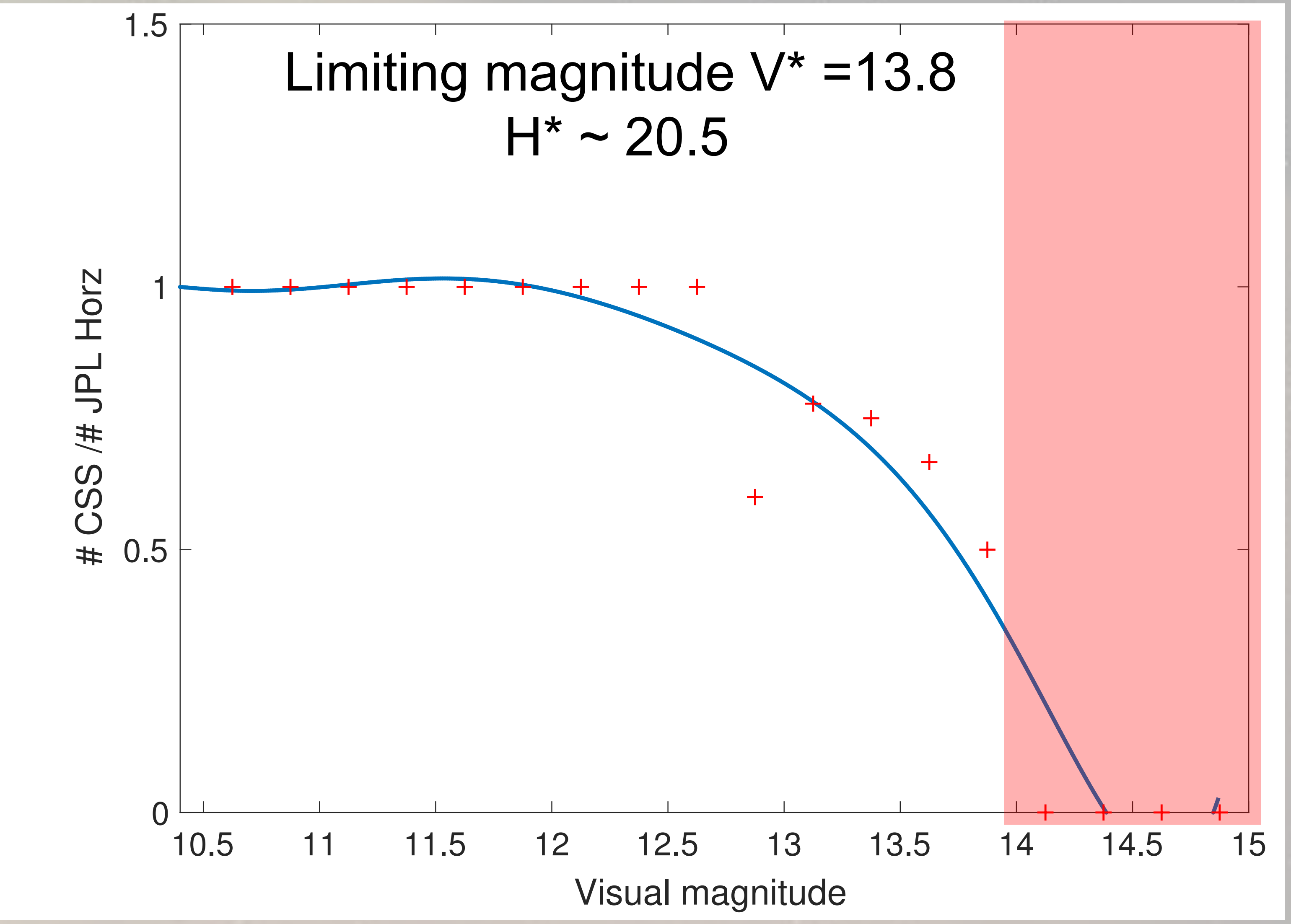

ET search with OSIRIS-REx: Results

Detected: 17 MBAs, 0 NEOs, 0 ETs

17 MBAs detected with a customized pipeline developed by Catalina Sky Survey (CSS) team

Comparison

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in the surveyed region
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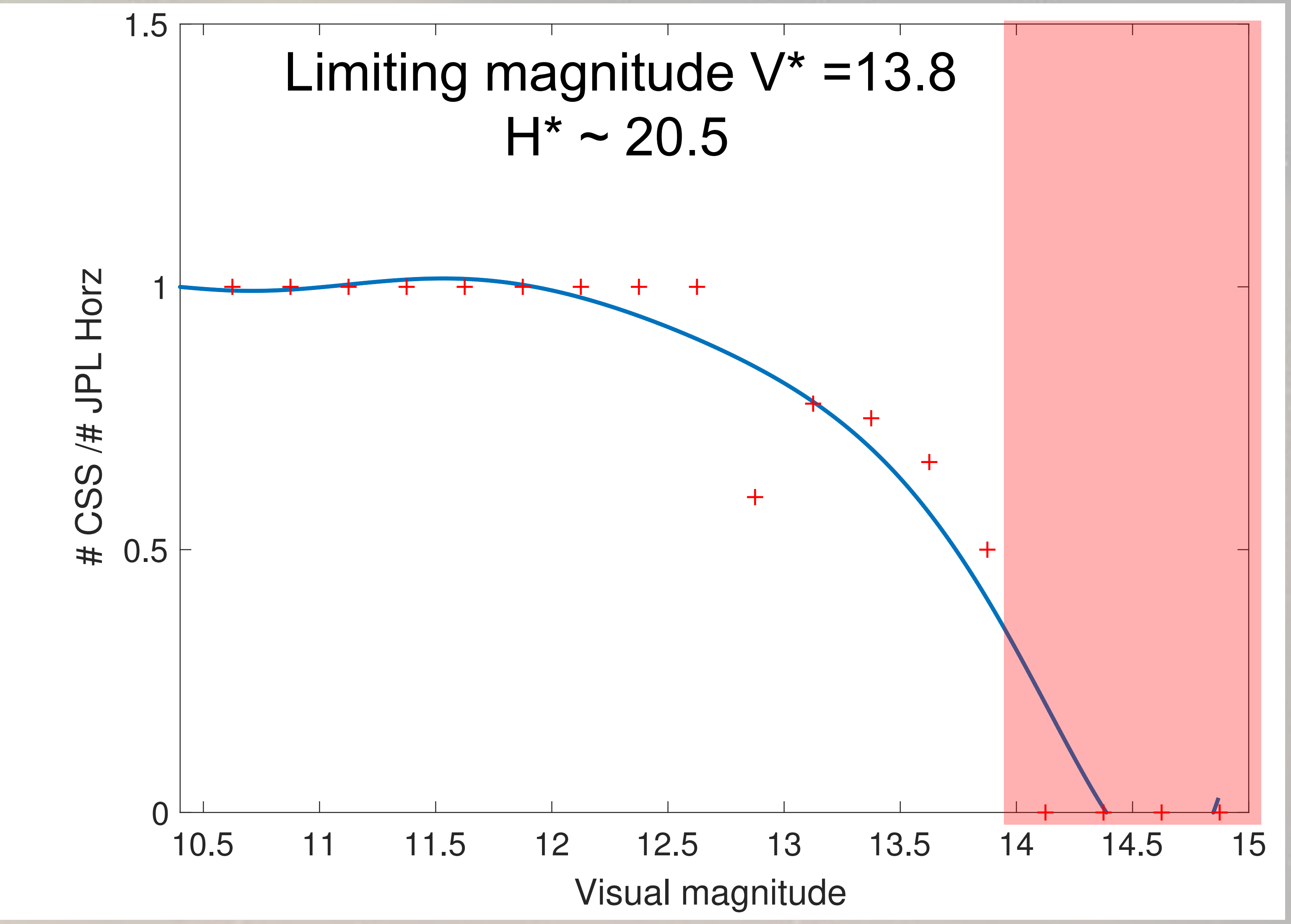
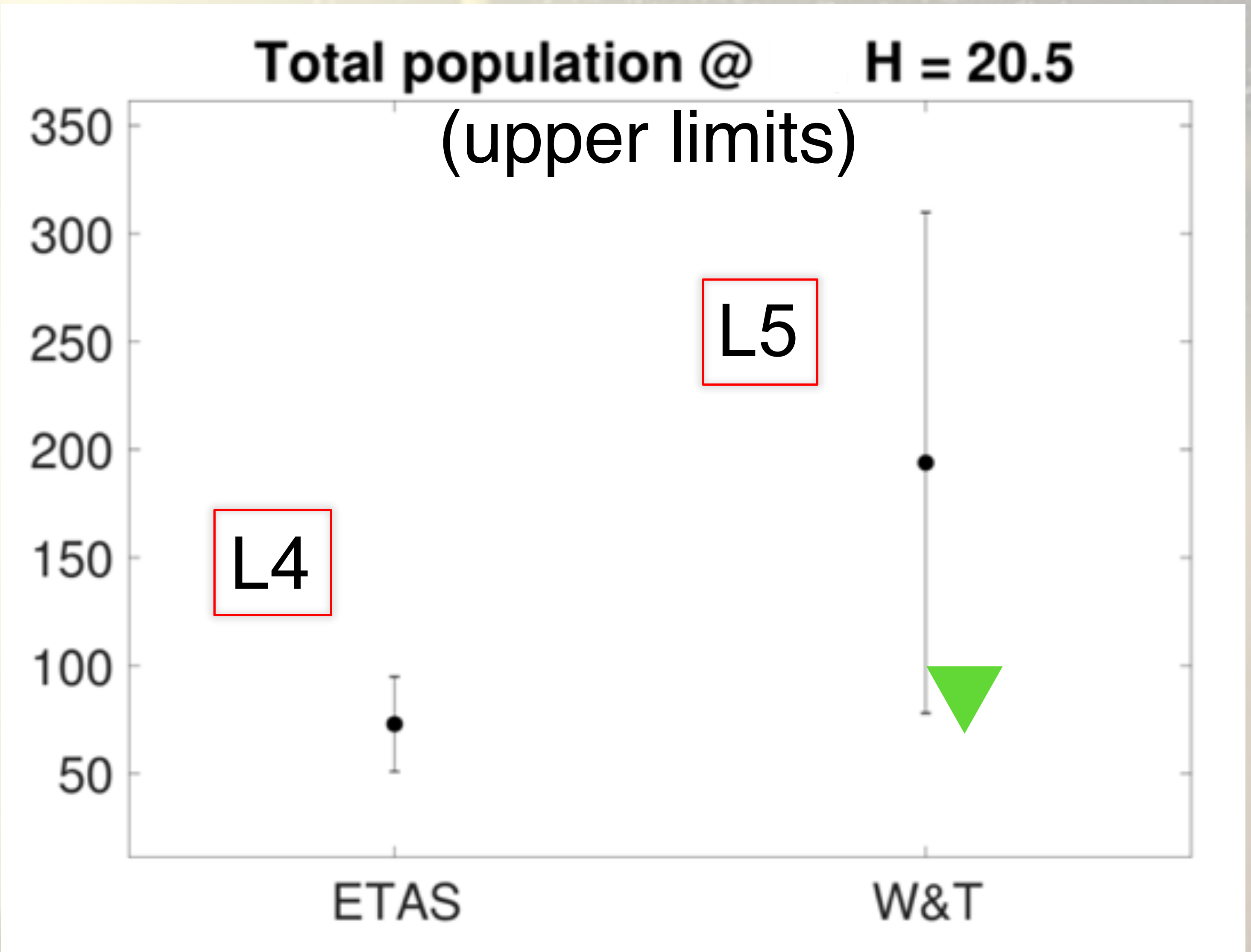


Preliminary results: ET population estimates



W&T = Whiteley & Tholen, 1998
ETAS = Earth Trojan Asteroid Survey with O-REx

ETAS result is consistent with the older W&T. The uncertainty of ETAS is smaller.

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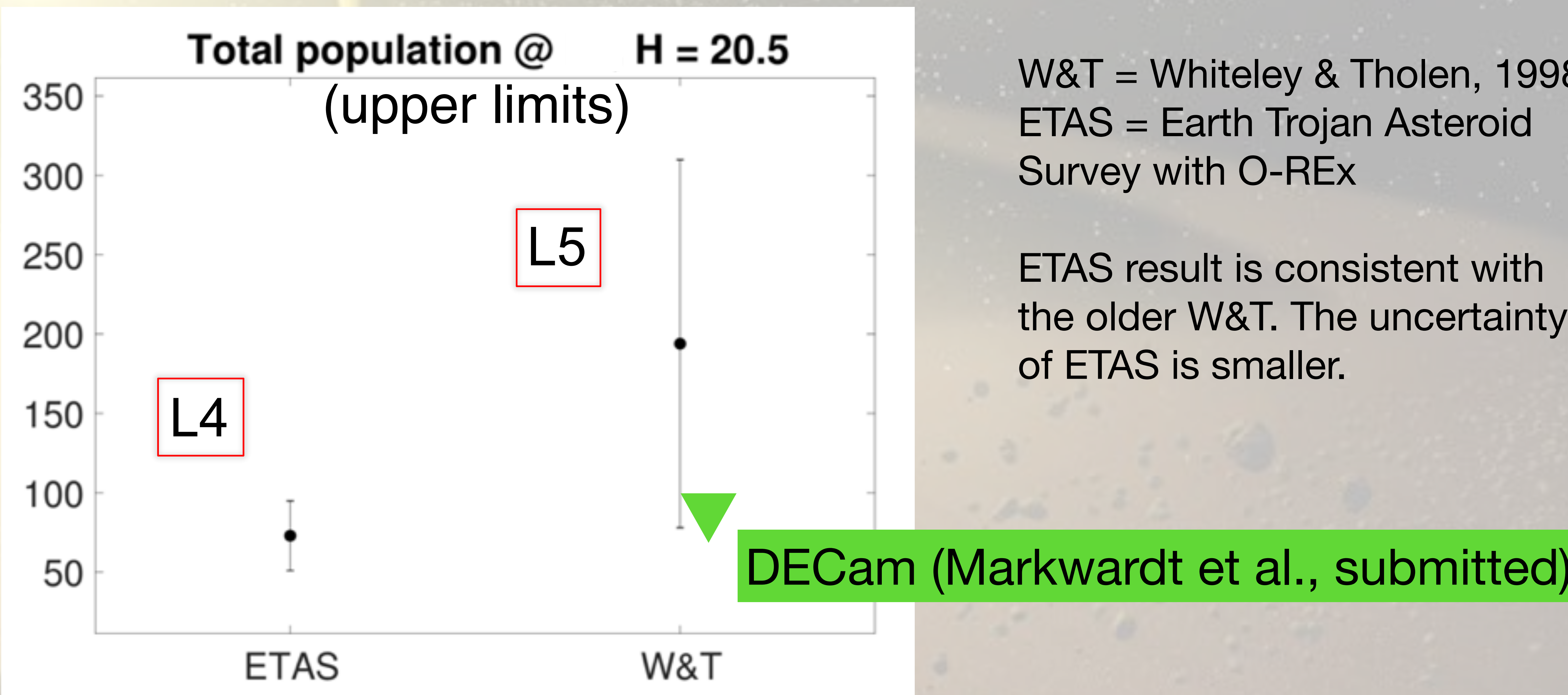

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Summary

- Earth's Trojan zones could potentially harbor a significant population of primordial planetesimals - dynamically stable for several gigayears ($D \gtrsim 300$ m).
- Primordial ETs are interesting for the provenance of Earth's building materials, including those critical for life.
- Two recent surveys (O-REx, DECam) have established improved upper limits (preliminary!): $N(D \gtrsim 300 \text{ m}) \lesssim 100$ each at L4, L5
- Better observational assessment requires twilight/dawn surveys with large FOV telescopes.

What does it mean?

- IF we can establish that "the Earth Trojan population of D > 300 m is much less than a few hundred", then we ask: what happened to it?

Possibilities:

- eroded by Yarkovsky/mutual collisions
- Moon progenitor perturbed it away
- de-stabilized by Earth's orbital migration/dynamical evolution

What does it mean?

- IF we can establish that "the Earth Trojan population of D > 300 m is much less than a few hundred", then what is the explanation for the lunar crater asymmetry?

Possibilities:

- Unlucky statistics (it is a ~2-sigma discrepancy)
- different orbital distribution of NEAs in the past ($\lesssim$1 gyr)
- larger lunar orbital velocity in the past
- tidal fragmentation of larger low velocity NEAs prior to impact
- an unknown channel for NEOs to evolve into low delta-v orbits