

# Detection of inner Solar System Trojan Asteroids by Gaia

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Gaia-FUN-SSO Workshop Paris

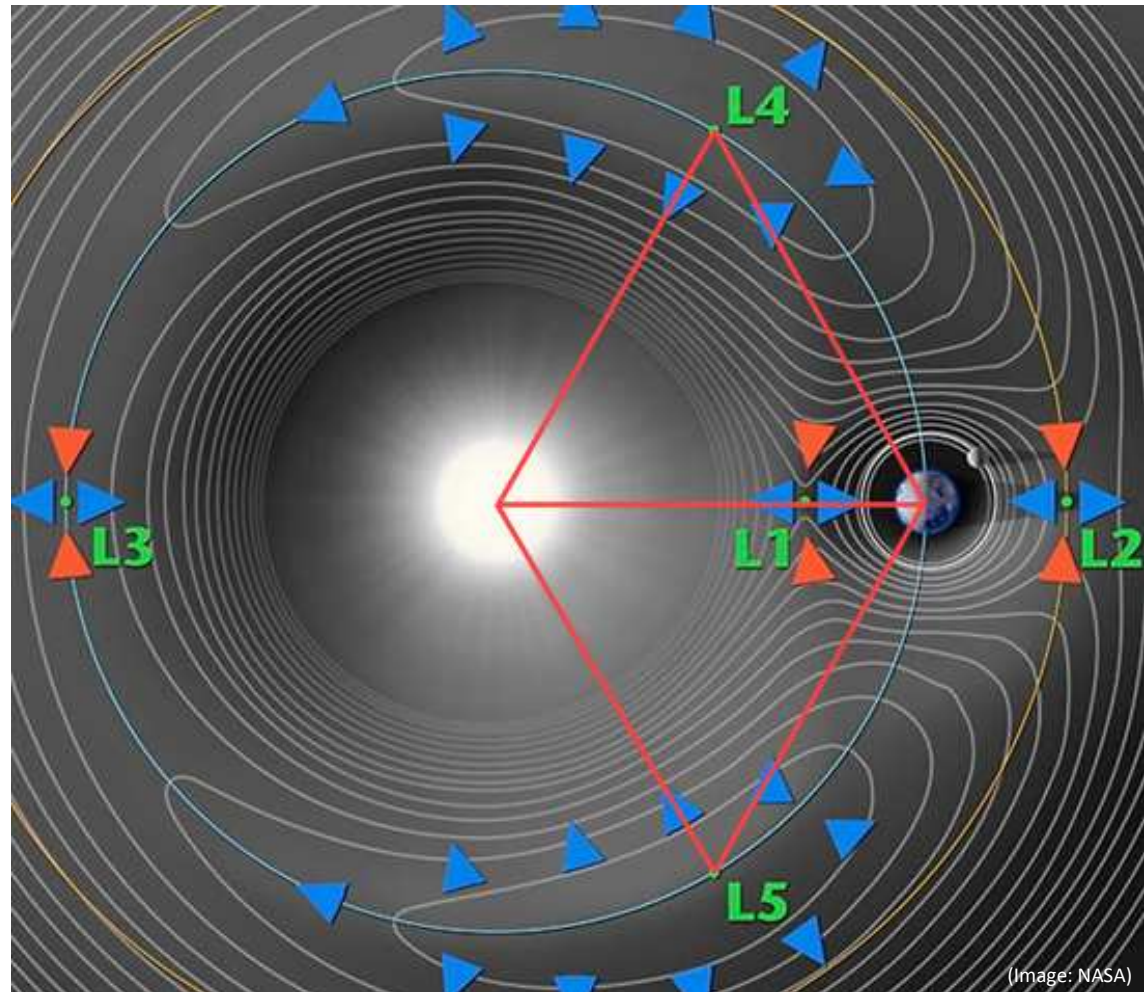
September 19-21, 2012



# What is a Trojan?

There are 5 Lagrangian points in a planet's orbit where an object can exist in a stable 1:1 mean motion resonance with the planet.

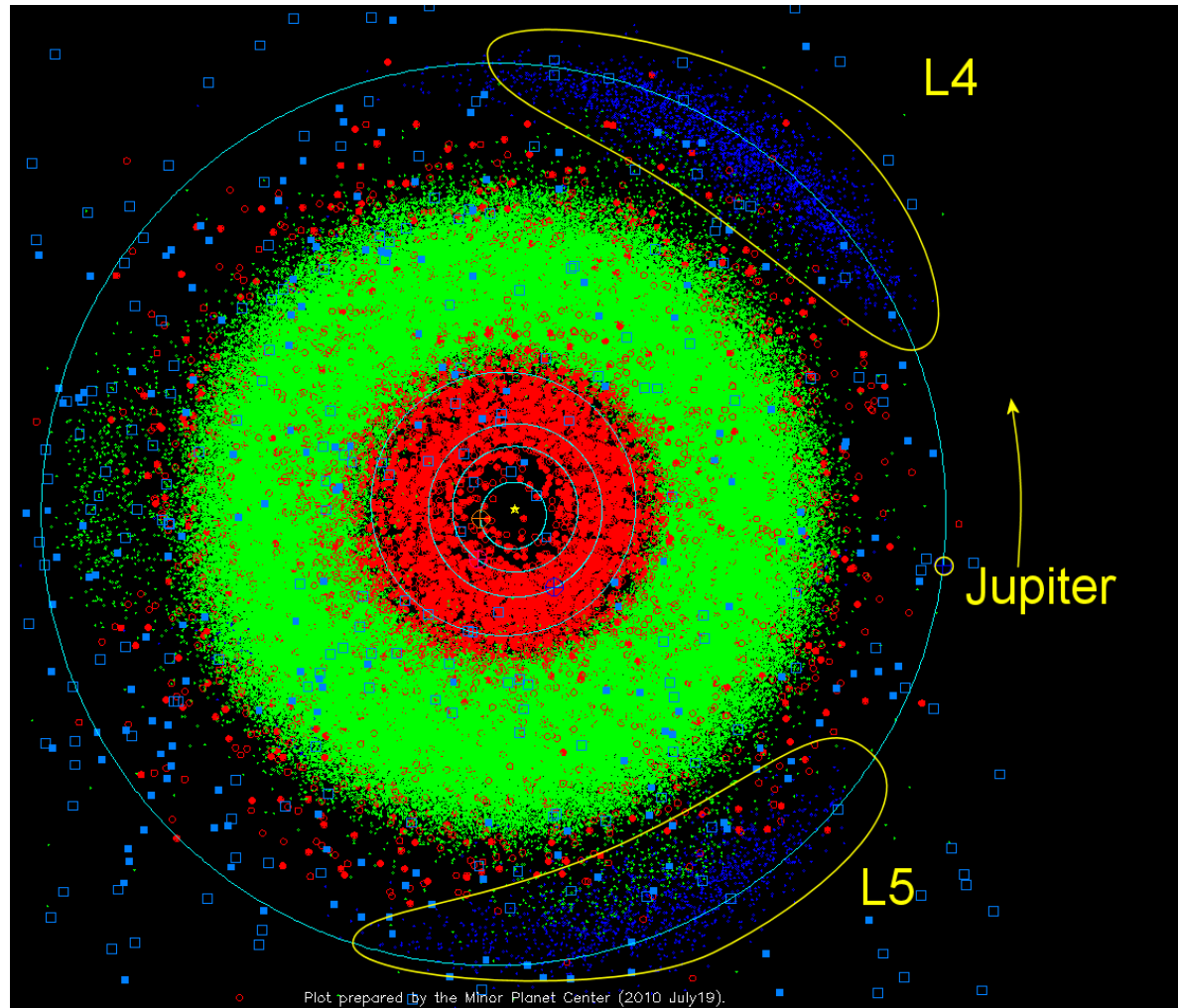
Objects in the stable zones near the equilateral L4 and L5 Lagrangian points are referred to as "Trojans".



# Jupiter Trojans

584,686 known<sup>1</sup>  
asteroids in the  
Solar System.

5,251 Jupiter Trojans



<sup>1</sup> as of May 13, 2012 ([www.minorplanetcenter.org](http://www.minorplanetcenter.org))

# Inner Solar System

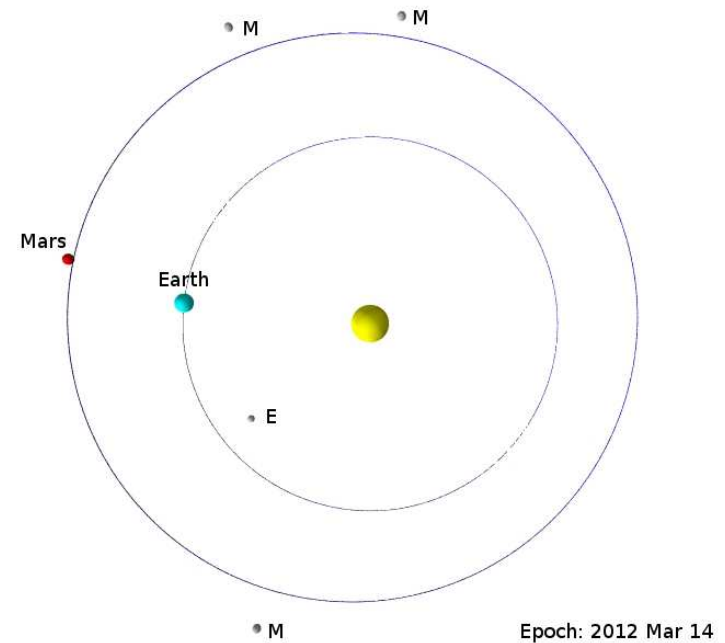
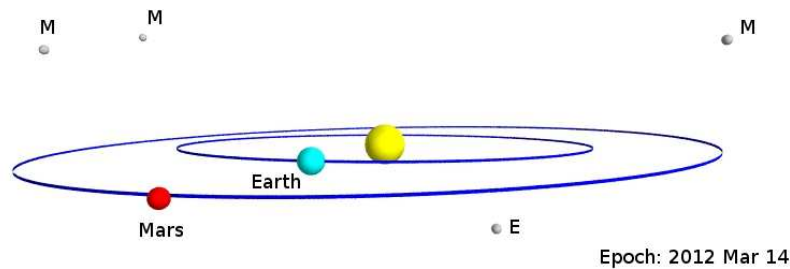
3 Mars Trojans (predicted to be ~50,  $r > 500\text{m}$ )

(Tabachnik & Evans 1999, 2000a,b)

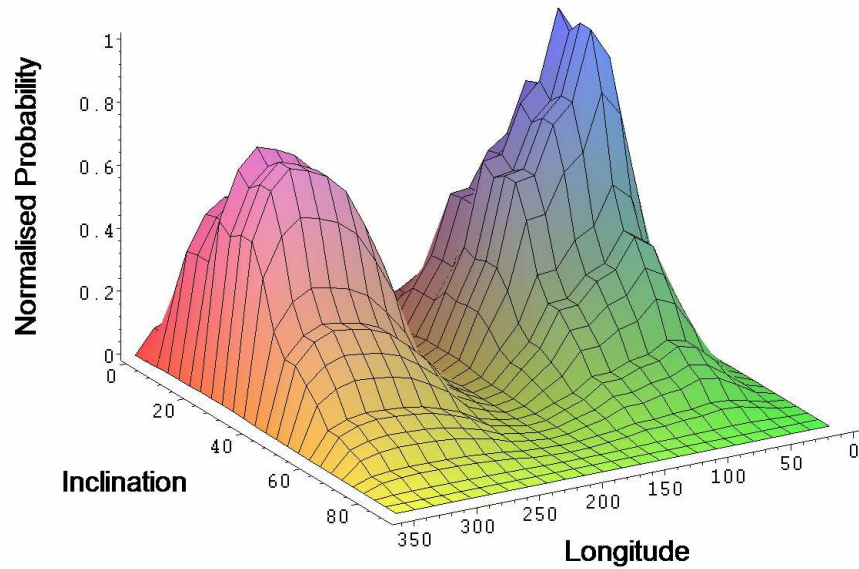
1 Earth Trojan (predicted to be ~17,  $r > 50\text{m}$ )

(Morais & Morbidelli 2002)

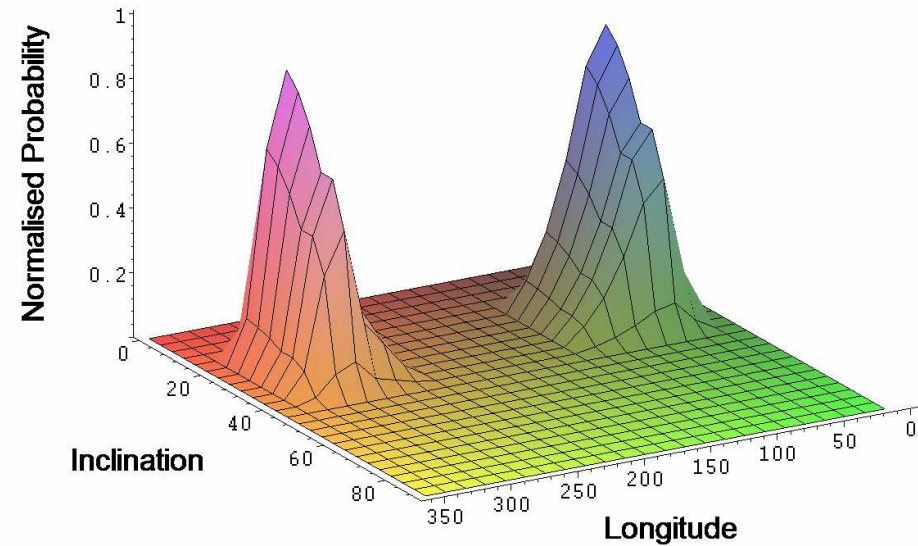
The numbers are small but  
many more should exist than  
have been discovered



# Probability distributions



Earth Trojans  
(Todd et al. 2012a)

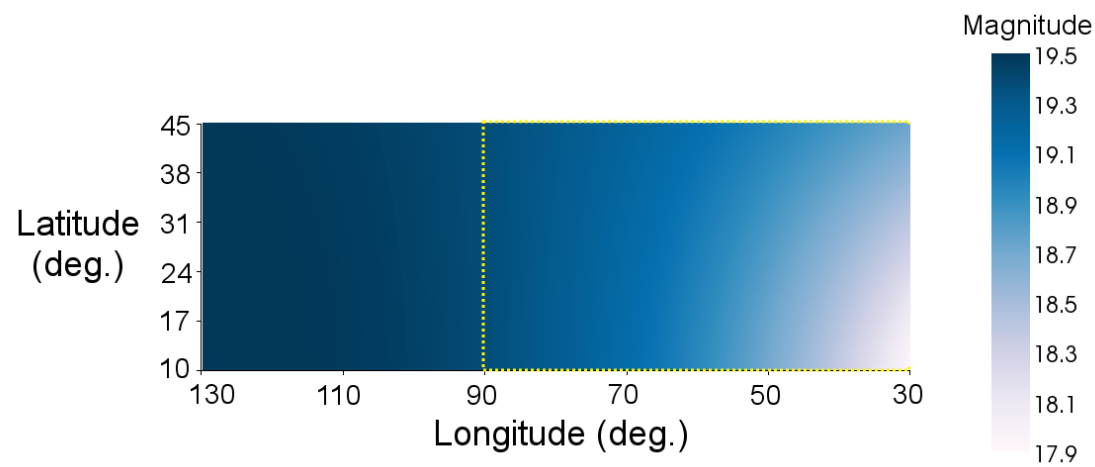


Mars Trojans  
(Todd et al. 2012b)

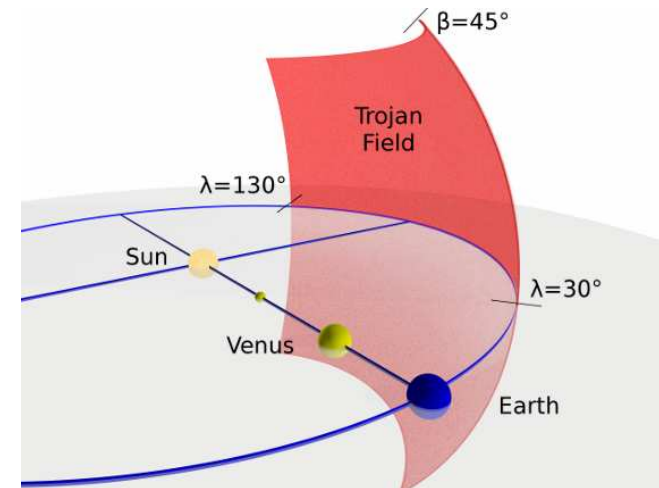
Peak detection longitudes are consistent with classical Lagrangian points, but bodies are unlikely to be co-planar

# Magnitudes – Earth Trojans

- Apparent magnitude for 1 km object ranges from 17.9 to 19.5
  - Assumed albedo 0.20
  - No atmospheric extinction



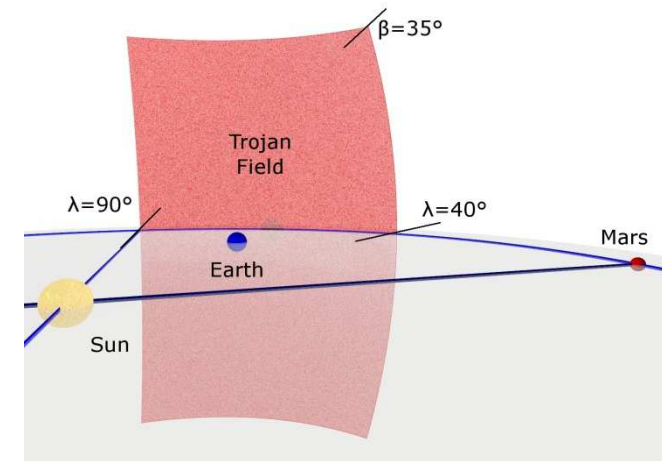
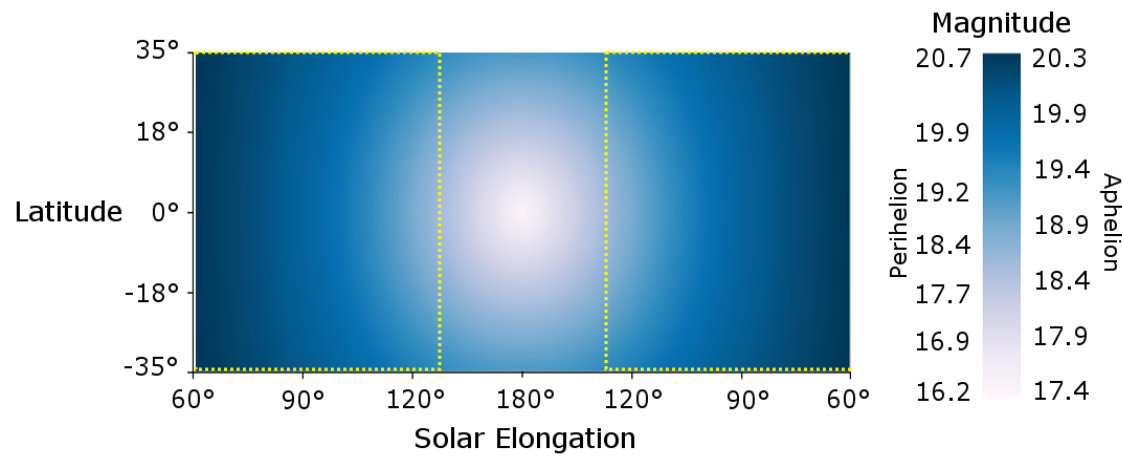
Variation in apparent magnitude across field.  
Elongations  $> 45^\circ$  ie within *Gaia*'s scanning limit  
(yellow dotted line)



Earth Trojan (L4) field

# Magnitudes – Mars Trojans

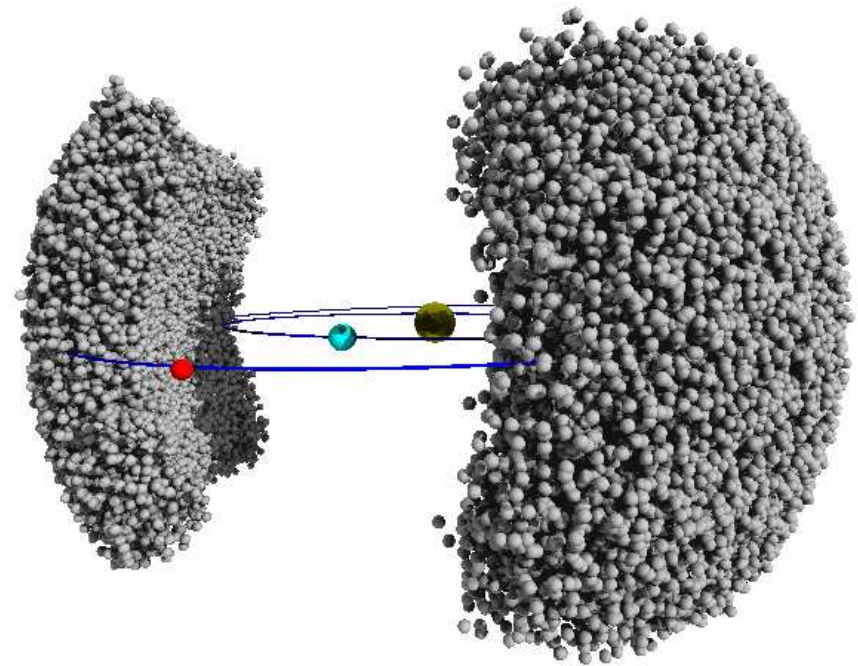
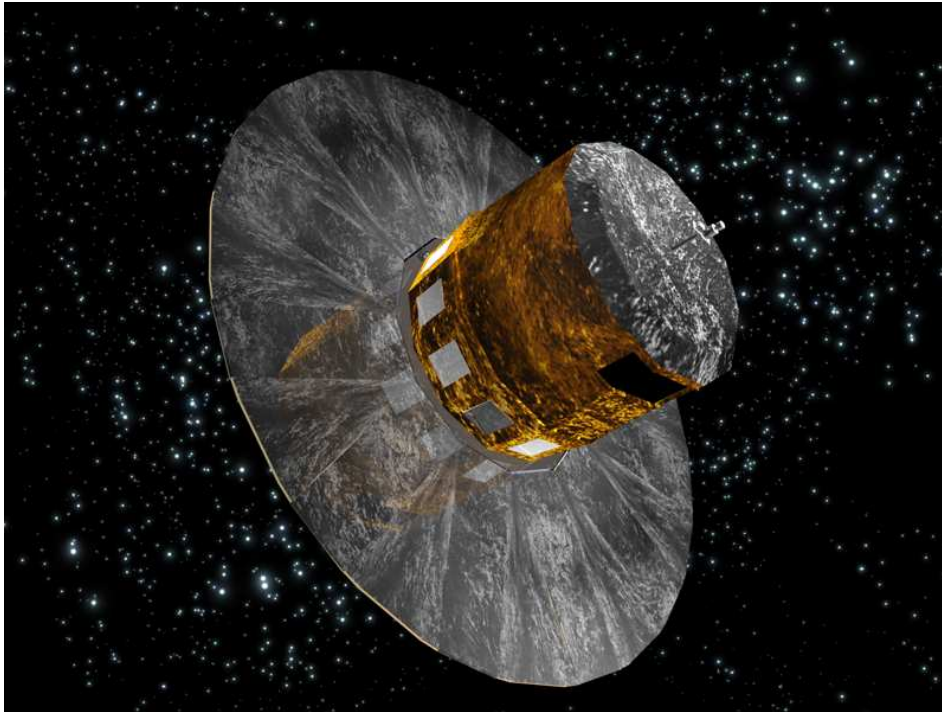
- Apparent magnitude for 1 km object ranges from 16.2 to 20.7
  - Assumed albedo 0.20
  - No atmospheric extinction



Mars Trojan field

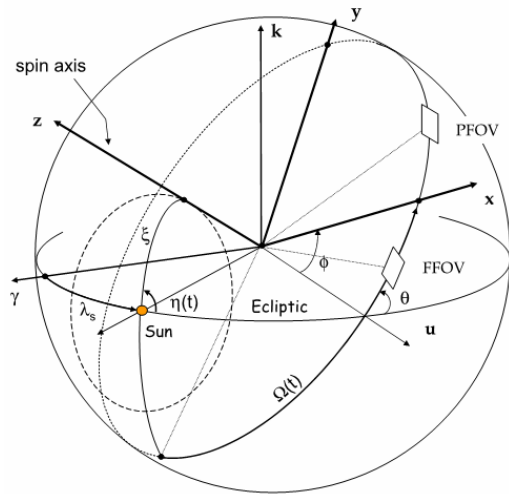
Variation in apparent magnitude across field.  
Elongations < 135° within *Gaia*'s scanning limit  
(yellow dotted line)

# Simulations for detection by *Gaia*

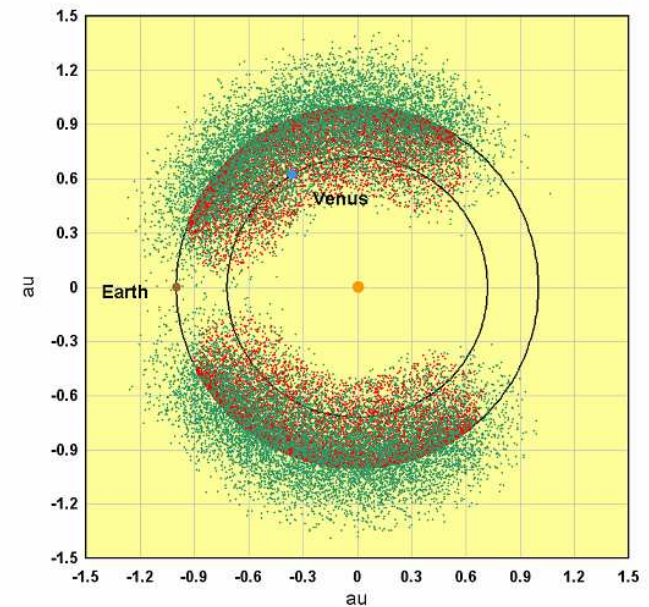
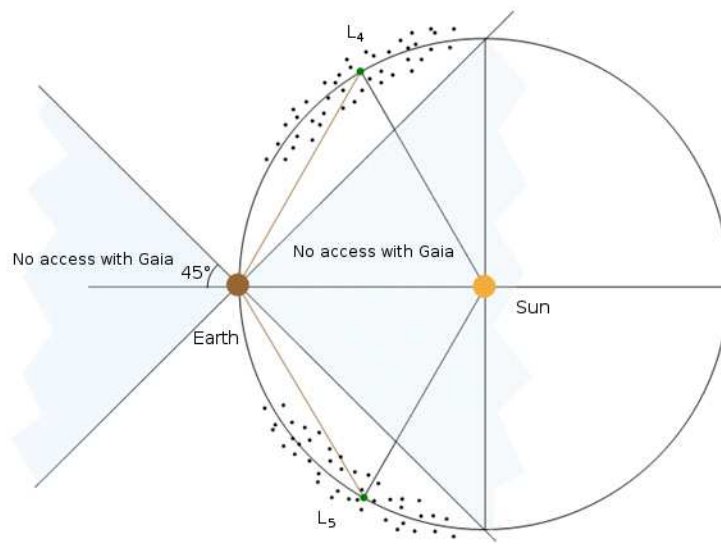




# Limitation: Gaia's scanning law

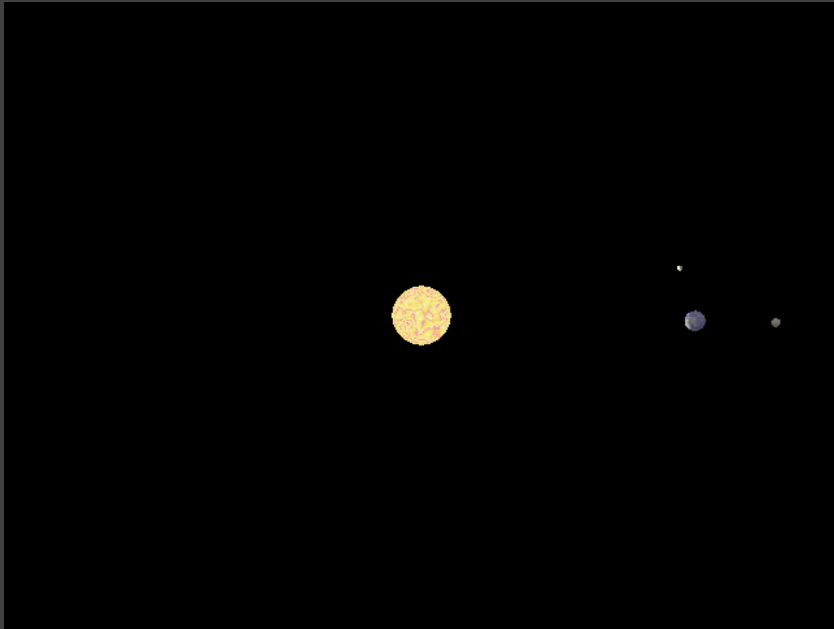


*Gaia's* rotation and orbit constrains observations to Solar elongations between  $45^\circ$  and  $135^\circ$



(Mignard et al. 2011)

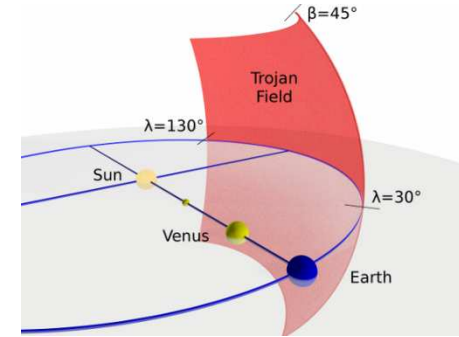
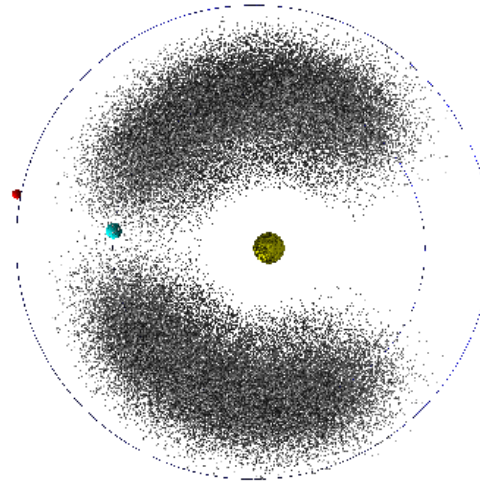
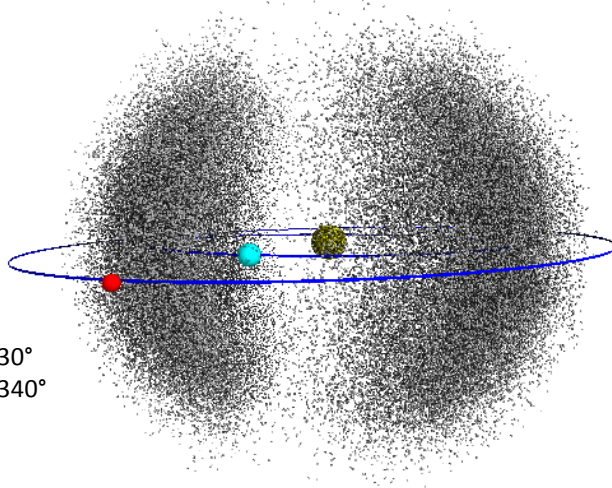
# Earth Trojan fields



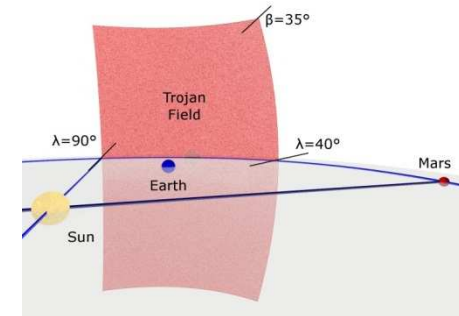
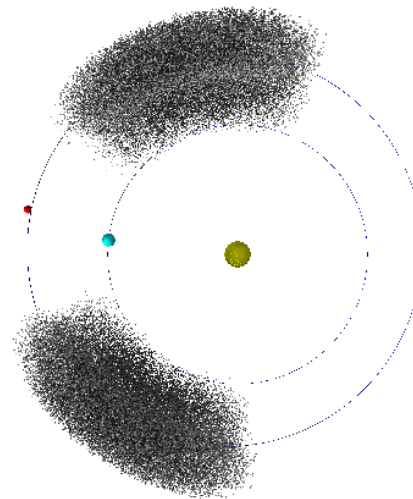
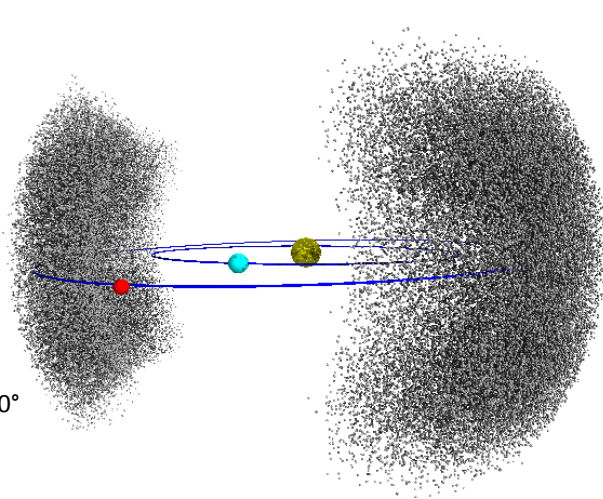
Simulated Earth Trojan orbit in a rotating frame

# Trojans simulation

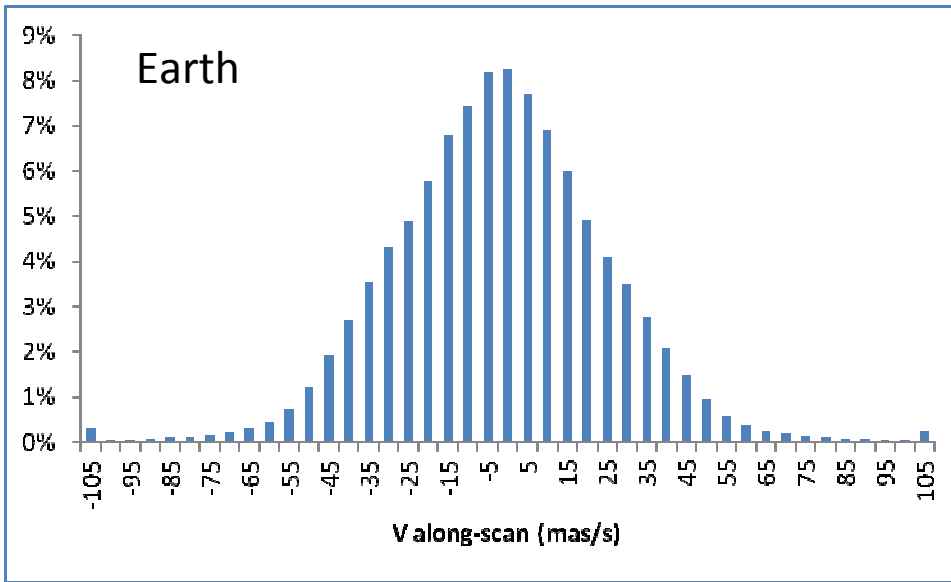
$0.9 < a < 1.2$   
 $0.0 < e < 0.2$   
 $10^\circ < i < 60^\circ$   
 L4:  $30^\circ < L < 130^\circ$   
 L5:  $240^\circ < L < 340^\circ$



$1.45 < a < 1.60$   
 $0.0 < e < 0.2$   
 $15^\circ < i < 35^\circ$   
 L4:  $40^\circ < L < 90^\circ$   
 L5:  $270^\circ < L < 320^\circ$



# Along-scan velocity



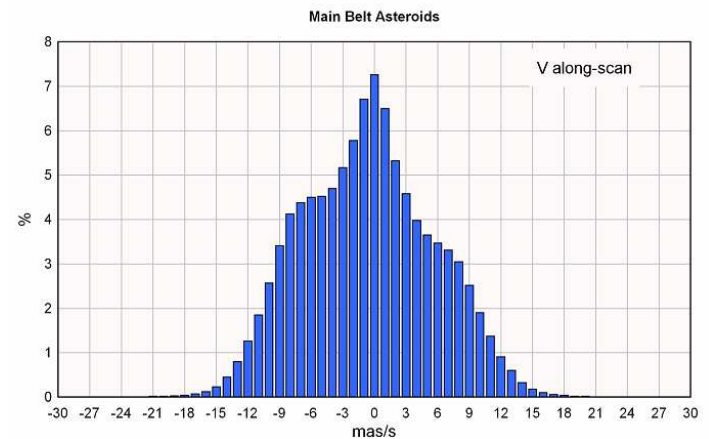
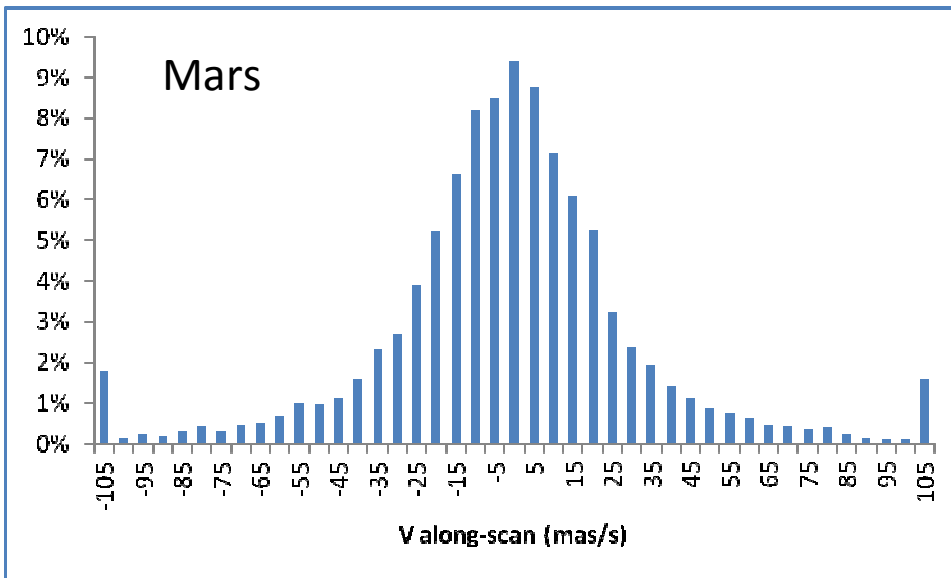
20 000 objects run on Gaia simulator

-assumed albedo 0.20

-diameter 1000 metres

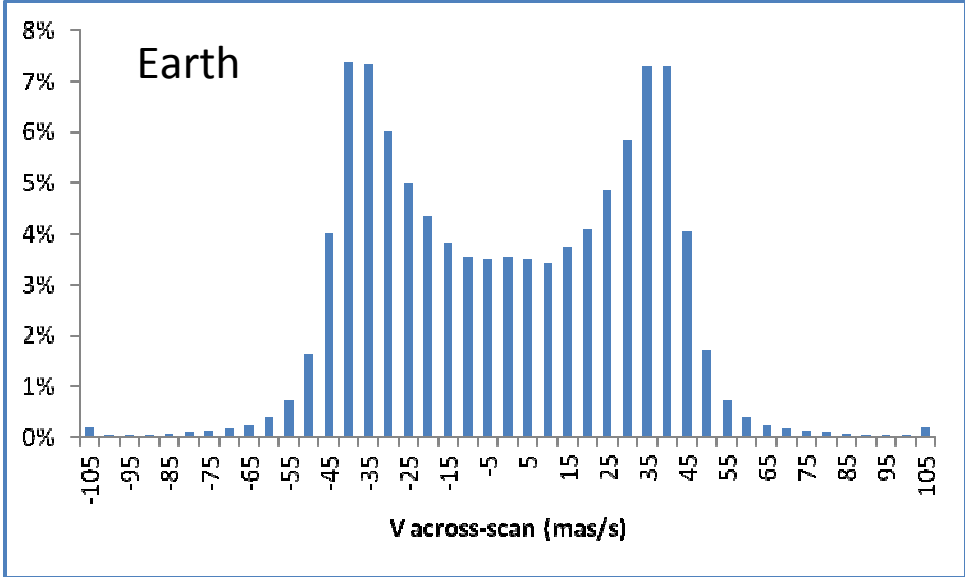
Along-scan velocity is significant

- much greater than for Main Belt

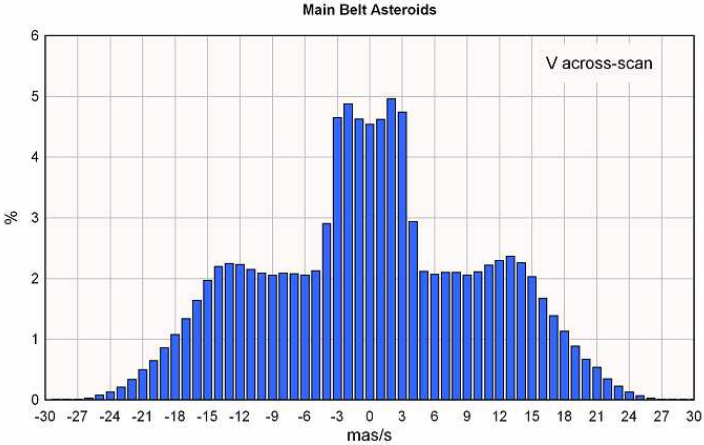
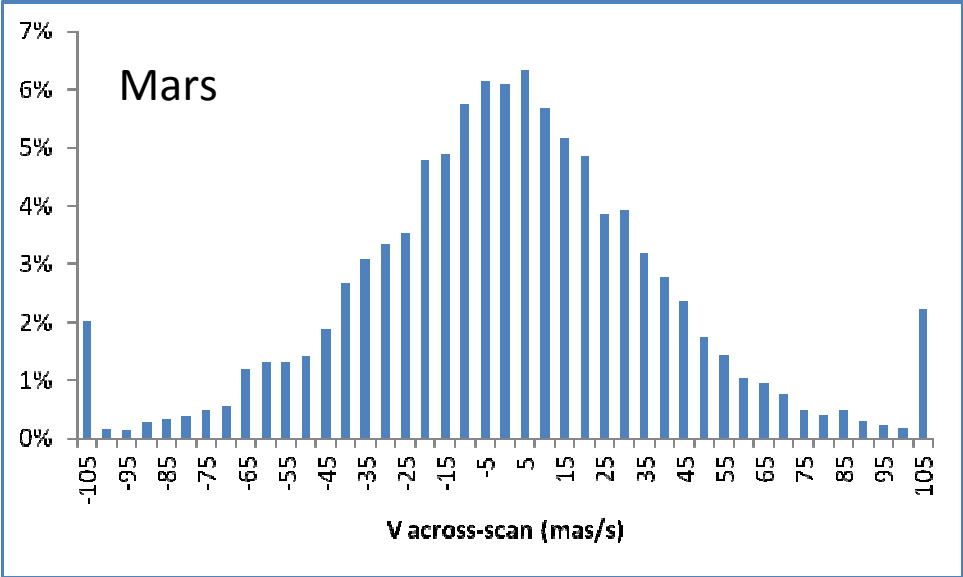


(Mignard et al. 2011)

# Cross-scan velocity

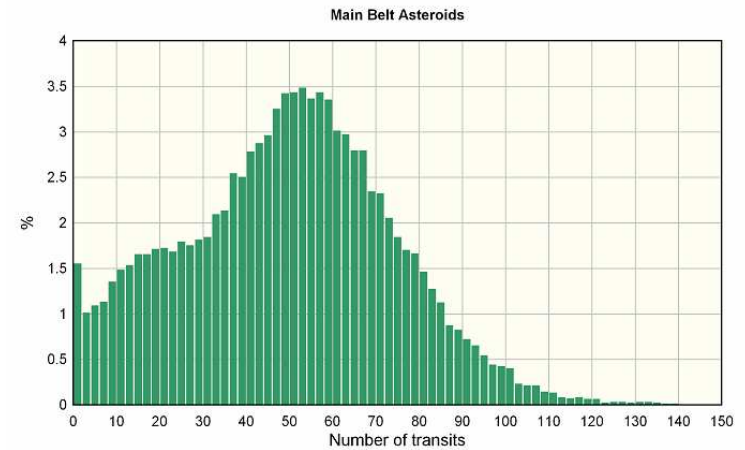
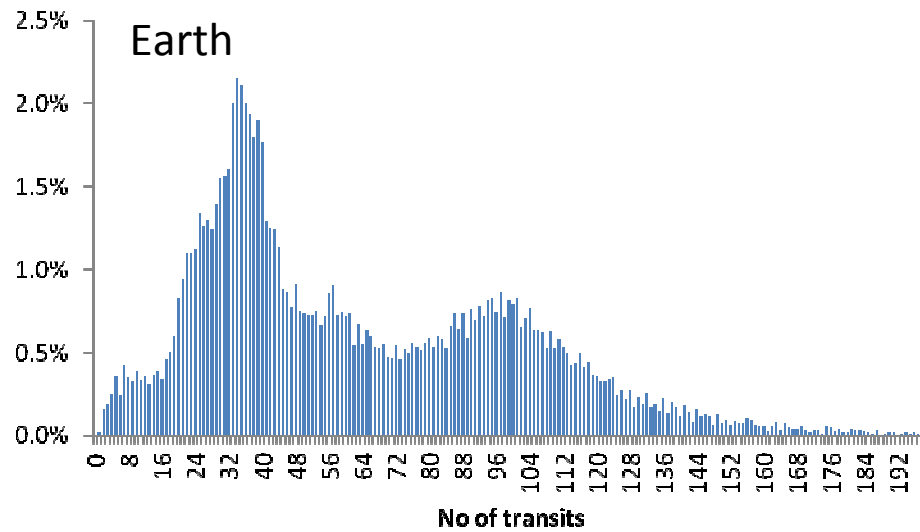


Across-scan velocity is also significant

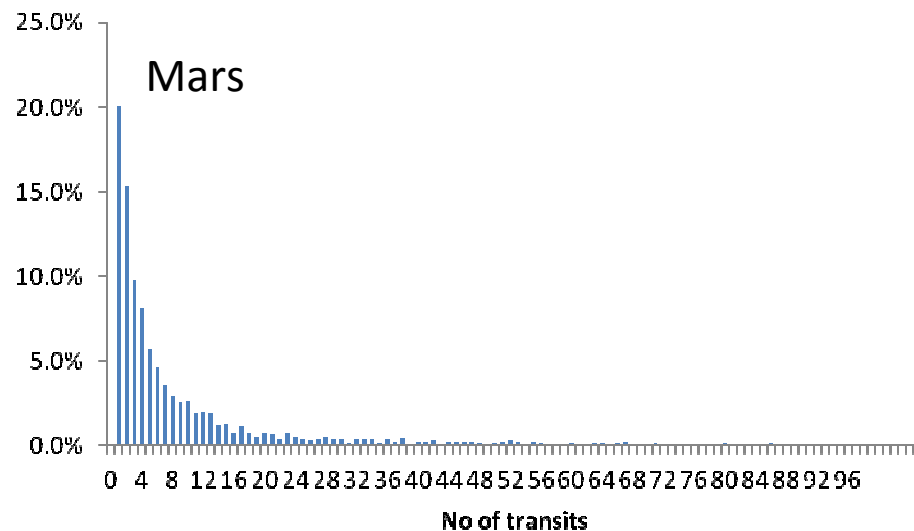


(Mignard et al. 2011)

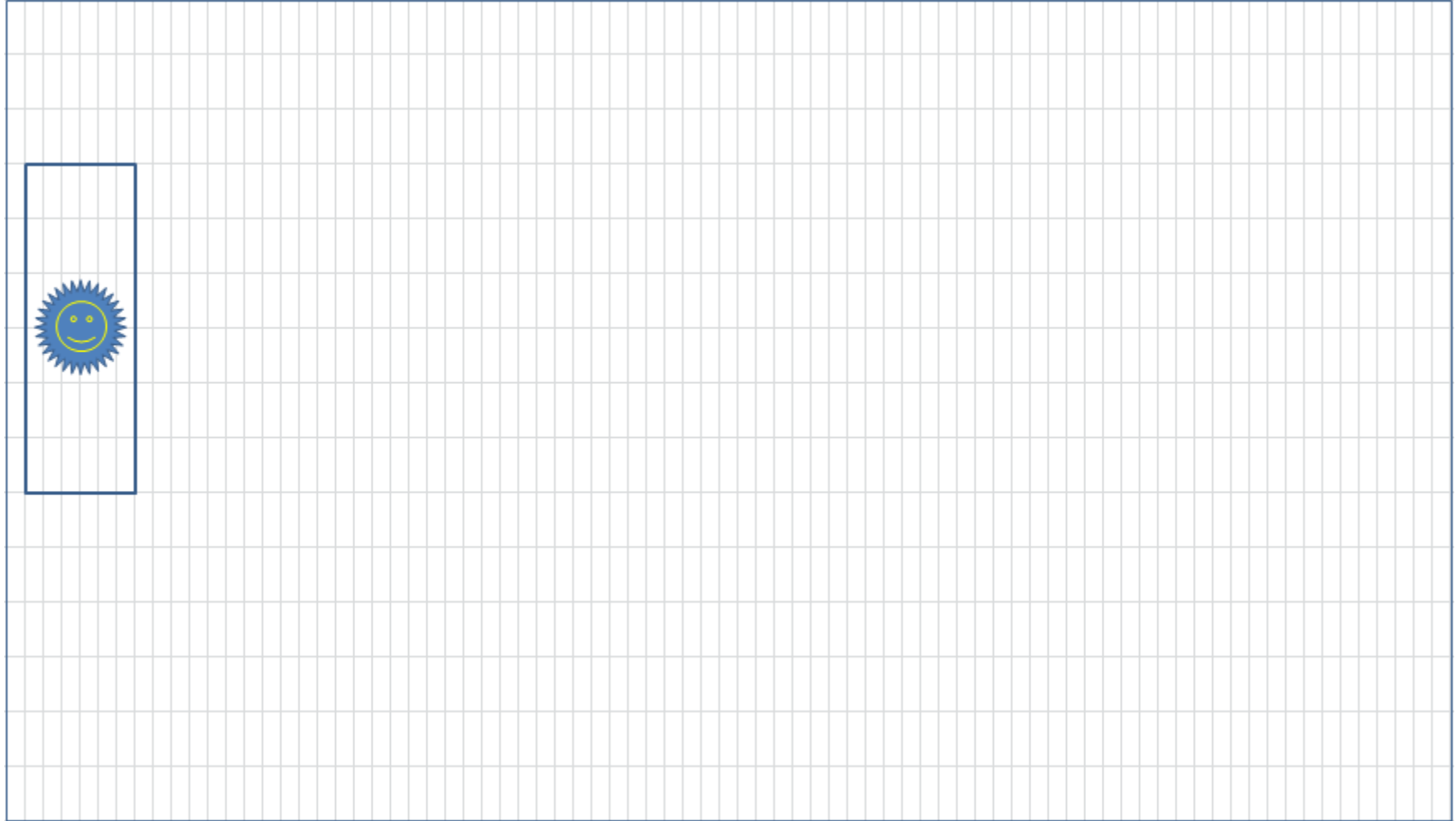
# No of transits



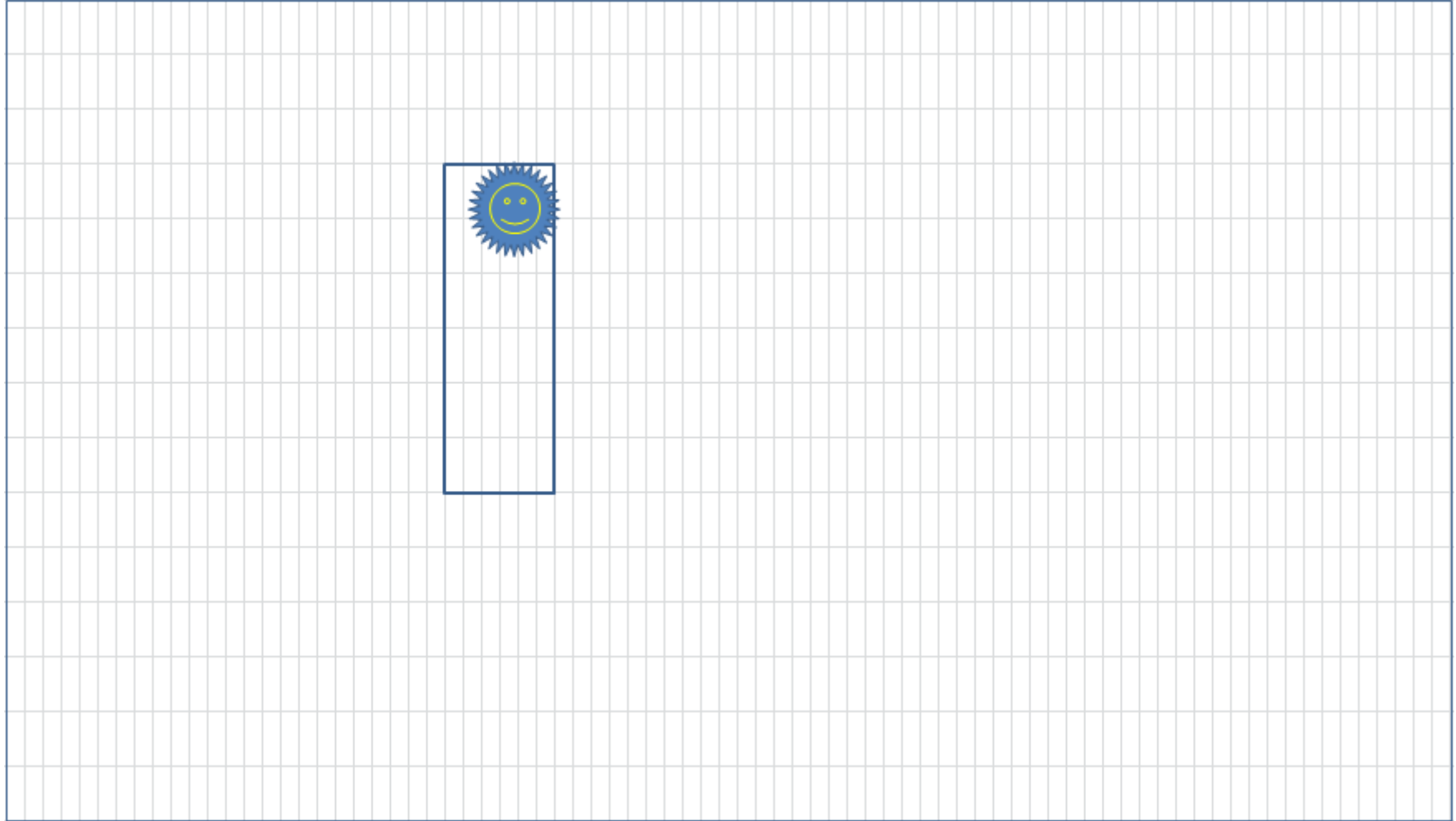
(Mignard et al. 2011)



Due to their orbits, the simulated Earth Trojans are observed more frequently than Main Belt  
The simulated Mars Trojans are observed less frequently.

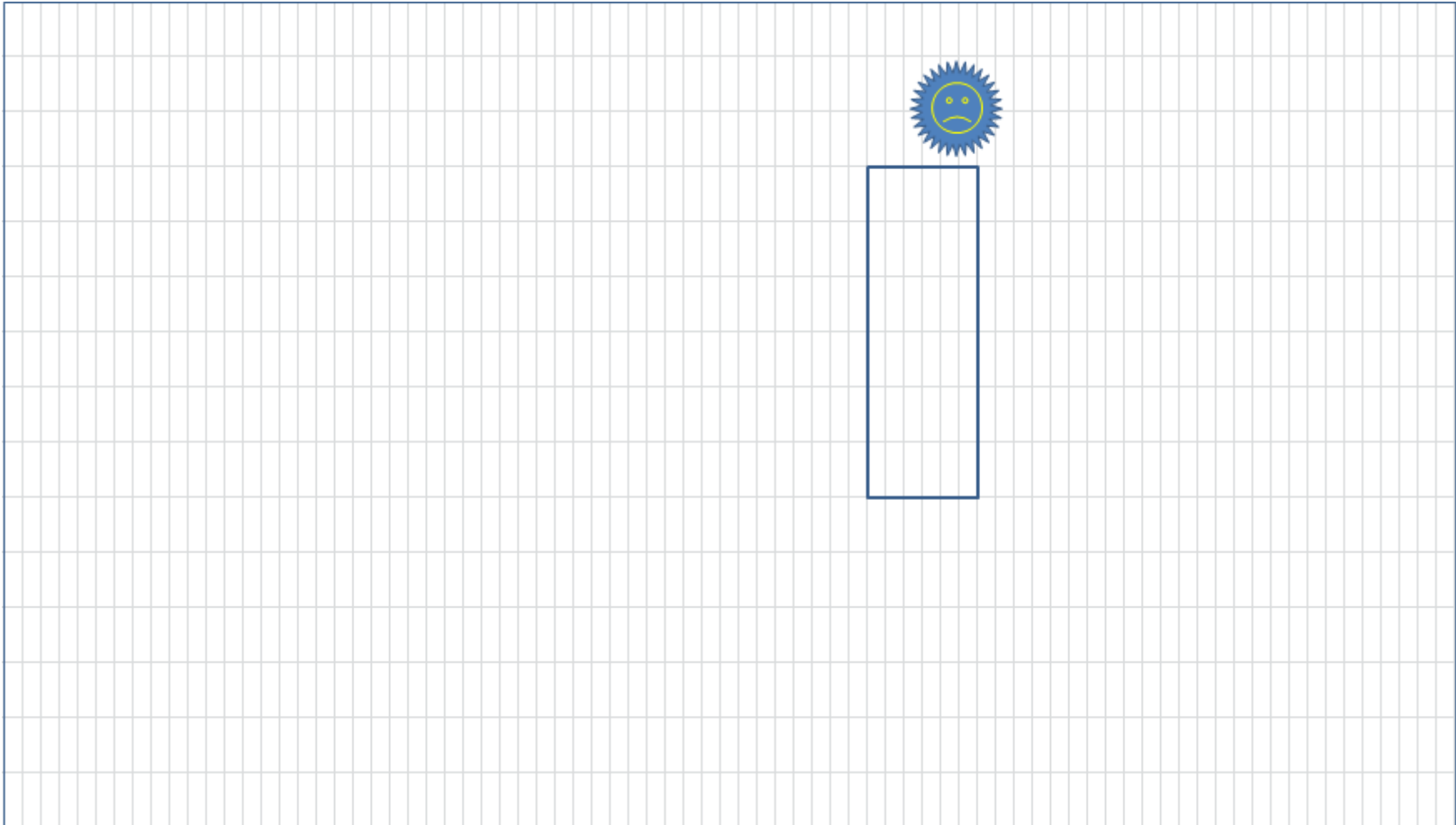


SM defines window on CCD



Relative motion along-scan and across-scan





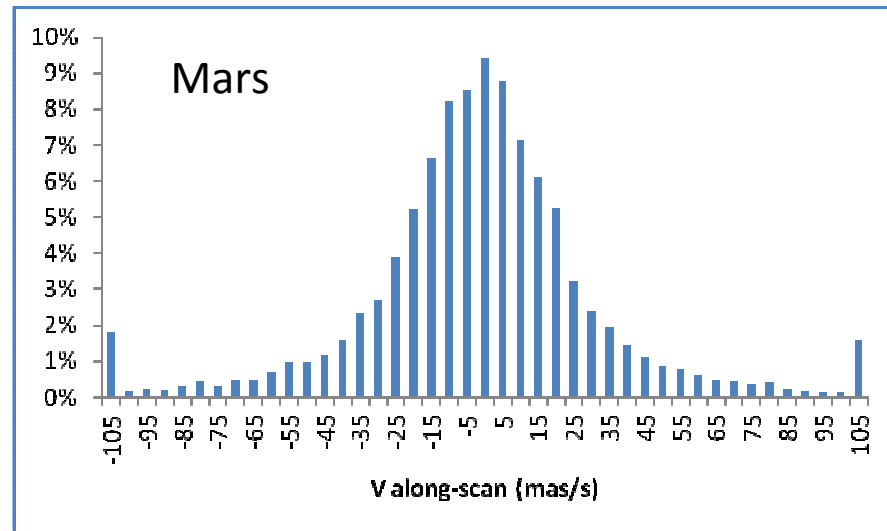
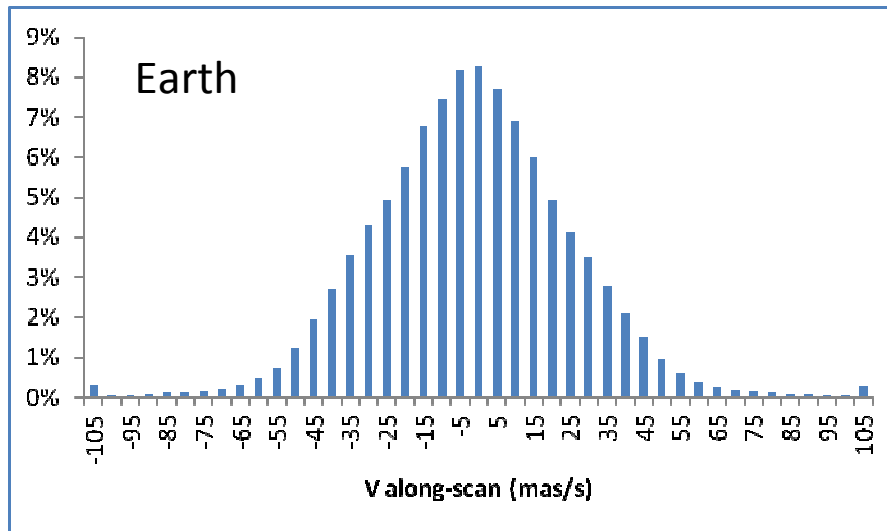
Source drifts out of window

# Along-scan velocity

- CCD window 6 pixels x 59 mas/pixel = 354 mas along-scan (AL)
- AL drift > 3.5 mas/s moves outside window during transit

# Along-scan velocity

- CCD window 6 pixels x 59 mas/pixel = 354 mas along-scan (AL)
- AL drift  $> 3.5$  mas/s moves outside window during transit

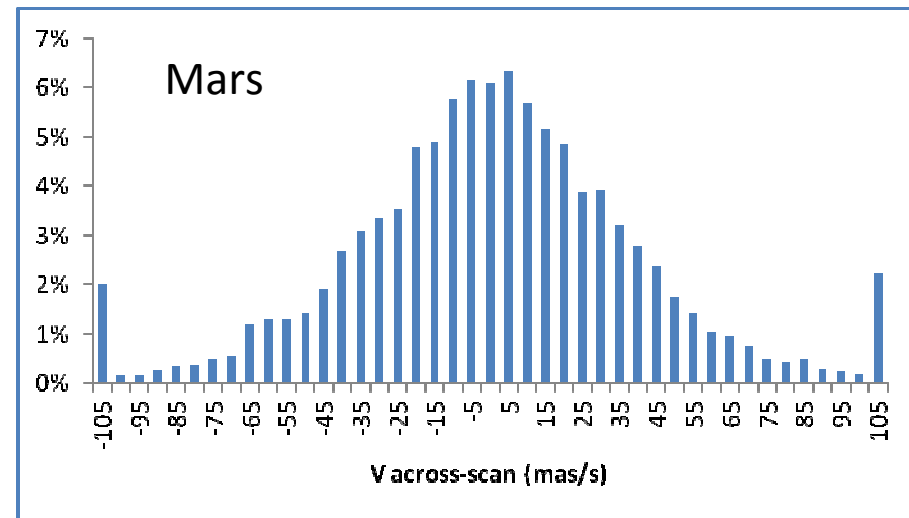
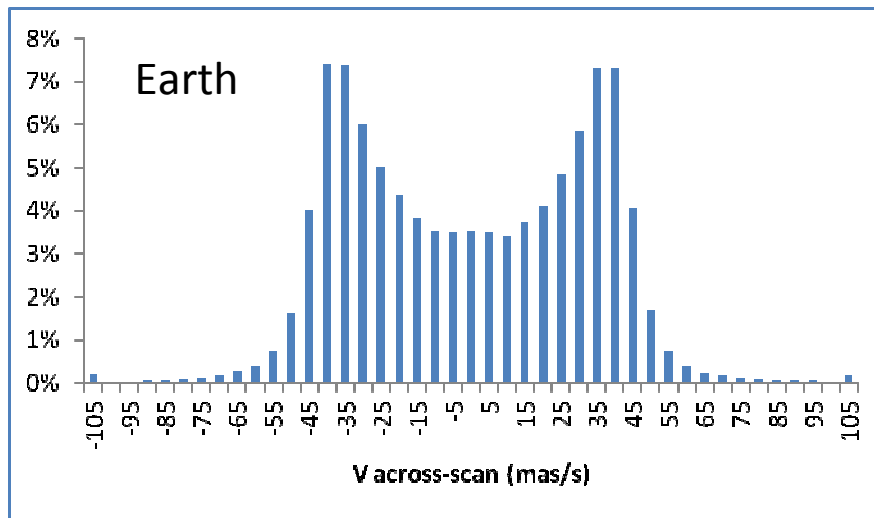


# Across-scan velocity

- CCD window 12 pixels x 177 mas = 2124 mas across-scan (AC)
- AC velocity  $> 195$  mas/s the SSO is only observed once (mean starting point at centre of CCD)
- AC drift  $> 21.2$  mas/s moves outside window during transit

# Cross-scan velocity

- CCD window 12 pixels x 177 mas = 2124 mas across-scan (AC)
- AC velocity  $> 195$  mas/s the SSO is only observed once (mean starting point at centre of CCD)
- AC drift  $> 21.2$  mas/s moves outside window during transit



# Earth Trojans

20 000 simulated objects

19 031 objects cross Gaia's field of view

18 885 detected in simulations ( $V < 20$ )

3 cannot be located (detected in only 1 aperture)

So ~19 000 possible from 20 000 = 94%

Why? Geometry – co-orbital so observed ~ every pass

BUT **very** unlikely to be any undiscovered with this size

# Earth Trojans

The known Earth Trojan 2010 TK7:

- magnitude between  $20.9 < V < 22.7$
- mean sky motion between 25 mas/s to 100 mas/s

Will *Gaia* detect it?

Unlikely – too faint

# Mars Trojans

20 000 simulated objects

19 858 objects cross Gaia's field of view

2 096 detected in simulations ( $V < 20$ )

420 cannot be located (detected in only 1 aperture)

So ~1600 possible from 20 000 = 8%

Why? Geometry – phase angle, distance...



# Mars Trojans

The known Mars Trojans:

5261 Eureka:

- magnitude between  $\sim 17.1 < V < 19.2$
- mean sky motion between  $\sim 4.5 \text{ mas/s}$  to  $23.5 \text{ mas/s}$

1998 VF31:

- magnitude between  $\sim 17.3 < V < 20.1$
- mean sky motion between  $\sim 6.5 \text{ mas/s}$  to  $35.5 \text{ mas/s}$

1999 UJ7

- magnitude between  $\sim 17.4 < V < 19.6$
- mean sky motion between  $\sim 4.5 \text{ mas/s}$  to  $23.0 \text{ mas/s}$

Will *Gaia* detect these?

We think so, some uncertainty. Proof will come...

# Conclusions

- Trojan regions occupy very large sky area
- *Gaia* will survey these regions multiple times
  - Many passes over Earth Trojan region
  - Fewer passes over Mars Trojan
  - High along-scan and across-scan velocities may be a problem
  - Unlikely to discover Earth Trojans
  - Some uncertainty but expect to detect Mars Trojans

# Acknowledgements

- Astronomical Society of Australia
- Gaia-FUN workshop SOC/LOC and sponsoring organisations



Merci de votre attention