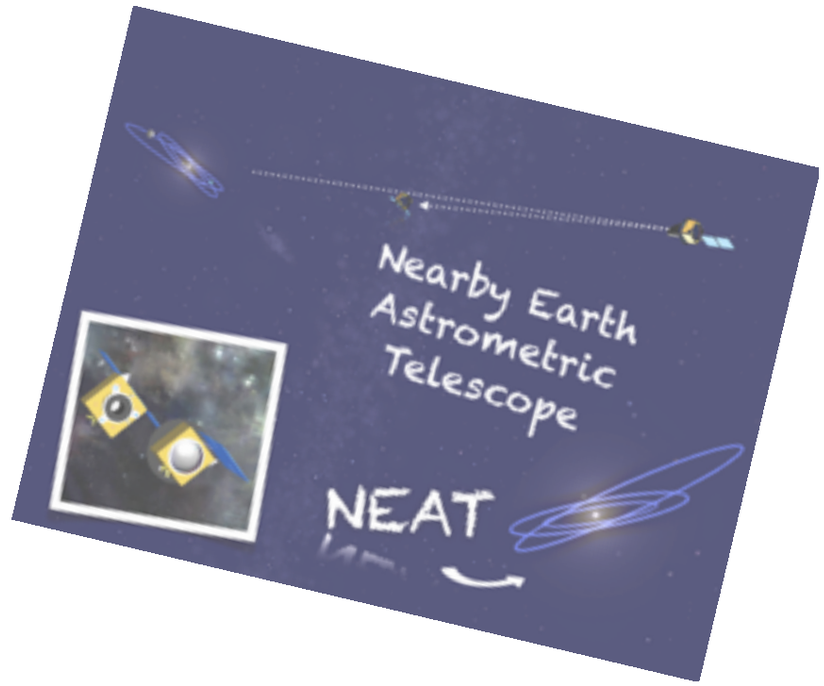
Toward an astrometric mission to detect and characterize nearby habitable planetary systems



Fabien Malbet

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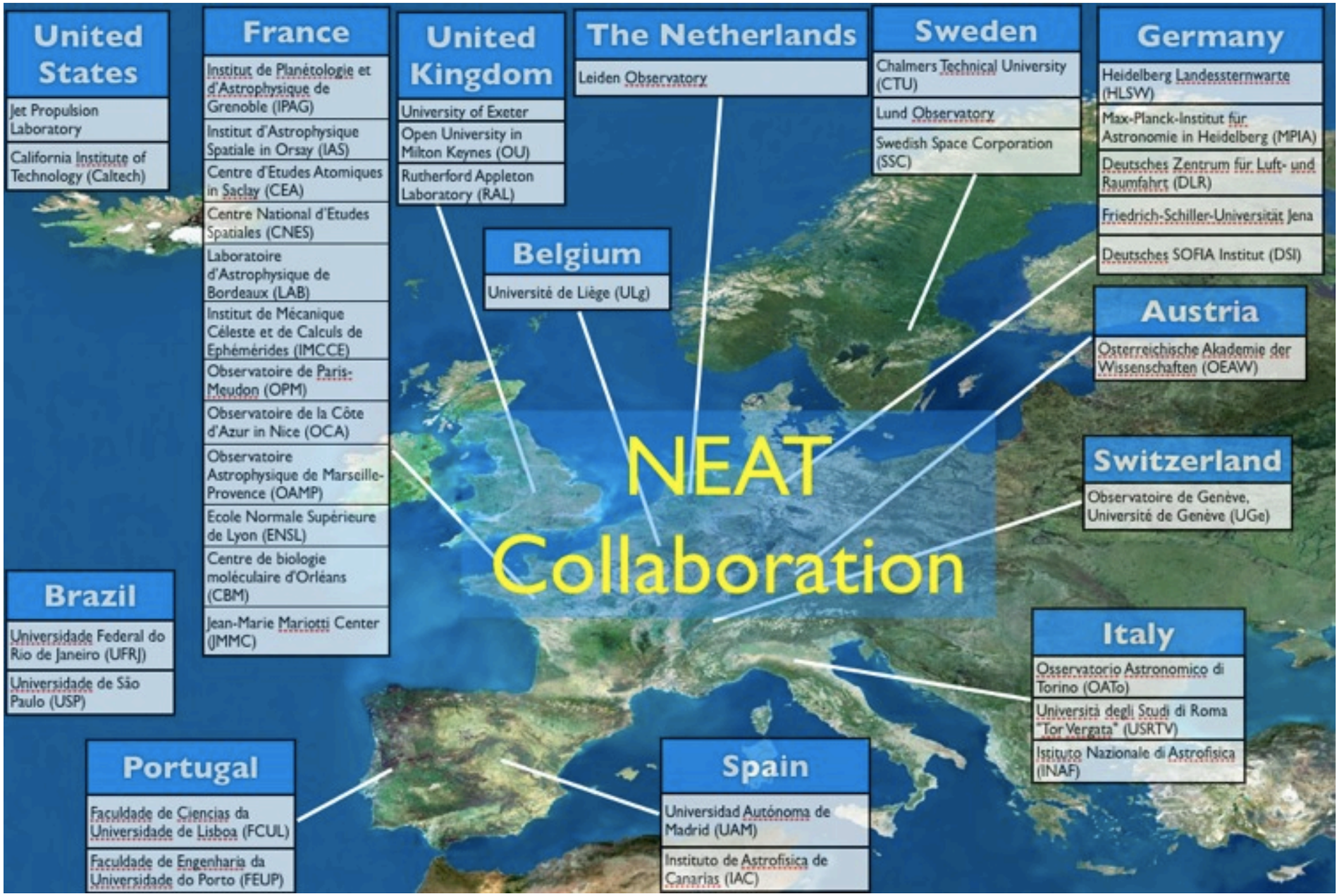
IPAG
Institut de Planétologie et d'Astrophysique de Grenoble

OSUG
Observatoire des Sciences de l'Univers de Grenoble

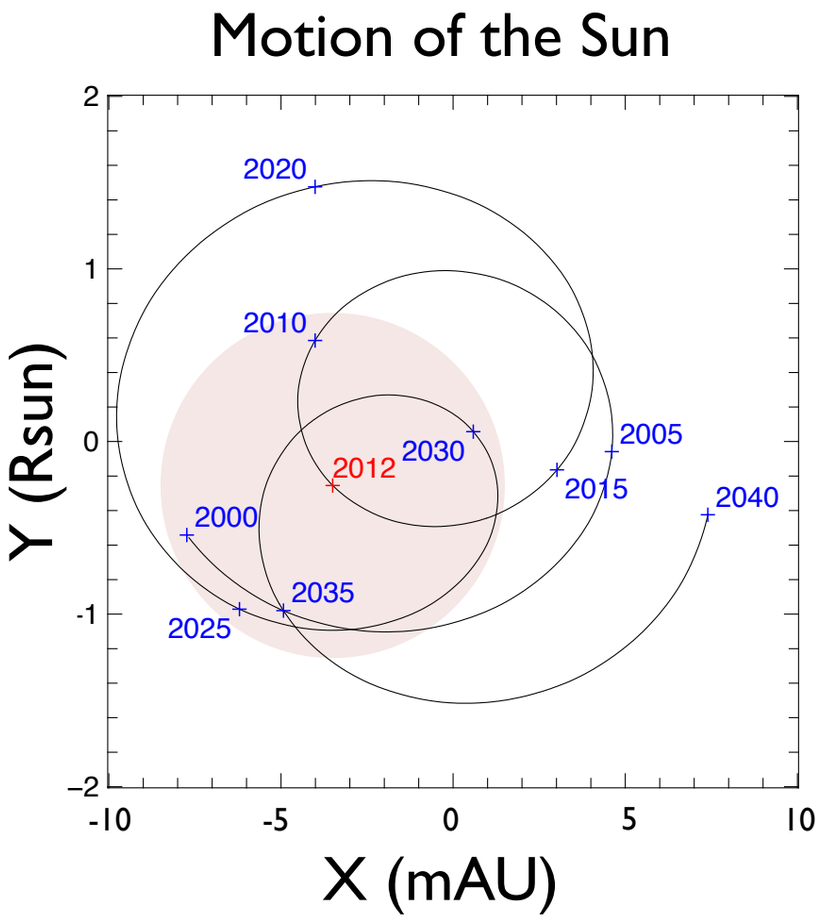
1st ITA - MPIA/Heidelberg - IPAG Colloquium
"Signs of planetary formation and evolution"
8-9 Oct 2012 Grenoble (France)

Mission submitted to ESA Cosmic Mission call for M3 in December 2010 by 70 scientists (full list at **http://neat.obs.ujf-grenoble.fr**)



Astrometry desired accuracy

$$A = 0.33\ (a_P / 1\ AU)\ .\ (M_P / 1\ M_E)\ .\ (M_* / 1\ M_S)^{-1}.\ (d / 10\ pc)^{-1} \quad \mu as$$



Sun @ 10pc	**Giants planets**	**Terrestrial planets**
M_P (M_E)	300	1
a_P (AU)	5	1
P (yr)	11	1
A (in μas)	**495**	**0.3**

Astrometry measures

$P, a_P, i, e, \omega, \Omega, T_0 \Rightarrow M_P$

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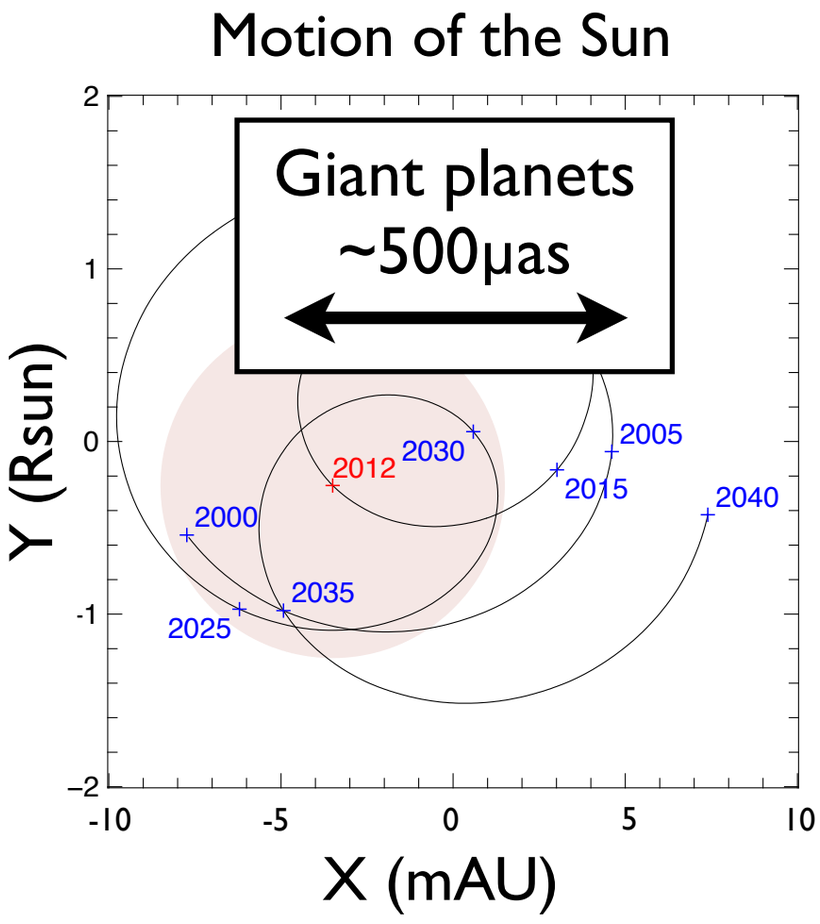

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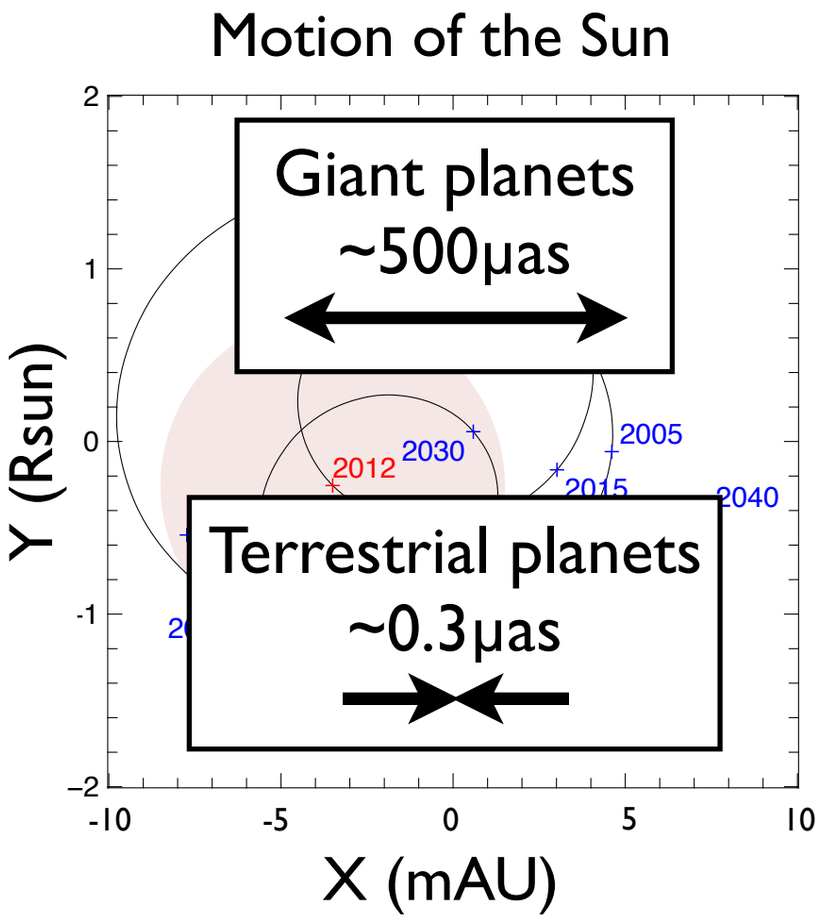

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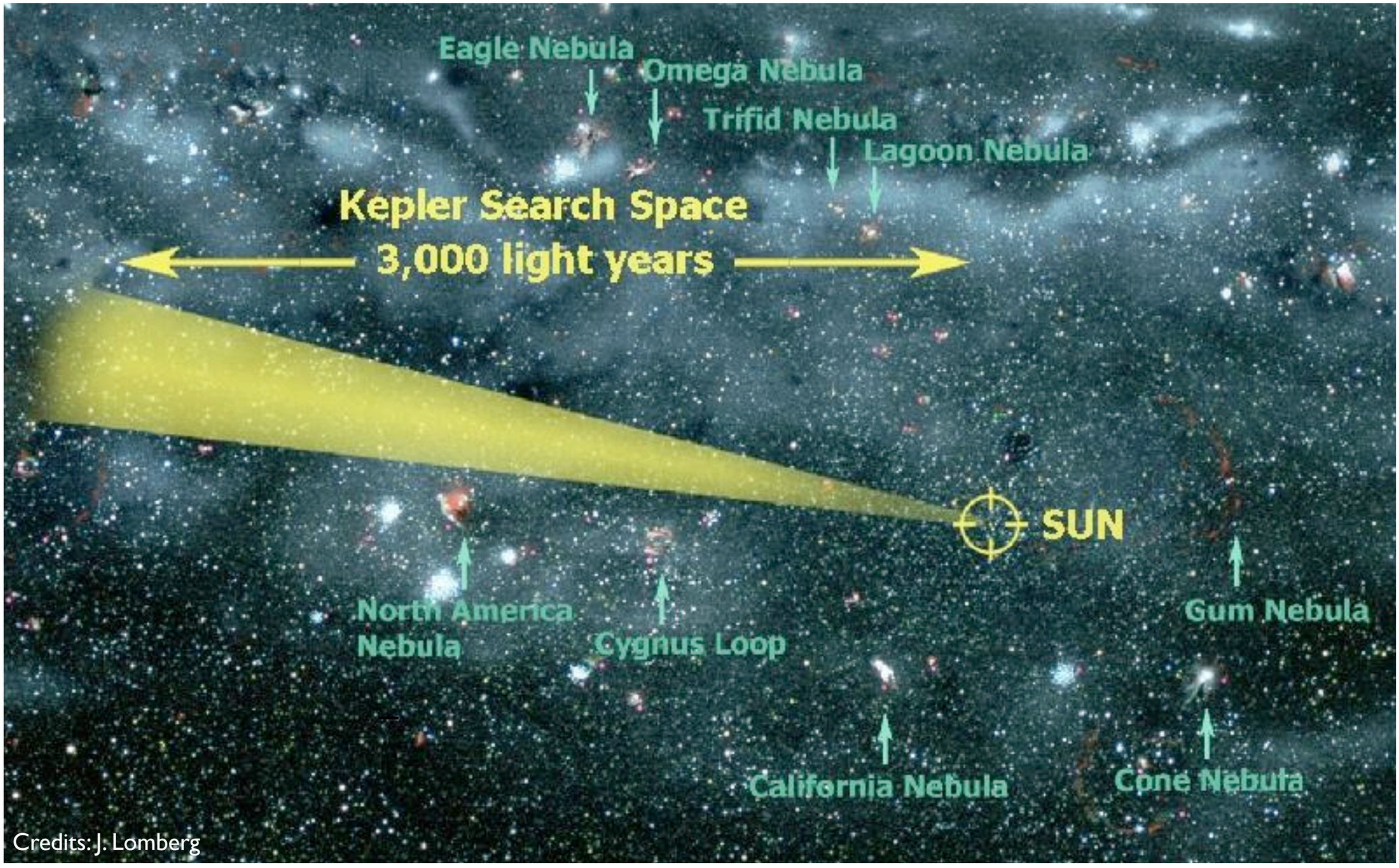
In order to detect a $1 M_{Earth}$ planet @10pc, one needs to detect signal $\geq 0.3 \pm 0.05$ µas

Which technique can search planetary systems around nearby solar-type stars ?



Credits: J. Lomberg

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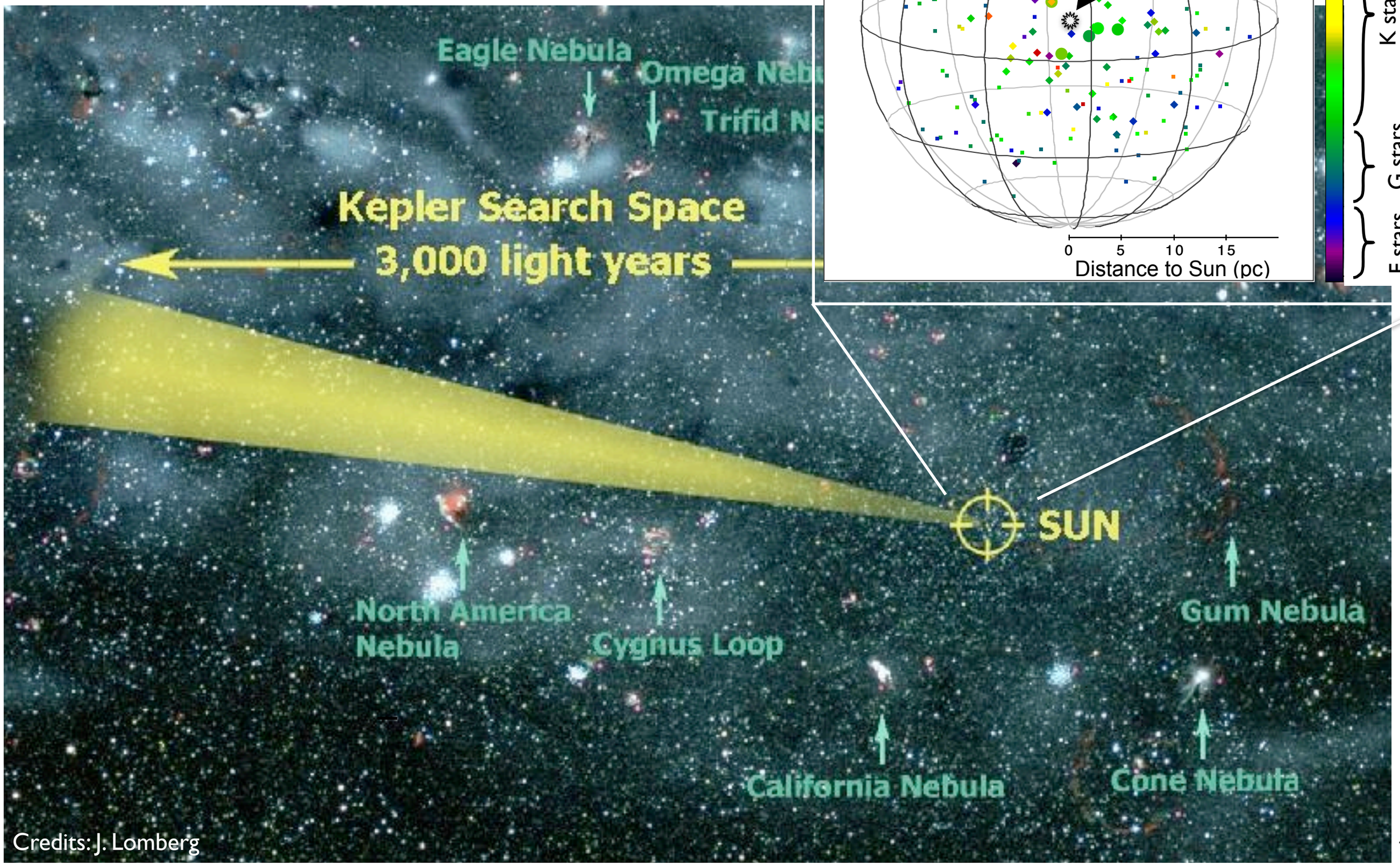

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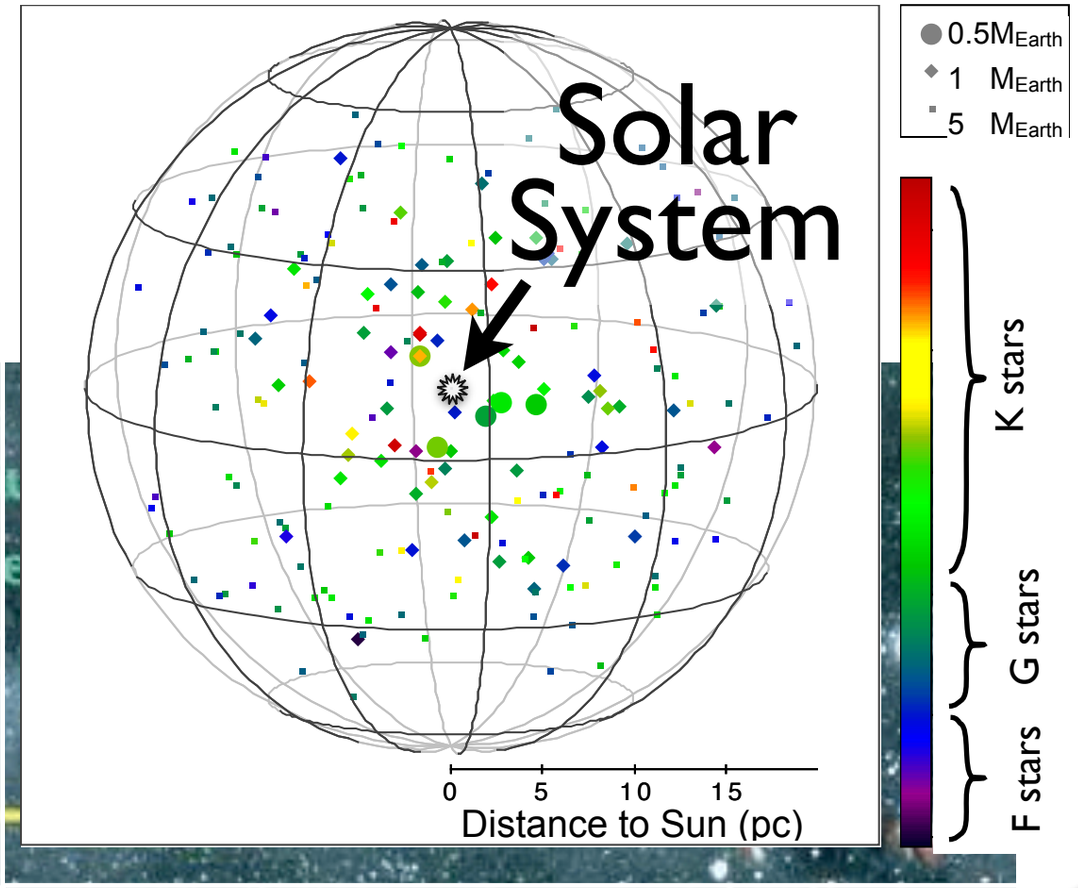

Eagle Nebula

Omega Nebula

Trifid Nebula

Kepler Search Space

3,000 light years

transits ?

⟷ microlensing ?

Gaia ?

SUN

North America Nebula

Cygnus Loop

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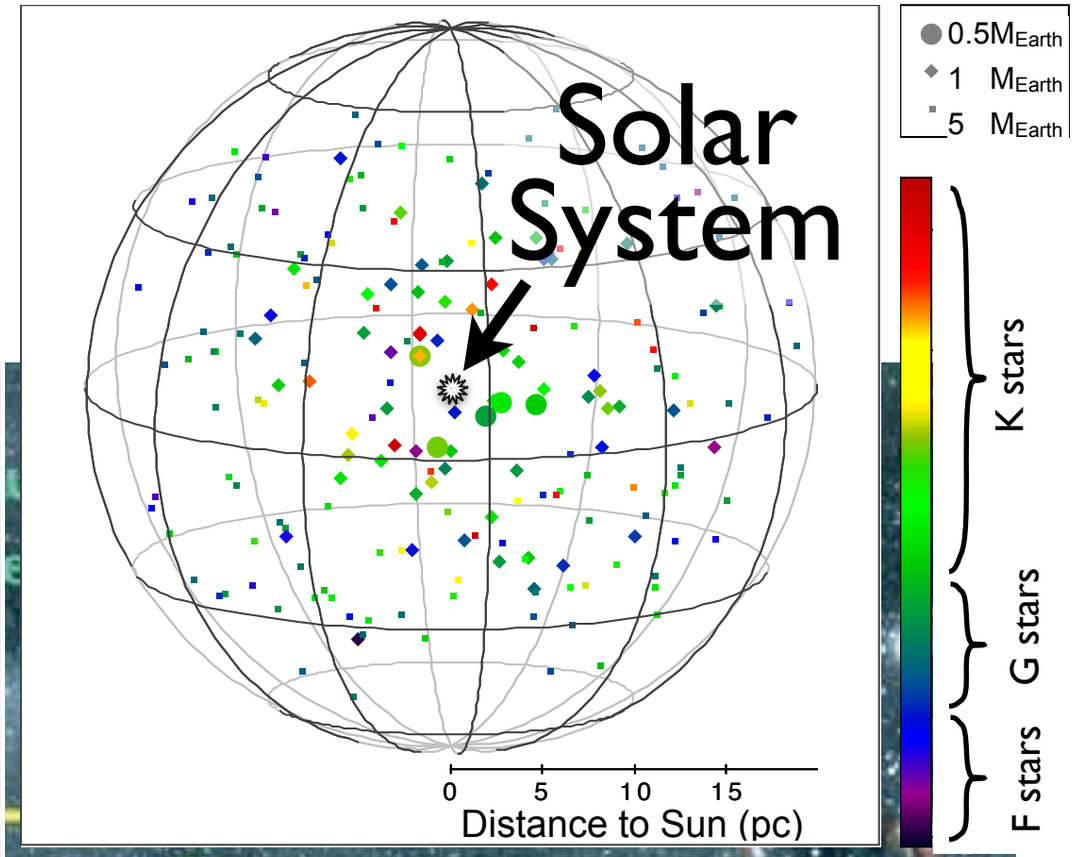

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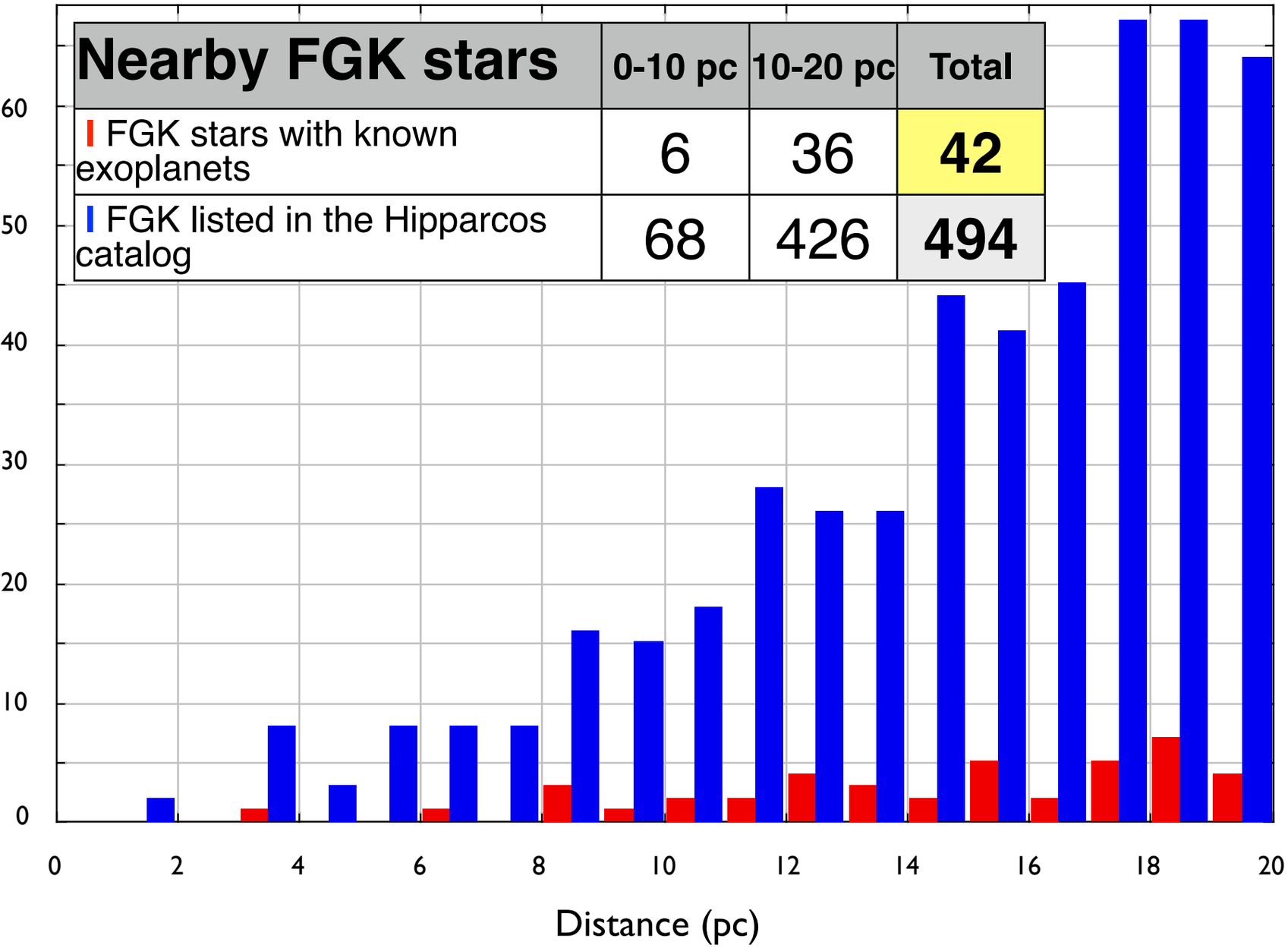
RV, imaging, astrometry

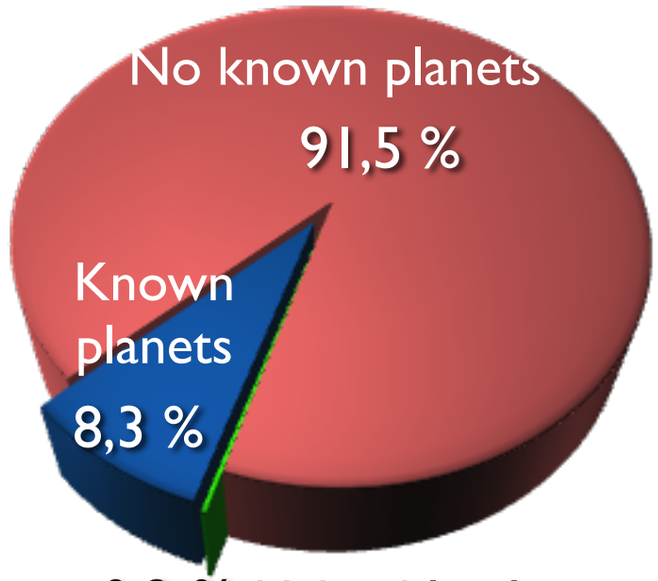
Credits: J. Lomberg

What has been detected thanks to RV around the nearby FGK stars?

Only 10% of nearby stars have known exoplanets so far !

Nearby FGK stars	0-10 pc	10-20 pc	Total
FGK stars with known exoplanets	6	36	**42**
FGK listed in the Hipparcos catalog	68	426	**494**

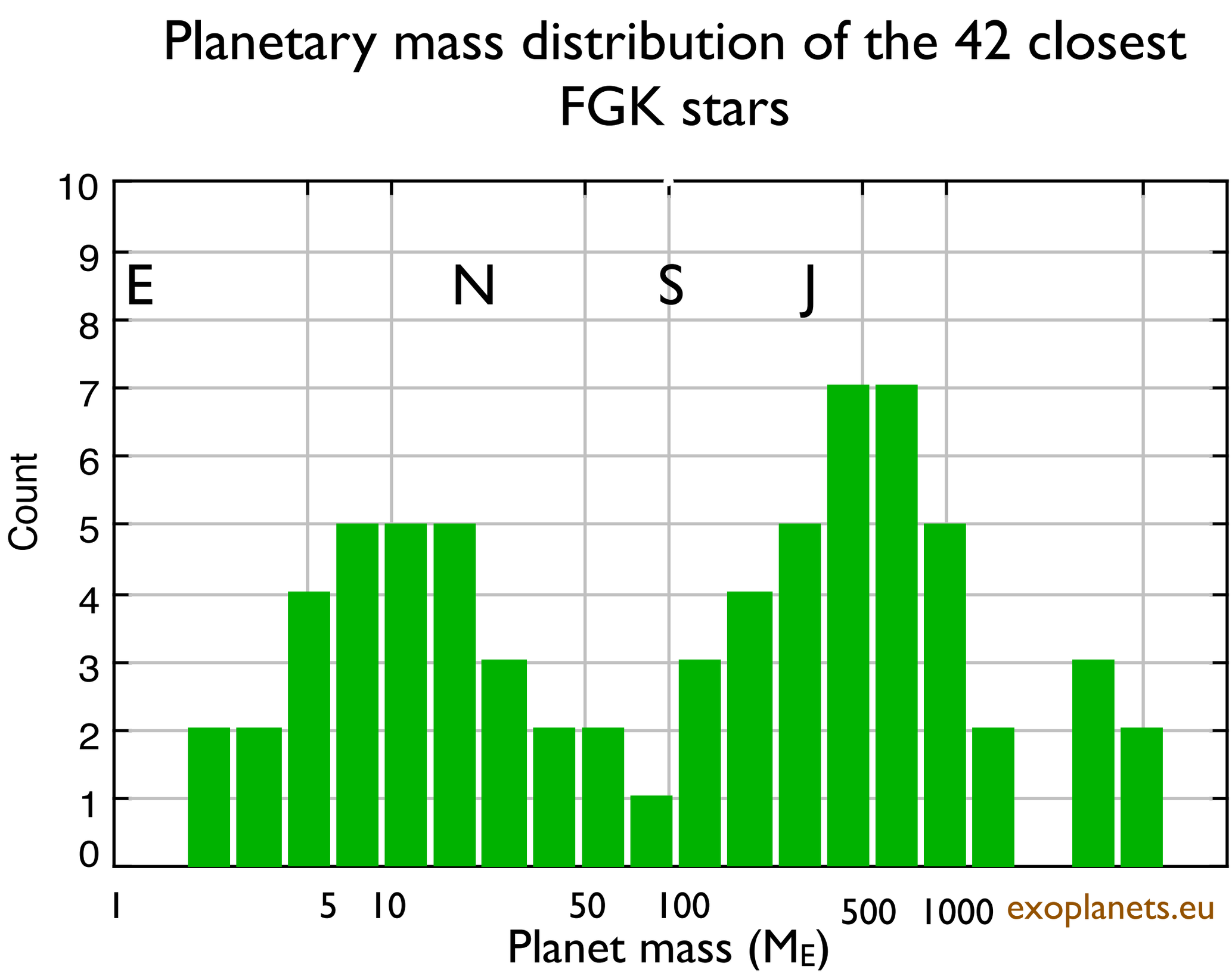




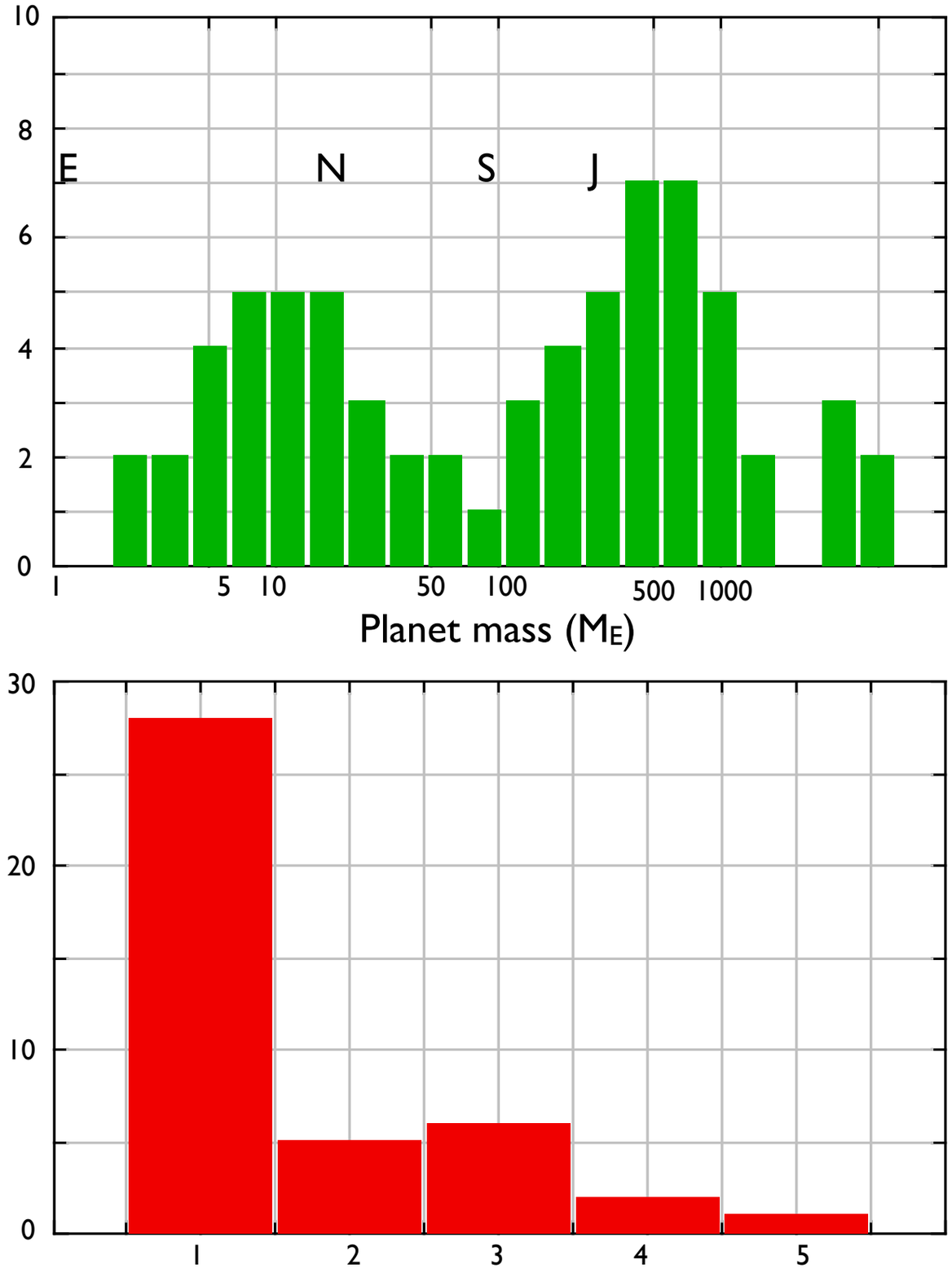
0,2 % Habitable planets

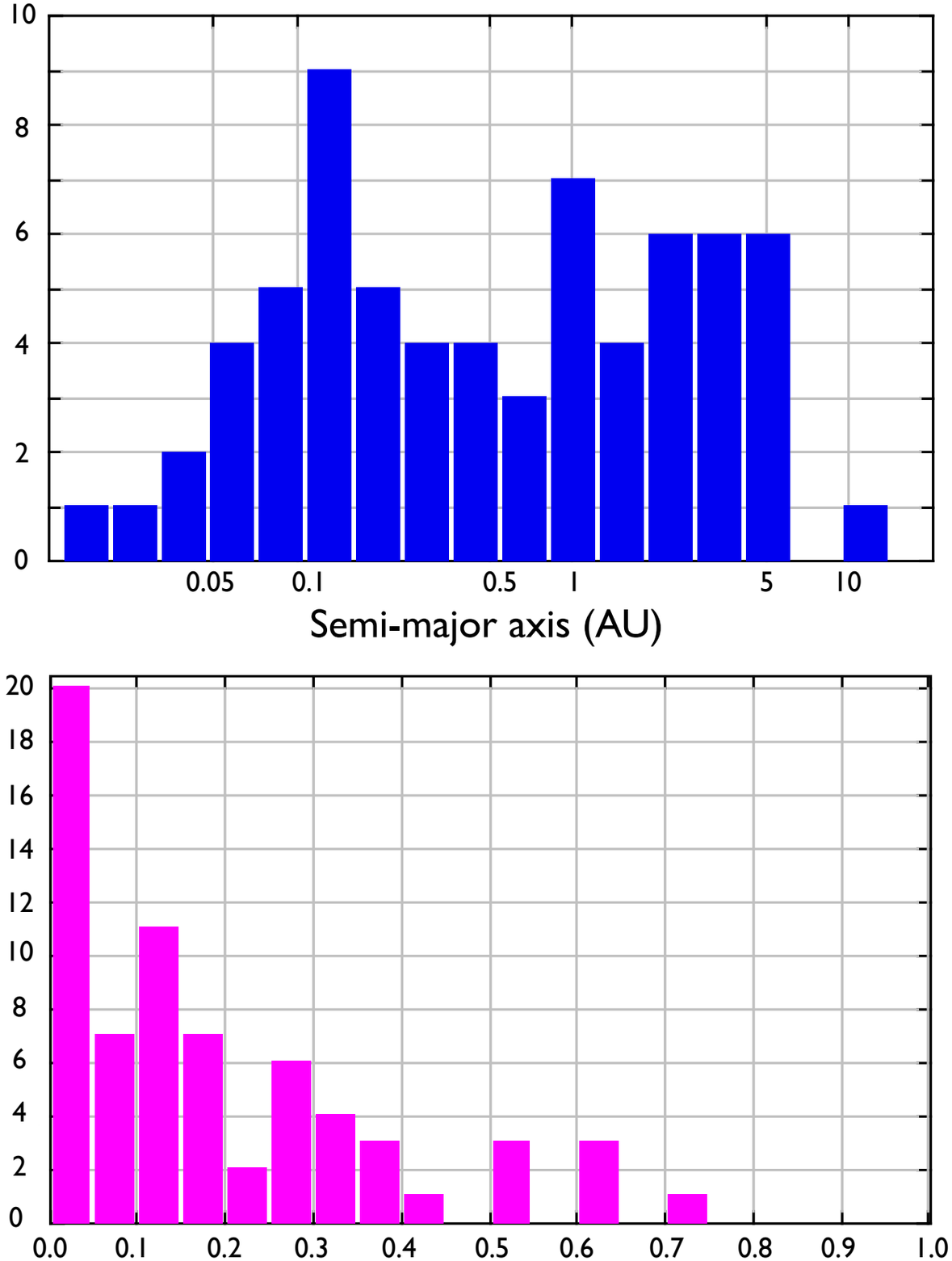
exoplanets.eu

What planetary components are we missing?



Statistics on exoplanets around the 42 nearby FGK stars





exoplanets.eu

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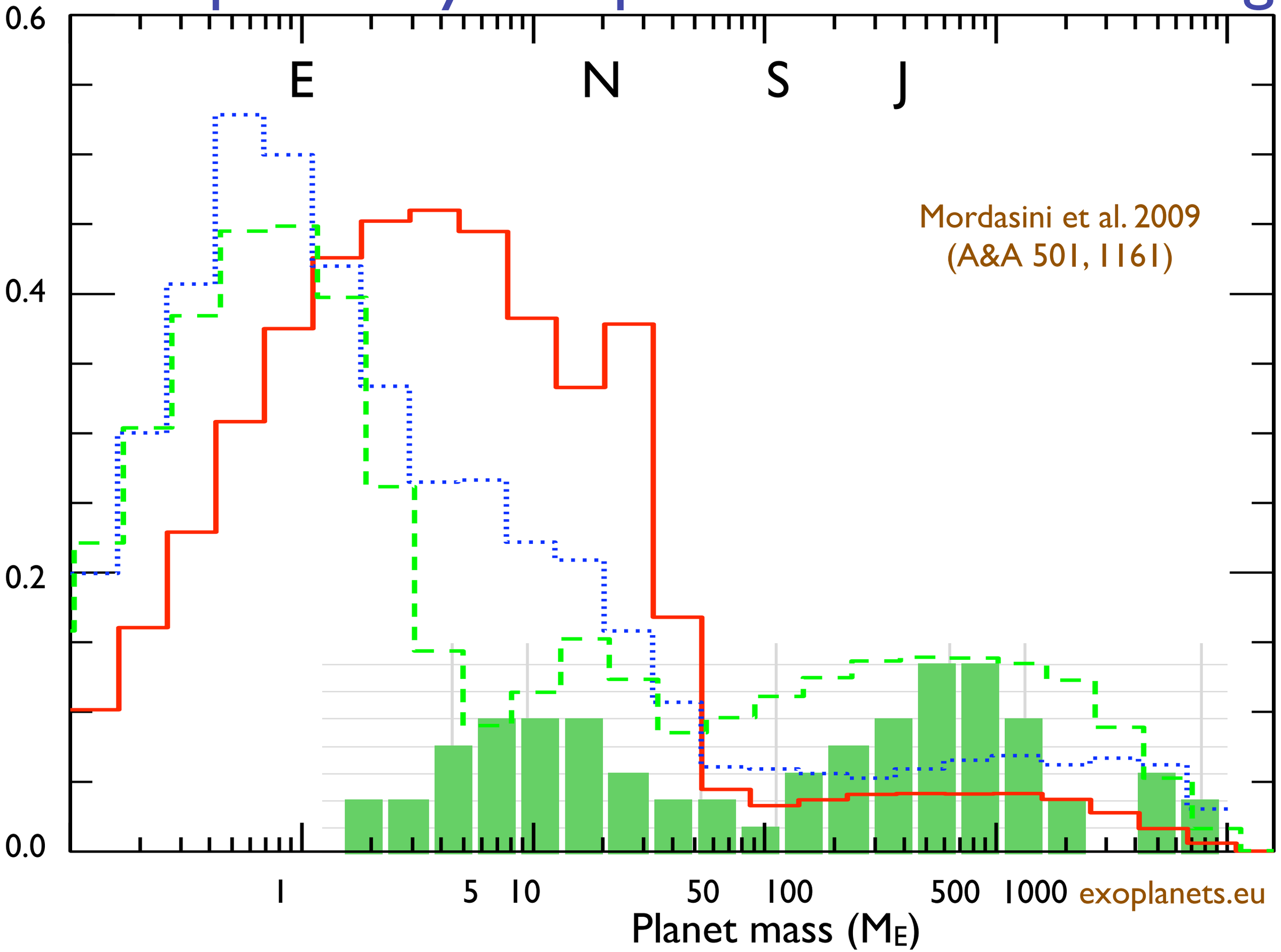

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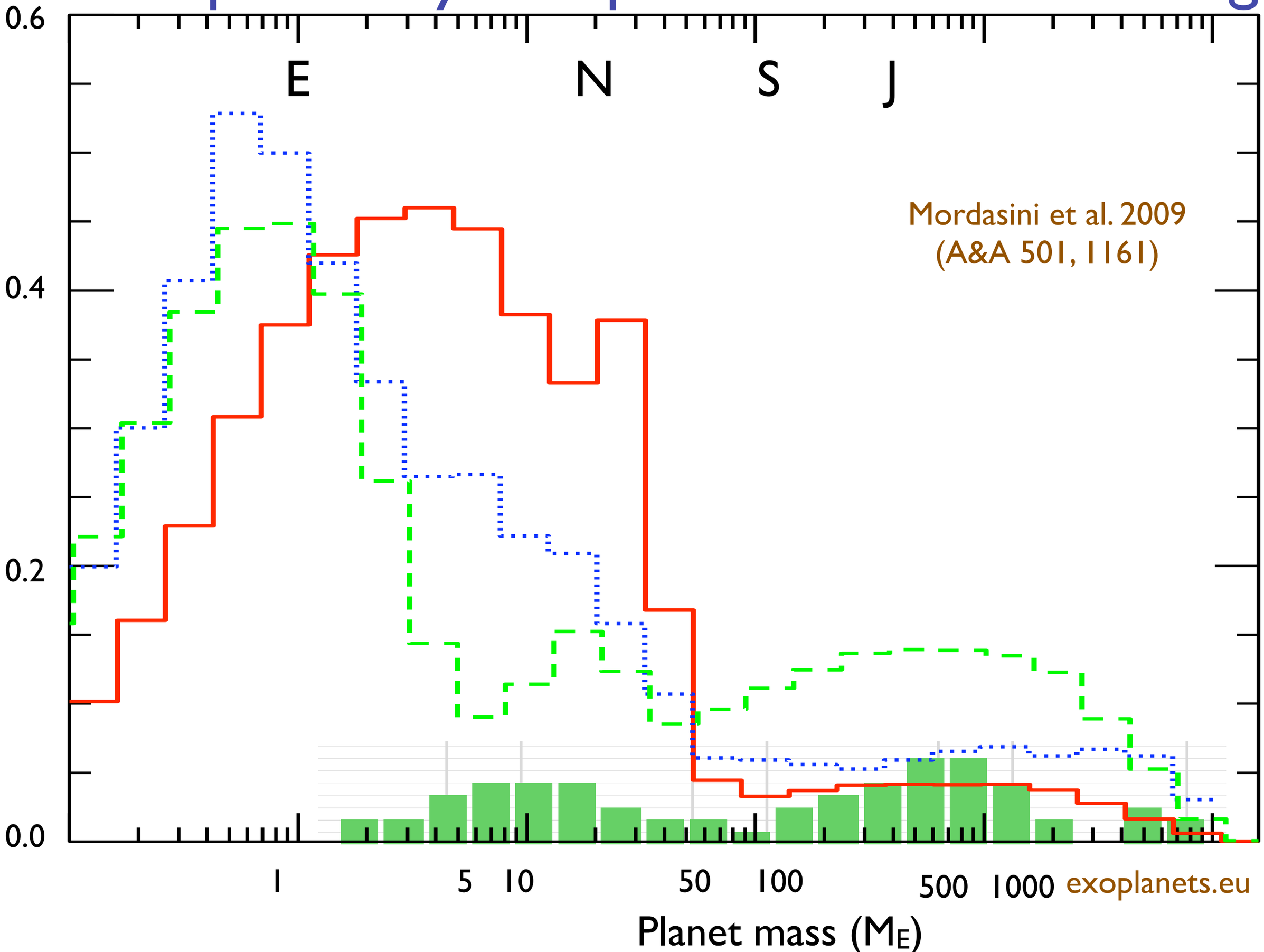

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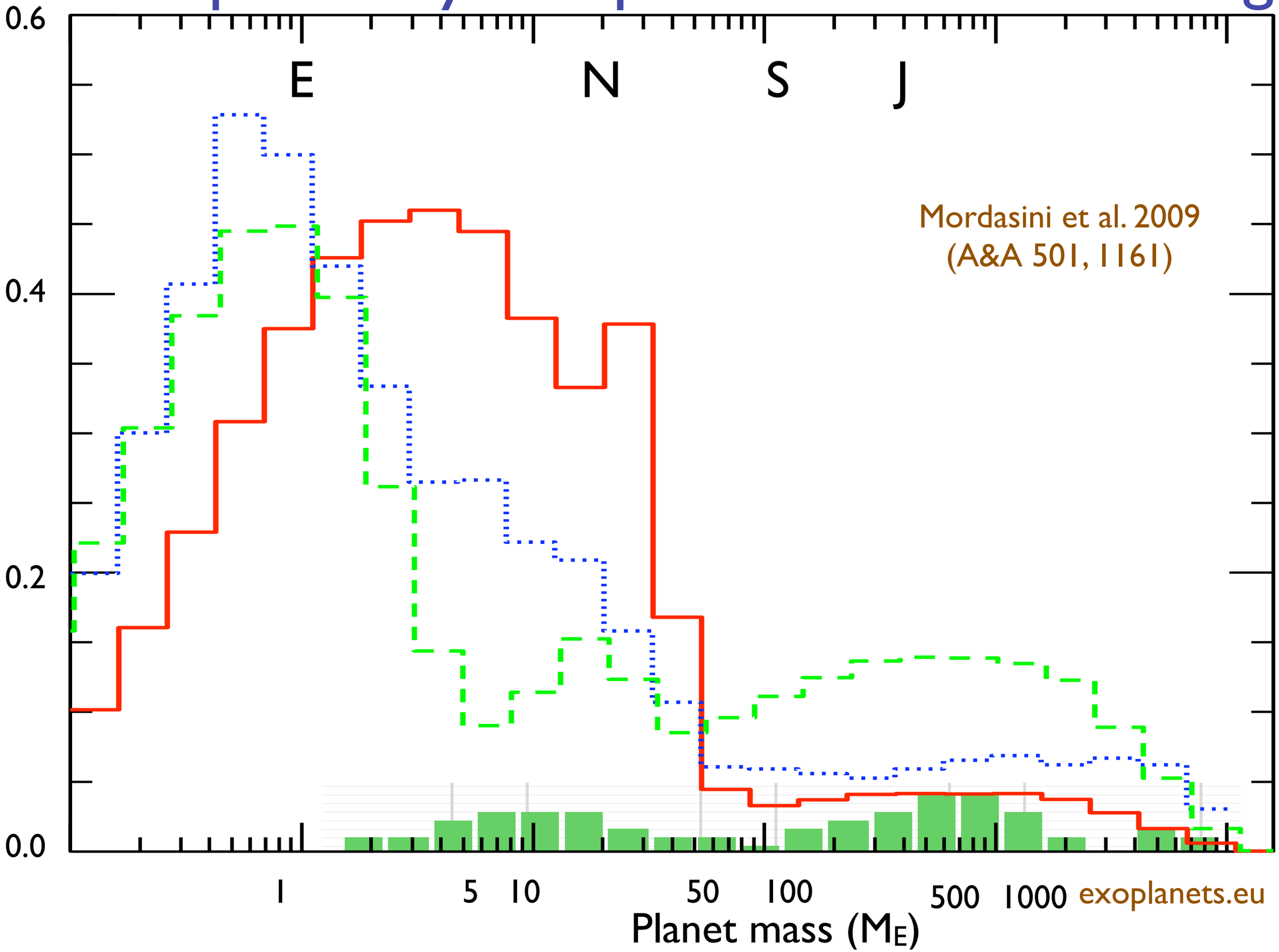

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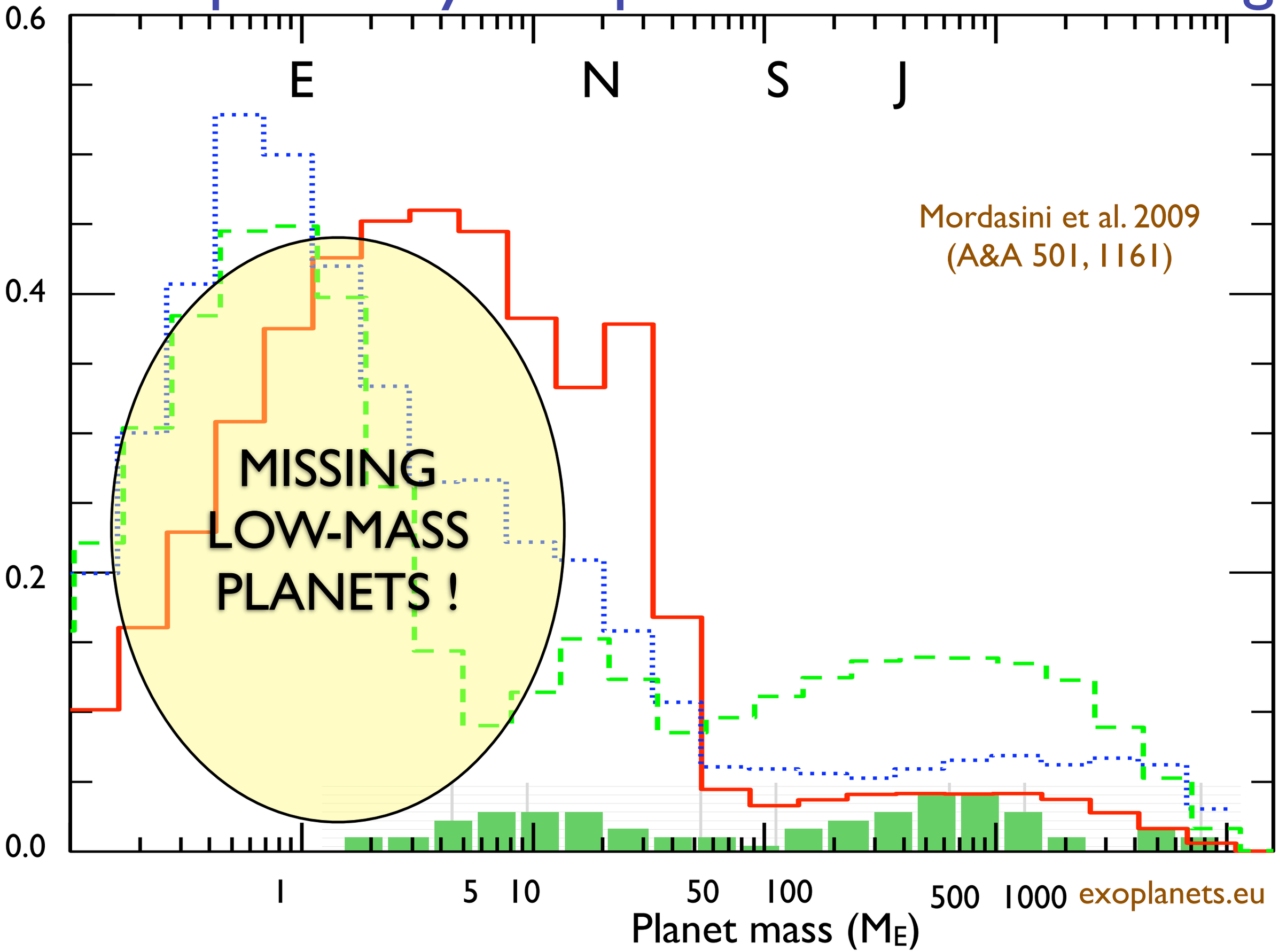
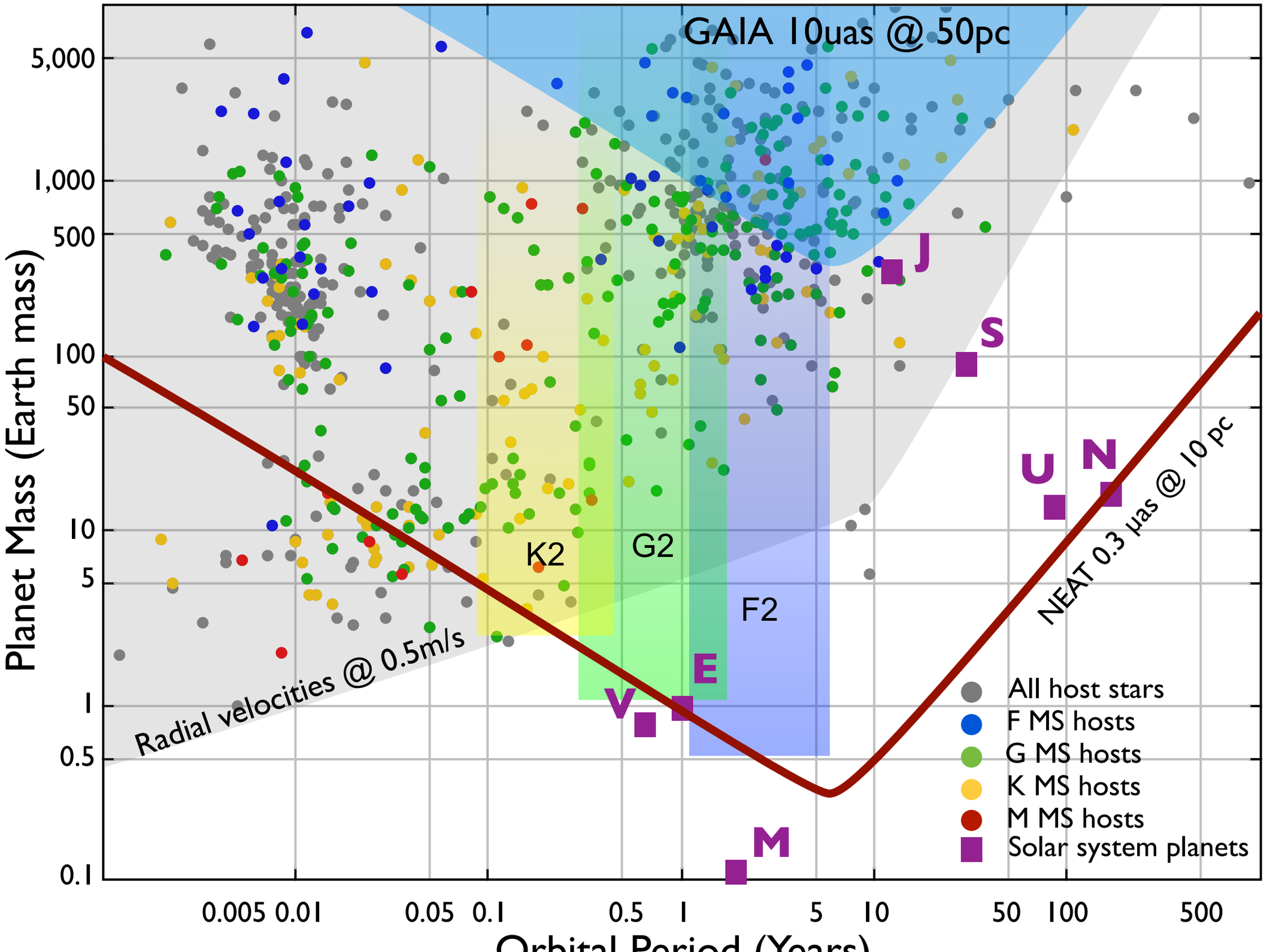


Parameter space

http://exoplanet.eu - 770 planets - June 2012



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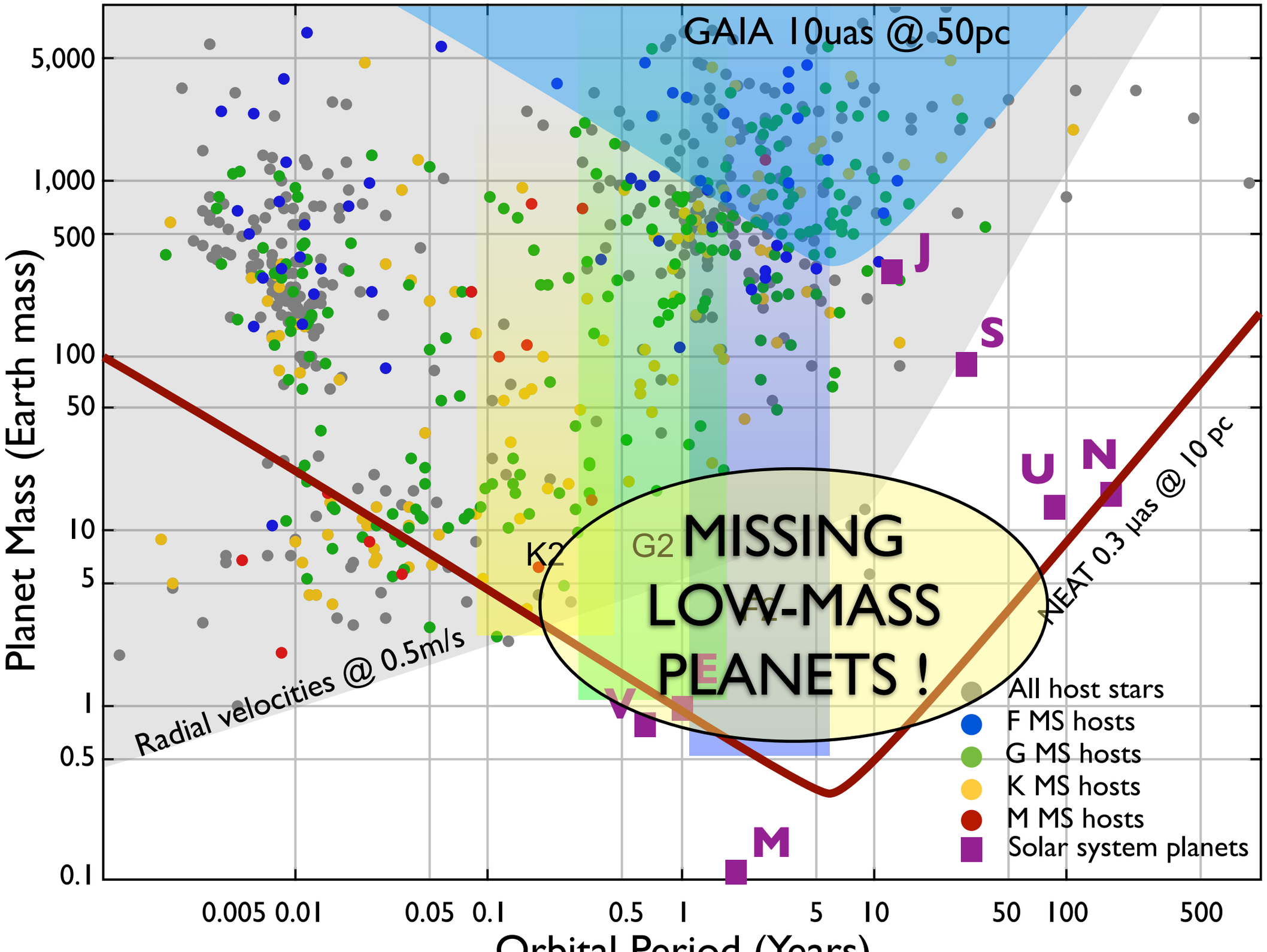
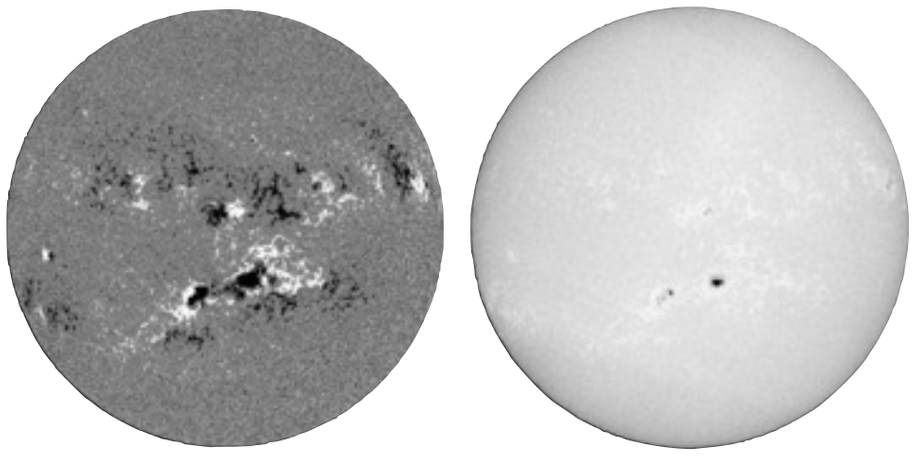
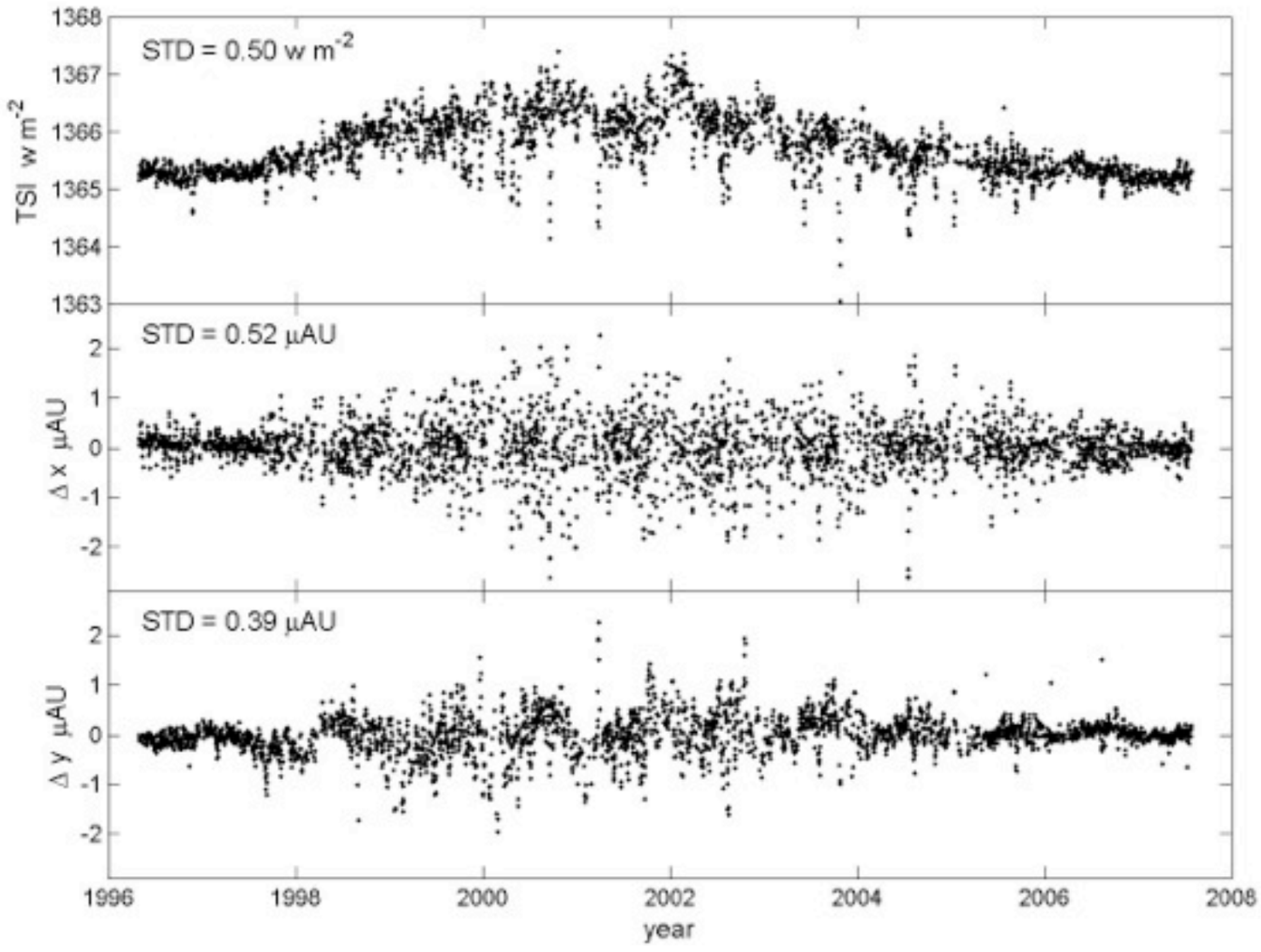


Astrometrical signal from the Sun located at





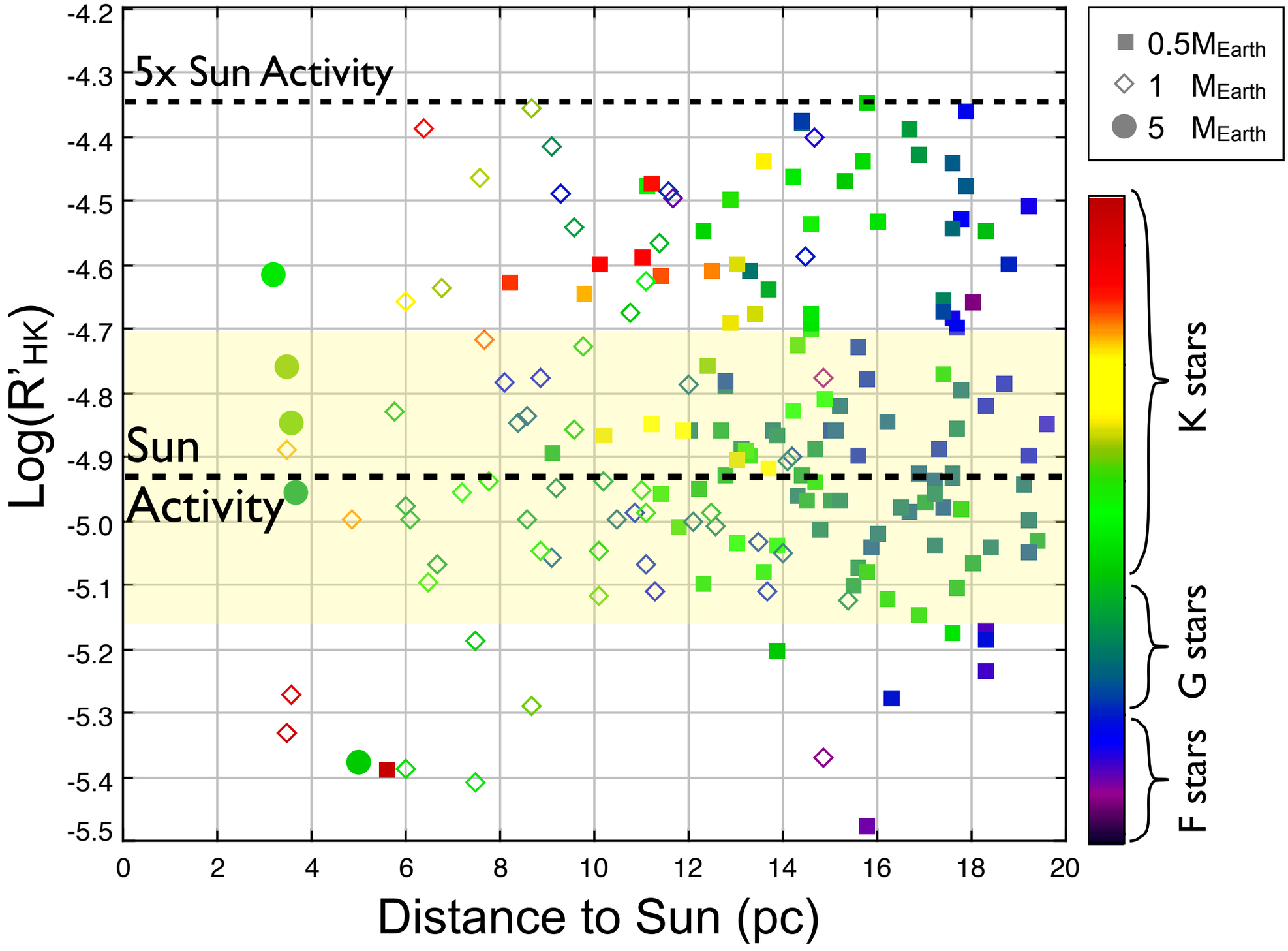
Astrometric jitter of a solar analog at 10 pc in the **equatorial dimension**
0.052 μas – negligible compared to the Earth signal 0.3 μas

⇒ Astrometry is working with stars x5 more active than the Sun

Makarov et al. (2009, ApJ 707, L73);
Lagrange, Desort, & Meunier (2010, A&A 512, A38)

Daily variations of the solar total irradiance (top panel), photocenter position in the east-west dimension (mid panel) and south-north dimension (lower panel) during 1996 – 2007

Stellar activity of FGK nearby stars



⇒ 98% of nearby FGK stars are less than x5 more active than the Sun

Why astrometry for nearby systems?

- Nearby systems are interesting because they can provide enough photons for characterization by direct imaging
- Transits and microlensing are probing too distant systems or with a very small probability
- Imaging works best at large distance and large planets
- Even if RV will discover Earth-like planets around some very quiet stars, RV cannot make a complete census within 20 pc
- Understanding planet formation requires to detect low-mass planets in planetary systems
- 0.3μas astrometry is challenging but within reach

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There are all ingredients for a space astrometry mission

⇒ **NEAT** (Nearby Earth Astrometry Telescope)

NEAT scientific objectives

The prime goal of NEAT is:

- to detect and fully characterize **planetary systems**
- with **all** components down to the **Earth mass**
- orbiting bright **solar-type stars** (FGK, $V \leq 9$)
- in the **solar neighborhood** ($d < 20$ pc)

with planetary architectures:

- similar to that of our Solar System
- or any one with Earth mass planets

➥ Key capability: detecting Earth-mass planets in the Habitable Zone

NEAT scientific cases

This mission will answer the following questions:

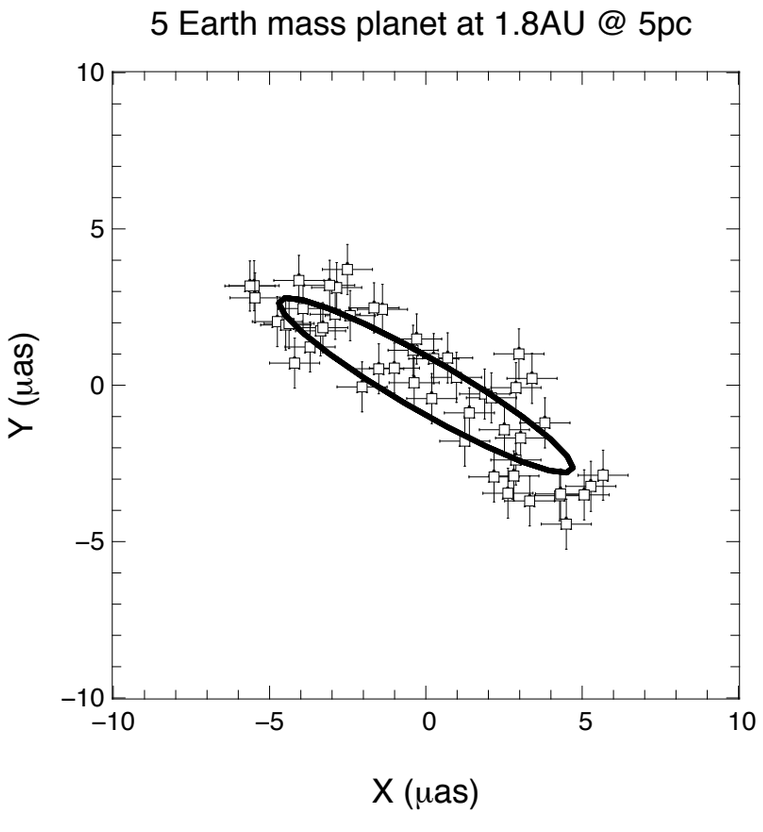
➡ What are the dynamical interactions between giant and telluric planets in a large variety of systems?

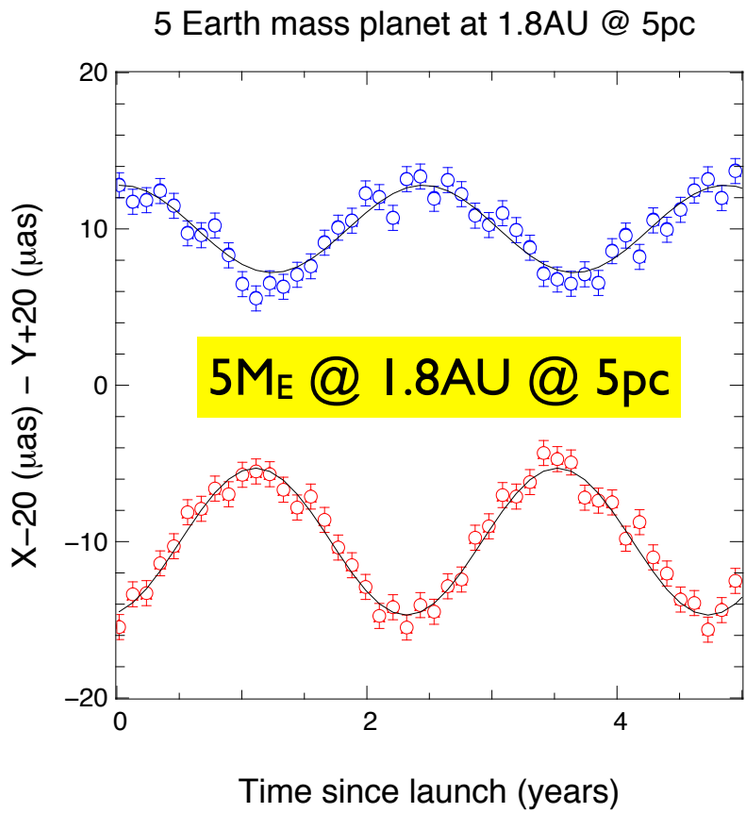
➡ What are the detailed processes involved in planet formation as revealed by their present configuration?

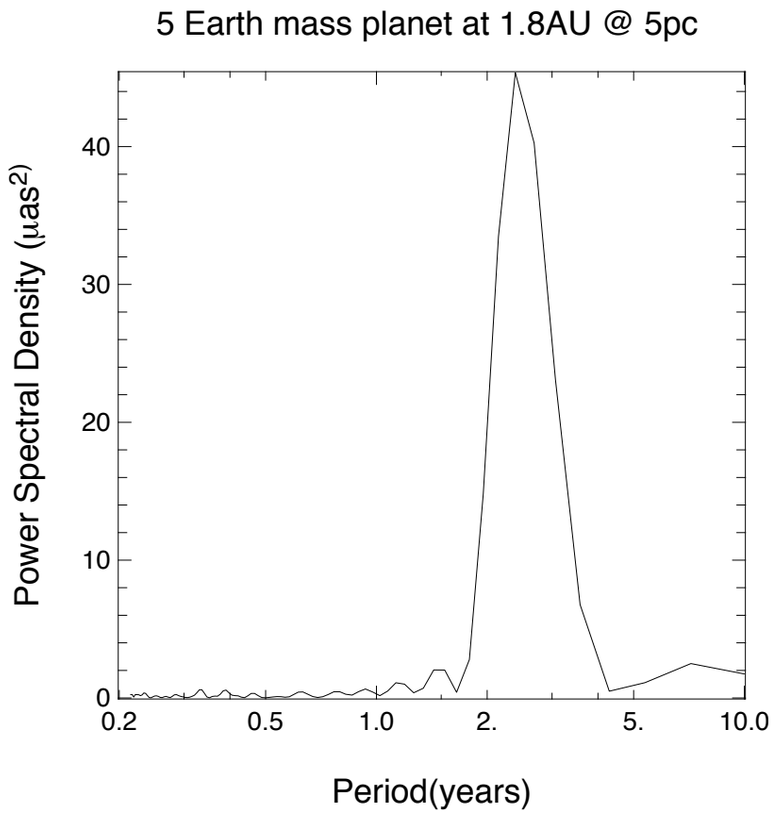
➡ What are the distributions of architectures of planetary systems in our neighborhood up to ~20 pc?

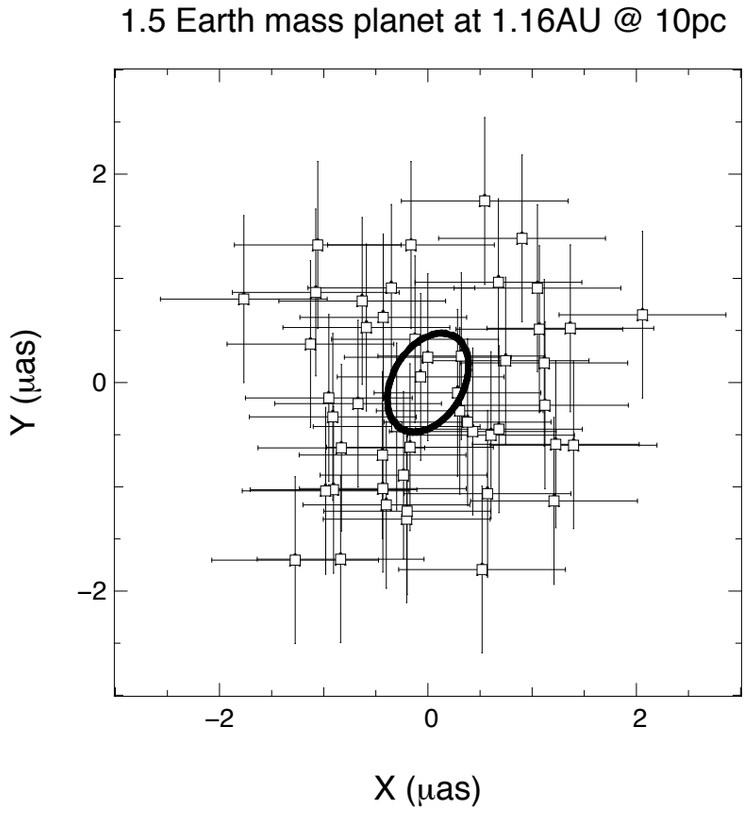
➡ What are the masses, and addresses, of telluric planets that are candidates for future direct detection and spectroscopic characterization missions?

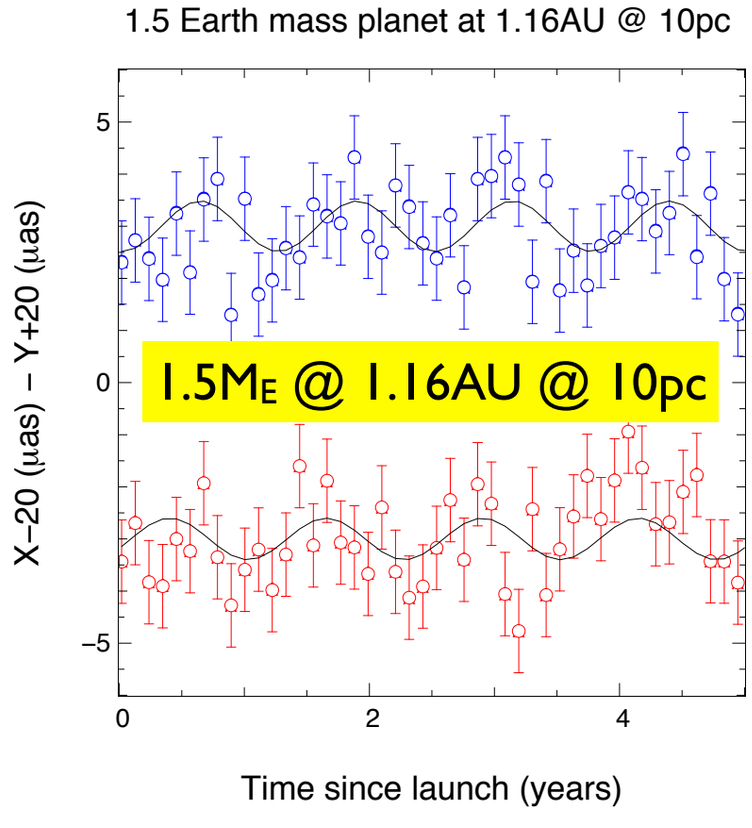
Examples of measurements

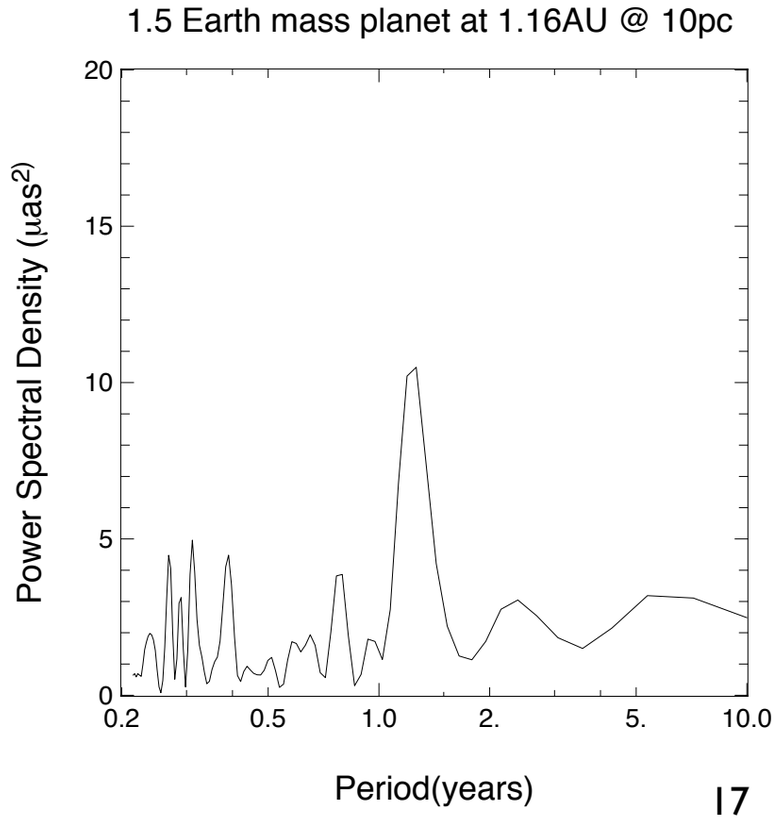




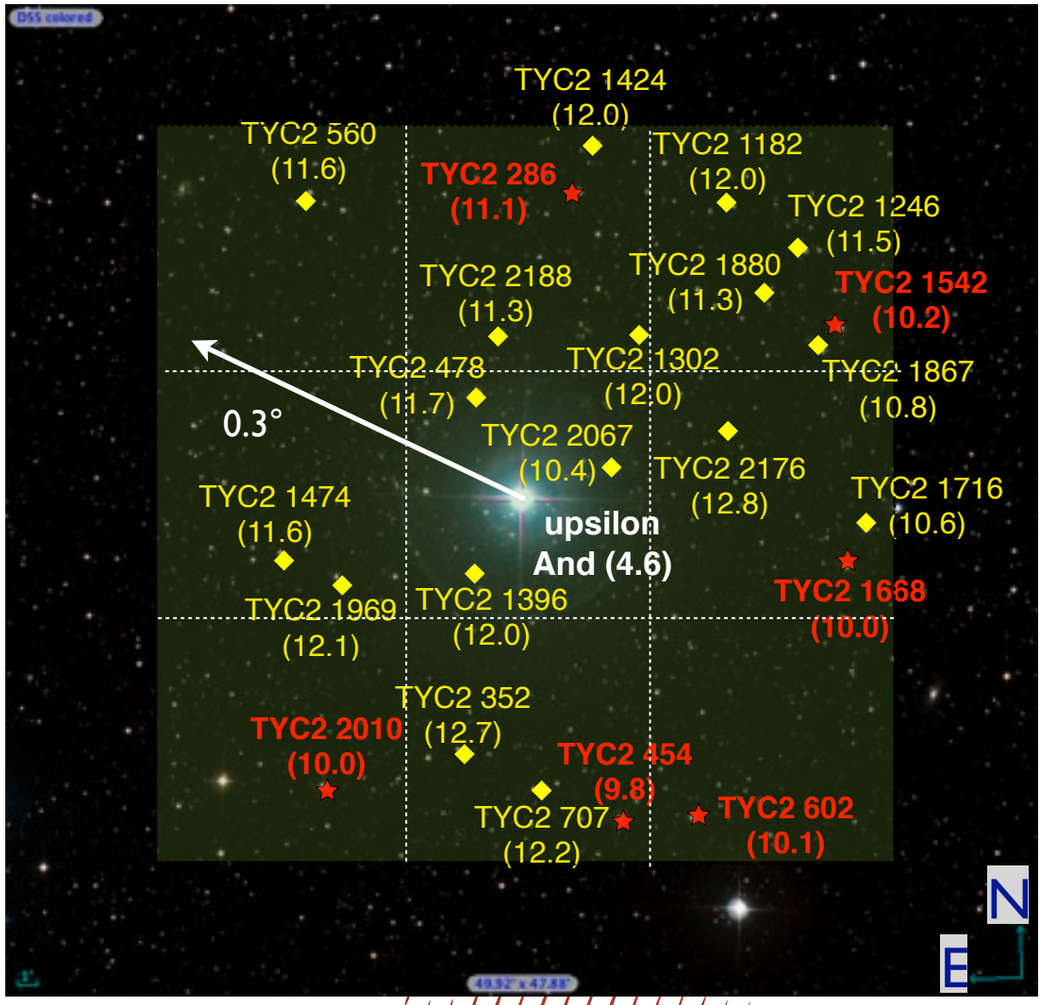






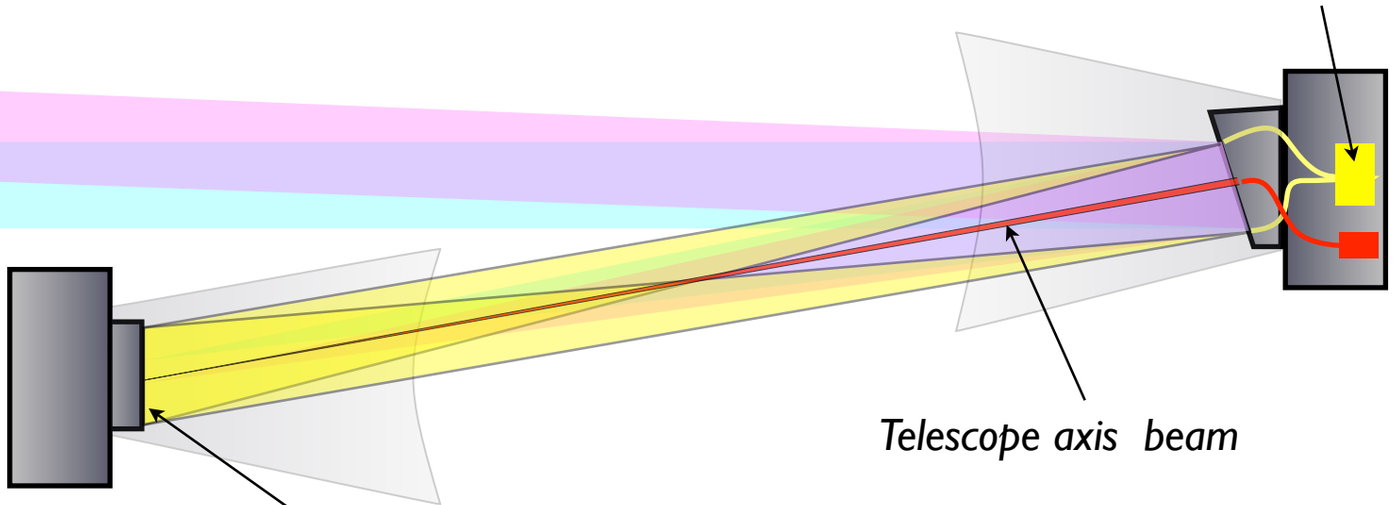


NEAT concept



Telescope spacecraft

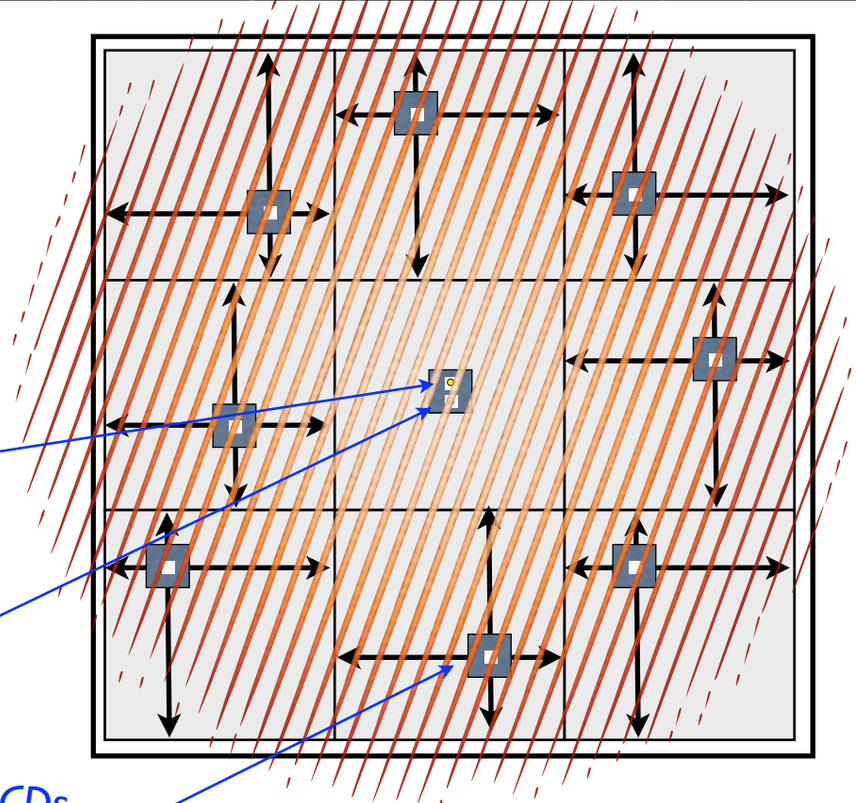
Metrology



Telescope axis beam

Detector spacecraft

Dynamical Young's interference fringes



1 fixed CCD (target star)

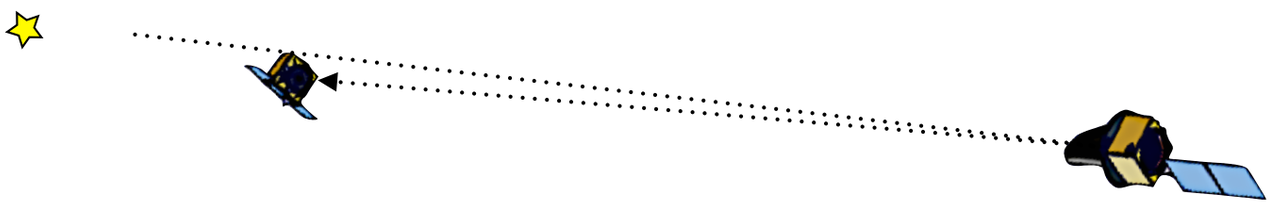
1 fixed CCD (telescope axis tracker)

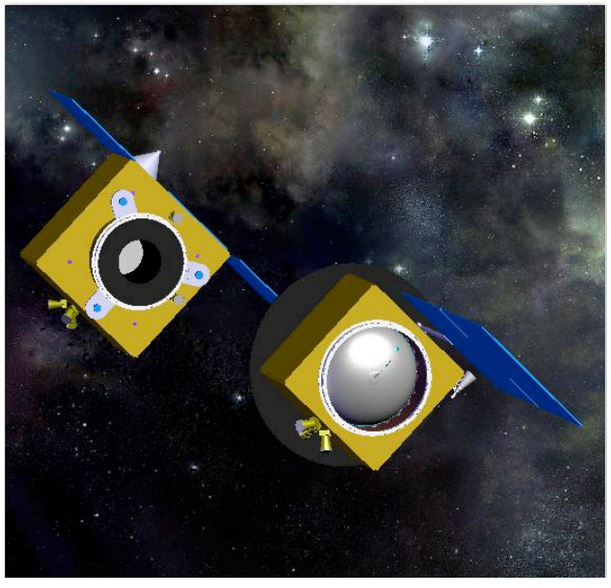
8 movable CCDs (reference stars)

Focal plane

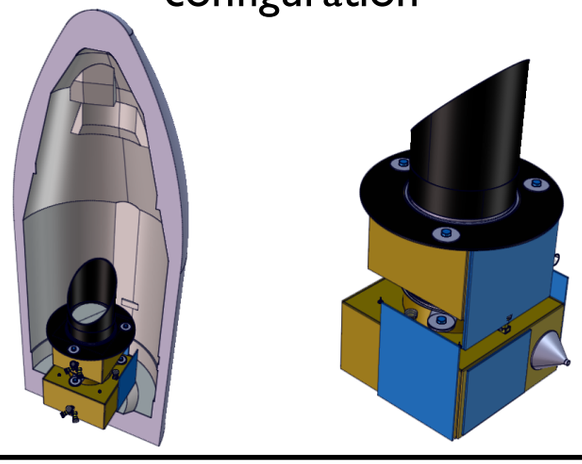
NEAT Spacecraft

- Mission orbit: L2 large Lissajous
- 2 satellites flying in formation
- 20,000 reconfigurations
- Reconfiguration time: 30mn

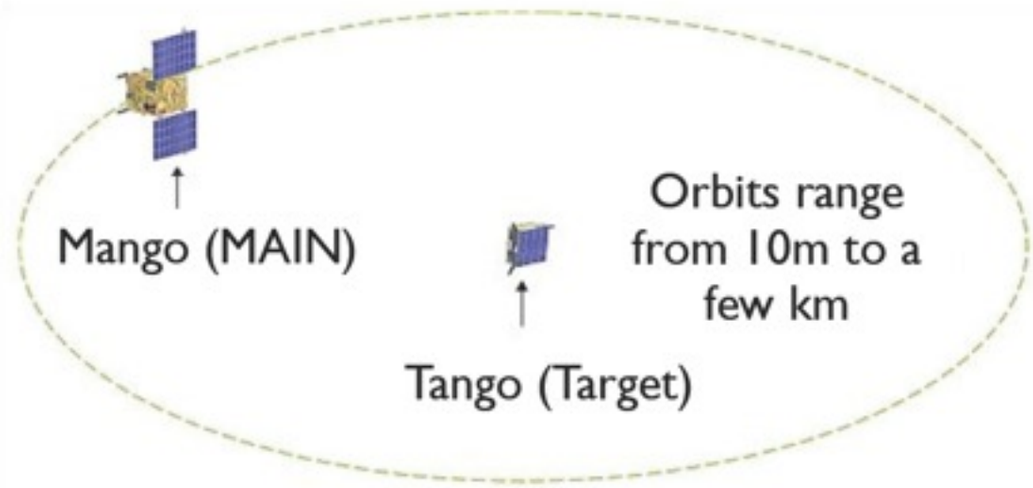




Launch configuration



PRISMA heritage



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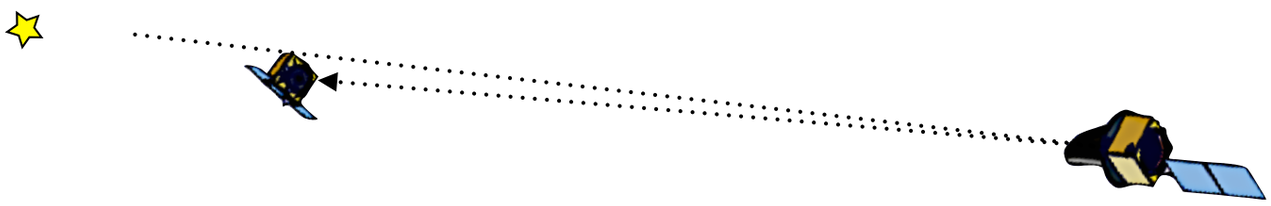

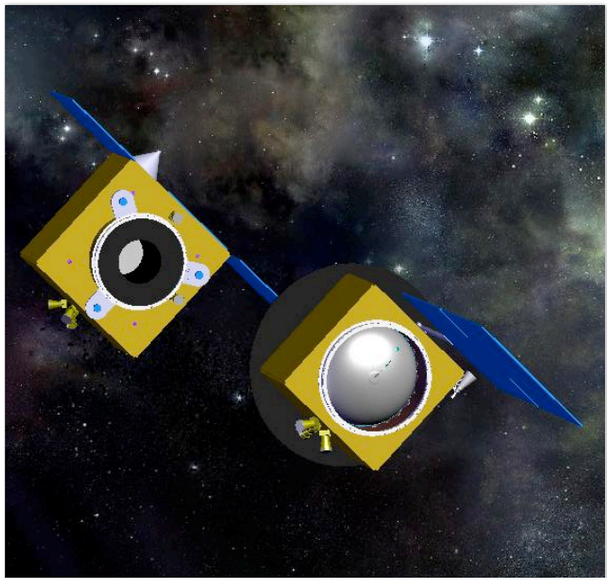

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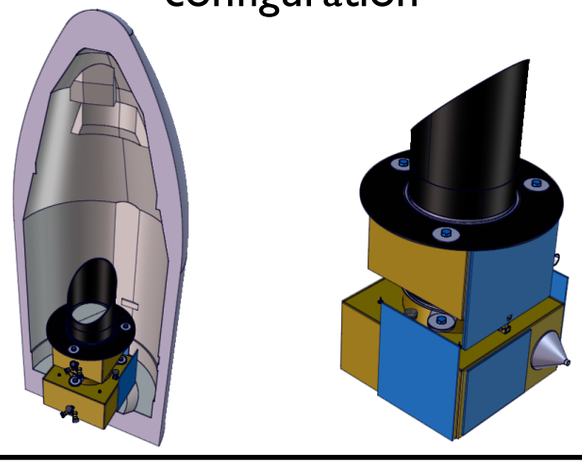

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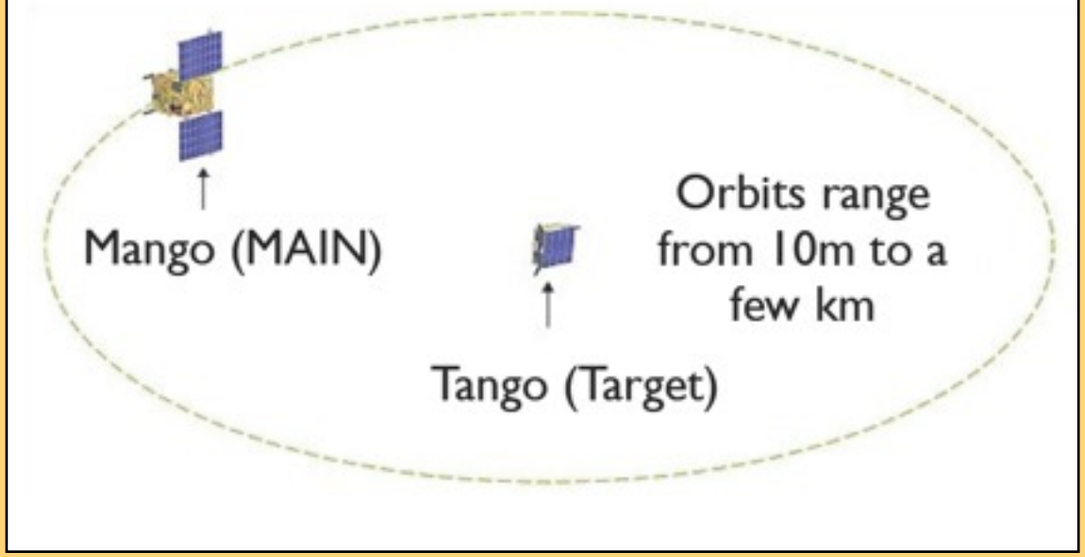
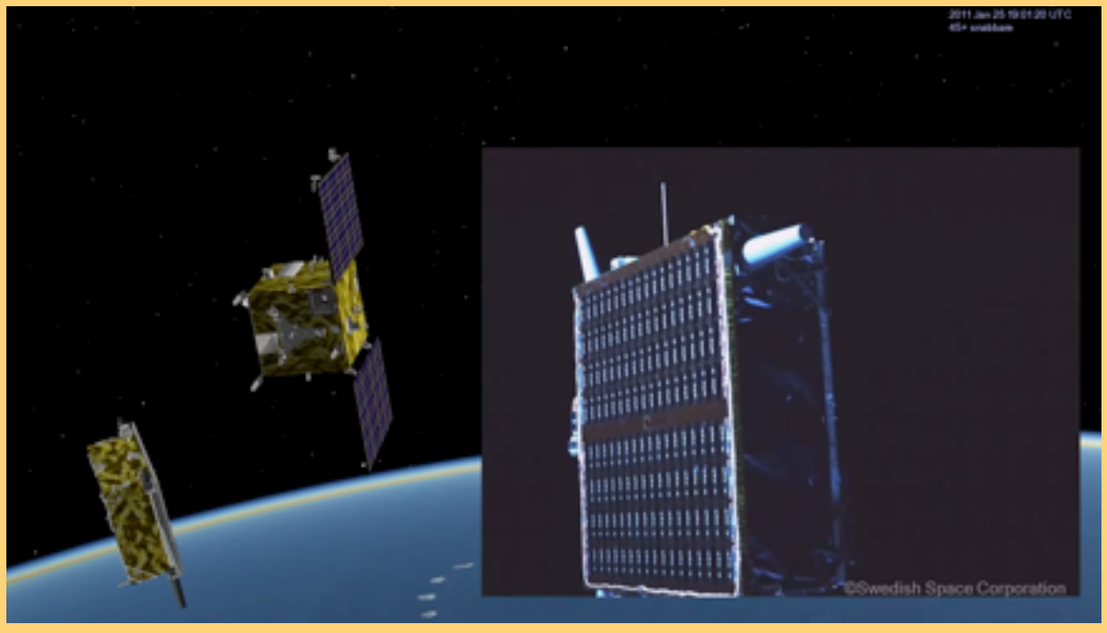
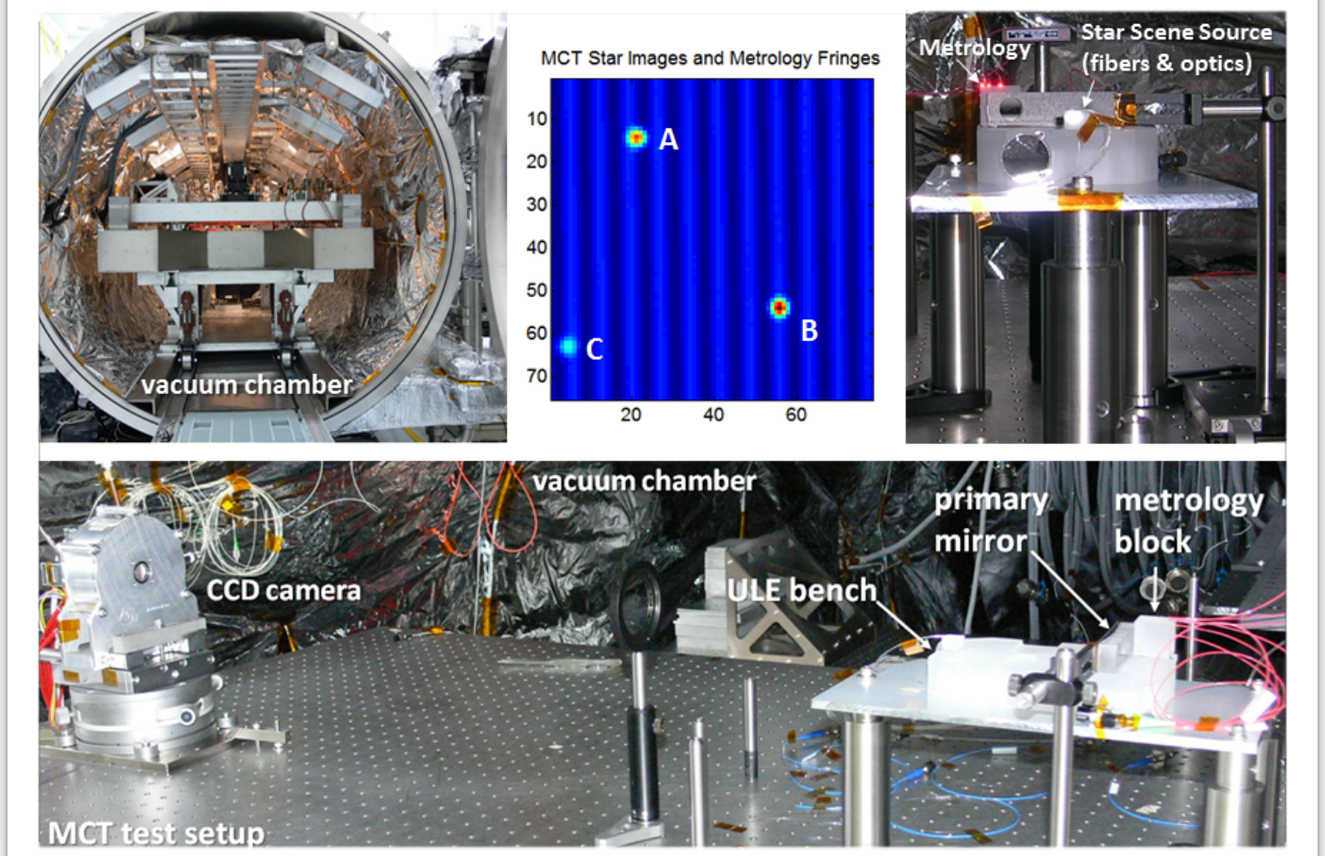
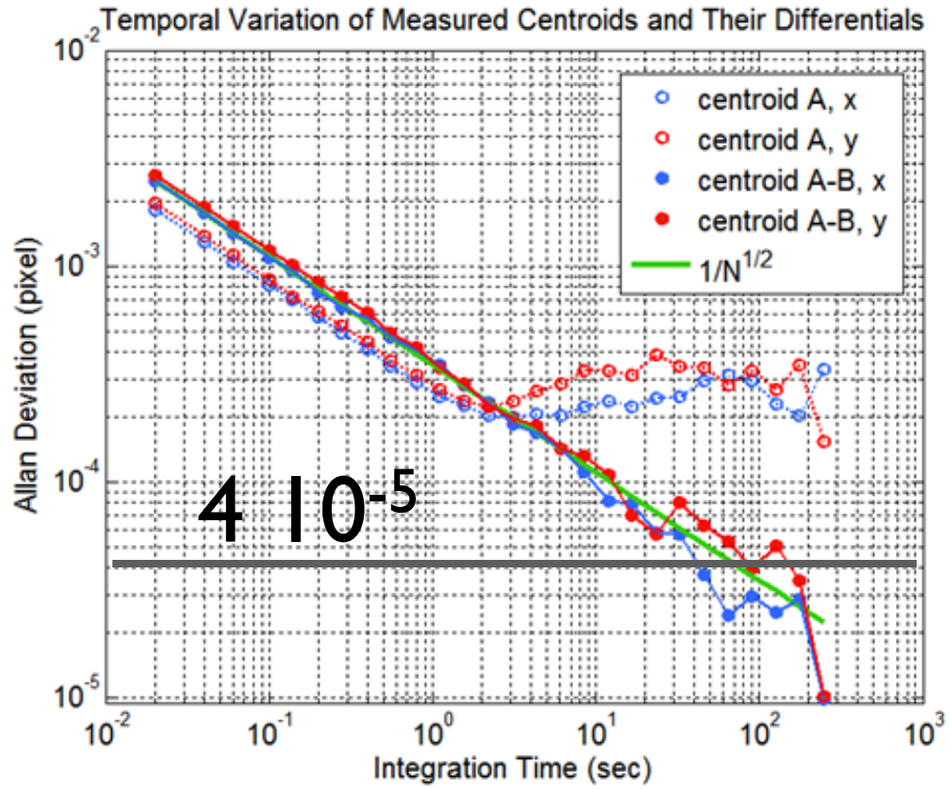




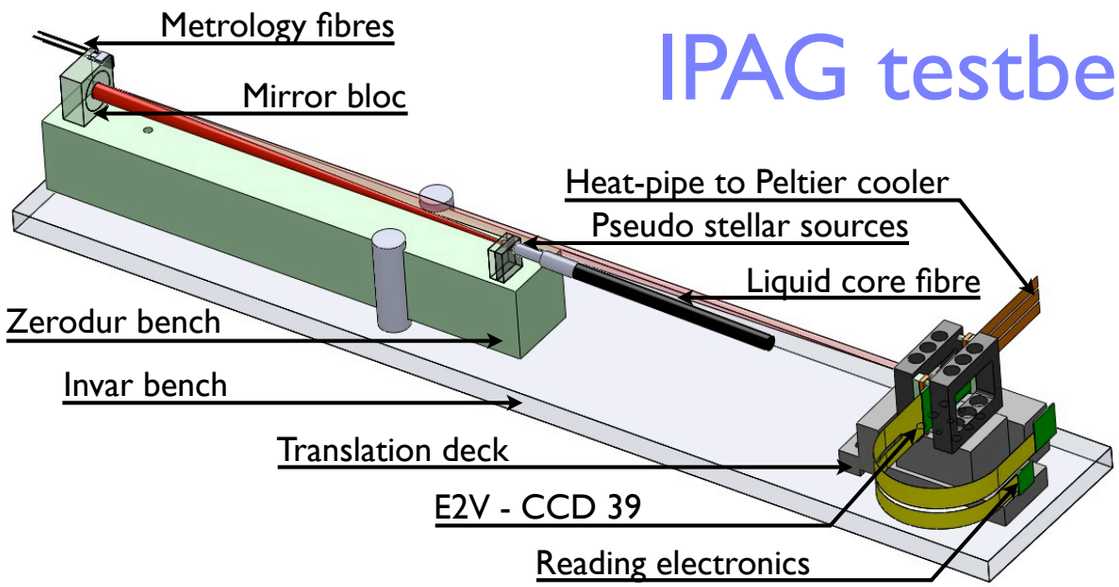
Laboratory testbeds

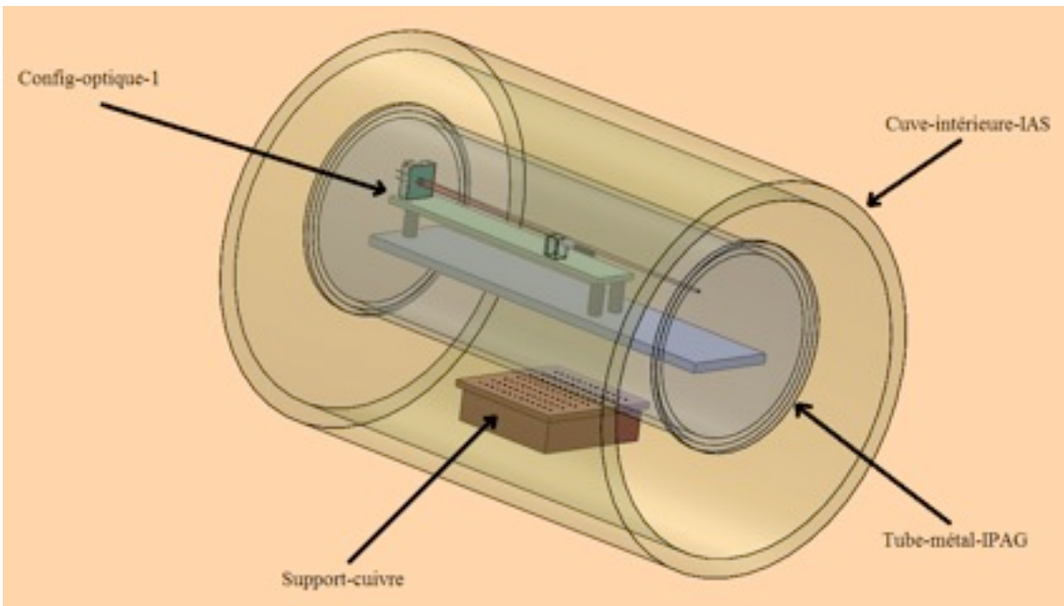




JPL testbed

IPAG testbed





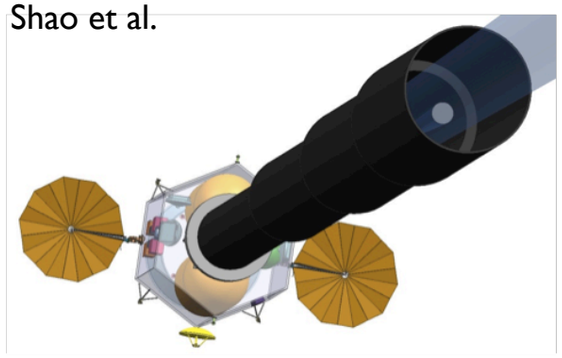
A scalable concept

Mission name	Mirror diameter	Focal length	Field of view diameter	Focal Plane size	Ref. star mean magnitude	DMA in 1h	# targets for a given mass limit		
	(m)	(m)	(deg)	(cm)	(R mag)	(μas)	$0.5M_\oplus$	$1\ M_\oplus$	$5\ M_\oplus$
NEAT plus	1.2	50	0.45	40	11.5	0.7	**7**	**100**	**200**
NEAT	1.0	40	0.56	40	11	0.8	**5**	**70**	**200**
NEAT light	0.8	30	0.71	35	10.5	1.0	**4**	**50**	**200**
EXAM	0.6	20	0.85	30	10.1	1.4	**2**	**35**	**200**
							$1M_\oplus$	$10\ M_\oplus$	$50\ M_\oplus$
μNEAT (*)	0.3	12	0.6	15	11	10.2	**2**	**25**	**200**

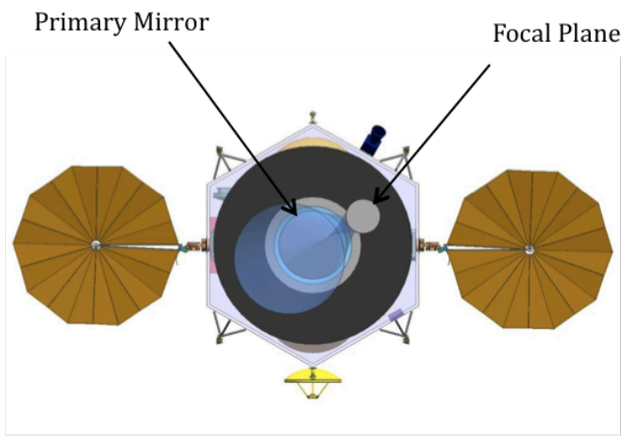
DMA = Differential astrometric Measurement Accuracy (rms); (*) centroiding requirement relaxed to 4e-5

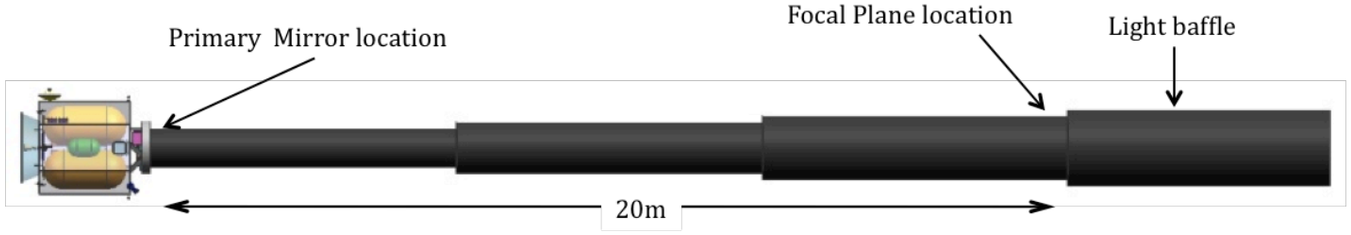
EXAM (NASA)

Shao et al.



View from Top Looking Down





Fully Deployed Spacecraft

μNEAT (ESA small mission)

Brandeker et al.

Current status

➠ Science highly ranked by ESA Astrophysical Working Group at the M3 evaluation.

What next?

- Lab demonstration under progress to demonstrate 5 μpixel centroiding
- Trade-off between Formation Flying vs deployable boom
- Science simulations: double blind test
- Extension of science cases: young stars, M dwarfs, NEO, ...

All information: **http://neat.obs.ujf-grenoble.fr**

COSMIC Vision Plan 2015-2025: Theme 1, Section 1.2

" On a longer timescale, a complete census of all Earth-sized planets within 100 pc of the Sun would be highly desirable. Building on Gaia's expected contribution on larger planets, this could be achieved with a high-precision terrestrial planet astrometric surveyor. "

We have designed NEAT to be this astrometric surveyor.