Theia and HWO astrometric power for Giant Exoplanets around solar-type stars

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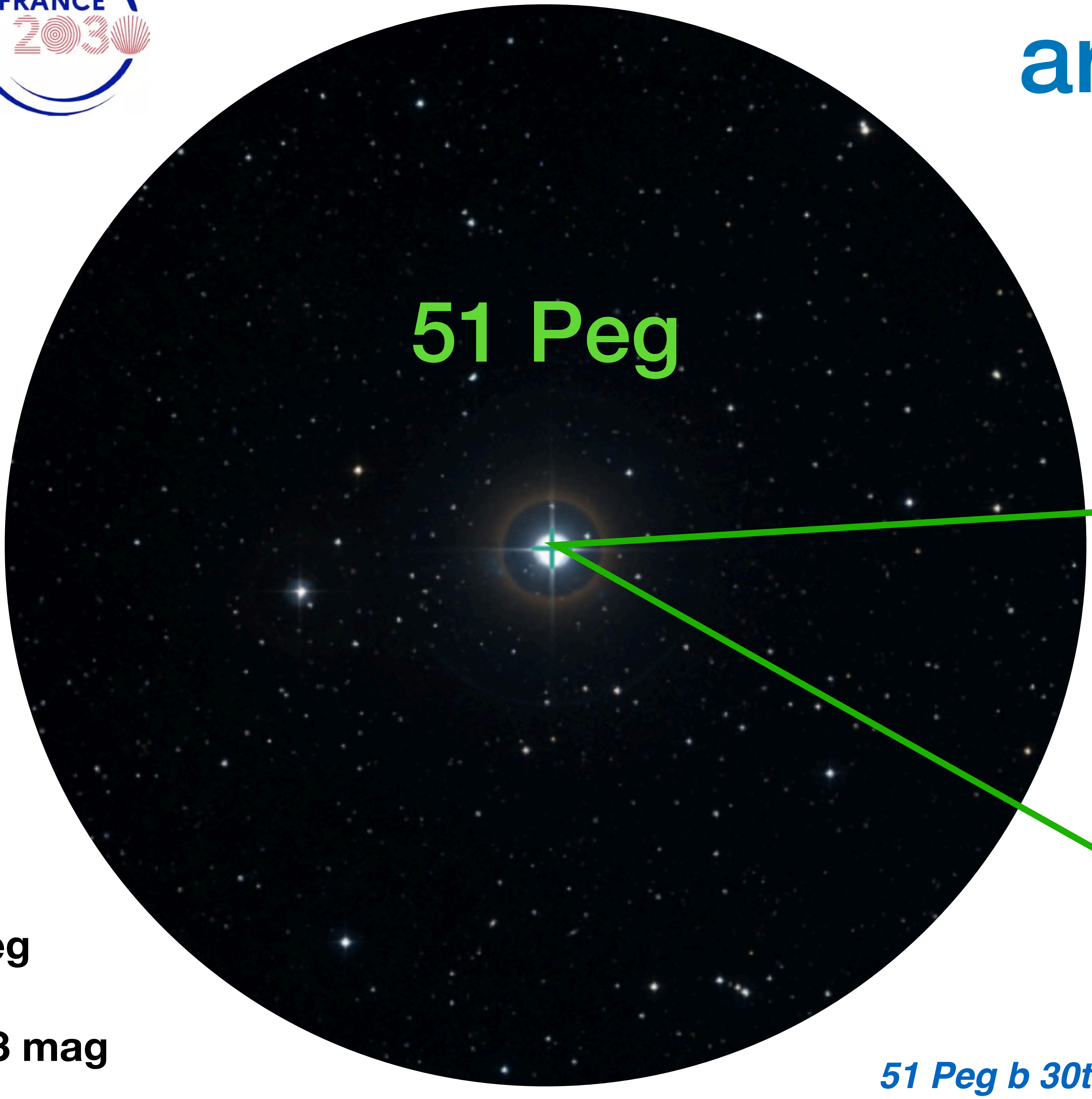
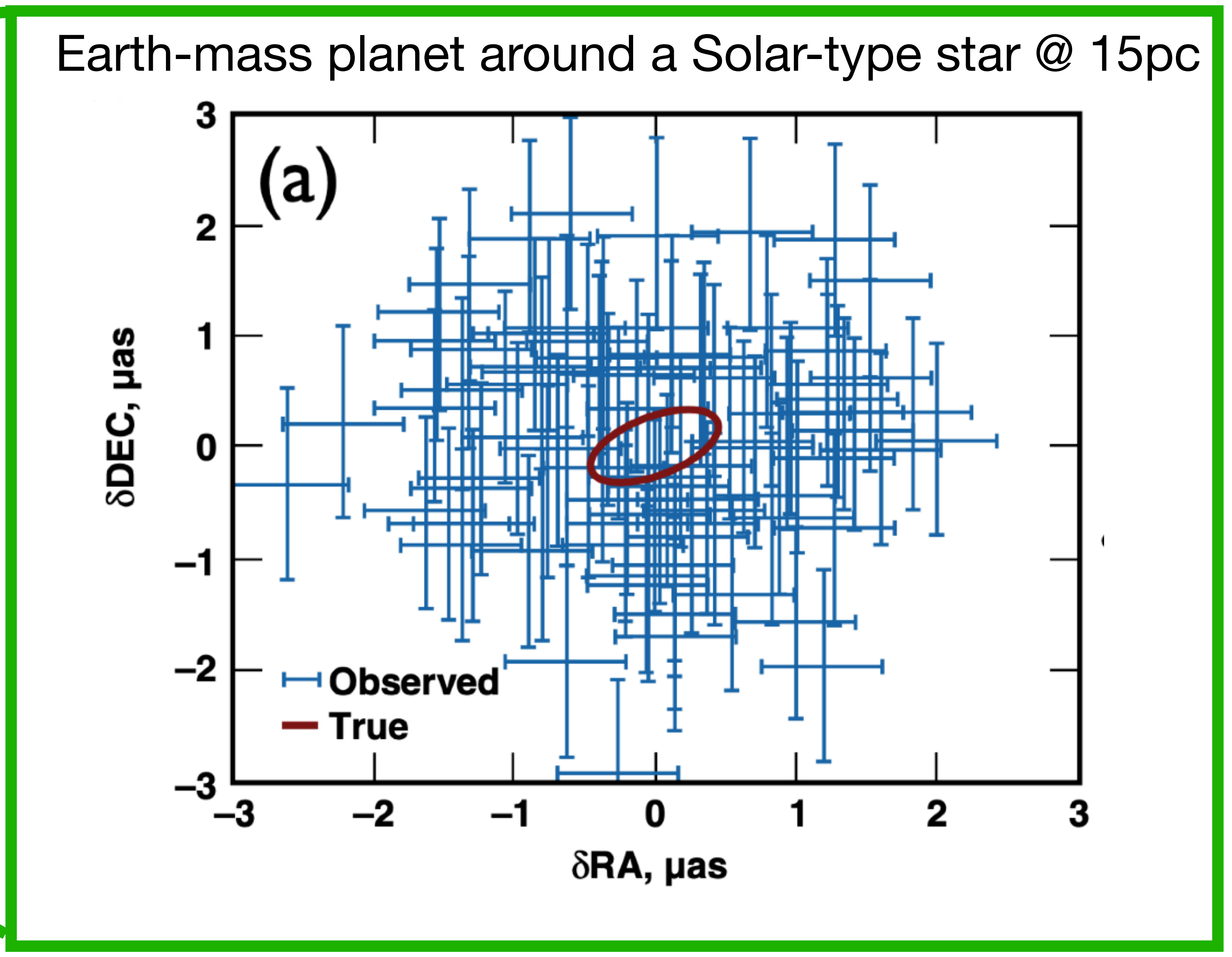
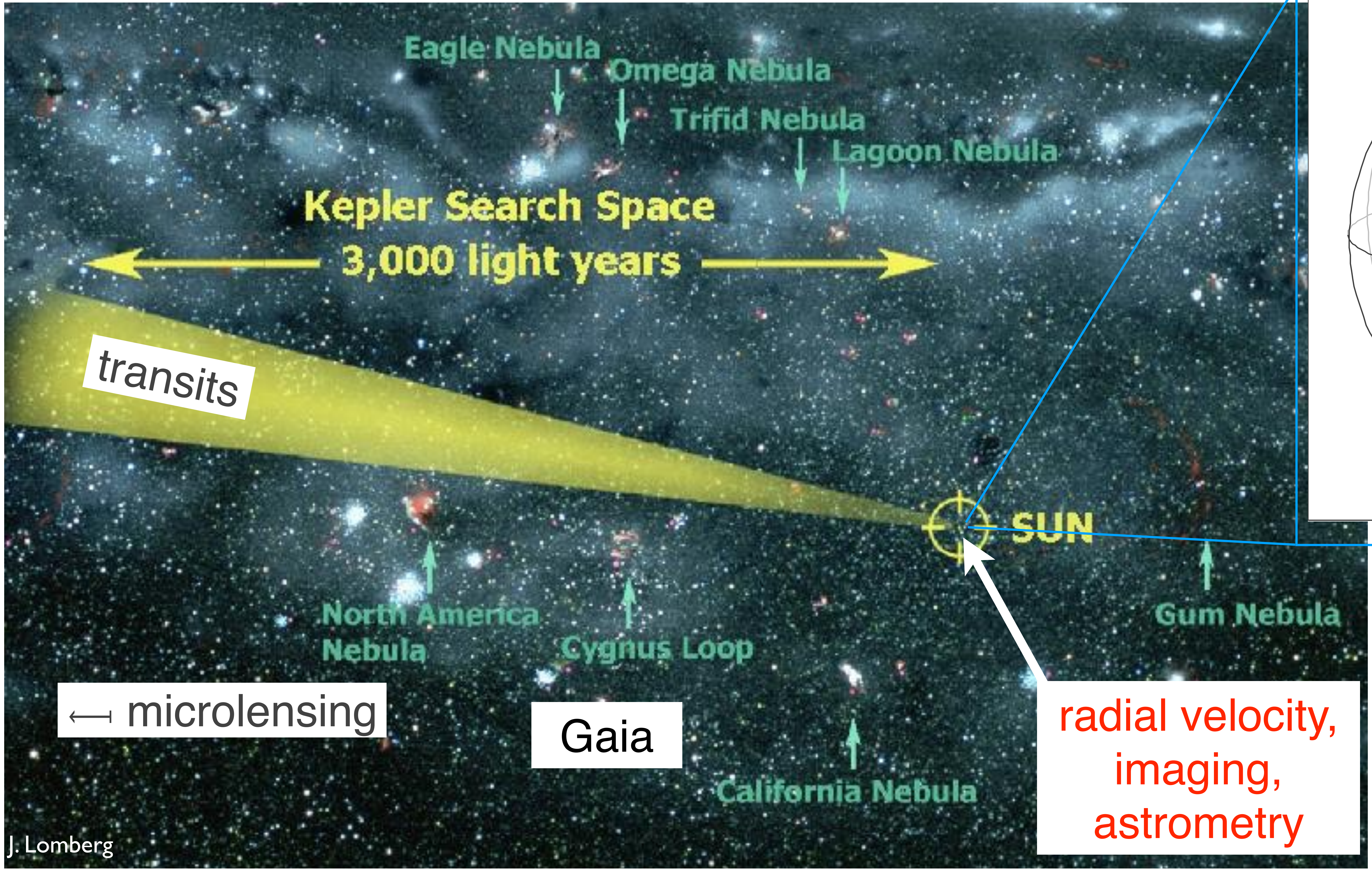


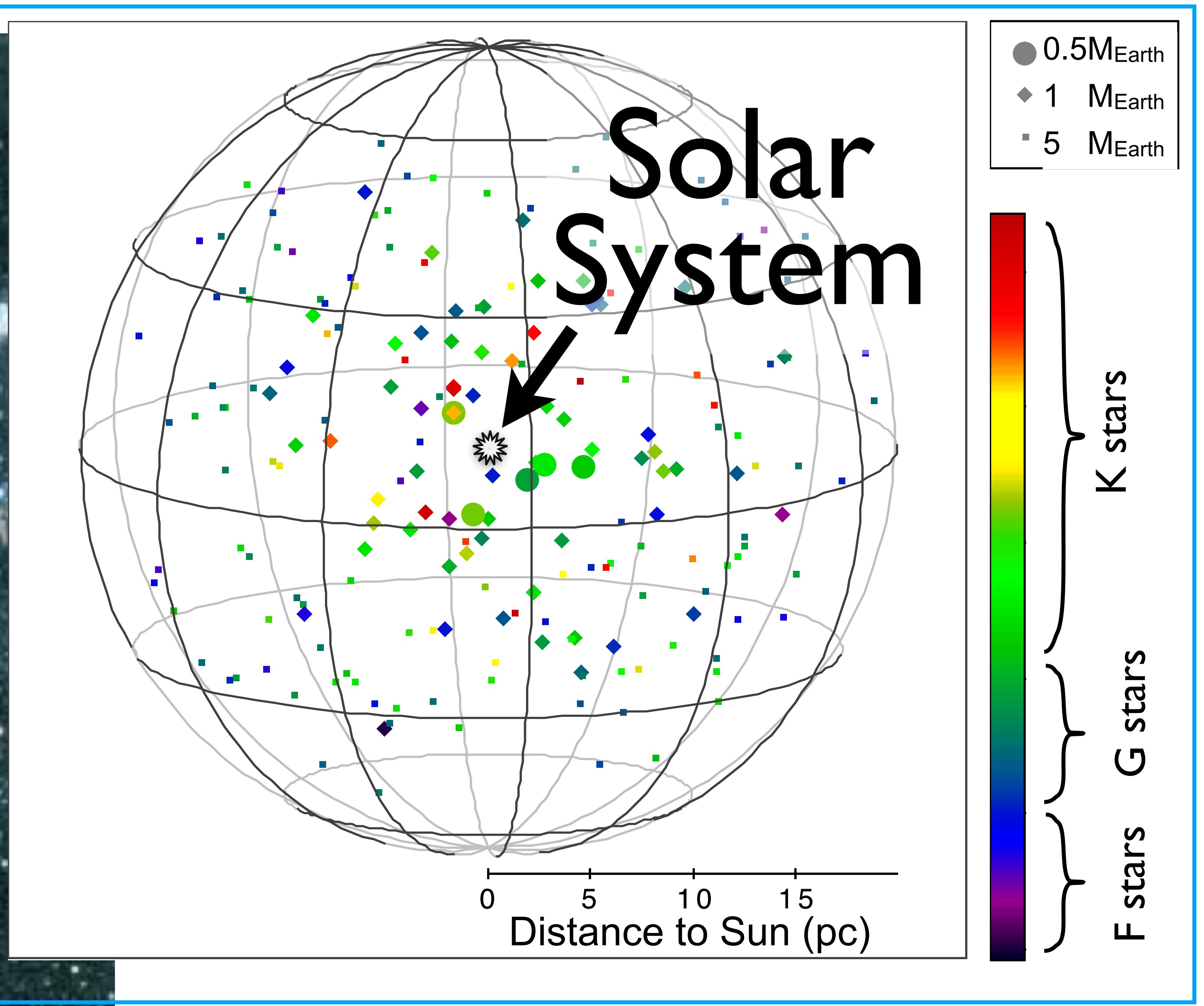


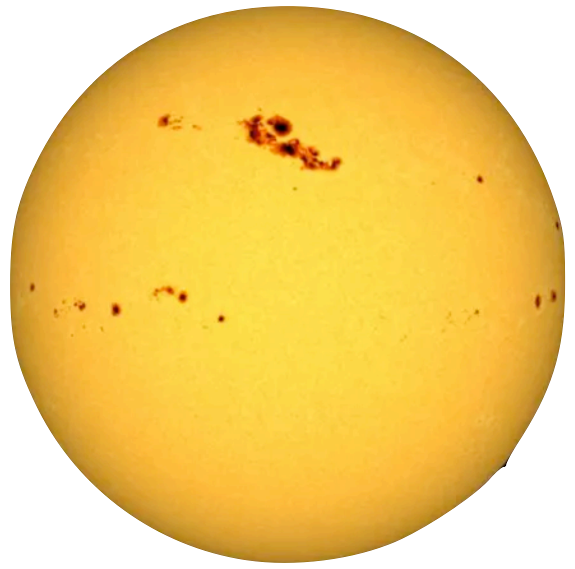
51 Peg
G2IV,
G=5.3 mag

51 Peg b 30th anniversary conference, Obs. Haute-Provence, 6-10 Oct. 2025

How to find planetary systems around nearby solar-type stars ?



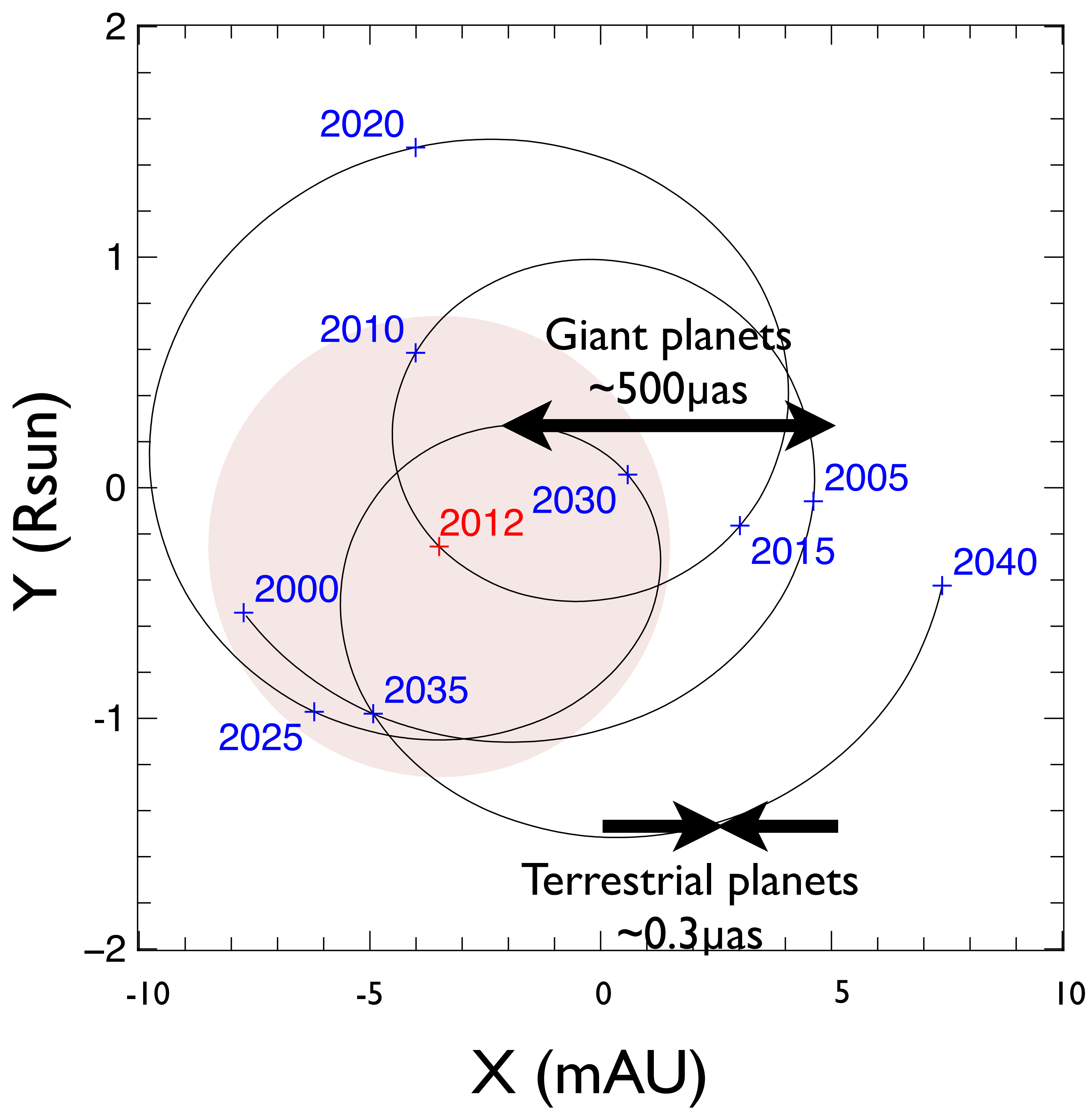




Stellar activity
Radial velocity
10x more
sensitive to spots
than astrometry

Astrometry ultimate accuracy

Motion of the Sun @ 10 pc



$$\alpha = 0.33 \left(\frac{M_P}{1\,M_\oplus}\right)\left(\frac{a_P}{1\,\mathrm{AU}}\right)\left(\frac{M_\star}{1\,M_\odot}\right)^{-1}\left(\frac{D}{10\,\mathrm{pc}}\right)^{-1} \mu\mathrm{as}$$

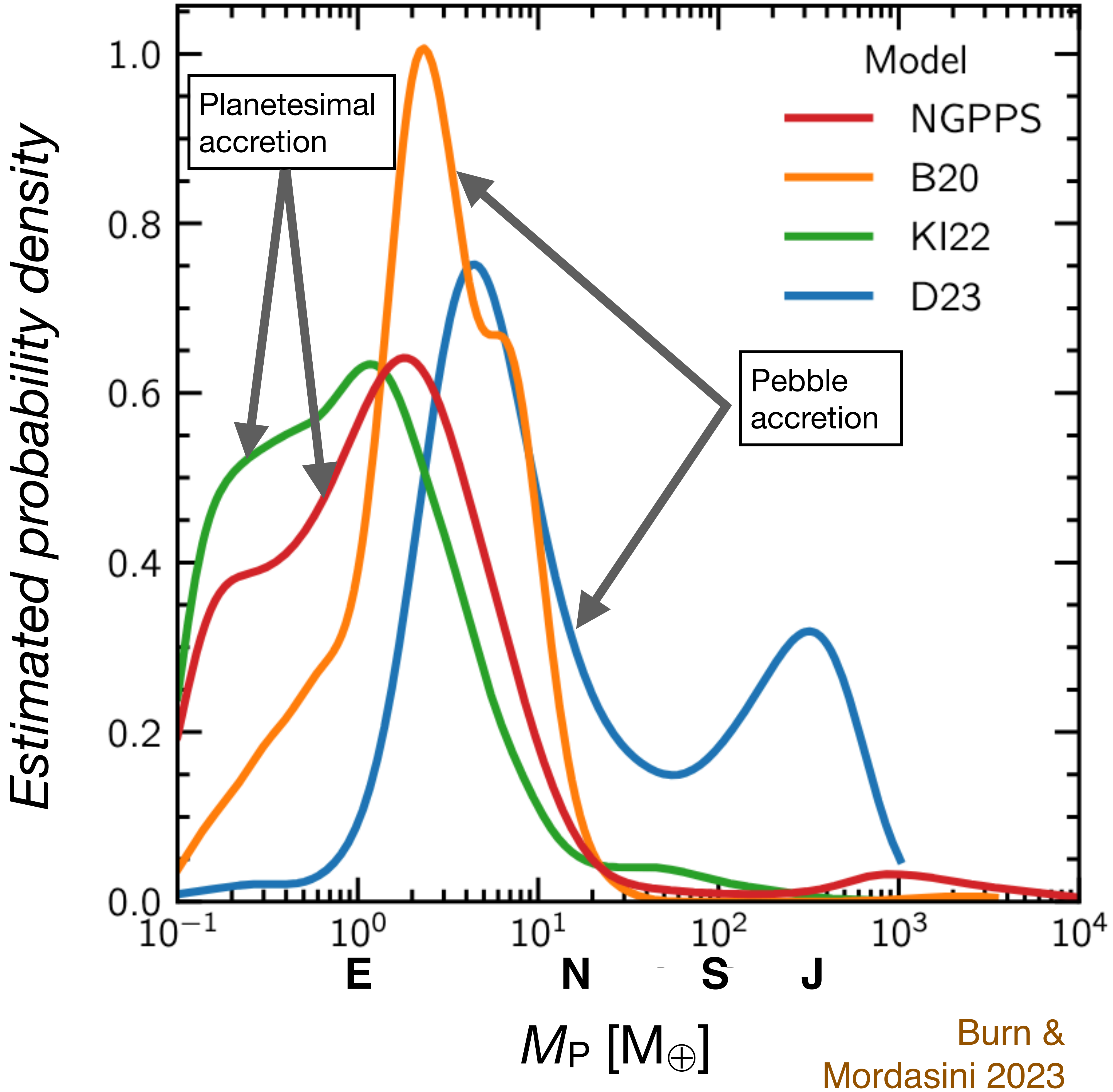
Solar system	**Giants planets**		**Terrestrial planets**	
	Jupiter@10pc	**Saturn@20pc**	**Super Earth@5pc**	**Earth@10pc**
M_P (M_E)	300	100	3	1
a_P (AU)	5	10	1	1
P (yr)	11	30	1	1
α (in µas)	**500**	**170**	**2**	**0.3**

Astrometry measures
$P, \alpha, i, e, \omega, \Omega, T_0 \rightarrow M_P$

Mostly limited by the mission duration for cool giant exoplanets!

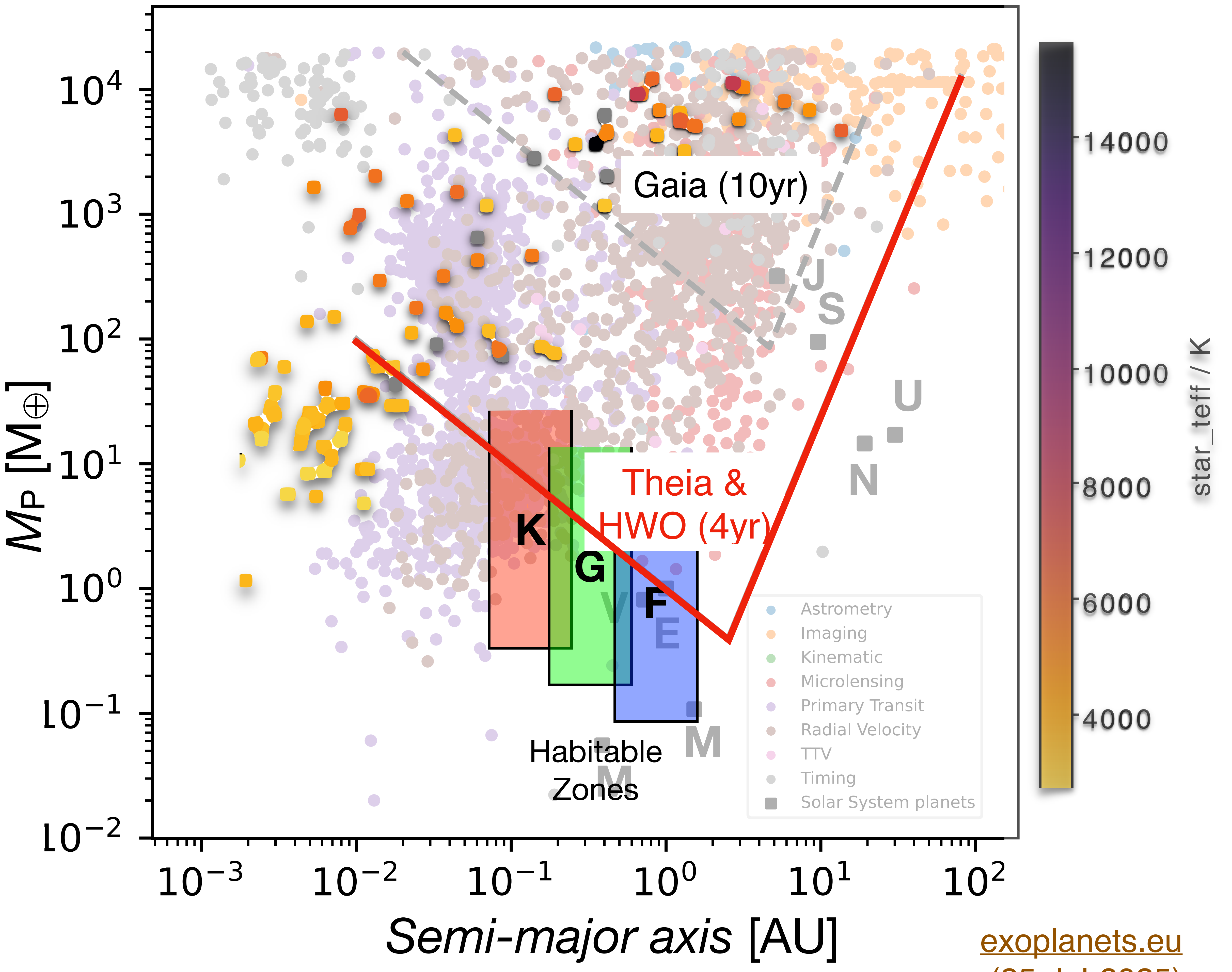
What planetary components are we missing?

Population synthesis model for planet formation



Burn & Mordasini 2023

Exoplanets found around nearby stars



exoplanets.eu
(25-Jul-2025)

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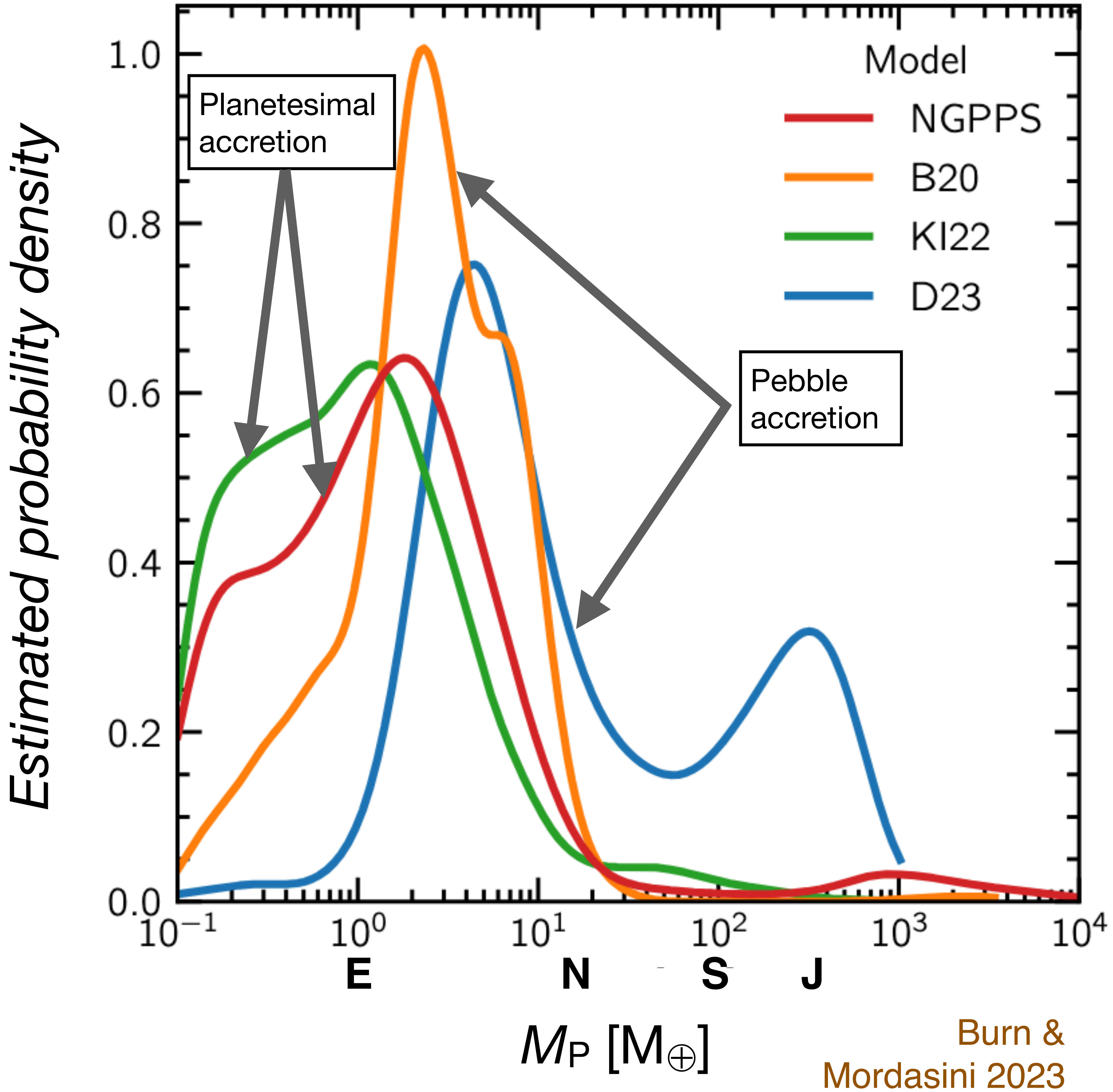

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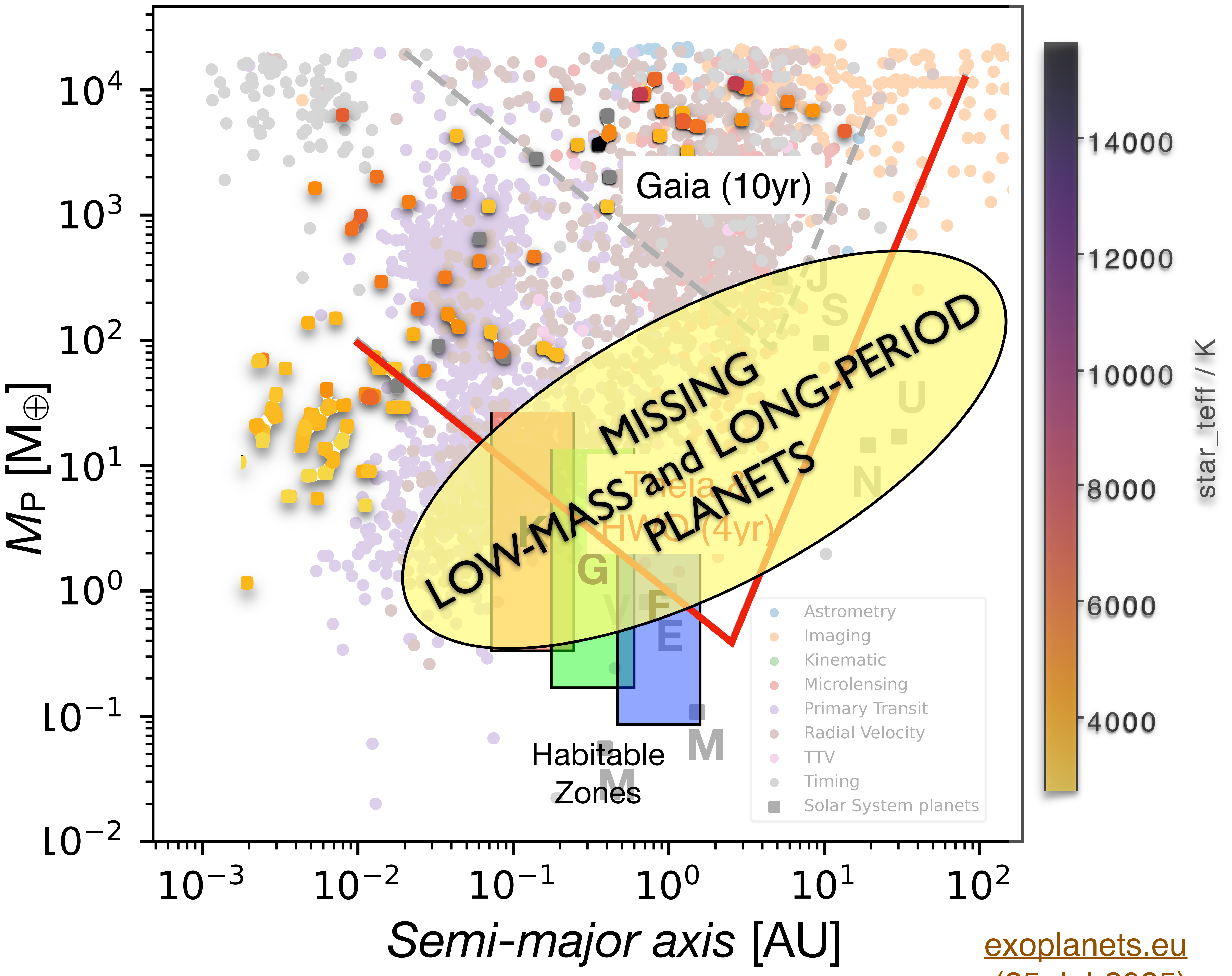
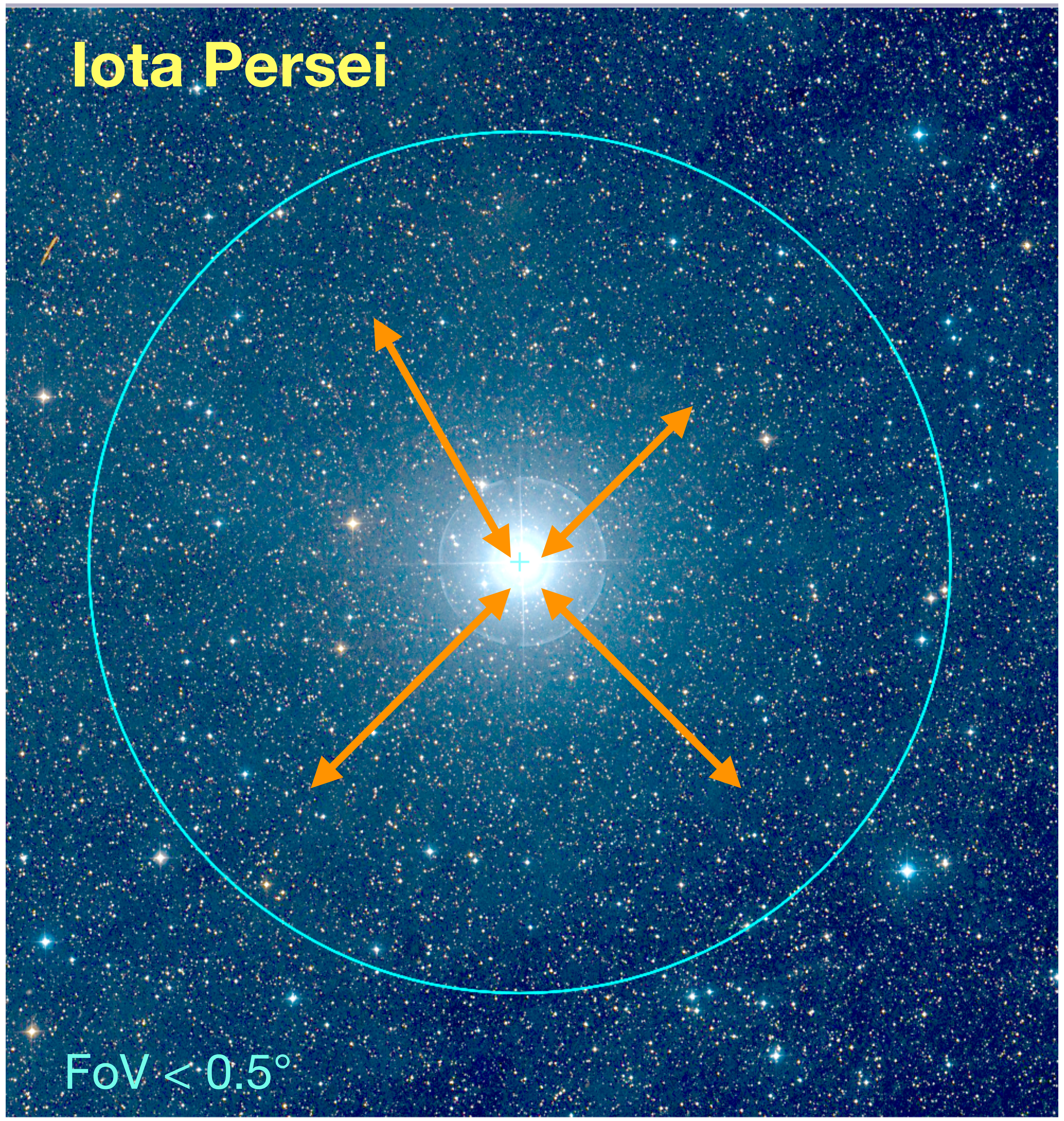
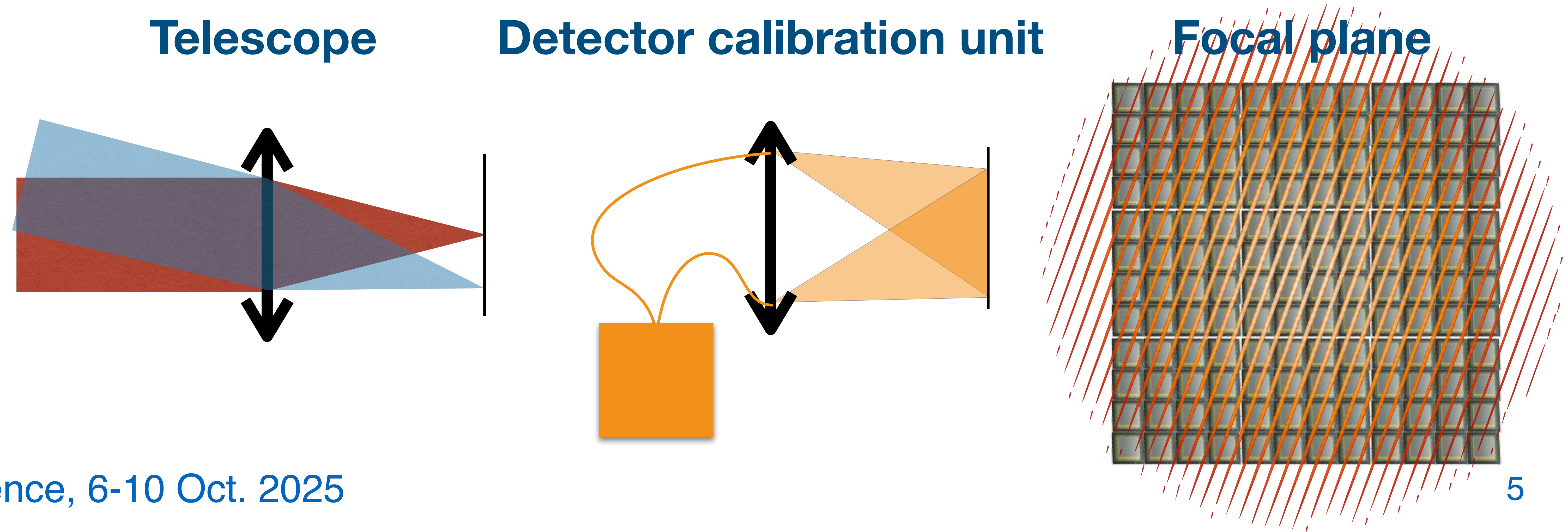


exoplanets.eu (25-Jul-2025)

Principle : relative and precise differential astrometry

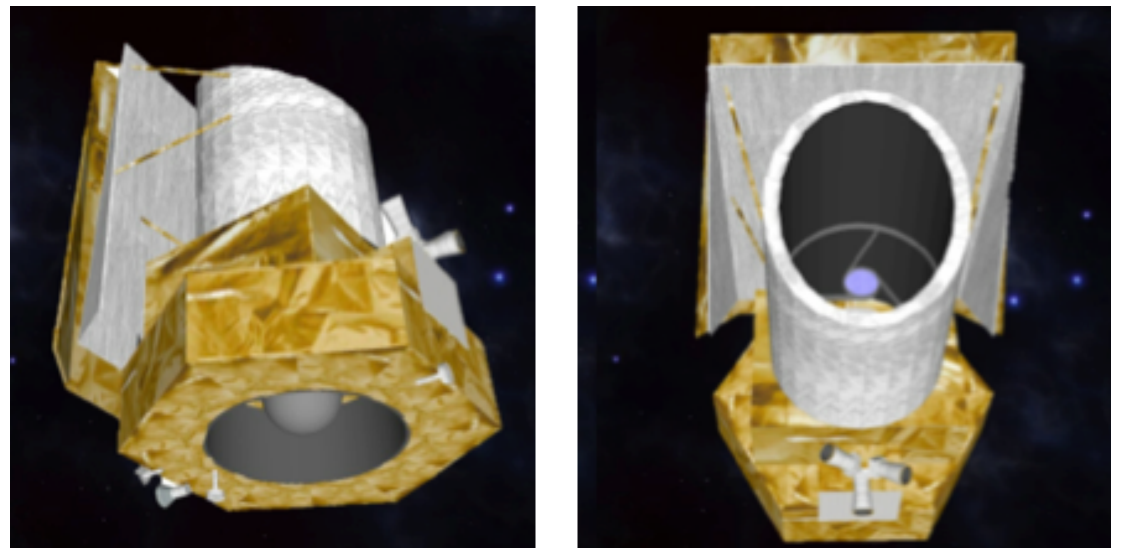


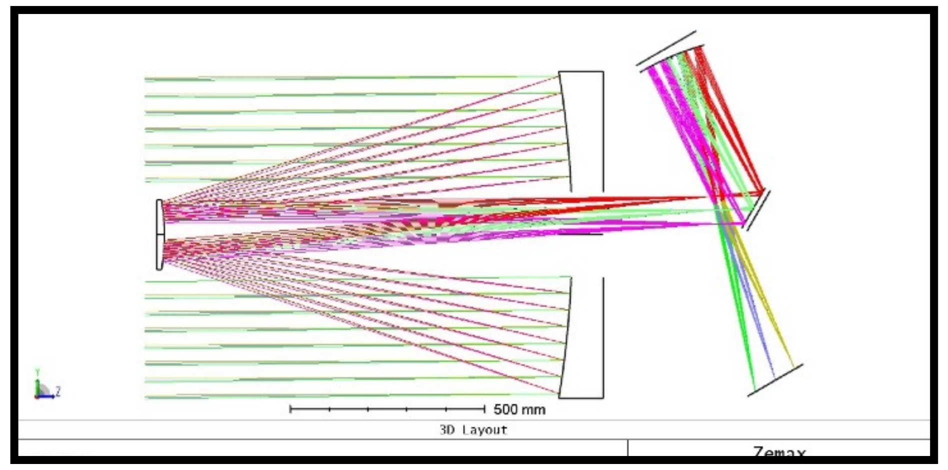
- ✓ The science target is at the center of the FOV
- ✓ We measure the offset angles between the target object (in the center) and the many reference stars
- ✓ The single measurement is repeated several times over the mission lifetime to reach the required accuracy on the target motion
- ✓ The detector calibration is done using interferometric modulated Young's fringes

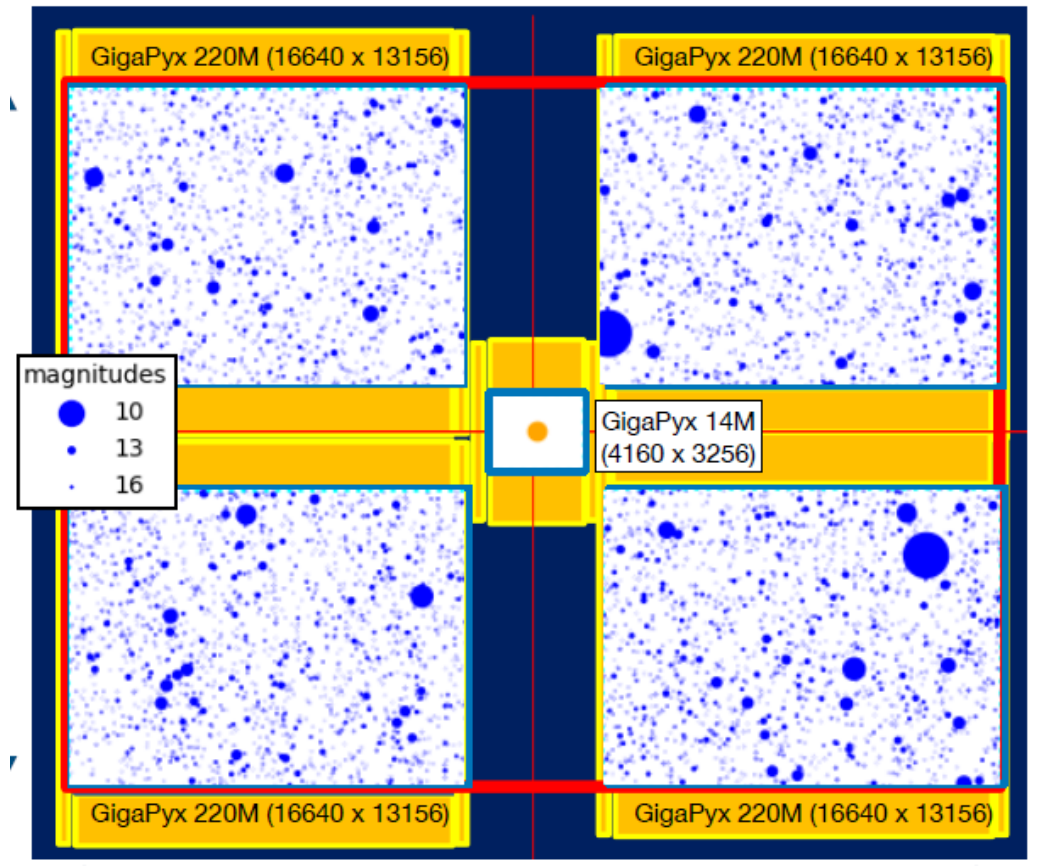


Two space missions in view

Theia



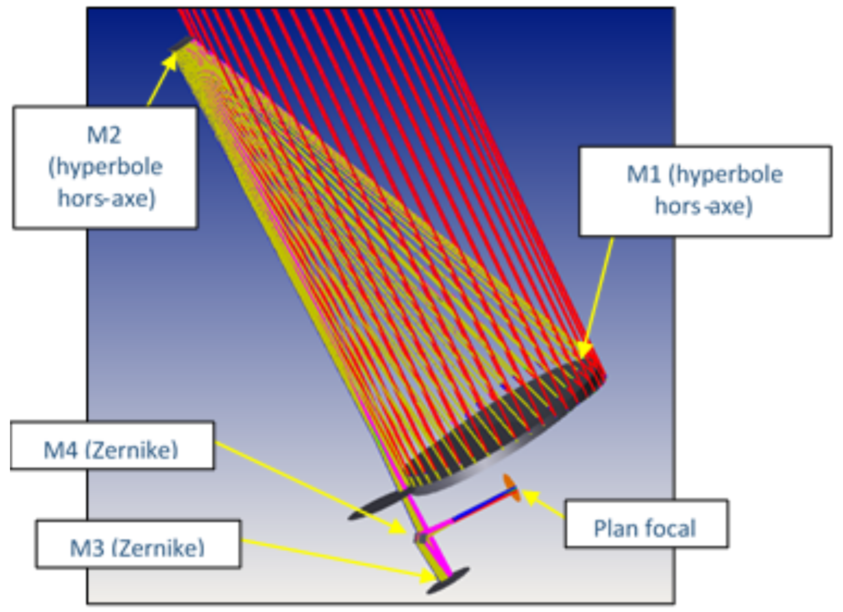


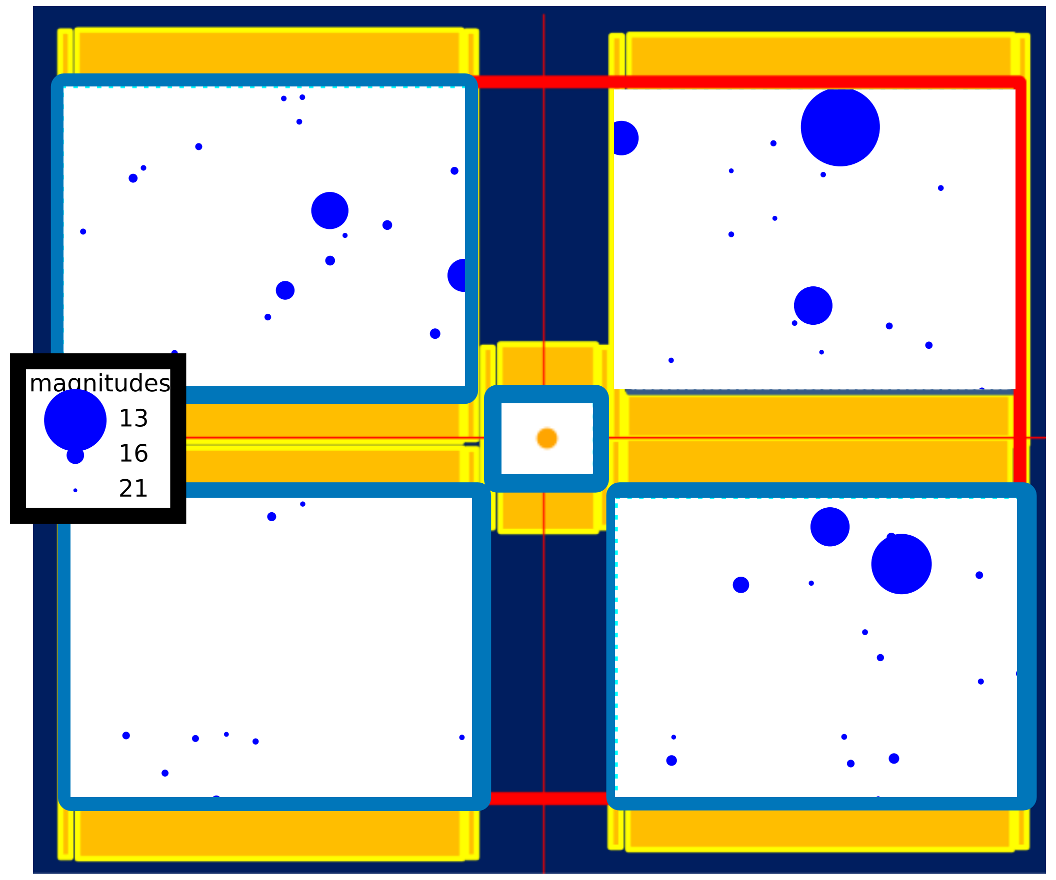


Theia		HWO
ESA	**Agency**	NASA
Medium (M8)	**Mission type**	Habitable World Observatory
0.8 m	**Telescope Diameter**	7 m
~2040	**Launch date**	~2040
L2 lissajous	**Orbit**	L2 lissajous
[450 nm - 900 nm]	**Wavelength domain**	[450 nm - 900 nm]
160 mas	**Diffraction limit**	14 mas
30x30 arcmin^2	**Field of View**	4x3 arcmin^2
22.500 x 22.500 px^2	**Focal plane size**	34.300 x 25.700 px^2
~500 MP	**#pixels**	~900 MP

Missions require a **gigapixel** focal plane

HWO



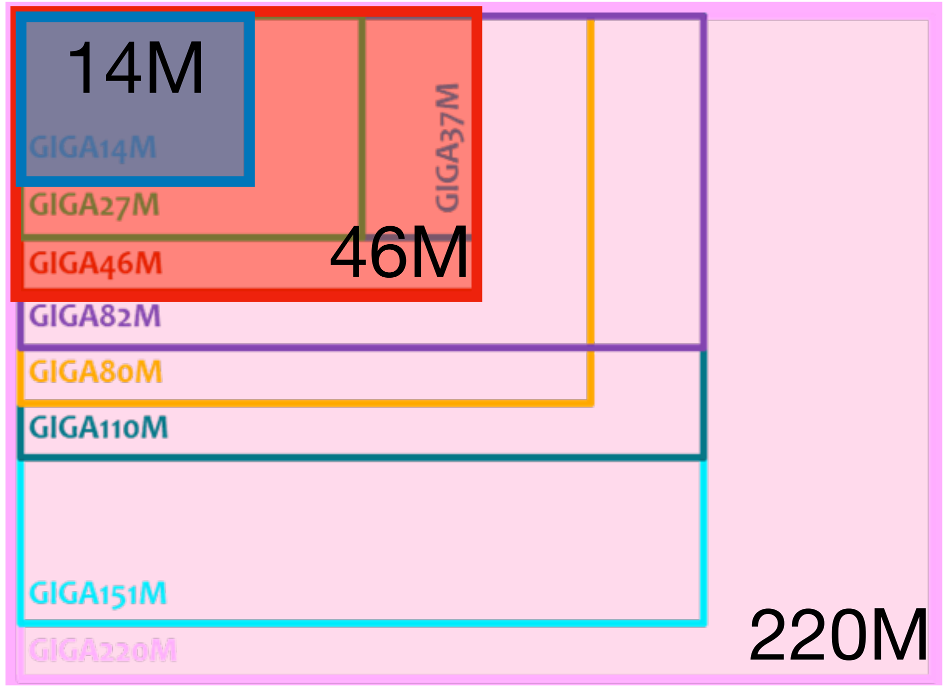


Which gigapixel detectors ?

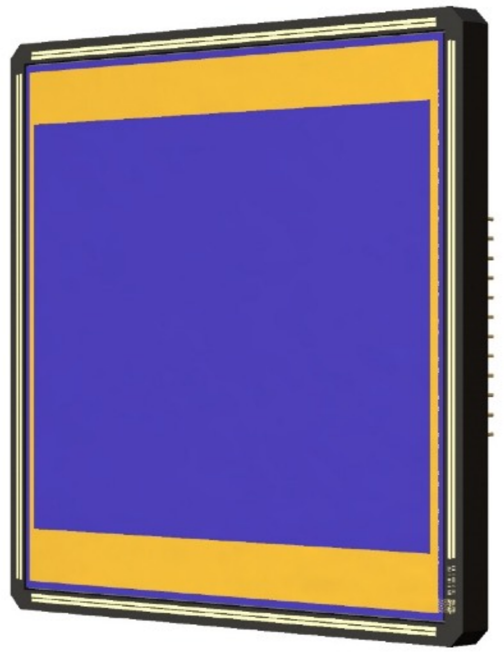
Instrument for relative Astrometry Measurement

- **Baseline detector solution:**
  4 Pyxalis CMOS GigaPyx 220 MP
  3 GigaPyx 14 MP at the center
  ~1 Gigapixel focal plane

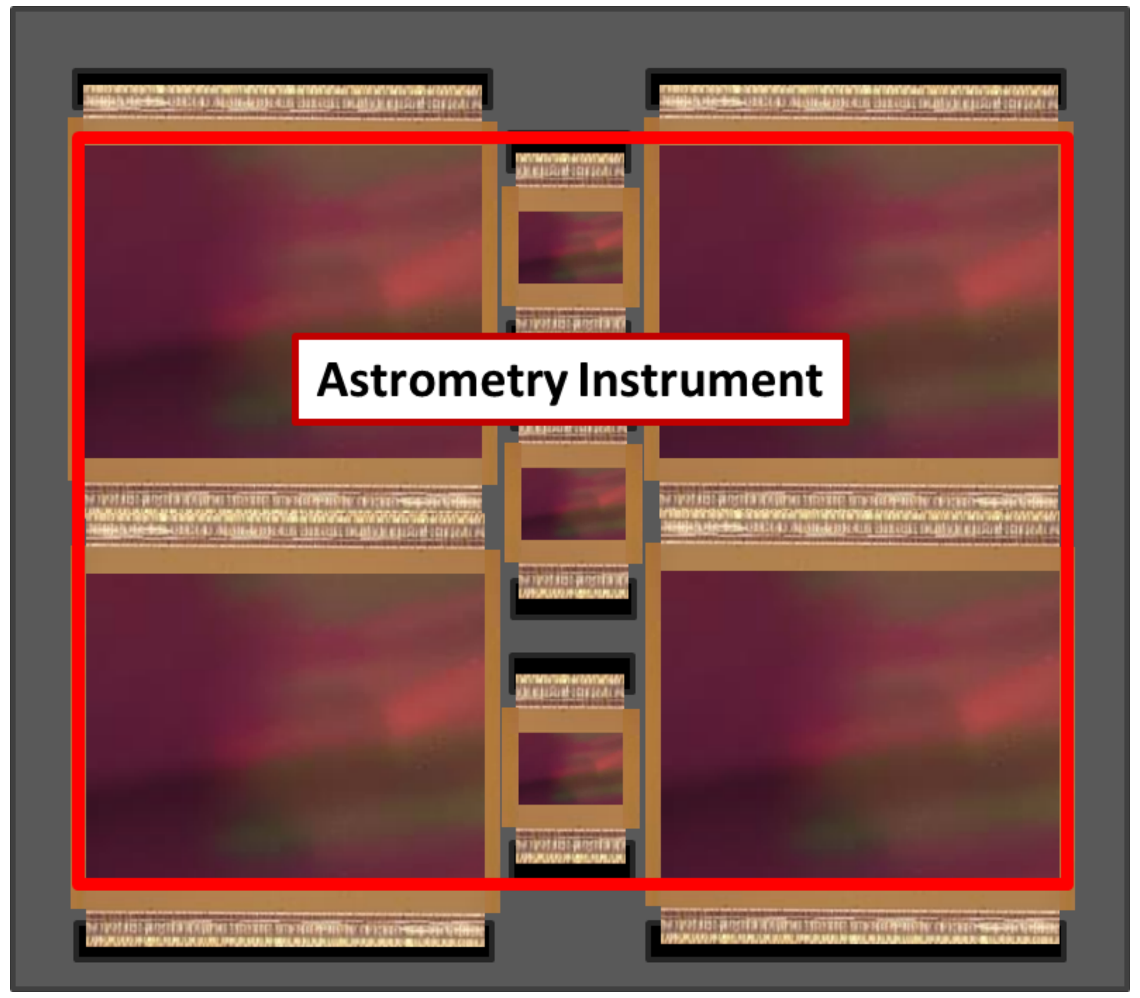
Pyxalis GigaPyx sensor family



GigaPyx (220 MP)

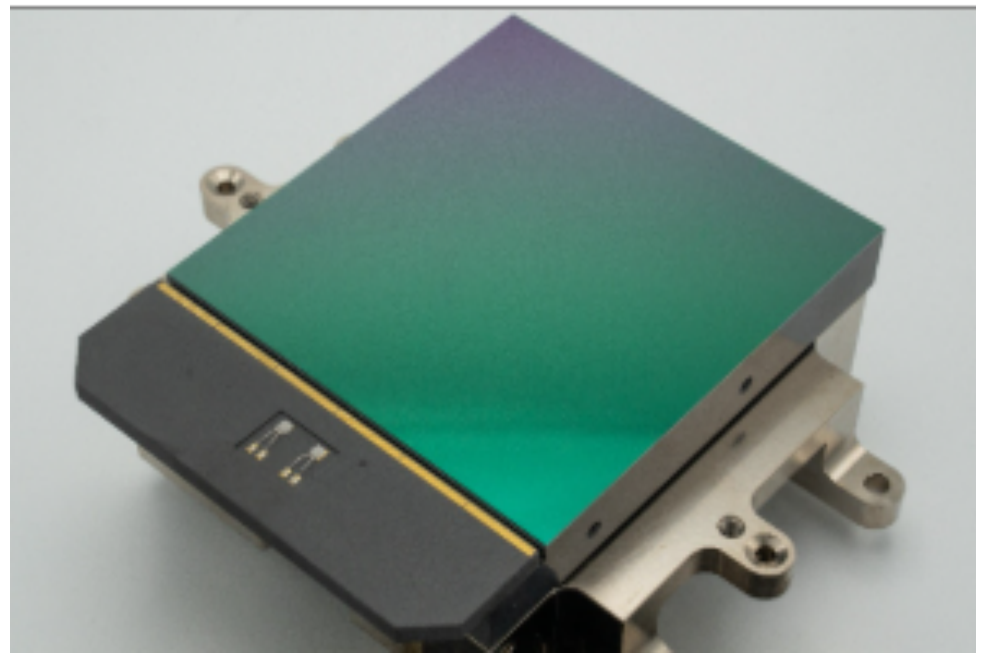


4x

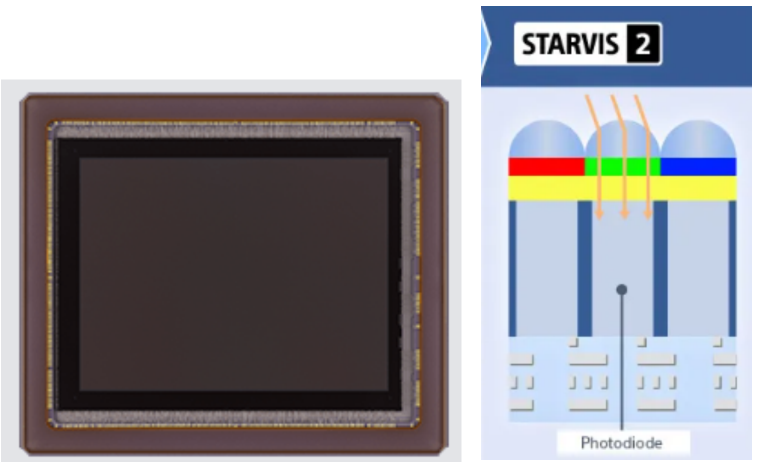


- **Alternative Detectors:**
  - **Teledyne e2V CIS 300**: larger pixels (10.0 µm)
  - **Sony IMX 411**: micro-lens array (3,8 µm calibration issue)
  - **Gpixel GSENSE 1517**: larger pixels (15.0 µm)

Teledyne e2v (81 MP)

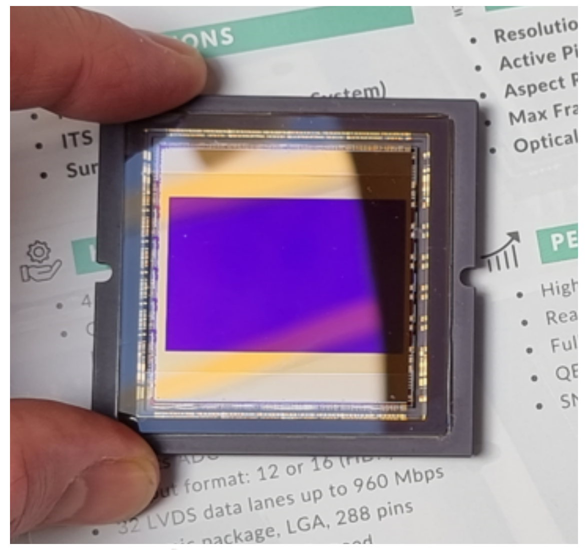


Sony (150 MP)



Gpixel (81 MP)

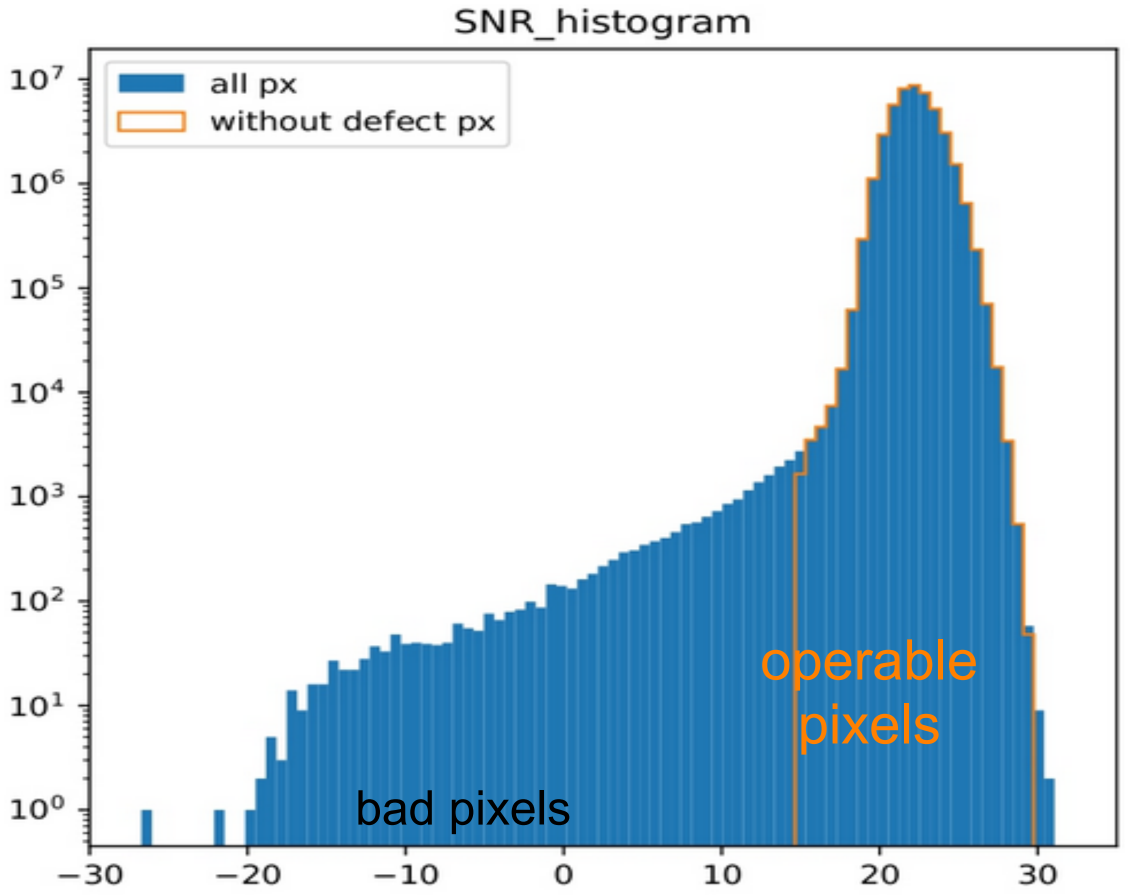
Performance of current Pyxalis GP 46MP detectors

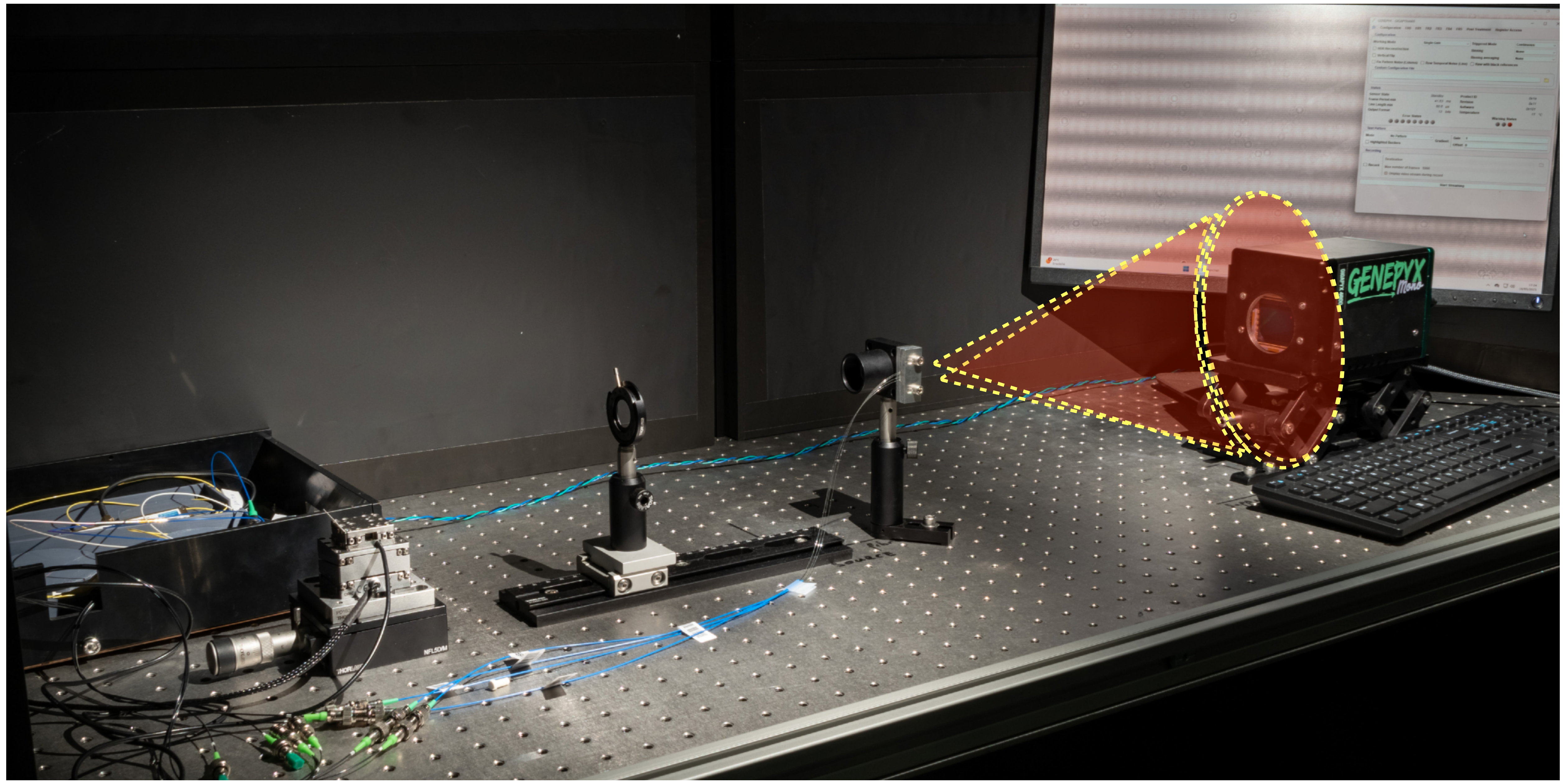


46Mpx Gigapyx already integrated on IPAG testbed, high performance compliant with Pyxalis measurements

Mission calibration currently tested on **IPAG bench** (optical distortion and focal plane geometry)

	Pyxalis	IPAG
Read out noise	1.6 e-	**0.8 e-**
Linearity	< 3%	**0.5%**
Bad pixels	0.1%	**0.04%**
Response non uniformity	2 %	**0.8%**
Full well (low gain)	50 000 e-	-



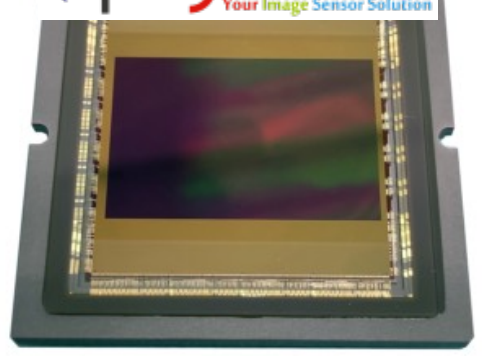


Funded by LabEx FOCUS

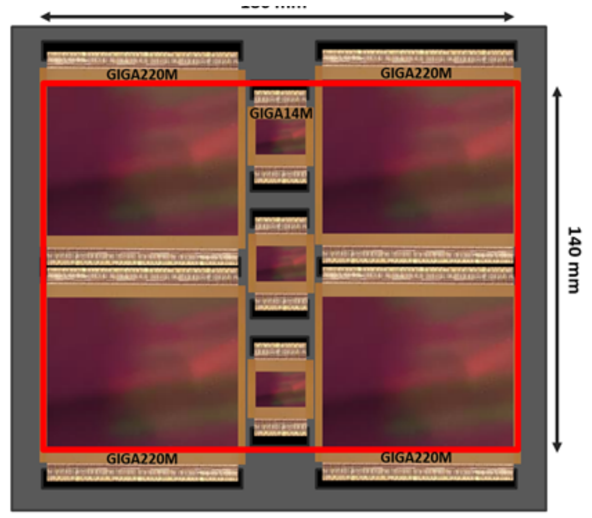
Measured performances are compliant with an astrometric instrument onboard HWO or Theia to detect Earth-like planets

Reaching Technical Readiness Level 3 for future astrometry focal plane instruments

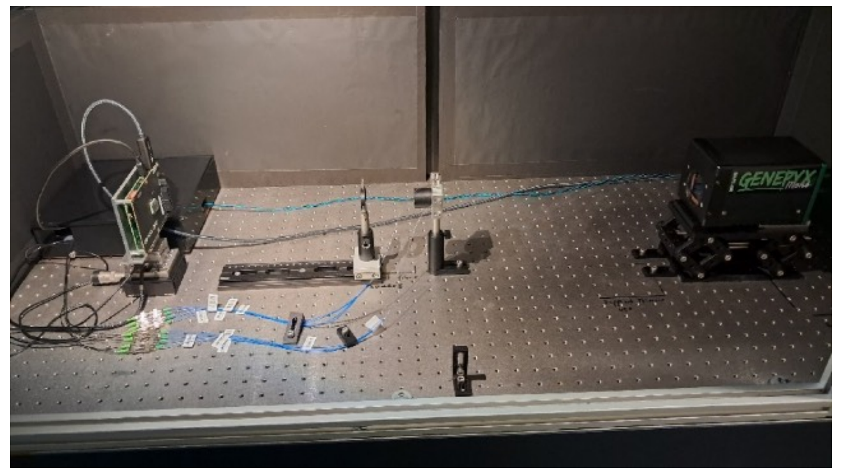
Today status



Exiting Large scale high sensititivity, high speed image sensor, GigaPyx 46 MP

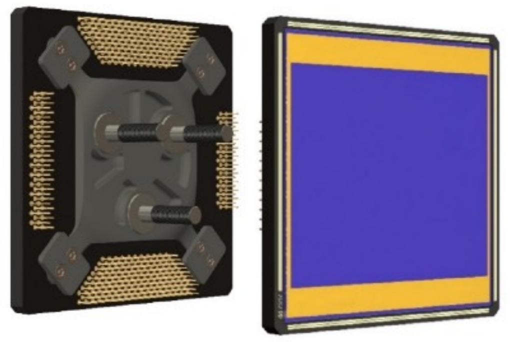


Astrometry focal plane preliminary studies with Gigapyx 220 MP

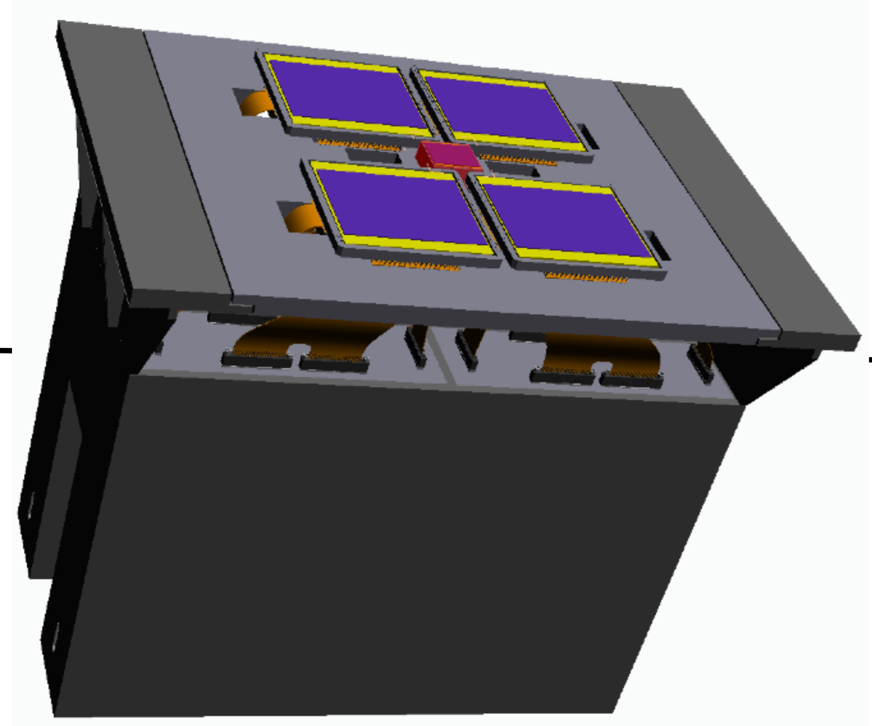


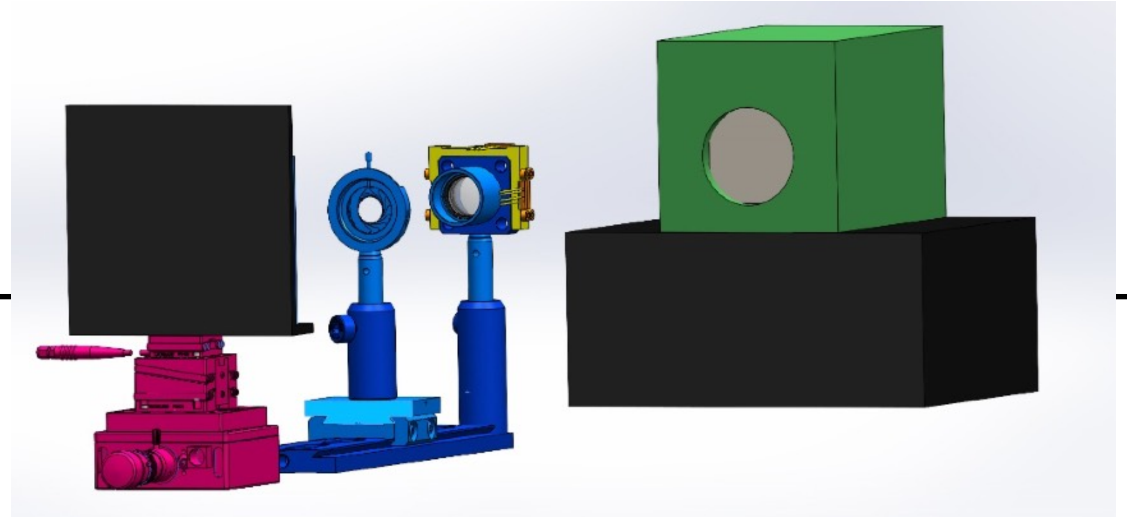
High precision Calibration system demonstrator

GigaPyx 220 MP

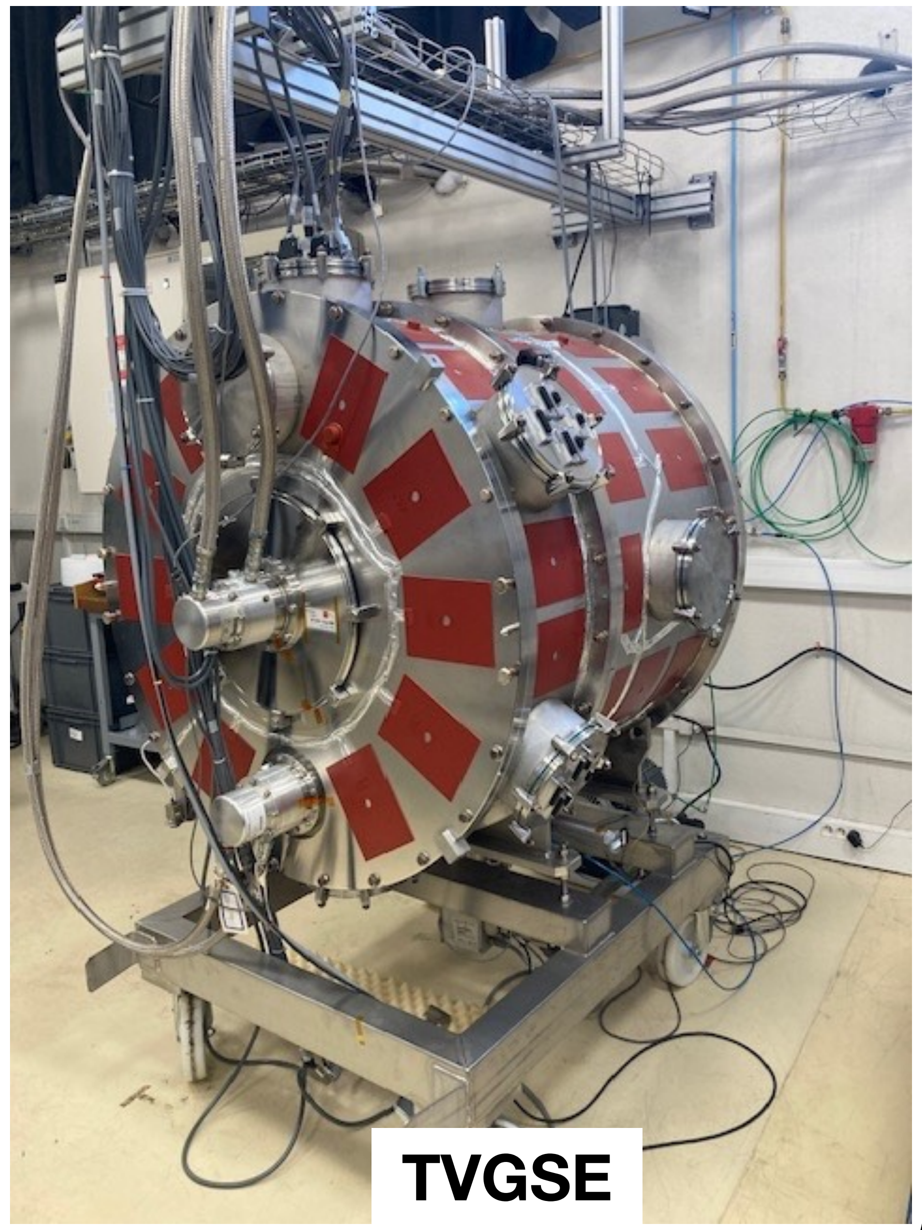


GigaPyx 220 MP « Astro »





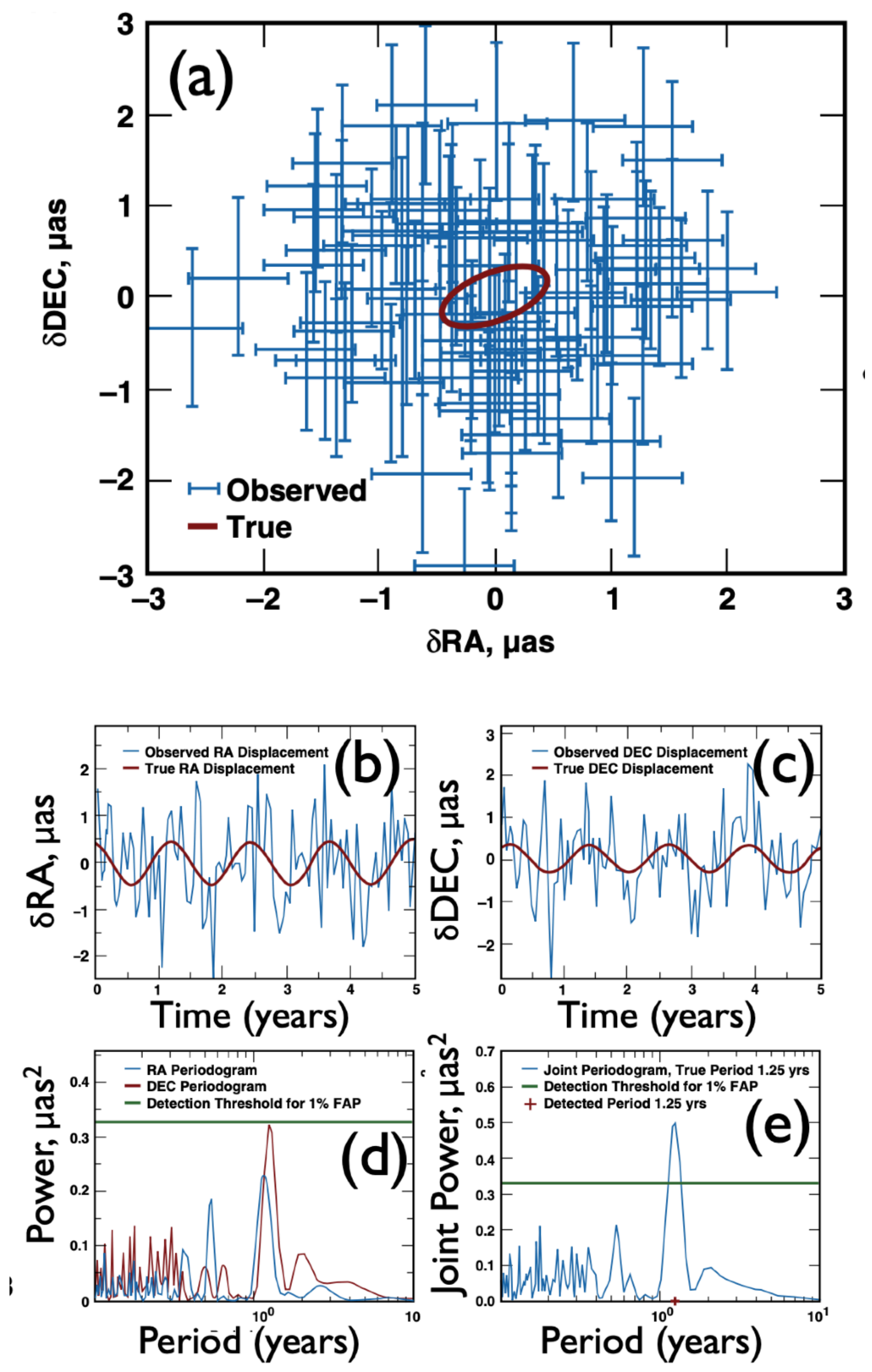
Development and characterization of RETINA camera performances



with existing tests benches

Submitted to PEPR Origins

Astrometric error budget for bright targets with Theia and HWO



Unwin et al. (2008)

Key Instrument Parameters

	Theia	HWO
Collector Diameter (m)	0,80	7,1
Field of View (arcmin^2)	45x36	3x4
Effective λ (nm)	700	675
PSF size (mas)	140	20
pixel size (um)	4,4	
Read Noise (e-)	1.6	
Dectectors	4 + 1	

Minimum detectable astrometric signature 0,30 uas

times

- 6 Signal-to-noise ratio
- Astrometric noise floor at the end of mission 0,05 uas

/sqrt(N)

	Theia	HWO
Observation Sequence mission lifetime (sec)	3240	2400
Number of integrations during mission lifetime	400	100
Differential Measurement Astrometric accuracy per 1h observation (μas)	**1,00**	**0,50**
	0,96	*0,50*

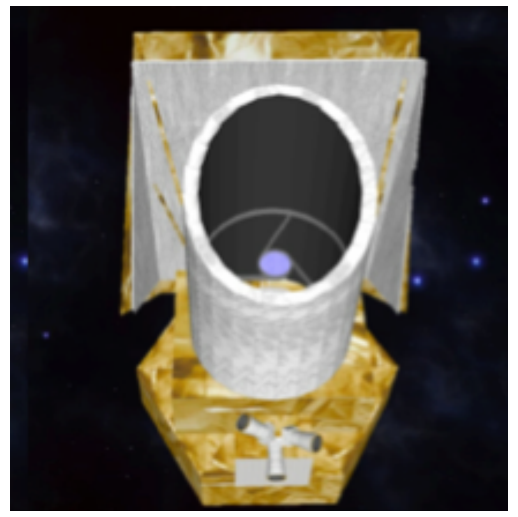
RSS

	Theia	HWO
Detection noise error **Target star** (μas)	0,35	0,03
Detection noise error **Reference stars** (μas)	0,58	0,23
Focal-plane metrology differential error (μas)	0,33	0,31
Field Distortion calibration Errors (μas)	0,52	0,31
Astrometric geometry Errors (μas)	0,30	0,06

	Theia	HWO	
Target star	7		mag
	1		star
	3240	2500	
Reference stars	10,8	15	mag
	12	20	stars
	3240	2400	sec
1 Targ. det vs. # Ref. det pixel calibration (px)	5E-06	5E-05	
Residual calibration error (pix)	1E-04	5E-04	

- Stellar aberation
- Ref. star geometry
- Companions

Conclusion



Theia

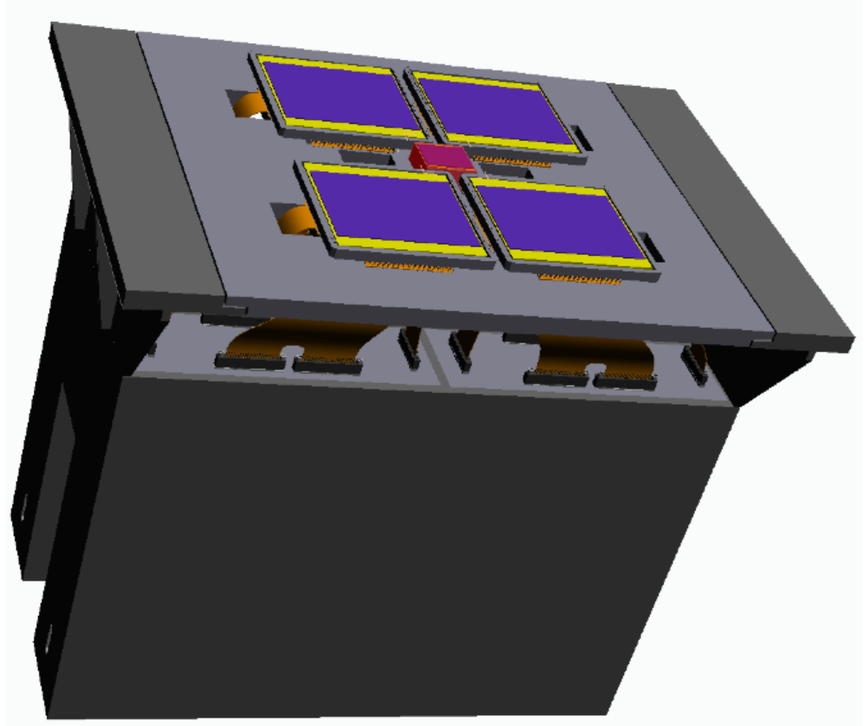
HWO

Science : high precision astrometry can probe Giant Exoplanets

- **Ultra-precise differential astrometry** can detect signals down to a few μas
- Sensitive to relatively **wide orbits (*a* > 3 AU)** depending on mission duration
- Census of cool giant exoplanets around solar-type stars within ~20 pc
- Characterization of **planetary system architectures** : mass, inclination, eccentricity
- Measurement of **planetary masses** is key to formation & structure models

Technology : same focal plane architecture and calibration system

- Both missions utilize **gigapixel** focal planes
- Pyxalis GigaPyx CMOS sensors **demonstrate good performance** : low noise, excellent linearity and uniformity.
- Calibration system reaches the **precision required**
- **Goal to achieve TRL-3** with validated focal-plane and metrology testbeds by 2030



Focal plane