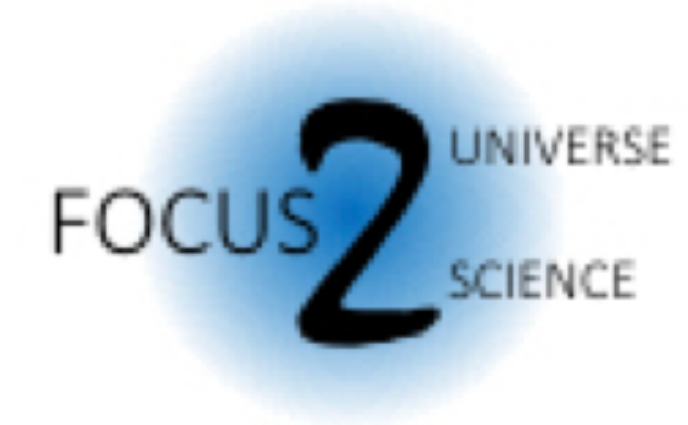




THEIA

Microarcsecond Astrometric Observatory



Pushing the limits of astrometry with THEIA

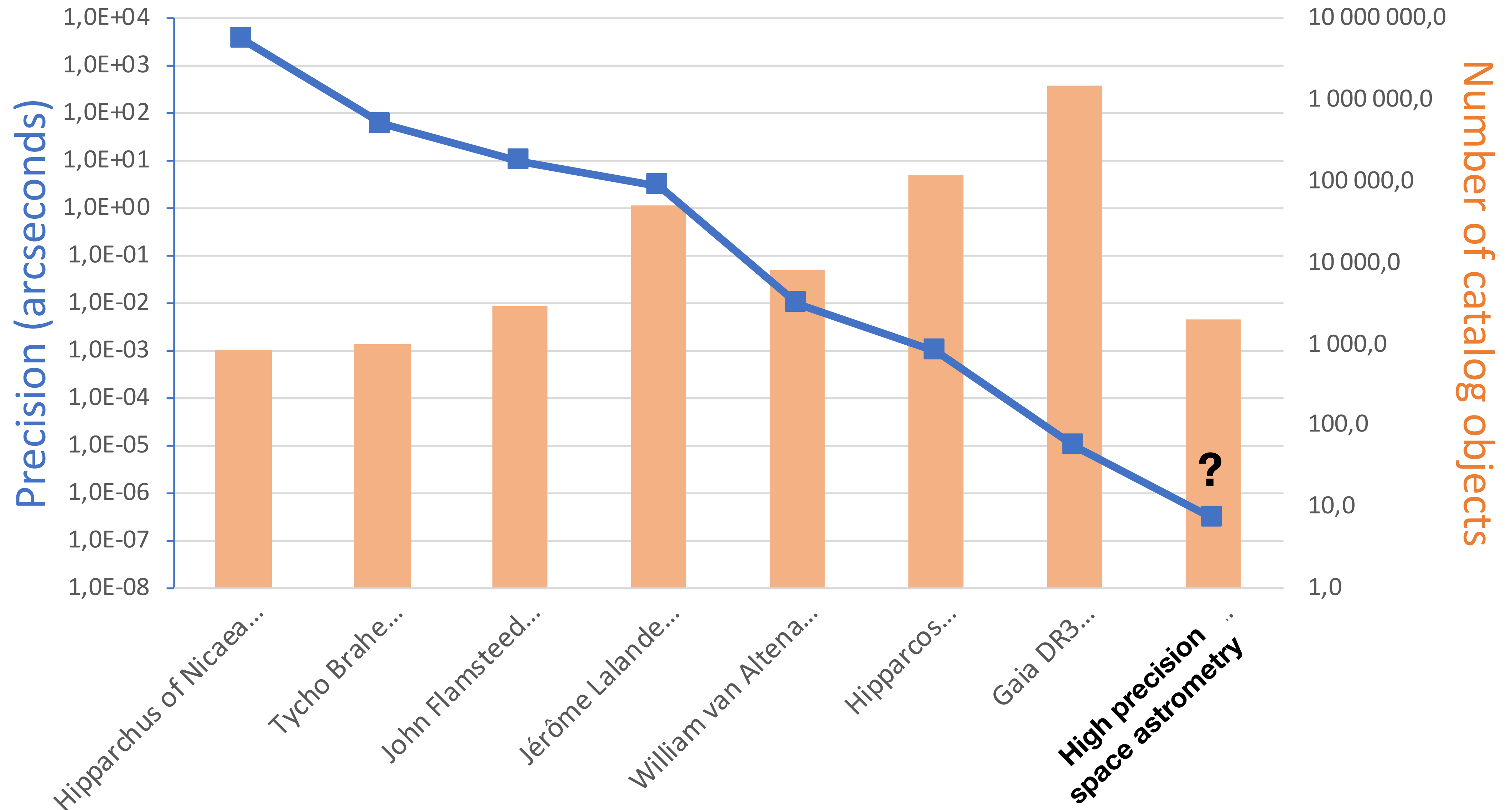
Fabien Malbet

*Université Grenoble Alpes (UGA) / CNRS
Observatoire des Sciences de l'Univers de Grenoble (OSUG)
Institut for Planetology and Astrophysics of Grenoble (IPAG)*

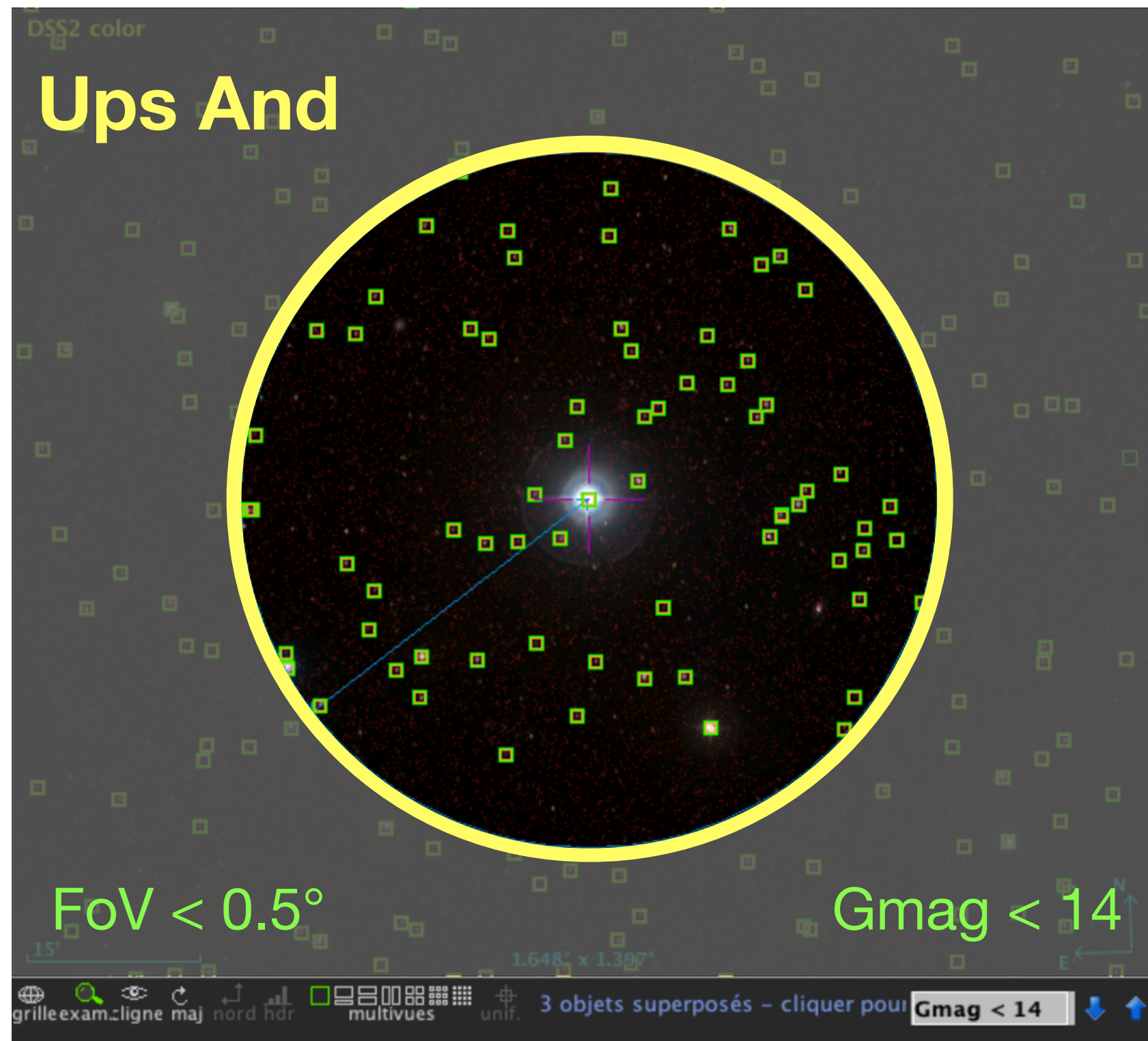
With Gary Mamon (IAP Paris), Lucas Labadie (Univ. Köln), Alessandro Sozzetti (INAF Torino), Manon Lizzana (IPAG Grenoble),
Thierry Lépine (IOGS Saint-Etienne), Alain Léger (IAS Orsay)



Astrometry precision through the ages

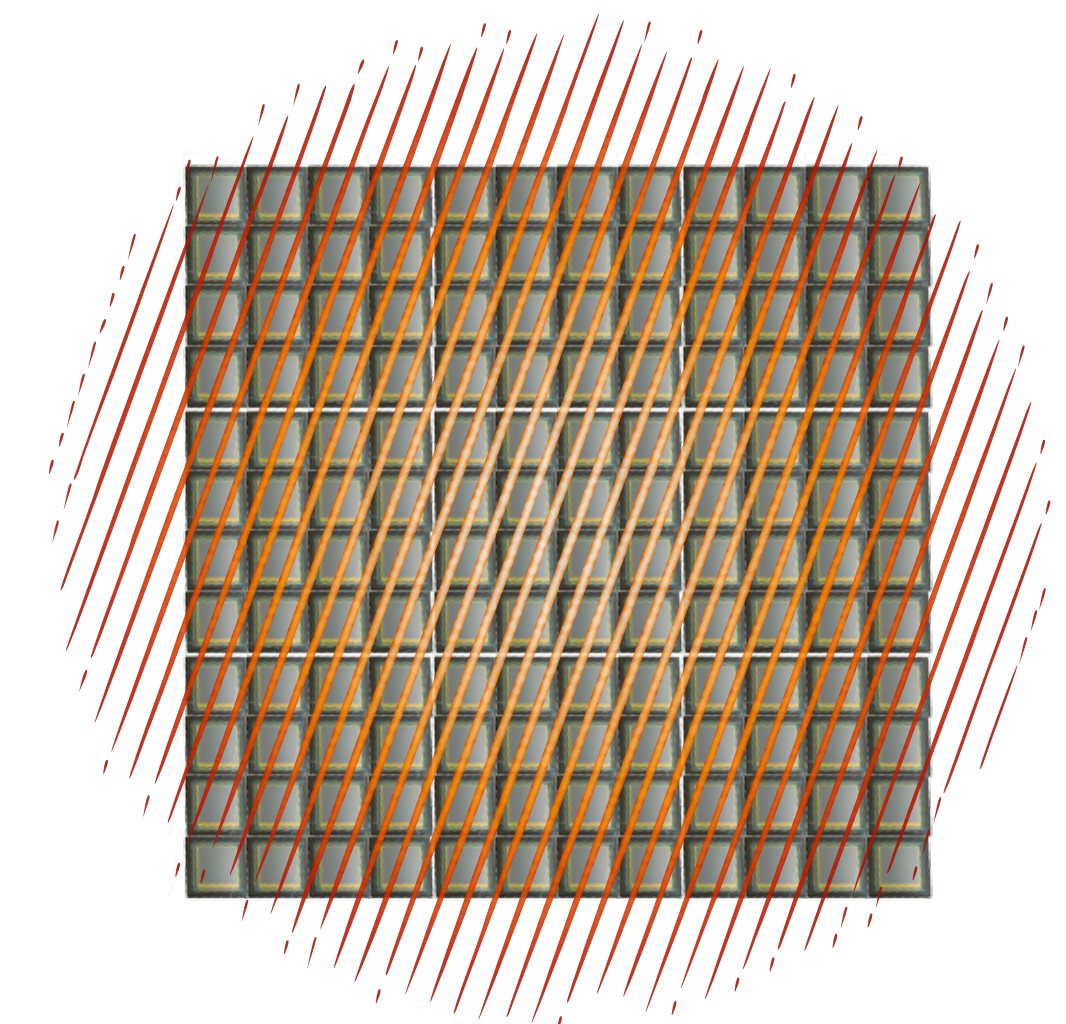
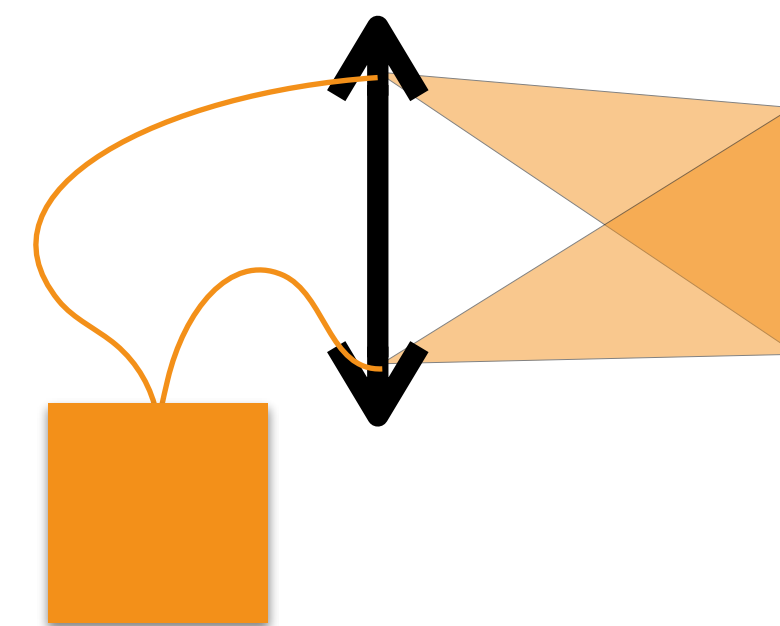
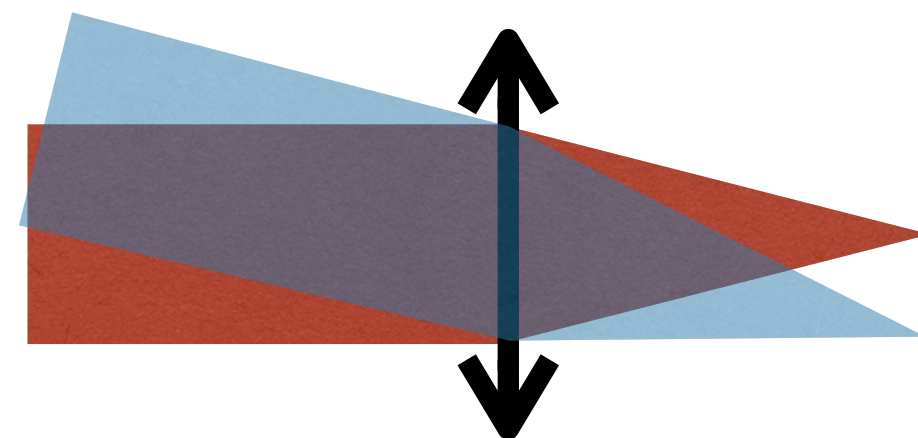


Principle : relative and precise differential astrometry



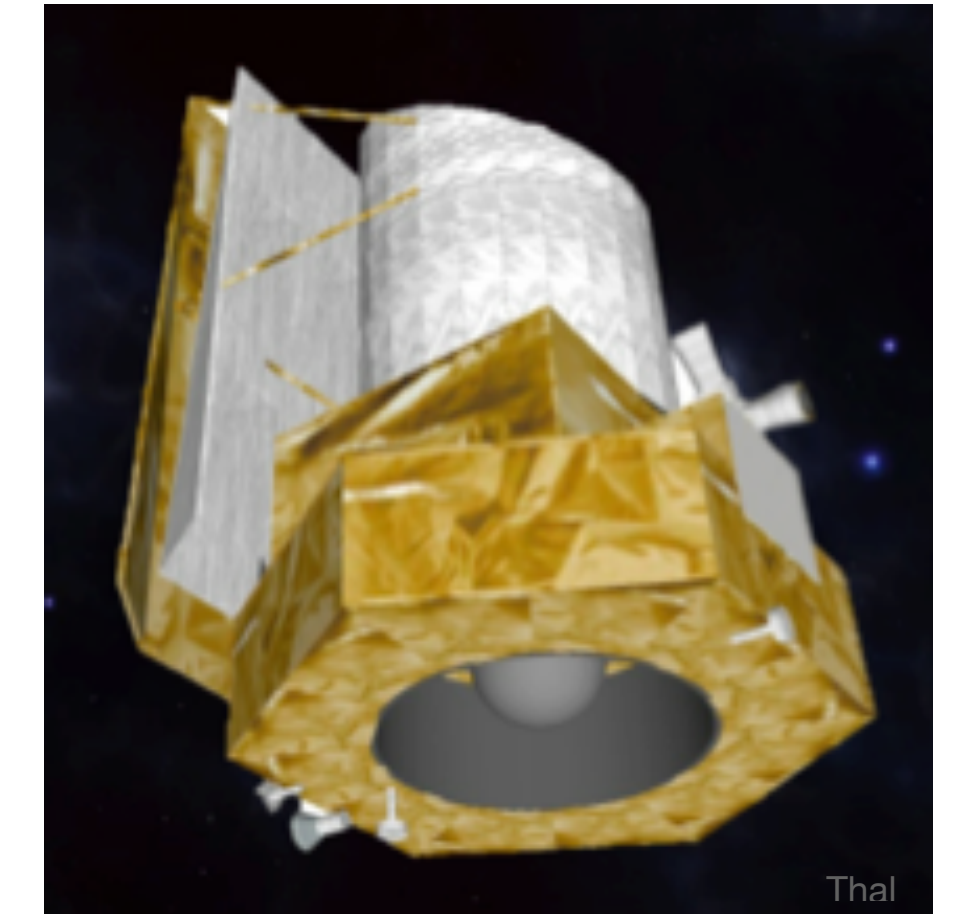
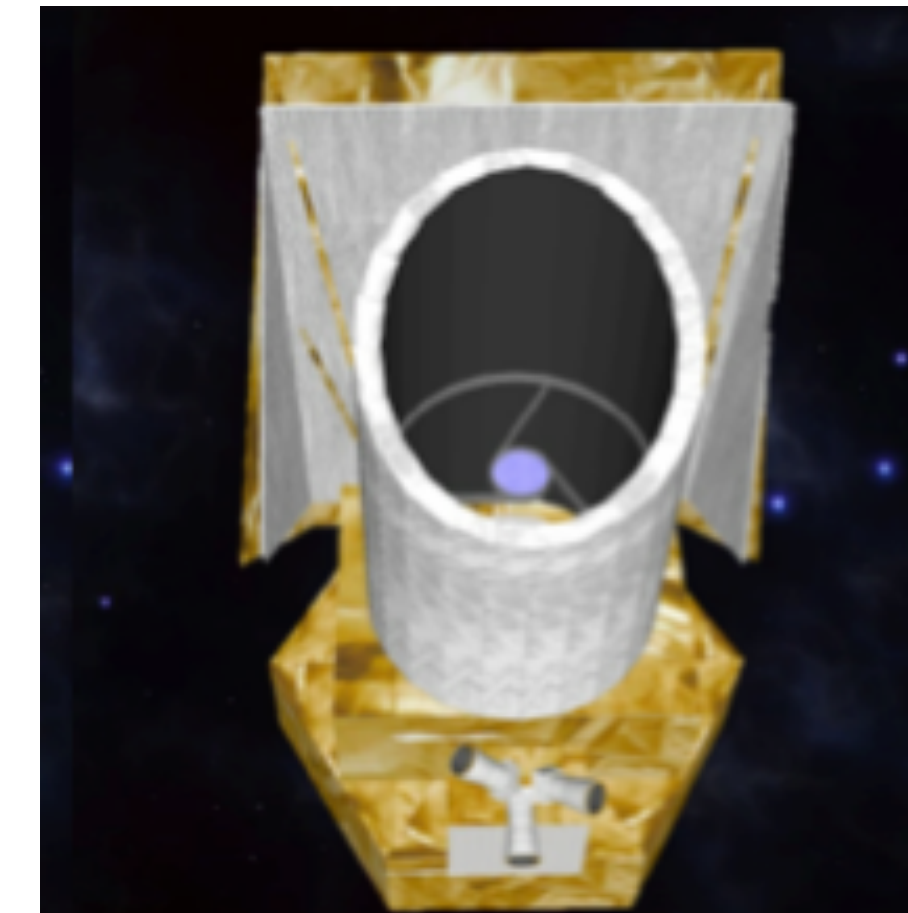
Gaia DR3 data

- ✓ The science target is at the center of the FOV
- ✓ We measure the offset angles between the target object (in the center) and the reference stars (other stars in green)
- ✓ 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



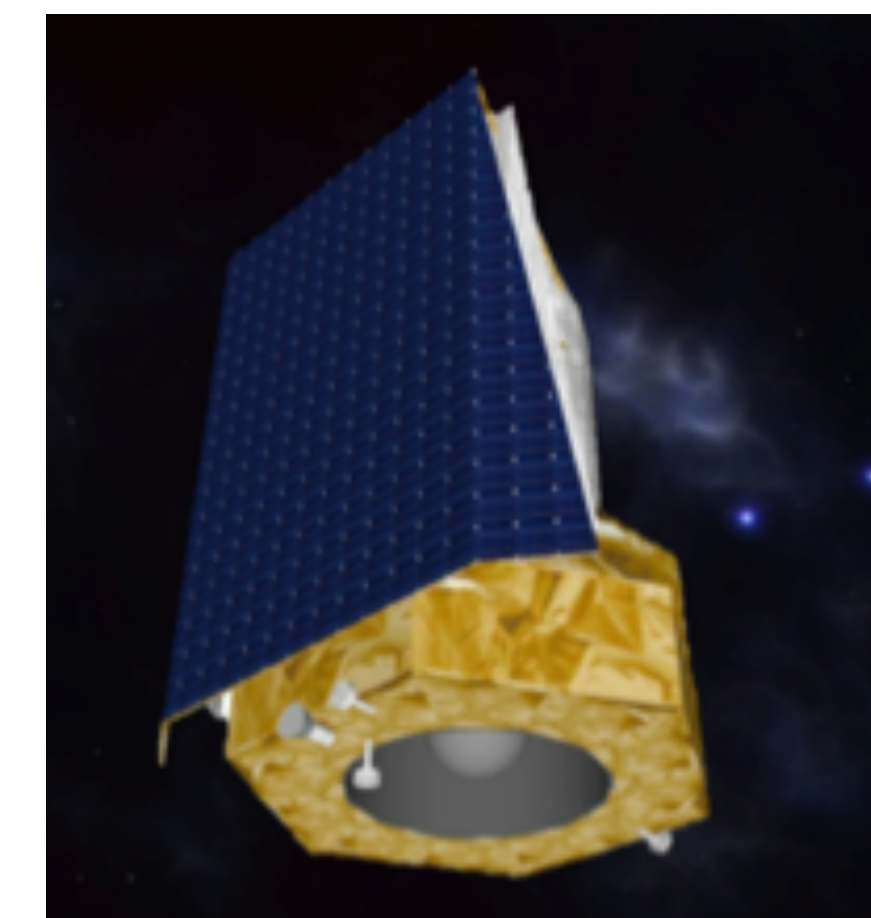
Theia mission profile

- **ESA-led, ESA-operated mission with consortium funded payload** (this is the normal type of ESA mission)
- Submitted for the **ESA M7 call** as an Ariane 6.02 launch
- Spacecraft dry mass with margin: 1063 kg. Total launch Mass: 1325 kg

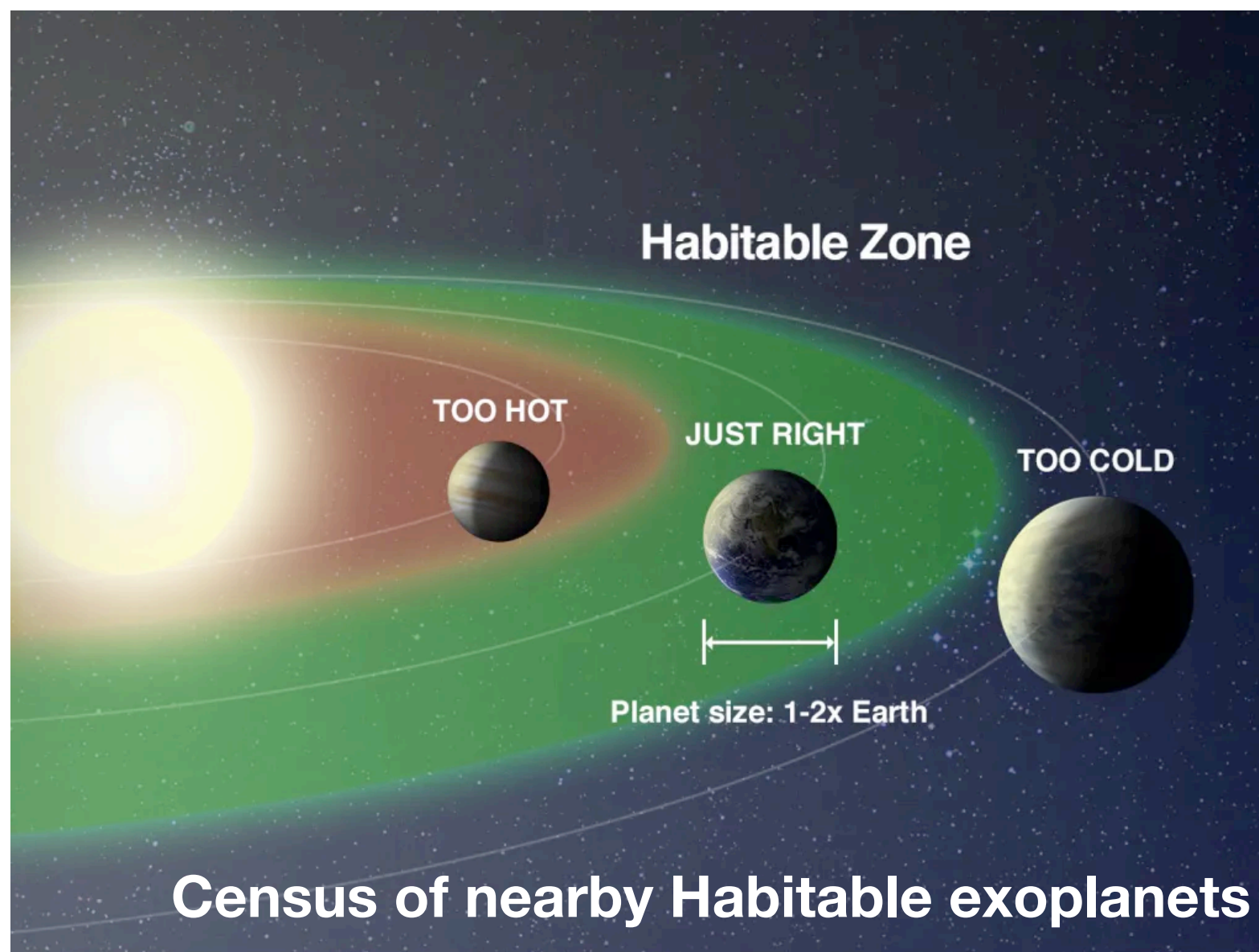
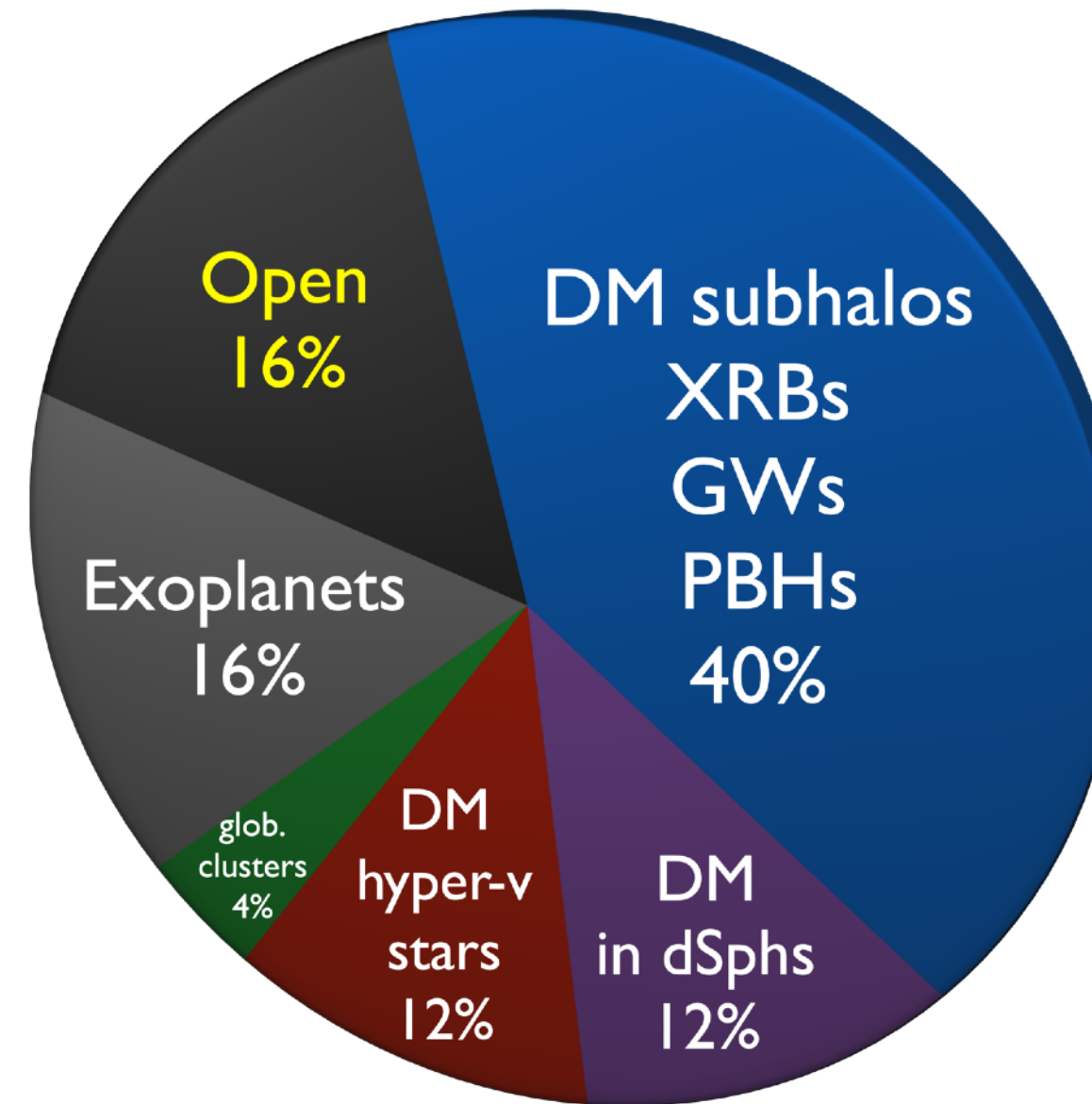
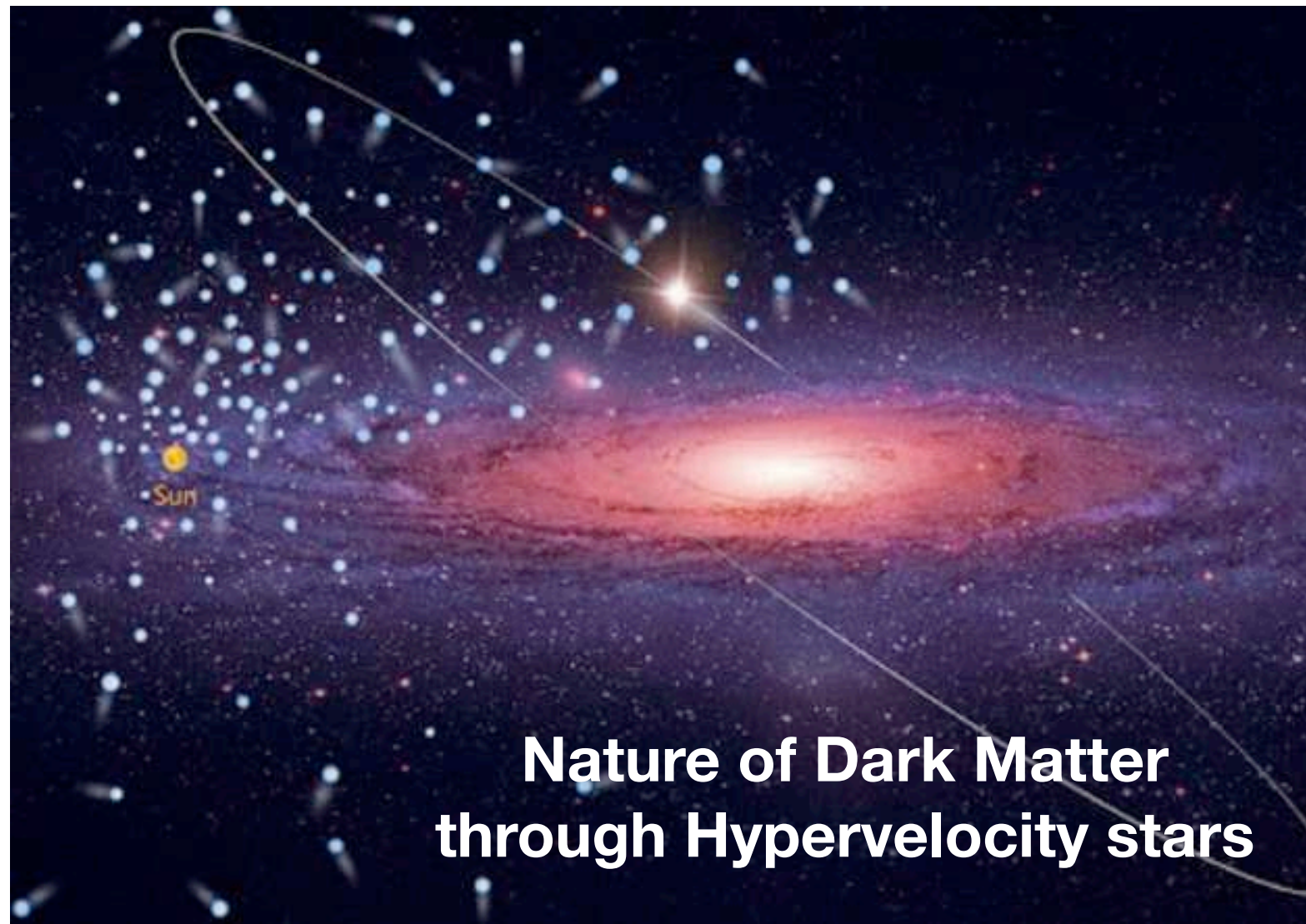


Thal

Launch date	No constraints, allowing launch date in 2037
Orbit	Large Lissajous in L2
Lifetime	<ul style="list-style-type: none"> • 4 years of nominal science operations • Technical operations: 6 months orbit transfer plus instrument commissioning and 1 month decommissioning
Concept	Single spacecraft, single telescope in the PLM, single camera in the focal plane, metrological monitoring of PLM
Communication architecture	75 Mbps, 4h/day

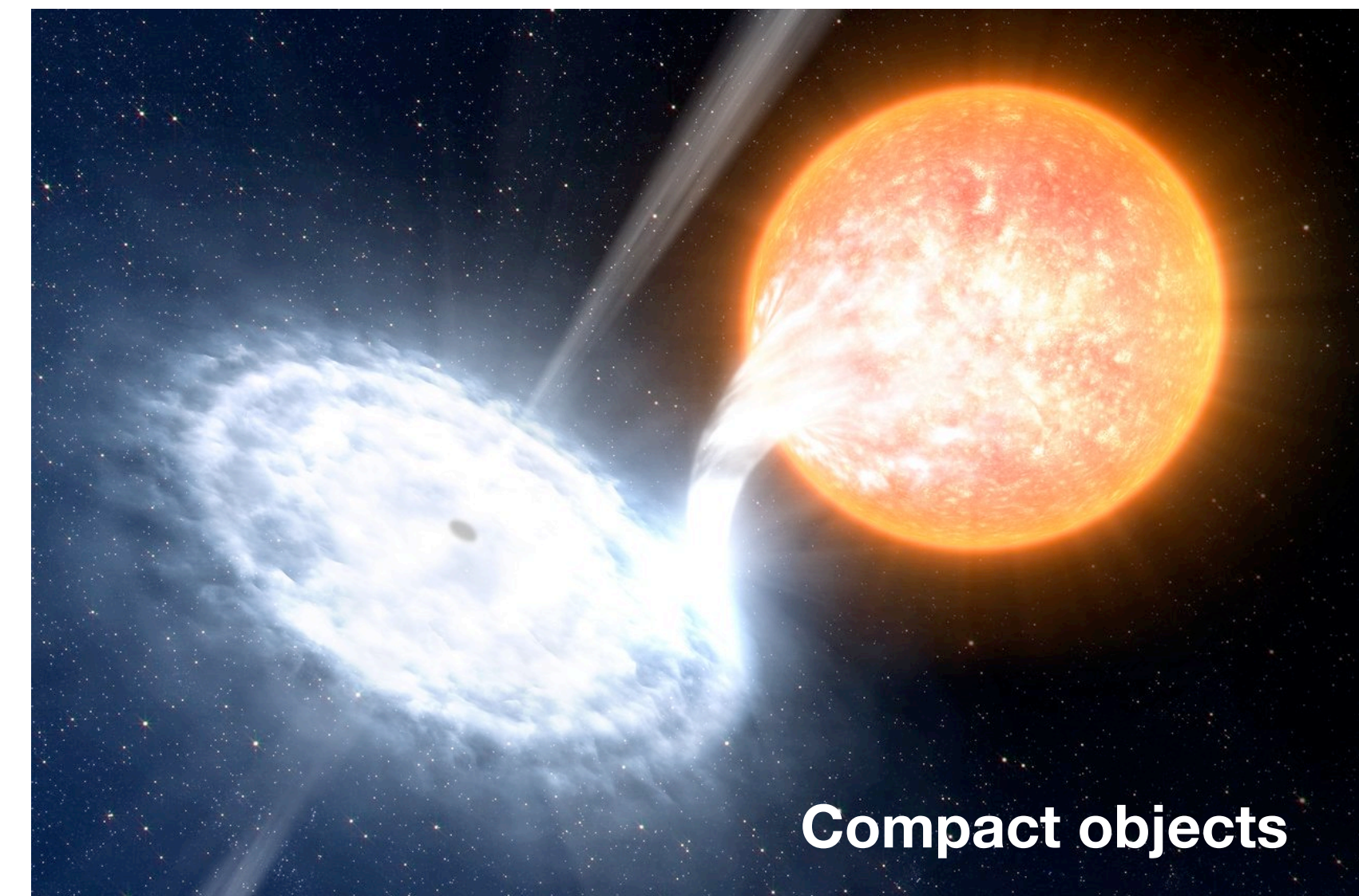


Theia's main science based on high precision astrometry



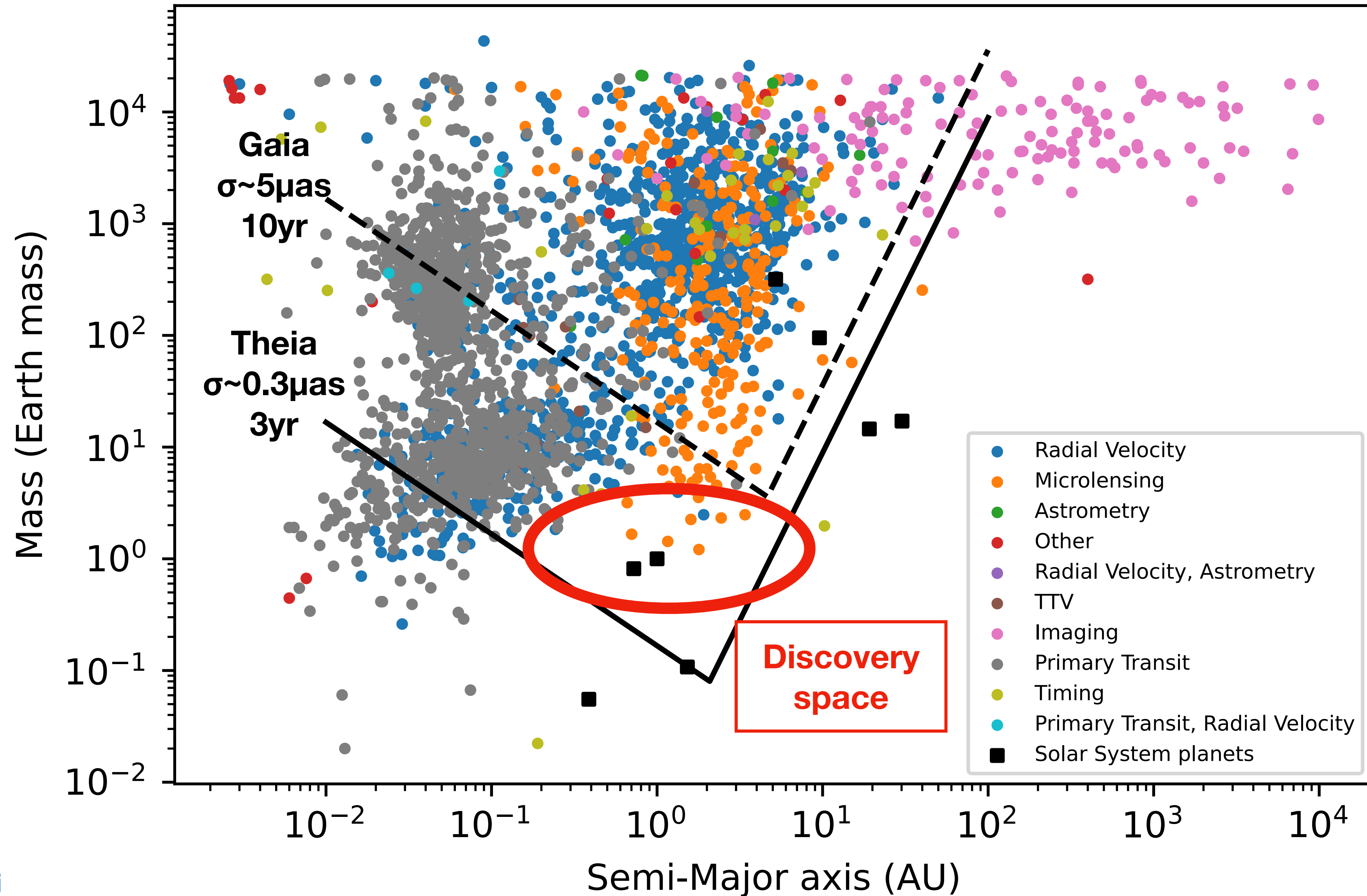
Two main observing modes:

- Faint star mode
- Bright star mode



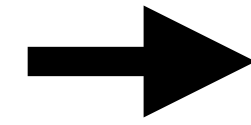
Exoplanets discovery space

Mass vs Semi-Major Axis Diagram (from exoplanet.eu)

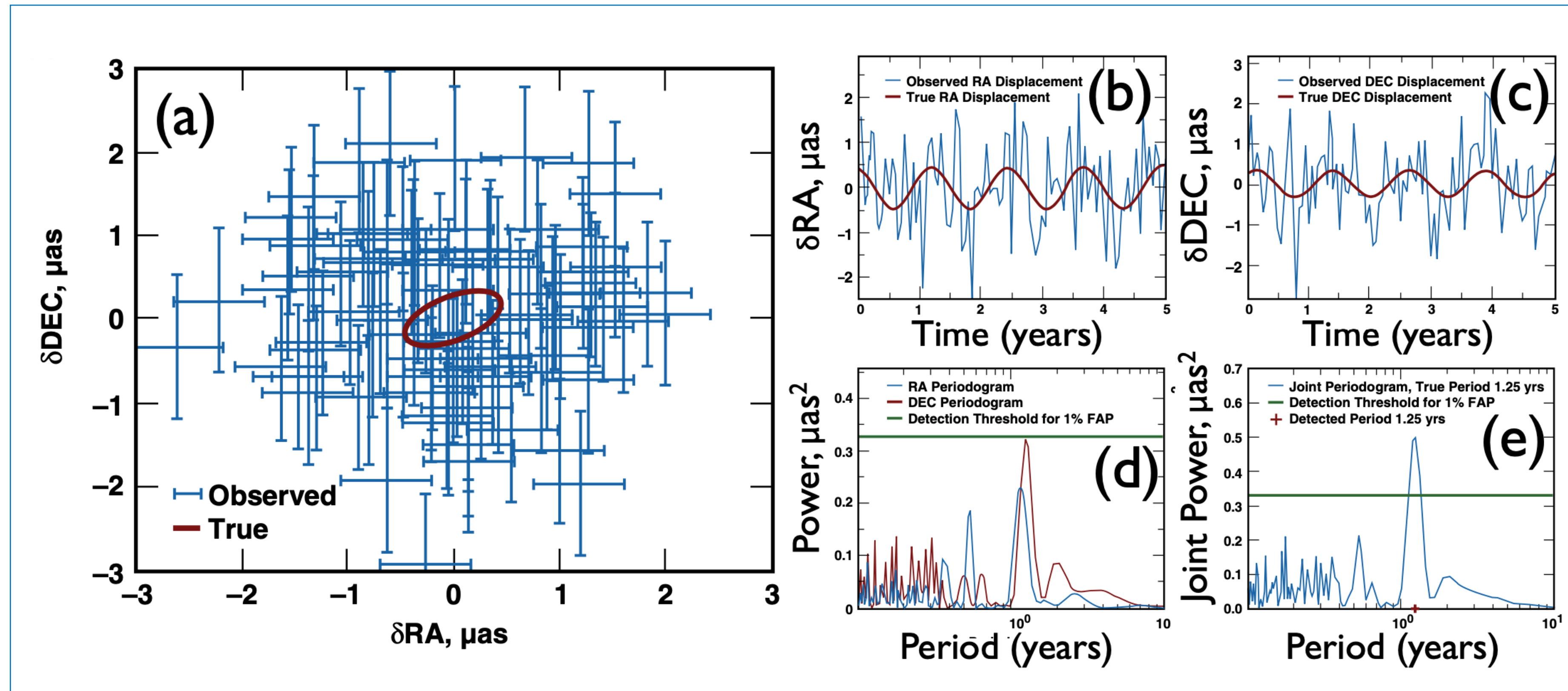
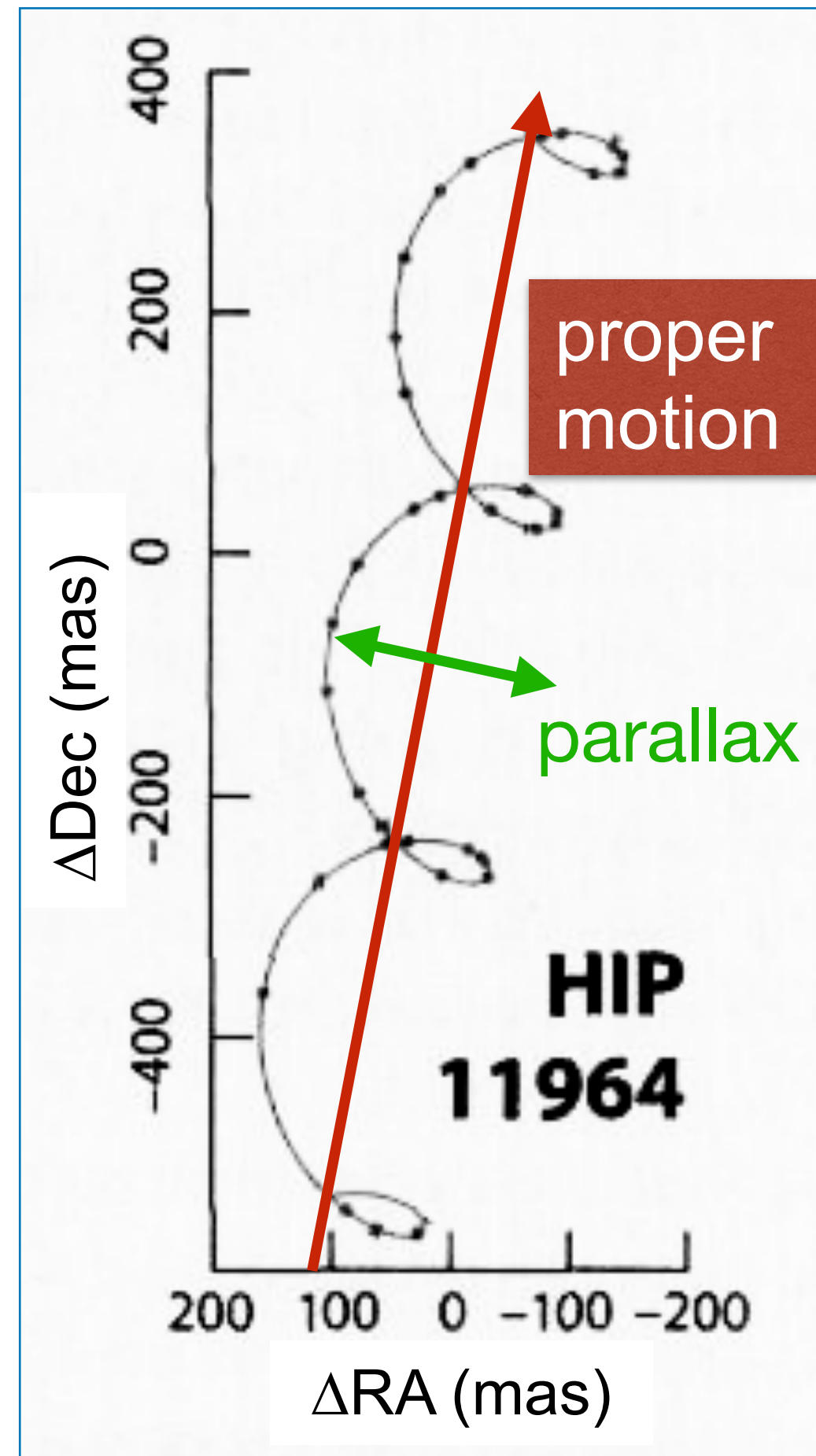


Astrometry: parallax, proper motion and reflex motion

Proper Motion + Parallax

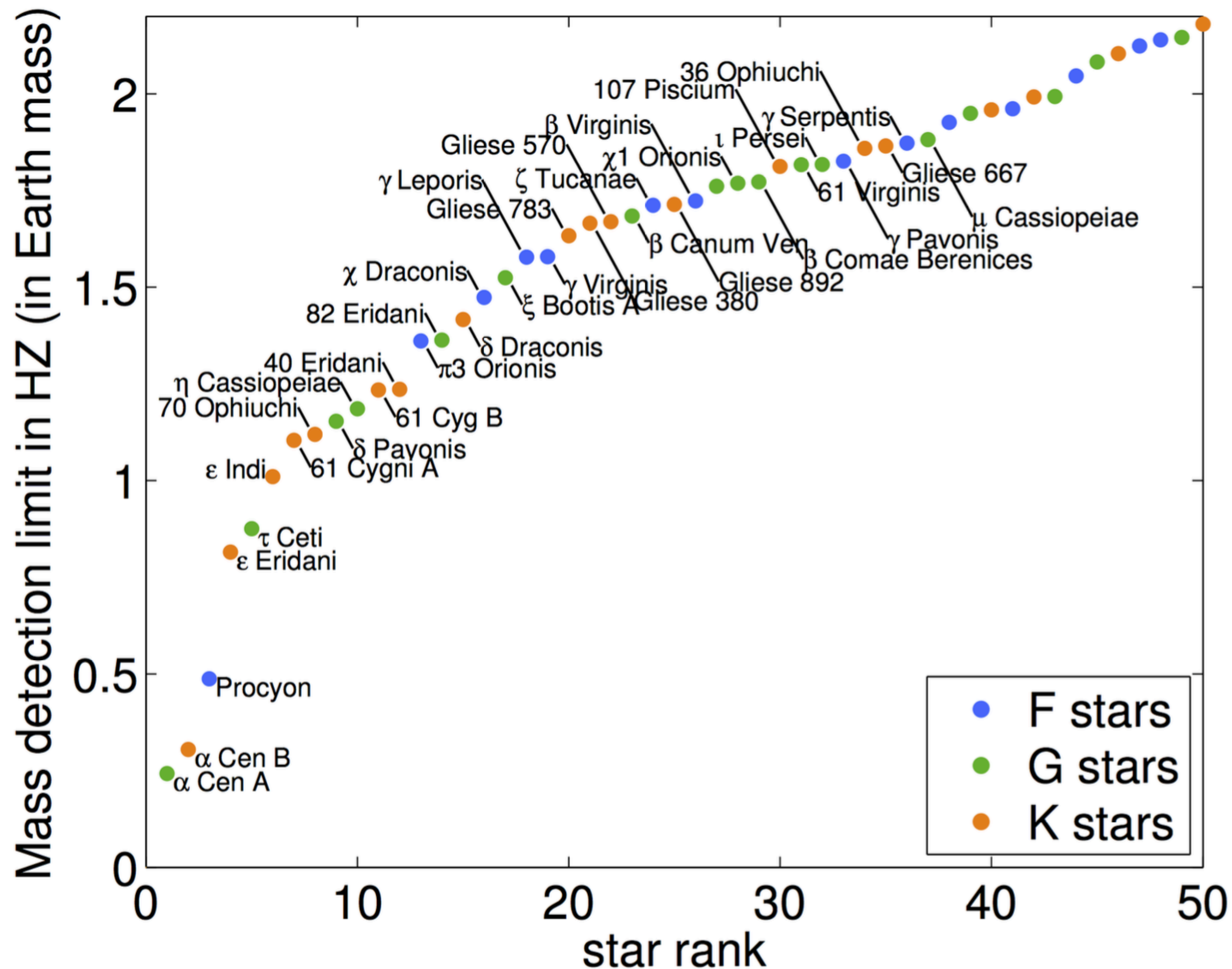


Residuals where (a) plots RA and DEC positions while (b,c) are positions with time and (d, e) are period-gram for each direction

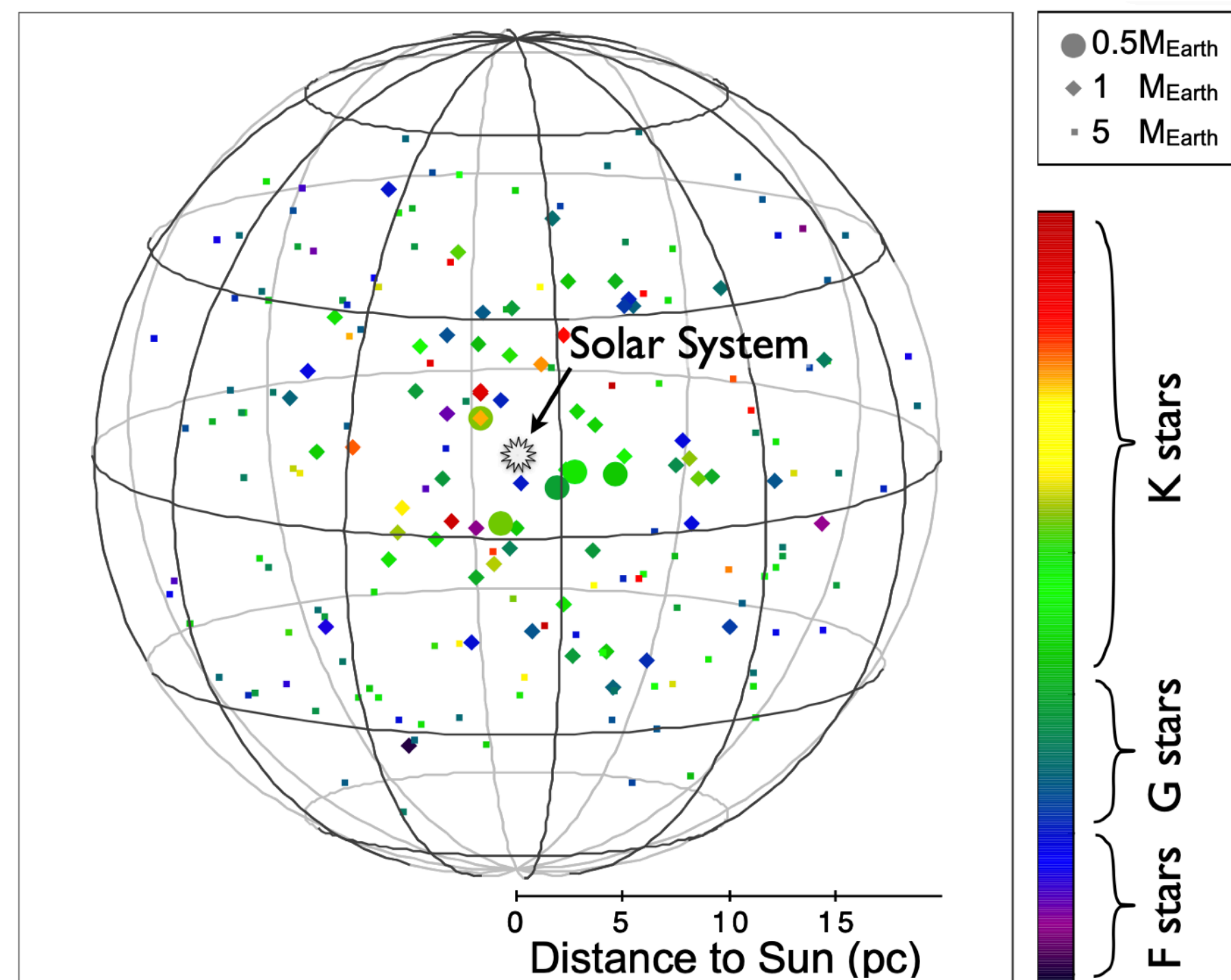


Unwin et al. (2008) ; Malbet et al. (2012)

Exoplanets primary goal : Earth-mass planets in HZ in the vicinity of the Sun

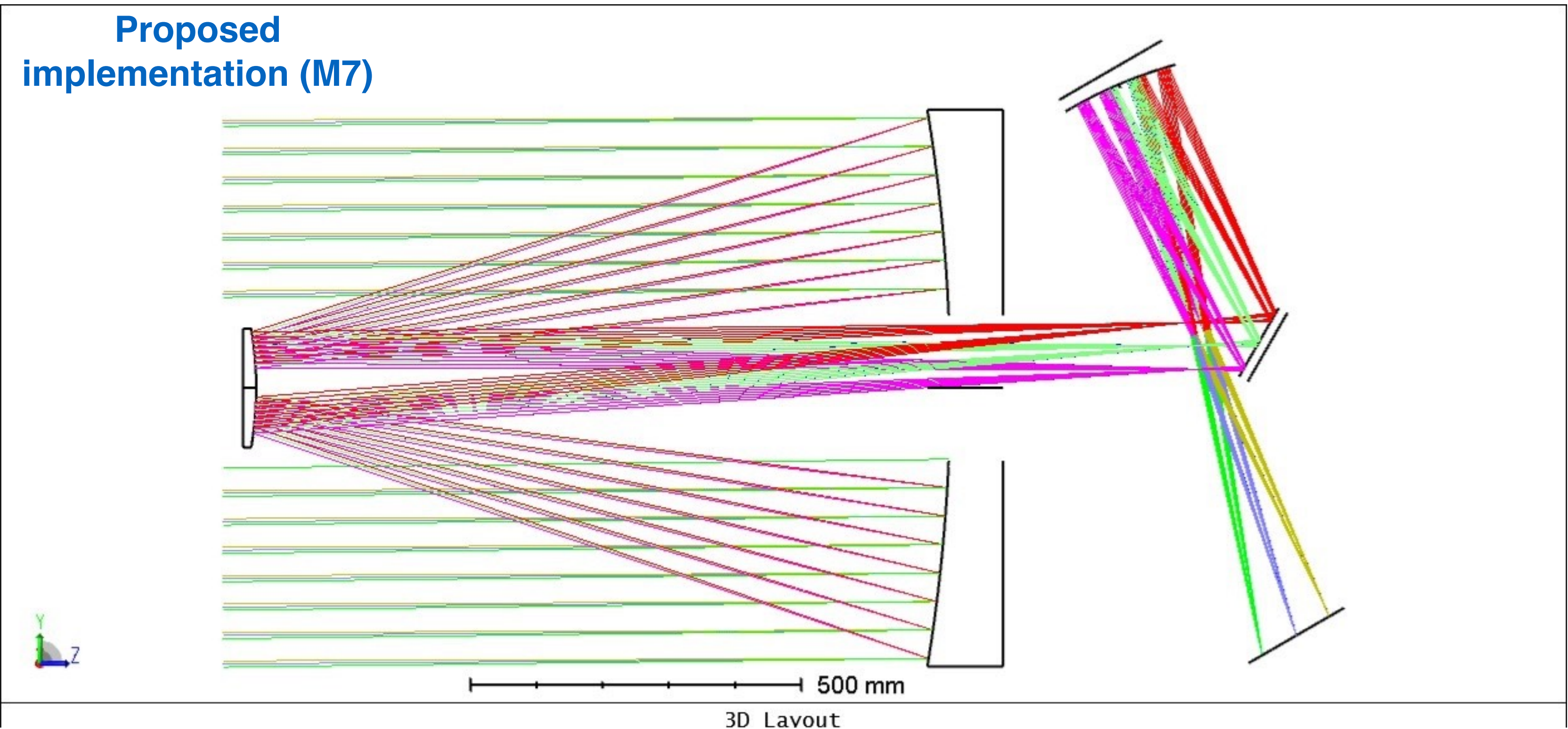


Complete census of exo-Earths, superEarths and mini-Neptune ($M < 5 M_{\text{Earth}}$) orbiting our 50 nearest Solar-type stars ($d < 10 \text{ pc}$)



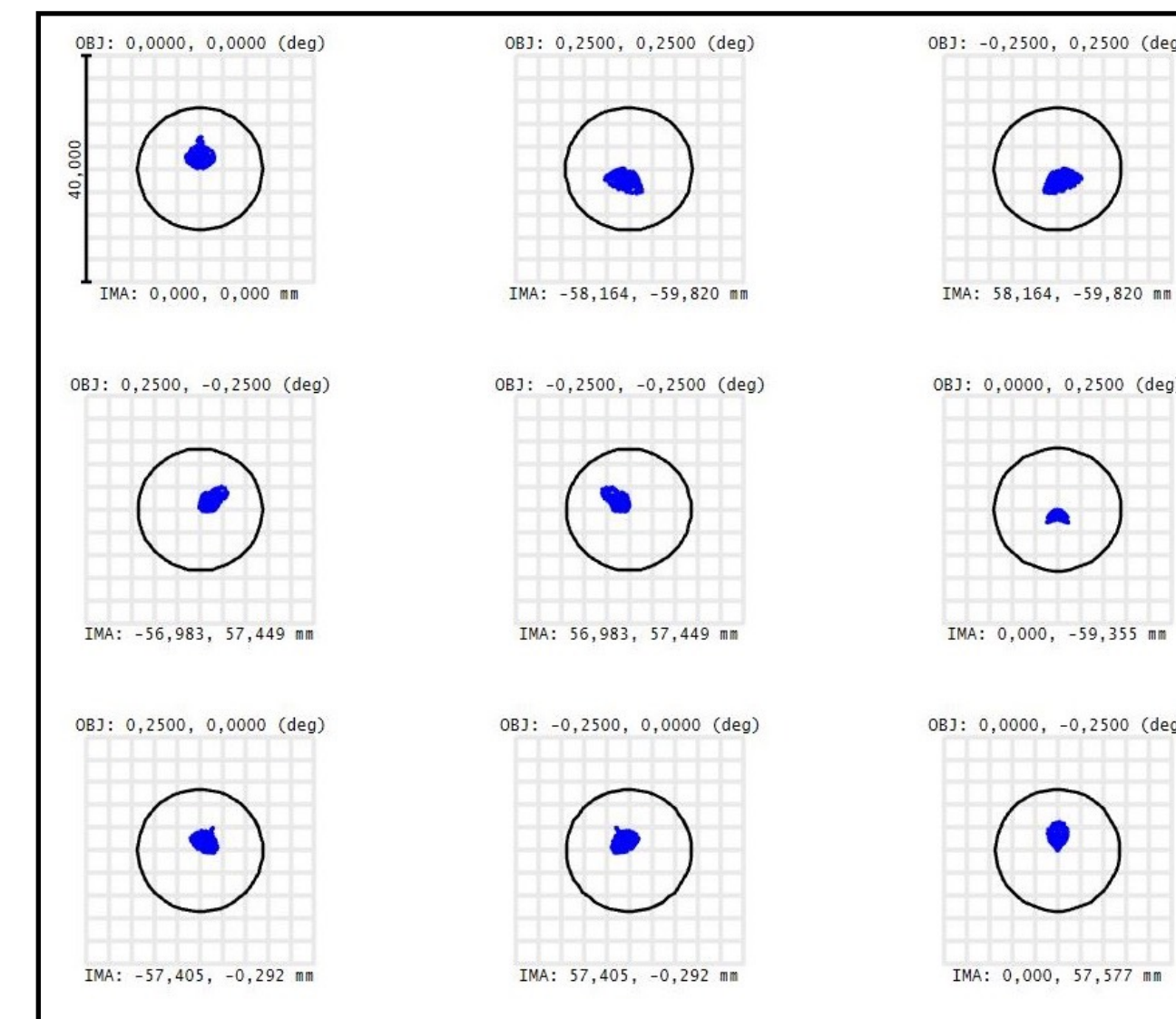
Theia optical concept

Theia characteristics :
 - 0.8-m telescope diameter
 - diffraction-limited 0.5° FOV

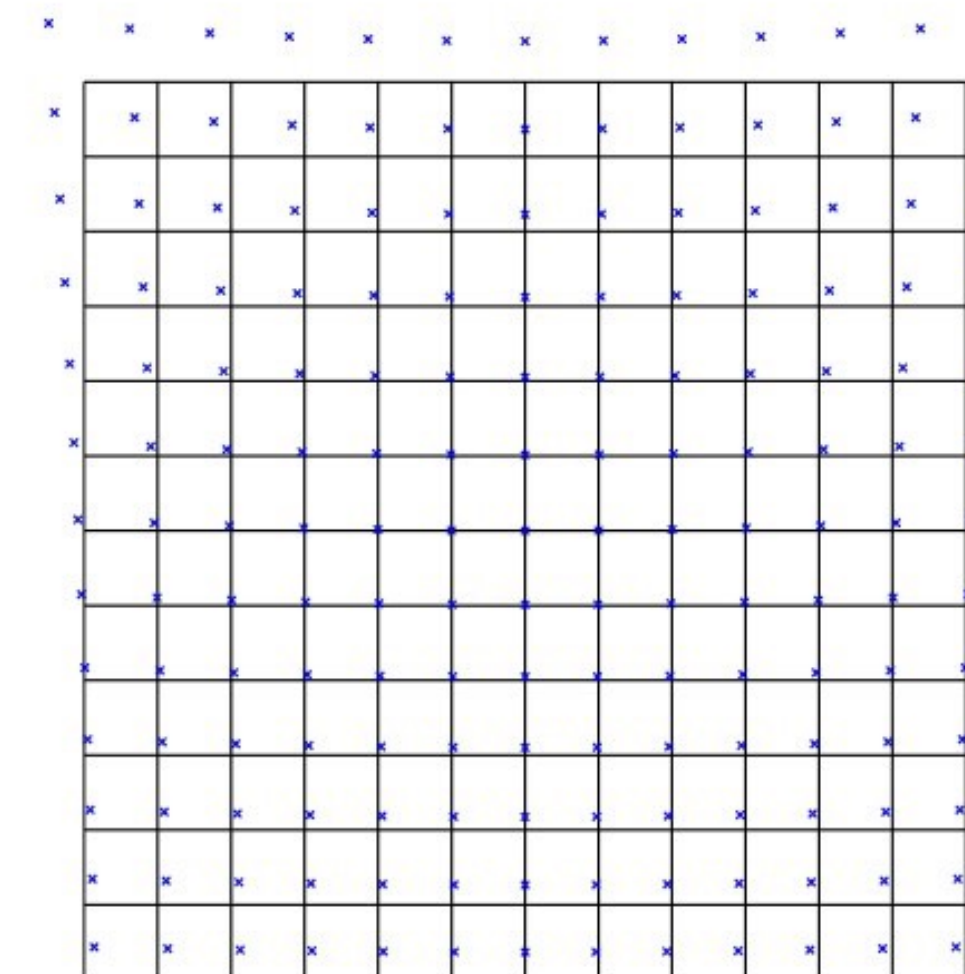


Three mirror anastigmat, Korsch design

Spot Diagram



Distorsion map



Focal plane instrument

Specifications:

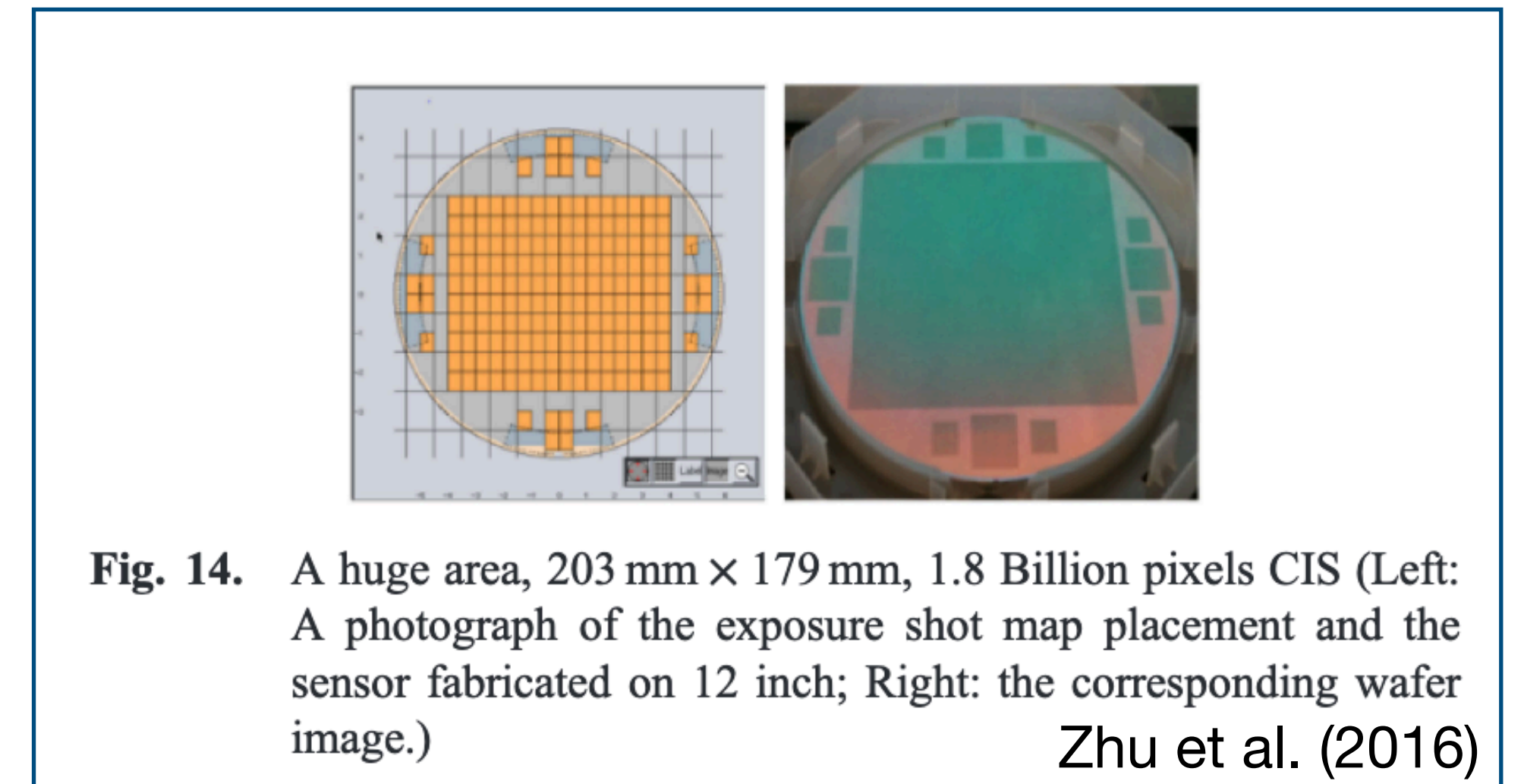
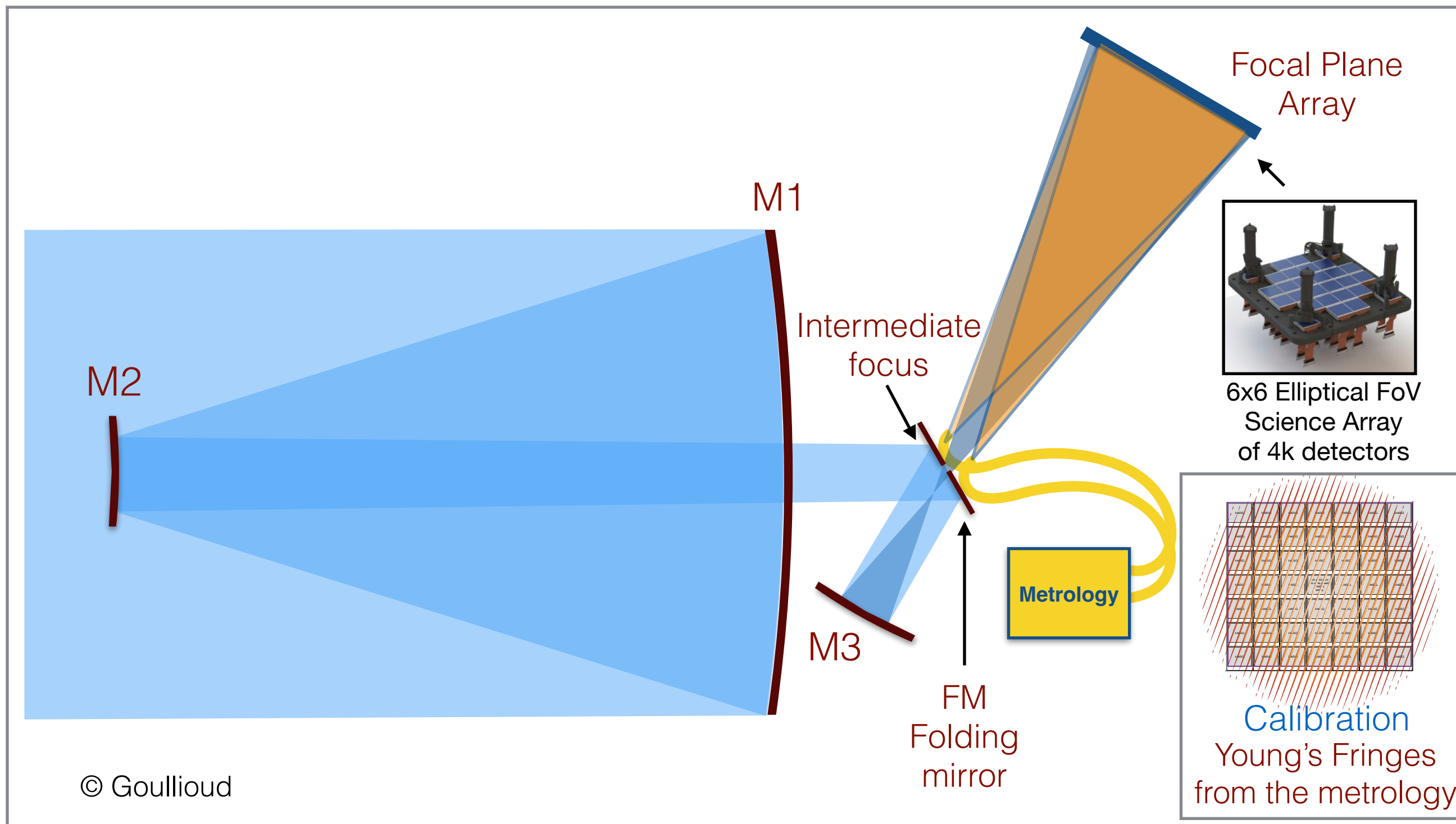
Diffraction-limited 0.5° FOV

$\sim 30,000 \times 30,000$ pixels

≤ 1 billion pixels

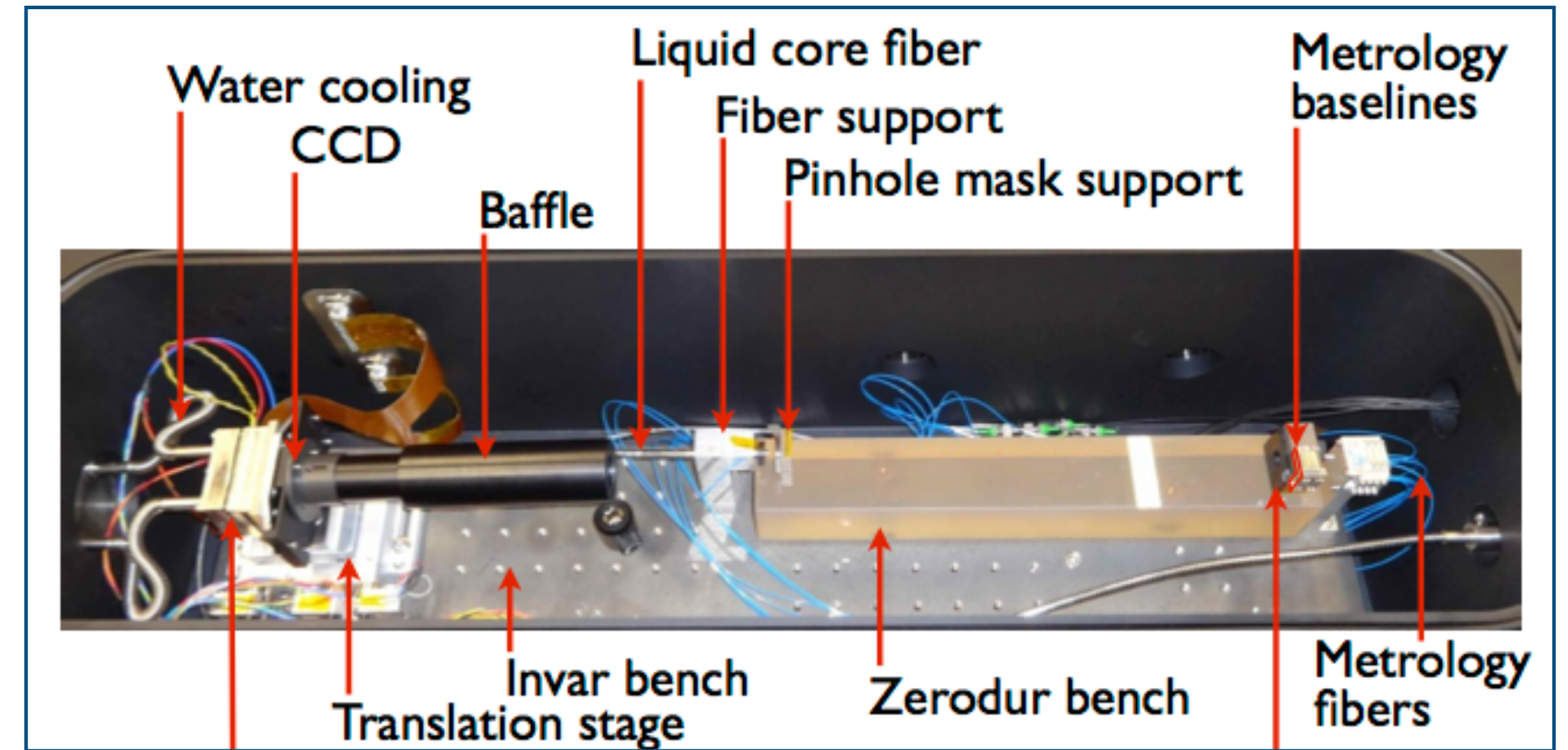
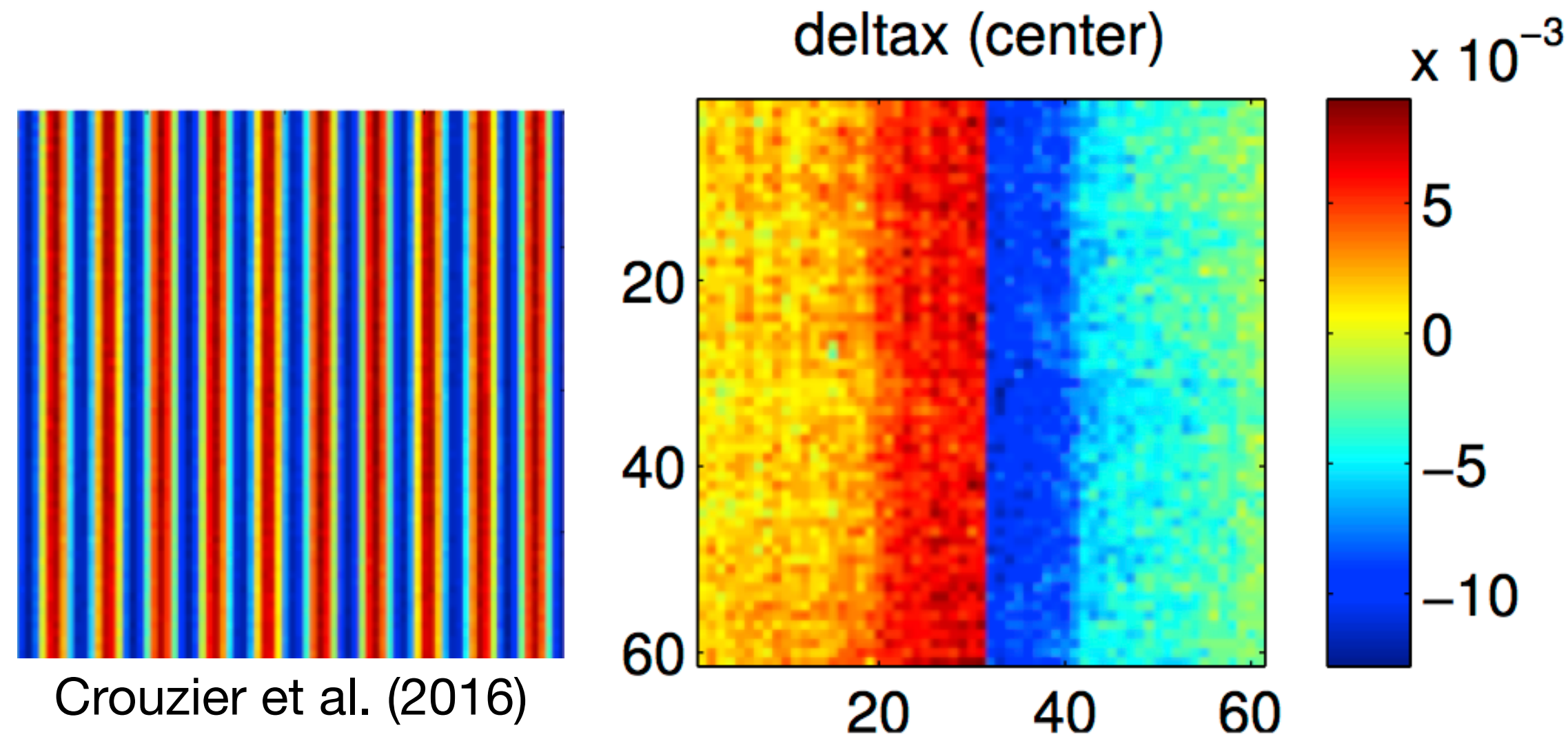
New large CMOS detectors with smaller pixels !

Proposed implementation (M7)

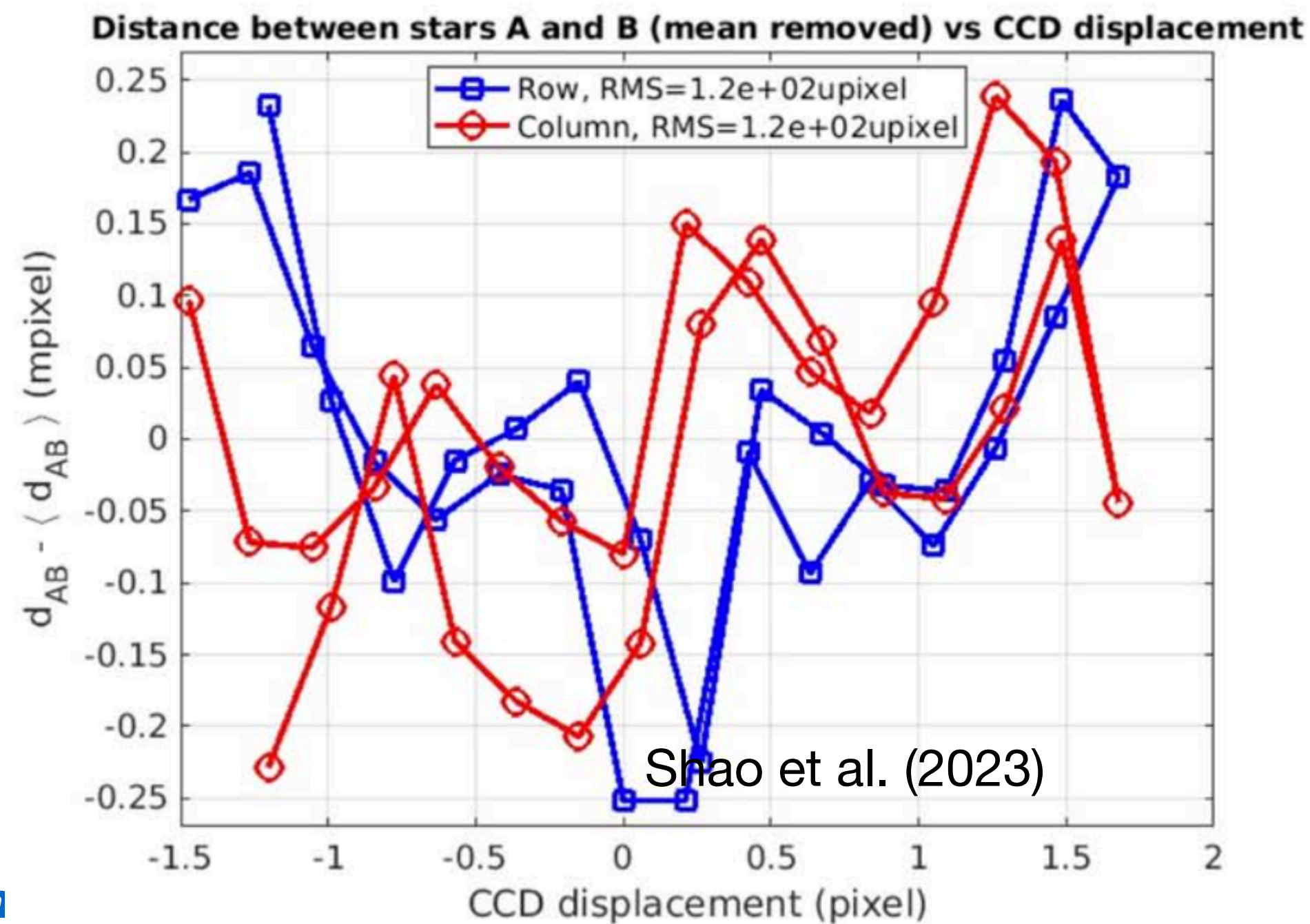


Pixels of $\sim 4\mu\text{m}$
 \Rightarrow array of $12 \text{ cm} \times 12 \text{ cm}$,
(ie. $30\text{k} \times 30\text{k}$ detector)
can be manufactured on a wafer of
 $12''$ (300mm)

Detector calibration: laboratory results



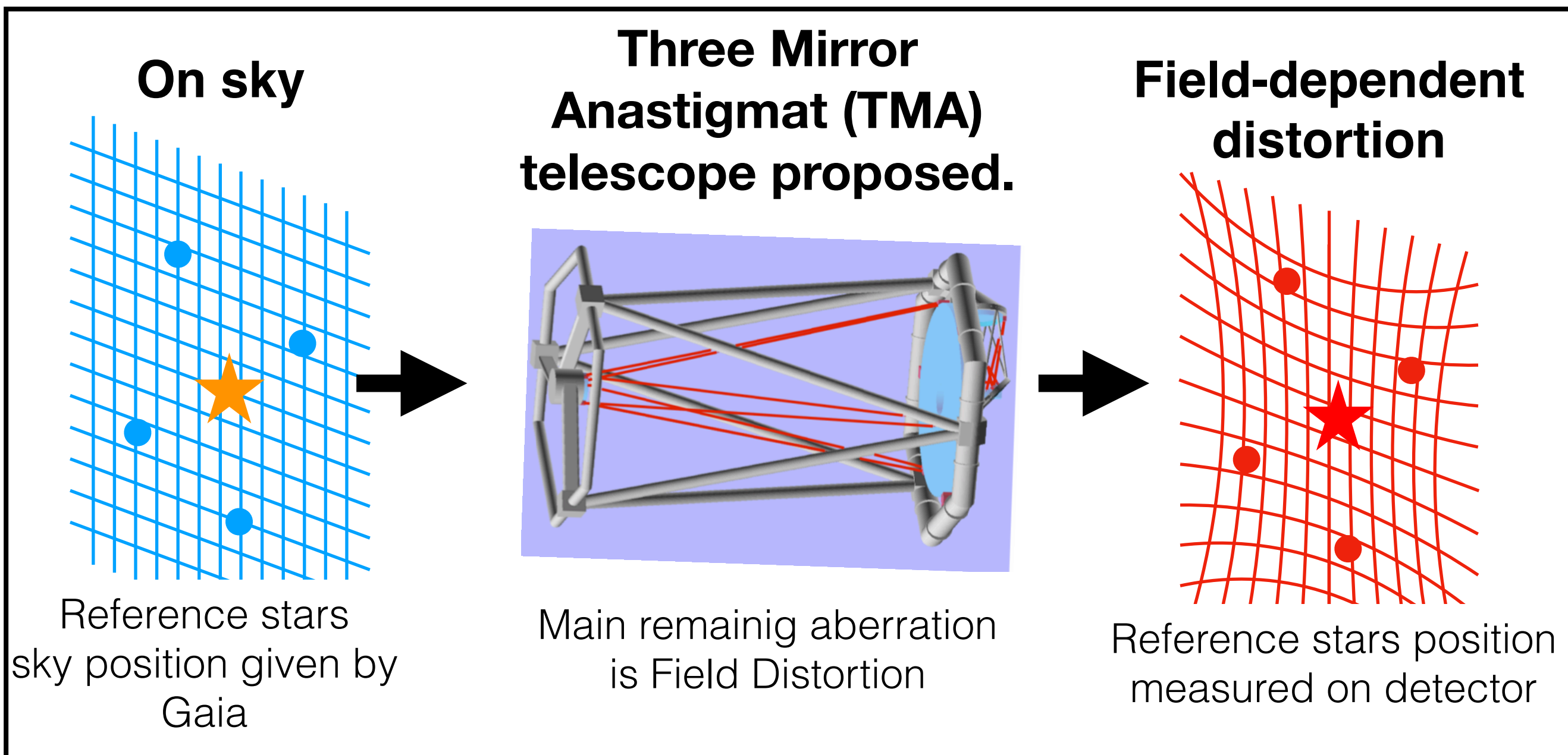
Crouzier et al. (2016)



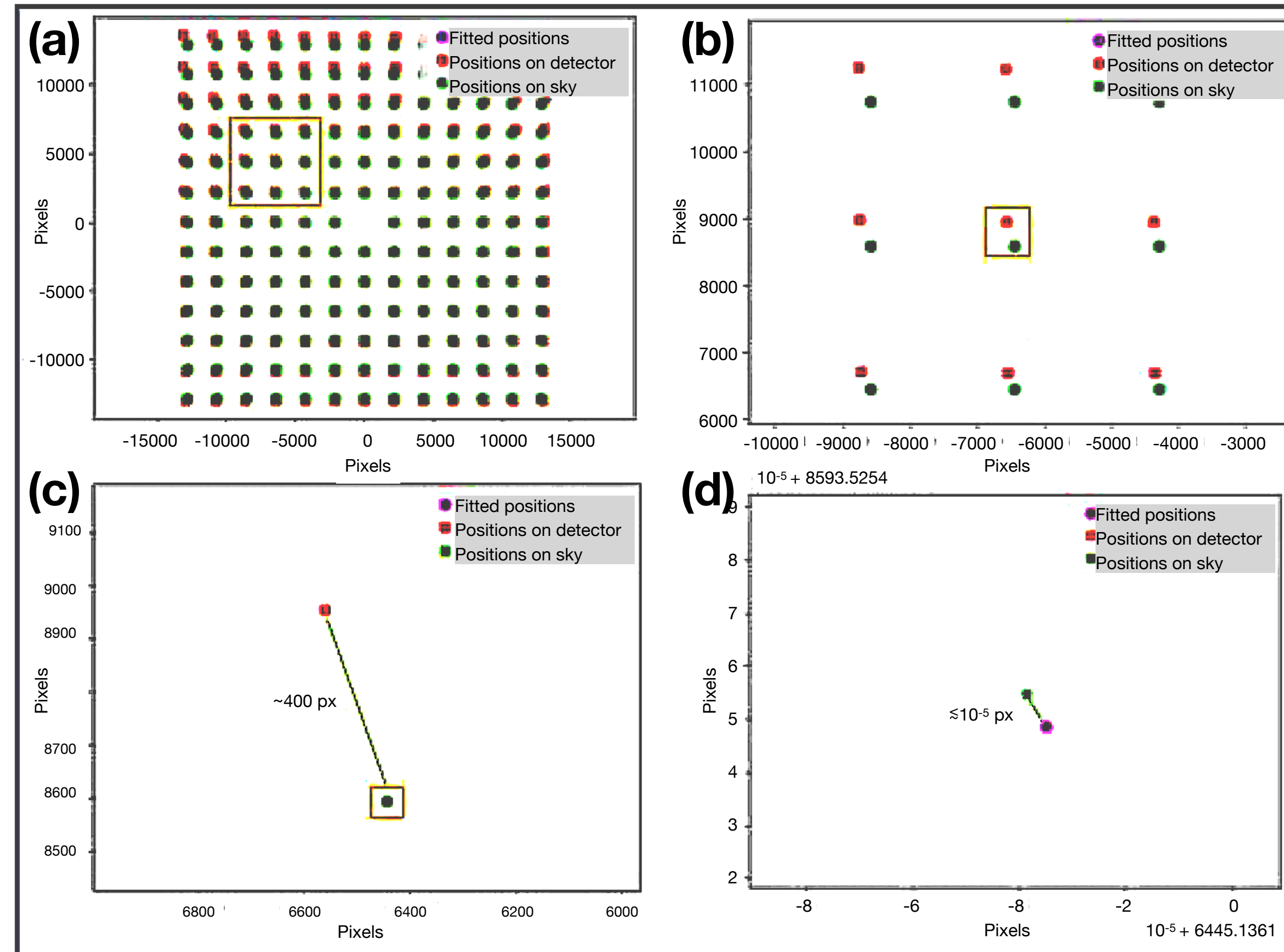
Best results so far:

- IPAG/CNES: $6 \cdot 10^{-5}$ pixels (Crouzier et al. 2016)
- JPL/VESTA: $3 \cdot 10^{-5}$ pixels (Shao et al. 2023)

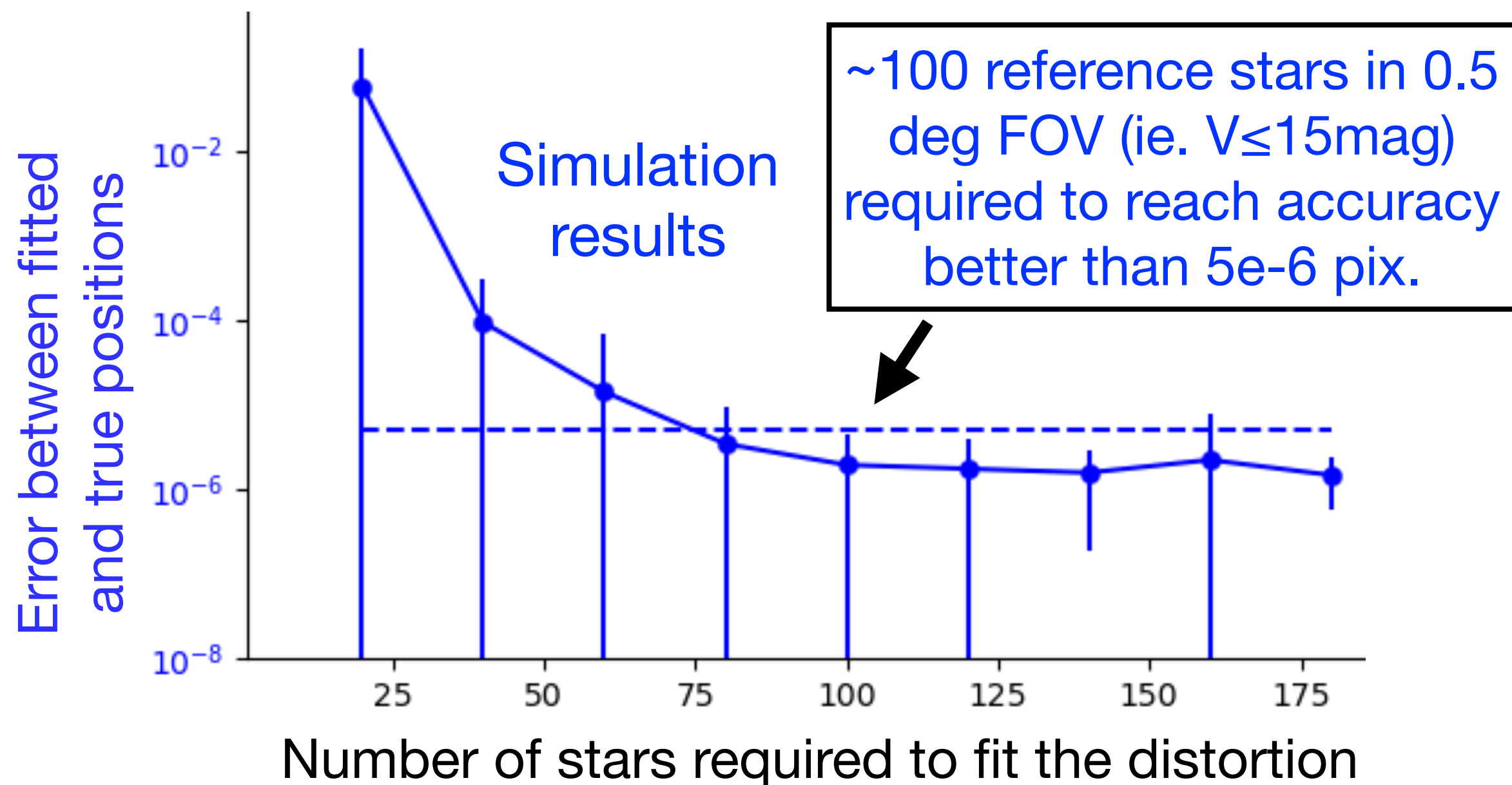
Telescope calibration : using reference stars to monitor the distortion



Distortion can be corrected by fitting the transformation (Sky \rightarrow Detector) as calculated by Ray-tracing (Zemax) by a 2D polynomial

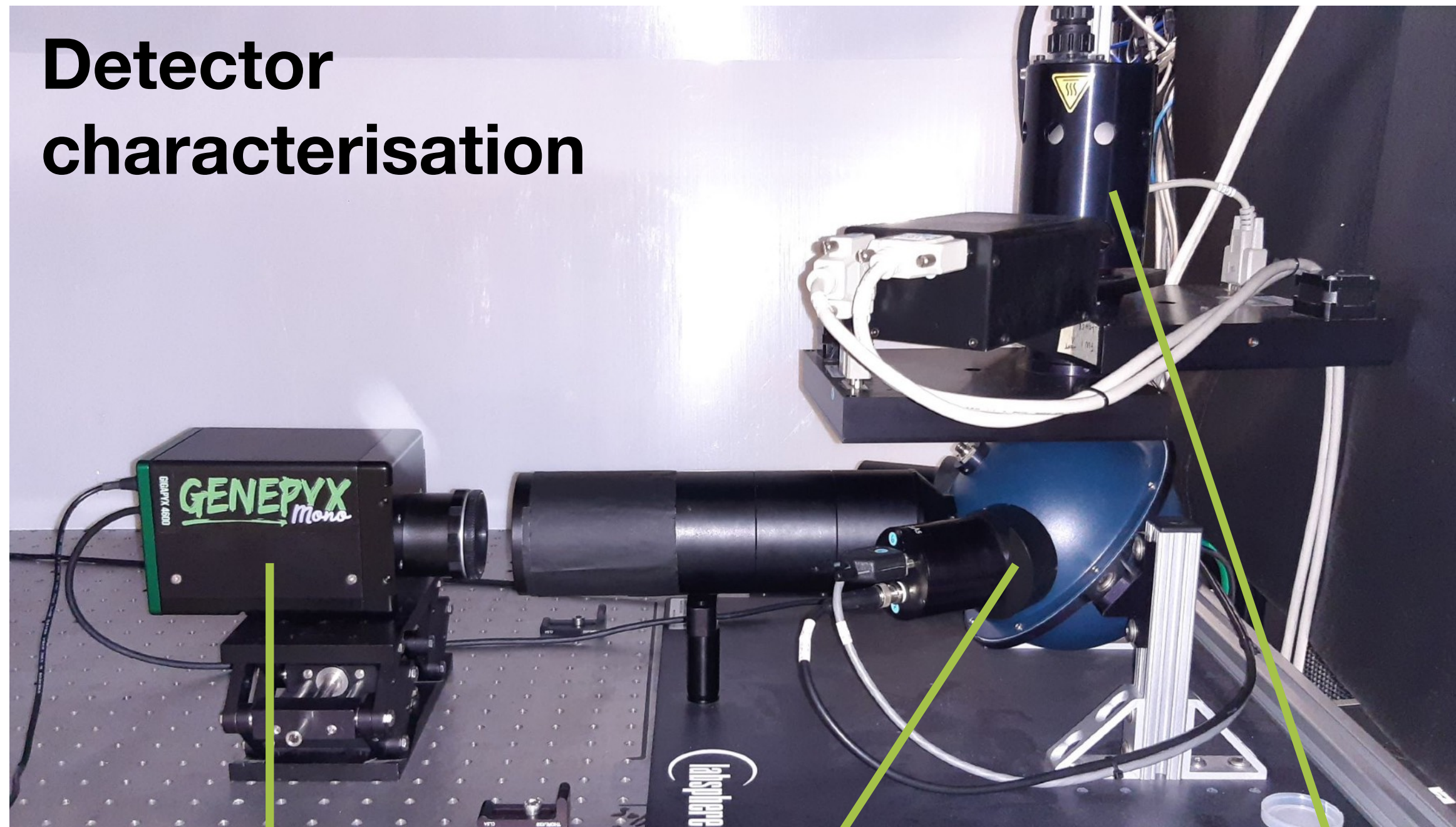


Simulated field-dependent distortion and fitted position



Ongoing test benches at IPAG

Detector characterisation



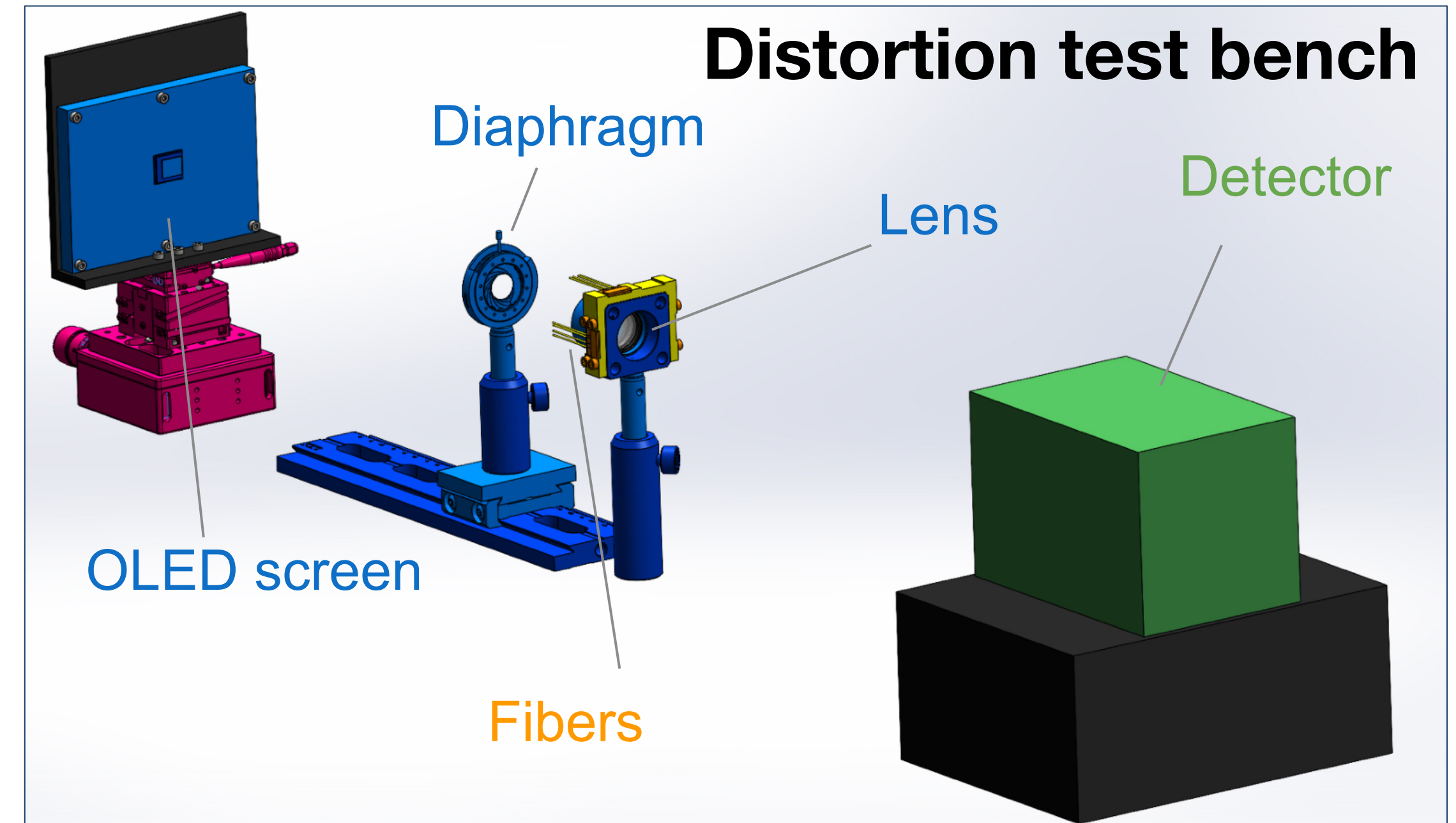
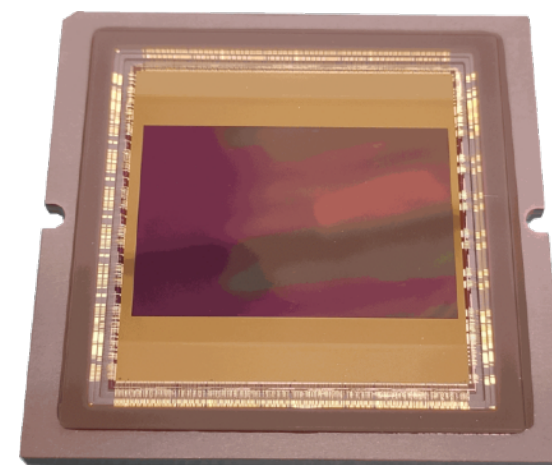
Detector

Integrating sphere

Source



GIGAPYX 4600
8320 x 5436
Pixel : 4,4 μ m pitch



See poster #194 on Wednesday (Pancher et al.)

See poster #205 on Monday (Lizzana et al.)

Conclusion and perspectives

- One of the most challenging science objectives is to identify planets down to the Earth mass ($M \leq 5 M_{\text{Earth}}$) exoplanets in the habitable zone of Solar-type stars in the vicinity of the Sun ($d \lesssim 15 \text{ pc}$)
- Pointed differential astrometry allows the number of exposures to be increased compared to global astrometry allowing to reach sub-microarcsecond accuracy
- Technical challenges are the focal plane array and mitigation of the optical distortion of the telescope: new detectors and new calibration strategy are under investigation with lab test benches.
- Frequent calibrations ($\tau_{\text{exposure}} \sim 0.1 \text{ s}$) using Gaia data reduces considerably telescope stability requirements