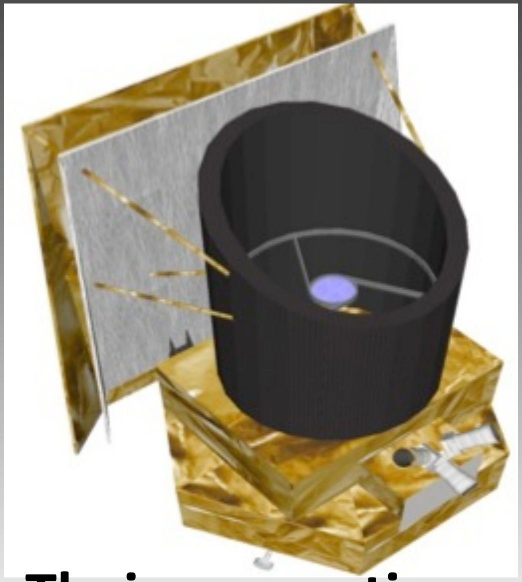
Measuring the masses of the habitable planets around the 50 closest solar-type stars with Theia

F. Malbet, A. Léger, G. Anglada-Escudé, A. Sozzetti, A. Crouzier,
Theia consortium

Pathways 2015: Pathways toward habitable planets – 16/07/2015

Acknowledgments:



Theia consortium

Astrometry on the host star: principle of the detection

Principle of the astrometric detection:

The gravitational pull of the planets causes the stars to orbit around the center of mass of the system (star + planets)

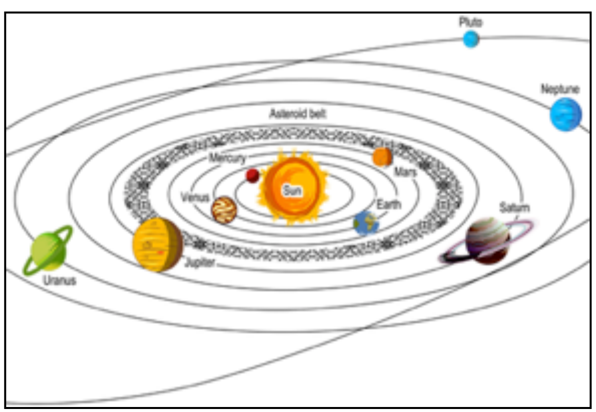
$$A = 3\mu as \frac{M\text{planet}}{M\text{earth}} \times \left(\frac{M\text{star}}{M\text{sun}}\right)^{-1} \times \frac{R(\text{AU})}{1\text{AU}} \times \left(\frac{D(\text{pc})}{1\text{pc}}\right)^{-1}$$

~ distance to nearest star

Astrometric signatures:

	Earth	Jupiter
1 pc	3 µas	5 mas
10 pc	0.3 µas	0.5 mas

A few hundred stars (~50 MS FGK)

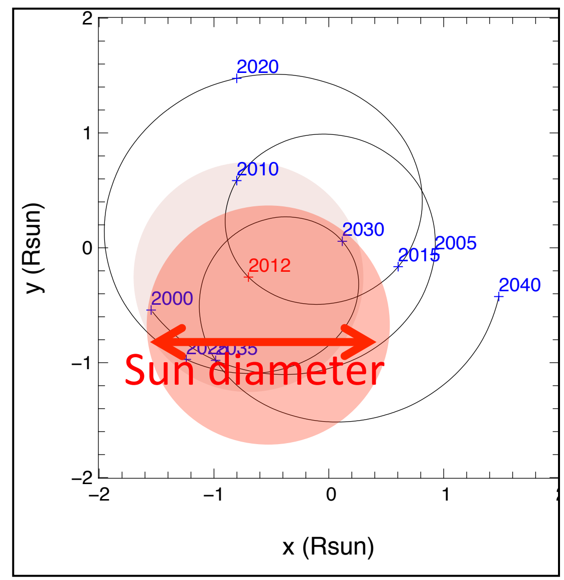


The Solar System

Observations

Modelling

- "Double blind" tests: Traub et al. (2009) Anglada et al. (2014)
- Stellar noise not an issue Lagrange et al. (2011)



The Sun Orbit

Precision differential astrometry

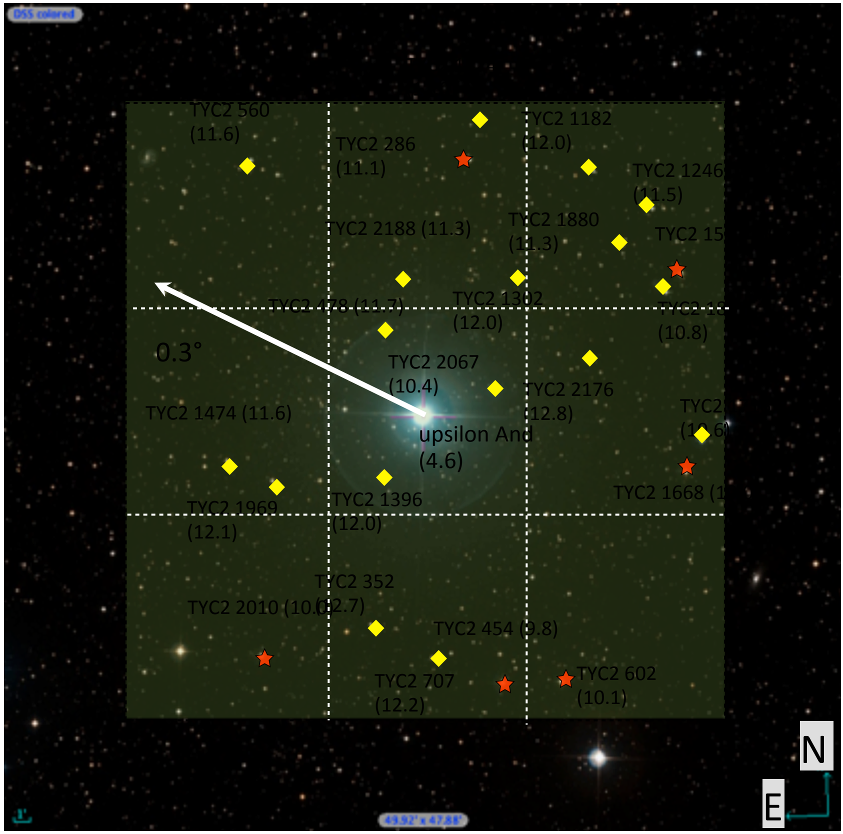
Differential astrometry: measurement of the position of an object compared to other ones located in the field

Field of view: approx 0.5 deg

Precision: 0.3 µas <-> ~1e-6 the PSF width <-> 5e-6 pixel

Pointed astrometry allows to increase the exposure for faint objects, but reduces the number of targets

Number of visits: ~100 per target star



Field of View

Science targets: our close galactic neighbourhood

We hardly know our neighbours !

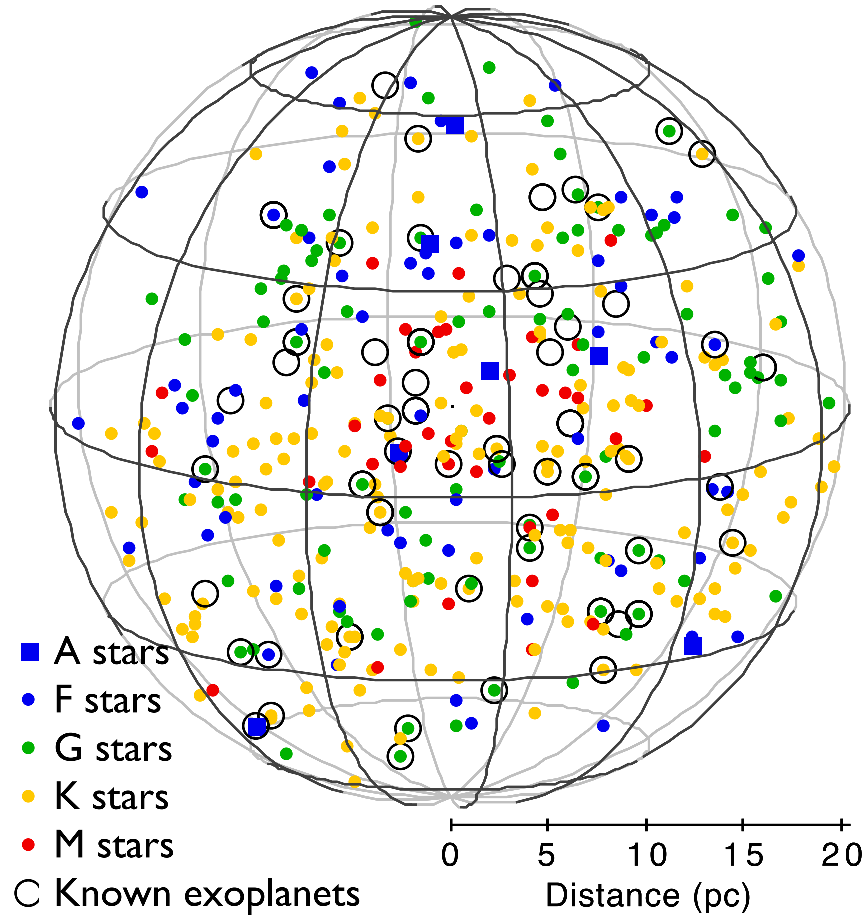
Need for astrobiology:

- *spectroscopic characterization*

- *not **only** around M stars!*

- terrestrial planets (<10 $M_{\oplus}$)
- in habitable zone
- around close Sun-like main sequence stars (<10 pc)

➠ **only ~50 FGK main sequence targets**



Source: exoplanet.eu, updated: 02/09/2014

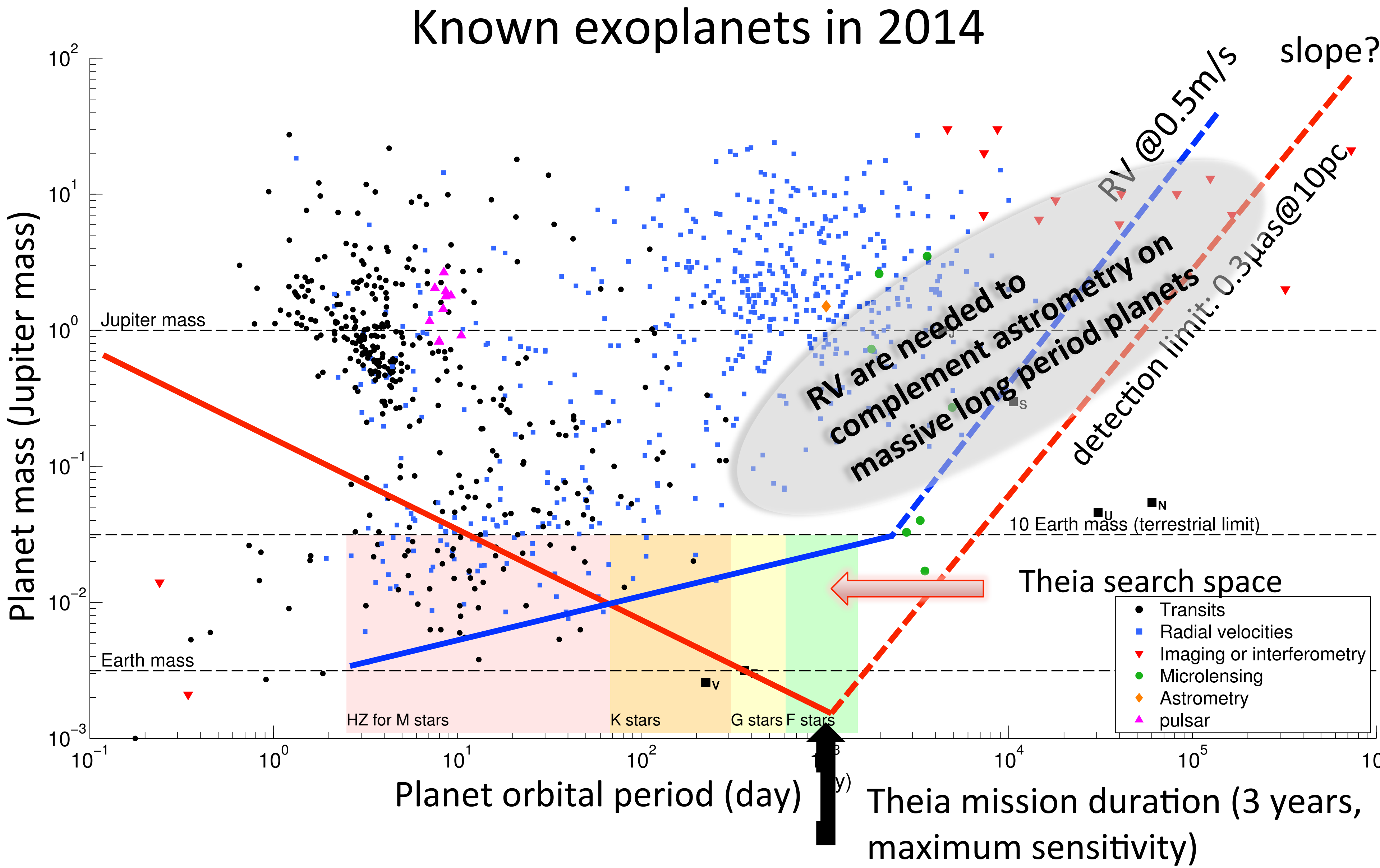
Current limitations:

- Transits: few close targets (geometric probability)
- RVs: Stellar noise. Possible around M stars. Very hard for Solar-like stars

We expect many more existing planets
[Howard, 2012]

The Solar neighbourhood: only about 9% of stars have known exoplanet(s)

Astrometry and RV: period-mass parameter space



- ❑ **<u>Precise mass measurement</u>**
- ❑ **<u>Mission optimization</u>**

•Astrophysical sources of false positives:
- Background stars
- Zodical dust clouds

•Ambiguities between planets because of projection effect

•Planets orbits can be partially into IWA

Synergy with direct imaging (why not just image first ?)

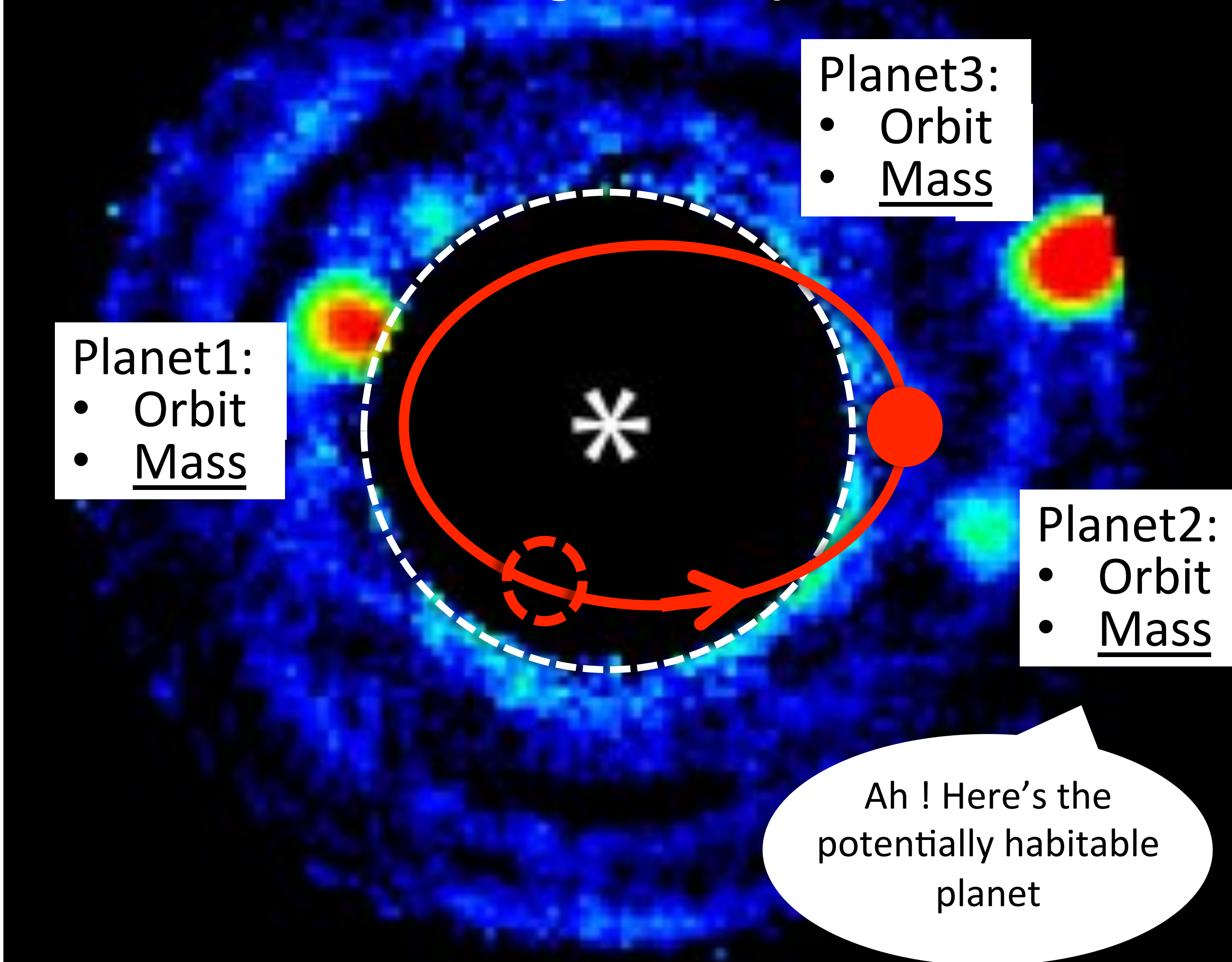
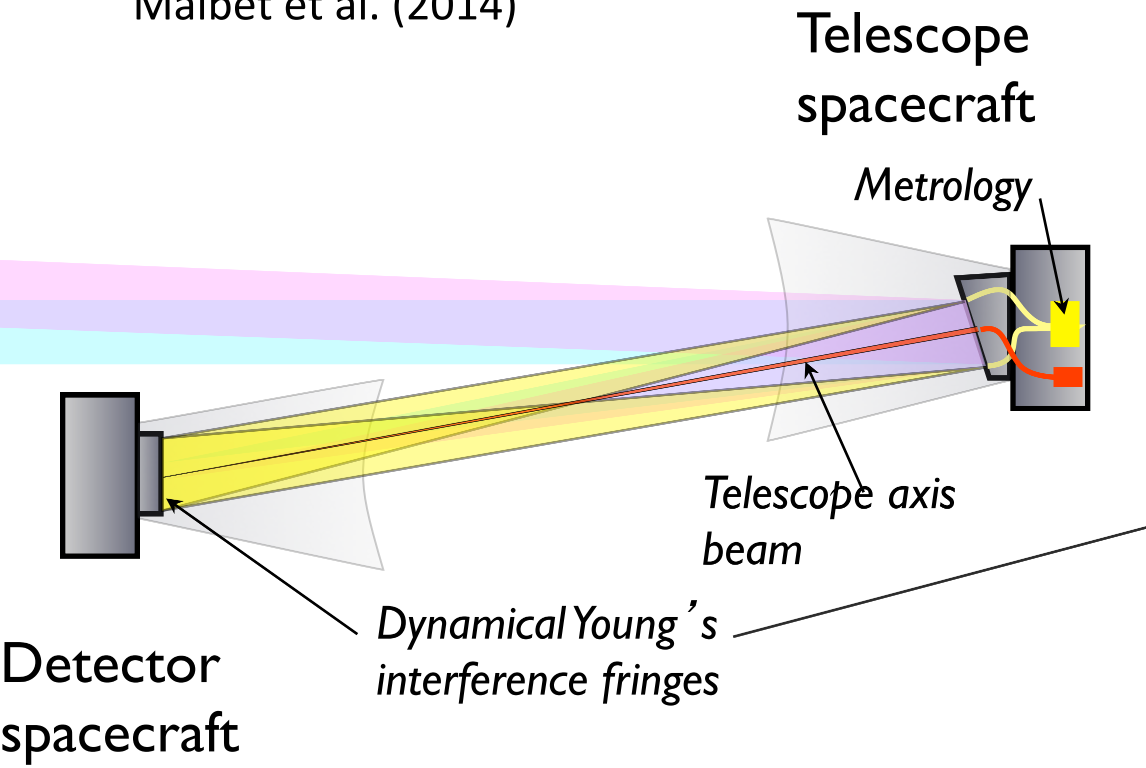
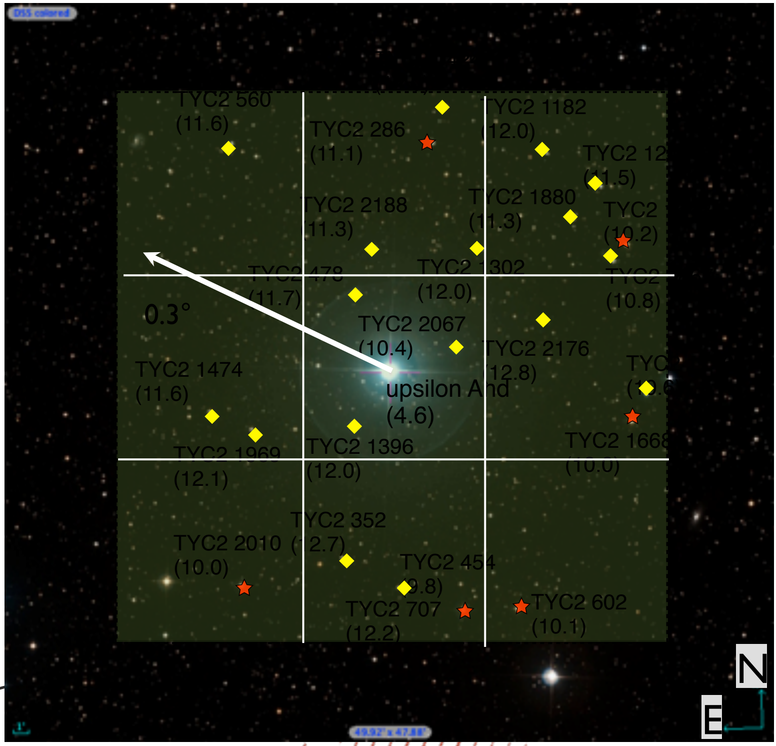


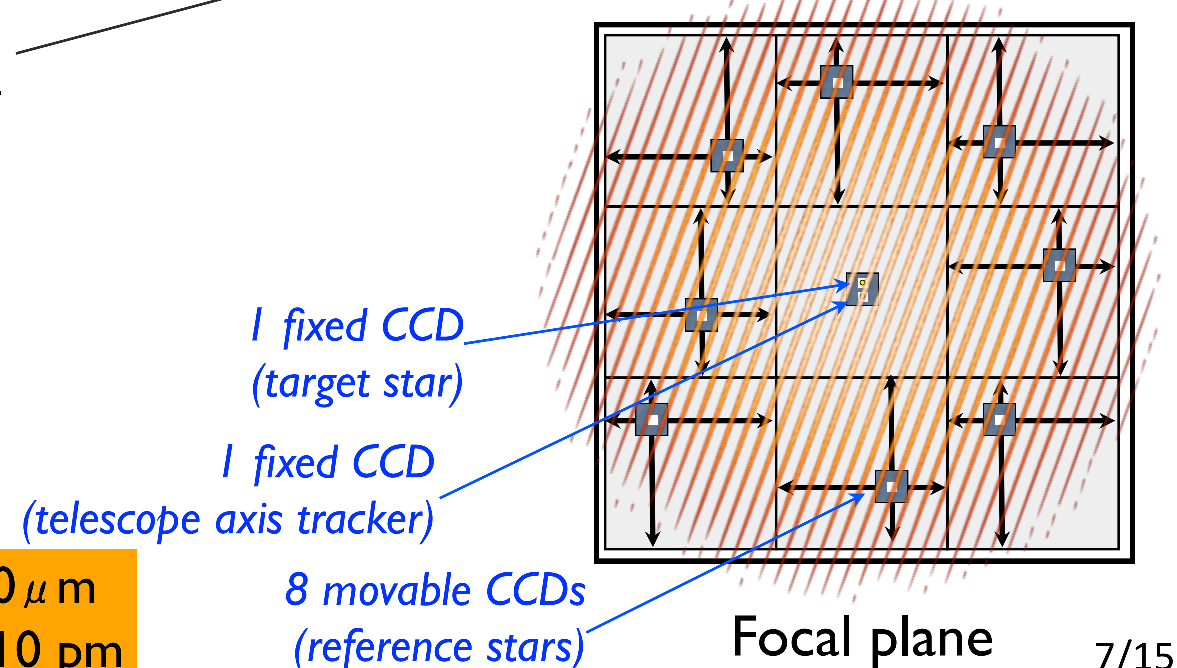
Image from High Contrast Imaging Testbed. Credit: NASA/JPL-Caltech

NEAT concept (M3 proposal)

Malbet et al. (2014)



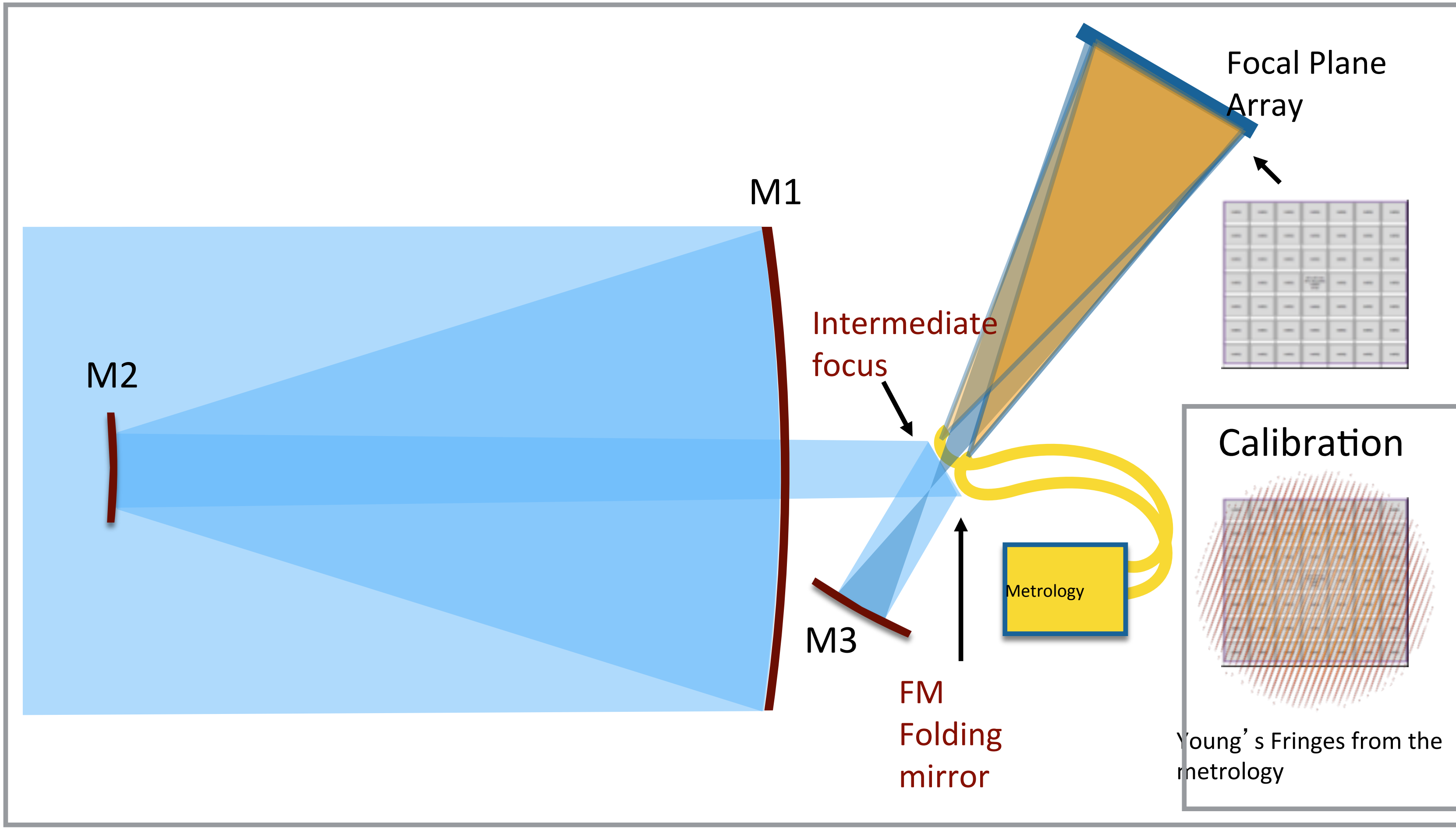




λ/D ~ 130 mas ~ 2 pixels of 10 μm

0.1 μas ~ 10^{-6} pixel accuracy ~ 10 pm

Theia concept (M4 proposal)



λ/D ~ 160 mas ~ 2 pixels of 10 μm
1 μas ~ 6.10^{-6} pixel accuracy

Theia - mission parameters & ESA evaluation

➢ <u>Mission parameters:</u>

- 3 year mission
- Ø 0.8m primary mirror (Ø 1m for NEAT)
- L2 orbit
- M4 cost envelop (450M€)
- Multipurpose ‘‘observatory’’: dark matter (34%), nearby Earths (17%), compact objects (11%), Gaia follow-up (11%), open time (15%)
- Main science case: **dark matter**, **detection of DM clumps** -> constraining the nature of dark matter

➢ <u>ESA feedback:</u>

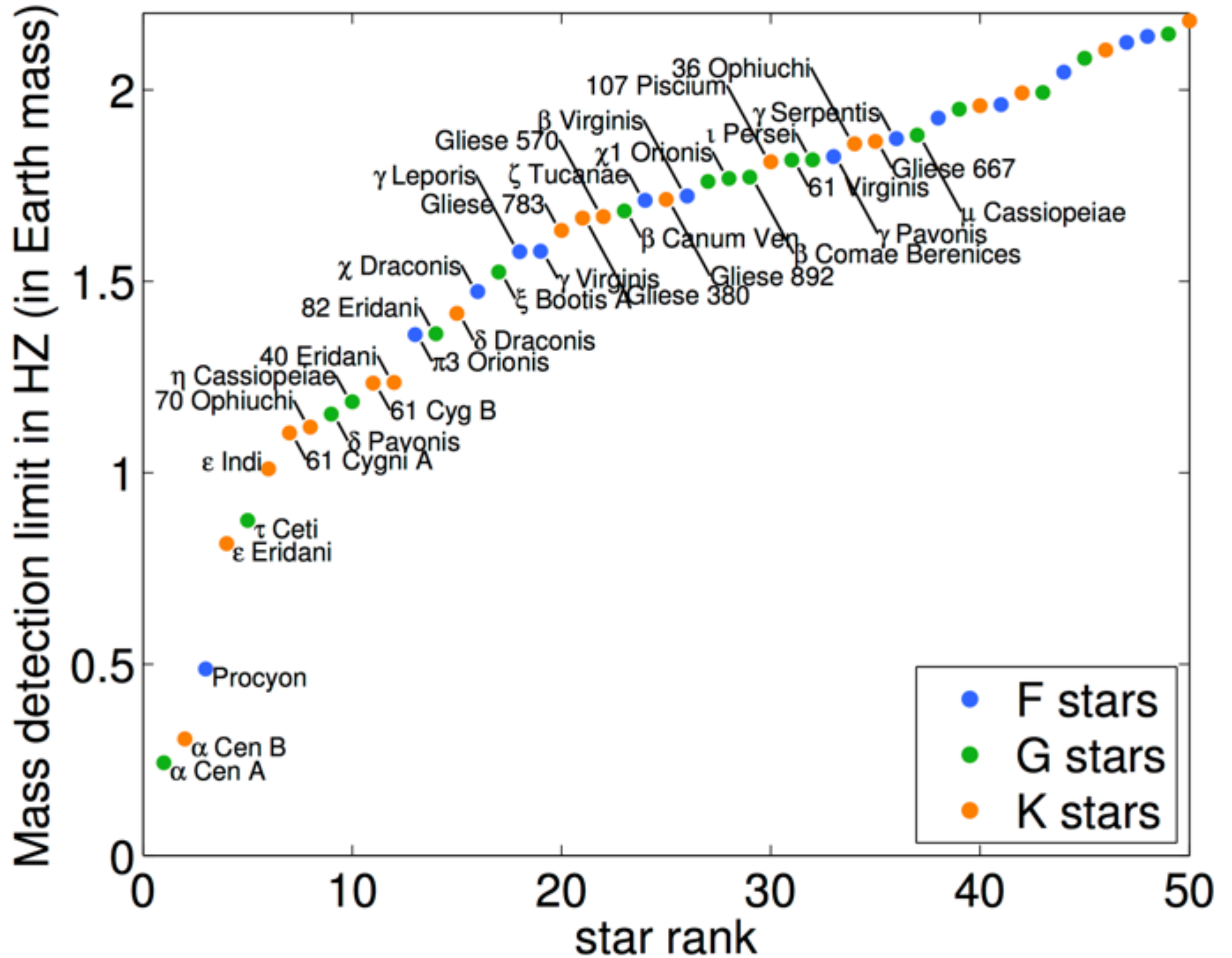
- Positive progression NEAT -> Theia
- Main ESA red flag: budget and programmatic
- Different CNES and ESA cost estimations (420M€ vs 546M€)

Expected detection thresholds of Theia

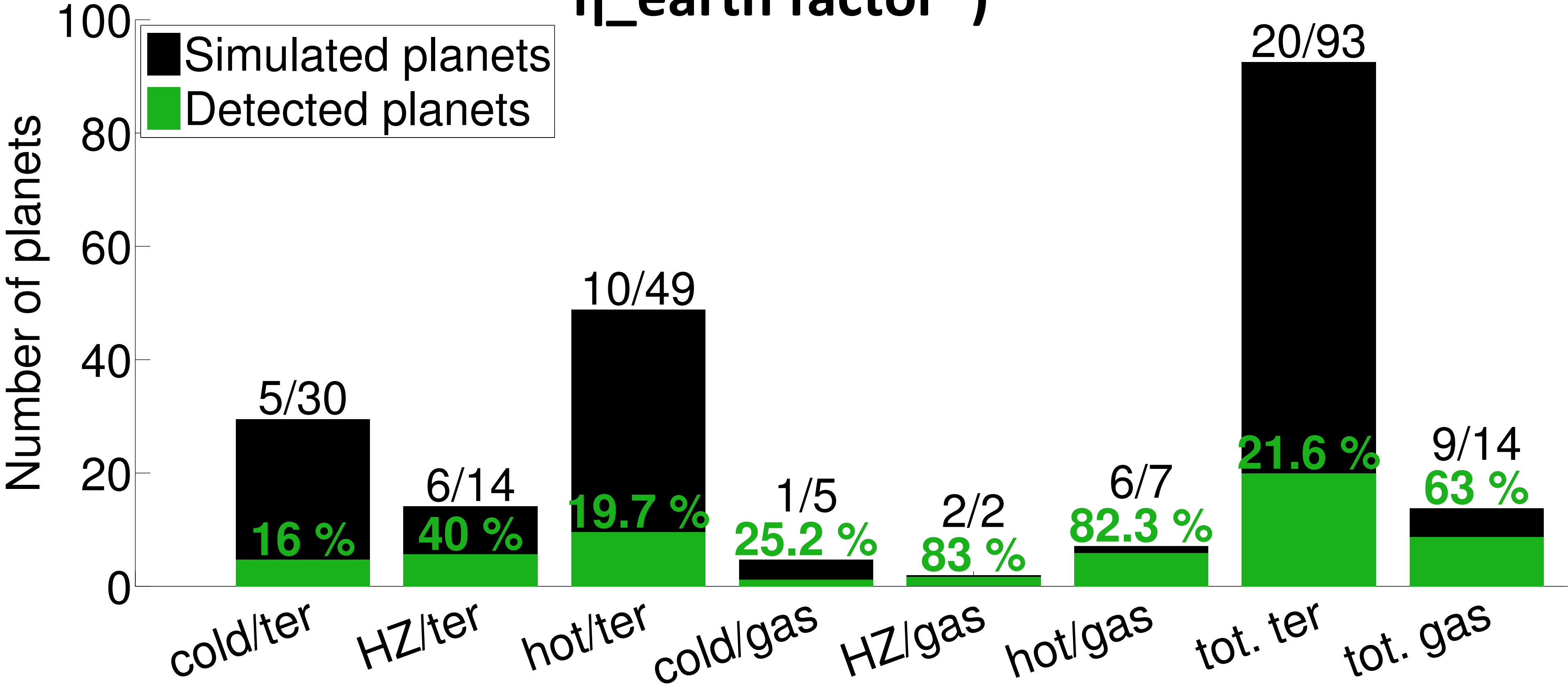
Main assumption: photon noise limited with Theia (0.5 FoV, Ø 0.8m)

Only 2600 hours, ie. **10%** of 3 years (7% used for RV follow-up)

Time distributed equally around the 50 easiest (~closest and Sun like) stars



Expected exoplanet yield of Theia ("accounting for the η_earth factor")



- Model based on Theia error budget & extrapolated Kepler distribution
  [Traub 2015]
  [Priv. comm., Traub & Crouzier]
- Statistical conversion Mass <-> radius
- Hard cutoff @ P = 3 years
- 6 categories: cold/HZ/hot and Terrestrial/Gaseous
- In average 6/14 potentially habitable planets detected

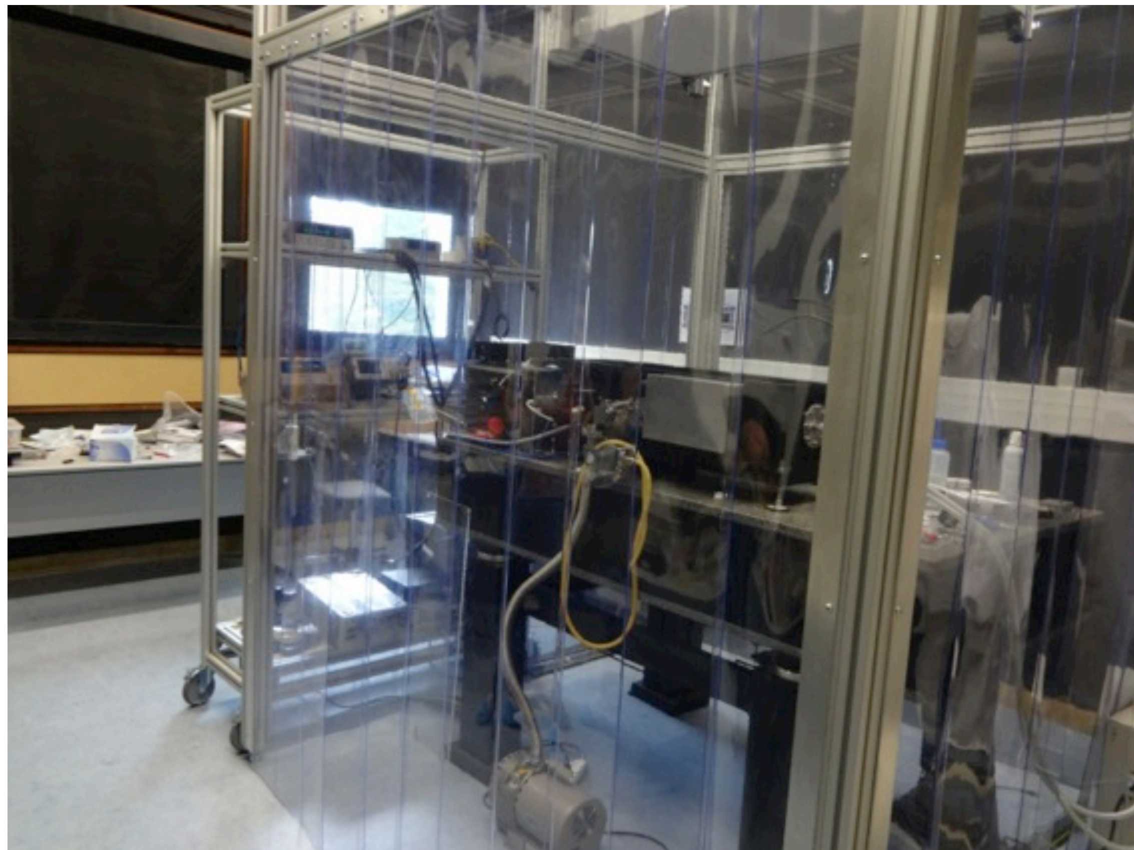
DICE (Detector Interferometric Calibration Experiment)

Crouzier et al. 2014

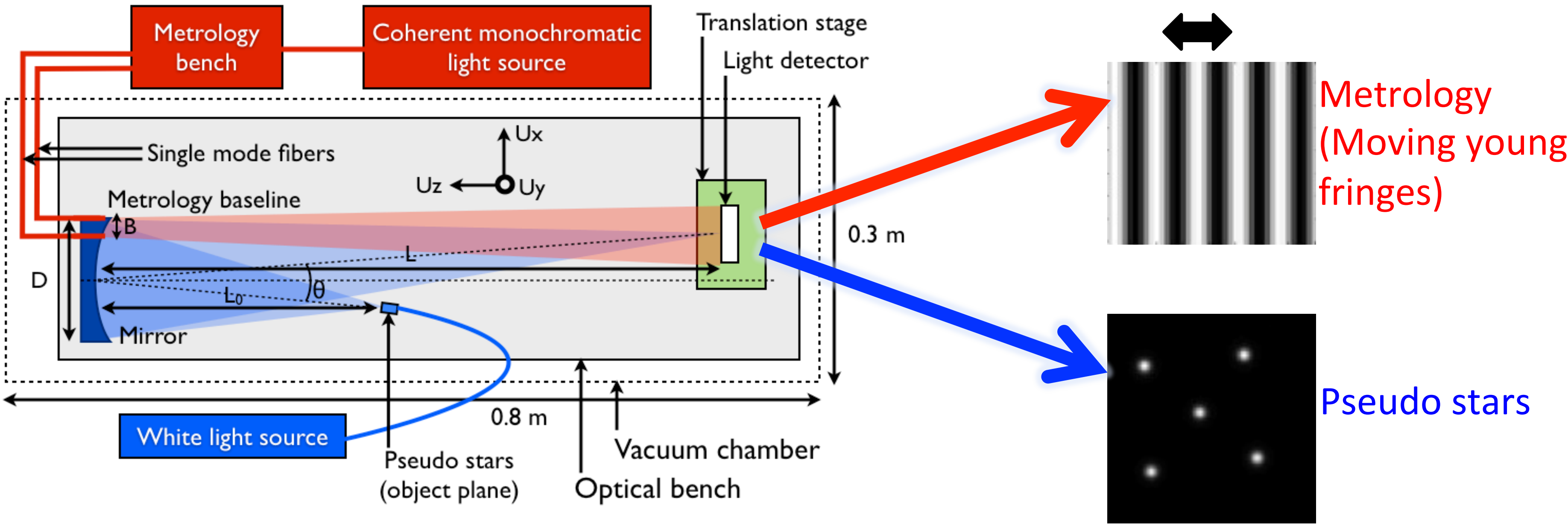
- An experiment to demonstrate CCD calibration for astrometry at a precision of 10 µpixel (~ 1µas with the Theia design)

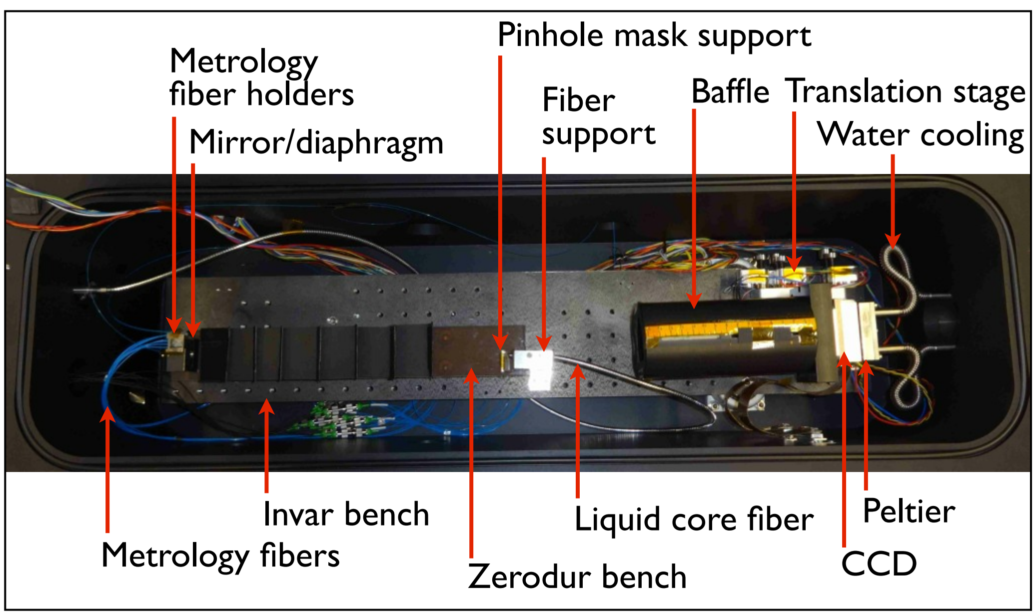
- Optical configuration imitates NEAT

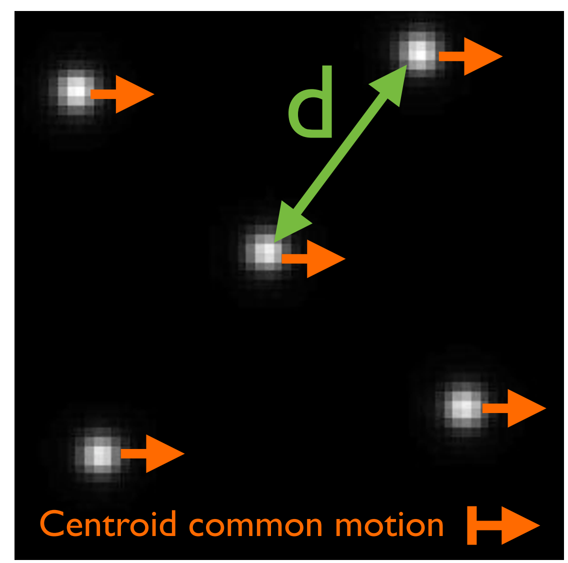
- Poster #66469 (Crouzier et al.) **The Detector Interferometric Calibration Experiment**



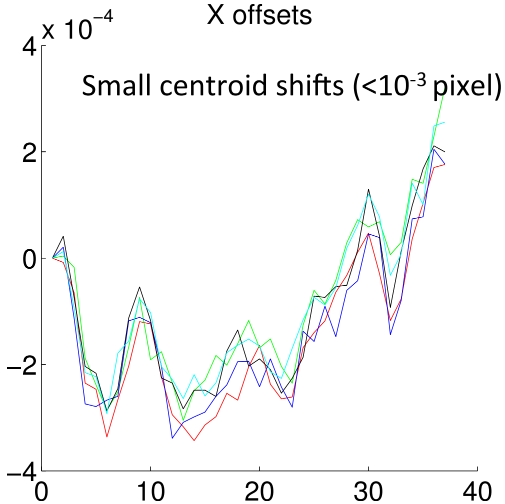
DICE (Detector Interferometric Calibration Experiment)

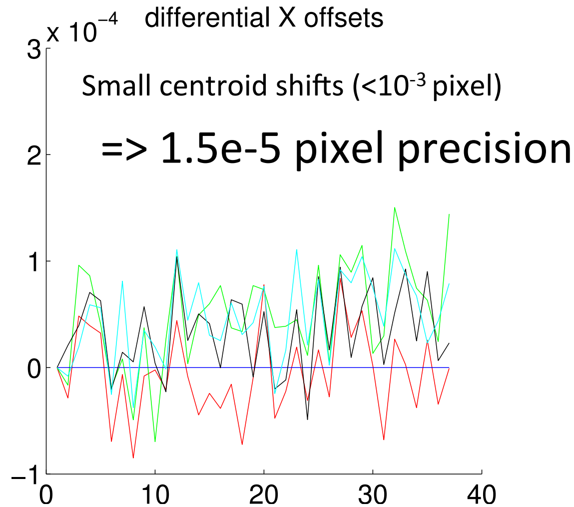


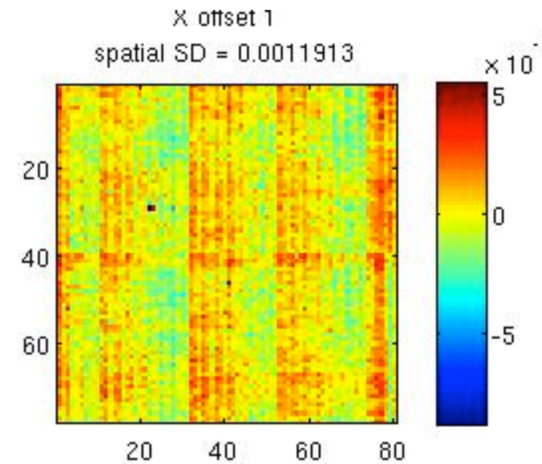


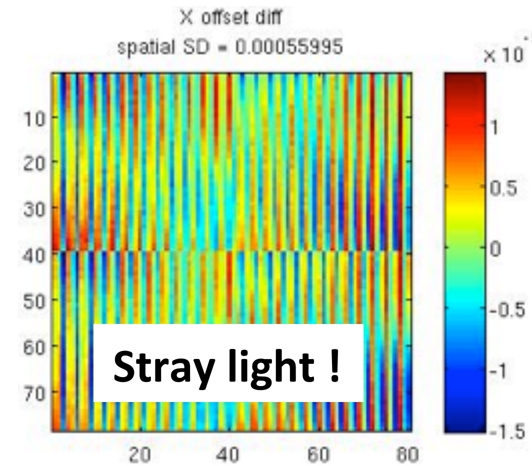


DICE: experimental results







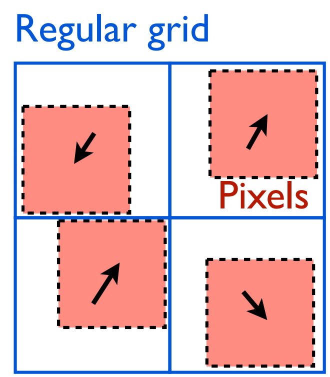


Improvement by:

- Use of jittering techniques
- Better stray light control

Calibrations:

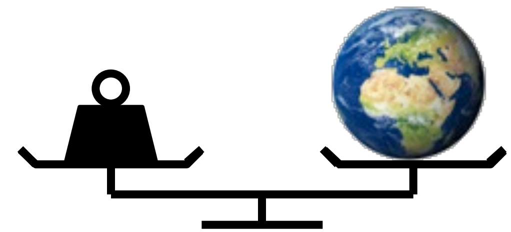
- Pixel QE map
- Pixel positions* map



-	No flat	flat
No metrology	$3.6 \pm 0.59 \times 10^{-4}$	$2.8 \pm 0.45 \times 10^{-4}$
Metrology	$5.9 \pm 0.94 \times 10^{-4}$	$4.3 \pm 0.69 \times 10^{-4}$

(goal : 1e-5)

Conclusion



- **A specific need still not addressed: measure the masses of HZ planets around nearby Sun-like stars**

(*hopefully soon)

- **Evolving concept, astrometry with diverse science cases, becoming closer to selection**

- **Improved instrument concept and performances**

- **Ongoing instrumentation efforts for detector calibration and optical stabilization + calibration (IPAG & JPL)**

Thank you for your attention !