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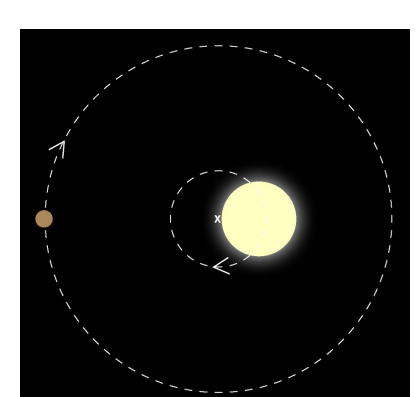
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Experimental tests of the calibration of high precision differential astrometry for exoplanets

Manon Lizzana (1,2,3), Fabien Malbet (1), Pierre Kern (1), Fabrice Pancher (1), Sébastien Soler (1), Thierry Lepine (4), Alain Leger (5)

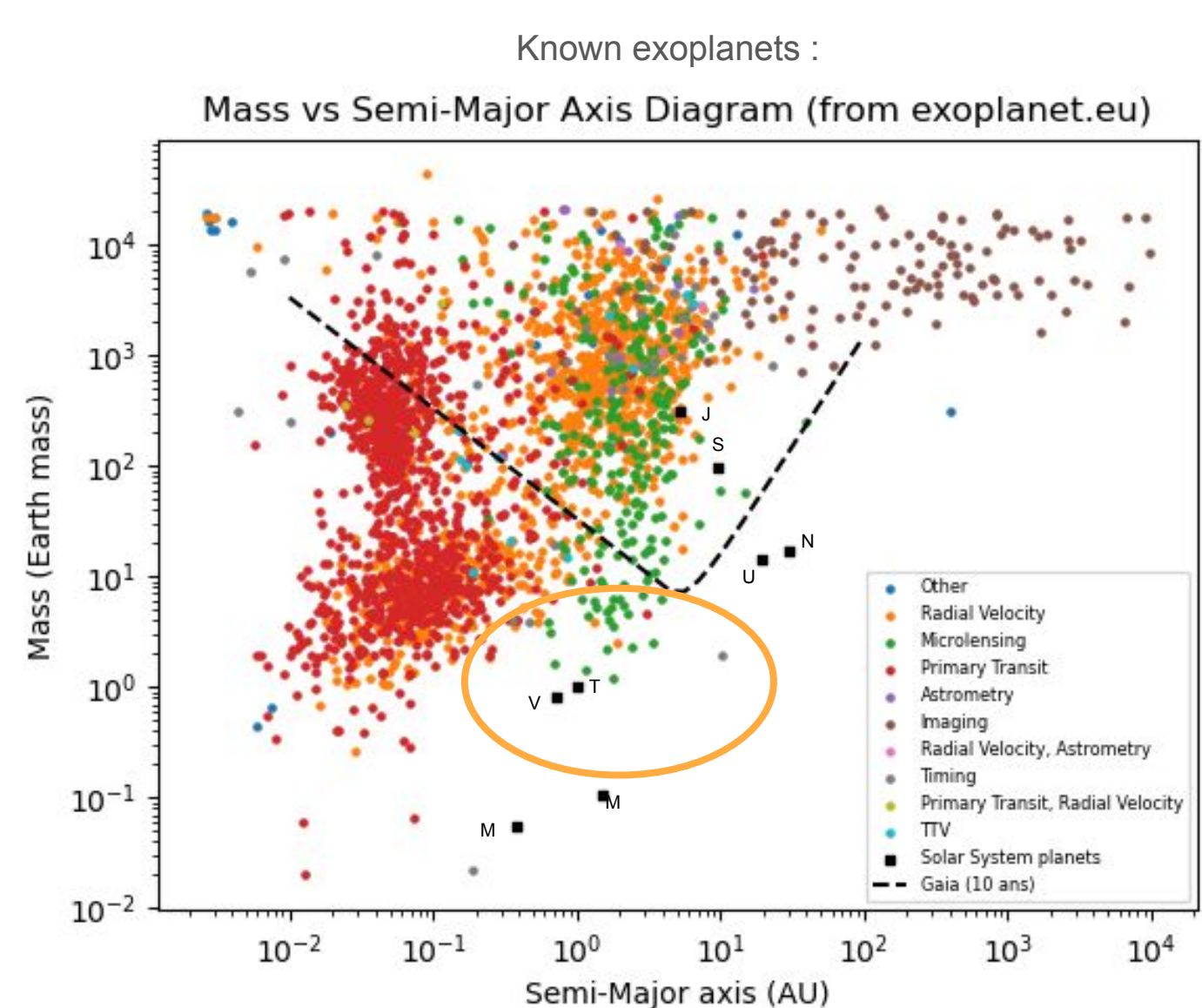
Scientific objectives :

- investigate the nature of the **dark matter in the Milky way** by studying the modification of star trajectories in the galactic plane
- Study compact objects and particularly X-binaries
- Explore **planetary systems** in the Sun's vicinity and draw up a list of potential targets for future spectroscopic missions (LIFE, HWO)
 - We focus here on **rocky exoplanets in the habitable zone** detection because it's the most demanding aspect

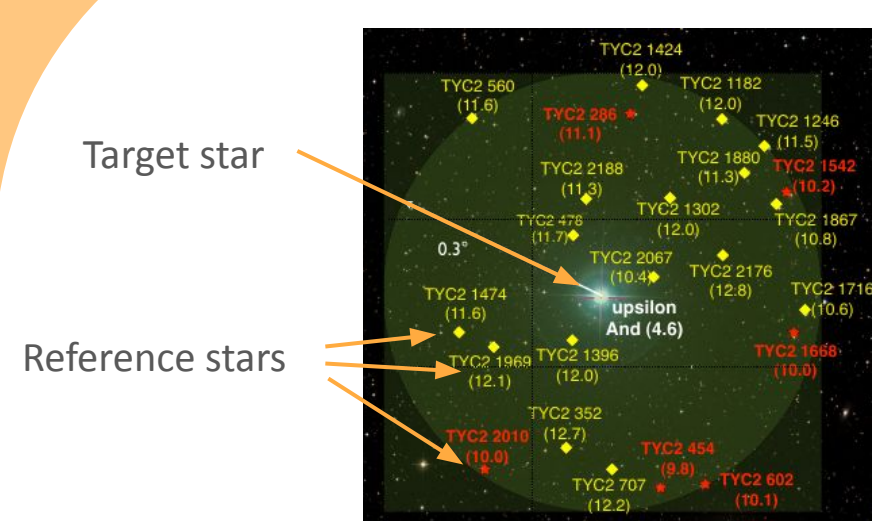


Exoplanets detection by astrometry

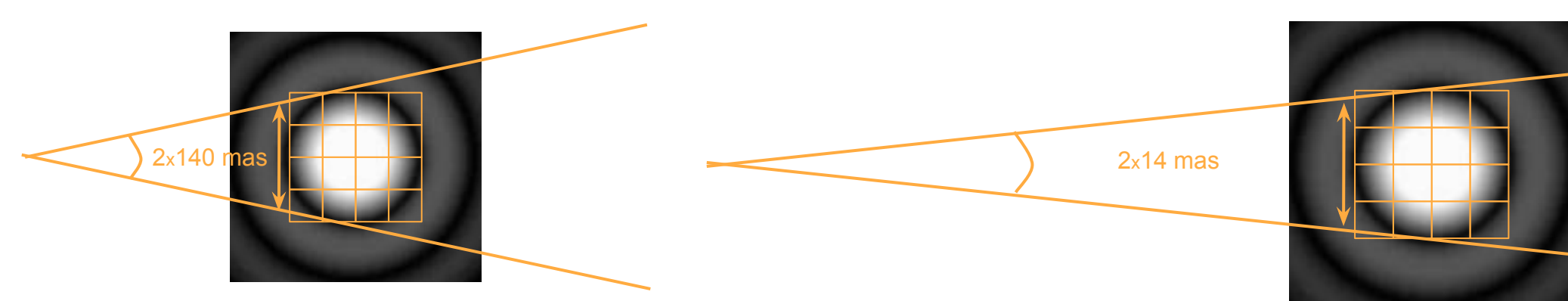
see poster 1016 (Fabien Malbet) for more details



Relevant space missions :

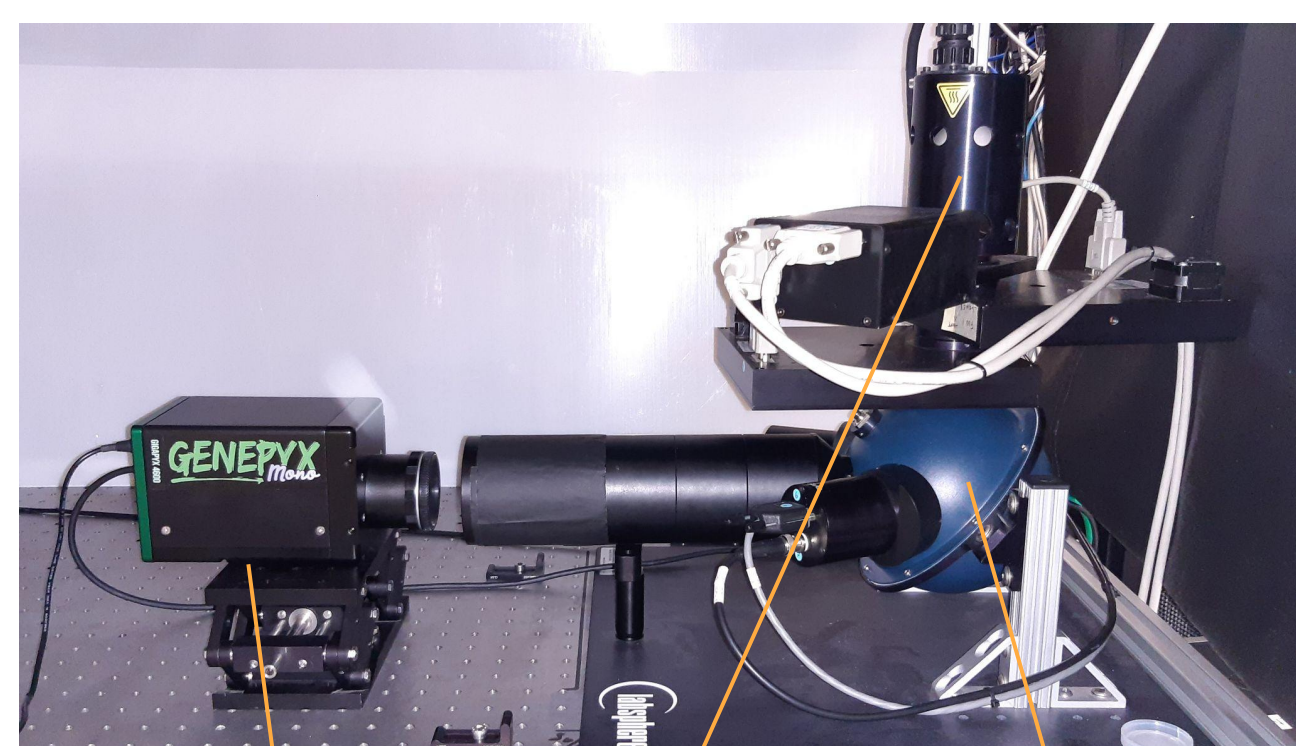


	Theia (at the age of Gaia)	HWO
wavelength	400 λ <math>< 900</math> nm	UV, visible et IR
Progress	Project (ESA call M8 - 1 an)	planned launch ~2040
Diameter (D)	0.8m	between 6.5 and 8m
Signal exo-Earth 10pc away $\rightarrow 0.3 \mu\text{s}$ (pixels $4 \mu\text{m}$)	PSF $\sim \lambda/D = 140 \text{ mas} \leftrightarrow 2 \text{ px}$ exo-Earth : $0.3 \mu\text{s} \leftrightarrow 5\text{-}6 \text{ px}$	PSF $\sim \lambda/D = 14 \text{ mas} \leftrightarrow 2 \text{ px}$ exo-Earth : $0.3 \mu\text{s} \leftrightarrow 5\text{-}5 \text{ px}$
Field of view	$30' \times 30'$ ($0.5^\circ \times 0.5^\circ$) $30\,000 \times 30\,000 \text{ px} \sim 1 \text{ Gpx}$	$2' \times 3'$ (wide field imager) TBC $20\,000 \times 30\,000 \text{ px} \sim 1 \text{ Gpx}$
Dynamic	$m_{\text{target}} \sim 6; m_{\text{ref}} \leq 14$ \Rightarrow dynamic $\sim 1\text{e}3$	$m_{\text{target}} \sim 6; m_{\text{ref}} \leq 20$ \Rightarrow dynamic $\sim 1\text{e}5$

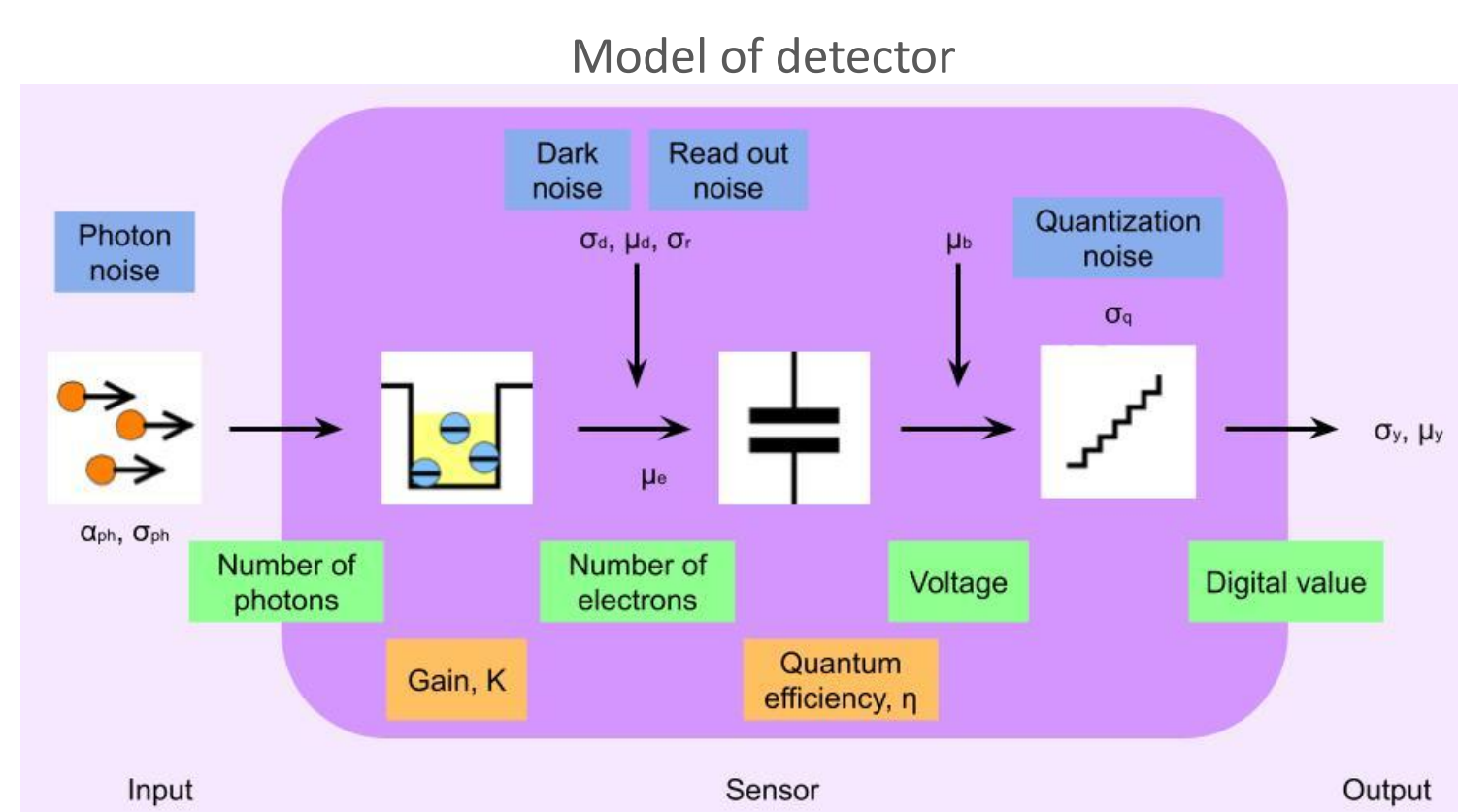


Characterize an adequate CMOS detector

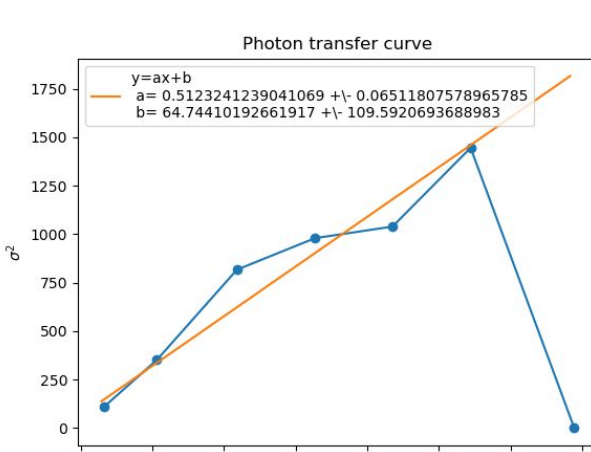
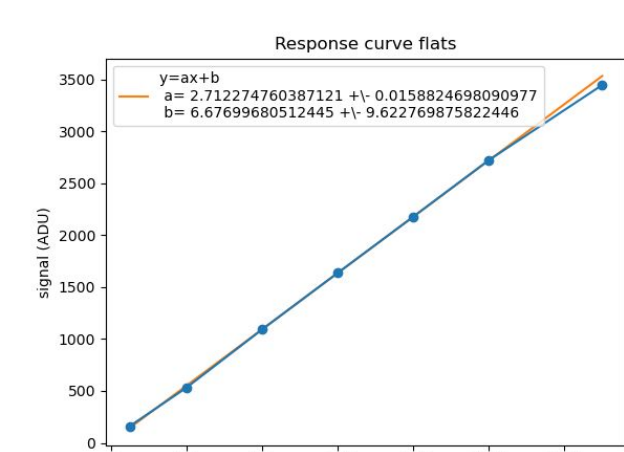
Global characterization : linearity, dark current, readout noise, gain, map of defective pixels, ...



detector Source integrating sphere



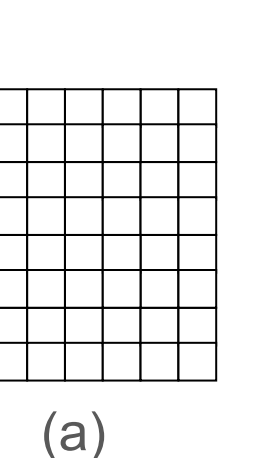
- Need for total field of view coverage : $30\,000 \times 30\,000 \text{ px} = 1 \text{ Gpx}$
- Current laboratory experiments : Gigapix (Pyxalis) CMOS $8320 \times 5436 \text{ px} = 46 \text{ Mpx}$ taille pixel $4.4 \mu\text{m}$ taille totale $24 \times 26 \text{ mm}$



TBC

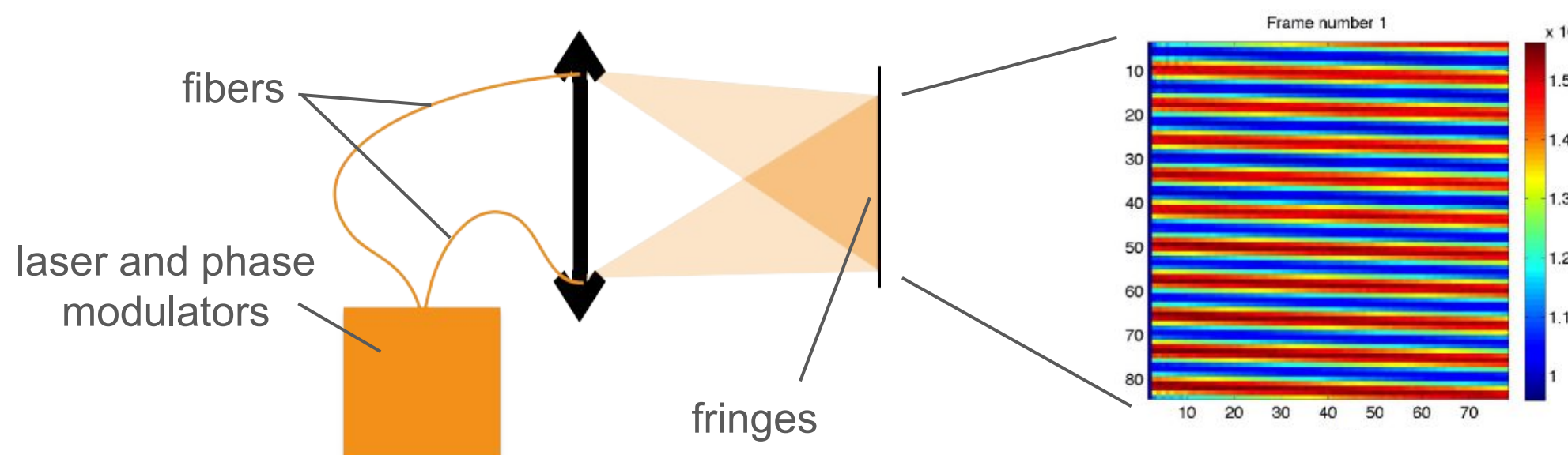
Interferometric calibration of the pixels centroid position

In a theoretical detector (a), rows and columns are well aligned, but in a real detector (b) the centroids are misaligned (because of fine pixel structure, quantum efficiency local variations ...)



Calibration procedure :

- Fibres create **Young's fringes** on the detector
- Phase modulators make the fringes scroll
- The modulation observed by each pixel provides the position of the centroids
- Precision required $\leq 5\text{-}6 \text{ px}$ (corresponding to $0.3 \mu\text{s}$, an exo-Earth signal)
- model the field distortion function by a 2D polynomial (T or T1oT2)
- Adjust T thanks to the reference stars in the field of view known with Gaia catalog
- Apply T to the target star to recover its undistorted position



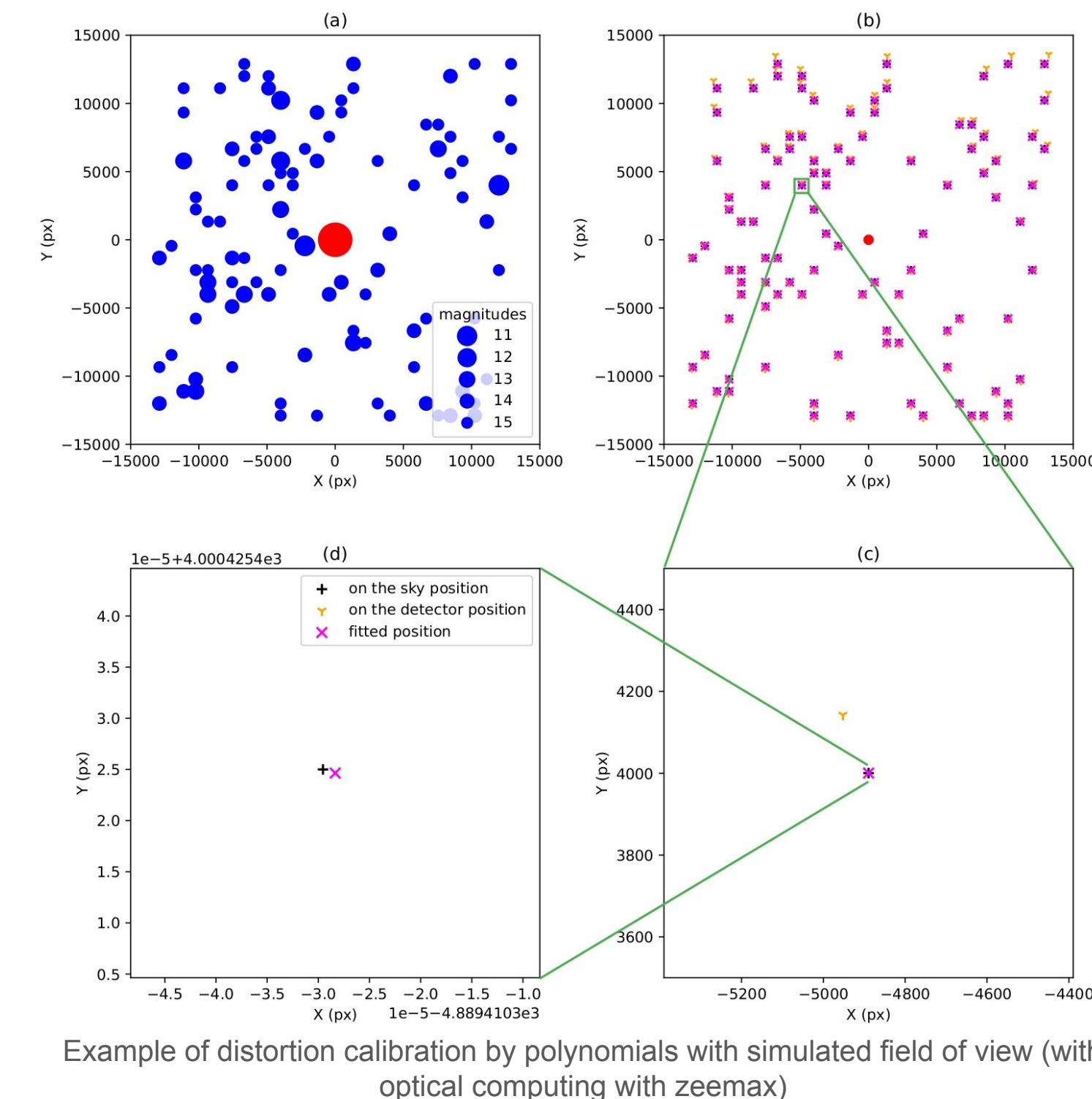
- Proof of concept on small matrices (Crouzier et al. 2016, A&A 595, A108) : $6\text{-}5 \text{ px}$
- performance needs to be validated on large matrices \rightarrow a testbed will be developed at IPAG

Calibration of optical distortion

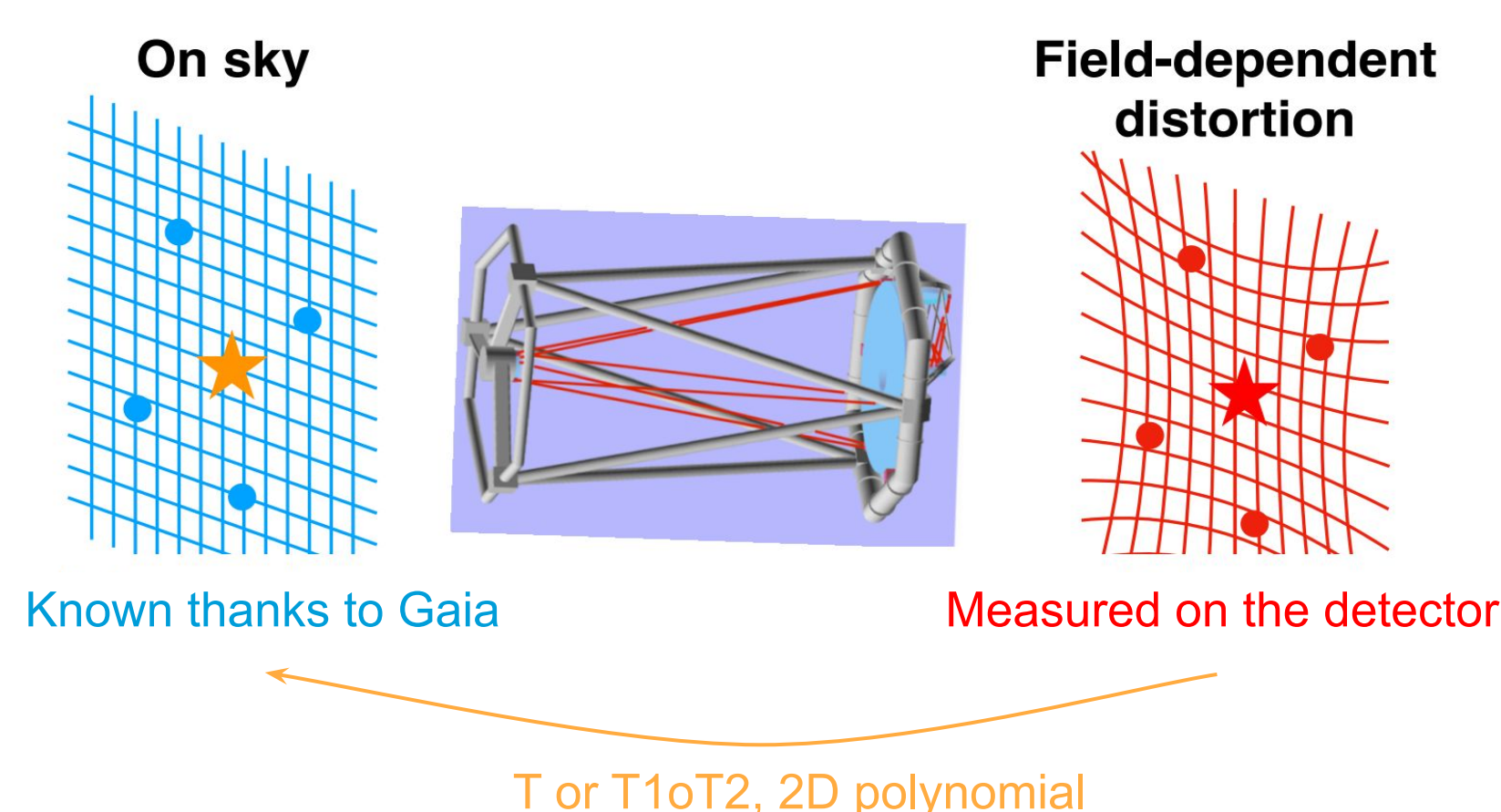
★ with simulations :

Objectiv : Show that a **polynomial model** is able to calibrate the telescope distortion with a precision smaller than $5\text{-}6 \text{ px}$ (corresponding to Earth like planet signal) Recent work on telescope stability (Malbet et al. 2022, SPIE 12180, 1F) has shown that the reference stars in the field of the telescope can be used as metrology sources in order to compute the distortion function

- model the field distortion function by a 2D polynomial (T or T1oT2)
- Adjust T thanks to the reference stars in the field of view known with Gaia catalog
- Apply T to the target star to recover its undistorted position

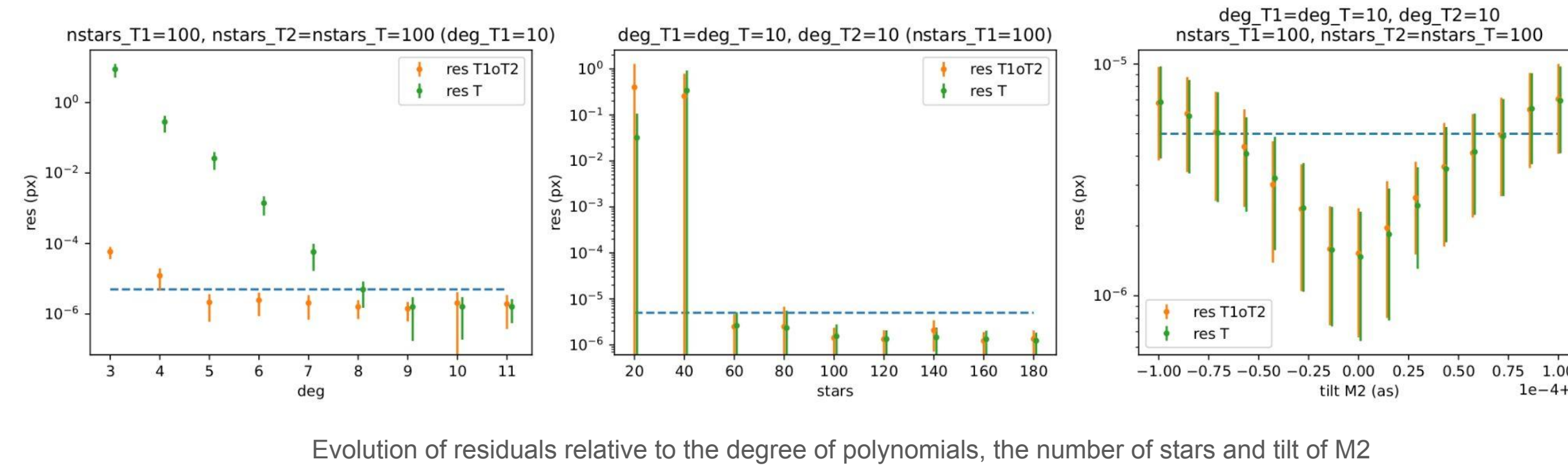


Example of distortion calibration by polynomials with simulated field of view (with optical computing with zeemax)



Paper in prep

T or T1oT2, 2D polynomial



Evolution of residuals relative to the degree of polynomials, the number of stars and tilt of M2

Simulation conclusion : A precision of $5\text{-}6 \text{ px}$ can be reached with about 100 stars and an 8th order polynomial

★ in laboratory :

Objectiv : show that the procedure described before works in laboratory

- Illuminating pseudo stars on the LCD screen
- Induce distortion with lens and diaphragm
- Recording distorted star images with the detector
- Apply the previous procedure to recover the undistorted image

