# NEAT: an astrometric mission to detect and characterize nearby habitable planetary systems


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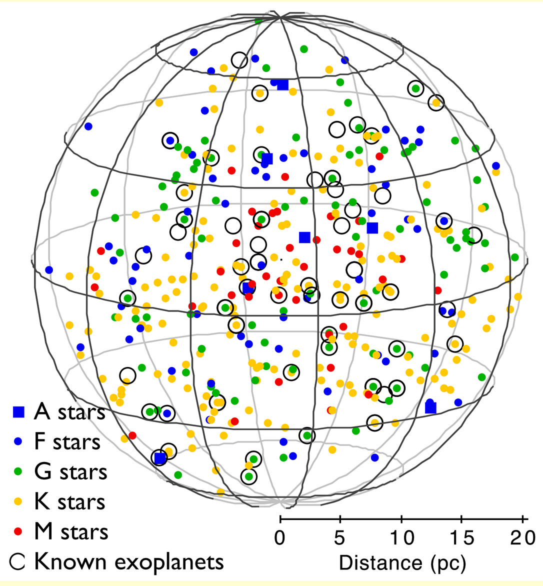
## Science objectives

The prime goal of NEAT is to detect and characterize, in an exhaustive way, planetary systems orbiting bright stars in the solar neighborhood that have a planetary architecture with planets in their Habitable Zone like that of our Solar System or an alternative planetary systems made of Earth mass planets. It will allow the detection around nearby stars of planets equivalent to Venus, Earth, (Mars), Jupiter, and Saturn, with orbits possibly similar to those in our Solar System. It will permit to detect and characterize the orbits and the masses of many alternate configurations, e.g. where the asteroid belt is occupied by another Earth mass planet and no Jupiter. The NEAT 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 ≈ 15 pc?
– What are the masses, and orbital parameters, of telluric planets that are candidates for future direct detection and spectroscopic characterization missions?

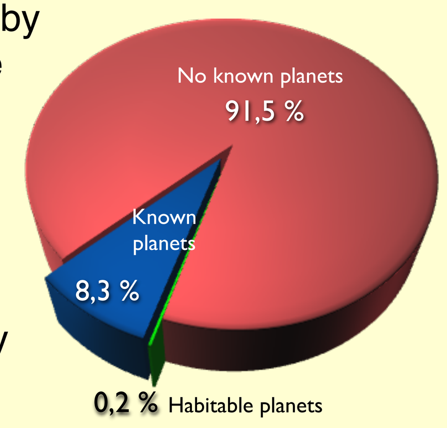
**Special emphasis is put on planets in the Habitable Zone** because this is a region of prime interest for astrobiology. Indeed orbital parameters obtained with NEAT will allow spectroscopic follow-up observations to be scheduled precisely when the configuration is the most favorable.

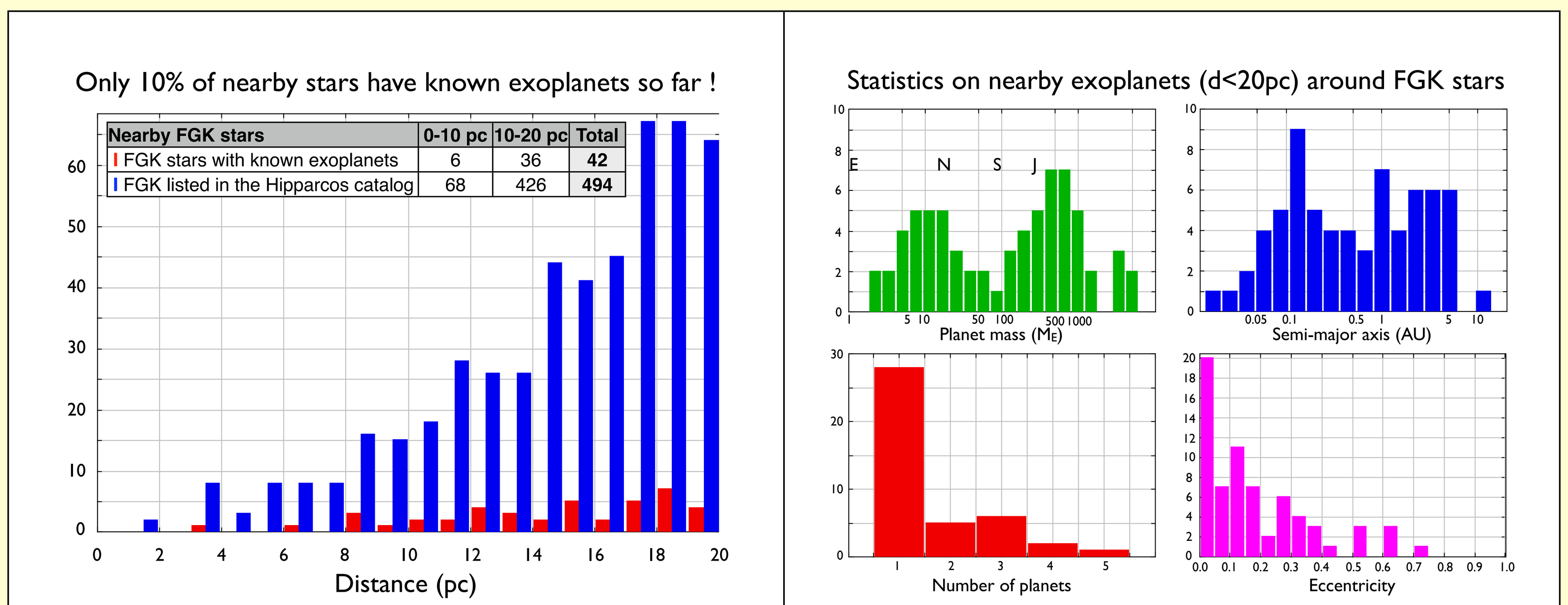



*Representation of the NEAT targets in the 3D sphere of our neighborhood (D up to ≈ 15pc). They correspond to a volume limited sample of all stars with spectral types between F and K.*

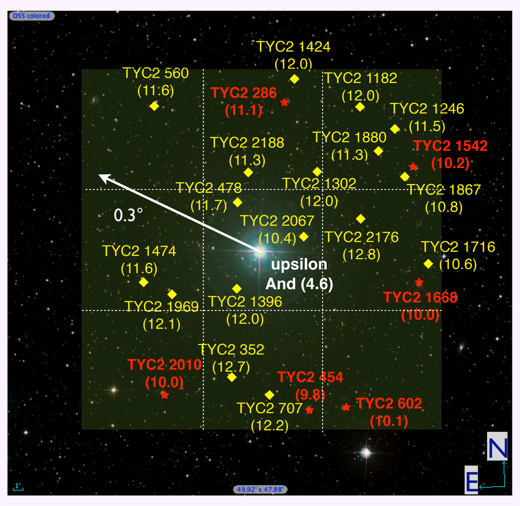
## How well do we know our neighbours (FGK stars,d≤20pc) ?

Interestingly, whereas we have detected now several hundreds and even reaching several thousands exoplanets, the number of planetary systems around nearby solar-type stars, a volume limited sample, is less than 10%, mainly because the key detection technique, transit search, can detect only planets with a special orbit (0.5% efficiency for a planet at 1 AU around a Sun-like star). However, planets around nearby stars are of special interest because one can conduct statistics or precise follow-up. These systems are also interesting because of their proximity that can yield direct spectroscopic studies with coronagraphic or nulling techniques. Therefore, an exhaustive method to detect them is very desirable.



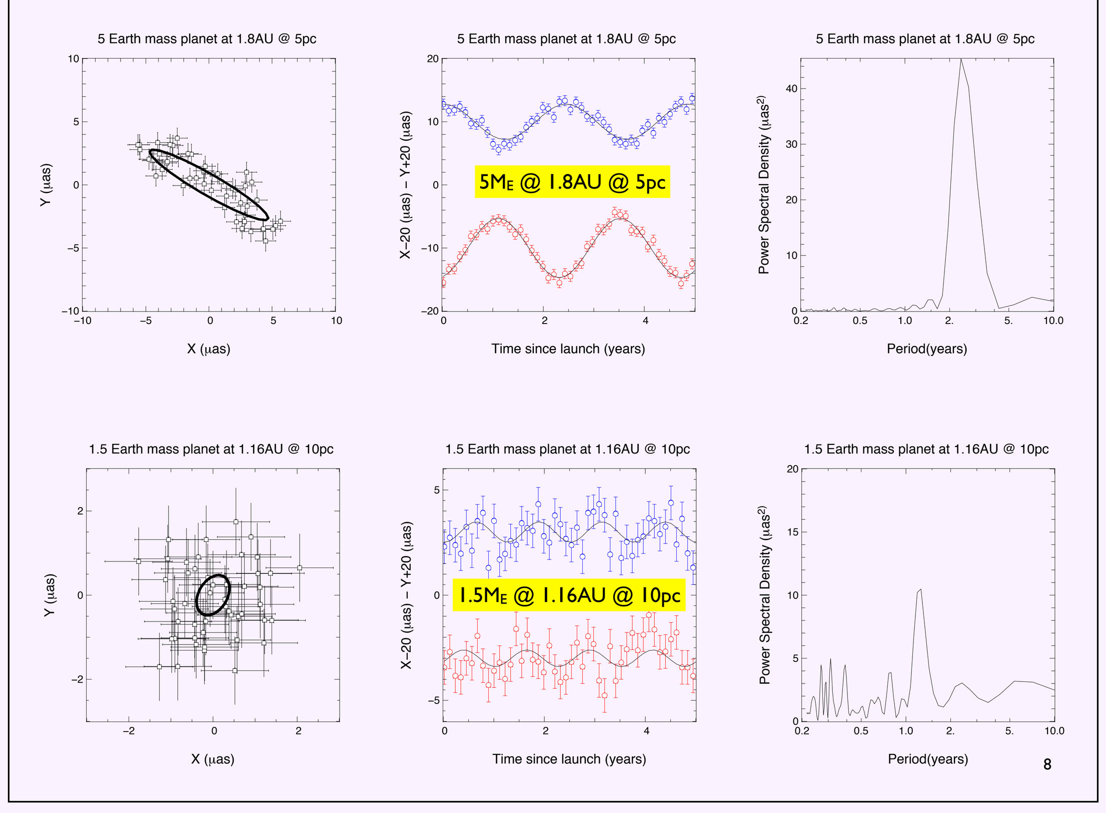

## High precision differential astrometry

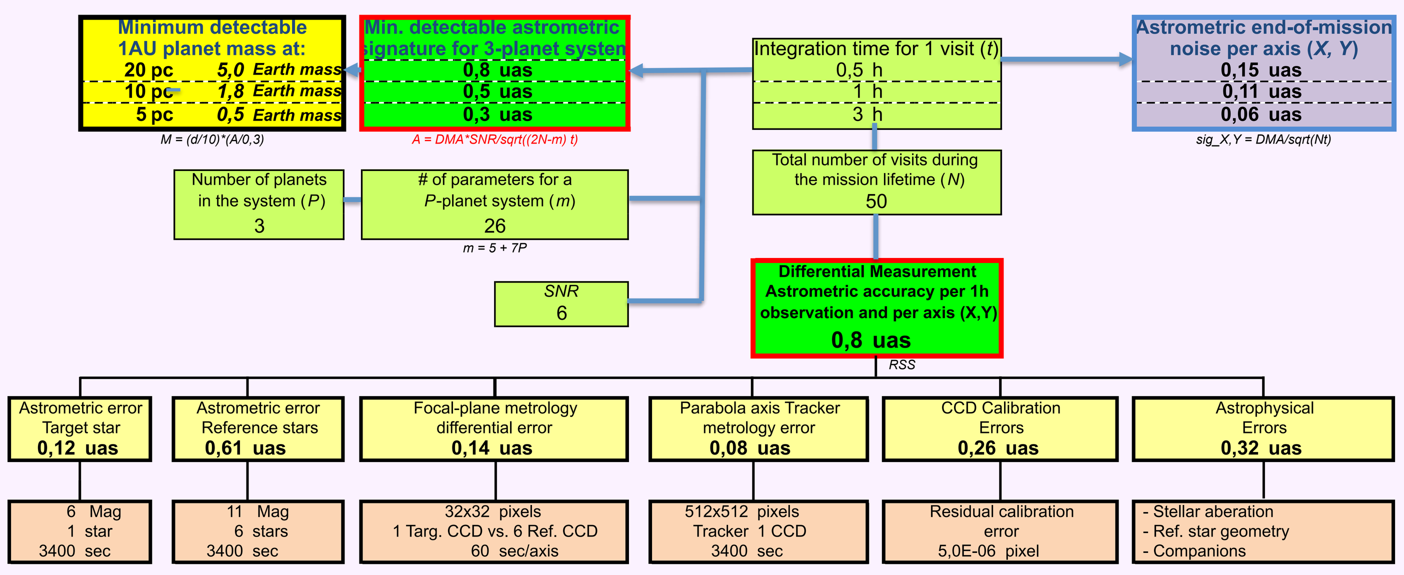


*Typical field of NEAT with a field of view of 0.6°*

The principle is to measure accurately the offset angles between a target and 6-8 distant reference stars with the aim of differentially detecting the reflex motion of the target star due to the presence of its planets. The output of the analysis is a comprehensive determination of the mass, orbit, and ephemeris of the different planets of the multiplanetary system (namely 7 parameters $M_P$ , $P$ , $T$ , $e$, $i$, $\omega$, $\Omega$), down to a given limit depending on the star characteristics, e.g. 0.5, 1 or 5M⊕.

*Simulation of astrometric detection of two type of planets with 50 NEAT measurements (RA and DEC) over 5 yrs. **Top row** parameters corresponds to an easy detection: $M_P$ = 5M⊕, a = 1.8AU, $M_*$ = 1M⊙, D = 5pc. **Bottom row** parameters corresponds to a more challenging detection: $M_P$ = 1.5M⊕, a = 1.16AU, $M_*$ = 1M⊙, D = 10pc. **Left panels**: sky plot showing the astrometric orbit (solid curve) and the NEAT measurements with error bars; **middle panels**: same data but shown as time series of the RA and DEC astrometric signal (an offset has been put to separate them); **right panels**: joint Lomb-Scargle periodogram for right ascensions and declinations simultaneously. All measurements corresponds to 1h visits with a 0.8µas/sqrt(h) precision.*

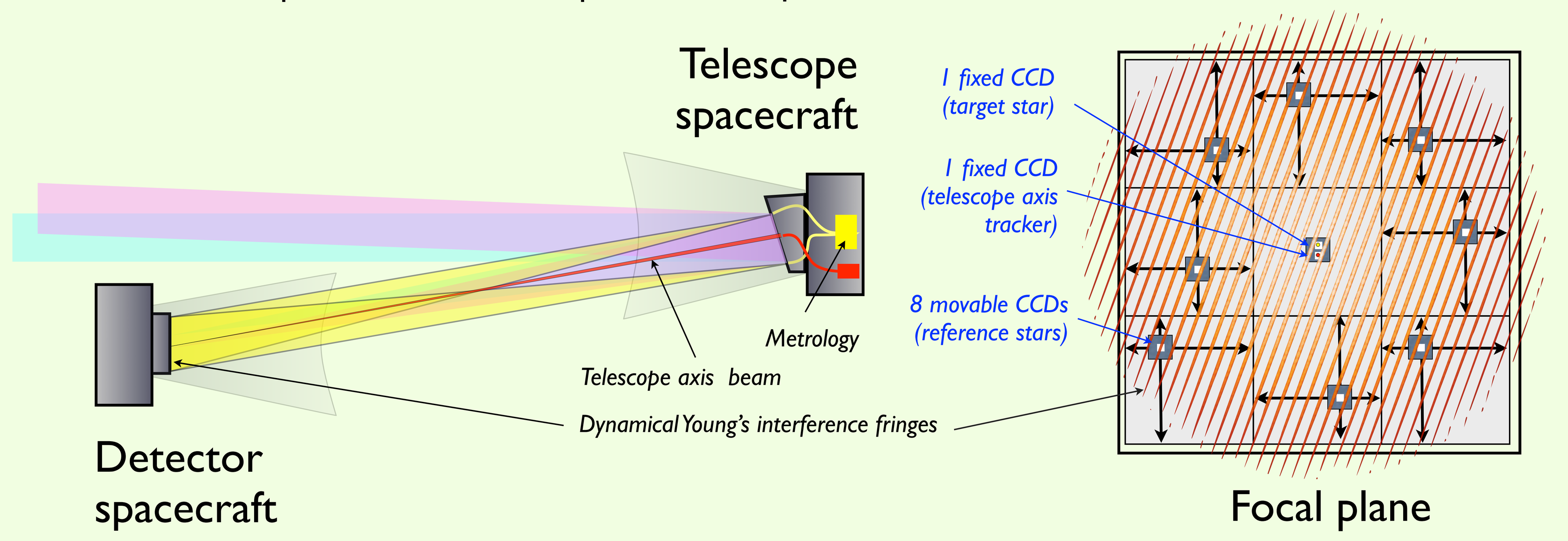



*Top-level error budget for NEAT that shows the major contributor to the overall budget. It also shows how the 0.8 µas/sqrt(h) accuracy enables the detection of 0.3 µas (resp. 0.5 µas and 0.8 µas) signatures with a signal to noise of 6 after 50 visits of 3 h (resp. 1 h and 0.5 h) of observation that allows a 0.5 M⊕ planet at 5 pc to be detected (resp. 1.8 M⊕ at 10pc and 5M⊕ at 20pc).*

## Instrumental concept

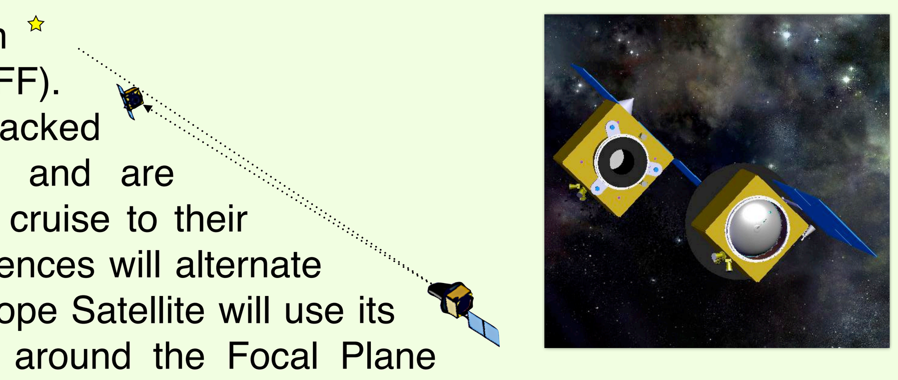
The concept consists of a primary mirror —an off-axis parabolic 1-m mirror— a focal plane located 40 m away to allow enough angular resolution and metrology calibration sources. The large distance between the primary optical surface and the focal plane can be implemented as two spacecraft flying in formation or a long deployed boom. The focal plane with the detectors having a field of view of 0.6° has a geometrical extent of 0.4m×0.4m. It is composed of eight 512 × 512 visible CCDs located each one on an XY translation stage in order to cover the whole field of view, while the central two CCDs are fixed in position. The CCD pixels are 10µm in size.




*The principle of the measurement is to point the spacecraft so that the target star, which is usually brighter (R ≤ 6) than the reference stars (R ≤ 11), is located on the axis of the telescope and at the center of the central CCD. Then the 8 other CCDs are moved to center each of the reference stars on one of them. To measure the distance between the stars, we use a metrology calibration system that is launched from the telescope spacecraft and that feeds several optical fibers (4 or more) located at the edge of the mirror. The fibers illuminate the focal plane and form Young's fringes detected simultaneously by each CCD (right panel). The fringes have their optical wavelengths modulated by acoustic optical modulators (AOMs) that are accurately shifted by 10 Hz, from one fiber to the other so that fringes move over the CCDs. These fringes allow us to solve for the XYZ position of each CCD. An additional benefit from the dynamic fringes on the CCDs is to measure the QE of the pixels.*

## Preliminary Spacecraft Design.

The proposed mission architecture relies on the use of two satellites in formation flying (FF). The two satellites are launched in a stacked configuration using a Soyuz ST launcher, and are deployed after launch in order to individually cruise to their operational Lis- sajous orbit. Acquisition sequences will alternate with reconfigurations, during which the Telescope Satellite will use its large hydrazine propulsion system to move around the Focal Plane Satellite and to point at any specified star. At the approach of the correct configuration, the Focal Plane Satellite will use a cold gas µ-propulsion system for fine relative motion acquisition. The Focal Plane Satellite will be considered as the chief satellite regarding command and control, communications and payload handling.



The mission relies on a 40 m focal length telescope, for which the preferred solution is to use two satellites in formation flying. The performance to be provided by the two satellites in order to initialize the payload metrology systems are of the order of magnitude of ±2mm in relative motion, and of 3 arcseconds in relative pointing, which are typically compatible with Formation Flying Units and gyroless AOCS6 architecture.

The mission aims at a comlete survey of a large number of targets and the maximization of the number of acquisitions will be a main objective of the next mission phases. The mission objectives require a threshold of 20,000 acquisitions. In addition, the time allocation for these reconfiguration maneuvers is quite limited, in order to free more than 85% of mission duration for observations.

An alternative mission concept would consist of a single spacecraft with an ADAM-like deployable boom (from ATK-Able engineering) that connects the telescope and the focal plane modules. A possible implementation, EXAM, made by JPL is shown on the left side (see «A scalable concept»).

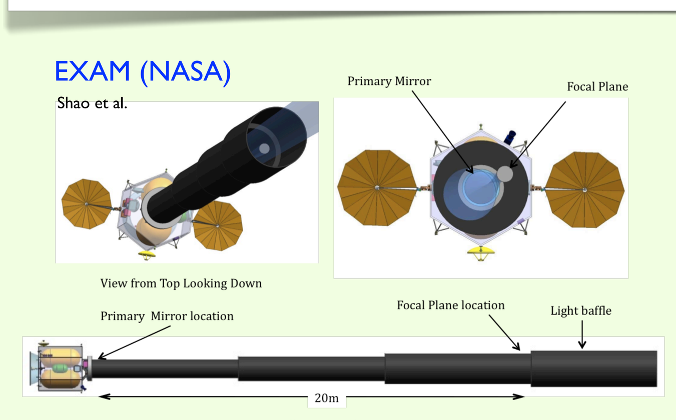
## A scalable concept

One of the strengths of NEAT is its flexibility, the possibility to adjust the size of the instrument with impacts on the science that are not prohibitive. The size of the NEAT mission could be reduced (or increased) with a direct impact on the accessible number of targets but not in an abrupt way. For instance, for same amount of integration time and number of maneuvers, the options listed in Table 3 are possible, with impacts on the number of stars that can be investigated down to 0.5 and 1 Earth mass. The time necessary to achieve a given precision depends on the mass limit that we want to reach: going from 0.5 M⊕ to 1 M⊕ requires twice less precision and therefore 4 times less observing time allowing a smaller telescope.

| 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** |

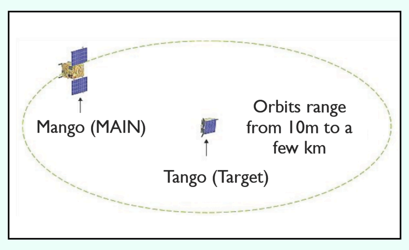
DMA = Differential astrometric Measurement Accuracy (rms); (*) centroiding requirement relaxed to 4e-5

µNEAT is a proposition submitted to ESA call for S mission in June 2012 based on existing and available technology (current FF performance and state of the art in metrology). The performance has been tuned to study giant planets in the HZ of solar-type stars and a few super Earths.





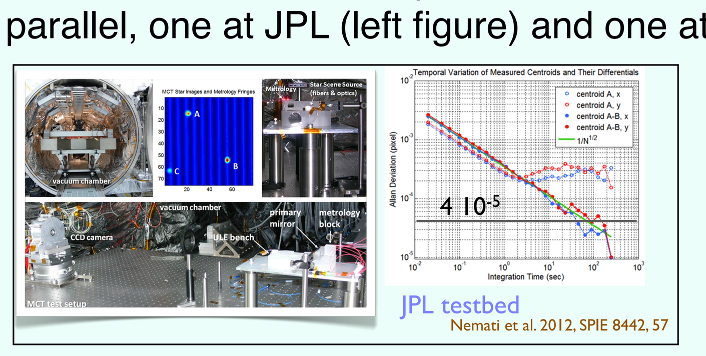
## Forthcoming tests to validate the mission

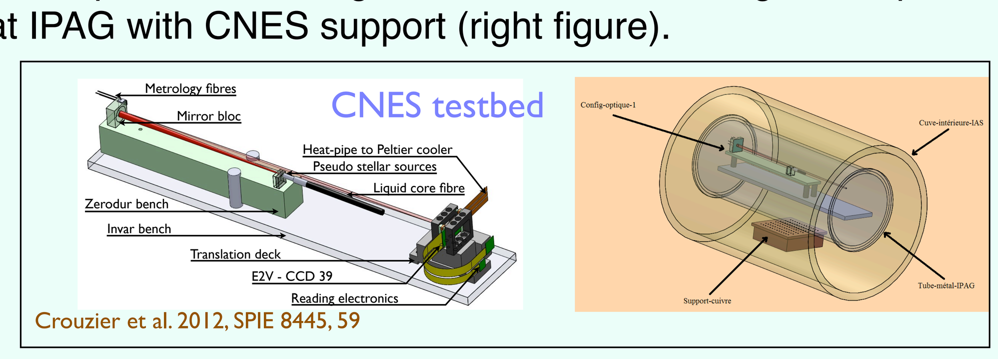



NEAT depends on two key technology: (1) formation flying (FF) or mast deployment and (2) high precision centroiding using metrology.

We are working on on-fly FF demonstration using the PRISMA satellites with CNES and OHB-Sweden that will mimic NEAT operation and demonstrate the attitude control performance.

For the validation of the performance for micropixel centroïding, two testbeds are being developed in parallel, one at JPL (left figure) and one at IPAG with CNES support (right figure).





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**Acknowledgments**: cnes JPL ThalesAlenia Space SSC IPAG OSUG