

Astrometric search of nearby Earths: the NEAT mission

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Abstract

We present the NEAT mission (Nearby Earth Astrometric Telescope) which goal is an exhaustive astrometric search of exoplanets down to $1 M_{\oplus}$ around a limited sample of F, G, K stars within 25 pc. As the astrometric technique is more sensitive to larger periods, the habitable zone around these Sun-like stars will be uniquely explored. This 5-year census will deliver the true mass and orbital parameters of possible Earth analogs, and build up a unique reservoir of Earth-like planets within the habitable zone of their parent star for future spectroscopic missions. The mission concept is based on a long-focal length (up to 40 m) telescope with a 1-m primary mirror. The astrometric position of the science PSF relatively to background reference stars can be monitored to an ultimate accuracy of $0.03 \mu\text{as}$ over the duration of the mission, which corresponds the astrometric signature of an Earth around a Sun at 10 pc. Already proposed as an M-mission in response to the ESA call for M3, the project will be further refined to become a candidate for the M4 call-for-proposal.

1. Introduction

Exoplanet research has grown explosively in the past decade, supported by improvements in observational techniques that have led to increasingly sensitive detection and characterization. Among many results, we have learned that the planets properties are much more diverse than originally thought. A challenge is the detection and characterization of planetary systems consisting in a mixed cortege of telluric and giant planets, with a special regard to telluric planets orbiting in the habitable zone (HZ) of Sun-like stars. The accomplishment of this goal requires the development

of a new generation of facilities. The proposed NEAT mission has been designed to enter a new phase in exoplanetary science by delivering an enhanced capability of detecting small planets at and beyond 1 AU through high-accuracy astrometry.

2. The NEAT science

The prime goal of NEAT is to detect and characterize planetary systems orbiting bright stars in the solar neighborhood that have a planetary architecture like that of our Solar System or an alternative planetary system 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. Special emphasis will be put on planets in the Habitable Zone because this is a region of prime interest for future astrobiology missions. The principle of NEAT 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, down to a given limit (e.g. 0.5, 1 or $5 M_{\oplus}$) depending on the star characteristics. The astrometric amplitude, A in μas , of a M_* mass star due to the reflex motion in presence of a M_P mass planet orbiting around with a semi-major axis a at a distance D from the Sun is:

$$A = 3 \left(\frac{M_P}{1 M_{\oplus}} \right) \left(\frac{a}{1 AU} \right) \left(\frac{M_*}{1 M_{\odot}} \right)^{-1} \left(\frac{D}{1 pc} \right)^{-1} \quad (1)$$

To detect such a planet, one needs to reach a precision $\sigma = A/\text{SNR}$ with a typical signal-to-noise ratio $\text{SNR} = 6$. If in one visit the achievable attainable accuracy is σ_0 (e.g. $\sigma_0 = 0.8 \mu\text{as}$ in 1 h), one can show that about $N_{\text{visits}} \approx 50$ are sufficient to solve for the parameters of 3 to 5 planets per system.

We considered a list of the nearest F, G, K stars deduced from the Hipparcos 2007 catalogue, disregarding spectroscopic binaries, and stars with an activity level 5 times greater than that of the Sun because of their astrometric noise (only 4% of the sample [1]). The NEAT targets are brighter than $V = 6$, and therefore will not be investigated by GAIA because of its brightness limit. In that respect, NEAT observations will be complementary to Gaia's ones.

3. The NEAT concept

Our goal is to detect the signal corresponding to the reflex motion of a Sun-like star at 10 pc due to an Earth-mass planet in its habitable zone, with an equivalent final SNR of 6. That astrometric signal is $0.30 \mu\text{as}$. The required noise floor is $0.05 \mu\text{as}$.

The proposed mission is based on a concept recently proposed by M. Shao and his colleagues that results from the experience gained in working with many astrometry concepts (SIM [2], SIM-Lite, coronagraphy). The concept is sketched in Fig. 1 and consists of an off-axis parabolic 1-m primary mirror, a focal plane 40 m away, and metrology calibration sources. The distance between the primary and the focal plane can be implemented as two spacecrafts flying in formation, or a long deployed boom. The focal plane with the detectors has a field of view of 0.6° . It has a geometrical extent of $0.4 \text{ m} \times 0.4 \text{ m}$. The focal plane is composed of eight 512×512 visible CCDs located each one on an XY translation stage while the central two CCDs are fixed in position. The CCD pixels are $10 \mu\text{m}$ in size. The principle of the measurement is to point the spacecraft so that the target star, which is usually brighter ($R \leq 6$) than the reference stars ($R \leq 11$), 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. The fringes have their optical wavelengths modulated by acoustic optical modulators (AOMs) that are

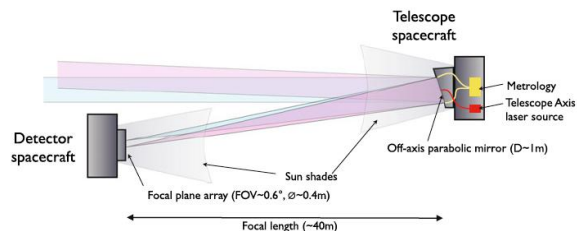


Figure 1: Possible concept for a very high precision astrometry mission. It consists in two separated modules, the first one carrying the primary mirror and the second one the detector plane.

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 (inter-, and intra-pixel dependence). The CCDs are read at 50 Hz.

4. Summary and Conclusions

In the Cosmic Vision plan for 2015-2025, the community identified the following need: *"On a longer timescale, a complete census of all Earth-sized planets within 100 pc of the Sun would be highly desirable. This could be achieved with a high-precision terrestrial planet astrometric surveyor."* We have designed NEAT to be this astrometric surveyor. Because of these recommendations, we believe that there is a place for a mission like NEAT in future space programs capable of detecting and characterizing planetary systems partly composed of Earth-mass planets.

Acknowledgements

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