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NEAT: Nearby Earth Astrometric Telescope

F. Malbet (1), A. Léger (2), A. Crouzier (1), M. Shao (3), R. Goullioud (3), P.-O. Lagage (4), L. Labadie (5) and the NEAT team
(1) Institut de Planétologie et d'Astrophysique de Grenoble (IPAG), UMR 5274, UJF-Grenoble 1/CNRS-INSU, BP 53, 38041 Grenoble cedex 9, France, (2) Institut d'Astrophysique Spatiale (IAS), UMR 8617, Université Paris Sud/CNRS-INSU, Bât. 120-121, 91405 Orsay cedex, France, (3) Jet Propulsion Laboratory (JPL), California Institute of Technology, 4800 Oak Grove Drive, Pasadena, CA 91109, USA, (4) Laboratoire AIM, UMR 7158, CEA-IRFU/CNRS-INSU/Université Paris Diderot, CEA Saclay, Bât 709, 91191 Gif-sur-Yvette Cedex, France, (5) I. Physikalisches Institut der Universität zu Köln, Zülpicher Str. 77, 50937 Köln, Germany (labadie@ph1.uni-koeln.de)

Abstract

NEAT (*Nearby Earth Astrometric Telescope*) is a candidate space mission whose goal is an exhaustive astrometric search of exoplanets down to 1 $M_\oplus$ around all 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 μas 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 ESA M4 call-for-mission.

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 Sun-Like 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. NEAT 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 very 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 σ = A/SNR with a typical signal-to-noise ratio SNR = 6. If in one visit the achievable attainable accuracy is σ_0 (e.g. σ_0=0.8 μas in 1 h), one can show that about $N_{\rm 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 μas. The required noise floor is 0.05 μas.

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 m$\times$0.4 m. The focal plane is composed of eight 512$\times$512 visible CCDs located each one on an XY translation stage while the central two CCDs are fixed in position. The CCD pixels are 10 μm in size. The principle of the measurement is to point the spacecraft so that the target star, which is usually brighter (R$\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 are modulated by phase modulators 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 Quantum Efficiency of the pixels (inter-, and intra-pixel dependence). The CCDs are read at 50 Hz.

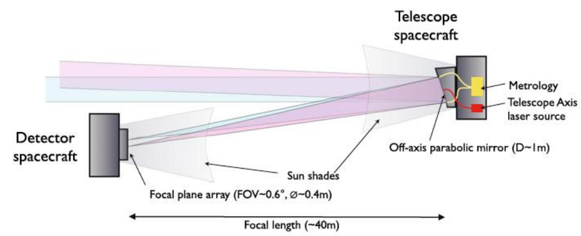

Figure 1: Possible concept for a very high precision astrometry mission. It consists in two separated modules, the first one carrying the primary mirror and the second one the detector plane.

4. Actual status

Since 2011, the team has been working on three main directions: (1) laboratory demonstration of the astrometric performance and in orbit demonstration of formation flying configuration (2) double bind test effort to demonstrate the detection capability and (3) exploration of other mission configuration (STEP and micro-NEAT).

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.

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