MICROARCSECOND ASTROMETRY TELESCOPE ON THE DSG I. Hahn, M. Shao, and S.G. Turyshev, Jet Propulsion Laboratory, 4800 Oak Grove Drive, Pasadena, CA. inseob.hahn@jpl.nasa.gov

Introduction: The Microarcsecond Astrometry Telescope (*MAT*) is a relatively small size (~0.5m) astrometric telescope on the Deep Space Gateway (DSG), which extends astrometric accuracy beyond that of the current space telescopes to a microarcsecond (μas) level, by measuring and correcting systematic errors in the telescope optics and the focal plane. The key technologies in this *MAT* instrument concept have been matured in ground testbeds and other flight systems, and will enable the μas-level astrometric measurements in a ~1-2 hours of integration on bright stars.

The primary science objectives of the *MAT*, are to conduct a set of unique astrophysics, and fundamental physics investigations relying on precision astrometric measurements. Through its ultra-precise, relative astrometry, the *MAT* can address many prime open questions in astrophysics and fundamental physics, namely:

1. *MAT* will be able to find a ~1$M_\oplus$ planet at 1AU (scaled to solar luminosity) orbiting one of the nearest ~60 FGK stars. This census of habitable exoplanets is crucial for future exobiology missions. The current estimate is ~20% of solar-like stars could have an Earth-like planet in or near the habitable zone. *MAT* can inform future direct exo-Earth imaging and spectroscopy missions, Habex or Luvoir, what stars to avoid because they do not host Earth like planets, and, equally important, to inform those missions to "keep looking" if the first few attempts at imaging fails because the planet is inside the inner working angle of the coronagraph, starshade or interferometer. *MAT* will measure the inclinations of ~10^3 RV planets and remove the *sin(i)* mass ambiguity, as well as find ~10^3 new Jupiters.
2. *MAT* will advance cosmology by determining the small-scale properties of the dark matter (DM) in the local Universe. It will be the first space observatory designed to test for signatures of models beyond the Standard Model of particle physics, and either confirm or invalidate Cold Dark Matter (CDM) and various theories of primordial inflation. *MAT* will: (i) examine whether DM in the inner part of faint dwarf spheroidal galaxies is cuspy or more homogeneously distributed; (ii) determine whether the outer halo of the Milky Way is prolate; (iii) detect small DM halos by finding the gravitational perturbations they have left on the Milky Way disc; and (iv) test inflationary models by detecting ultra-compact mini-halos of DM.
3. The instrument will serve as a pathfinder for a future stand-alone astrometric satellite to conduct a set of investigations recommended by the recent Decadal Surveys including the search and study of exoplanets, and investigations in cosmology, astrophysics, and fundamental physics.

Instrument description: *MAT* will conduct a set of unique investigations relying on a precision astrometry. It will use a stable telescope with in-orbit calibratable focal plane to perform differential astrometric measurements of nearby stars. It will also perform targeted astrometric observations of extragalactic sources. The *MAT* payload concept includes i) a single 3-mirror anastigmatic telescope with a ~0.5-m primary mirror and laser metrology subsystems, and ii) a camera. The camera focal plane array (FPA) consists of a multiple detector array, providing a Nyquist sampled FOV of 0.4°. The laser metrology subsystems will perform detector's position, QE, dark level calibrations, to ensure that *MAT* instrument can achieve ~1 μas astrometric precision in a couple of hours, which is needed to detect habitable exoplanets in our stellar neighborhood.

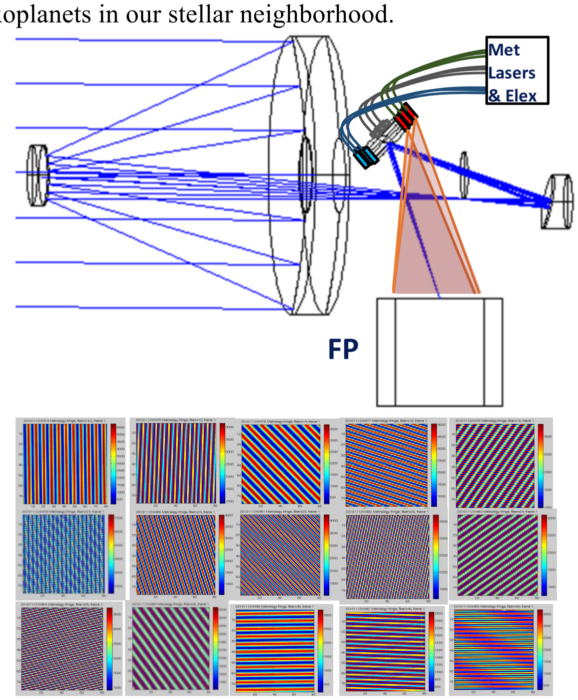

Figure 1. A concept demonstrating the on-orbit FP calibration laser metrology system with a TMA telescope (top) and an example image from our laser metrology testbed showing laser fringes of multiple spatial frequencies (bottom).

The *MAT* instrument would be a ~0.5 m telescope with a large focal plane, 0.4° field of view (FOV) with the point-spread function (PSF) being Nyquist-sampled, and with the metrology systems that will calibrate out the instrumental errors in the focal plane and the telescope optics at the μas level. It will be located on the exterior surface of the DSG, and will have a thermal system for good stability. High precision observations can be performed within the estimated mission life time of 3 years. The conceptual drawing for the *MAT* instrument is shown in Fig.2.

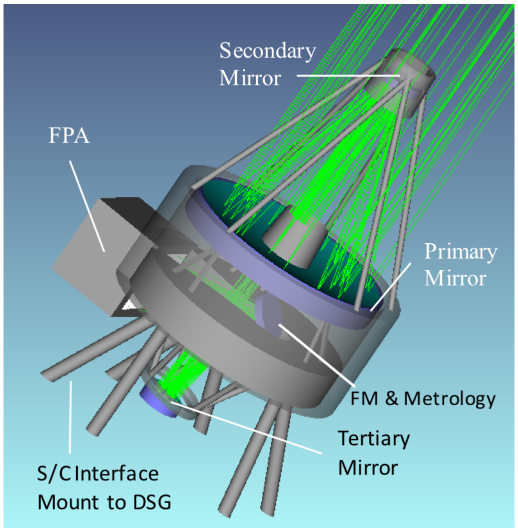

Figure 2. A conceptual drawing of the *MAT* instrument. A shun-shield, light baffles, and thermal radiator are not shown.

The instrument will weigh 65-90 kg, including a gimbal and ~30-50 kg for thermal radiator. *MAT* will occupy an estimated volume of <1.0 m^3 and will require ~70W electrical power. The *MAT* will generate a total estimated data volume of ~100 GB for the entire 3 years of its anticipated operational time. The instrument will be thermally insulated from extremal mounting fixtures. In general, very stable temperature environment is desired for observations. An ideal orbit would allow to observe sources with the Sun-exclusion angle of ~45°.

The cost of the robotic *MAT* mission would be in the range ~$75-90M, including technology maturation and data analysis. The astronaut involvement and potential servicing may allow for cost reduction.

Technology Readiness: Most of the required technologies for *MAT* are mature. For example, a large number of even larger, 1-m telescopes have been flown in space. There are three technology areas where flight qualification should be addressed. One is the on-board metrology system to measure the geometry of the FPA. All of the components, such as lasers, modulators, fibers have been flown in space, but the system was not flown. The second technology is the diffractive pupil, should we decide to use it as a primary mean for a field distortion calibration. A diffractive mask on the primary optics is passive, hence there should be no major issues with respect to flight qualification. The main technology challenge is putting it on a large optic (~0.5m). A potential third technology is a laser metrology system to measure changes in the alignment of the telescope/focal plane. Again, all individual components have flight heritage, but a *MAT*-like system is not yet flight qualified.

Conclusion: Unlike the Doppler and transit methods, only *astrometry* can determine the true mass and three-dimensional orbital geometry of an exoplanet reliably and precisely, which are the fundamental inputs to models of planetary evolution, bio signature identification, and habitability. With recent advances in detector calibration techniques, newly-developed flight metrology techniques, availability of the highly-precise astrometric catalogues, and existence of various mission concepts, a space astrometry mission is an ideal candidate for the future standalone mission.

1-μas astrometry in general and with *MAT* in particular, has the potential to bring major advances in many fields of modern astrophysics, namely: 1) discover most of the potentially habitable planets around the nearest ~100 stars to the Sun, 2) directly measure their masses and system architectures, and 3) provide the most complete target list and vastly improve the efficiency of detecting potential habitats of complex exo-Life with the next generation space and ground-based telescopes.

The μas-level astrometry will be a new tool for precision cosmology. By studying the gravitational perturbations in the local Universe, *MAT* can determine the small-scale properties of the DM. This space-based observatory will provide unique opportunities to study the signatures of models beyond the Standard Model of particle physics and fields, not available otherwise; it will either confirm or invalidate CDM and various theories of primordial inflation.

MAT will also push high-precision tests of gravity into a new regime. It will explore the physics of the universe by measuring the curvature of space-time around the Sun, represented by the parameterized-post Newtonian Eddington's parameter γ, reaching the accuracy of 1×10^{-6} (today's best is 2.3×10^{-5}).