The Joint Milli-Arcsecond Pathfinder Survey (J-MAPS) Mission: Application for Space Situational Awareness

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ABSTRACT

Rapid and accurate threat assessment and characterization are key elements in the quest for space superiority. These often depend on rapid orbit determination, accurate orbit propagation and object characterization. Threat scenarios involving new launches or vehicle maneuvers demand rapid and precise position metrics to determine and propagate new orbital elements. Existing and planned ground and space-based optical surveillance systems are optimized for the detection of Resident Space Objects (RSOs), which unfortunately, compromises their ability to determine position metrics at the highest possible accuracy levels. A Space Situational Awareness (SSA) architecture would potentially benefit from supplementing existing and planned detection assets with a dedicated high metric accuracy orbit determination asset or assets, with the potential for 24/7 taskability and near-real time capability. By optimizing an instrument to perform position measurement rather than detection, significant improvement may be realized in rapid orbit determination vs. current and envisioned systems, enabling rapid and accurate threat assessment and characterization.

The United States Naval Observatory (USNO) is developing the space-based J-MAPS mission to support current and future star catalog and star tracker requirements. By its very nature, USNO's J-MAPS mission, a microsatellite designed to take very high precision measurements of star positions (astrometry), is ideally suited to make high metric accuracy measurements for brighter GEO RSOs. The J-MAPS mission will demonstrate novel and innovative measurement techniques and technologies, including new focal plane technologies such as CMOS-Hybrid active pixel sensors. The J-MAPS baseline also includes a novel filter-grating wheel, of interest in the area of non-resolved object characterization. We discuss the status of the J-MAPS mission, including the current mission baseline, and discuss Space Situational Awareness applications of the J-MAPS mission, including RSO orbit determination and SOI.

1. INTRODUCTION

The Joint Milli-Arcsecond Pathfinder Survey (J-MAPS) is a space astrometry mission scheduled for launch in the 2011—2012 time frame. The primary objective of the mission, consistent with the Navy mission as described in relevant DoD Directive and JCS instructions, is to observe all bright stars, measure their positions and parallax to 1 milli-arcsecond (mas) accuracy and determine proper motion to 1 mas yr^{-1} and generate a new, 2012—epoch star catalog.

The instrument and spacecraft required is optimized to determine stellar positions with very high accuracy. The same instrument can be used to observe resident space object (RSO) positions (e.g. for geosynchronous and other high-altitude orbits), and using the background grid of reference stars—determined to very high accuracy as a result of the main mission—determine the position of the RSO with very high metric accuracy. These measurements can then be used to derive orbital solutions with unprecedented accuracy. In addition, the photometric- (i.e., brightness) and color-sensing capabilities, used to measure starlight, can also be used to characterize RSO health.

In this paper, we discuss the J-MAPS instrument and these capabilities. Currently, the mission is designed to spend 90% of mission time performing the astrometric (and related) observations over the mission life; up to 5% of the mission time may be available for SSA-type experiments, including both high metric accuracy orbit determination and photometric/spectroscopic (i.e., color) observations.

2. INSTRUMENT AND SPACECRAFT DESCRIPTION

Instrument: The baseline J-MAPS instrument is a 7.5”, ultra-low distortion, on-axis optical/near IR (NIR) telescope, an advanced, CMOS-Hybrid focal plane assembly (FPA), and supporting, on-board readout, control and processing electronics (see Fig. 1). Total instrument mass is approximately 30 kg, and orbital average power use by the instrument is approximately 100 W. The telescope optics and metering structure are composed of Silicon Carbide in order to achieve maximum stiffness-to-weight and to control thermal effects. The CMOS-Hybrid FPA combines CCD-like performance with the flexibility of a CMOS readout, supporting advanced capabilities. The readout electronics using SIDECAR application specific integrated circuits (ASICSs) technology developed for NASA’s James Webb Space Telescope (JWST) and Hubble Space Telescope (HST) programs, is optimized to both control the CMOS-Hybrid FPA as well as digitize the output signals.

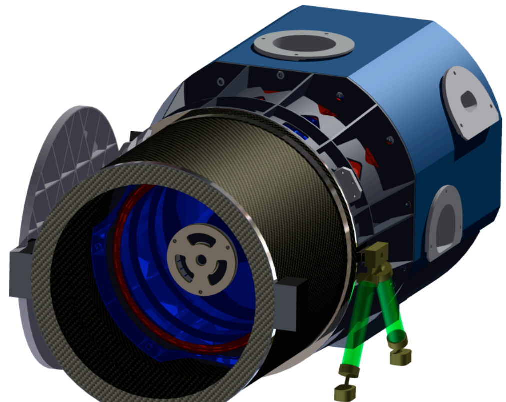

Fig. 1. J-MAPS Optical Telescope Assembly. The telescope observes in the visible and near-IR (NIR) portion of the spectrum and includes dispersive spectral gratings.

The primary bandpass for astrometry is approximately 700—900 nm (NIR, close to astronomical I band). A filter wheel system also includes a broad-band channel and two reflective gratings.

The combined instrument has a 1.1° field of view (FOV). Stars will be measured to a positional accuracy of 5 mas per exposure, with 1 mas positional accuracies presented in the final catalog. When these angular measurements are converted to a linear measurement at a GEO orbit, the single exposure stellar grid accuracy is 1 m, with the final catalog providing a reference grid of backgrounds stars good to 20 cm. The noise equivalent magnitude (NEM) is 14.2 for the astrometric band.

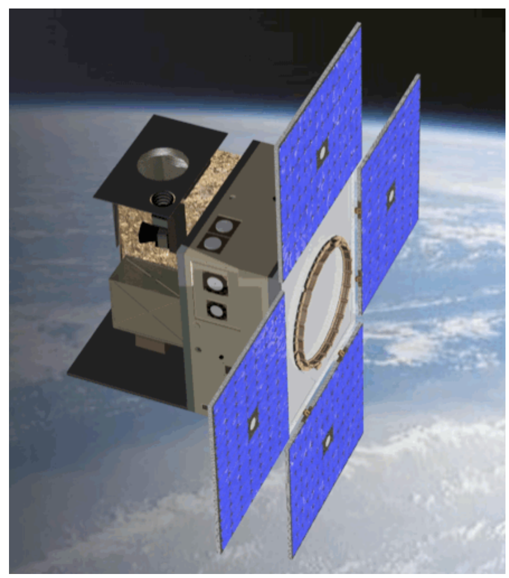

Fig. 2. J-MAPS spacecraft. The spacecraft mass is approximately 114 kg. It is deployed in a 900-km sun synchronous orbit.

Spacecraft: The J-MAPS spacecraft consists of the payload deck (hosting the instrument) and a microsat bus, as shown in Fig. 2. The baseline design uses a customized AeroAstro Astro200 bus. Pointing control at the 50 mas level is enabled by using the primary instrument as the attitude determination system (ADS) fine guidance sensor. This is made possible by the unique readout capabilities of the CMOS-Hybrid sensor. The current baseline is required to meet a two year mission with 90% certainty; in order to accomplish this, the entire system is designed with selective component redundancy. The baseline orbit is a 900 km Sun Synchronous terminator orbit, thus affording more-or-less constant viewing of the brightest regions of the GEO belt. Tracking modes include both sidereal (i.e., star) and orbital rate (e.g., GEO) tracking.

3. APPLICATIONS

Precise, Rapid Orbit Determination: The J-MAPS instrument, as described above, is designed to emphasize position measurement above all else. As such, it is not the result of a compromise between multiple design drivers. One implication of this is that the instrument can physically resolve satellites at smaller separations than current and existing optical SSA assets, thus allowing for resolution of constellation components.

A second implication is that instantaneous plane-of-sky positional measurements of extremely high metric accuracy are possible, enabling rapid RSO orbit determination with unprecedented accuracy. It is important to note that since J-MAPS is in a LEO, its orbit provides a trigonometric parallax baseline; observations separated by 55 minutes (one half a J-MAPS orbit) are also separated by approximately 14,000 km.

In order to quantify the effects on orbit determination, contractors supporting U.S. Air Force Space Command (AFSPC) A-5 and A-9 performed covariance analyses using a variety of different observing assumptions. Their results have been presented elsewhere and are available upon request. To summarize, the J-MAPS satellite may be capable of determining orbits at unprecedented accuracy levels, even when the orbits are projected 24 hours into the future. This capability, once demonstrated on-orbit, will be critical for conjunction analysis and orbit deconfliction. By generating much small error volumes around satellites, the number of maneuvers required by satellites will be significantly reduced.

The current baseline design of the J-MAPS system supports approximately 40 very high accuracy orbits per day. Design modifications, if desired, could increase that significantly.

High Precision Photometry: The J-MAPS instrument will be extremely well calibrated both on the ground and on-orbit by the nature of the observations being made. The instrument is being designed to achieve better than 1% photometric precision over the mission life, and a combination of on-board, stellar and ground-based reference sources will be used to tie the instrument to absolute radiometric standards.

The instrument will thus be able to detect very small variations in the light curve of RSOs, and allow analysts to perform time-series analyses in order to identify, classify, detect changes in and infer the state of specific RSOs.

Spectral Observations: J-MAPS will also access spectral (i.e., color) data for both stars and RSOs using two reflective gratings. A low-resolution grating will provide basic color data while preserving high signal-to-noise ratio (SNR) for fainter targets. A moderate resolution grating will provide more finely resolved color data, allowing for more detailed analysis of color at the expense of SNR.

In addition to dispersing incoming light into a spectrum, gratings also have the useful property of allowing some fraction of the incoming light to pass without being spectrally dispersed. This so-called "zeroth order" data is point-like in appearance and can be used for both position and photometric measurements. Thus, J-MAPS will be able, in principle, to simultaneously measure position, brightness and color for multiple objects over the field of view simultaneously. This concept has been demonstrated from the ground at the Naval Observatory's Flagstaff Station (NOFS) (see Fig. 3).

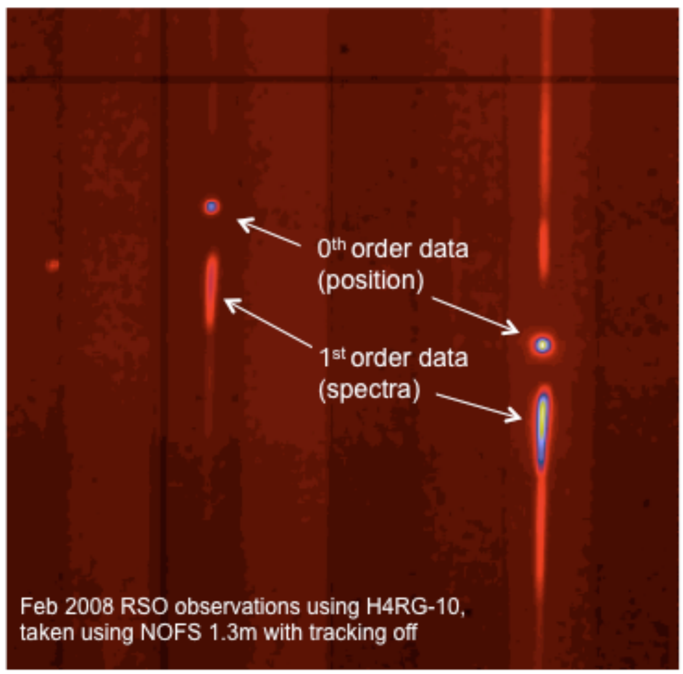

Fig. 3. Two RSOs and spectra observed using spectral grating and pathfinder CMOS-Hybrid focal plane assembly.

4. SUMMARY

J-MAPS is a space astrometry mission intended for launch in the 2011/2012 timeframe. The unique astrometric (position measuring) nature of the instrument combined with the photometric and spectroscopic measurement capabilities make it a potentially powerful SSA asset. J-MAPS intends on performing a limited number of SSA experiments during the primary mission. The mission is soliciting assistance from potential users of the data to help specify observational requirements, set up the experiments, and analyze the data. These experiments could be directed at a variety or purposes, including testing new concepts, characterizing the accuracy of specific concepts, and quasi-operational observations of targets of interest.

A major issue that potential users could help address is whether the mission should be designed for a post-primary mission operational phase. There are no consumables on board and the CMOS-Hybrid FPA technology is more radiation-tolerant than CCDs. As a result, it is possible that the satellite could function for a decade or more as an operational asset. Additional selective redundancies could be added to the design to significantly increase the probable mission life if there is desire to do so.

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