Metrology for Space-based Science Missions

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The desire for higher angular resolution, greater sensitivity and dynamic range has driven the trend towards large collecting area and ultra-precise optics on space-based observing systems. No longer capable of being launched as monolithic units, these systems are being implemented as deployable structures or distributed over multiple spacecraft. Precise metrology is increasingly important for the stabilization of these large distributed systems, in which tolerances are often measured in picometers.

There are a number of challenges to be faced in developing a metrology system for such applications. In addition to the great precision that is often demanded, the systems must be guaranteed to operate without human intervention for mission durations of 5 to 10 years, after surviving the stress and vibration of launch and the radiation environment of space. Mass and power are extremely valuable commodities, and materials must be carefully chosen to avoid contamination. The failure of the metrology could compromise missions that may cost in excess of $1 billion.

A wide range of current and future space science missions are dependent on metrology. Example applications include Synthetic Aperture Radar (SRTM), measurement of the Earth's gravity field (GRACE), measurement of stellar positions (GAIA, SIM-PlanetQuest), direct imaging of Earth-like planets around other stars (TPF-C, Darwin, TPF-I), detection of gravity waves (LISA), and imaging of black hole event horizons (Black Hole Imager). This presentation will describe two of these– the SIM-PlanetQuest and TPF-I missions – in more detail, followed by a summary of the MSTAR absolute metrology system that has been developed at the Jet Propulsion Laboratory.

The Space Interferometry Mission (SIM) is an optical interferometer with a baseline ~10 m, designed to measure the positions of stars to within 4 microarcseconds – an exquisite level of accuracy far beyond the current capability. Scheduled for launch in 2010 with a cost of $1 billion, SIM is essentially one big metrology experiment, demanding precision at the 10's of picometer level. An extensive technology development effort has demonstrated the technical feasibility of the mission, and detailed design is underway. The basic principle of operation is described.

The Terrestrial Planet Finder Interferometer (TPF-I) will directly image Earth-like planets around nearby stars at mid-infrared wavelengths. To achieve the angular resolution needed to separate the planet from the star, the collecting apertures are located on separate spacecraft flying in formation, and relay their beams to a central combiner spacecraft. The array is phased to null the light from the star which is some 10 million times brighter than the planet. Effective nulling requires that the pathlengths through the instrument are controlled at the 1 nm level.

The MSTAR (Modulation Sideband Technology for Absolute Ranging) system was designed to address the needs of missions such as TPF-I. Based on phase modulation of a single stable laser, we have demonstrated absolute range accuracy of 100 nm in the lab, sufficient to resolve the integer cycle ambiguity of the optical phase measurement. The system is briefly described, along with a plan to demonstrate MSTAR on the Space Technology 9 mission.