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SPACE INTERFEROMETER CONSTELLATION: FORMATION MANEUVERING AND CONTROL ARCHITECTURE

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Abstract

Concepts for optical space interferometers have been proposed for over a decade. A number of single-structure configurations have been studied and tested. Practical limitations of deployment constrain monolithic structures to collecting aperture separation baselines on the order of 100 meters. Longer baselines on the lunar surface would still be limited by surface curvature to about 10 km. imaging angular resolutions at visible wavelengths fine enough to characterize extra-solar Jupiter size planets and to detect exo-Earth size planets require interferometer baselines on the order of 100 km. For this capability separated multiple spacecraft interferometry is the only feasible approach.

Unlike filled aperture telescopes, resolution (baseline) and sensitivity (total collecting area) are independent variables in an interferometer so that very high resolutions are possible with a dilute array of small apertures of 0.5 m to 1 m. This leads to the concept of an advanced Multiple Sciencecraft Interferometer Constellation (MUSIC) that can be realized with a modest number of 16 small starlight collector sciencecraft (< 200 kg including electric propulsion) arrayed in a Cornwell-ring formation about one combiner sciencecraft of similar size. This array geometry allows a more optimum u-v plane coverage. The concept for MUSIC resulted from a 1995 study by a JPL team which examined the parameter space for an ambitious interferometer architecture that is along the technology path for characterizing extra-solar planets.

The constellation is deployed using a Lunar swingby trajectory into a long time-constant quasi-stable orbit at the 1,2 Lagrange point. This provides a very low disturbance environment with near zero gravity-gradient effects, and enables low energy orbit maintenance and replacement of sciencecraft for an extended observatory lifetime.

Following deployment the constellation geometry is formed using a GPS derived relative position and orientation sensor system to initialize the locations of each sciencecraft to an accuracy of a few centimeters. Then laser metrology links between collectors and combiner are established leading to fine acquisition and calibration of the array optical links to the nanometer level. From 2 to 4 laser metrology beams may be used by each collector to achieve the required "spatial stiffness" of the array.

The 16 *collector sciencecraft* relay starlight to a Michelson *combiner sciencecraft* located on center above the plane of the ring formation. The geometry of the constellation is that of an f/0.5 parabolic reflector. At a baseline of 100 km the propagation distance from each collector to the combiner is 70 km, 3-D stationkeeping control to several millimeters and laser metrology between adjacent collectors, and between selected collector nodes and the combiner replace the elements of a monolithic structure, providing in effect an "optical truss". The combiner line-of-sight to the target star provides the reference for an inertially stabilized constellation.

To further enhance the 3-D space rigidity of the system a second "mirror combiner" is added to the optical truss below the plane of the collector array and a laser beam connects the two combiners. The system geometry is now that of a "spoked wheel" with the axis between the two combiners serving as the "axle". The constellation is transformed into a "virtual interferometer observatory" which behaves as an equivalent rigid body under the direction of a multi-level distributed autonomous command and control system.

In addition to stationkeeping and infrequent orbit maintenance maneuvers, there are three global movements or reconfiguration of the constellation as a science instrument that take place. These are baseline expansions or contractions of the array along each collector's radius vector, retargeting of the constellation by formation pivoting about the Cornwell aperture tip and tilt axes, and aperture filling rotation of the formation about the target line-of-sight. At a given baseline, a full set of predetermined targets is observed before changing to the next baseline and recalibrating the system.

During science data acquisition, with the collectors placed irregularly on the circumference of the Cornwell ring, the interferometer aperture u-v plane is sufficiently filled by a slow 180 degree rotation of the wheel about its axle. The collectors do not rotate about their body axes, rather they arc translated along the Cornwell circle by rectilinear accelerations in the plane of the circle using pulsed-plasma micro-thrusters (PPT's). This provides the required tangential and centripetal balance of forces for tracking the curvilinear trajectory about the target star line-of-sight represented by the "axle" of our constellation. Operating with baselines of 1 km to 100 km such an observatory can explore visible light resolutions of 100 E-6 arcseconds down to 1 E-6 arcseconds (ex-Jupiter planet characterization).

This paper focuses on the MUSIC science observation phase maneuvering and control system architecture, instrumentation, dynamic and autonomous control laws, fuel requirements and electric propulsion trades. Results provide insights into the implementation issues, control technology needs, and architectural vision for space interferometers in the new millennium.

Keywords: constellation, virtual interferometer, aperture baseline, extra-solar planets, optical truss.

Biography:

Edward Mettler has been with JPL's Avionic Systems Division for over 24 years. He has been the task leader for Modeling and Robust Control Synthesis research, team leader for Autonomous GN&C technology development, and GN&C lead for the Tactical Imaging Constellation Architecture design. He has held prior positions as systems engineer for the Precision Segmented Reflector Figure and Vibration Control, cognizant ACS engineer for the Defense Communications Satellite Autonomy design, Voyager spacecraft ACS systems engineer and technical manager. He has 10 NASA Awards for technology innovations, a JPL Outstanding Group Achievement award for the Tactical Imaging Constellation design, and a NASA Outstanding Group Achievement Award for the Voyager ACS design. He has a BSME from the [University of Massachusetts, and his graduate work is in Applied Mathematics at Adelphi University, and Control Systems at UCLA. He is a Senior Member of the AIAA, member of SPIE and AAS, and has published many papers in technical journals and conferences.

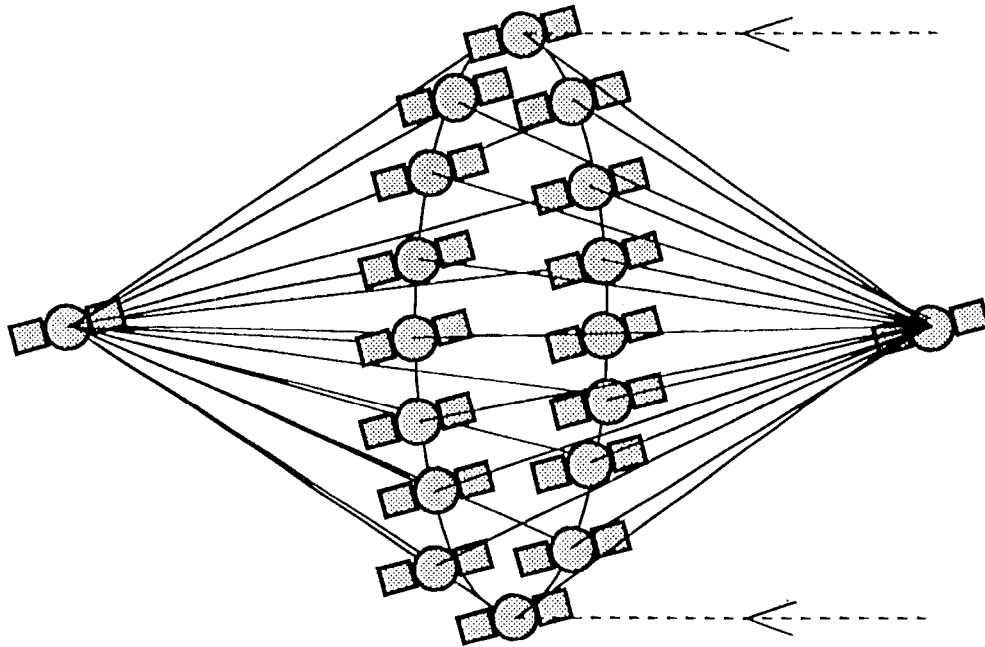


Figure 1. MUSIC concept for multispacecraft interferometer using 16 Collector spacecraft and 2 Combiner spacecraft

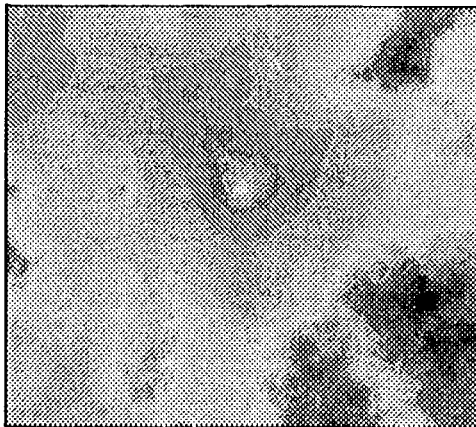


Figure 2. Typical celestial image reconstructed from (u,v) plane measurements