

## Formation Flying of Components of a Large Space Telescope

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A conceptual space telescope having an aperture tens of meters wide and a focal length of hundreds of meters would be implemented as a group of six separate optical modules flying in formation: a primary-membrane-mirror module, a relay-mirror module, a focal-plane-assembly module containing a fast steering mirror and secondary and tertiary optics, a primary-mirror-figure-sensing module, a scanning-electron-beam module for controlling the shape of the primary mirror, and a sunshade module.

Formation flying would make it unnecessary to maintain the required precise alignments among the modules by means of an impractically massive rigid structure. Instead, a control system operating in conjunction with a metrology system comprising optical and radio subsystems would control the firing of small thrusters on the separate modules to maintain the formation, thereby acting as a virtual rigid structure. The control system would utilize a combination of centralized- and decentralized-control

methods according to a leader-follower approach.

The feasibility of the concept was demonstrated in computational simulations that showed that relative positions could be maintained to within a fraction of a millimeter and orientations to within several microradians.

*This work was done by Edward Mettler, Marco Quadrelli, and William Breckenridge of Caltech for NASA's Jet Propulsion Laboratory. For more information, contact [iaoffice@jpl.nasa.gov](mailto:iaoffice@jpl.nasa.gov). NPO-45199*

## Laser Metrology Heterodyne Phase-Locked Loop

*NASA's Jet Propulsion Laboratory, Pasadena, California*

A method reduces sensitivity to noise in a signal from a laser heterodyne interferometer. The phase-locked loop (PLL) removes glitches that occur in a zero-crossing detector's output [that can happen if the signal-to-noise ratio (SNR) of the heterodyne signal is low] by the use of an internal oscillator that produces a square-wave signal at a frequency that is inherently close to the heterodyne frequency.

It also contains phase-locking circuits that lock the phase of the oscillator to

the output of the zero-crossing detector. Because the PLL output is an oscillator signal, it is glitch-free. This enables the ability to make accurate phase measurements in spite of low SNR, creates an immunity to phase error caused by shifts in the heterodyne frequency (i.e. if the target moves causing Doppler shift), and maintains a valid phase even when the signal drops out for brief periods of time, such as when the laser is blocked by a stray object.

*This work was done by Frank Loya and Peter Halverson of Caltech for NASA's Jet Propulsion Laboratory. Further information is contained in a TSP (see page 1).*

*This invention is owned by NASA, and a patent application has been filed. Inquiries concerning nonexclusive or exclusive license for its commercial development should be addressed to the Patent Counsel, NASA Management Office-JPL. Refer to NPO-40080.*

## Spatial Modulation Improves Performance in CTIS

**Computed spectra are more accurate when scenes have spatial structure.**

*NASA's Jet Propulsion Laboratory, Pasadena, California*

Suitably formulated spatial modulation of a scene imaged by a computed-tomography imaging spectrometer (CTIS) has been found to be useful as a means of improving the imaging performance of the CTIS. As used here, "spatial modulation" signifies the imposition of additional, artificial structure on a scene from within the CTIS optics.

The basic principles of a CTIS were described in "Improvements in Computed-Tomography Imaging Spectrometry" (NPO-20561) *NASA Tech Briefs*, Vol. 24, No. 12 (December 2000), page 38 and "All-Reflective Computed-Tomography Imaging Spectrometers" (NPO-20836),

*NASA Tech Briefs*, Vol. 26, No. 11 (November 2002), page 7a. To recapitulate: A CTIS offers capabilities for imaging a scene with spatial, spectral, and temporal resolution. The spectral disperser in a CTIS is a two-dimensional diffraction grating. It is positioned between two relay lenses (or on one of two relay mirrors) in a video imaging system. If the disperser were removed, the system would produce ordinary images of the scene in its field of view. In the presence of the grating, the image on the focal plane of the system contains both spectral and spatial information because the multiple diffraction orders of the grating give rise to multiple, spectrally dispersed images of the scene.

By use of algorithms adapted from computed tomography, the image on the focal plane can be processed into an "image cube" — a three-dimensional collection of data on the image intensity as a function of the two spatial dimensions ( $x$  and  $y$ ) in the scene and of wavelength ( $\lambda$ ). Thus, both spectrally and spatially resolved information on the scene at a given instant of time can be obtained, without scanning, from a single snapshot; this is what makes the CTIS such a potentially powerful tool for spatially, spectrally, and temporally resolved imaging.

A CTIS performs poorly in imaging some types of scenes — in particular, scenes that contain little spatial or spectral

variation. The computed spectra of such scenes tend to approximate correct values to within acceptably small errors near the edges of the field of view but to be poor approximations away from the edges. The additional structure imposed on a scene according to the present method enables the CTIS algorithms to reconstruct acceptable approximations of the spectral data throughout the scene.

The structure can be imposed in any of a number of alternative ways. In preliminary experiments, the structure was imposed by means of a digital multi-mirror device at the field stop in an all-

reflective-optics CTIS. Any of the mirrors could be turned on or off to make a desired pattern. The optimum pattern has not yet been determined; a checkerboard pattern was used in the experiments. (In one alternative, in the case of refractive optics, the structure could be imposed by use of a suitably patterned opaque mask at the field stop.) A full image could be acquired by shifting the pattern by use of software or by moving the mirror device or mask.

*This work was done by Gregory H. Bearman, Daniel W. Wilson, and William R.*

*Johnson of Caltech for NASA's Jet Propulsion Laboratory.*

*In accordance with Public Law 96-517, the contractor has elected to retain title to this invention. Inquiries concerning rights for its commercial use should be addressed to:*

*Innovative Technology Assets Management  
JPL*

*Mail Stop 202-233  
4800 Oak Grove Drive  
Pasadena, CA 91109-8099*

*E-mail: iaoffice@jpl.nasa.gov*

*Refer to NPO-41557, volume and number of this NASA Tech Briefs issue, and the page number.*