Wide-field spatio-spectral interferometry for far-infrared space applications

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The NASA Astrophysics Roadmap includes a space-based far-IR interferometer in the 2020s, as well as several later interferometry missions for which a far-IR interferometer sets the stage. Such a mission has been steadfastly recommended by the far-IR community for over a decade, as multiple high-priority science goals demand high sensitivity, spectroscopy, and imaging in the spectral range ~ 25 - 400 µm with sub-arcsecond angular resolution (see SPIRIT poster), better than that practically attainable by any other means.

The three major enabling technologies for a far-IR interferometer are: low-noise, high-speed detectors in small (~16² pixel) arrays; a demonstrated capability to cool optical system components to ~4 K and focal planes to tens of mK with cryo-coolers; and the spatio-interferometry (“double Fourier”) technique through which wide-field integral field spectroscopic data can be derived from interferometric measurements.

This poster reports on the current status of wide-field spatio-spectral interferometry and plans for maturation of the technique to space-flight readiness. Thus far, relatively simple spatial-spectral test patterns have been observed with the Wide-Field Imaging Interferometry Testbed (WIFT) at NASA’s Goddard Space Flight Center, and hyperspectral image cubes representing the observed scenes have been constructed based on the measured interferograms. A critical future milestone is the accurate construction of an astronomically realistic, spatially and spectrally complex scene.

Objects and Methodology

The goal of this project is to develop the wide-field spatio-spectral interferometry technique to NASA Technology Readiness Level 6 (TRL 6) from its current readiness level 3 for the space-based far-IR interferometer SPIRIT (see panel to the right). This is somewhat analogous to the maturation of Webb Telescope and Control for WHT. Specifically, our aim is to demonstrate wide-field spatio-spectral interferometry in a relevant environment with a laboratory testbed: characterize all error and noise terms relevant to space-based far-IR interferometry, and produce spatio-spectral synthesis software capable of processing data from a mission-like SPIRIT.

The Figure below illustrates key elements of our approach (Leisawitz et al., 2012), which can be summarized as follows:

- **Observe astrophysically realistic test scenes with an optical scale model (hardware testbed) equivalent to SPIRIT in terms of functionality, operation, and factors that limit data quality.**
- **Compare observed interferograms with those predicted by a high-fidelity computer model of the testbed in which error terms associated with individual hardware components are modeled and can be switched on or off.** Understand and document the effects of all significant error terms and sources of fringe visibility loss.
- **Compare hyperspectral test image cubes derived from the interferometric data with “truth images” of the observed test scenes.**
- **Determine residual differences between the derived output and measured input images in terms of factors relevant to a far-IR interferometer in space, such as imperfect optical system alignment, optical components and detectors, undersampling of the spatial/frequency components, photon noise, motion smoothing due to interferometer rotation, and artifacts associated with image construction.**

The Space Interferometric Telescope (SPIRIT)

A Probe-class far-IR mission designed to:

- Image protostellar disks and measure the distributions of water vapor and/or to know how the conditions for habitability arise during the planet formation process.
- Image structures in a large number of debris disks to find and characterize unseen exoplanets.
- Make profound contributions to our understanding of the formation, merger history, and star formation history of galaxies.

Calibrated Hyperspectral Image Projector (CHIP)

The CHIP uses Digital Light Processing (DLP) technology to produce the communication spectrally diverse scenes we observe in the lab. CHIP scenes have spatial resolution finer than that realizable with the interferometer. Each CHIP pixel can take on a unique spectrum in the wavelength band 0.2 - 14 µm with approximately 3 mm spectral resolution. Spectral calibration is achieved with an on-board fiber coupled spectrometer. The yellow line in the photograph above traces the optical path through the system. See Bolcar et al. (2012) for details.

Schematic view of the WIT

The testbed performance is well understood:

- **Input “truth images”**
- **Computer Optical System Model of WIT**
- **Computed Optical System Model of WIT**
- **Wide-Field Imaging Interferometry Testbed (WIFT)**
- **Calibrated Hyperspectral Image Projector (CHIP)**

Represented testbed data:

- A combination of spatial and spectral information is encoded in the interferograms:
  - Measured interferograms
  - Predicted interferograms

Comparison of measured and predicted interferograms:

- Source spectrum: M1 star (75K, 6.7 - 11.5 µm)
- Band: NIST traceable
- Baseline: 110 mm, F/
- Measured interferogram
- Predicted interferogram
- CPD (°)
- SHAF (degree)
- SHRF (degree)

Our computational optical system model (COSMO) predicts interferograms that closely match those seen in the lab. The model error sources can be identified individually, all at once (“unraveled”), and deconvolved to predict the performance of an ideal interferometer.

Future Plans:

During the next two years, we aim to:

- **Demonstrate excellent agreement between synthesized interferometric data cubes and observed, astronomically real “truth images.”**
- **Systematically account for any measured differences in terms of understood instrumental effects, and completely verify the performance of a hyperspectral image construction algorithm.**

Acknowledgments:


The Wide-Field Imaging Interferometry Testbed (WIFT) works at visible wavelengths for convenience and to save cost, but it is functionally and operationally equivalent to the space-based far-IR interferometer SPIRIT.