Experimental twin telescope enables new scientific studies

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The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) is a potent new astronomy tool that operates on a high-altitude balloon.

Astronomical studies at IR wavelengths have revolutionized our understanding of galaxies, stars, and planets, as well as their origins. But further progress on major questions has been stymied because the spatial resolution of single-aperture telescopes degrades at long wavelengths. Exciting physical processes lie beneath our current far-IR (FIR) resolution, including clustered-star formation, powerful interactions between normal matter and monstrous black holes at the cores of galaxies, and planetary systems’ formation. Interferometry is a path to high angular resolution in the FIR, making it extremely useful for scientific discovery.

Cold objects (<100K), such as collapsing cloud cores in the earliest stage of star formation, emit most of their radiation at wavelengths longer than ~30μm. At later stages, protostars are surrounded by dust, which absorbs short wavelength radiation in the UV and optical ranges and reradiates at IR wavelengths. On a much larger scale, distant galaxies are at high red shifts, which pushes important spectral features to longer wavelengths. These examples highlight the unique potential of IR observations. Unfortunately, the opacity and emission from the Earth’s atmosphere limit ground-based IR astronomy. By getting above most, if not all, of the atmosphere, this difficulty can be avoided.

The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII) project is a collaboration between NASA’s Goddard Space Flight Center and the University of Maryland, with assistance from the Far-Infrared Telescope Experiment team in Japan.1 It has an 8m boom and operates in the FIR (30–90 μm) on a high-altitude balloon (see Figure 1). When it is flown, the long baseline will provide unprecedented angular resolution (~0.5") in this band. These wavelengths are inaccessible from the ground. The high atmospheric transmission at balloon altitudes, combined with BETTII’s unique double-Fourier instrument, will allow spectral resolution of up to

Figure 1. The 8m boom of the BETTII will provide angular resolution of ~0.5" at 40mm. Carbon fiber construction creates a stiff boom structure while keeping the overall payload weight low.

R = λ/Δλ ~ 200 (see Figure 2). By combining these capabilities, BETTII will provide spatially-resolved spectroscopy on astrophysically-important sources. BETTII’s first flight will isolate the FIR emission from forming stars in cluster environments, allowing us to tightly constrain cluster-formation models.

The scientific goals of BETTII drive key technical requirements for its design. BETTII is a Michelson interferometer combining the light from two separated collector mirrors (siderostats) at a 50/50 beam splitter in the pupil plane. A scanning optical delay line is used to vary the optical path difference between its two arms. The interferometric fringe pattern is recorded on the detector. Relative astrometric information is derived from the optical path difference between the fringe packets corresponding to discrete sources. The angular size of a source can be determined from the ratio of the fringe amplitude to that from an unresolved calibration source. The fringe envelope contains spectral information. Thus, an interferometer like BETTII, when used to observe a source with a large number of baselines, yields integral field-spectroscopic data or a spatial-spectral data cube.

One of the greatest technical challenges for an interferometer is to control jitter to a small fraction of the observed wavelength. Should the payload vibrate, the path-length difference between the two interferometer arms can change at relatively high frequencies. This leads to the fringes blurring, which in turn causes loss of signal-to-noise ratio and complications with data

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Figure 2. By observing at different times, BETTII obtains data at different baseline orientations by taking advantage of the Earth’s rotation (a). This enables accurate derivation of the relative positions of sources unresolved by the BETTII’s primary beam from the fringe packets’ position as measured by the zero path difference point, where the two arms of the interferometer are exactly in phase. Simultaneously, the spectrum of each source is derivable from the corresponding fringe envelope (b), as shown in (c) via Fourier transform. RA: Right ascension. Dec: Declination.

analysis. However, a combination of knowledge and control can effectively mitigate the effects of jitter. BETTII will use both a laser metrology system and a near-IR (NIR) fringe tracker. The laser metrology system provides knowledge of the optical path difference to within 0.2 μm at frequencies above 10Hz, allowing accurate reconstruction of the interferometric fringes. The NIR fringe tracker monitors the path length difference between the two arms by measuring the NIR source’s fringe pattern. Feedback from the NIR sensor allows mitigation of low frequency (<10Hz) oscillations due to undamped payload motions.

A successful flight of BETTII will pave the way for future space interferometry by demonstrating key technologies, including wide-field phase referencing for image reconstruction and the technique of double-Fourier interferometry. A traditional Michelson interferometer uses a single detector and has a field of view determined by the size of the individual light collecting apertures. By using a detector array, one observes interferograms corresponding to multiple contiguous primary beams simultaneously on different pixels. This technique—wide-field double Fourier interferometry—has been demonstrated in a laboratory testbed, but never in a flight-like environment.\(^3\)

Assuming funding support, the first flight of BETTII is planned for Spring 2015. Acquired data will be complementary to observations with space observatories such as Herschel and the James Webb Space Telescope, exploring the FIR wavelength range with unprecedented high angular resolution. These data will serve as powerful tools for understanding star formation in clusters. Further, BETTII will validate technologies and retire risks for future space interferometers, such as the Space Infrared Interferometric Telescope.\(^3\)

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References