The Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII)

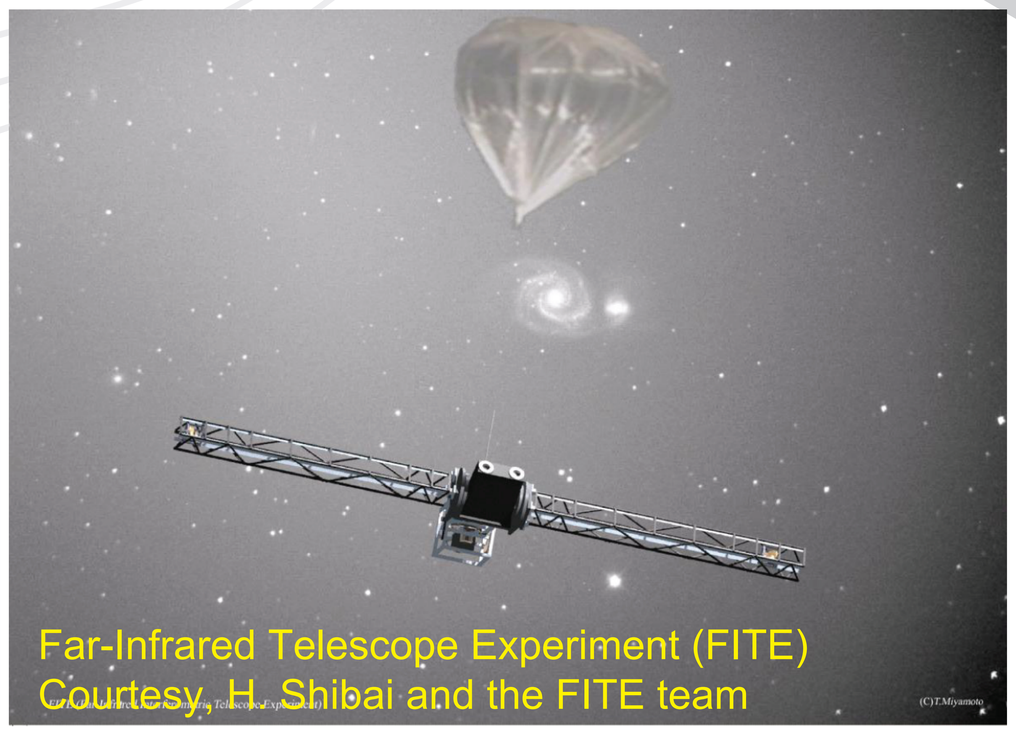
S. A. Rinehart[1], C. Allen[1], R. K. Barry[1], D. Benford[1], W. Danchi[1], D. Fixsen[2], D. Leisawitz[1], L. Mundy[2], R. Silverberg[1], J. Staguhn[2]

1: NASA's Goddard Space Flight Center
2: University of Maryland, College Park

Contact : SAR at Stephen.A.Rinehart@nasa.gov

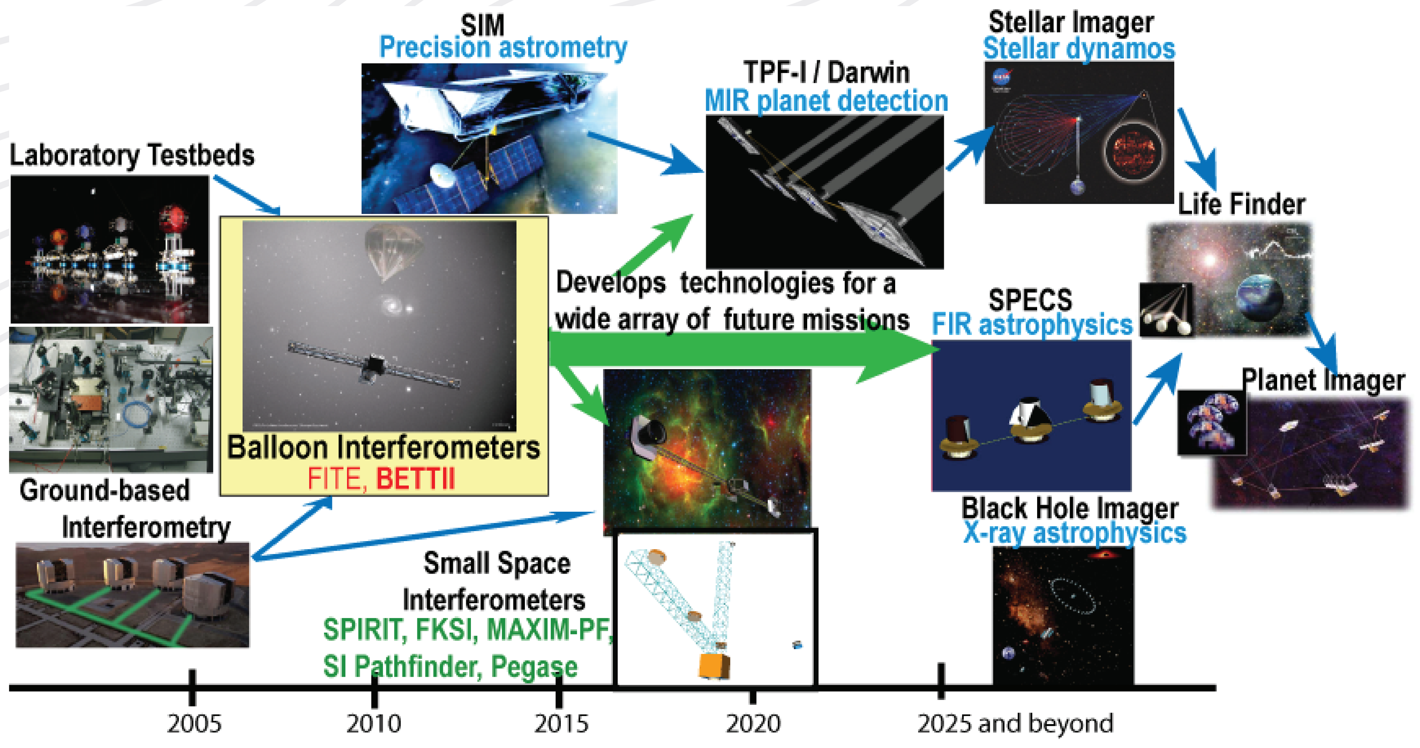
NASA/GSFC
UNIVERSITY OF MARYLAND

Abstract:
Astronomical studies at infrared wavelengths have dramatically improved our understanding of the universe, and observations with Spitzer, the upcoming Herschel mission, and SOFIA will continue to provide exciting new discoveries. The relatively low angular resolution of these missions, however, is insufficient to resolve the physical scale on which mid- to far-infrared emission arises, resulting in source and structure ambiguities that limit our ability to answer key science questions. Interferometry enables high angular resolution at these wavelengths - a powerful tool for scientific discovery. We will build the Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII), an eight-meter baseline Michelson stellar interferometer to fly on a high-altitude balloon. BETTII's spectral-spatial capability, provided by an instrument using double-Fourier techniques, will address key questions about the nature of disks in young star clusters and active galactic nuclei and the envelopes of evolved stars. BETTII will also lay the technological groundwork for future space interferometers.

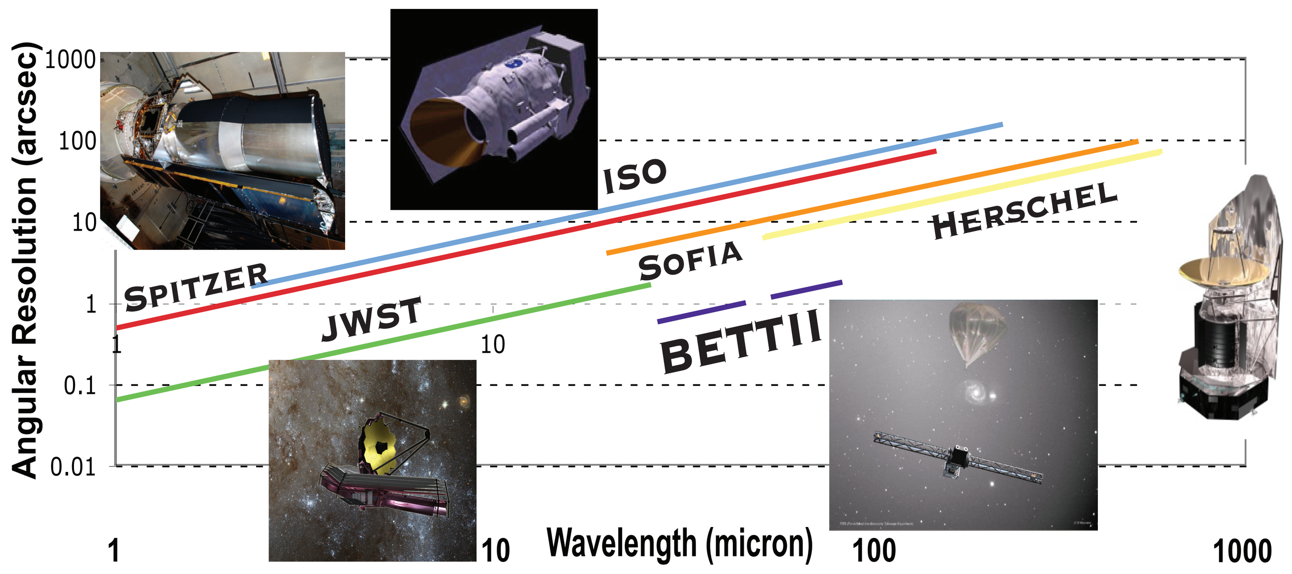


Far-Infrared Telescope Experiment (FITE)
Courtesy, H. Shibai and the FITE team

Design and fabrication of BETTII will be greatly simplified through our collaboration with the Far-Infrared Telescope Experiment (FITE) team in Japan, led by H. Shibai. FITE will provide the first demonstration of the technical feasibility of a balloon-borne interferometer, and BETTII will build on that experience to provide spatial-spectral data for studying star formation, evolved stars, and active galactic nuclei (AGN).



BETTII occupies a central place in the progression towards space-based interferometry. It will provide a clear demonstration of the technologies and methods needed for future space interfoerometers.



BETTII fills a critical need for high angular resolution in the FIR, with angular resolution 20x better than *Spitzer* at 30-50μm, a band outside the range of both JWST and *Herschel*. At 60-90μm, BETTII will provide angular resolution 6x better than *Herschel*.

Scientific Objectives and Technical Requirements

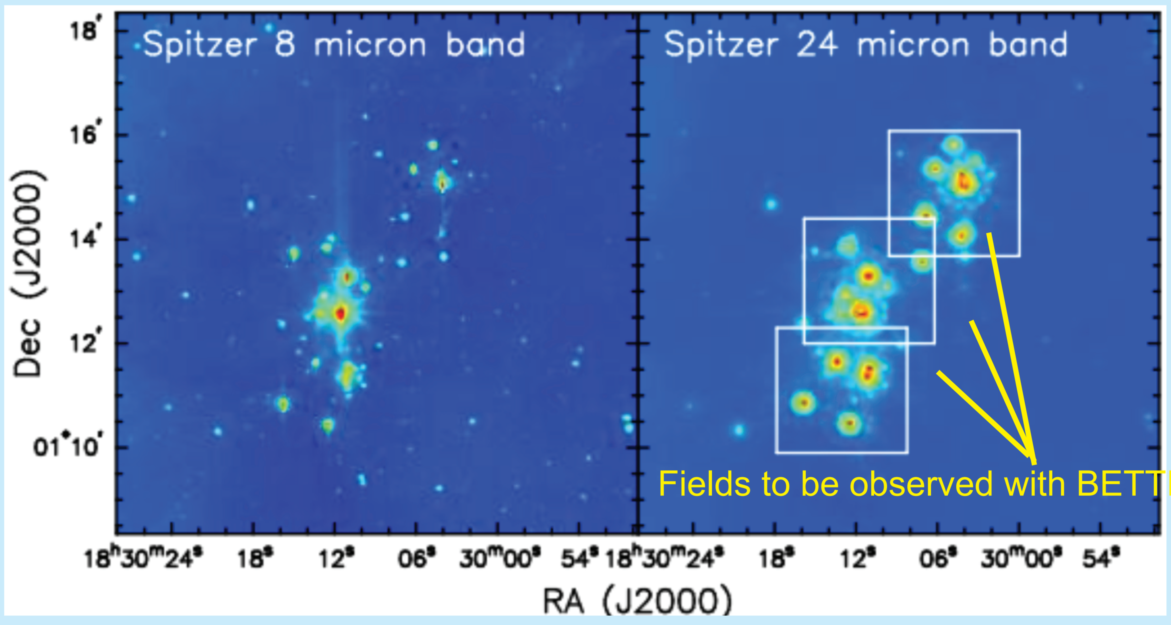
The high angular resolution data provided by BETTII will be valuable for exploring important scientific questions; our primary target for BETTTII's first flight will be a star formation region (Serpens); secondary observations willl allow us to examine evolved stars (μ Cep) and AGN (NGC 1068). The scientific objectives lead directly to the technical requirements for BETTII.

Our scientific goals lead to technical requirements for BETTII. We list the most significant of these here.

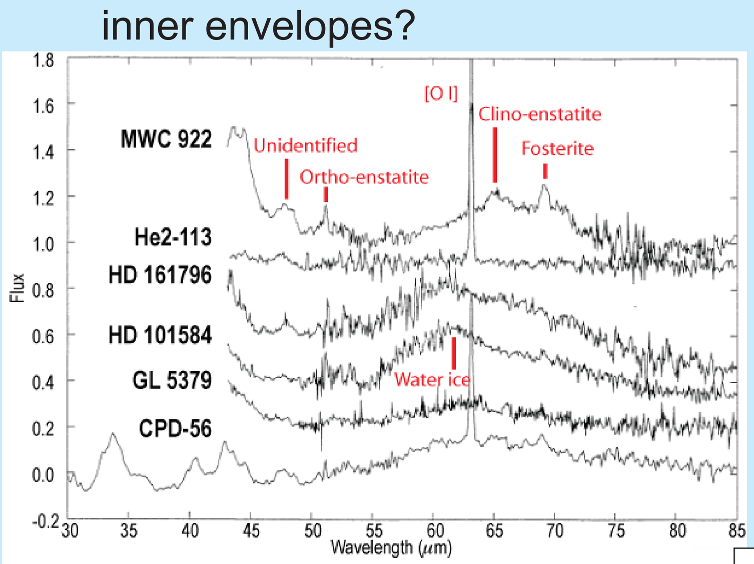
Parameter	Value	Science Requirement	Instrument Requirement
Field-of-View	2 arcmin	Coverage of young star clusters	8x8 detector arrays
Sensitivity	<10 Jy, 5σ, 10min.	Detection of cores in star clusters	Siderostat size, cryo-detectors
Spectral Resolution	R~20	Detection of broad spectral features	Delay line stroke length (>1.8mm)
Spatial Resolution	1 arcsec	Resolution of cores	8-meter baseline, Metrology[1]
Wavelength Range	30-90 μm	Map warm dust	BUG detector arrays
Pointing Stability	1.5"	Control of beam drift	Star Camera, Ring Laser Gyro
Pointing Jitter	0.1", >10 Hz	NIR fringe tracking capabilty	Stiff structure, vibration damping
Pathlength Knowledge	0.2 μm, >10 Hz	Knowledge of interferometric phase	Laser metrology

Footnote 1 - Spatial resolution is primarily dependent upon knowledge and control of the optical path lengths, not siderostat pointing.

The Science

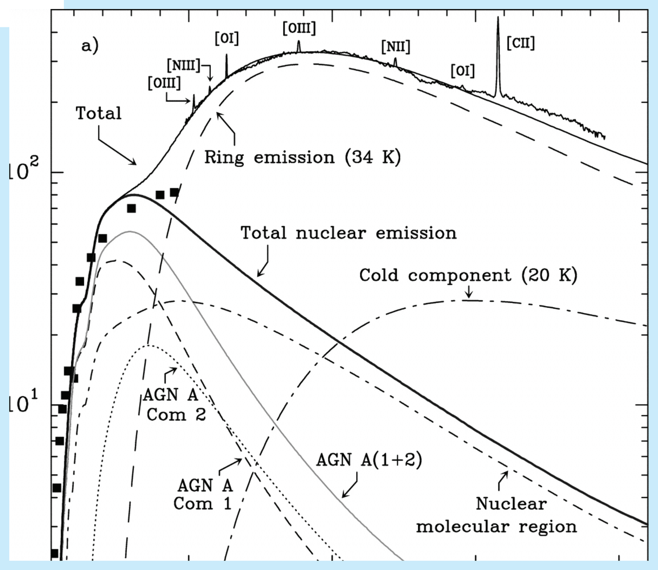


BETTII will address questions about star formation, including:
- Does star formation in clusters differ from that in isolated regions?
- What FIR emission arises from disks of individual stars? From inner envelopes?



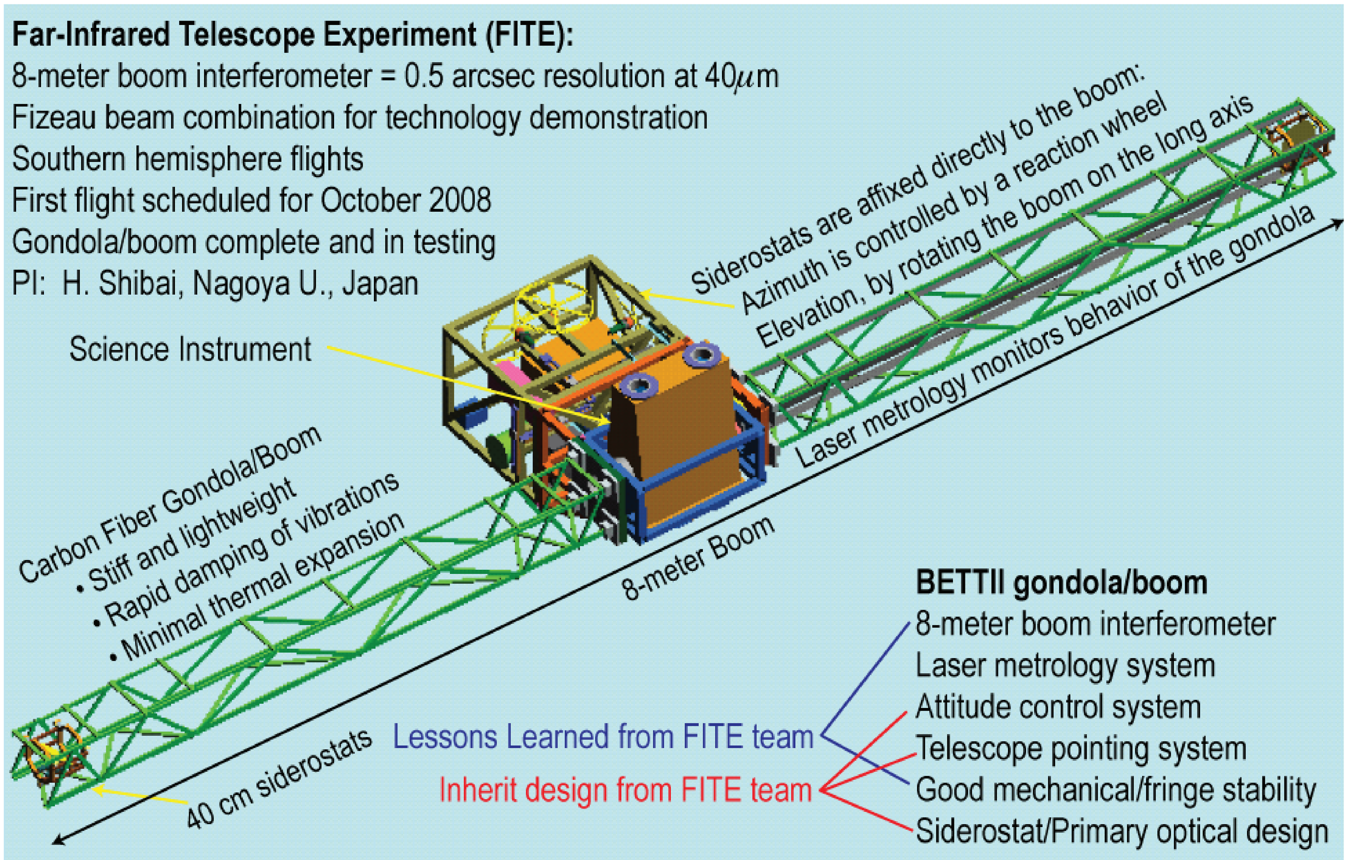
The rich spectral region explored by BETTII will address questions about evolved stars, including:
- How does dust form near evolved stars?
- How does it diffuse into the ISM?

BETTII will also enable new studies of AGN:
- What are the starburst energetics near the galactic nucleus?
- How do they differ from star formation in the outer starburst ring?

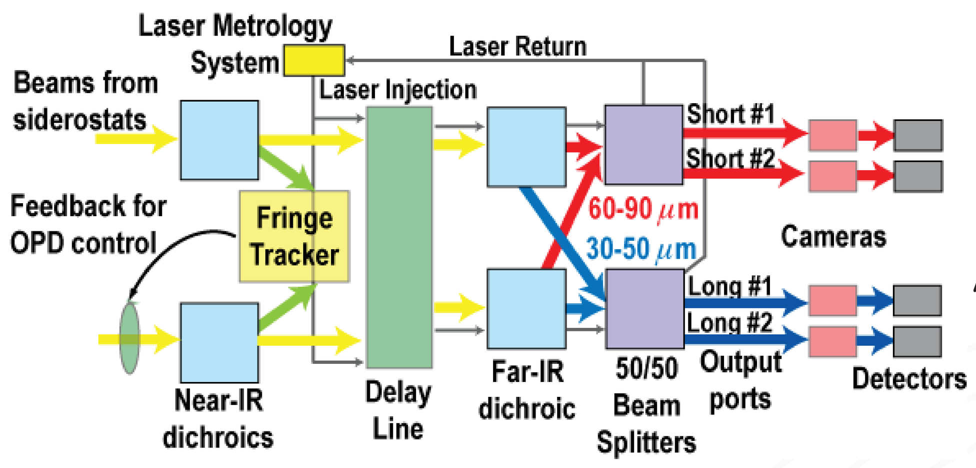


Development of BETTII will be undertaken through a collaboration between NASA's Goddard Space Flight Center and the University of Maryland, College Park, as well as with the FITE team in Japan. For further details, please contact S. Rinehart.

The Experiment



BETTII will take advantage of several elements of the FITE gondola, including carbon-fiber structure, attitude monitoring system, and the interferometer pointing system. We will also include a laser metrology system to ensure high-quality data.



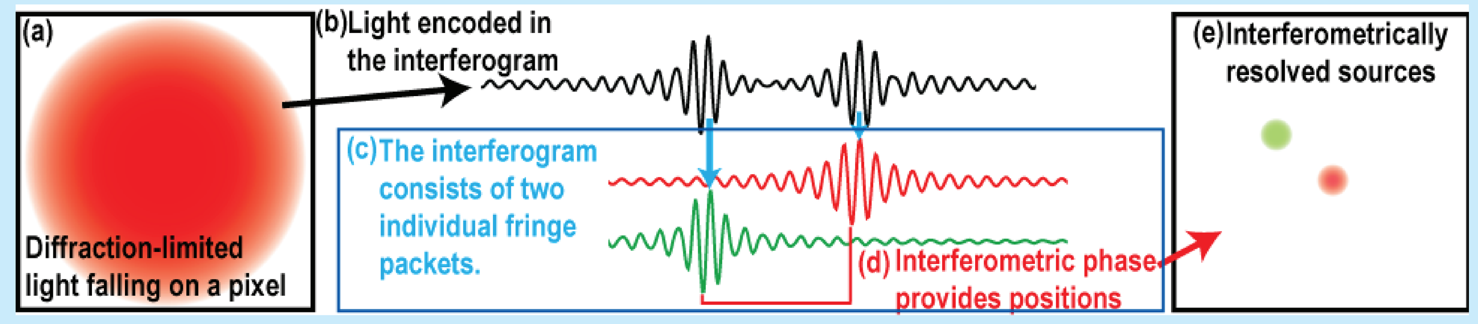
BETTII's optical design will give us high angular resolution in two bands (30-50 μm and 60-90 μm), with spectral resolutions of up to 200 and a wide field of view (2').

We identify technology risks, our mitigation strategies, and their current TRL.

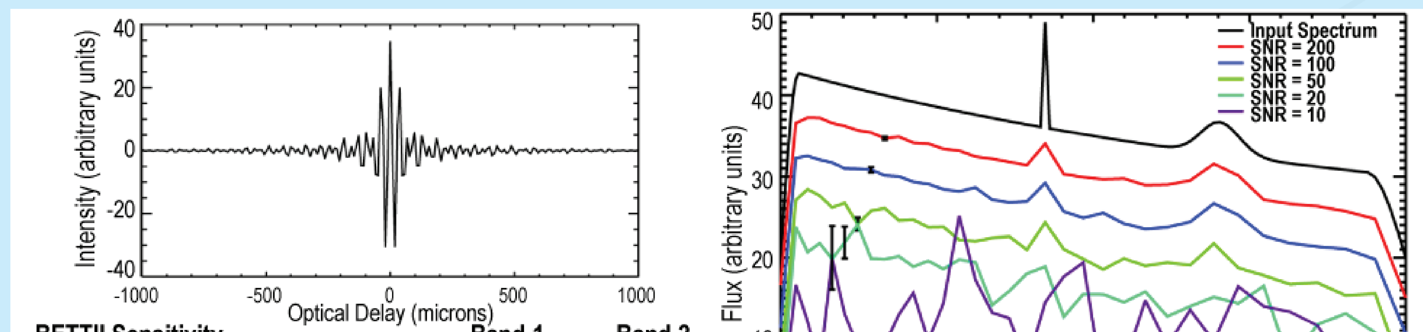
Element	Risk	Mitigation	TRL
Gondola	Medium	Analysis of FITE flights; GSFC experience with large balloon payloads	5
Delay Line	Low	Legacy of similar mechanisms at GSFC; leverage from internal funding	5
Detectors	Low	Similarity to existing detectors; detector development programs at GSFC	6
Integration	Low	Extensive team experience with balloon integration	-
Pointing System	Low	Sharing of FITE design; GSFC balloon experience; UMd experience with CARMA	5
Interferometric Stability	Low-Medium	FITE flight data and application of lessons learned; GSFC experience with WIIT; End-to-end ground testing of BETTII, including gondola and instrument	4
Delay Tracking	Medium	Leverage from internal funding; team experience with interferometer design	4

While BETTII faces several important technical challenges, we have attempted to develop mitigation strategies for each. Further, by addressing these issues with BETTII, we reduce risk for future space-borne interferometers.

Performance

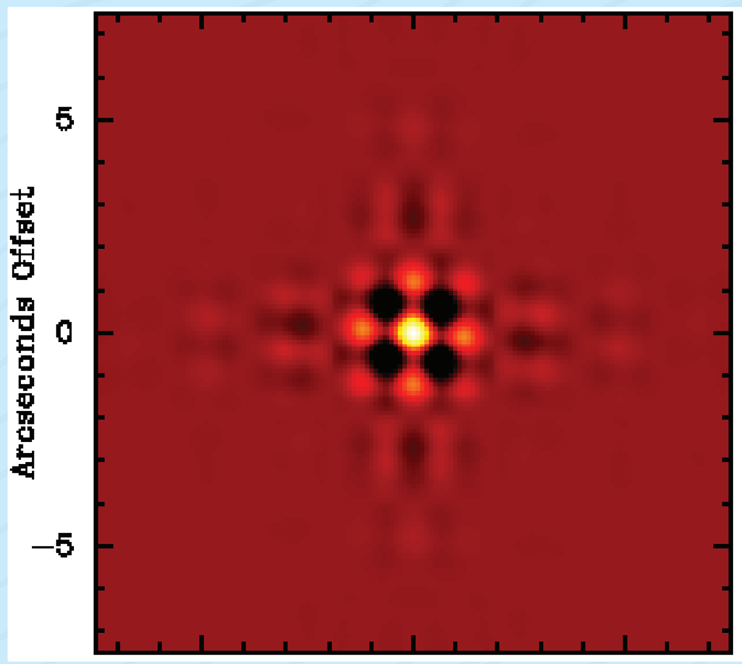


BETTII's double-Fourier design encodes both spectral and spatial information from a source into an interferogram. Relative phase between sources provides astrometric information, visibility of fringe packets contains angular information about individual sources, and the shape of the fringe packet contains spectral information.



BETTII Sensitivity (600 s, 5σ)	Band 1 (30-50μm)	Band 2 (60-90μm)
Photometric	4.1 Jy	3.9 Jy
Spectral Energy Distribution (R=3)	8.3 Jy	7.8 Jy
Broad Spectral Features (R = 10)	41.5 Jy	39.1 Jy

We have used Monte Carlo simulations of BETTII data to estimate the sensitivity. This sensitivity can be characterized by the SNR on the central fringe. Even with relatively low SNR, photometer and broad spectral energy distributions can be recovered, while at high SNR it may be possible to observe individual emission lines.



Using two observations at separate (u-v) points produces a PSF that is insensitive to extended emission but which has angular resolution of 0.5 arcsec for compact sources.