Probe-class missions in the far-infrared

M. J. Rizzo[1], S. A. Rinehart[2], D. J. Benford[2], L. G. Mundy[1], D. T. Leisawitz[2]
[1]University of Maryland, College Park, MD
[2]NASA Goddard Space Flight Center, Greenbelt, MD

In June 2015, members of the COPAG Science Interest Group 1 (SIG1) met at the Far-Infrared (FIR) Surveyor Workshop to discuss the scientific potential of future observations in the FIR, and potential mission architectures that would enable such observations. This led to the writing of a white paper *From Early Galaxies to Habitable Planets: The Science Case and Concept for a Far-Infrared Surveyor*, submitted to the COPAG. In the white paper, key scientific questions are identified, and a nominal architecture is presented, consisting of a large, cold, single-aperture telescope with a diverse and exquisitely sensitive instrument suite to provide imaging, spectroscopic, polarimetric and surveying capabilities. To maintain focus on the large FIR Surveyor mission concept, the white paper deliberately did not discuss the scientific benefits that would be achieved with smaller (<$1B) probe-class missions in the FIR. In this white paper, we briefly present several potential such missions, and encourage the COPAG to recommend the study of probe-class missions by NASA.

Why Probes? As can be seen in the SIG1 white paper, there is a wide range of scientific questions that can be addressed by a large, cold, single aperture, but these questions correspondingly span a wide range of observing requirements. To cover all of these observing requirements could potentially prove to be prohibitive with a FIR Surveyor, due to lifetime limitations, cost considerations, and/or system complexity. However, probe-class missions could provide complementary capabilities that would enhance the scientific value of a FIR Surveyor, or could be optimized to address a subset of the key science questions, allowing a simplification of the potential instrument suite for the FIR Surveyor. Such Probes would be smaller, dedicated observatories and would help develop the technologies (e.g. detectors, cryocoolers) needed for the FIR Surveyor. In fact, because of the shorter project life cycles, Probes could dramatically accelerate technology development, while also being more responsive to new discoveries from other facilities (e.g. JWST, ALMA) than is possible with a large mission with a long development cycle.

While the mission architectures for the FIR Surveyor, as discussed at the Workshop, were relatively well developed over the past decade, smaller probe-class missions need to be studied to determine their full scientific potential, their role as technology maturation platforms, and their overall costs. We provide here a few clear candidates for FIR Probes that would have significant scientific merit.

1. All-sky spectroscopic survey mission

Much of the key science for the FIR Surveyor is achieved through spectroscopic surveys. A Probe dedicated to an all-sky spectroscopic survey, albeit with a smaller aperture than the FIR Surveyor, could achieve the broadest science goals, allowing the FIR Surveyor to focus on targeted observations with higher spectral resolution, greater sensitivity, and/or small field maps which take advantage of its superior angular resolution. Scientifically, this survey would provide the richest dataset on galaxy evolution, detecting every ultraluminous galaxy (whether powered by star formation or AGN) out to a redshift of z~2, tracing both the rise of SMBH and stellar mass over time as the global star formation epoch subsides.

As a preliminary mission concept, we envision a 1m class, cryo-cooled single aperture with a single instrument at the back-end: a low-resolution (R~few hundred), wide-field spectrometer, coupled to a large format detector array. The observatory would conduct an all-sky survey using a "push-broom" technique, wherein the spectrograph slit is scanned across the sky in swathes. This would allow the mission to cover the entire sky approaching the confusion limit within a relatively short (few year) mission lifetime. A near-polar, sun-synchronous orbit for the observatory (similar to IRAS, COBE, and WISE) would meet the requirements of this Probe. Notably, a similar low-resolution spectrometer is envisioned for the FIR Surveyor, providing greater sensitivity but with more stringent noise and size requirements. This cryogenic Probe would advance the Technology Readiness Level (TRL) of key components of the FIR Surveyor (e.g. detectors, cryocoolers), while providing substantial return and allowing the larger FIR Surveyor to focus science on the high-sensitivity pointed observations of which it is capable.

2. Multi-epoch continuum survey mission

One area currently of great interest to the astronomical community is time-domain astronomy. Time-domain science covers a wide range of fields, from gamma-ray bursts to time-variable accretion to searches for Trans-Neptunian Objects (TNOs), all of which depend upon multi-epoch observations. By conducting an all-sky survey multiple times over the course of a ~2 year mission, and higher cadence targeted surveys, a mission operating at long wavelengths (25-400 microns) would provide data complementary to other ground and space based instruments.

Such a survey could be carried out with a 1-meter class cryo-cooled telescope, with four-band imaging in a single instrument. With a wide field of view, and taking advantage of the significant improvements in detectors achieved since Spitzer and Herschel, this Probe could survey the entire sky down the confusion limit very rapidly, and with orders of magnitude greater sensitivity than ever achieved in an all-sky survey at these wavelengths. Such a mission would be a particularly powerful machine for discoveries within our galaxy and within our own solar system. The sensitivity, saturation power, confusion limits, and mapping speed are all important considerations in the definition of such a mission, and in determining the full scientific capabilities, but historically such all-sky surveys have proven to have lasting value across a wide range of scientific endeavors. Such a mission, with the relatively simple instrument, would likely be most the cost-efficient of the Probes discussed here.

3. High-Angular Resolution Pointed Survey

While the FIR Surveyor Workshop resulted in the endorsement of a large, cryogenic single aperture telescope as the preferred architecture, a significant portion of the community favored the development of a FIR interferometer, providing significantly better angular resolution than the single aperture telescope in exchange for reduced sensitivity. The support for a FIR interferometer was driven both by its intrinsic scientific capabilities and by the recognition that future scientific questions may be addressed only by breaking from traditional space telescopes. Within the Astrophysics Roadmap, the value of interferometry was clearly identified, and all of the “Visionary Era” missions within the Roadmap are interferometers. Further, the Roadmap noted that since system requirements scale as the observation wavelength, a FIR interferometer is the logical first step towards the “Visionary Era” missions.

The white paper produced by the FIR Surveyor Workshop focused on the science that could be achieved with a single aperture telescope, but there are scientific questions that can be addressed only with the advantage of higher angular resolution. This is particularly true for Galactic astronomy. For example, a 12-meter-baseline interferometer at 100 microns is sensitive to structures as small as 8000 AUs at the distance of the Galactic center, probing the relevant scales for star formation. Such a small interferometer, with two ~60 cm cryogenic apertures and a central beam combiner would improve upon the sensitivity of *Spitzer* and *Herschel*, with an order of magnitude improvement in angular resolution. Operating in the 25-160 micron regime, the interferometer would have the sensitivity to pursue a wide range of Galactic science without requiring optics to be cooled to 4K. While a significant amount of study has gone into larger interferometer concepts, detailed study of the trade space between aperture size, baseline length, *u-v* coverage, and spectral resolution is needed.

Summary: While the FIR Surveyor, as envisioned within the SIG1 white paper, would be a powerful tool for scientific discovery, there is significant scientific value in examining Probe concepts such as discussed here. Such Probes would provide several key advantages:

1. Probes can pave the way for the FIR Surveyor, providing complementary data and greatly improving the efficiency of a FIR Surveyor.
2. Probes can address some of the key science questions identified for the FIR Surveyor, on shorter timescales and at a much lower cost.
3. Probes can accelerate technology maturation necessary for the FIR Surveyor, and for future flagship missions in the far-IR
4. An interferometric Probe would provide the fundamental system-level demonstration needed to make space-based interferometry viable at other wavelengths.
5. Probes can carry out powerful scientific campaigns that will reduce requirements on the FIR Surveyor by allowing it to focus on a more specialized instrument suite.
6. Any single FIR Probe will achieve several of these advantages, so while multiple concepts may be worth studying, these advantages will be realized even if only one comes to fruition.