MAXIMIZING SCIENCE CAPABILITY FOR FAR-INFRARED SPACE MISSIONS

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Abstract

The far-infrared and submillimeter region (20μm–800μm) has perhaps the greatest potential of all wavelengths for advancement in astronomy. When viewed in terms of the cosmic backgrounds, the far-IR is extremely important: half of the total luminosity in the Universe is emitted at rest wavelengths ~80–100 μm. At the highest known galaxy redshifts (z~6) this energy is redshifted to ~600 μm. Existing and planned missions have a broad range of capabilities, defined in terms of their spectral coverage, spectral resolution, angular resolution, mapping speed, and sensitivity. In this 5-dimensional parameter space, the far-IR is substantially be-hind most other wavelength bands. The opportunity for future missions with great discovery potential is evident. Such missions will be well-suited to answering fundamental questions about the history of energy release in the Universe, the formation and evolution of galaxies, and formation of stellar and protoplanetary systems. We discuss the parameter space that can be filled by a few well-chosen space missions, specifically a submillimeter all-sky survey and a far-IR to submillimeter observatory. Ultimately, a long baseline submillimeter interferometer is necessary to provide sensitivity and angular resolution.

Introduction

Your experience – if you are like most FIR/Submm astronomers – will fail you.

The majority of astronomers who observe in the FIR/Submm are familiar with the difficulties involved in using ground based (CSO, JCMT, HHT, etc.) telescopes and airborne (KAO, balloon) platforms. Much of the difficulty involved in making sensitive measurements is purely due to the weather and the warm telescope you're looking through. Even in space (Herschel), the telescope emission alone can be a tremendous degrading influence on the sensitivity of observations. Contrary to what this experience tells you, the FIR/Submm is the darkest region of the spectrum, as shown in Figure 1.

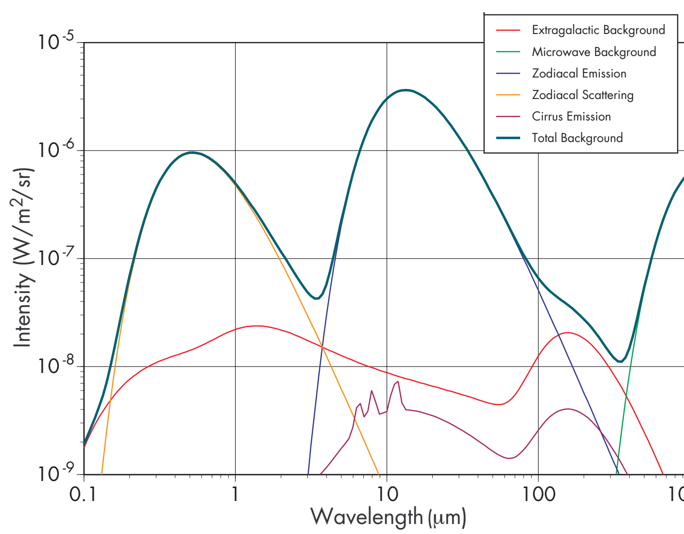


Figure 1. Extragalactic background light components; the darkest regions of the spectrum are at ~3μm and ~300μm.

Furthermore, the light from galaxies - shown in Figure 2 is a spectrum of the Milky Way - happens to be peaked at very nearly the darkest two regions of the UV to radio spectrum.

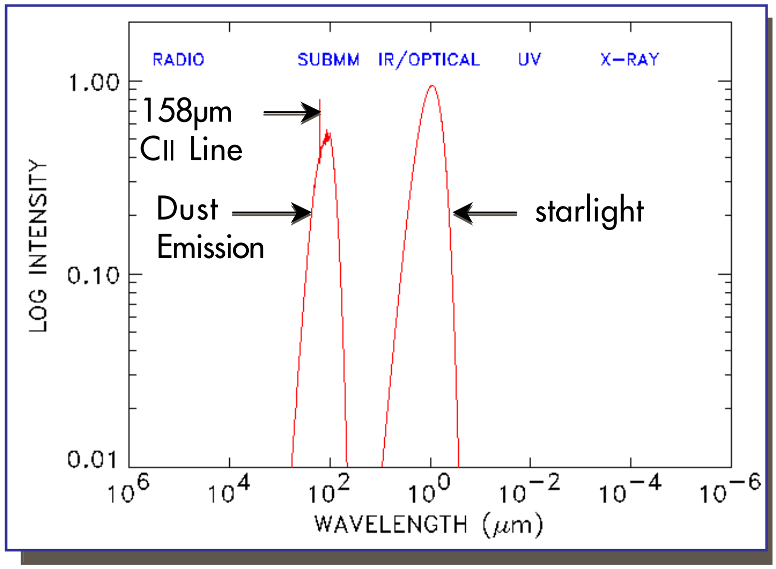


Figure 2. Spectrum of the Milky Way from radio to X-ray wavelengths.

The ~3μm and ~300μm infrared windows on the Universe - particularly the 100-500μm band - are vastly underexploited as compared to other spectral regions.
Part of the reason for this is that any telescope must be cooled until its thermal emission is less than that of the background; this can require a 4K telescope for the longest wavelengths, as shown in Figure 3.

In order to image to a given sensitivity limit, telescopes need both angular resolution and collecting area. At radio wavelengths, widely separated, small telescopes are needed to achieve both; in the optical, a single mirror suffices. The dividing line is near 100μm, as shown in Figure 4. In this region, both filled aperture and interferometers are useful; in fact, the optimal telescope might well be a partially-filled single aperture telescope.

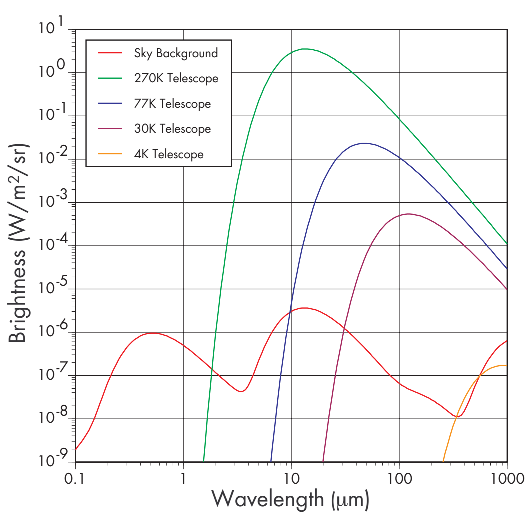


Figure 3. Brightness of the sky compared with that of a 5% emissive telescope.

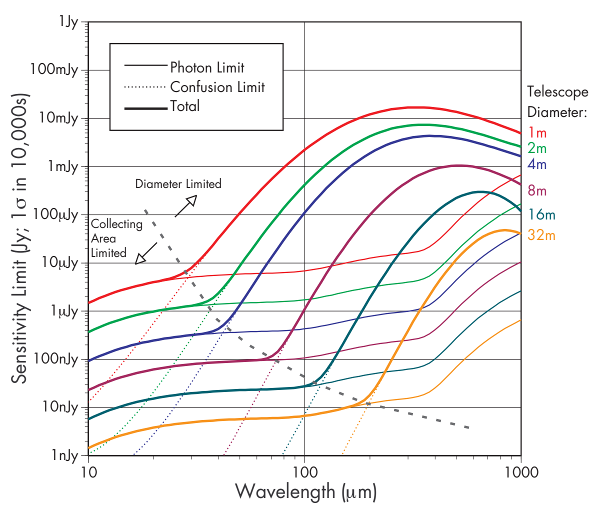
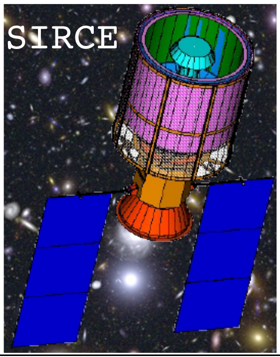
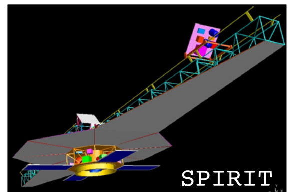


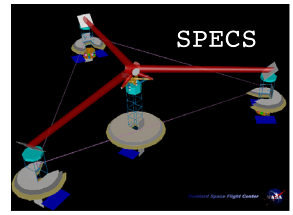
Figure 4. Sensitivity of telescopes as a function of diameter; longer wavelengths need angular resolution whereas shorter wavelengths require collecting area.

POSSIBLE FUTURE FAR-INFRARED MISSIONS:

We consider the potential role played by four mission concepts for far-IR space-based telescopes:







SIRCE: The Survey of Infrared Cosmic Evolution is a 2m-class cryogenic telescope with rapid broadband imaging capability optimized for an all-sky far-IR survey; it can see ultraluminous galaxies to z~5.
SAFIR: Single Aperture Far IR telescope, recommended by the Decadal Review, is envisioned as an 8m-class observatory for the far-IR. It will provide unprecedented sensitivity at wavelengths longward of 30μm to complement NGST.
SPIRIT: Space IR Interferometric Telescope is a scientific & technical pathfinder for far-IR interferometric imaging.
SPECS: The Submillimeter Probe of the Evolution of Cosmic Structure is a 3-element, long baseline interferometer capable of achieving sensitivity and resolution comparable to HST in the optical, NGST in the near-IR, & ALMA in the radio.

OBSERVATORY PARAMETER SPACE

Five key parameters for observatories are: spectral coverage, spectral resolution, angular resolution, mapping speed, and sensitivity. Different science investigations require more performance in some parameters than in others, so it is useful to compare missions in this parameter space to see what capabilities exist and which are neglected. Here, we shall plot all parameters versus wavelength, which illustrates spectral coverage. Four planned missions - NGST, SIRTF, Herschel, and ALMA - shall be used as demonstrative of the existing capability. (See Thronson et al. 1995 for similar discussions)

SENSITIVITY:

This is often considered to be the most important criterion for new observatories. If we look at the existing missions (Figure 5; in black), we see that a large gap exists in the 30-300μm range. Note that warm telescopes (e.g., SOFIA, JCMT, CSO) are typically at or off the top of this scale. The four possible future missions fill in this gap to yield comparable sensitivity across the visible to radio spectrum. SAFIR should be flown within a decade in order to fill in the crucial gap between NGST and ALMA.

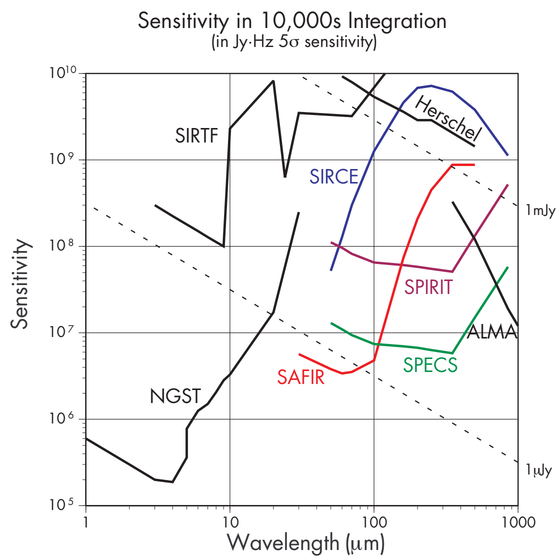


Figure 5. Sensitivity in Jy·Hz (5σ) in a 10,000s integration. Flux limits are shown as diagonal lines.

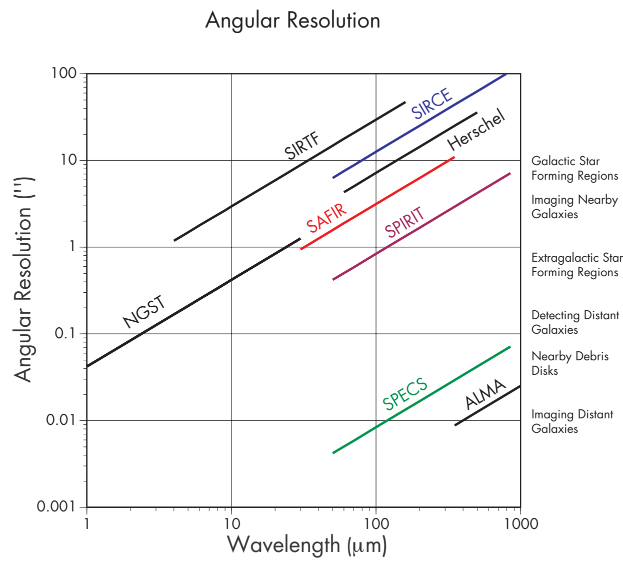


Figure 6. Angular resolution for a variety of single aperture and interferometric telescopes.

Angular Resolution:

Many science investigations require high – often sub-arcsecond – angular resolutions (Figure 6). NGST will provide this capability at $\lambda<28\mu m$, while interferometers such as ALMA and the SMA will provide it at submillimeter wavelengths where the atmosphere permits observations. In the 30-300μm regime, a long-baseline interferometer like SPECS will ultimately be required. The Decadal Review indicates such a mission should be started at the end of the decade.

Mapping Speed:

This parameter combines sensitivity and field of view to represent how quickly an area can be imaged. Although the angular resolution of SPECS and ALMA is unmatched, their small field of view means that these observatories will never conduct blind searches for objects (Figure 7). An all-sky survey such as SIRCE would be an ideal scientific precursor for ALMA, SAFIR, and SPECS.

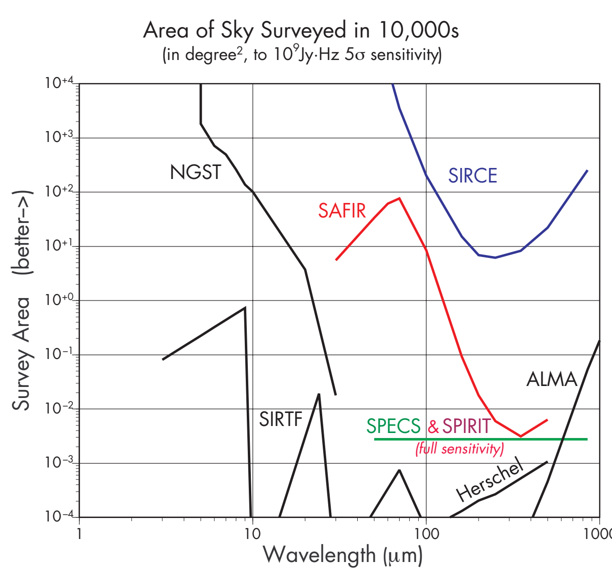


Figure 7. Mapping speed (survey area to a fixed sensitivity of 10^9 Jy·Hz, 5σ, in 10,000s). This comparison is necessarily somewhat qualitative.

SPECTRAL RESOLUTION:

If we momentarily disregard Herschel (which has a capable instrument complement, but is not extremely sensitive due to its warm telescope), it is clear that both continuum (R<10) and high resolution (R>1000) instruments do not exist for 30-300μm. Any of the four possible missions can help to fill this gap. The design of the instrument package in each mission will determine the spectral resolution and wavelength coverage. SAFIR is a likely candidate for very high resolution (R~10^6) spectroscopy.

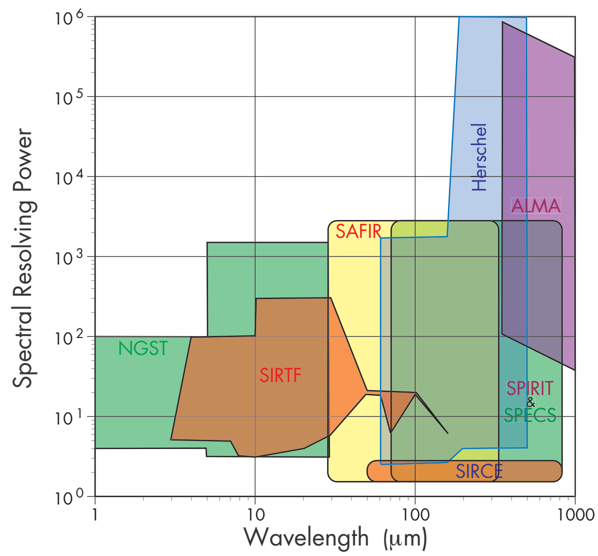


Figure 8. Spectral resolution for present and possible future missions.

CONCLUSION

To quote John Mather (these proceedings), "we must do everything simple and cheap before we can do anything complicated and costly . In this sense, we must plan on a logical mission line that ranges from simple to complicated, cheap to costly. At the same time, we should seek to gain scientific knowledge and technical experience so that each successive mission is better and more cheaply executed.

The parametric view of missions presented in this paper is not supposed to replace the detailed scientific cases for each of these missions, but rather to bolster them. There is so much yet unknown about the universe as seen with far-infrared eyes that it seems impossible to predict accurately what will be discovered by a far-future mission such as SPECS. Therefore, it makes sense to design missions that will maximize the amount of new capability present in the far-infrared as these new missions are built.

As a summary of the findings, it seems a logical mission progression is evident: in the coming decade, SIRCE and SAFIR should be flown, followed closely by SPIRIT as a predecessor to SPECS.

REFERENCES

Mather, J.C. 2002, "Complementarity of NGST, ALMA, and far IR space observatories", these proceedings

Thronson, H.A., Rapp, D., Bailey, B., & Hawarden, T.G. 1995, "Ecological Niches in Infrared and Sub-Millimeter Space Astronomy: Expected Sensitivity as a Function of Observatory Parameters", *PASP*, 107, p.1099