# SURVEYING GALAXY EVOLUTION IN THE FAR-INFRARED
# A FAR-INFRARED ALL-SKY SURVEY CONCEPT

D.J. Benford, M.J. Amato, E. Dwek, M.M. Freund, J.P. Gardner, A. Kashlinsky†, D.T. Leisawitz, J.C. Mather, S.H. Moseley, R.A. Shafer, J.G. Staguhn†

NASA / Goddard Space Flight Center †SSAI

## Abstract

Half of the total luminosity in the Universe is emitted at rest wavelengths ~80–100$\mu$m. At the highest known galaxy redshifts (z≥6) this energy is redshifted to ~600$\mu$m. Quantifying the evolution of galaxies at these wavelengths is crucial to our understanding of the formation of structure in the Universe following the big bang. Surveying the whole sky will find the rare and unique objects, enabling follow-up observations. SIRCE, the Survey of Infrared Cosmic Evolution, is such a mission concept under study at NASA's Goddard Space Flight Center. A helium-cooled telescope with ultrasensitive detectors can image the whole sky to the confusion limit in 6 months. Multiple wavelength bands permit the extraction of photometric redshifts, while a large telescope yields a low confusion limit. We discuss the implications of such a survey for galaxy formation and evolution, large-scale structure, star formation, and the structure of interstellar dust.

## Justification

The Cosmic Infrared Background (CIRB) is the integral of the light from all sources at all distances. Much of this light comes from ultraluminous infrared galaxies, but some fraction arises in AGN and from normal galaxies. The energy released by the formation of stars and in regions around AGNs is absorbed and reemitted by dust. Half the total luminosity in the Universe is emitted at infrared wavelengths, much of it at ~100$\mu$m (Figure 1). The fraction of dust emission was higher in the past than it is today, implying that dusty galaxies produce a greater portion of the luminosity at high redshifts.

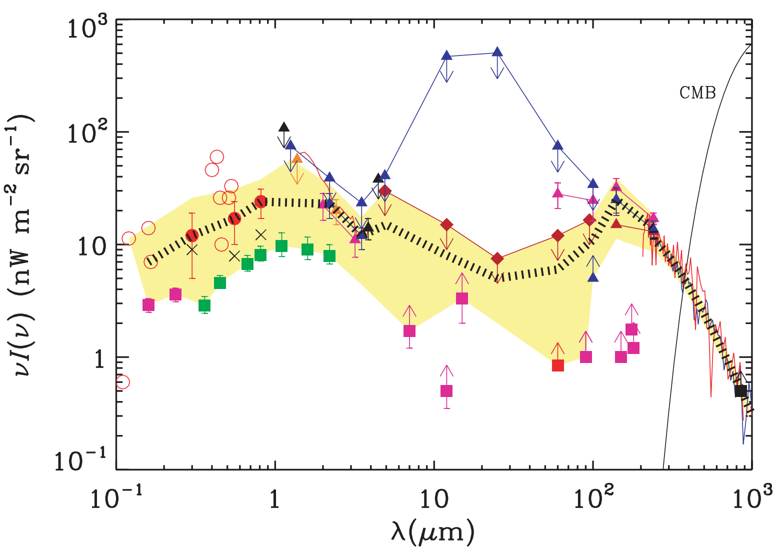


Figure 1: Extragalactic background light (Hauser & Dwek 2001). DIRBE & FIRAS measured this at long wavelengths; two peaks are known, at ~1$\mu$m and ~100$\mu$m.

A complete picture of star formation and AGN activity in the Universe can be obtained only when far infrared observations reach the ability to probe to high redshifts comparable to that at shorter wavelengths. Determination of the cosmic star formation rate history, the growth of cosmic structure, and the accompanying energy release requires direct observations of the sources that dominate the luminosity of the early Universe, which were previously seen only as a component of the CIRB. Surveying the history of the Universe – particularly for star formation – becomes harder in the optical as we look to higher redshifts and greater visual extinctions. The strong inverse-K correction at far-infrared and submillimeter wavelengths makes it possible to see galaxies to great distances (Figure 2).

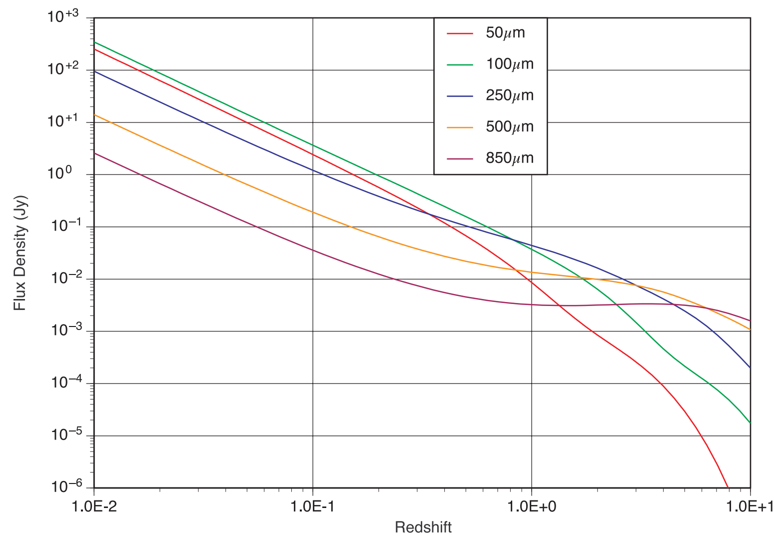


Figure 2: Flux density of an ultraluminous infrared galaxy (ULIRG) as a function of redshift illustrates the sensitivity of submillimeter wavelengths to high redshift galaxies.

At achievable flux density limits (1mJy at 100$\mu$m, roughly 1000 times more sensitive than IRAS), thousands of dusty sources at z>7 can be discovered – if they exist. Shown at right are the fluxes of a set of template galaxies (Figure 3). If we redshift these galaxies until they become too faint to resolve (Figure 4), their fluxes at three fixed observed wavelengths will trace out paths in a color-color-color space. The paths are generally well separated, enabling reliable photometric estimates of redshift and hence luminosity.

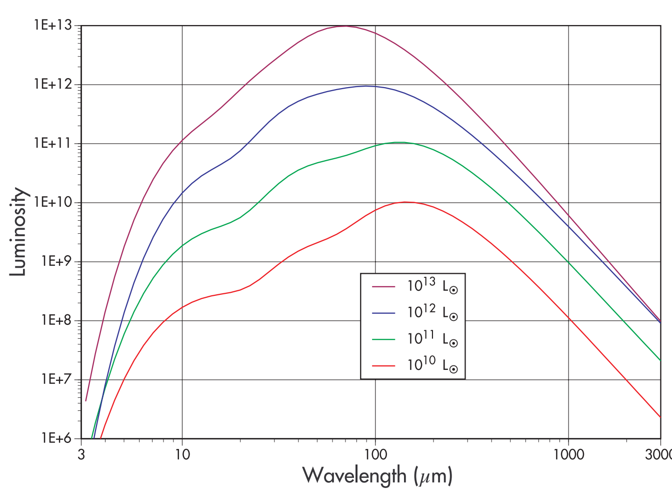


Figure 3: Template spectra of galaxies showing the strong dust emission peak near 100$\mu$m.

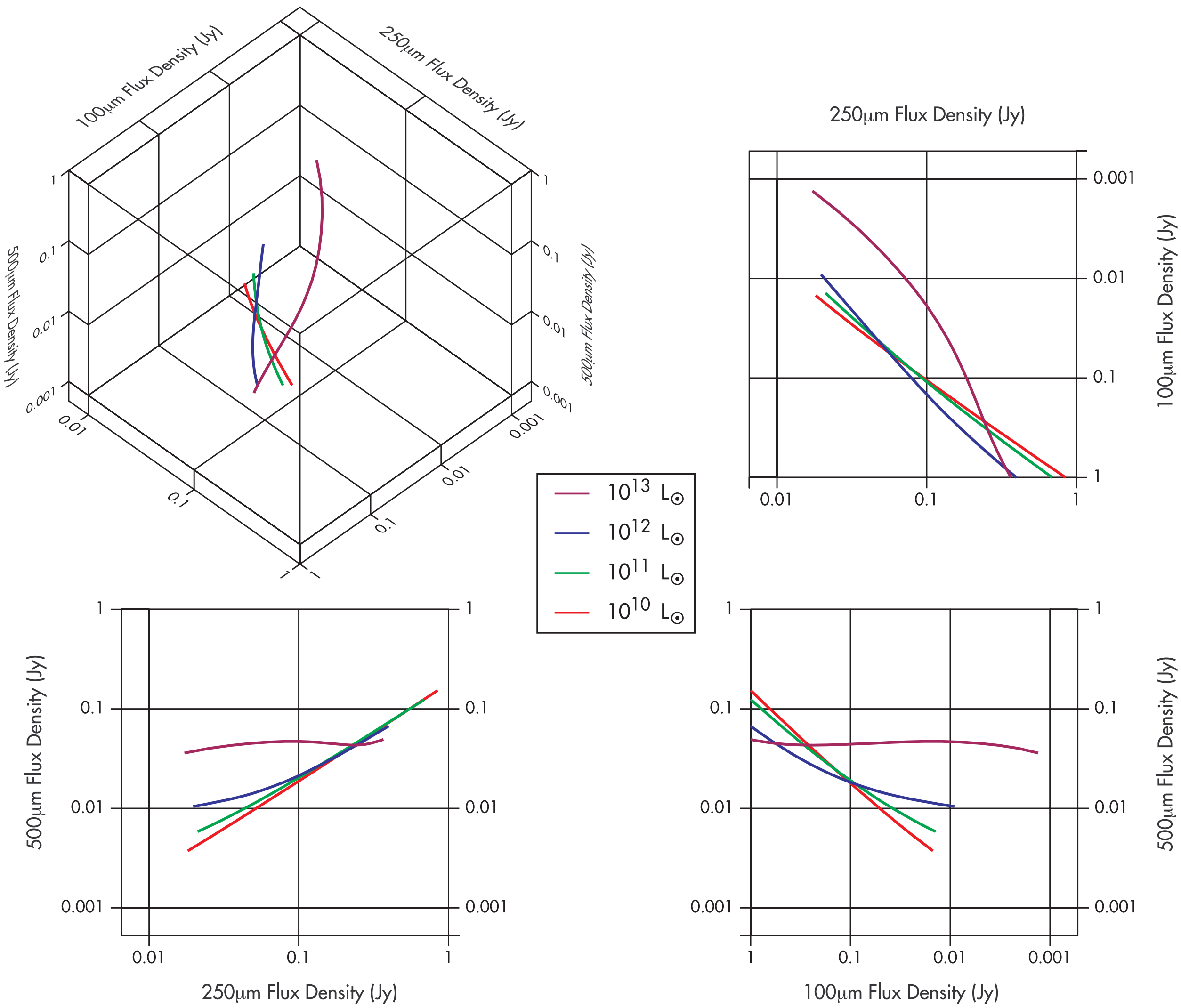


Figure 4: Paths of template galaxies observed in three far-infrared bands as they redshift until becoming fainter than the confusion limit.

The key scientific questions to be answered include:

- History of energy release in the Universe
- Evolution of the different source types with redshift
- Relative importance of nuclear and gravitational energy release
- Nature, redshift distribution and spatial distribution of the CIRB sources
- Epoch of initial star formation in the Universe

## MISSION CONCEPT

How can we learn more about the sources which make up the CIRB, and how do we learn about the history of energy release in the Universe?

A space-based observatory can be built with existing technology which will:

- Map the sky at high spatial resolution at far infrared wavelengths
  *Requires large telescope; large format detector arrays*
- Achieve sensitivity high enough to detect very distant objects
  *Telescope must be cryogenically cooled and operate at wavelengths up to 500μm*
- Cover enough sky to enable statistically significant discoveries
  *All sky survey a necessity*
- Integrate until images are confused
  *Very high detector sensitivity is required to complete survey in finite lifetime*

This observatory, called **SIRCE** (Survey of Infrared Cosmic Evolution), is shown in a cutaway view in Figure 5.

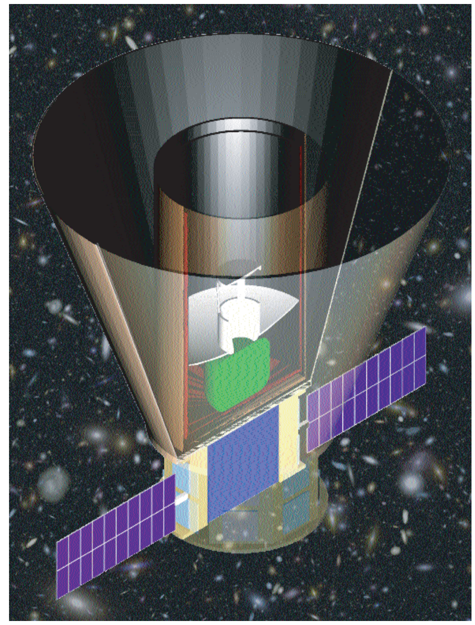

Figure 5: Cutaway view of a cryogenically cooled telescope for imaging the far-infrared sky to the confusion limit.

Why be confusion limited? For the extraction of point sources, confusion-limited images have the faintest detection limits available for a given telescope size. Furthermore, since the statistics of confusion-limited images are not noise-dominated, they are useful for constraining the distribution of sources below robust detection limits. The confusion limit is shown below in Figure 6; a representative confused image is shown below in Figure 7.

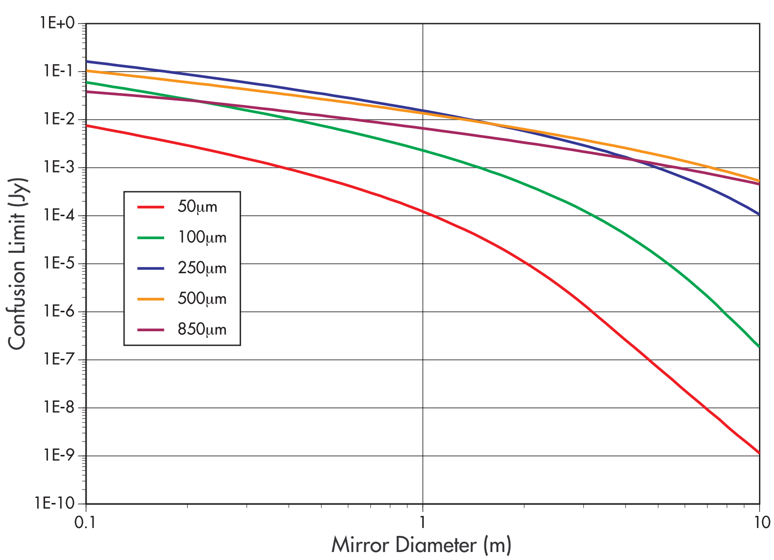


Figure 6: Confusion limit vs. mirror diameter for relevant wavelengths (from Blain 1999).

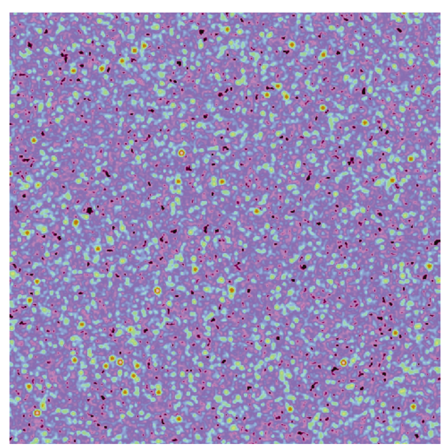

Figure 7: Simulated confused image of a 1° square region of the sky. Every source is a galaxy; very little dark sky remains.

Several questions need to be answered in the development of a far-infrared survey mission:

- How big does the telescope have to be to detect sources at great distances?
- What wavelengths must be covered?
- How cold must the telescope be?
- How sensitive do the detectors have to be?

TELESCOPE SIZE:

At left (Figure 8) is a comparison of the Galactic vs. extragalactic confusion; in order to determine the distribution of galaxies, a 1–2 m mirror will minimize Galactic confusion. At right (Figure 9) is an estimate of the differential source counts for a 2m telescope. Such a telescope can find tens of thousands of z>7 galaxies, measuring star formation activity back to an era unreachable by existing telescopes.

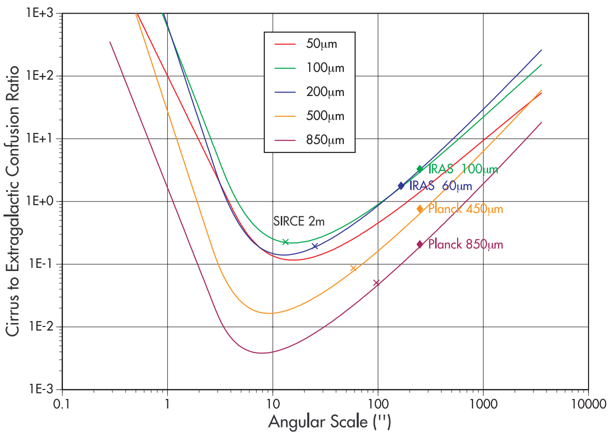


Figure 8: Galactic-to-extragalactic confusion limit ratio.

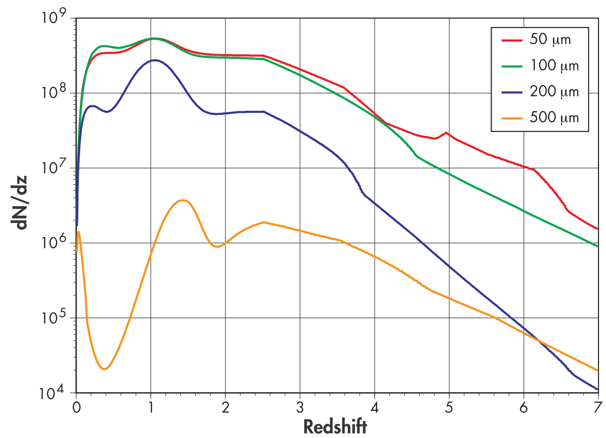


Figure 9: Differential source counts vs. redshift and wavelength for a 2m telescope (from Pearson 2001).

WAVELENGTH RANGE:

In order to determine photometric redshift accurately, measuring fluxes at wavelengths around a feature such as the dust emission peak at ~80-100$\mu$m is required. The short wavelength requirement is that the short wavelength side of this peak be seen in nearby galaxies; therefore ~50$\mu$m is a good choice. The long wavelength cutoff of the observatory should permit the peak to be seen in z~5 galaxies of the higher luminosities (those with ~80$\mu$m rest frame peaks). This sets the wavelength at about 500$\mu$m. Clearly, a longer wavelength would be beneficial, but the difficulty of overcoming confusion requires ever larger apertures. Fortunately, very high redshift (z>5) objects can be selected using a 500$\mu$m dropout technique.

DETECTOR SENSITIVITY:

Large format detector arrays with extremely high sensitivity (i.e., bolometers with NEP≈$6{\cdot}10^{-19}$ W/√Hz) can integrate down to the confusion limit as they scan at the orbital rate for a survey with a helium-cooled telescope; therefore the telescope sees everything it can see as fast as it can observe!

Telescope Temperature:
Maximizing sensitivity implies that the dominant photon background must come from the distant sky, not from the telescope. Figure 10 shows the relative contributions of background power from the sky in space compared to the emission of a 5% emissivity telescope. The telescope must be cooled to around 4K to suppress self emission below the natural sky backgrounds.

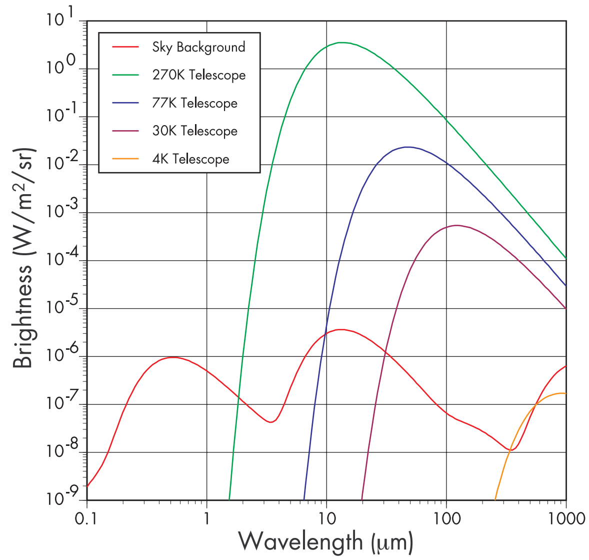


Figure 10. Photon background from the space environment compared with telescope emission.

## Conclusion

We have developed a far-infrared all-sky survey mission concept with the goal of answering a specific set of important questions about the evolution of galaxies over cosmic time. A helium-cooled telescope with ultrasensitive detectors can image the whole sky to the confusion limit in 6 months. SIRCE has been developed by the Goddard Space Flight Center for launch within the decade. It is an ideal candidate for the proposed expanded Explorer mission line.

## References

Blain, A.W., 1999, *"Future millimeter, submillimeter and far-infrared surveys and their successful follow up"*, in ASP Conference.Series #191 `Photometric Redshifts and the detection of high-redshift galaxies', p. 255-264

Hauser, M.G. & Dwek, E. 2001, *"The Cosmic Infrared Background: Measurements and Implications"*, ARAA #39, p.249-307

Pearson, C.P. 2001, *"Evolutionary constraints from infrared source counts"*, MNRAS #325 (4), p.1511-1526