

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 [†]Raytheon/ITSS



Half of the total luminosity in the Universe is emitted at rest wavelengths $\sim 80\text{--}100\ \mu\text{m}$. At the highest known galaxy redshifts ($z \approx 6$) this energy is redshifted to $\sim 600\ \mu\text{m}$. 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

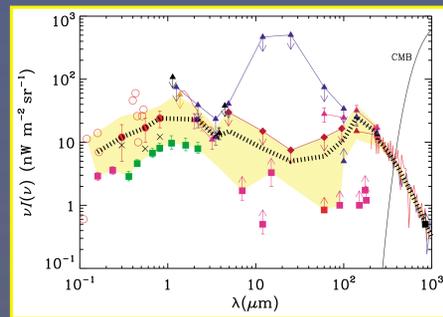
The Cosmic Infrared Background (CIRB) is the integral of the light from all sources at all distances. Much of this light comes from ultraluminous infrared galaxies, but some fraction arises in AGN and from normal galaxies.

The energy released by the formation of stars and in regions around AGNs is absorbed and reemitted by dust.

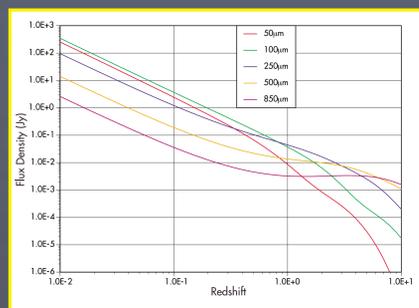
Half the total luminosity in the Universe is emitted at infrared wavelengths, much of it at $\sim 100\ \mu\text{m}$. The fraction of dust emission was higher in the past than it is today, implying that dusty galaxies produce a greater portion of the luminosity at high redshifts.

→ 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.

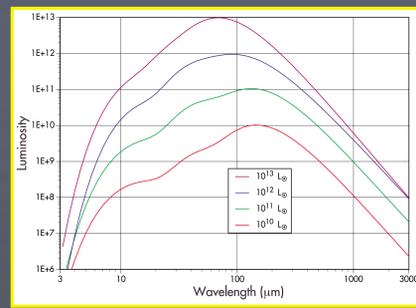


Extragalactic background light (Hauser & Dwek 2001). DIRBE & FIRAS measured this at long wavelengths; two peaks are known, at $\sim 1\ \mu\text{m}$ and $\sim 100\ \mu\text{m}$.



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

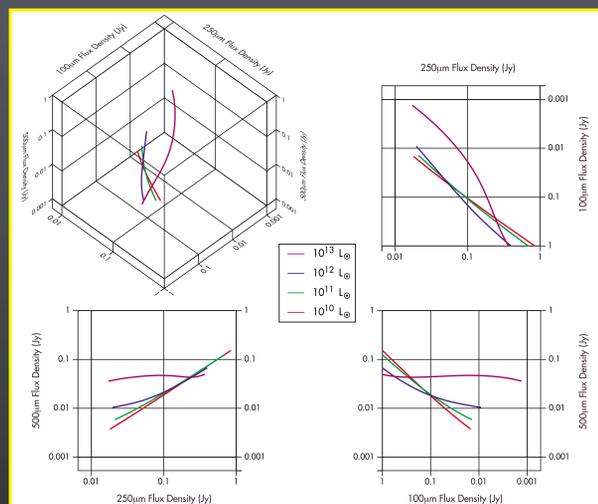
- Surveying the history of the Universe – particularly for star formation – becomes harder in the optical as we look to higher redshifts and greater visual extinctions. The strong inverse-K correction at far-infrared and submillimeter wavelengths makes it possible to see galaxies to great distances.



Template spectra of galaxies showing the strong dust emission peak near $100\ \mu\text{m}$.

- At achievable flux density limits (1 mJy at $100\ \mu\text{m}$, 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 redshifted until they become too faint to resolve. The paths are generally well separated, enabling reliable photometric estimates of redshift and hence luminosity.



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

Key questions:

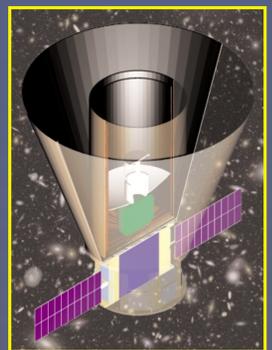
- History of energy release in the Universe
- Evolution of the different source types with redshift
- Relative importance of nuclear and gravitational energy release
- Nature, redshift distribution and spatial distribution of the CIRB sources
- Epoch of initial star formation in the Universe

Mission Concept

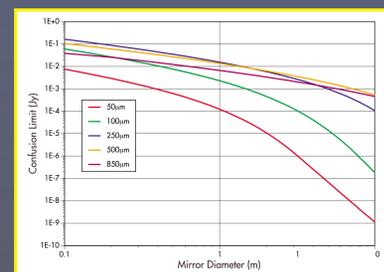
How can we learn more about the sources which make up the CIRB, and how do we learn about the history of energy release in the Universe?

A spaceborne 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 $500\ \mu\text{m}$
- 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



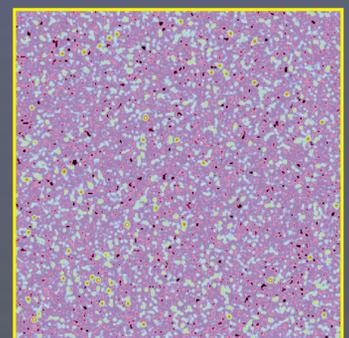
Cutaway view of a cryogenically cooled telescope for imaging the far-infrared sky to the confusion limit..



Confusion limit vs. mirror diameter for a relevant wavelengths (from Blain 1999).

Why be confusion limited?

- Confusion-limited images have the faintest detection limits available for a given telescope
- Statistics of confusion-limited images are not noise-dominated, so are useful for constraining number counts below source detection limits.



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

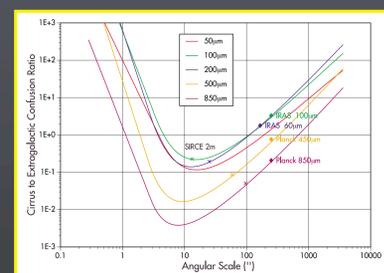
Questions:

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?



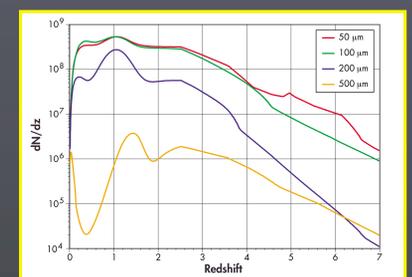
Galactic-to-extragalactic confusion limit ratio.

unreachable by existing telescopes.

Large format detector arrays with extremely high sensitivity (bolometers with $\text{NEP} \approx 6 \cdot 10^{-19}\ \text{W}/\sqrt{\text{Hz}}$) 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!

The wavelengths are chosen to enable photometric redshifts for detections out to $z > 5$. This requires coverage from $100\ \mu\text{m} \leq \lambda \leq 500\ \mu\text{m}$. The telescope must be cooled to around 4K to eliminate self-emission. ULIRGs can be identified out to $z = 5$ with such a telescope.

SIRCE is a MIDEX mission concept in preparation at the Goddard Space Flight Center for launch in 2007. It will perform an all-sky survey of the Universe out to $z > 5$ in a six month mission lifetime.



Differential source counts vs. redshift and wavelength for a 2m telescope (from Pearson 2000).