The Single Aperture Far-InfraRed Observatory (SAFIR)

The next step in the far-IR beyond SIRTF and Herschel

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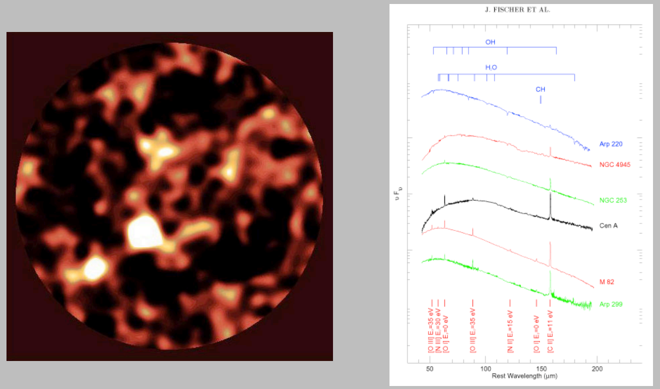
SAFIR SCIENCE HIGHLIGHTS

Formation of the first stars and galaxies

Collapse of the primordial ISM to form the first stars is likely driven by cooling in the rotational H_2 lines at 28, 17, 12, 9.6,. 8.1, 6.9 μm. At the redshifts of the first stars' formation, z~20-100, this suite of lines will be observed between 40 and 1000 μm. Theoretical studies suggest that half or more of the gas associated with a virialized dark matter halo can form stars, and that as little as 10^8 solar masses of dark matter would produce enough star formation for H_2 lines to be detected with SAFIR.



Left: The SCUBA Image (D. Hughes et al.) resolves the diffuse background at 850 μm into discrete galaxies. Most are thought to be at redshifts between 1-4, the period of peak activity in the universe. Right: Far-IR spectroscopy makes an excellent probe of ISM conditions and energy sources in such galaxies, as well as providing redshifts, charting the history of the dust-enshrouded universe. (J. Fischer et al, ISO LWS)

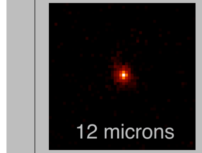
After the first stars have enriched the ISM with metals, structure formation proceeds with smaller objects coalescing into larger, eventually forming the progenitors of the present-day galaxies. Much of the history of galaxy formation and evolution is obscured at optical wavelengths by dust. In the next decade, the SIRTF and HSO missions will resolve thousands of continuum sources from the far-IR background. The continuum surveys can provide redshift estimates based on local templates, but do not directly probe the nature of the sources. Moderate-resolution spectroscopy with near unity bandwidth is required to determine the ISM conditions throughout the bulk of the galaxies, and determine the energy production mechanisms (starburst or nuclear accretion).

Black hole – host galaxy interaction

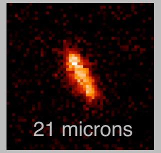
The energy source for AGN galaxies is thought to be accretion onto the nuclear black hole. The mechanism by which some galaxies feed their nuclear black holes while others do not is not well understood. A dominant model for Seyfert galaxies incorporates a dense torus of material around the central black hole, which obscures the very central object at optical wavelengths. If true, this circumnuclear torus may be an important intermediate step in the delivery of gas from the host galaxy to its nuclear black hole. Validating the torus model in nearby Seyfert galaxies requires arcsecond spatial resolution to distinguish the torus from the gas of the host galaxy. At this spatial resolution, spectroscopy of H_2, CO and atomic species such as Ne with SAFIR can confirm or deny the presence of a dense torus, the central feature in our current theory of active black holes in galaxies

Origin of planetary systems and biological building blocks

Detailed study of the formation planetary systems has been challenging because the ~100 AU size scales required to capture the formation of giant planets corresponds to arcsecond spatial resolution at a typical 100 pc distance. SAFIR will for the first time provide this capability at mid- and far-IR wavelengths which are the most important for proto-planetary disks. Within the mid- and far-IR, multi-wavelength imaging and spectroscopy are essential because planetary systems are formed from material at a wide range of distances (1-1000 AU) from a central protostellar source.



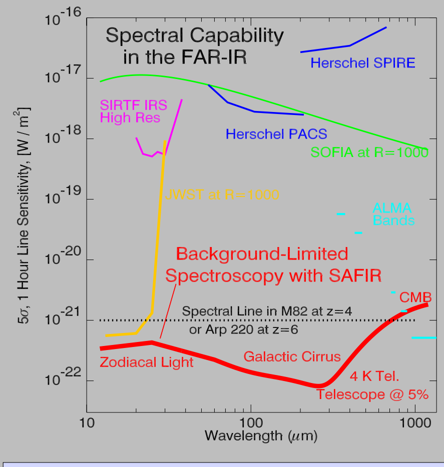
These images of the disk around the sun-like star HH4796 demonstrate the importance of the far-IR for studying proto-planetary disks. Obvious at 21 μm, the disk is completely absent at 12 μm. Wavelengths longer than 20 microns will give an even better measure of the overall size and structure, but are not observable from the ground. Images from MIRLIN on Keck II (Koerner, Ressler & Werner, JPL).



Sensitive spectroscopy of these disks in the far-infrared and submillimeter will also likely reveal the presence of large, organic molecules, uniquely identifiable through their torsional and floppy vibrational modes. With its exquisite sensitivity to these species, SAFIR may be deemed the first true astrobiology observatory.

SAFIR is a 10-meter, 4 K space telescope optimized for wavelengths between 20 microns and 1 mm. The combination of aperture diameter and telescope temperature will provide a raw sensitivity improvement of more than a factor of 1000 over presently-planned missions. The sensitivity will be comparable to that of the JWST and ALMA, but at the critical far-IR wavelengths where much of the universe's energy has emerged since the origin of stars and galaxies. In consideration of its enormous scientific potential and technological feasibility, the mission was recommended by the National Academy of Sciences Astronomy Decadal Committee as 'the next step in exploring this important part of the spectrum.'

SAFIR Mission Overview

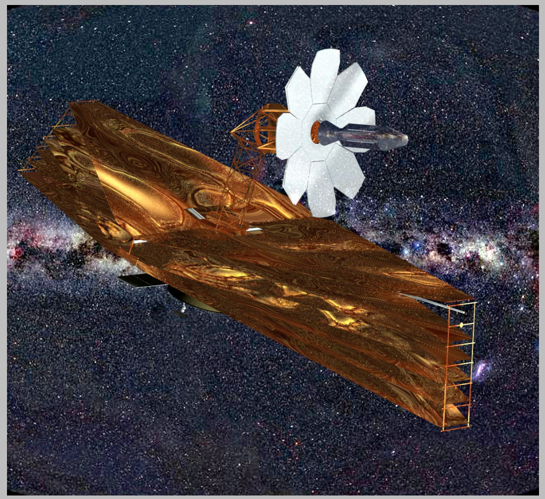


Above: SAFIR will provide a sensitivity improvement of about 4 orders of magnitude over planned systems between JWST and ALMA. The ultimate sensitivity for spectroscopy is determined by the Zodiacal and Galactic Cirrus backgrounds. The dotted line shows a far-IR spectral line flux for local templates redshifted to the early epoch of galaxy formation.

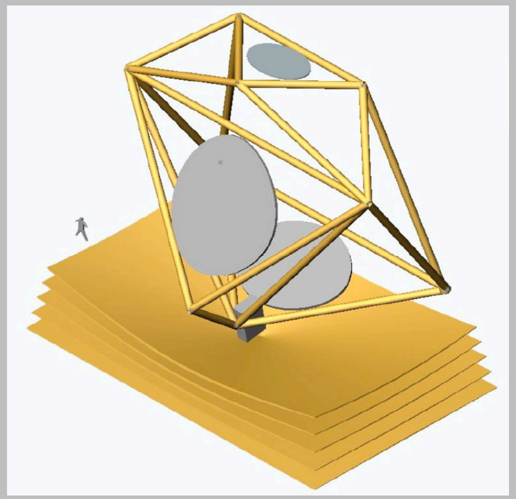
Telescope Diameter	10 meters
Telescope Temperature	5 K or lower
Wavelength Coverage	20 μm to 1 mm
Instruments on Board	• Kilo-pixel imaging arrays for all wavelengths. • Broad-band direct-detection spectrometers with background-limited sensitivity. • Heterodyne spectrometers operating at the quantum noise limit.
Orbit	Sun-Earth L2 Halo Orbit
Mission Lifetime	5 Years
Schedule	Launch between 2015-2020

More information at http://safir.jpl.nasa.gov, http://safir.gsfc.nasa.gov

Mission Concepts



SAFIR concept based on JWST technology. JWST will employ a 6 meter deployable mirror in a conventional telescope, the extension to 10 meters for SAFIR would be a modest advance, particularly as the surface and figure requirements for SAFIR are less stringent than for JWST because of its longer wavelength



SAFIR concept based on the new DART architecture. The two large mirrors are membranes stretched into cylindrical sections, each focusing in one dimension. The small mirror is analogous to a conventional secondary, providing a focus near the first mirror with appropriate plate scale for the far-IR instruments.

KEY TECHNOLOGIES FOR SAFIR

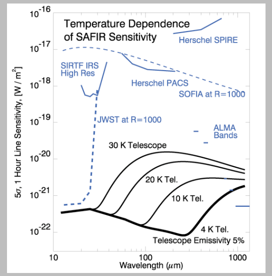
Already in development for other programs

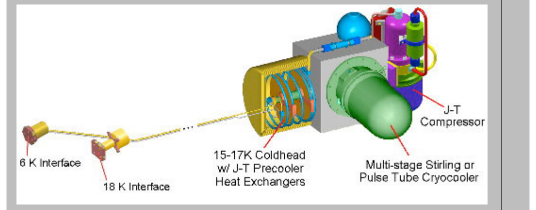
Large cryogenic primary mirror

The arcsecond angular resolution required for studies of proto-planetary disks and galactic nuclei requires a telescope about 10 meters in diameter, far larger than any yet launched. Because launch vehicles cannot enclose this size, the telescope mirror will be deployed on orbit. Segmented mirror telescopes using classical optical designs are under development for other missions such as the JWST and TPF. A new architecture, DART, based on ultralight membrane mirrors is also under development. Both technologies show excellent promise for providing SAFIR's large primary mirror

Active cooling system to provide T = 5 K or lower

To take full advantage of the low background available in space at far-IR and submillimeter wavelengths, the telescope mirror must be cooled to below 5 K, much lower than is possible with passive (radiative) cooling schemes. Active cooling systems are preferable to a large volume of stored cryogens because they can allow an extremely long mission life. With the cryogenic needs of the JWST, TPF and Con-X missions in view, NASA's Advanced Cryocooler Technology Development Program (ACDTP) is funding engineering of cooling systems for space use. With these missions already served in advance, the incremental cost to SAFIR for cryocooler systems will be a small fraction of the total development cost.

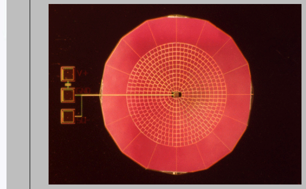


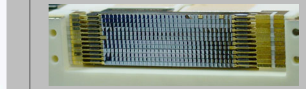


Above: Schematic of a cryocooler system being developed by industrial contractors under the NASA ACTDP initiative.
Left: Temperature dependence of SAFIR's sensitivity.

Multiplexed background-limited detectors for continuum and spectroscopic observations

A variety of detector technologies are used between the mid-IR and the millimeter. For the shorter wavelengths, photoconductors have been constructed in modest–sized arrays for SIRTF and Herschel. Beyond about 200 μm, the best choice for detectors is likely bolometers, a technology which has recently seen rapid development. Over the past 3 decades, mapping speed has doubled roughly every year, due to improvements in both individual pixel sensitivity and the number of elements in each array. Further development, however, is required for SAFIR. At present, the demonstrated sensitivities are about an order of magnitude away from the background limit for R=1000 spectroscopy of a few x 10^{-20} W $Hz^{-1/2}$. Also, for arrays with thousands of pixels, a multiplexing scheme is required to read out the large array.

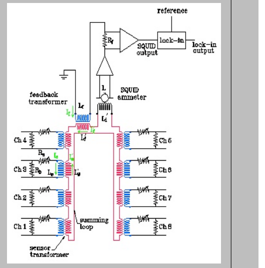




Top Left: SiN micro-mesh bolometer similar to the devices that will be used in the Herschel SPIRE instrument but with a super-conducting transition-edge sensor as the thermometer. (Bock et al., JPL)

Botton Left : Bolometer array for the SHARC II 350 μm camera, currently the largest cryogenic bolometer array. (Benford et al., GSFC)

Right: Schematic of a frequency-domain SQUID-based multiplexer, one potential MUX technology for SAFIR (Yoon, Lee et al., Berkeley)



Quantum-limited heterodyne spectrometers

Heterodyne spectrometers are essential for velocity-resolved spectra of proto-stars and proto-planetary disks. Herschel is using heterodyne instruments in its HIFI instrument, but further development will be required for SAFIR. Keys to effective heterodyne instrumentation include frequency-agile local oscillators, and quantum-noise limited mixing elements with broad bandwidths. Also, spatial arrays of heterodyne spectrometers would dramatically increase the astronomical capability by providing instantaneous mapping.