Far-Infrared Heterodyne Interferometry with IRASSI: What Can It Give Us? Can It Be Done?

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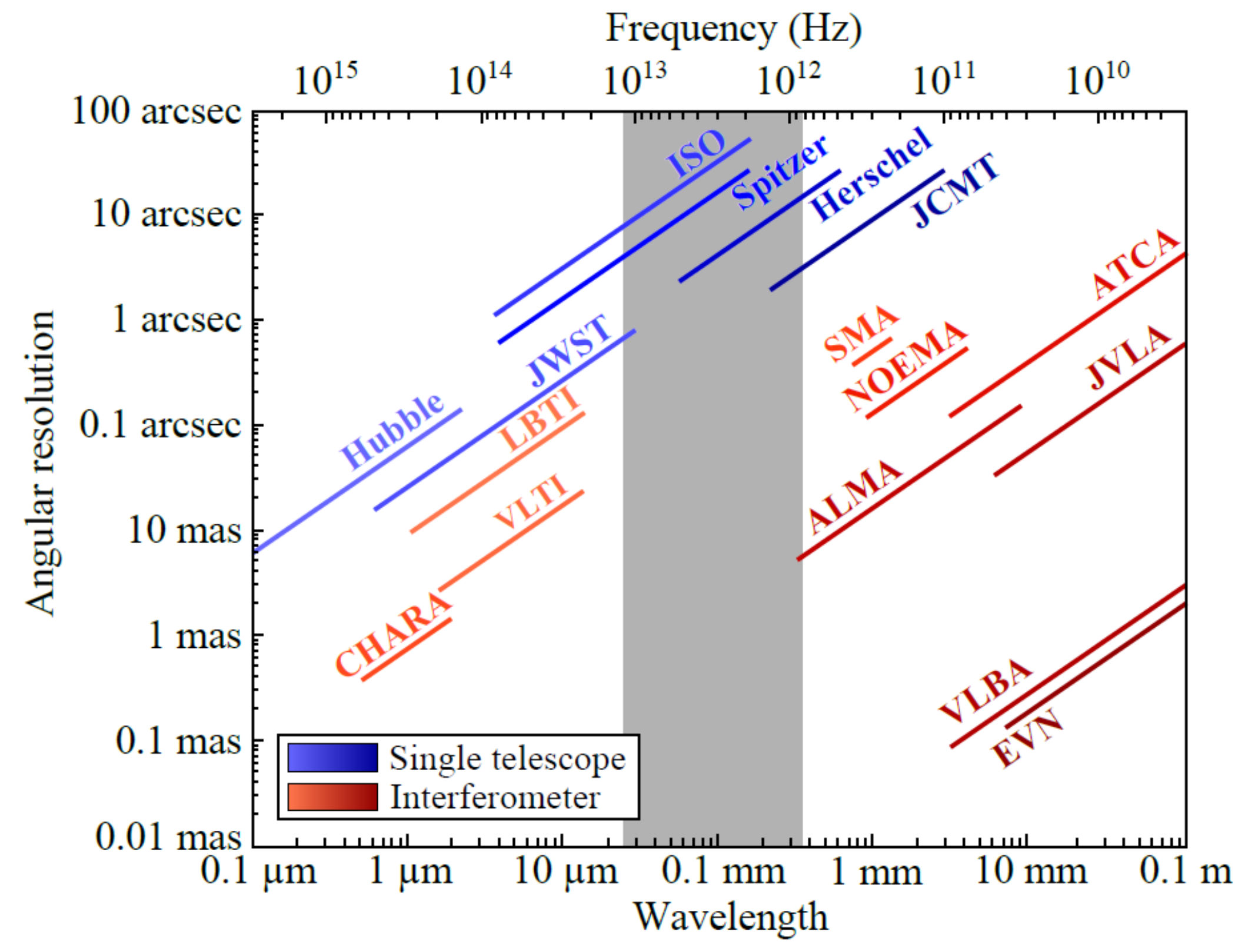
The far-infrared (FIR) regime is one of the few wavelength ranges where no astronomical data with sub-arcsecond spatial resolution exist yet. For many research areas, however, information at high spatial AND spectral resolution in the FIR would open the door for transformative science. These demands call for interferometric concepts. We present here first results of our feasibility study IRASSI (InfraRed Astronomical Swarm Satellite Interferometry) for an FIR space interferometer. It features heterodyne interferometry within a swarm of 5 satellite elements. The satellites can drift in and out within a range of several hundred meters, thereby achieving spatial resolutions of <0.1 arcsec over the whole frequency range of 1-6 THz.

What is the situation? What is desired?

Also medium-term satellite projects like SPICA, MilliMetron, or the Origins Space Telescope (OST) will not resolve this malady!

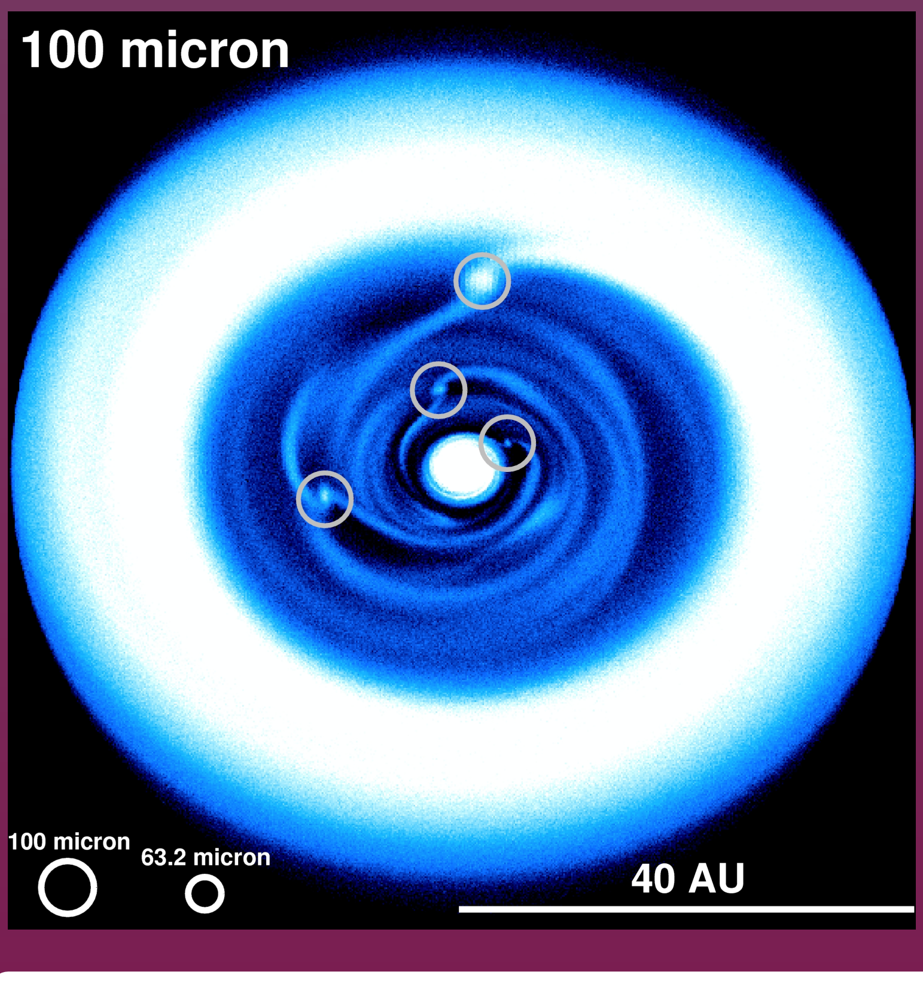


The current situation with regard to spatial resolution available for different wavelength ranges. The grey vertical band marks roughly the FIR range. The lack of high spatial resolution capabilities is obvious.

Valuable tracers in the FIR:

- Fine-structure transitions of the main cooling lines in the ISM:
  [12CII] and [13CII] at 158 µm (just 11.2 km/s apart!)
  [OI] at 63 and 145 µm, [OIII] at 88 µm, [NII] at 205 µm, [CI] at 370 µm
- high-lying transitions of CO (dense molecular gas, shock indicator)
- H_2O lines !!! (shock tracer in star formation, water budget in disks)
- HD at 112 µm and 56 µm (mass reservoir)
- Dust continuum at the peak of the SED for cold astronomical objects (star-forming cores, outer parts of disks etc.)

IRASSI can address all this by providing velocity-resolved maps of all these line tracers with a spatial resolution of < 0.1"!



Science Teaser:

Radiative transfer simulation on top of a Hydro simulation for 4 embedded Jupiter-mass planets forming in a pre-transitional disk (Kraus et al. 2014, Proc. SPIE 9146, 914611). Indicated are the beam sizes achievable with IRASSI, assuming a disk at d=140 pc. At least outermost planet 20 au away should be possible to distinguish with IRASSI.

Related Workshop in 2019:

When : Summer 2019 (details coming soon)

Where : MPIA Heidelberg, Germany

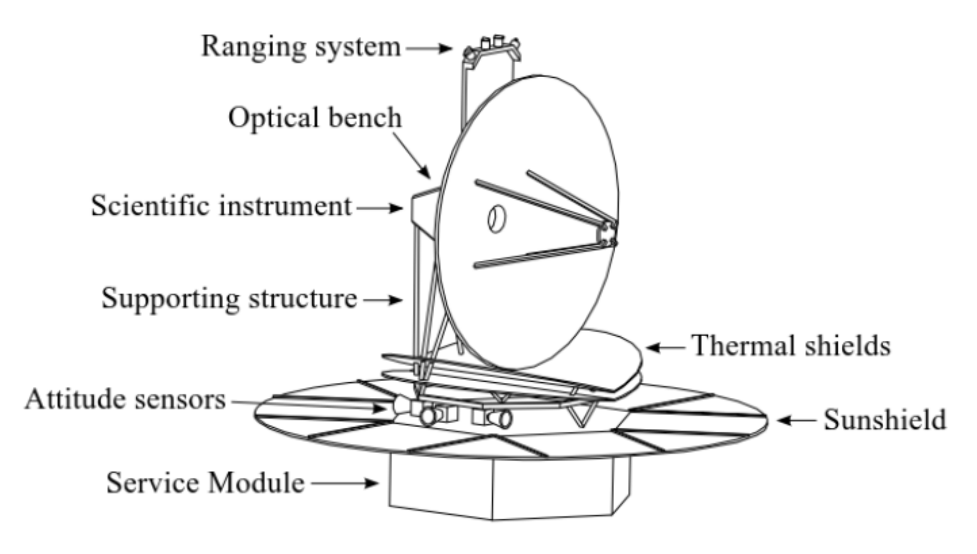
What : Discuss prospects for FIR space astronomy

→ Science motivation
→ Technology development
→ Self-organisation of the interested community

If you are interested: contact Hendrik Linz (linz@mpia.de)

Our principle concept for IRASSI

IRASSI is based on principle ideas worked out in the ESPRIT study (Wild et al. 2008, Proc. SPIE 7013, 70132R). It is also an extension since it actively addresses questions of navigation, internal calibration, and the swarm dynamics.



Our concept for the satellite elements has evolved and now is similar to SPICA. However, the IRASSI satellites have just to be cooled passively by a sunshield. Note the location of the Laser Ranging System which shall employ laser frequency combs.

Parameter	Required Value
Number of telescopes	5
Number of baselines	10 (N telescopes, $\frac{N(N-1)}{2}$)
Size of telescope mirrors	3.5 m primary mirror
Spacecraft configuration	Free-flying in 3D
Length of baselines	7 to 850 m
Wavelength (λ) range	50 to 300 μm
Frequency range	1 to 6 THz
Field of view (for each telescope)	3 to 18 arcsec (frequency-dependent)
Angular resolution	0.1 arcsec (at $\lambda = 300\ \mu$m)
Telescope pointing accuracy	0.4 arcsec
Accuracy of spacecraft baseline measurements	5 μm
Temperatures	80 K main dish; 4 K mixer

With 5 interferometric elements one gets:
- 10 immediate Fourier phases and amplitudes
- 6 immediate independent closure phases
- 5 immediate independent closure amplitudes

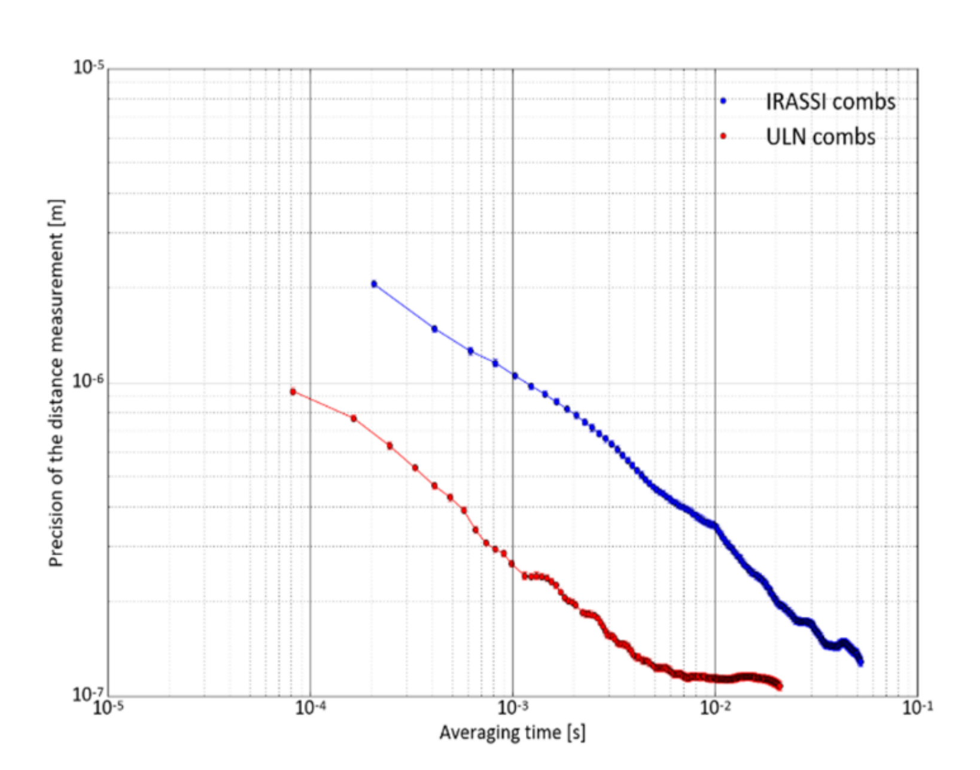
Working Principles:

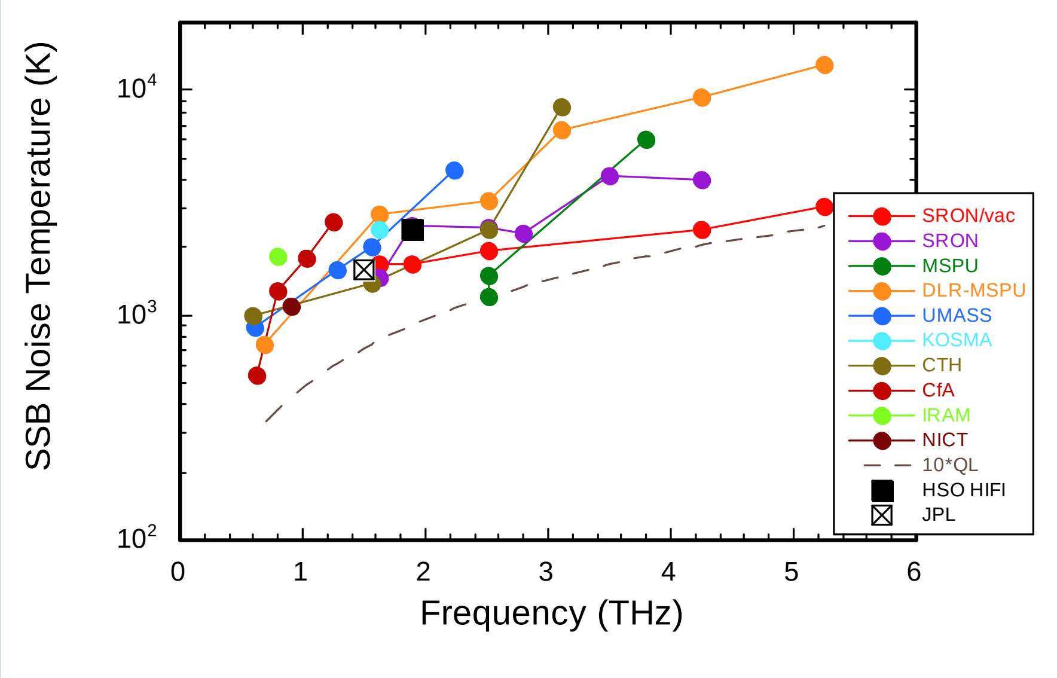
- freely drifting baselines to sample the (u,v)-plane
- Heterodyne interferometry: satellite distances do not have to be *controlled* as in Direct-Detection missions like DARWIN, but just accurately *measured* and communicated to the correlator.
- Huge raw data rates (5.67 Peta-Bit for 2 GHz bandwidth after 20 hours of operation → makes on-board correlation imperative!
- Frequency-distributed correlator: every satellite correlates 1/5 of the total bandwidth (ASIC design with low power demands anticipated)

Further technological progress in several fields

Laser Frequency Combs:

Our industry partner Menlo Systems produces and tests comb devices for high-precision metrology. At repetition rates of 1 kHz, the IRASSI combs achieve distance accuracies ~ 1 µm in time-of-flight mode. Ultra-low-noise (ULN) combs could even perform at higher rates for the same accuracy.





THz receivers and mixers:

Overview compiled by Imran Mehdi (JPL), January 2014. The dashed line marks 10 times the quantum limit hν/k, a magic border that indicates competitiveness with direct-detection system. A new study (Krause et al. 2018, IEEE Trans. 8, 365-371) achieved 5 hν/k for their HEB mixers at 1.3 THz recently.

Conclusions:

→ no immediate technology show stoppers
→ considerable work to internally calibrate such a facility (e.g., local tie to link the laser metrology terminals to the phase centers for the science signals)