Bringing high resolution to the Far-Infrared

Hendrik Linz (MPIA Heidelberg) on behalf of the High-res FIR author team





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A severe resolution gap in the FIR



Very schematic view on the status quo of spatial resolution vs wavelength

The grey area marks roughly the classical farinfrared range.

In the 2-6 THz range, Herschel data with >5" resolution are still state of the art.

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The FIR: A large portfolio of unique spectral lines

- Most important cooling lines of the ISM: [CII] 158 μm, [OI] 63+146 μm, [OIII] 52+88 μm, [NII] 121+205 μm
- Many water (H₂O) gas lines with low to moderate/high excitation temperatures
- Light molecule HD as H_2 proxy \rightarrow molecular gas mass tracer plus more light hydrids (CH, HF, ...)
- Higher-excited CO line series as shock tracer

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Following the Trail of Water





2014 PPVI Review

van Dishoeck+

Water ground transition seen with HIFI@Herschel towards different evolutionary stages

Where does the water reside?



H₂O abundance regulated by complex interplay: grain evolution, grain surface chemistry and freezeout, photodesorption and photodissociation, and radial and vertical mixing processes

Integral modelling can only advance if there is observational access to all phases of water!

Only FIR/sub-mm regime gives good access to bulk of cold/luke-warm H₂O gas reservoir

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Disk Tomography

Different water lines can trace different water gas regimes: Left: disk height over radius Right: kinematic line profiles



Theoretical underpinning for this tomography approach: Notsu+ 2016, 2017, 201830 October 2019High resolution in the FIR

Breaking the 0.1" barrier: Emergence of compelling structure

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BIMA:



How do protostars gain their mass: strict constraints on infall



Red-shifted NH_3 absorption at 1.81 THz towards high-mass protostars (SOFIA: Wyrowski+ 2016)

Line absorption against strong FIR continuum of young embedded protostars

 \rightarrow avoids interpretation pitfalls of blue-skewed line profiles at mm

 \rightarrow GREAT@SOFIA could do this with a 15" beam (infall on clump scales)

→ sub-arcsec resolution necessary to pinpoint accretion on actual protostar

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Star formation dynamics and efficiencies in external galaxies



FIR fine-structure lines as decisive tool to investigate global star-formation modes and energetics in external galaxies

 \rightarrow SF efficiencies, effects of metallicity, feedback processes

Limited spatial resolution: gas heating by young high-mass stars mixed with shocks, turbulence, cloud-cloud collisions

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¡We need a vast improvement in spatial resolution!



Blue: previous FIR missions **Black:** currently operating (excluding balloon missions) **Green:** concrete plans

Solid lines for high spectral resolution

Red: possible implementation for higher spatial resolution

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Space Interferometry: an upcoming theme



Formation flying relevant for several White Papers:

LIFE (Sascha Quanz et al.): Exoplanet Nulling, moderate baselines (~150 m)

← THEZA (Leonid Gurvits et al.): Event horizon imaging, long baselines (<15,000 km), but shorter baselines could be accommodated in special mode for H_2O observations

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An interferometric solution to beat the 0.1" barrier



Combination of heterodyne detection and formation flying: ESPRIT (2008) & IRASSI (2019)

 \rightarrow swarm of 5 telescopes in 3D \rightarrow baselines of up to ~ 1 km

- \rightarrow dynamic reconfiguration to sample the (u,v)-plane
- → distributed correlator to cope with the large raw data rates
- → laser frequency comb metrology for baseline estimation

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Detailed studies on interferometer operations aspects



Formation flying with relatively short baselines (<20 m ... 1 km): High demands on autonomy

Lab systems for laser comb metrology manage < 1 μ m rms within 1 ms of integration time

THz heterodyne receiver technology advances fast ... on route to reach ~3 x quantum limit

High resolution in the FIR

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Summary:

We propose to consider a space facility that enables FIR observations with high spatial **and** spectral resolution.

 Circumstellar disks, the trail of water and the connection to planet formation as a main motivation

Facility to operate as an Observatory, not as a mission:

 → many more important science cases (ISM physics and chemistry, star formation, AGN feedback), for the galactic and extragalactic community

 More concrete implementation plans with detailed follow-up studies for single-dish and interferometric option in recent years

Project in the L-class bracket of the ESA implementation categories
 Migh resolution in the FIR

Thank you for your attention!

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Circum-protoplanetary disks in reach for (heavy) Proto-Jupiters



Model predictions for CPD continuum fluxes

Radiative transfer on top of hydro simulation for embedded proto-planets

40 AU

100 micron

63.2 micron

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