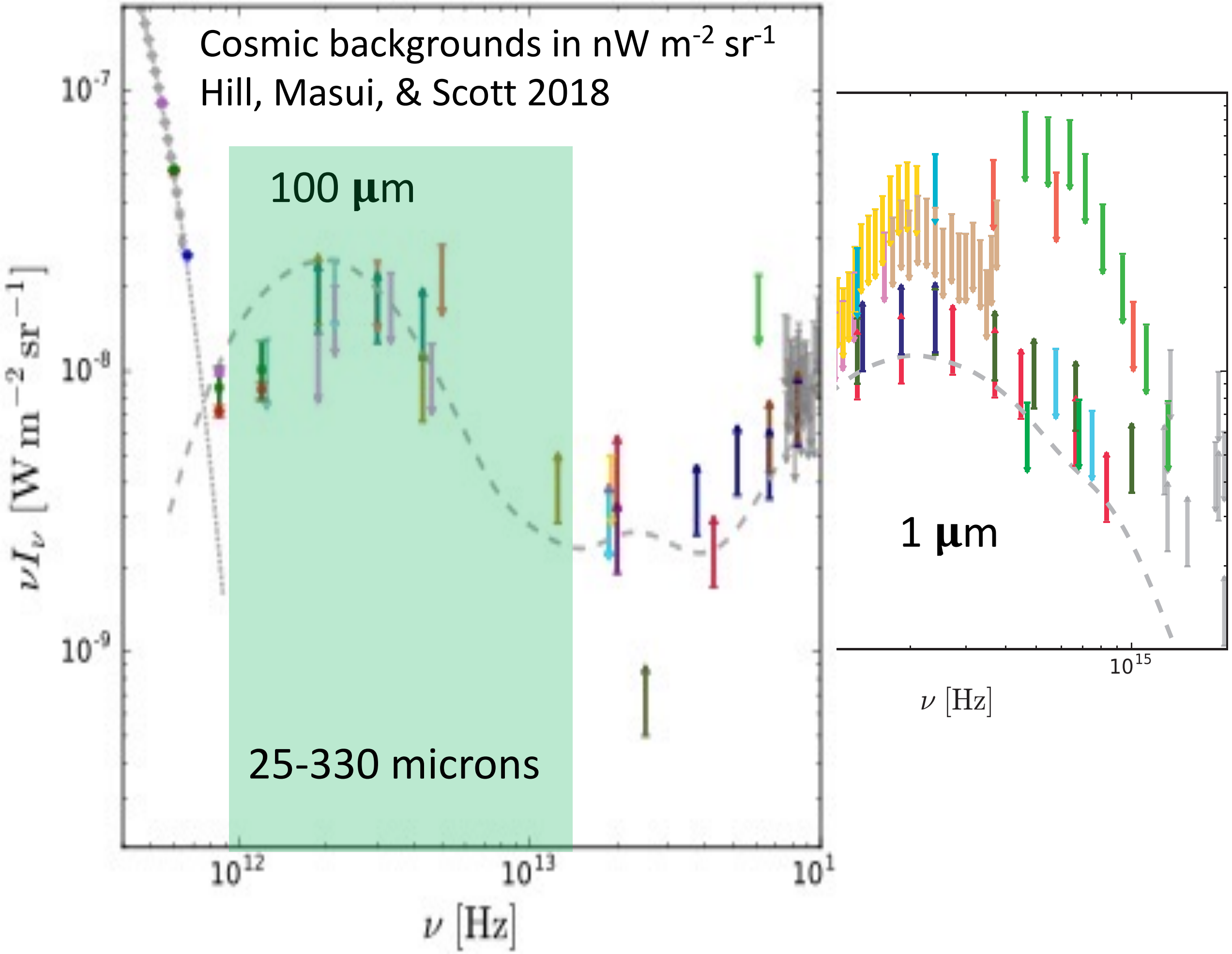
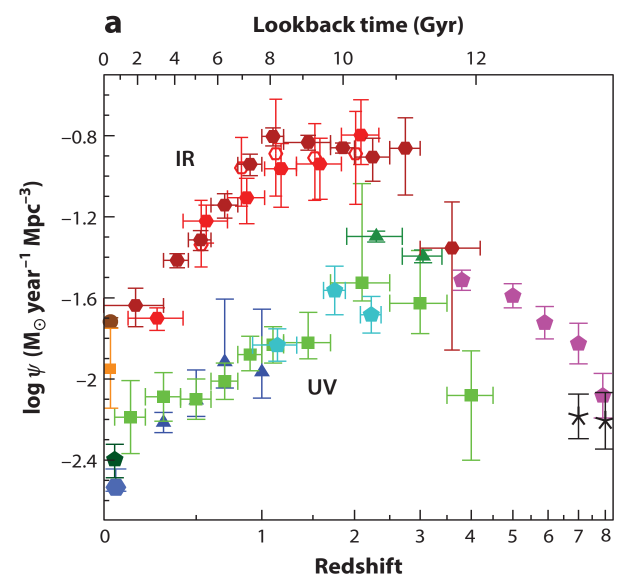
Envisioned PRIMA Capabilities

Matt Bradford

Far-Infrared Astronomy



Energy output from galaxies:
Madau & Dickinson, 2014



Most of energy from star formation and accretion activity emerges in the far-IR.

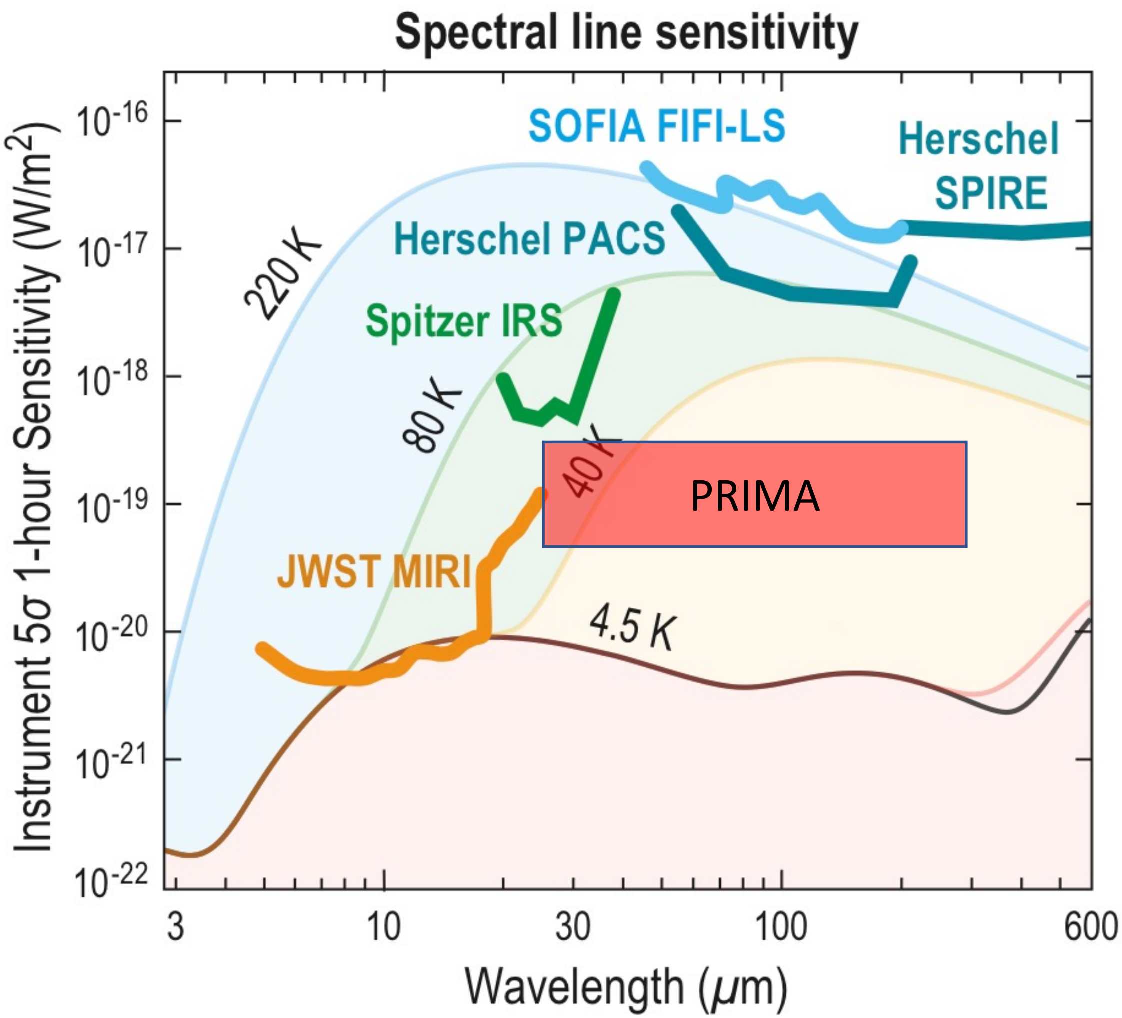
~Half of the remnant electromagnetic light from stars and galaxies is in the far-IR.

Far-IR background is a cosmological background, not a low-redshift phenomenon.

Mechanisms driving these transformative processes, and the results are inaccessible in the optical / NIR.

Earth's atmosphere is largely opaque.

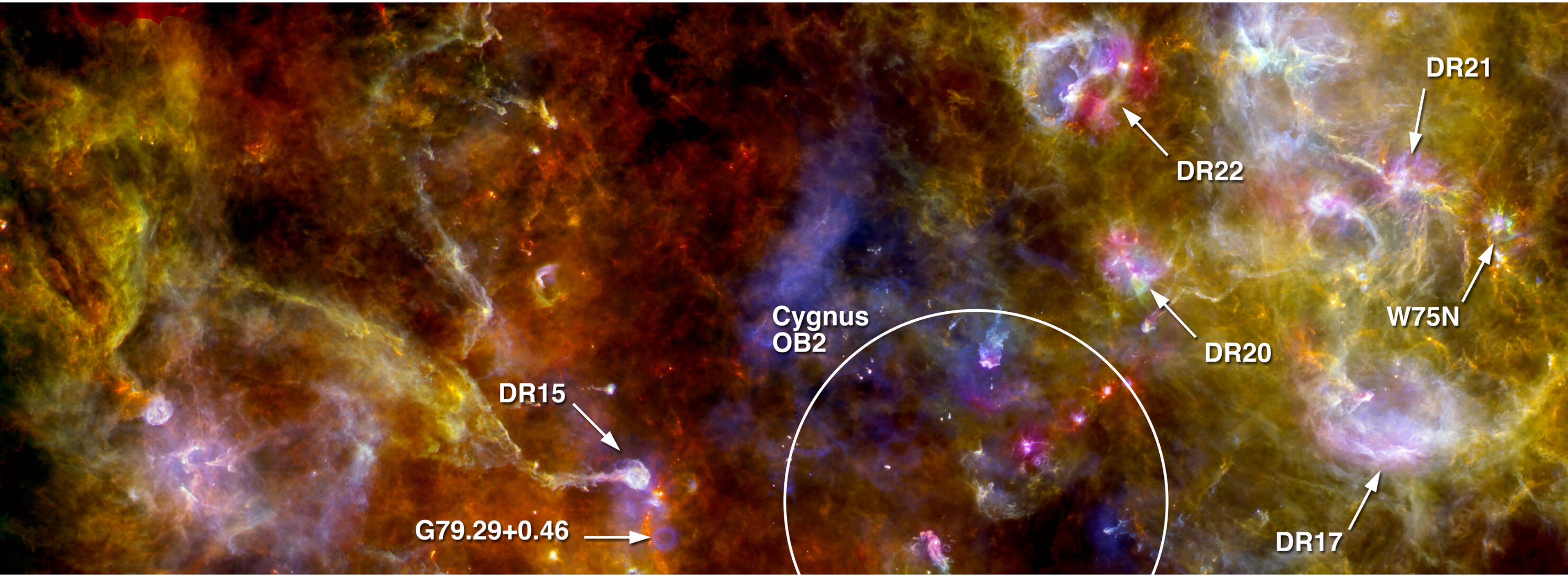
Cryogenic telescope is a powerful opportunity.



Comparing low-emissivity 300 K system to zodiacal light background is about a factor of 1 million, e.g. at 60 microns. Sensitivity is the square root of brightness, speed is this ratio.

Daytime to darkest 20% at Mauna Kea: V-band brightness ratio is 30 million

Reminder of Herschel – beautiful multiband imaging of dust heated by starlight

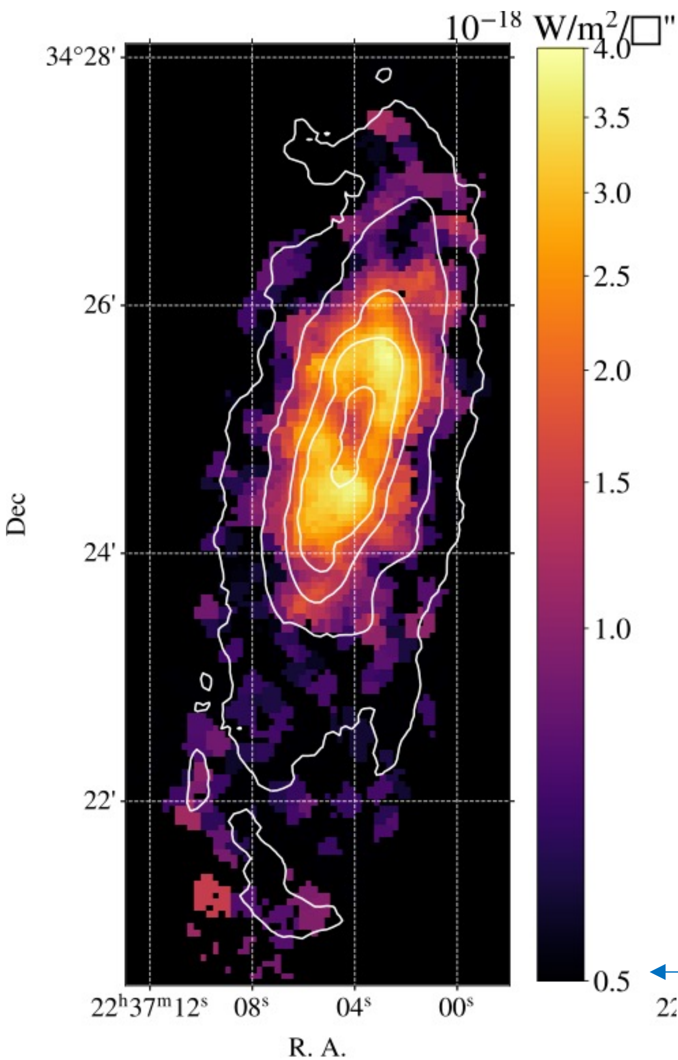


~6 degrees

70, 160, 250, 350, 500 micron composite. PACS and SPIRE instruments

Martin Hennemann & Frédérique Motte,
Laboratoire AIM Paris-Saclay, CEA/Irfu - CNRS/INSU - Univ. Paris Diderot, France

Low-surface brightness Line mapping.

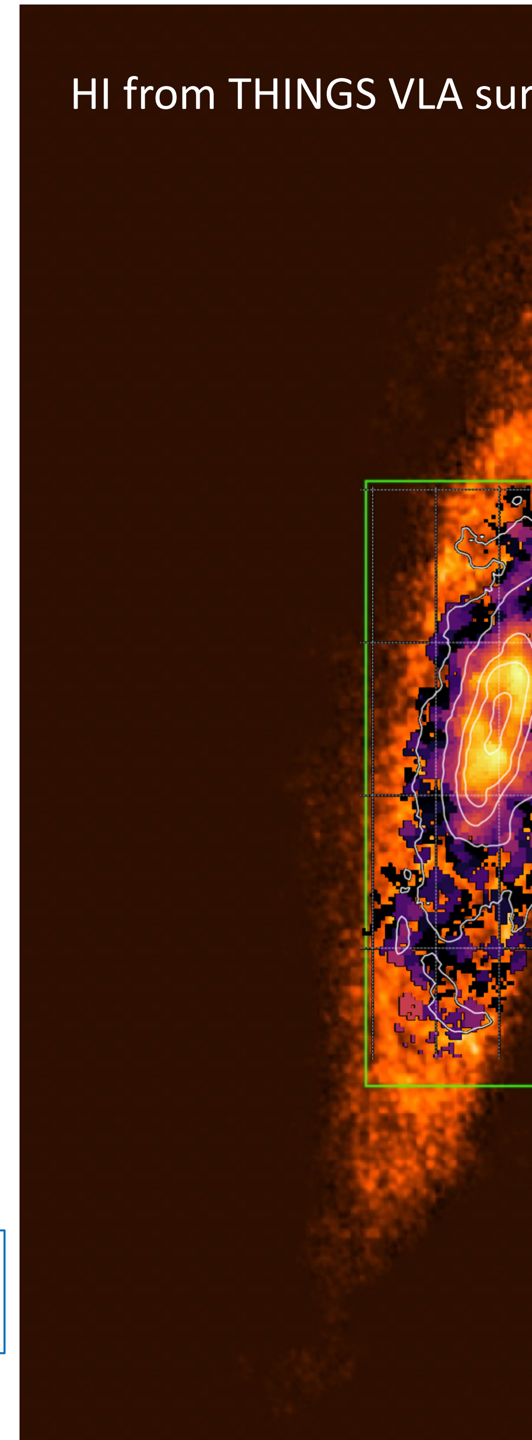


NGC 7331
[CII] map from SOFIA FIFI-LS. Sutter & Fadda 2022
4.5 hours flight time.

Single line, Limited to bright, dense gas.

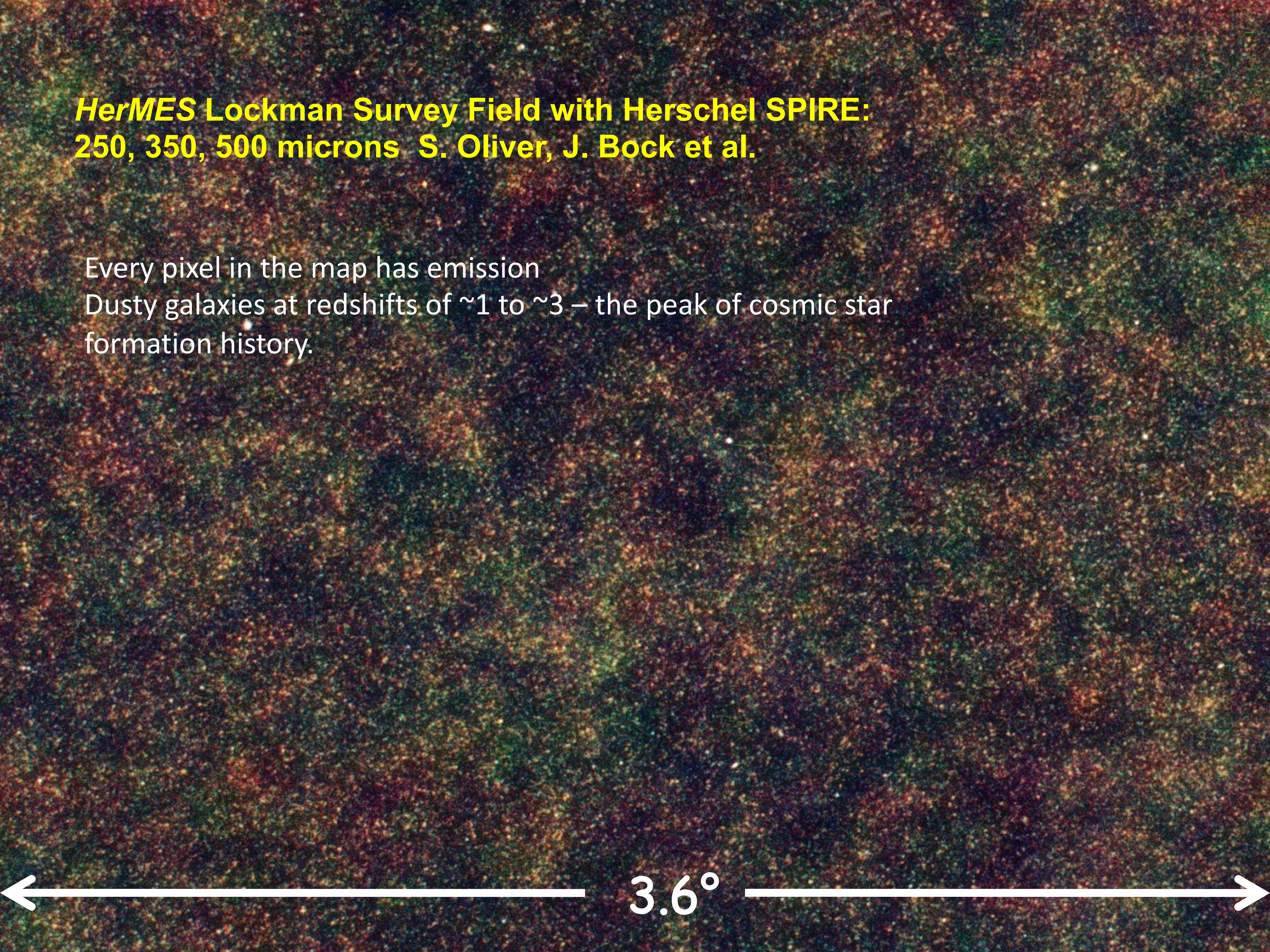
PRIMA will be thousands of times faster, measuring CII cooling in galaxy halos and outer disks. Comparison with HI provides cooling per baryon. Other lines also measured at the same time.

10 sigma, 1 second, PRIMA, per beam!

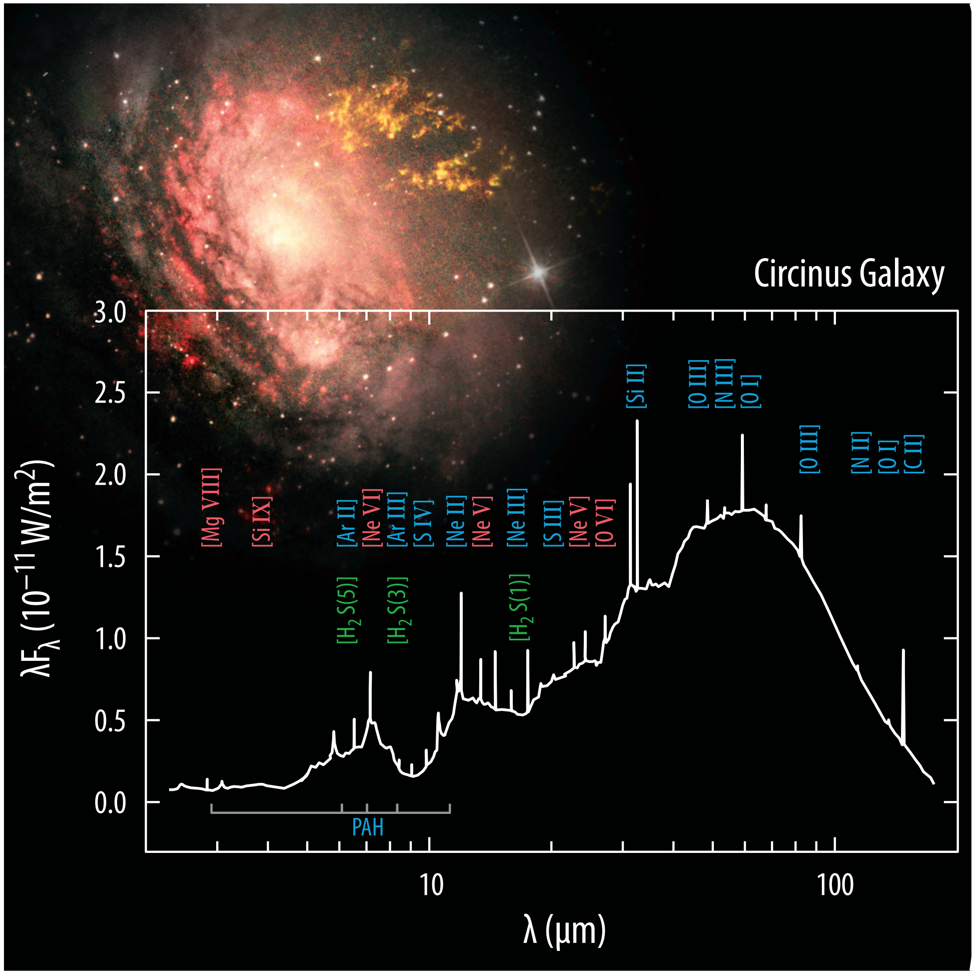


HerMES Lockman Survey Field with Herschel SPIRE: 250, 350, 500 microns S. Oliver, J. Bock et al.

Every pixel in the map has emission
Dusty galaxies at redshifts of ~1 to ~3 – the peak of cosmic star formation history.

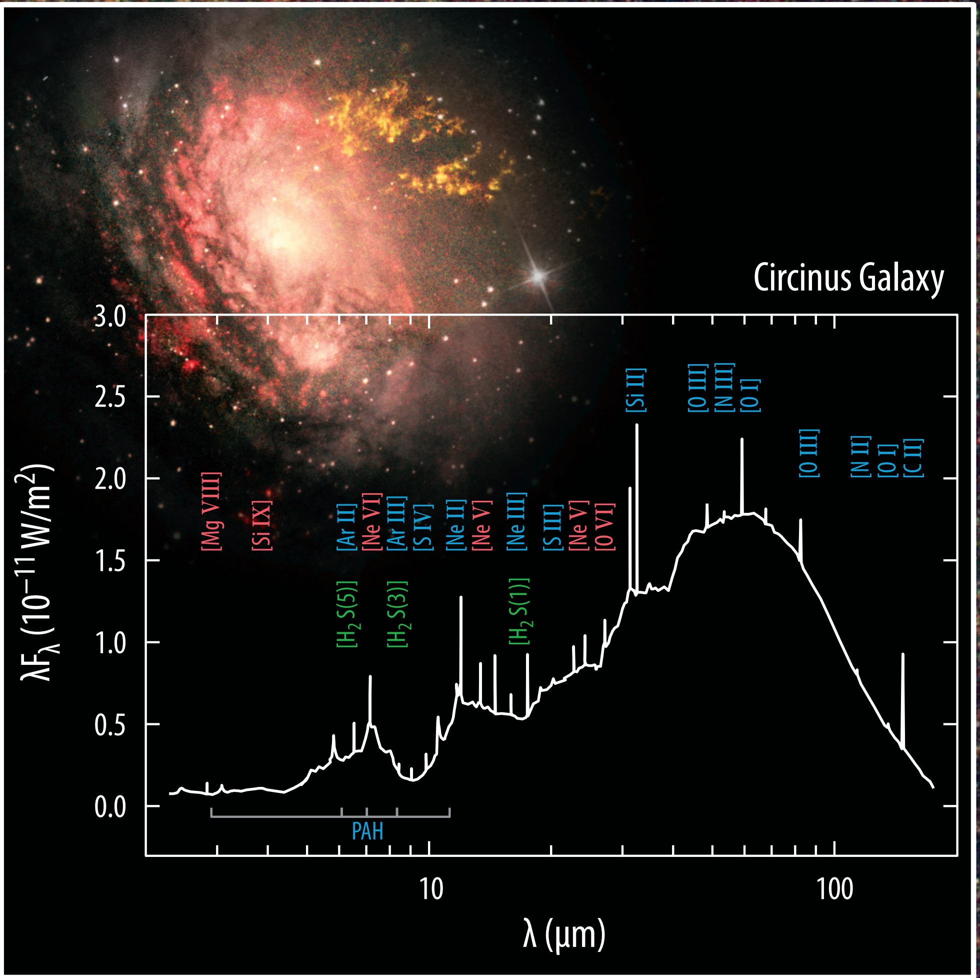


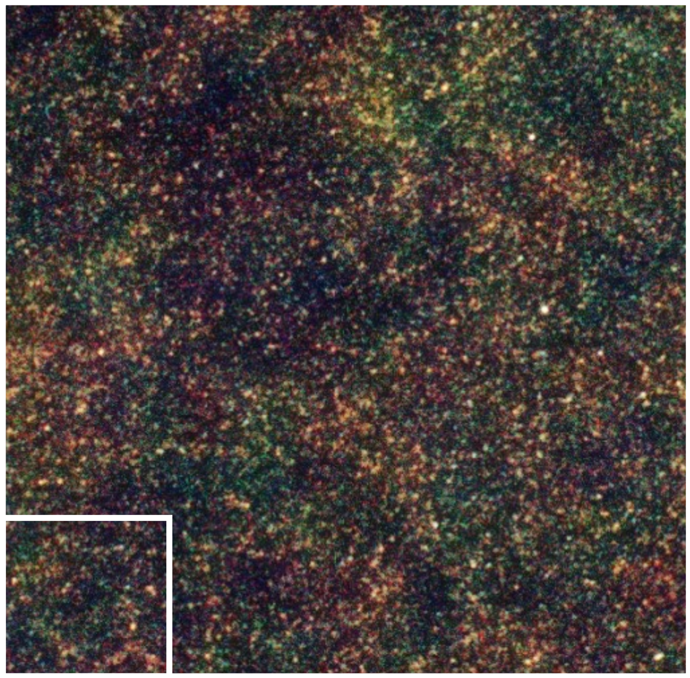
Low-resolution spectroscopy with PRIMA



....Hundreds to thousands of individual galaxies, and/or large spectral maps.

Low-resolution spectroscopy with PRIMA



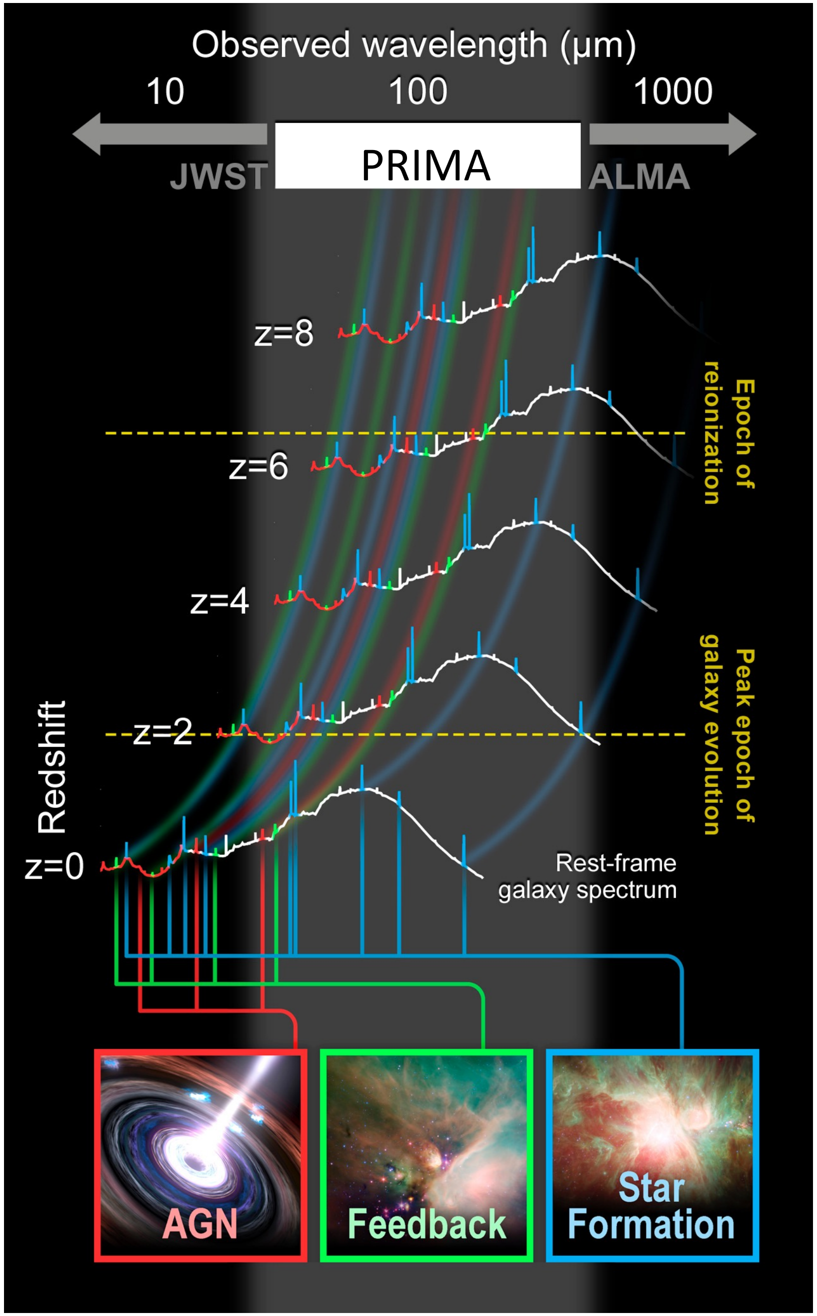


Example Field-Filling Spatial / Spectral Surveys: Deep, Medium

A data cube with every pixel having a spectrum

Source confusion not an issue for spectral lines. E.g. M. Bonato+ 2019

Wideband Survey Spectroscopy with the PRIMA

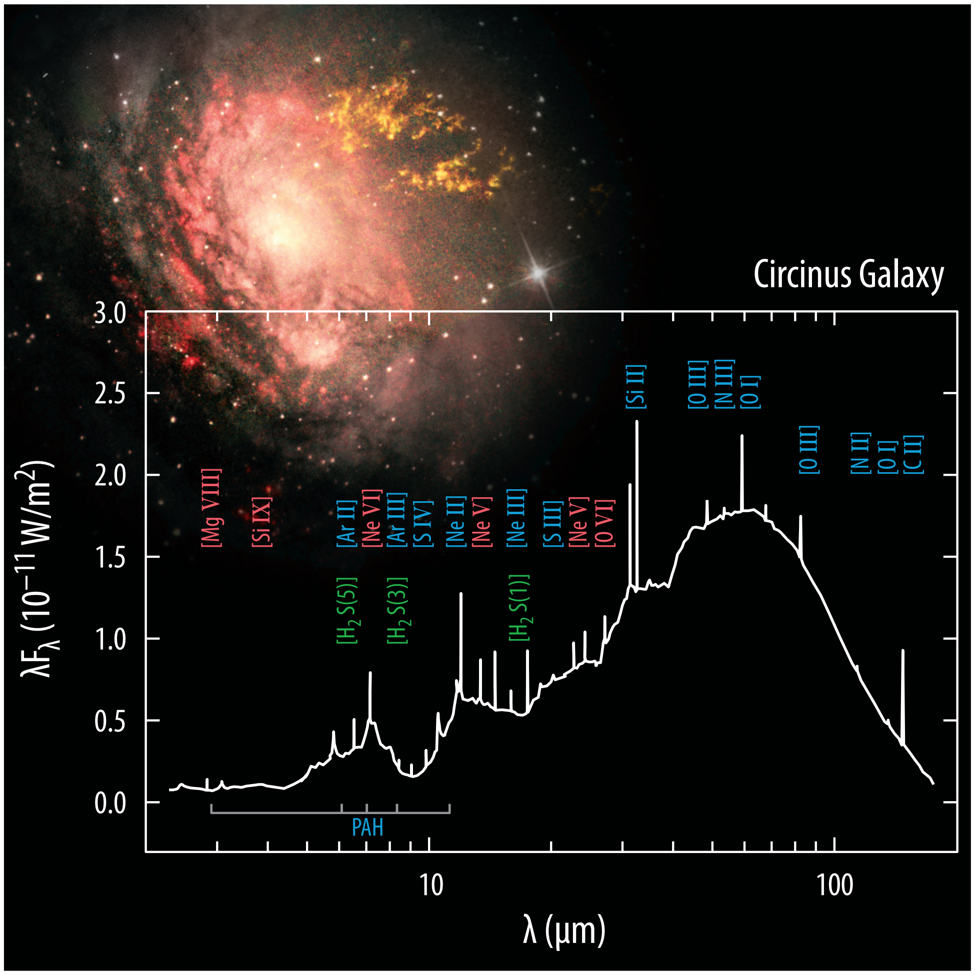


Key requirements

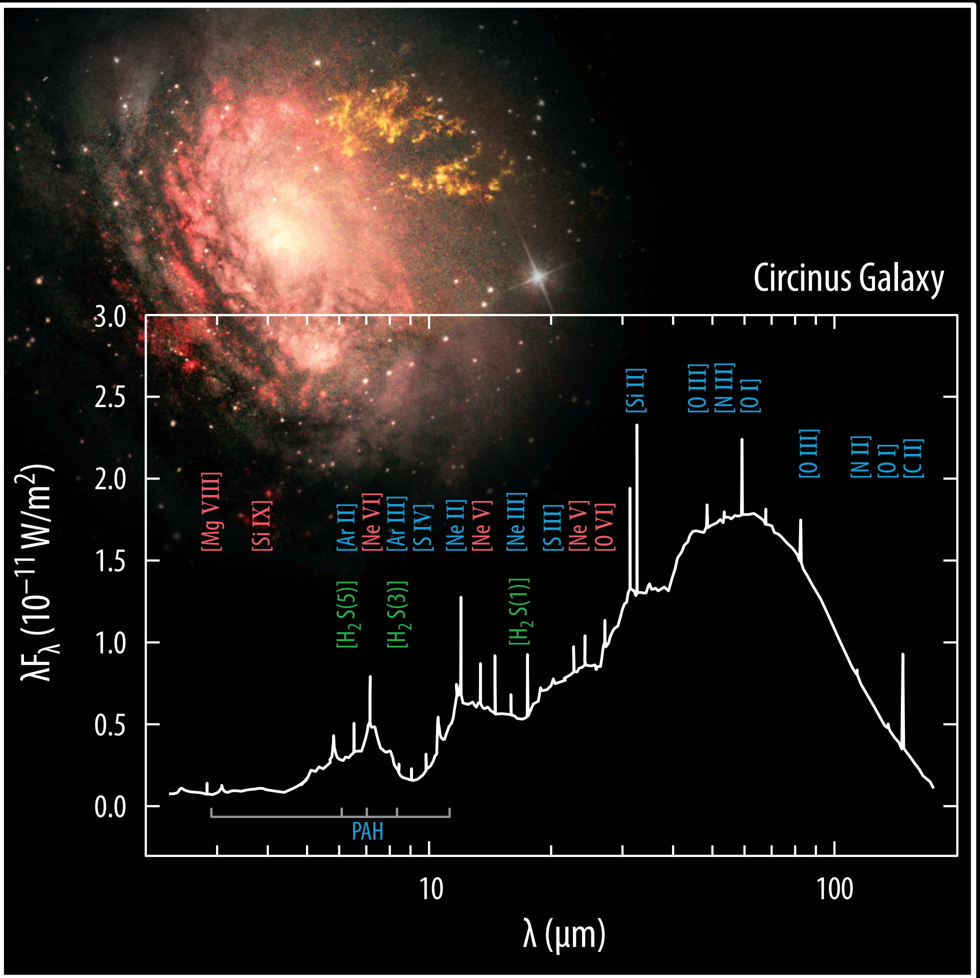
- Modest resolving power. Most important attribute is detecting lines, so looking at integrated line sensitivity. Sensitivity dependence on resolving power is modest, but resolving power drives mass and pixel count.
- Large spatial coverage (limited by practicalities such as mass / size and array format)
- **Also require ability to go deep on single objects when necessary.**
- **→ Drives us to wideband, R~200 long-slit grating modules.**
- Wavelength coverage under study. Longer is larger.

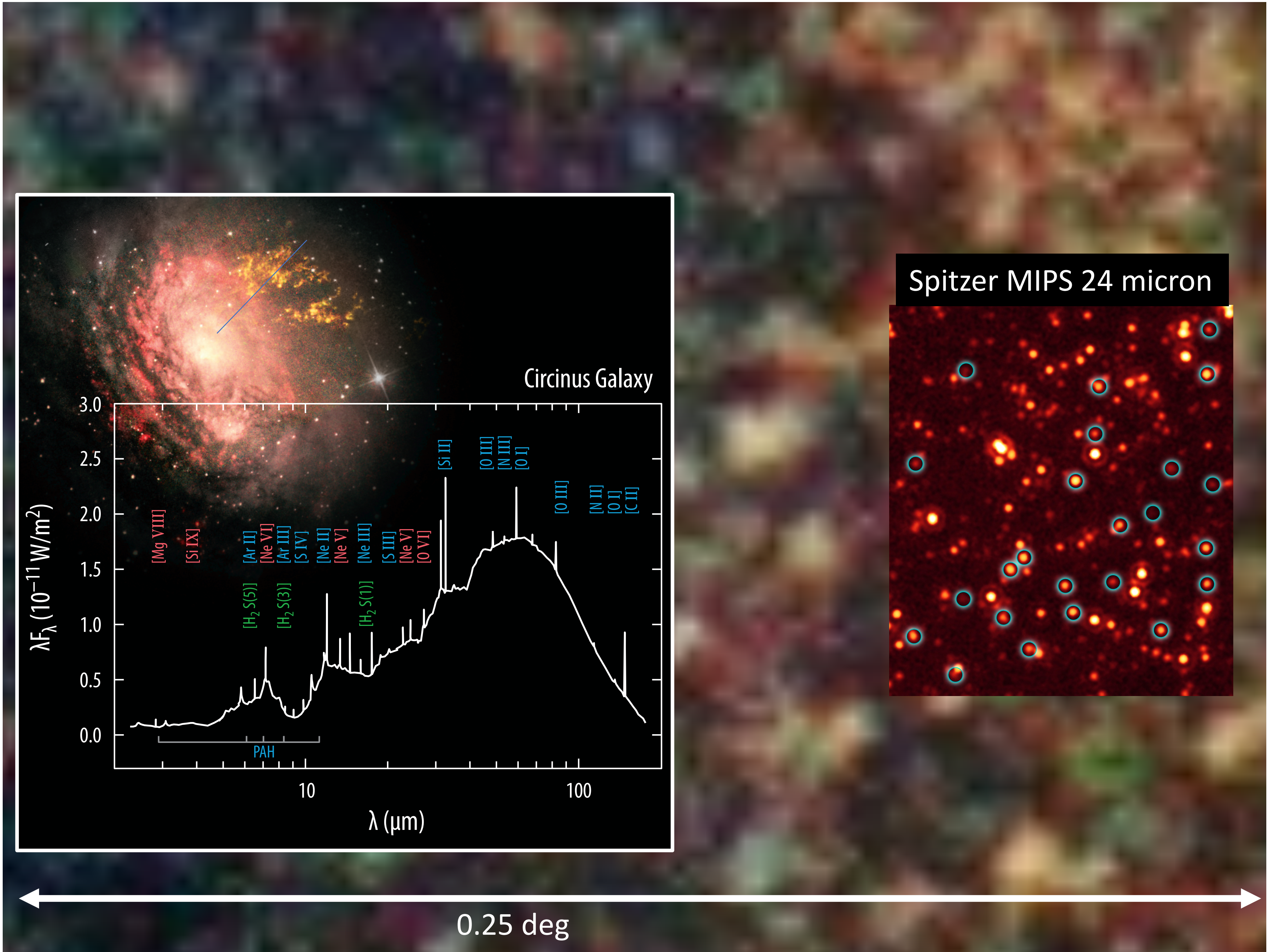
Alexandra Pope (for Origins, but same idea)

Low-resolution spectroscopy with PRIMA

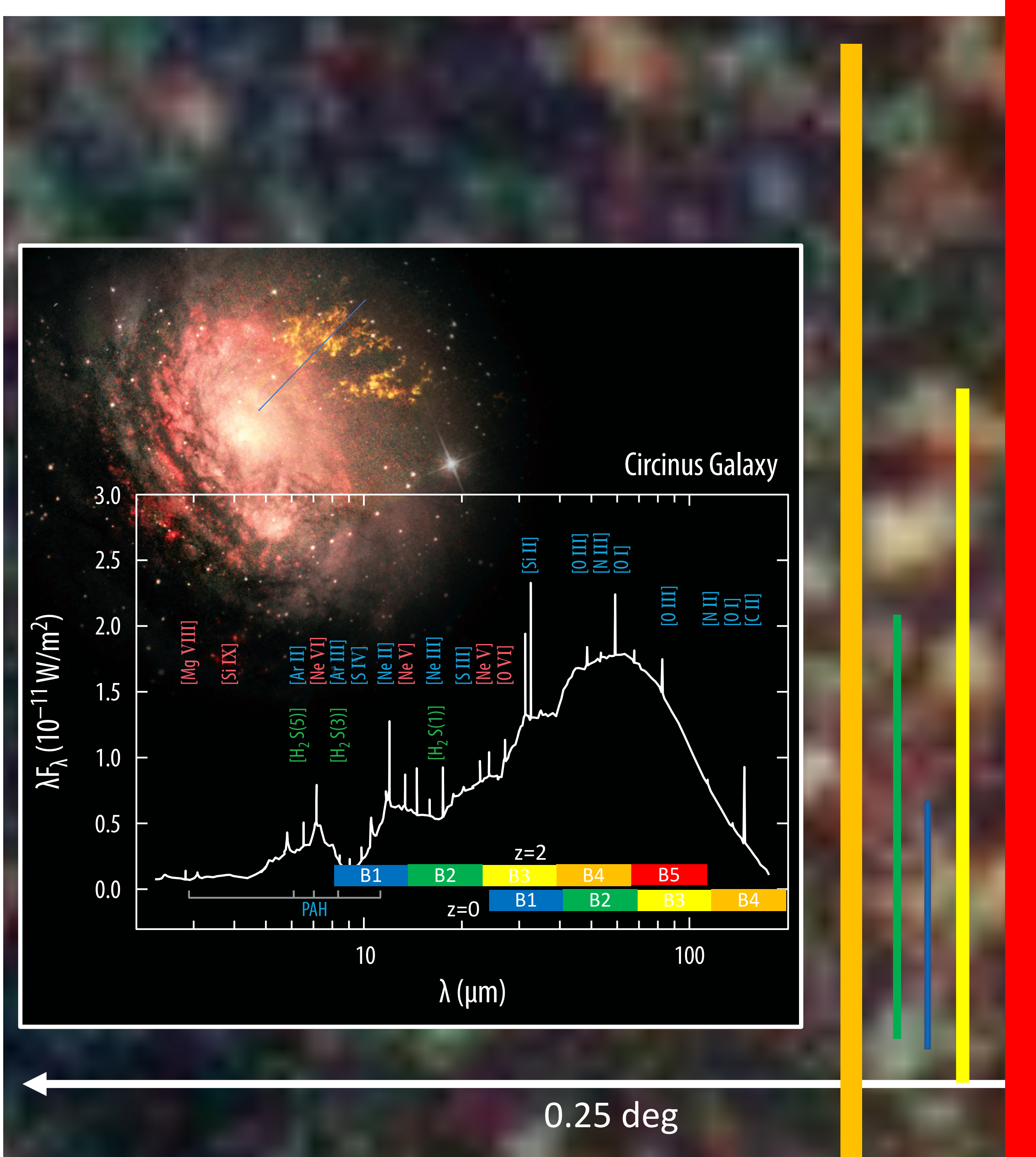


Low-resolution spectroscopy with PRIMA





Circinus Galaxy
Spitzer MIPS 24 micron
λFλ (10−11 W/m2)
λ (μm)
[Mg VIII]
[Si IX]
[Ar II]
[Ne VI]
[Ar III]
[S IV]
[Ne II]
[Ne V]
[Ne III]
[S III]
[Ne V]
[O VI]
[Si II]
[O III]
[N III]
[O I]
[O III]
[N II]
[O I]
[C II]
[H2 S(5)]
[H2 S(3)]
[H2 S(1)]
PAH
0.25 deg



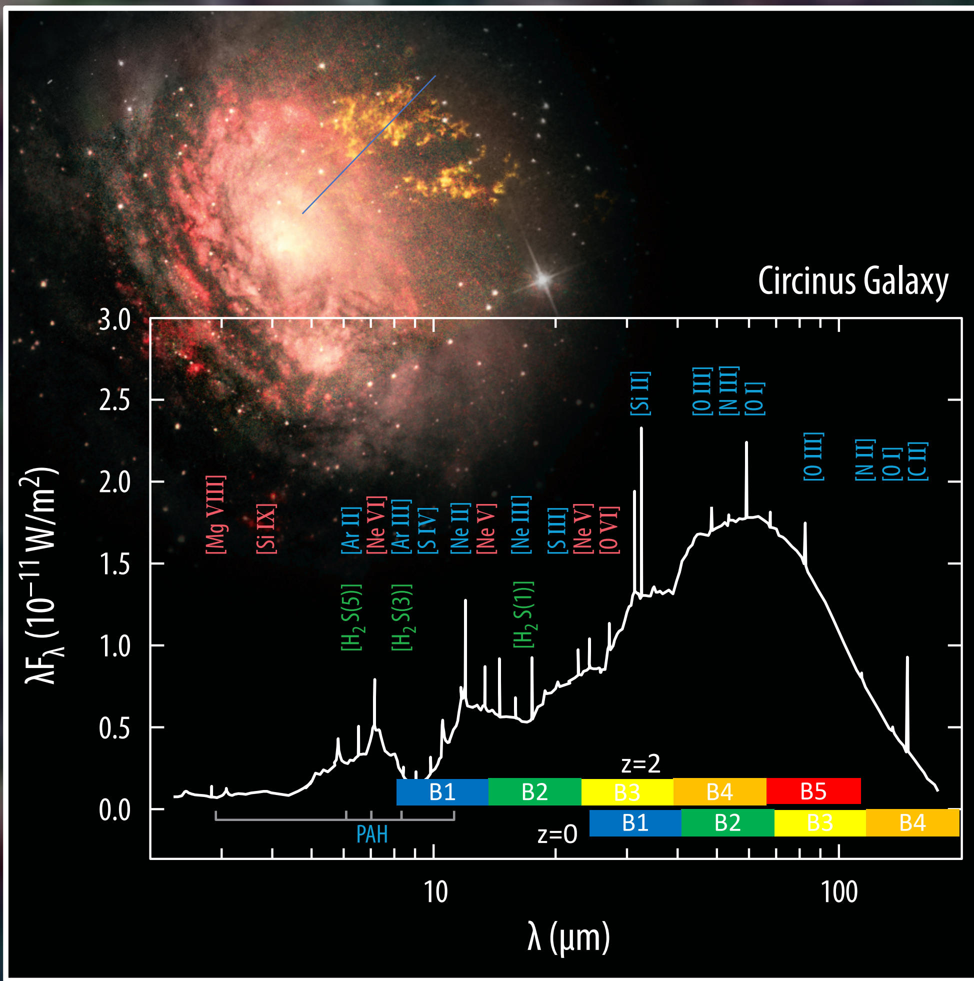
Four or five slit-fed spectrometer modules.

Each slit is 1 beam wide (e.g. 4 arcsec at 30 microns, 25 arcsec at 265 microns).

Slits 20-50 beams long, will likely push for longer slits at shortest wavelengths

Start at 25 microns, but open to optimization. Where to overlap with JWST given large performance gradient with

Goal to reach to 330 microns in Band 5.



Would like to align slits so that a single source can couple all 5 instantaneously.

But have incur sensitivity penalty of 20-40%

0.25 deg

PRIMA

The PRobe far-Infrared Mission for Astrophysics

A community-driven general-observer-accessible far-IR-optimized observatory for 2030.

- JPL implementation lead, GSFC key contributions.
- International partnerships in development.
- A cryogenic telescope with a target aperture of 2-3 meters.

Science and hardware formulation underway – inputs welcome.

Potential instrumentation capabilities:

Imaging / Polarimetry: ~10 to 300 μm

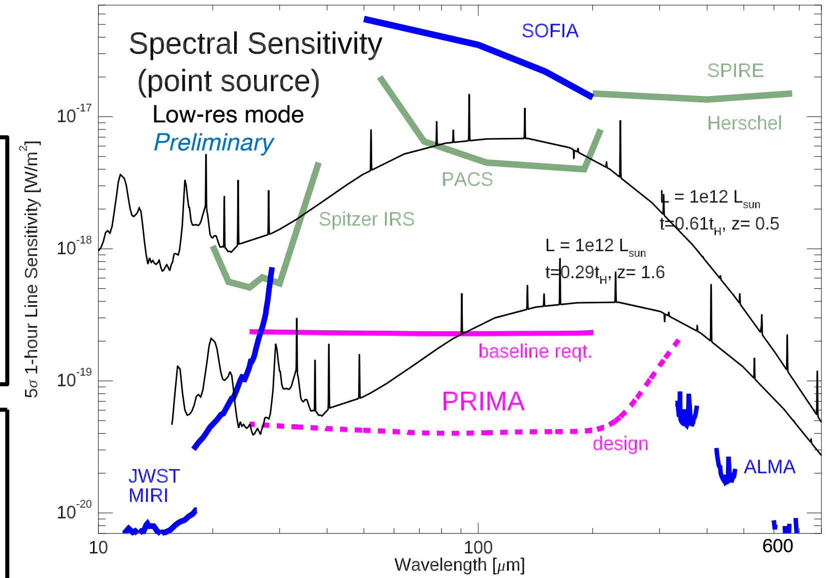
- Mapping speed: ~10 $\left(\frac{\text{deg}^2}{\text{hour}}\right)\left(\frac{\text{F}}{1\ \text{mJy}}\right)^2\left(\frac{1}{\text{SNR}}\right)^2$ (Extragalactic confusion limited for λ>70 μm).

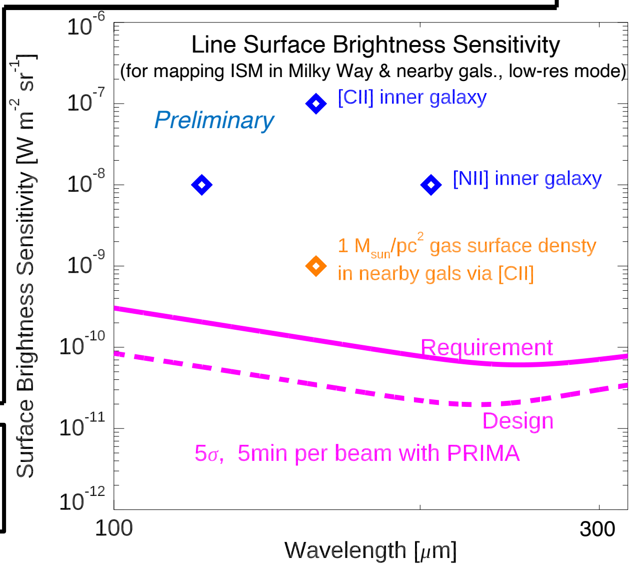
Base low-resolution spectroscopy w/ wideband gratings: ~25 to 330 μm.

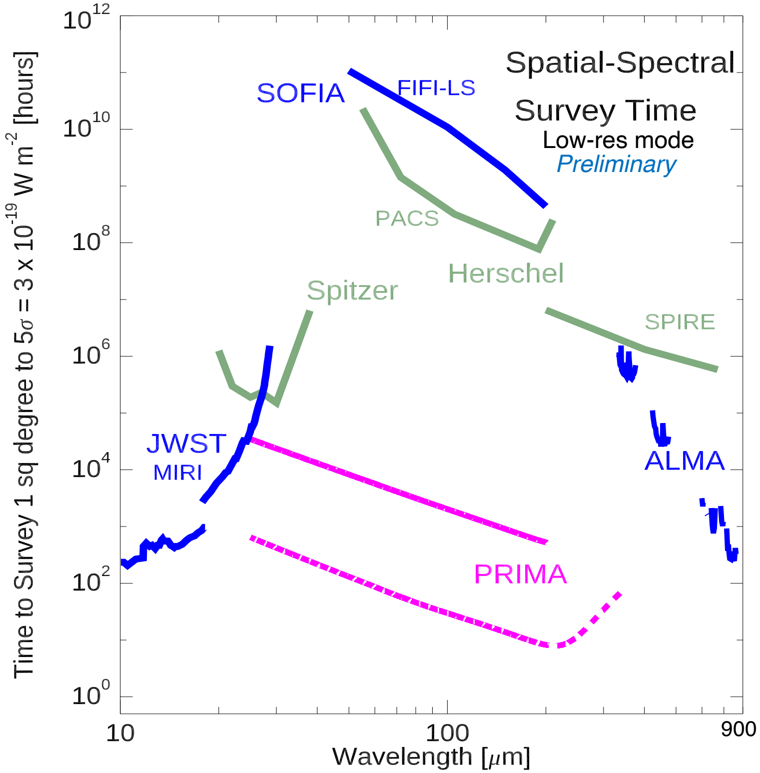
- Resolving power 60 to 250.
- Unprecedented line surface brightness sensitivity (bottom center figure).
- Spectral-line sensitivity when pointed: 5σ, 1 hour of 5x10^{-20} to 2x10^{-19} W/m^2 (top right).
- Full instantaneous coverage of at least one ~octave bandwidth spectrometer band at a time, multiple bands simultaneously on source is a goal.
- Mapping speed: 10^{-1} to 10^{-4} sq degrees per hour to 3x10^{-19} W/m^2 (bottom right figure).

Medium-resolution capability using addition to low-resolution gratings: same 25-330 μm band.

- Available resolving power: up to 5000-8000.
- Sensitivity range: 5σ, 1 hour of 10^{-19} to 2x10^{-18} W/m^2 per spectral resolution element (or unresolved line).
- Mapping speed in medium-res mode: modest, to be determined, depends on R desired.







Contact with questions:
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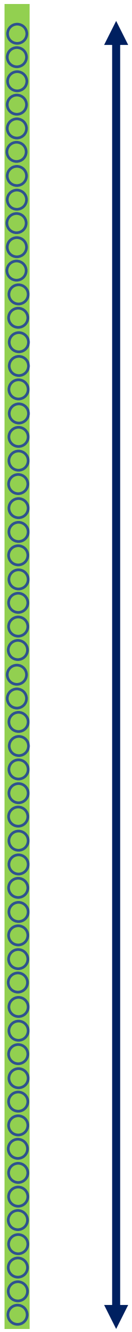
Matt Bradford (matt.bradford@jpl.nasa.gov)

PRIMA factsheet version 1.1, 22 Feb 2022

Slit spectrometer maps to 2-D array with spatial & spectral dimensions

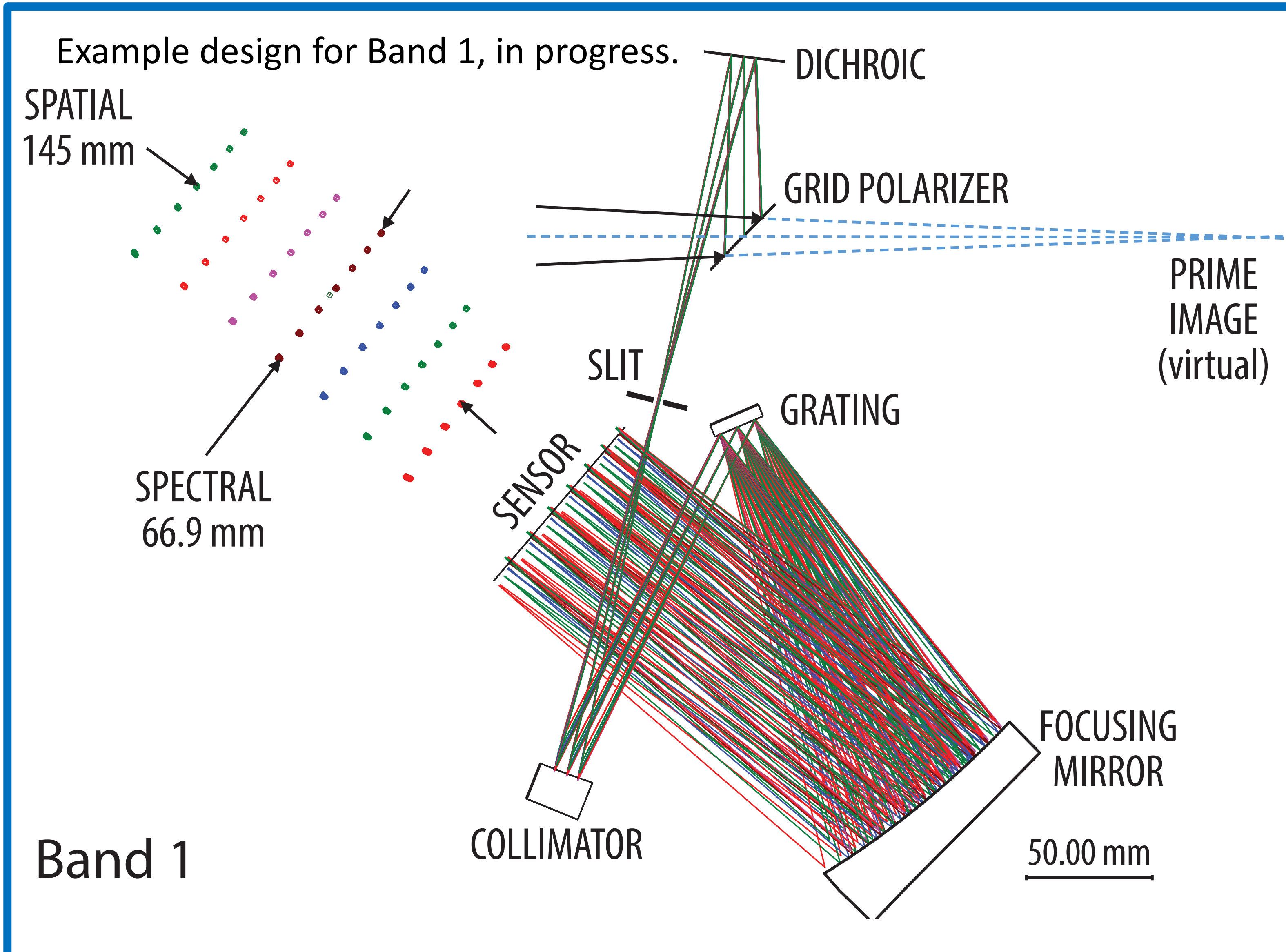


Slit: 1 x N beams on the sky. N > 30.
Circles indicate individual detector power patterns on the sky

Spatial direction e.g. 10 arcminutes at 100 microns

Spectral direction: e.g. 70-120 microns in 100 bins

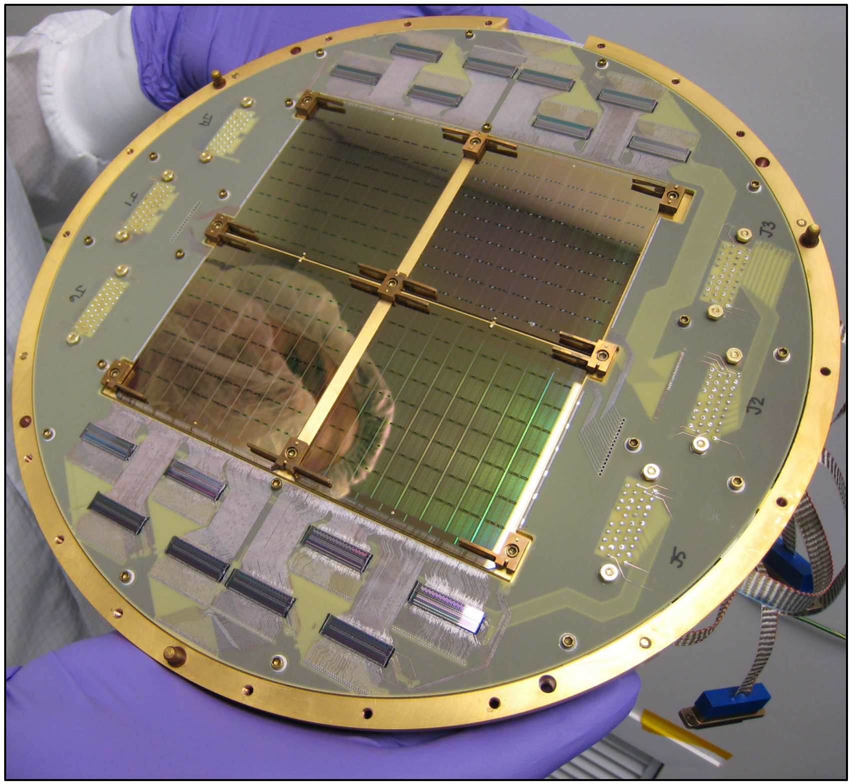
Slit spectrometer maps to 2-D array with spatial & spectral dimensions



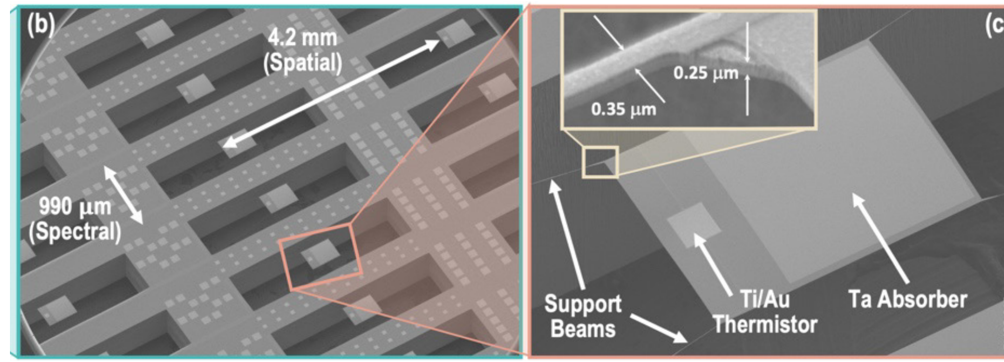
Key Enabling Technology is Detector Arrays

Sensitive detectors for the far-IR have no commercial providers – must be build by science / technology community.

JPL and NASA have invested over the last 2 decades – now paying dividends.



Bolometer arrays for the microwave background work. Fielded on the ground and in balloons. Here 512 total pixels **Works great, but PRIMA requires greater sensitivity & number.**

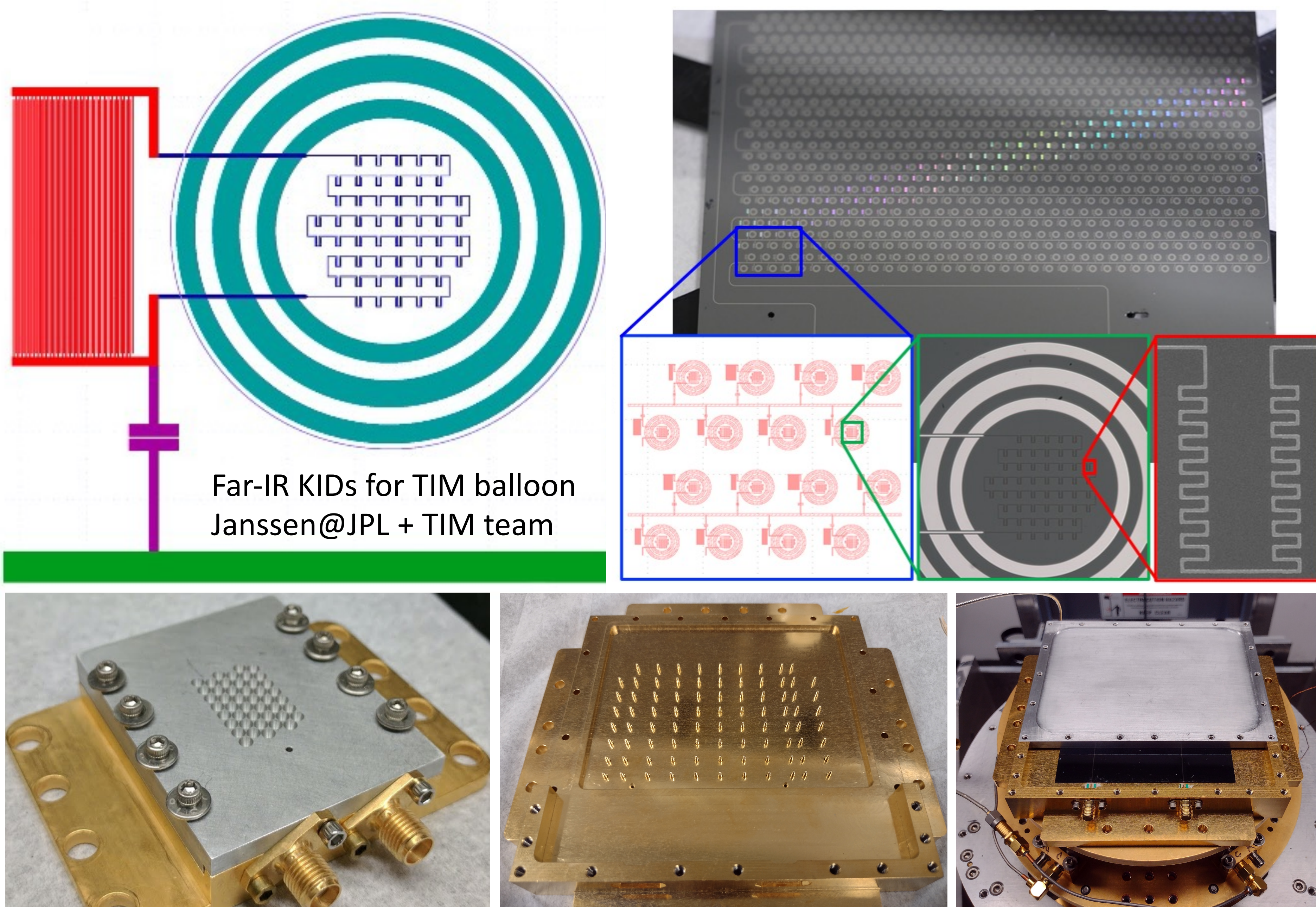


Example devices built for far-IR space sensitivities.

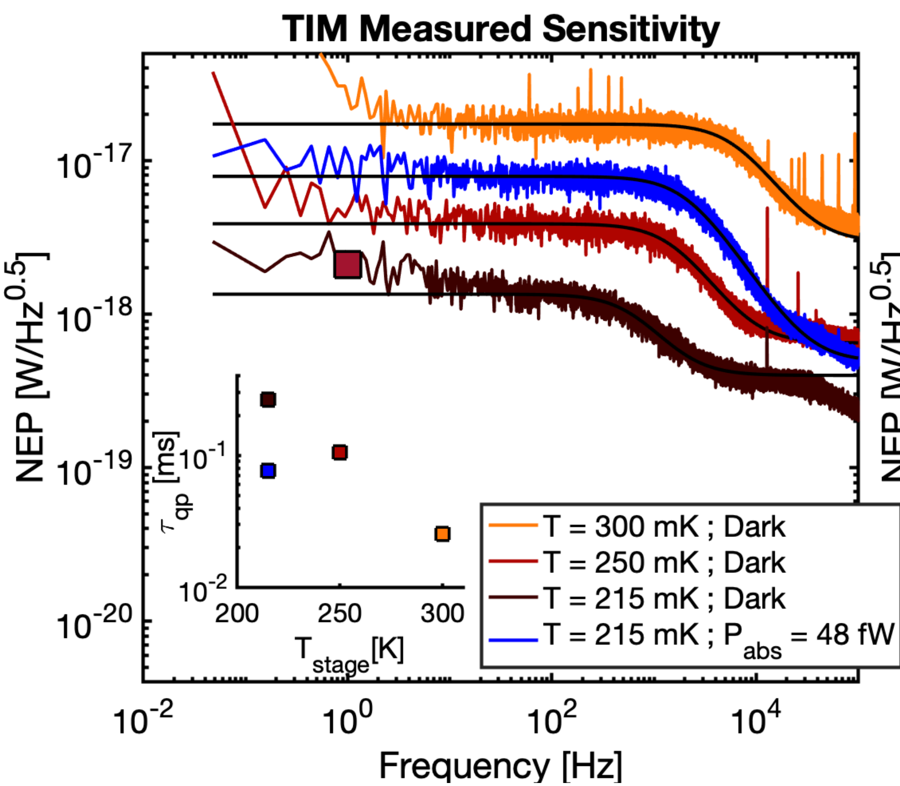
<u>Sensitive Far-IR Detectors:</u>

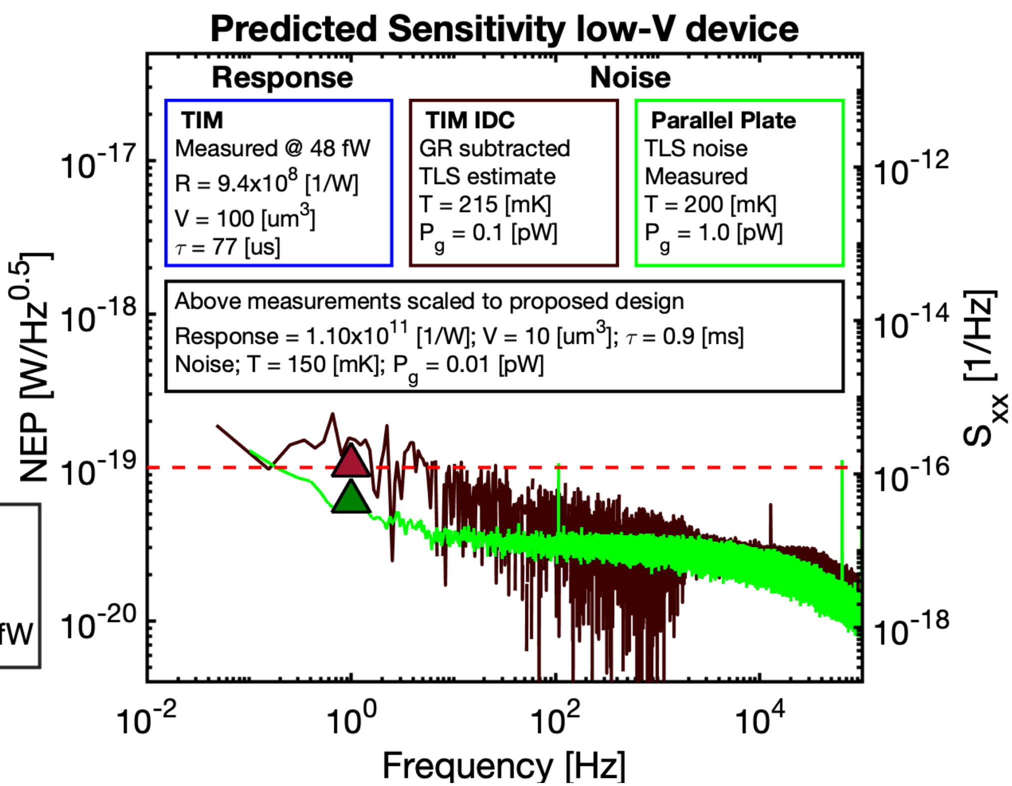
- Use superconductivity in one form or another
- Operate at temperatures of 50-100 mK
- Require microdevices fabrication professionals and low-temperature physics expertise.

Key Enabling Technology is Detector Arrays



KID Sensitivities now hitting background limit





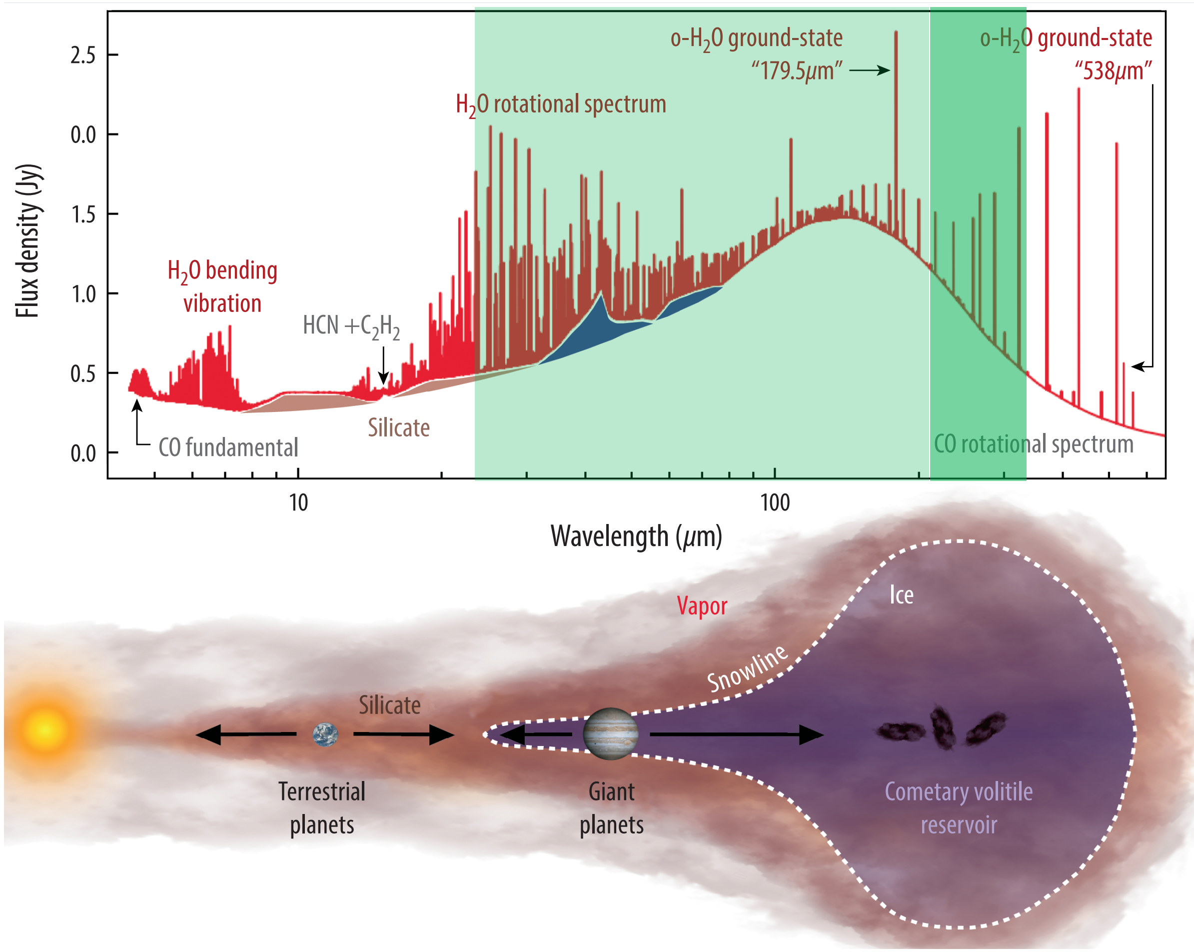
R. Janssen, S. Liu, S. Hailey-Dunsheath @ JPL / Caltech. TIM arrays provide framework for aluminum KIDs, they are well-behaved.

R. Janssen, P. Day, R. LeDuc (JPL) w/ J. Glenn. Early measurements from P. Echternach @ JPL confirming volume scaling

- KID sensitivities now below 10^{-19} W/sqrt(Hz), very close to PRIMA-spectrometer background limit.
- SRON / Delft also showing similar results
- Work still to do for full-band coverage, coupling optics (lenses / horns).

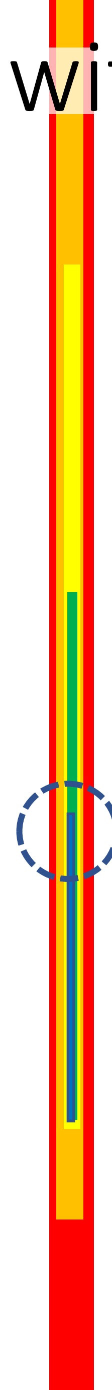
JPL

High Resolution Spectroscopy with PRIMA



Water spectrum and HD (mass tracer) unique to far-IR

Question for PRIMA: how does this science scales with spectral resolving power. Integrate with observatory in optimized manner.



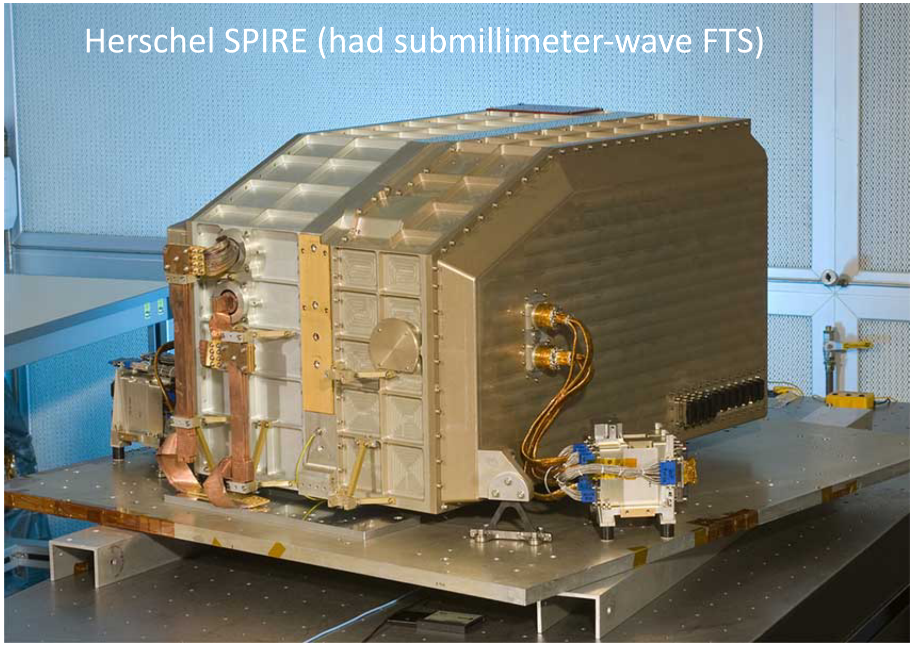
One approach: Pick off small field common to all slits. Process through FTS and re-insert into beam to be detected by grating spectrometers.

Targeting R of a few thousand across the band.

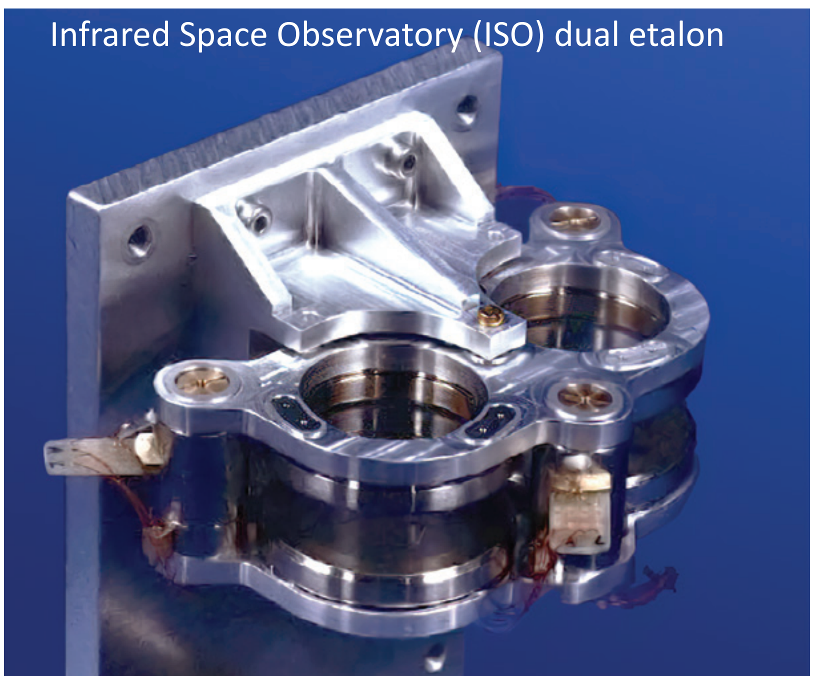
Line sensitivity will be degraded somewhat relative to grating: e.g. 2x

R value to be determined. Larger R increases instrument volume, mass

High-resolution mode – strong heritage for our two potential approaches.

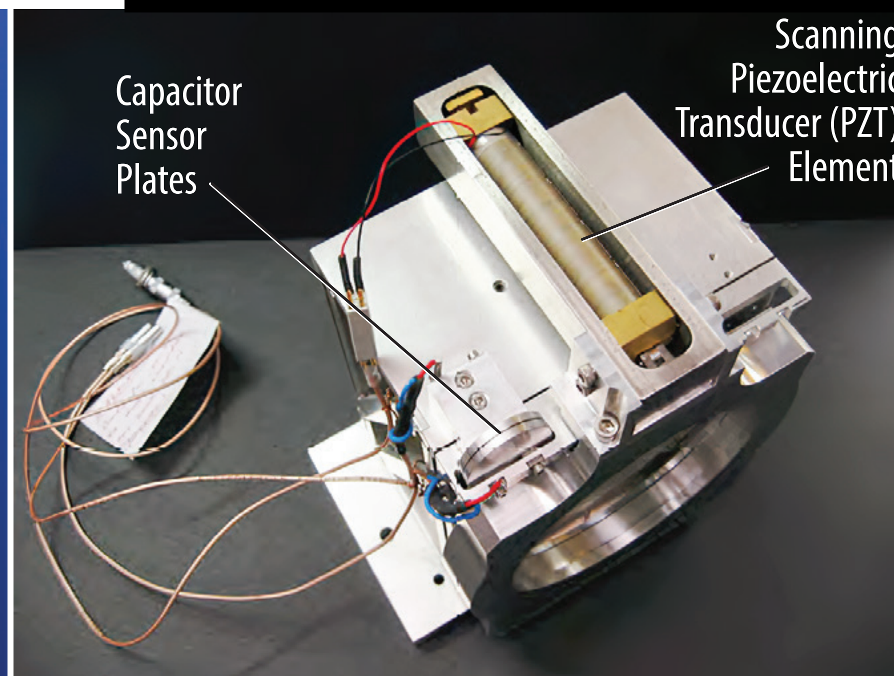


Herschel SPIRE (had submillimeter-wave FTS)

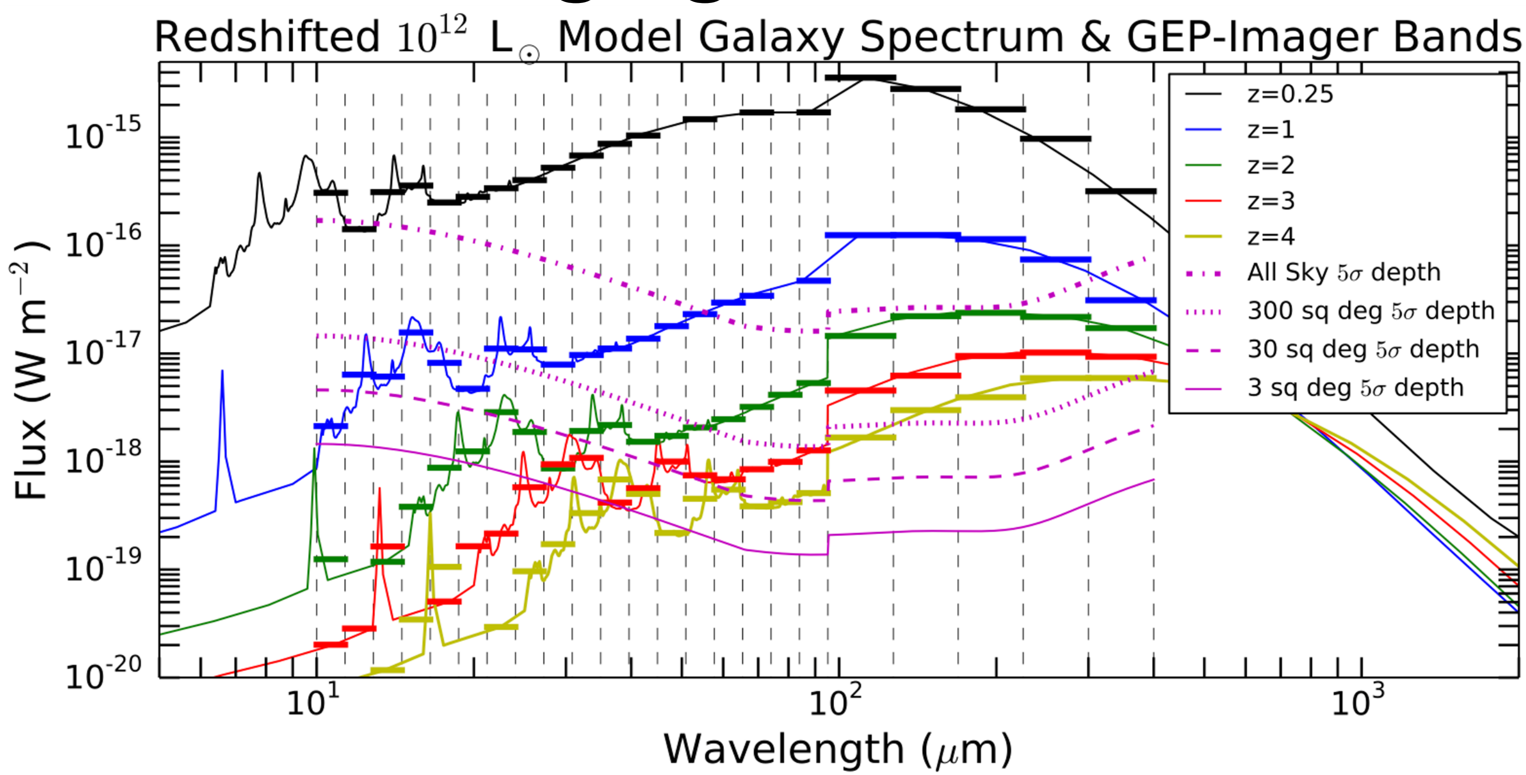


Infrared Space Observatory (ISO) dual etalon

SOFIA HIRMES etalon from Stacey group @ Cornell: R=100,000 at 112 microns, F=50.



Imaging with PRIMA



J. Glenn

- Powerful opportunity for:
  - Wide-field coverage: tens to hundreds of square degrees.
  - Excellent depth, can resolve the CIB at ~50-100 microns.
  - Narrow-band spectrophotometry (figure), can provide PAH redshifts.
  - Multi-band dust polarimetry.
- Collaborating with French (D. Burgarella / L. Ciesla, et al.) / Dutch (W. Jellema / P. Roelfsema) consortium that is working to develop PRIMA imager in Europe.