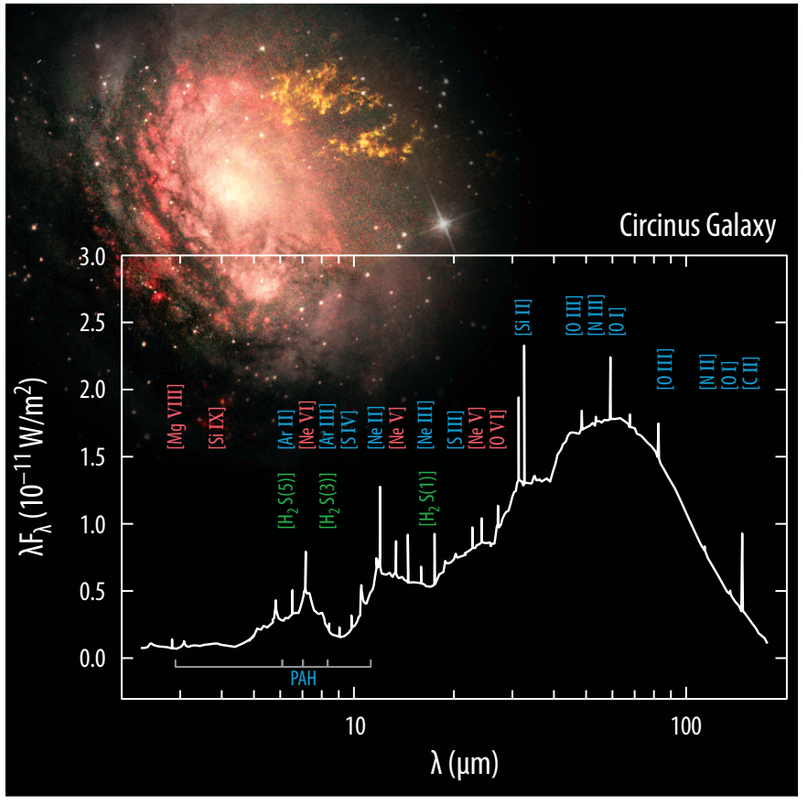
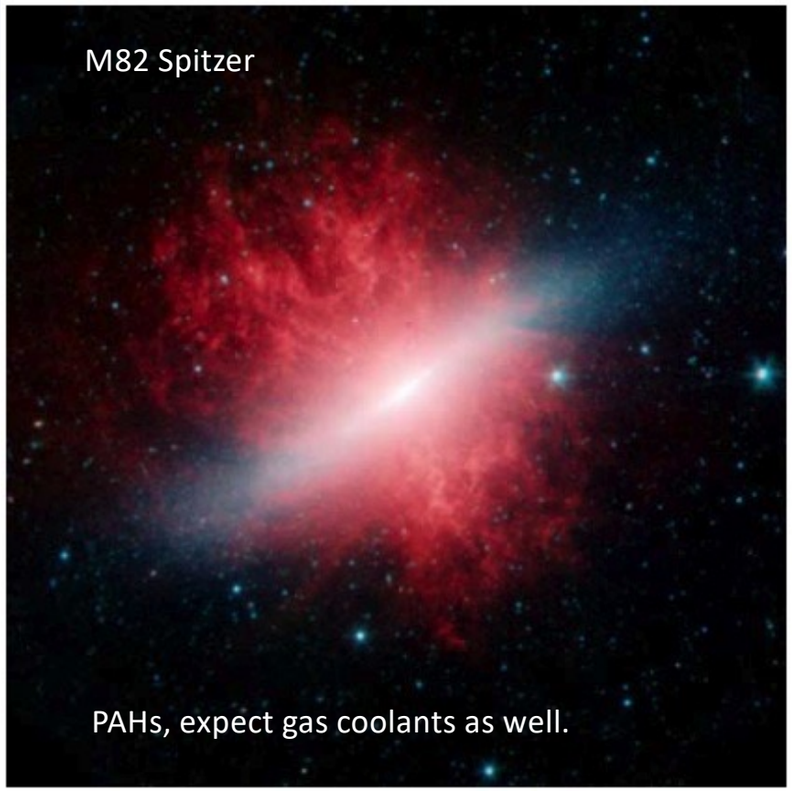
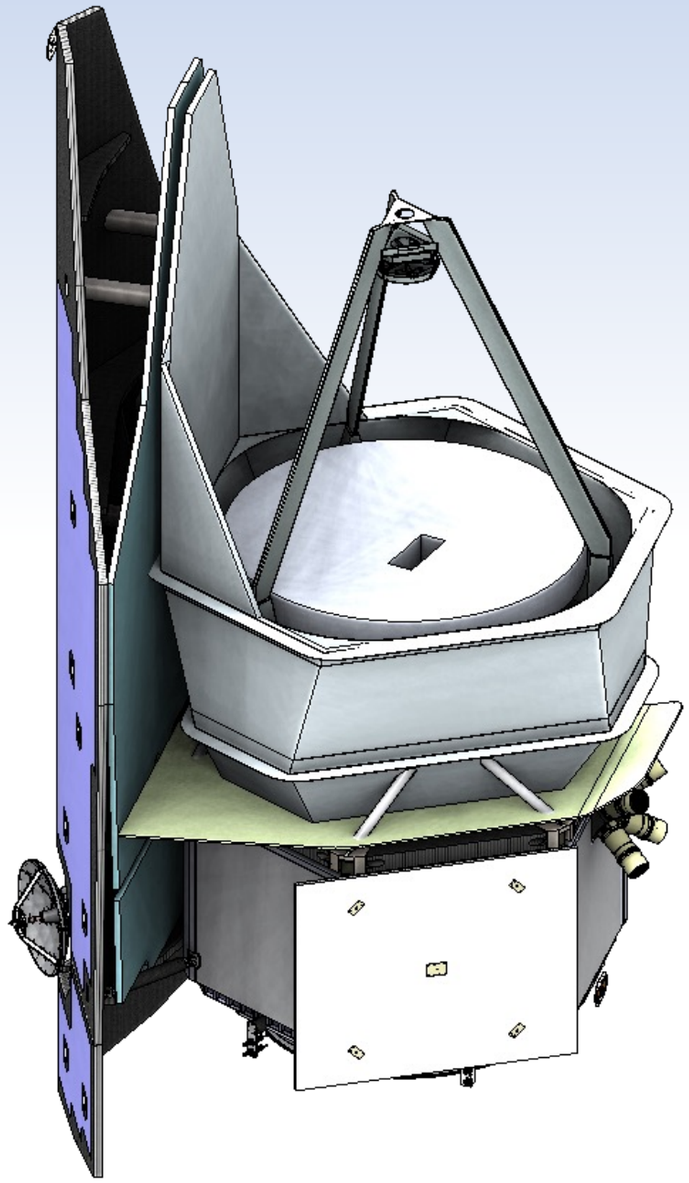
PRIMA Far-IR Enhanced Survey Spectrometer (FIRESS)

Matt Bradford

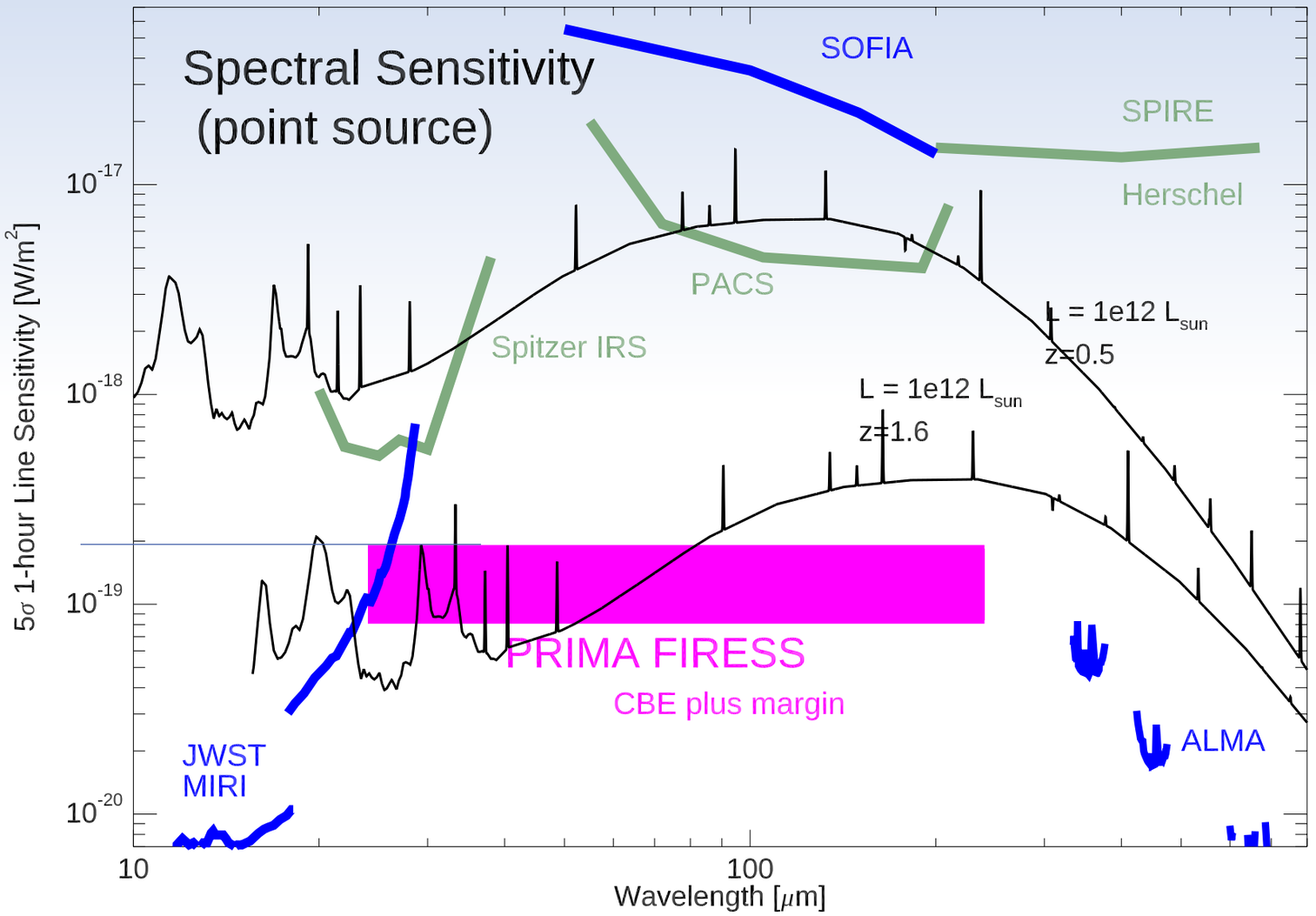
2023 March 29







PRIMA-FIRESS Multimode Spectrometer



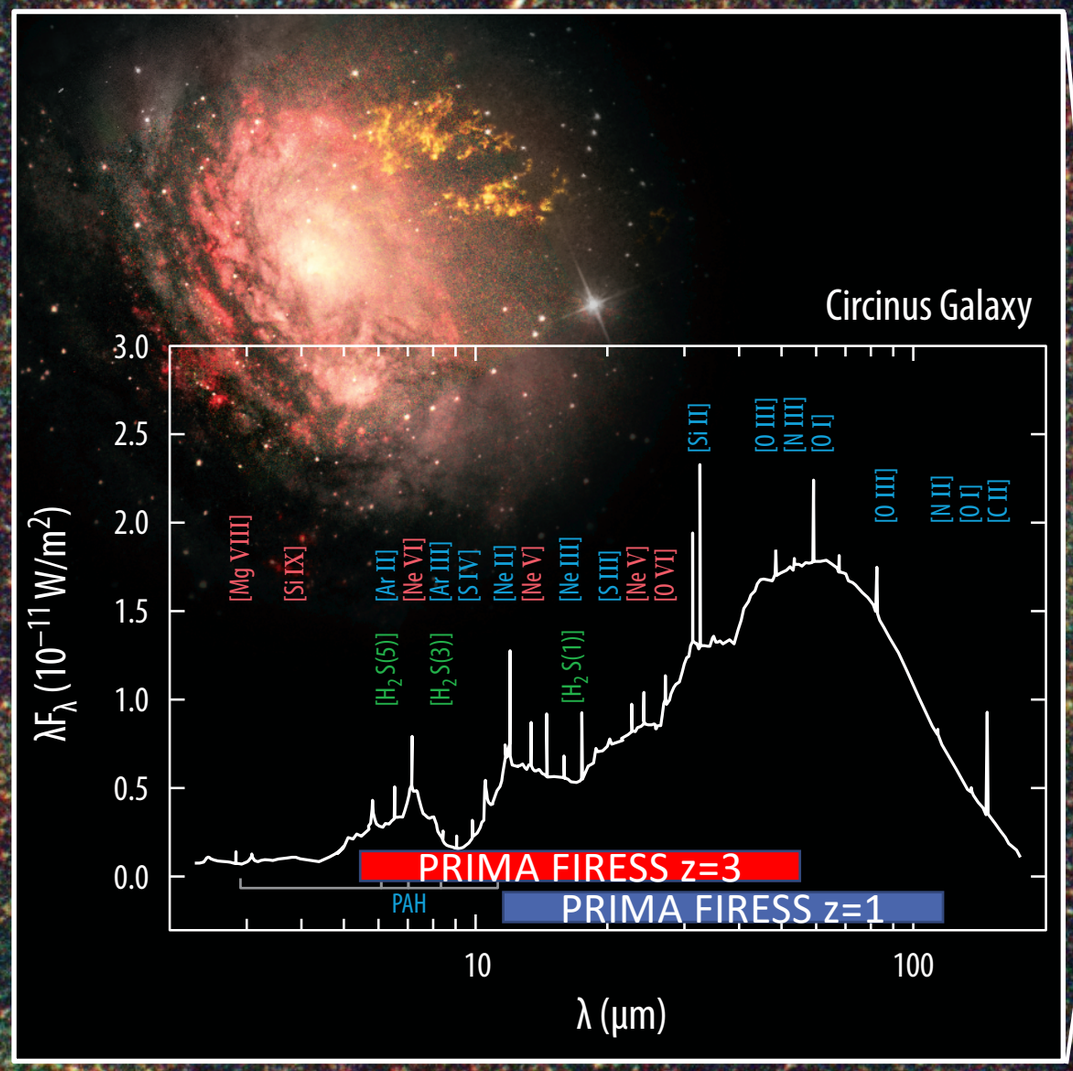
Low-res base grating mode provides R~130 and covers band shown.
24 to 239 microns

Bar envelopes wavelength dependence under optimization. **1.8×10^{-19} W/m^2 is a safe bet for the current PRIMA configuration for low-background sightlines.**

A given source requires 2 pointings to cover the full PRIMA FIRESS band.

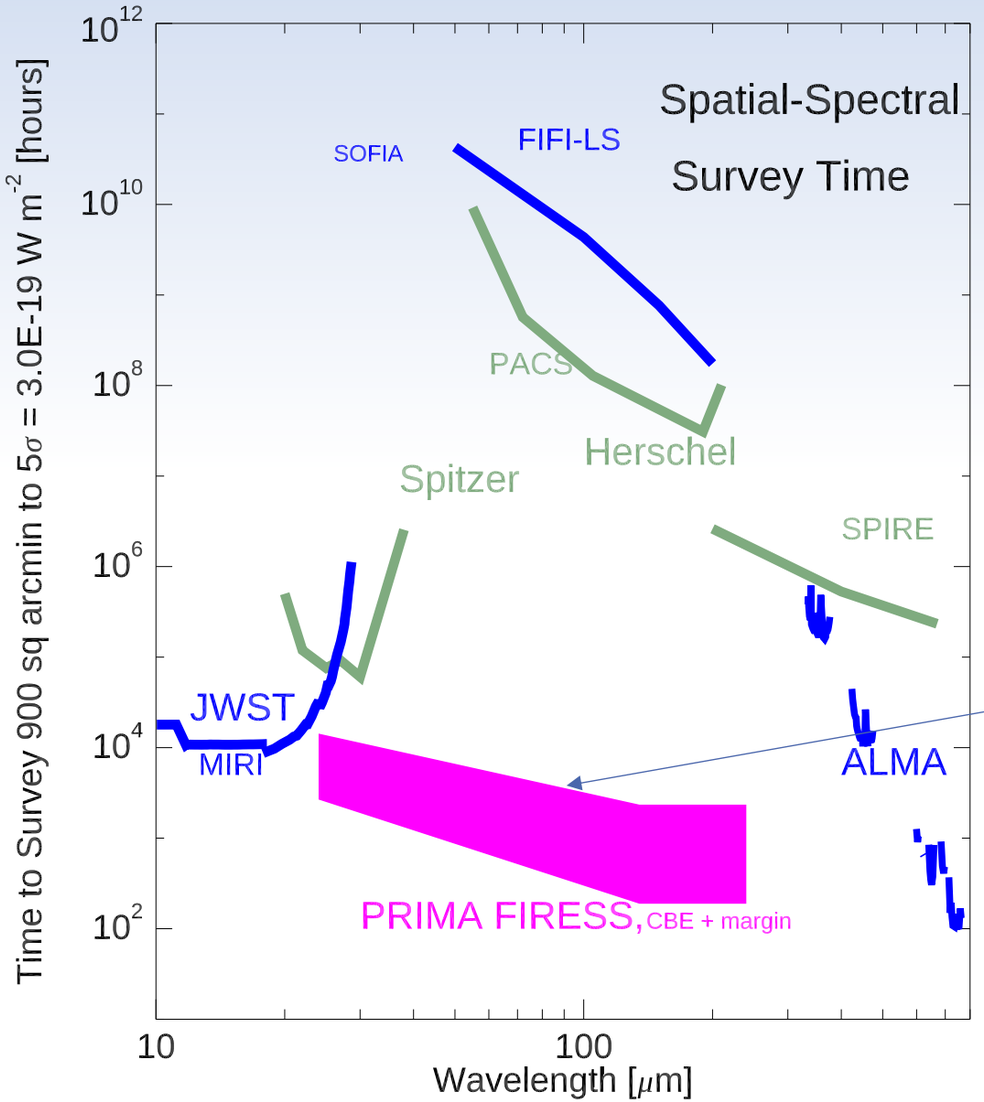
Assumes point source and narrow (unresolved) line.

Expect bright fine-structure line in z=2 ULIRG galaxy to be detected in ~15 minutes.



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

FIRESS mapping

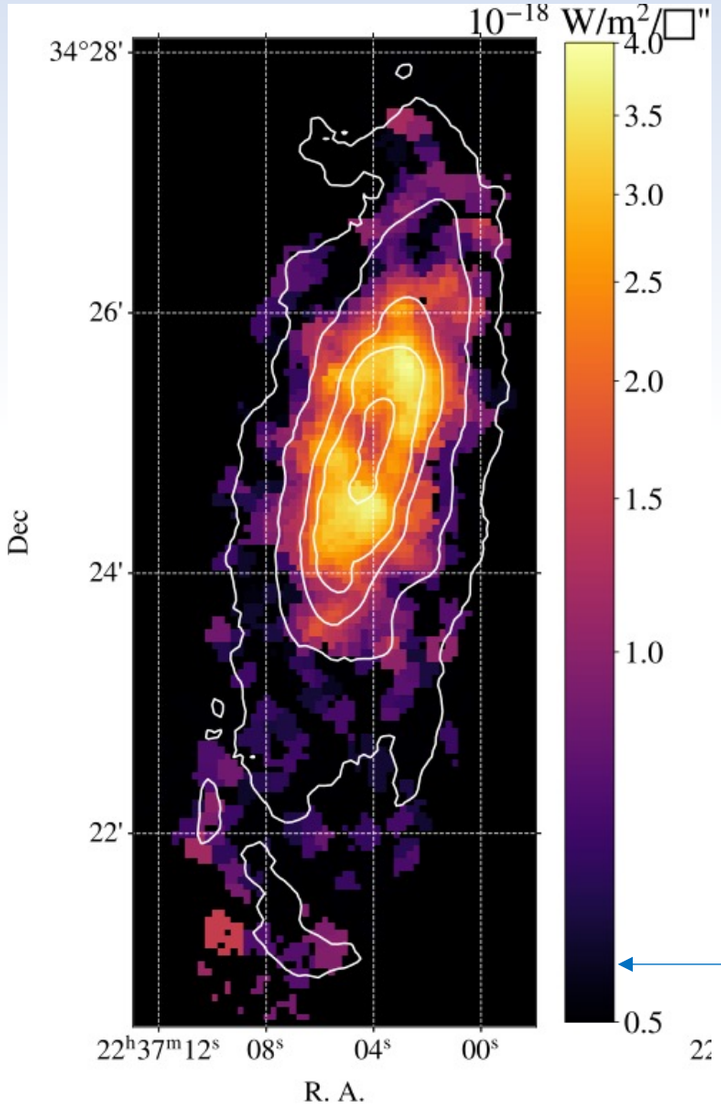


- FIRESS has Long slits -> 30-40 pixels along slit in all bands.
- Maps a quarter square degree to 5×10^{-19} W/m^2 in less than 1200 hours at 100 microns.
- Depth scales with sqrt (Area / time).
- Small and large map modes available via spacecraft scan and steering mirror.
- Blind surveys with FIRESS yield large detection rates through cosmic noon, particularly in [OIII].
- Large-scale maps can be used in stacking / correlation analyses with Roman / Euclid grism surveys to yield high-SNR full far-IR spectra.
- Excellent for low-surface-brightness experiments in nearby galaxies.

- **Safe time estimate to reach a depth of 3×10^{-19} W/m^2 over 900 square arcminutes with the current PRIMA configuration:**
  - **8300 hour x (λ /24 μm)$^{-0.84}$ for λ < 135 μm.**
  - **1960 hour for λ > 135 μm.**

- **Assumes low-zodi field.**
- **Time scales with Area / depth^2.**
- **Remember 2 pointings for full spectrum.**
- **Neglects map overheads for now, PRIMA team will check your case to see if this is important.**

PRIMA FIRESS Low-surface brightness Line mapping.

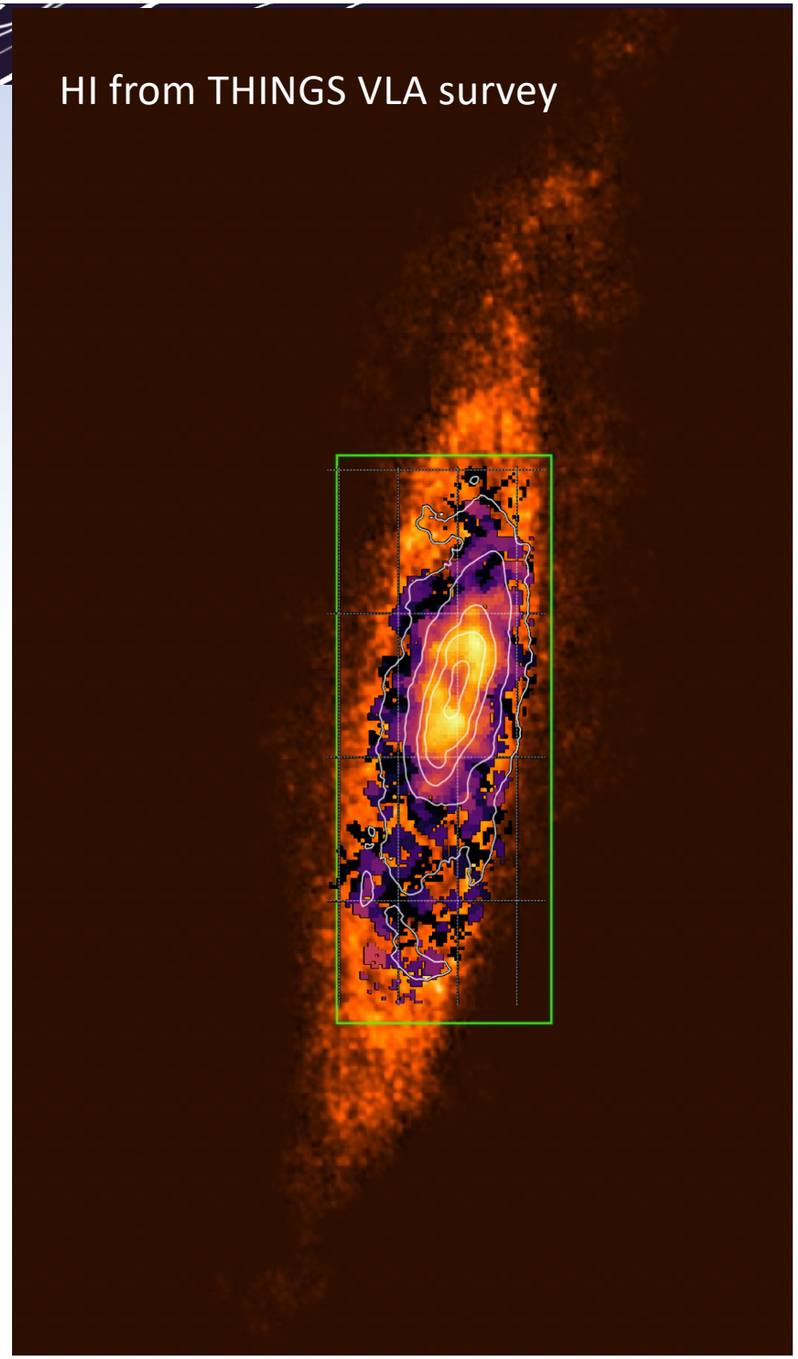


NGC 7331
[CII] map from SOFIA FIFI-LS.
Sutter & Fadda 2022
4.5 hours flight time.

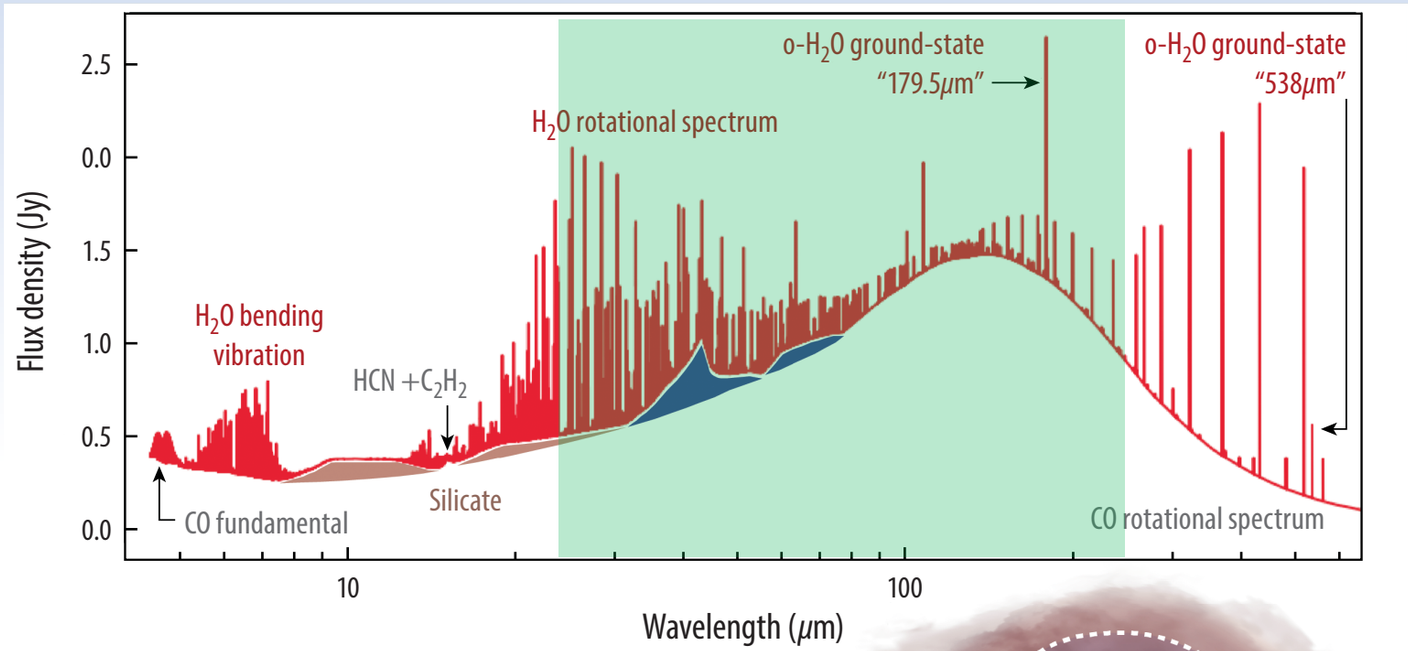
Single line, Limited to bright, dense gas.

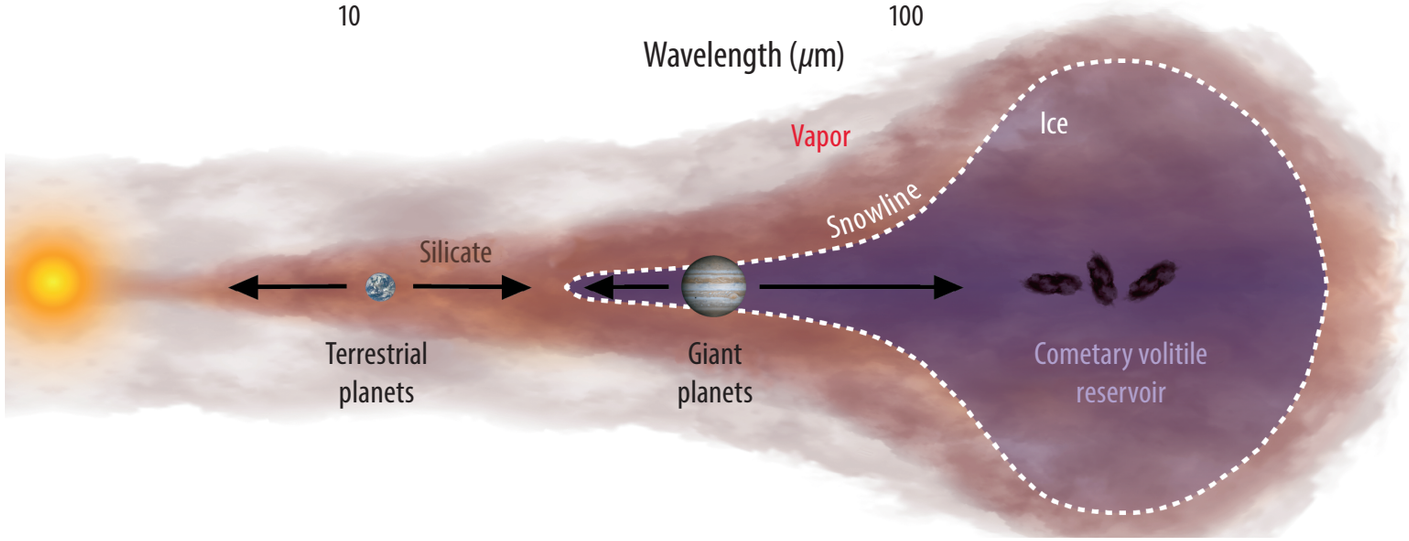
PRIMA will be thousands of times faster, measuring CII cooling in galaxy halos and outer disks. Comparison with HI provides cooling per baryon. Other lines also measured at the same time.

>10 sigma, 1 second, PRIMA, per beam!



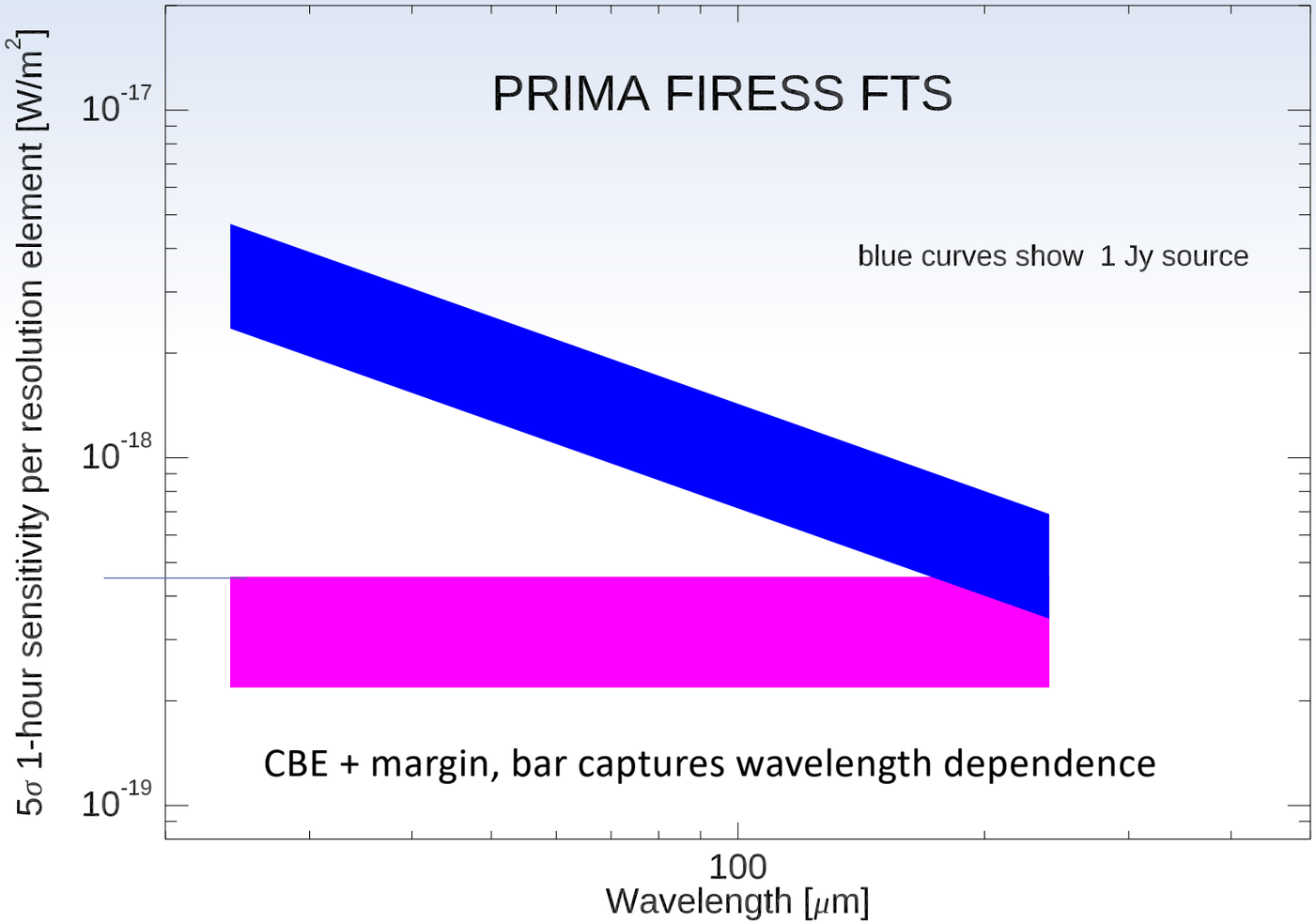
FIRESS High-res mode.





- High resolution capability operates over the full band using Fourier-transform interferometer in front end to process light prior to arrival.
- Resolving power is tunable by adjusting scan length in FTS.
- 4400 at 112 microns is allows lifting HD flux from the continuum, and discriminating nearby water lines.
- Tunable approach allows optimal R to maximize sensitivity intermediate resolving power experiments such as measuring galactic-scale outflows.
- Two pointings cover the complete band for a given source.
- High-res mode sensitivity to unresolved line emission

PRIMA high-res mode



FTS mode sensitivity
For narrow lines in point sources.
With current PRIMA configuration:

Faint source limit:
4.5×10^{-19} W/m² (5 sigma 1 h)

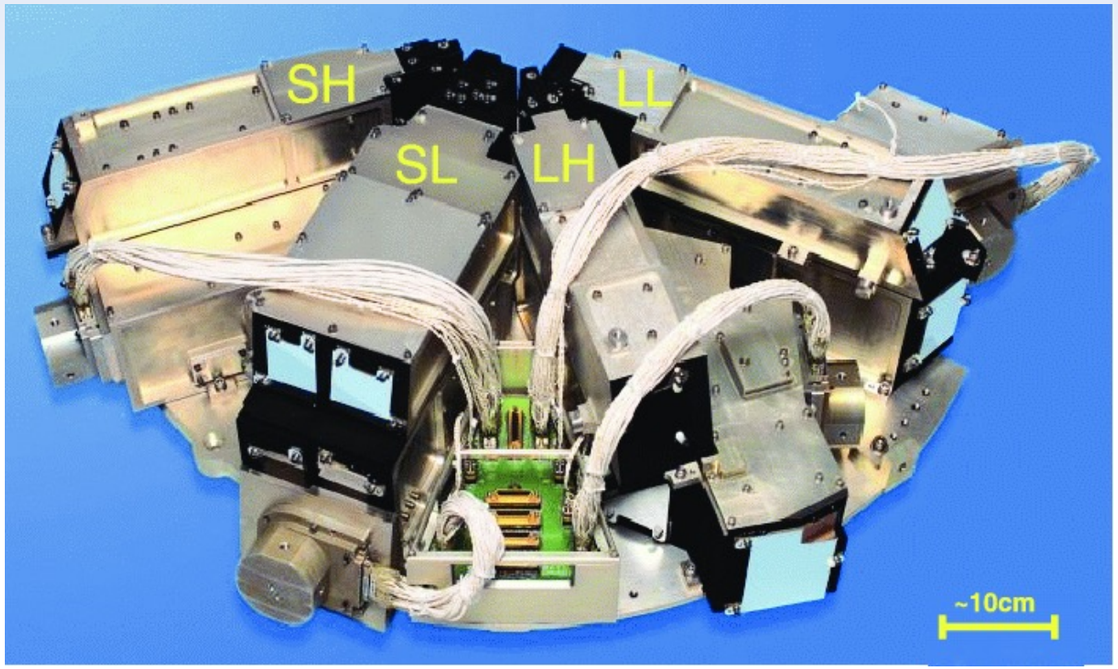
In the presence of source flux:
4.7×10^{-18} W/m² x (24 μm/λ)
x sqrt (Flux /1 Jy)

Add these in quadrature.

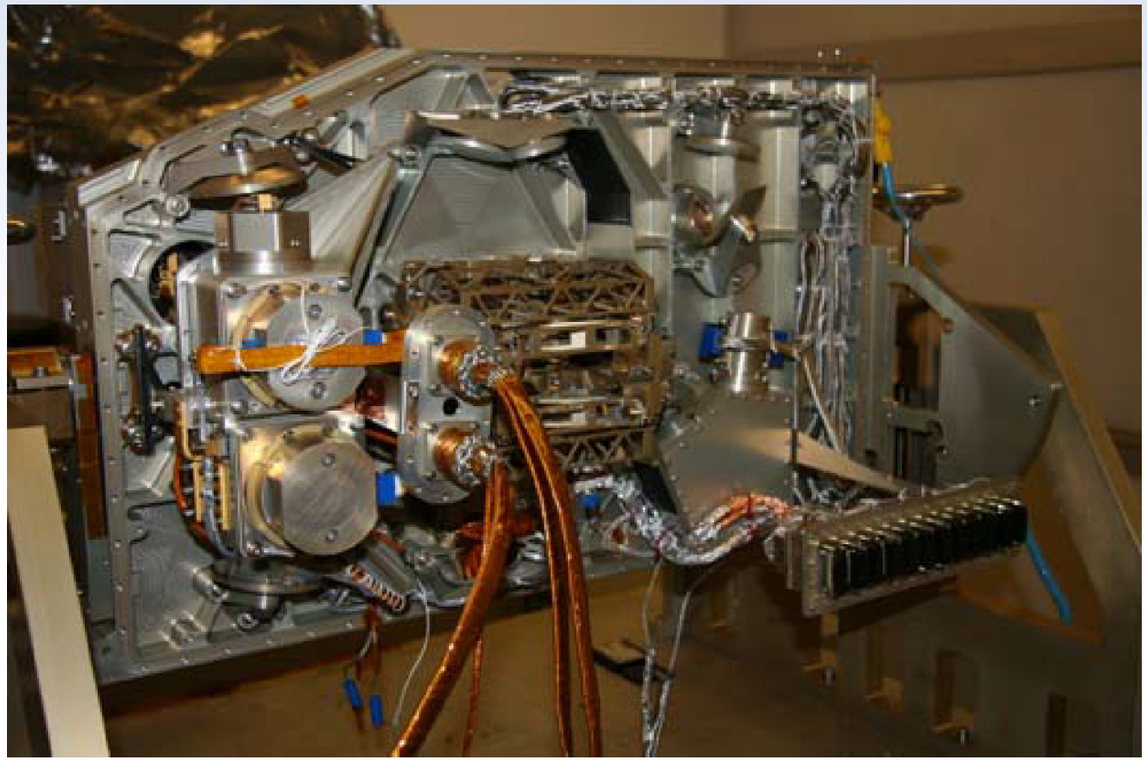
Depth scales as 1/sqrt(time)

FIRESS Spectrometer Heritage

FIRESS has high-heritage approach -> same approach as on Spitzer IRS and Herschel SPIRE FTS.

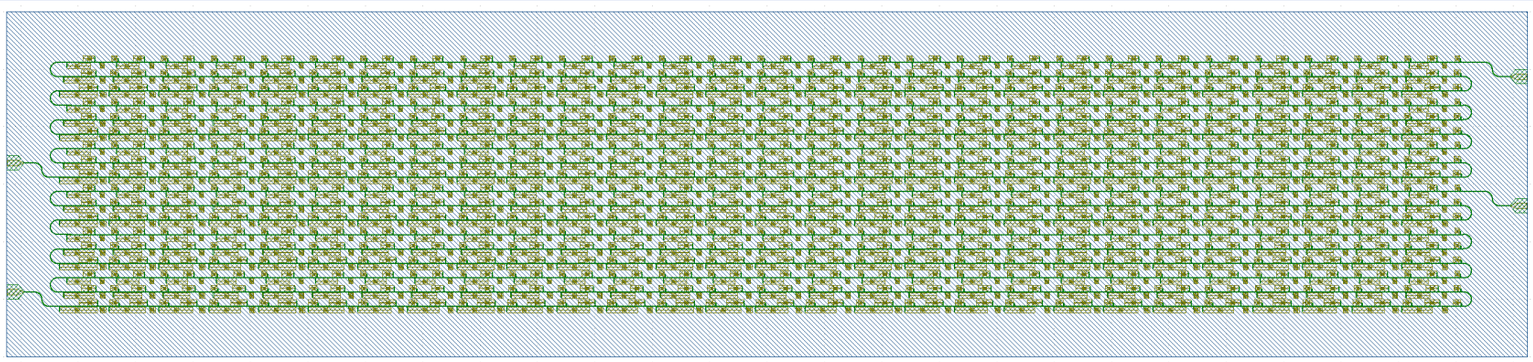


Spitzer Infrared spectrograph -> all aluminum grating modules with no moving parts. Houck et al.

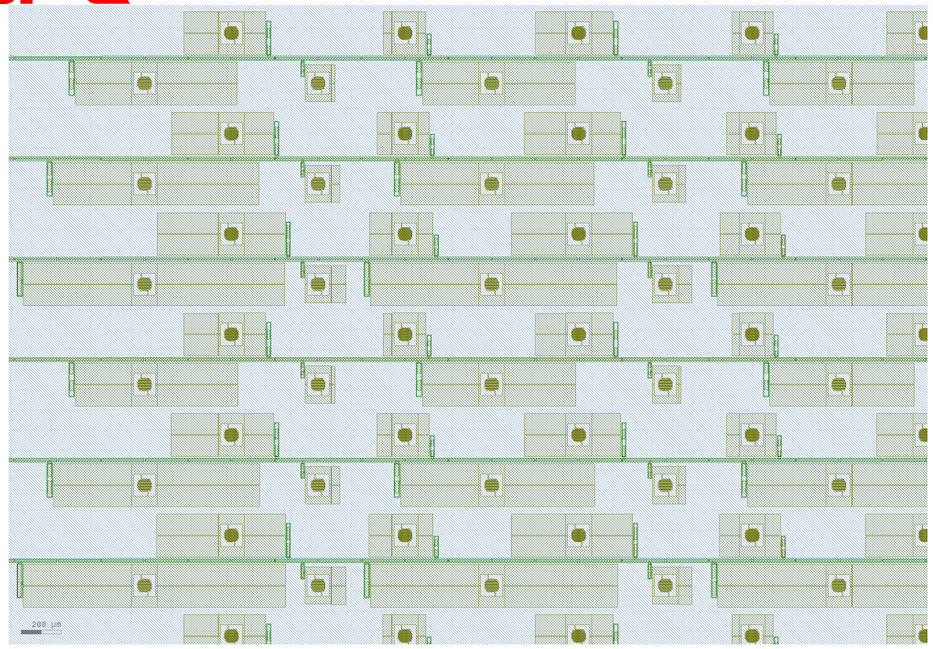


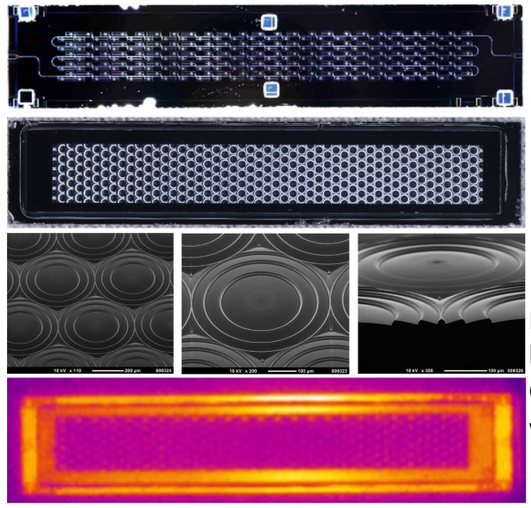
Herschel SPIRE FTS. PRIMA FIRESS FTS team uses the same team for the scan mechanism. FIRESS much more sensitive with with cold telescope and narrow band on detector.

PRIMA (FIRESS & PRIMAger) kinetic inductance detector (KID) arrays. World's best groups in collaboration

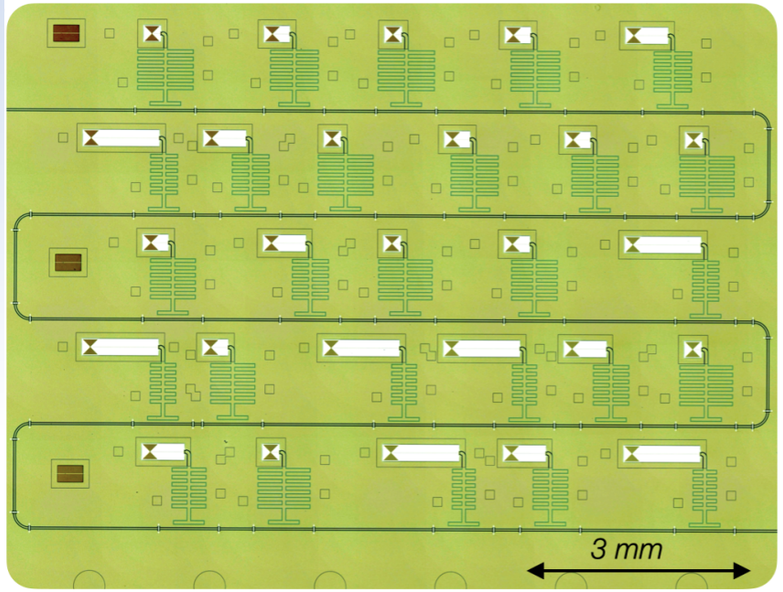


JPL 1000-pixel PRIMA subarray at JPL, >90% yield already





Etched micro-lens arrays from GSFC, interface with JPL KIDs.



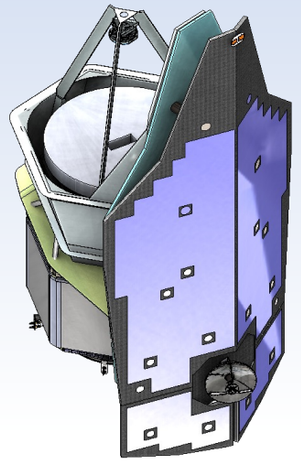
SRON Netherlands Institute for Space Research

World's most sensitive KIDs from SRON.

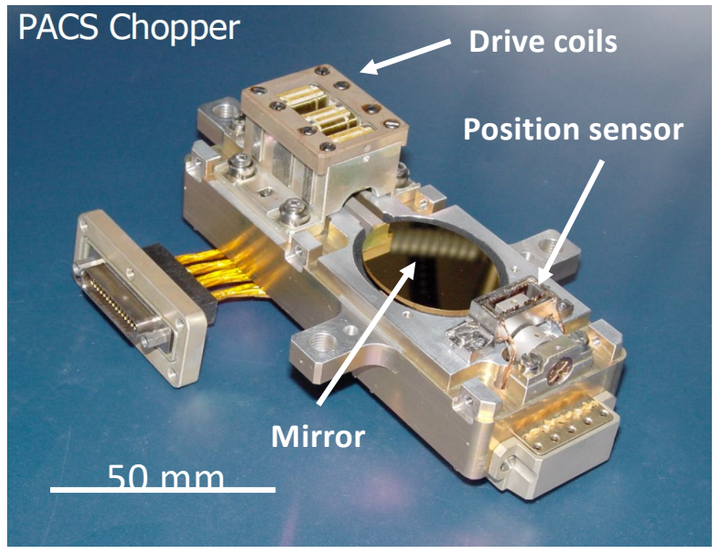
Both JPL and SRON labs have demonstrated devices with sensitivity exceeding PRIMA's requirements.

PRIMA Observing Modes: Modulation provided by scan, steering mirror, or FTS.

Mode	Modulation	Signal frequencies
Maps spanning many degrees: PRIMAger or FIRESS	Observatory scan map	10 to 100 Hz, slower at turnarounds
Maps of degree-scale fields (larger than 15 arcmin) for PRIMAger or FIRESS	Observatory scan, combined with steering mirror	zero to 100 Hz
Small maps of fields <15 arcmin or smaller for PRIMAger or FIRESS	Steering mirror executes raster or Lissajous scan in 2D	1 to 200 Hz, higher at shorter wavelengths
Point source spectroscopy with FIRESS	Steering mirror chop at 10 Hz along slit direction.	10 Hz and higher harmonics
FTS spectroscopy with FIRESS	FTS scan provides modulation	50 to 500 Hz

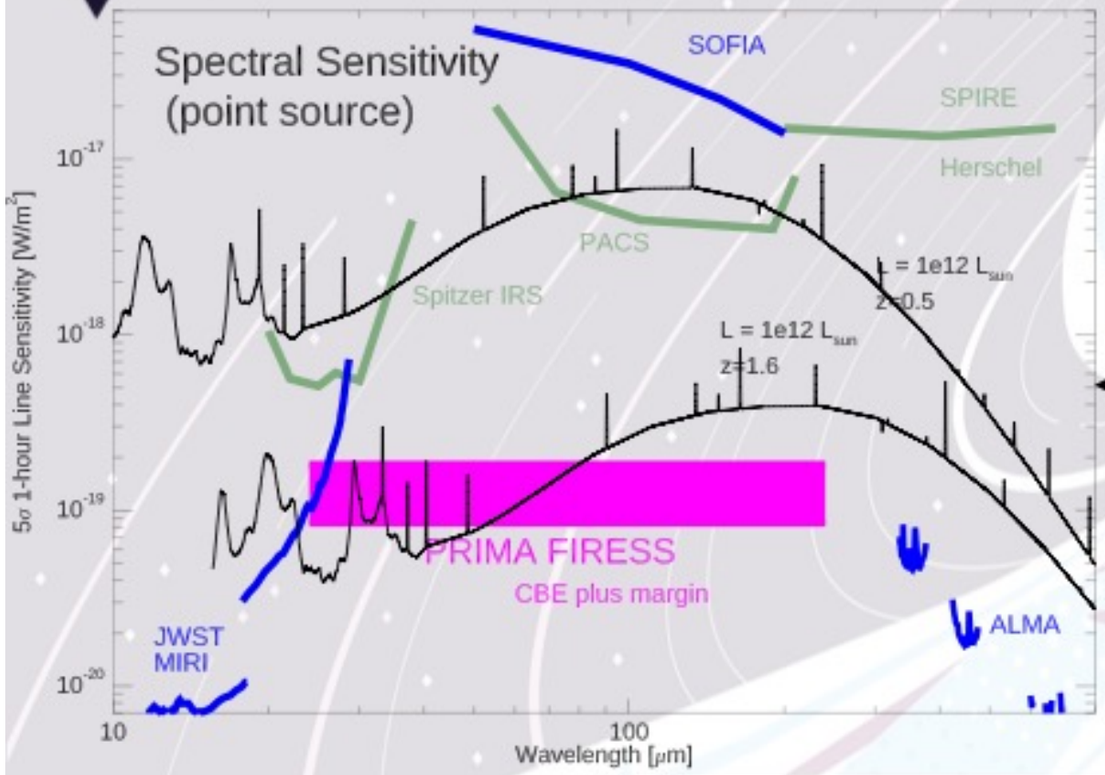


PRIMA observatory / spacecraft will be agile.



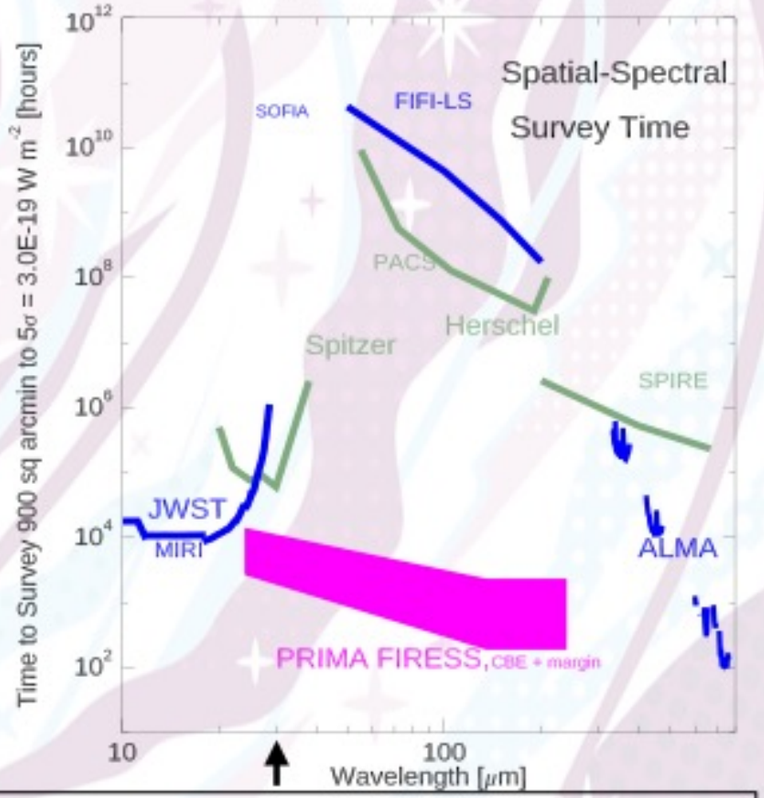
PRIMA Steering mirrors: provided by same team at MPIA Heidelberg as delivered Herschel PACS chopper

PRIMA FAR-INFRARED ENHANCED SURVEY SPECTROMETER (FIRESS)



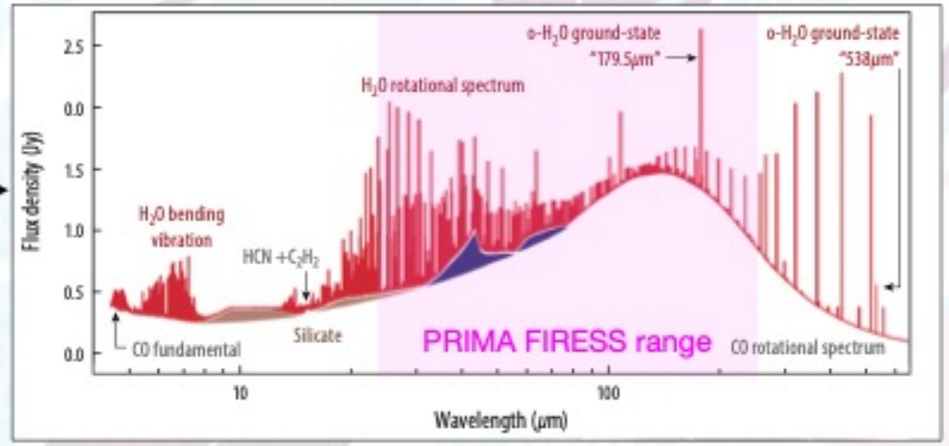
Low-Resolution Mode

- Provides R~130 and covers with **complete full-band** shown in two pointings.
- Sensitivities shown are for unresolved spectral lines in point sources, assume north ecliptic pole backgrounds. Higher background regions will have increased limits.
- Bar envelopes wavelength dependence under optimization. 2x10^{-19} W/m^2 is a safe assumption for estimation purposes.



High-Resolution Mode

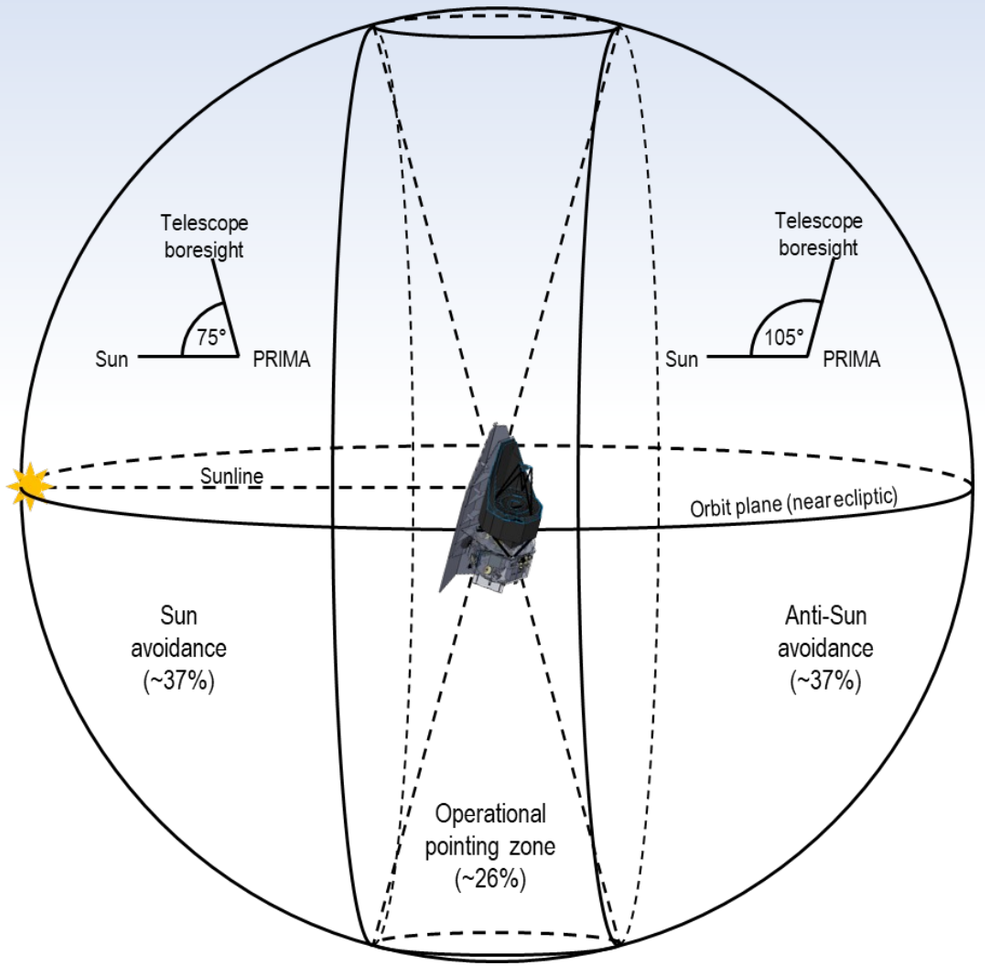
- Also covers the **full complete band** in 2 pointings.
- Provides tunable resolving power up to R=4,400 at 112 microns, R=17,000 at 28 microns.
- Only modest sensitivity penalty relative to low-resolution mode.



Mapping Modes

- Long slits -> maps a square degree to 3x10^{-19} W/m^2 line flux in 1000 hours at 100 microns. Full band covered in two pointings.
- Small and large map modes available with observatory scan and steering mirror. Map depth scaled by area / time^2
- **Excellent surface brightness sensitivity** for low-surface-brightness line emission: 5 sigma below 10^{-10} W/m^2/sr, **per beam** in 5 minutes at [CII], [NII] wavelengths.

PRIMA field of regard



+/- 15 degrees from plane normal to sun-earth line.

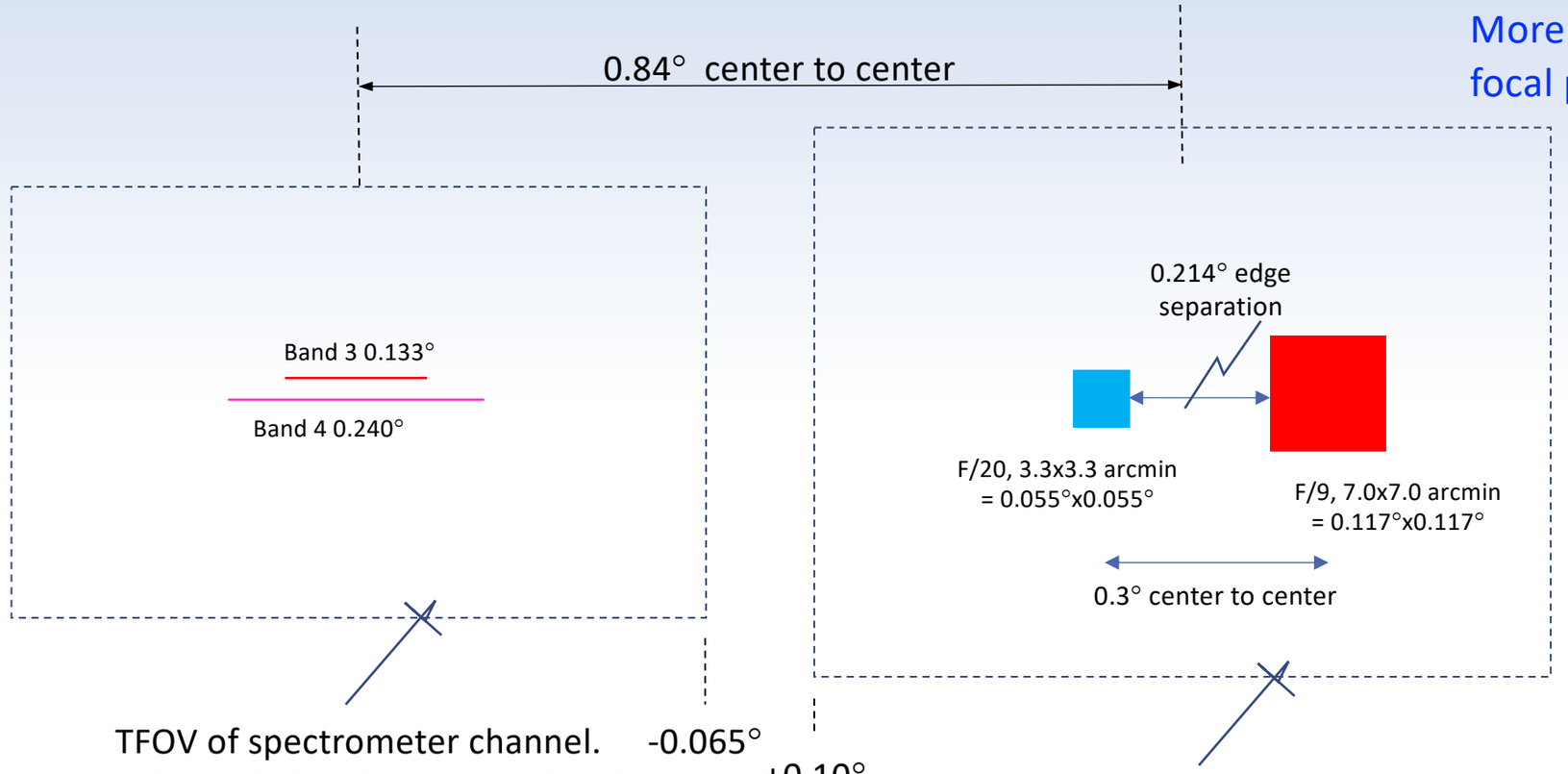
26% of sky at any given time.

Equatorial fields visible 2 x 30/360 = 17% of the time.

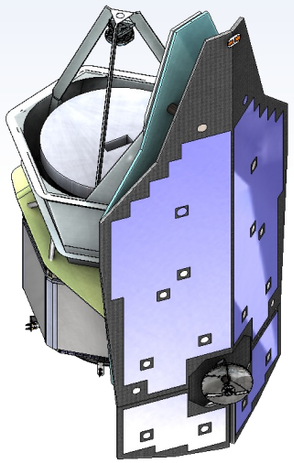
Slew speed is 0.3 deg / sec, so can slew around the sky in 10 minutes.

Expect settle times to be short.

PRIMA Field of View



More detail on PRIMAger focal planes from Laure



TFOV of spectrometer channel.
±0.125° X and ±0.10° Y beyond slit FOVs.
TFOV = 0.490° x 0.20° spatial x spectral.
Equivalent of +/- 0.025° is used by scan mirror to repoint between the two slits

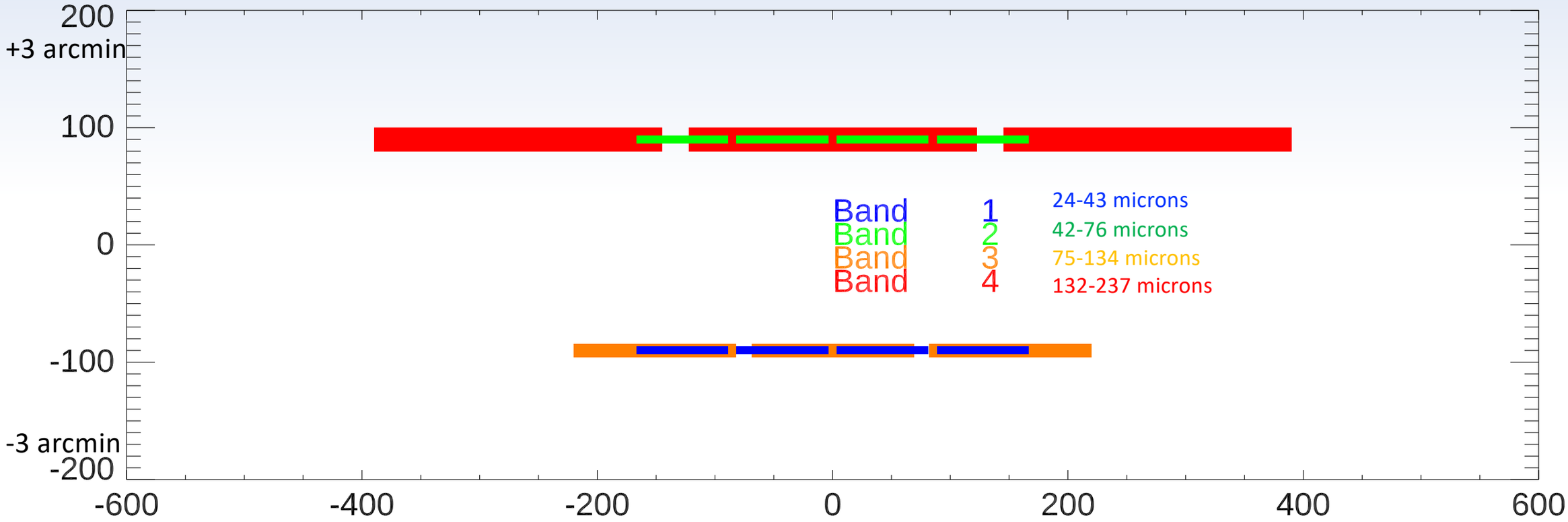
TFOV of imager channel.
±0.125° all around, beyond focal plane FOVs.
TFOV = 0.636° x 0.367° spatial x spectral

Instruments do not observe simultaneously

Mike Rodgers, Jim McGuire, optical design.

PRIMA FIRESS Slit orientation of View

Bands 1 and 3 overlap
Bands 2 and 4 overlap
Provides high transmission in dichroics

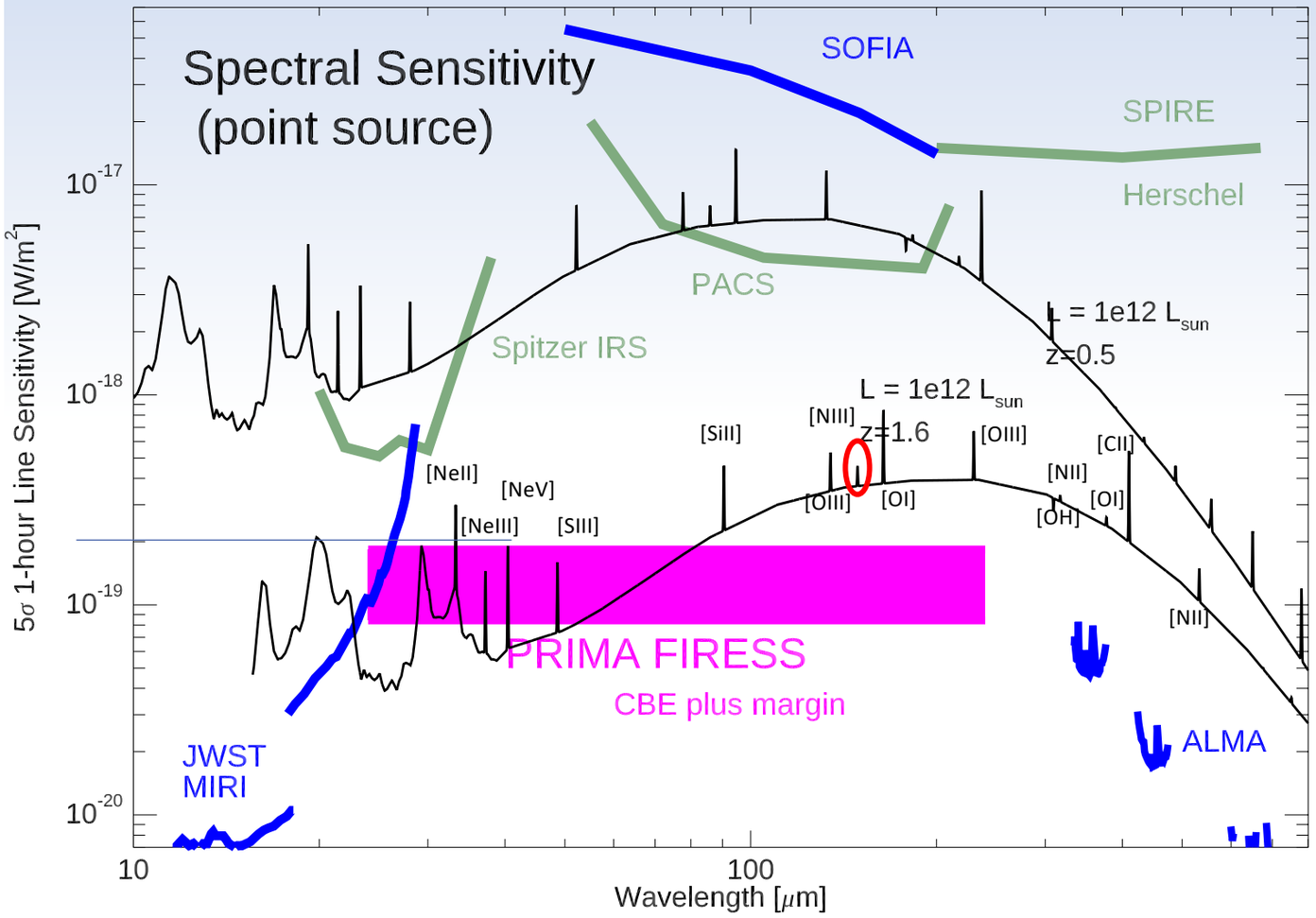


-10 arcmin

Steering mirror will cover +/- 15 arcmin in x, +/- 10 arcmin in y

+10 arcmi

Example sensitivity calculation.



Example: [NIII] 57 micron transition in low-background field.

When combined with one of the (brighter) [OIII] transition, measures the absolute O/N ratio which is a measure of integrated stellar processing and thus metallicity.

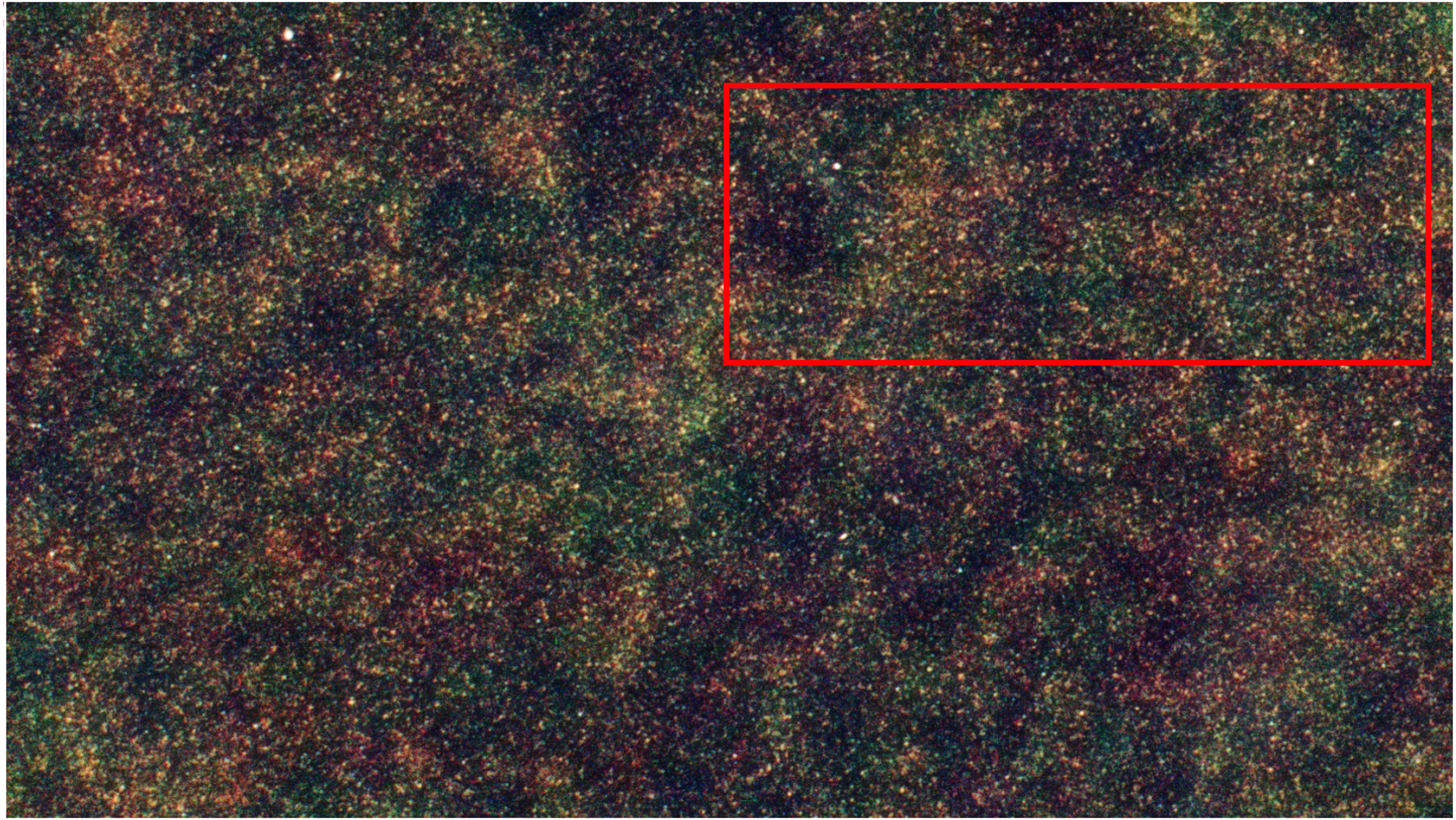
[NIII] is typically weaker than [OIII] and carries the metallicity dependence.

At 0.5 solar we expect [NIII] in a ULIRG has a flux of 7×10^{-20} W m^{-2}. This requires a time of

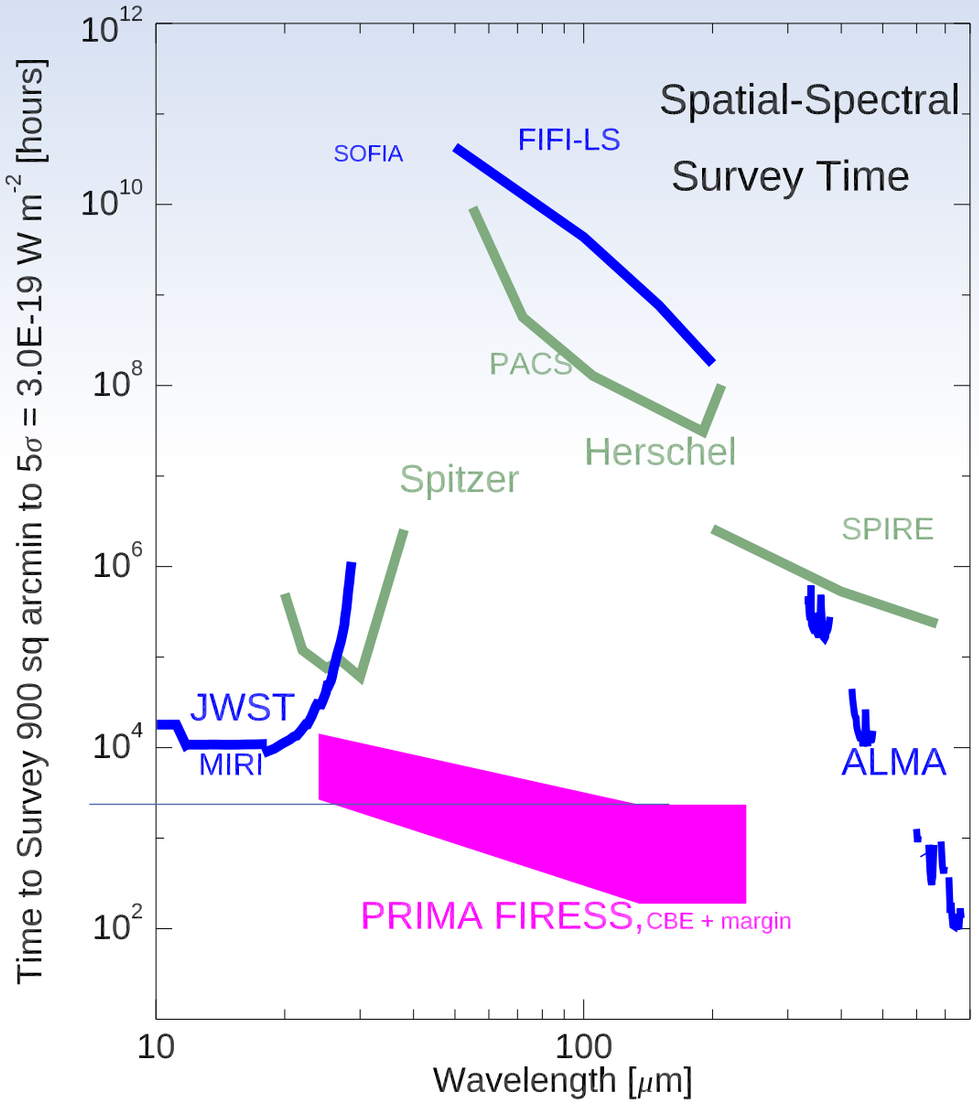
1 hour x $(2 \times 10^{-19} / \text{depth})^2$
Which is
$(2 \times 10^{-19} / 7 \times 10^{-20})^2$ = 8 hours.

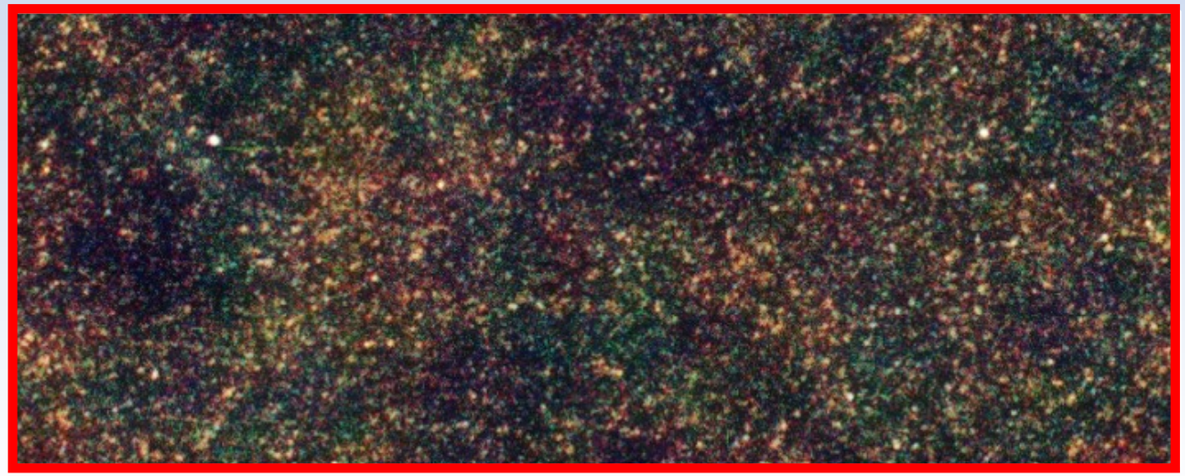
In this measurement, the other key fine-structure lines would be detected as well since they are weaker

But need 2 measurements for the full spectrum.



Example Sensitivity calculation -- mapping





Blind detections of [OIII] L=1e12 L_{solar} galaxies in half square degree (1800 square arcminute) field at z=1.4 (1/3 the age of the Universe).

Target depth: 4.7×10^{-19} W m^{-2}

Time required:
2000 hours
x [area / 900 sq arcmin]
x [3×10^{-19} Wm^{-2} / depth]^2

= 1650 hours. This covers 2 out of 4 bands.