SPIRE Spectroscopy: An Introduction

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(on behalf of the SPIRE ICC, HSC & NHSC)

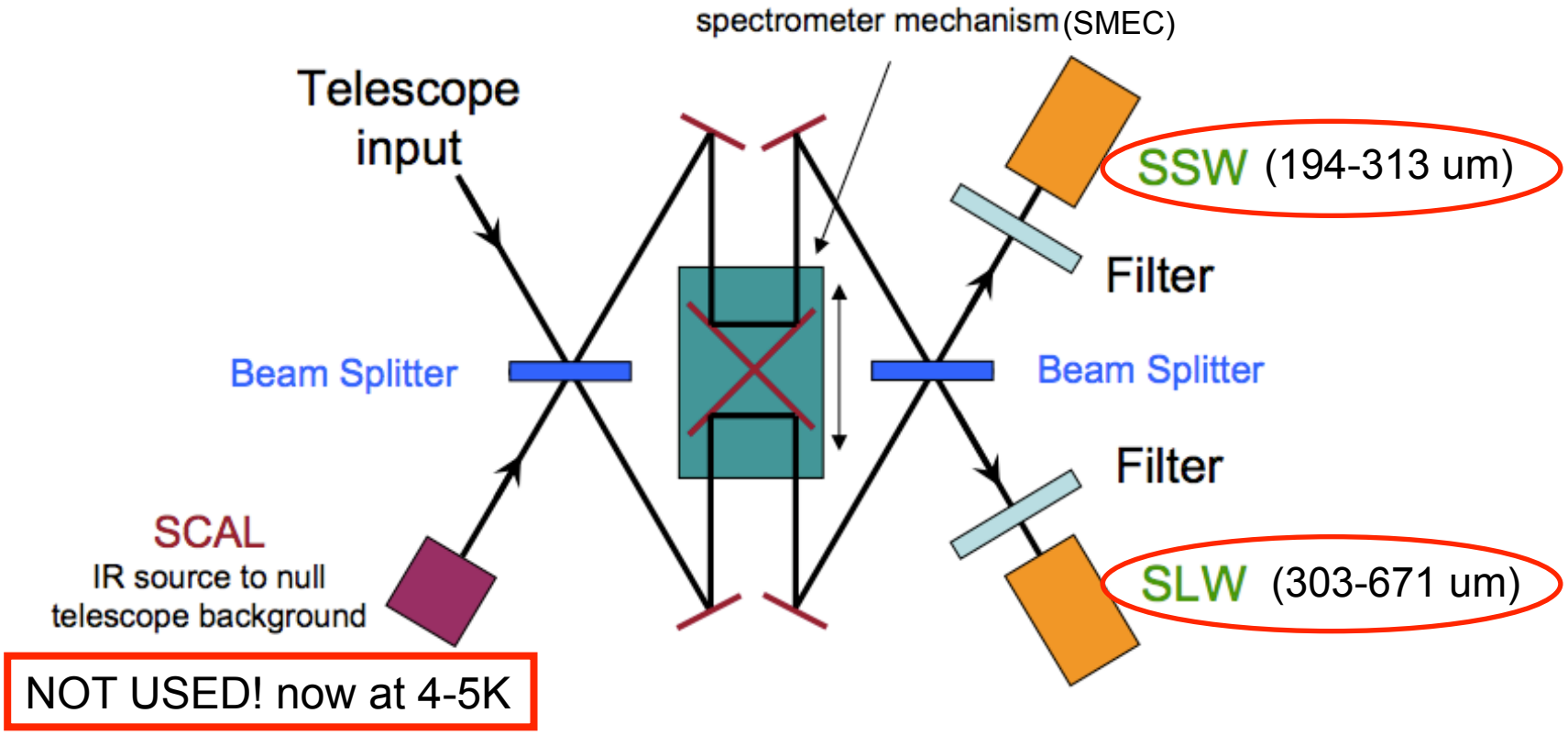
Topics Covered

- SPIRE spectrometer
- Pipeline data products

SPIRE Spectrometer

SPIRE Spectrometer

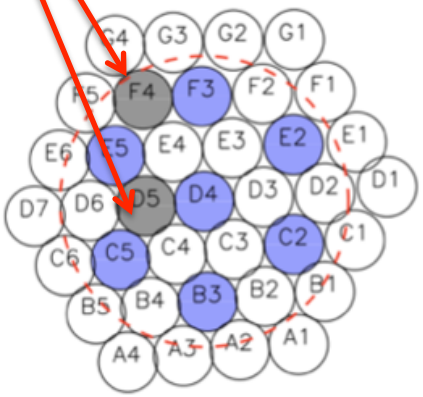
Fourier Transform Spectrometer (FTS): The entire spectral coverage of 194-671 micron is observed in one go!



Two Bolometer Detector Arrays

Two dead detectors

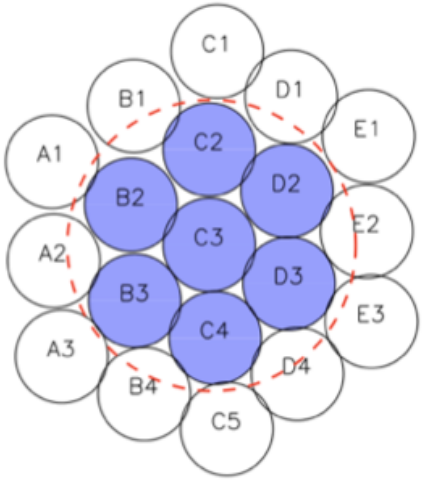
SSW



194 – 313 microns

Beam = 17”- 21”

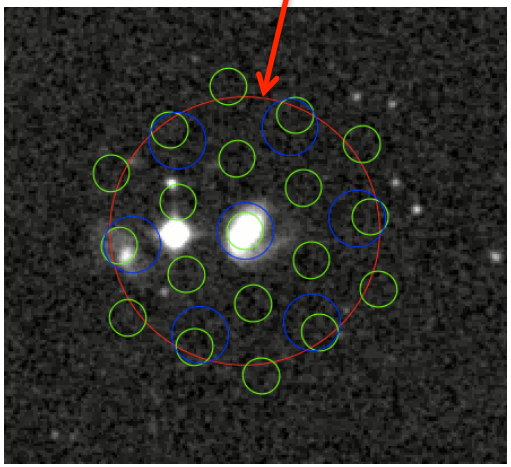
SLW



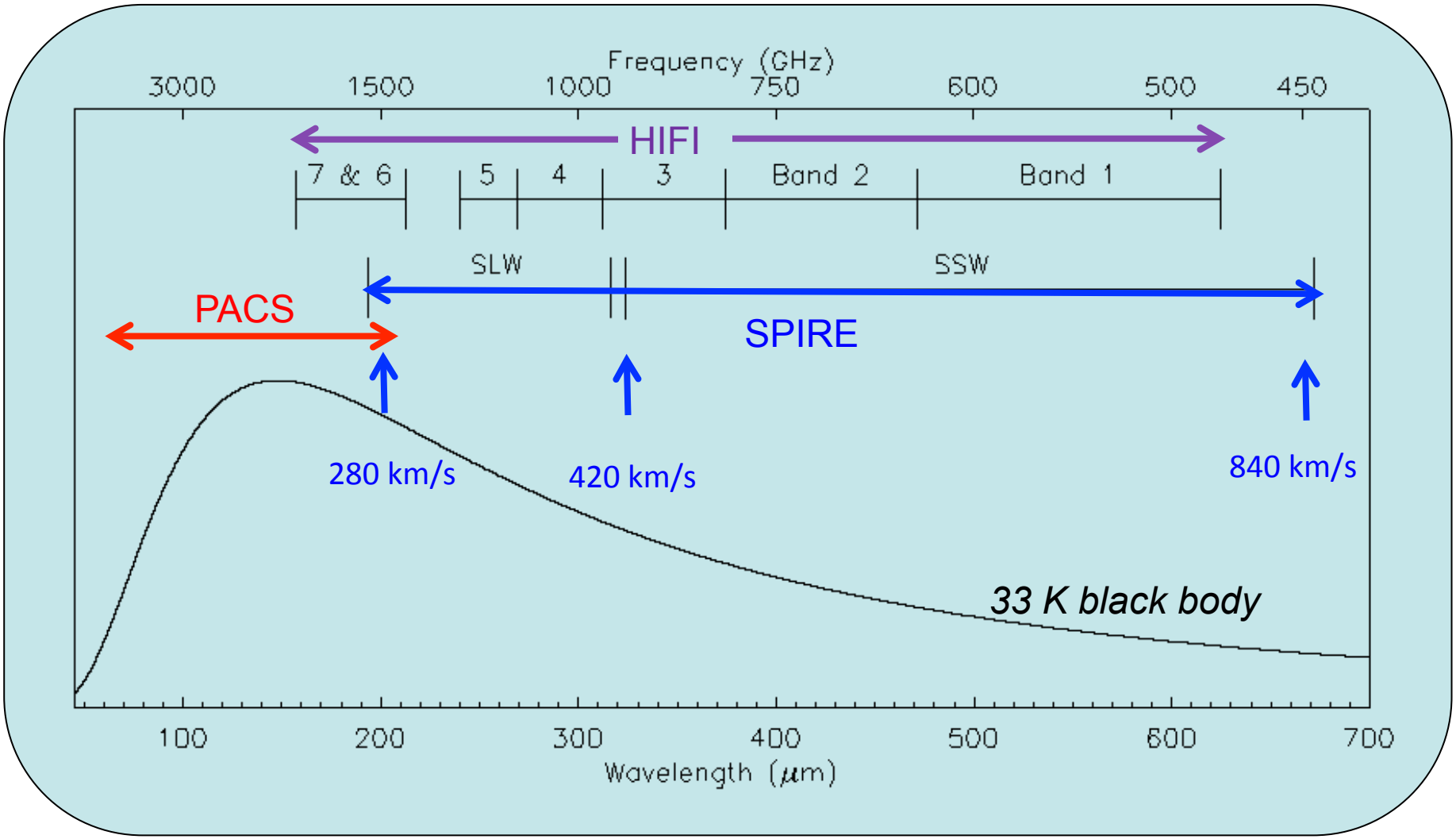
303 – 671 microns

Beam = 29”- 42”

2’ diameter

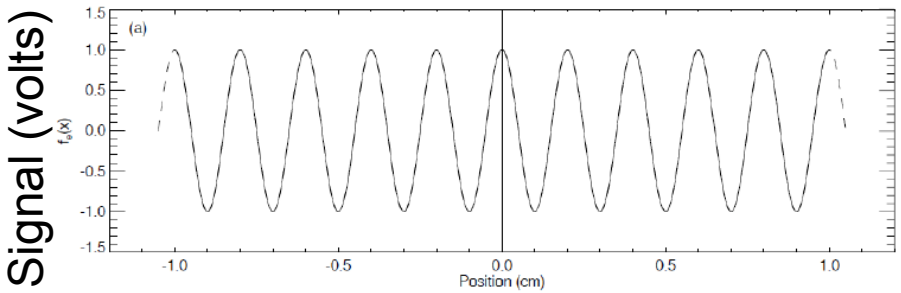


Foot print on sky

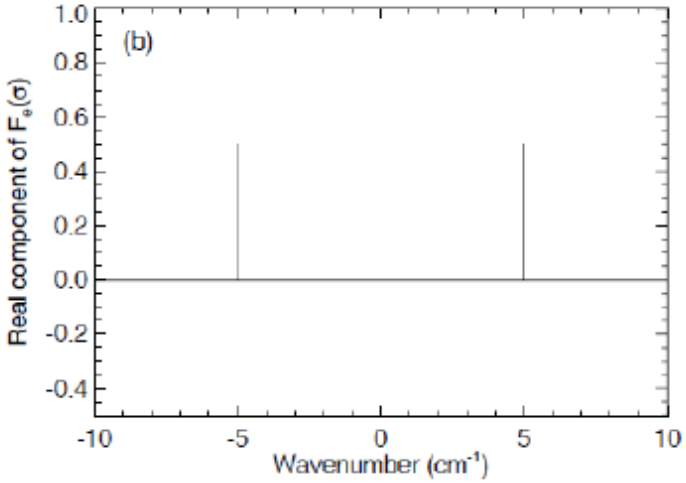

Frequency (GHz)
3000
1500
1000
750
600
500
450
HIFI
7 & 6
5
4
3
Band 2
Band 1
SLW
SSW
PACS
SPIRE
280 km/s
420 km/s
840 km/s
33 K black body
100
200
300
400
500
600
700
Wavelength (μm)

Fourier Transform: Interferogram to Spectrum

Interferogram I(x)



Source Spectrum B(σ)

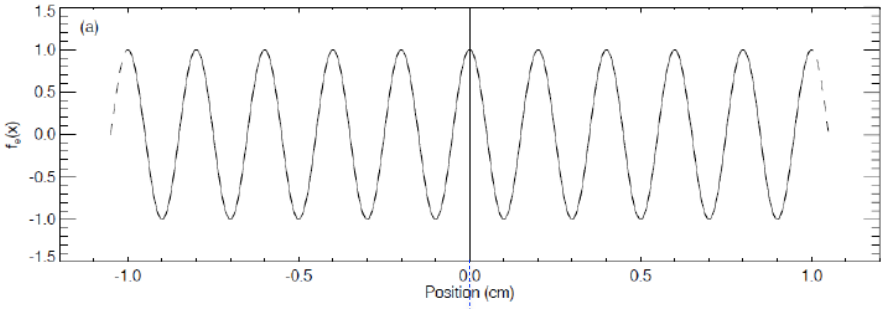


Fourier Transform

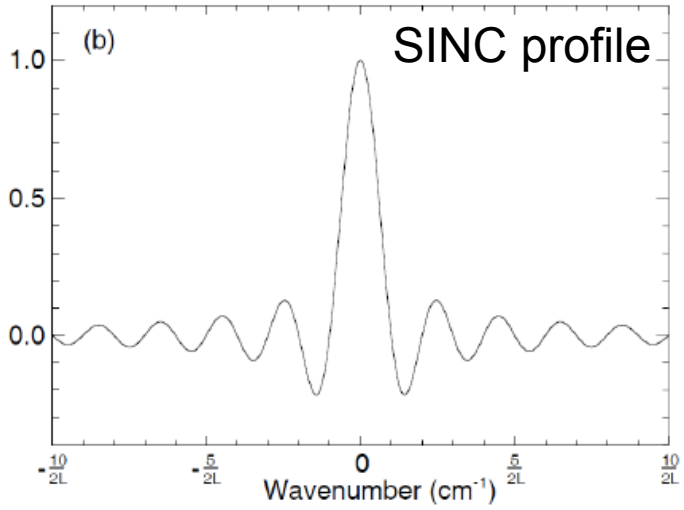
cos(ax)

$\delta(\sigma - 0.5a/\pi) + \delta(\sigma + 0.5a/\pi)$

Real World: Finite Interferogram

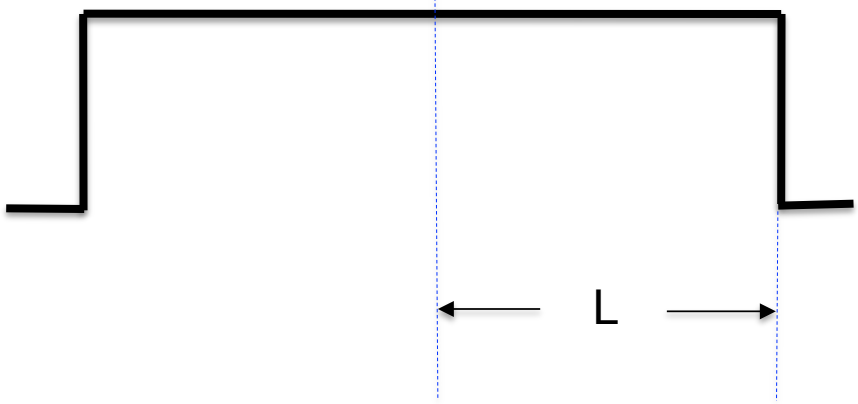


Fourier Transform



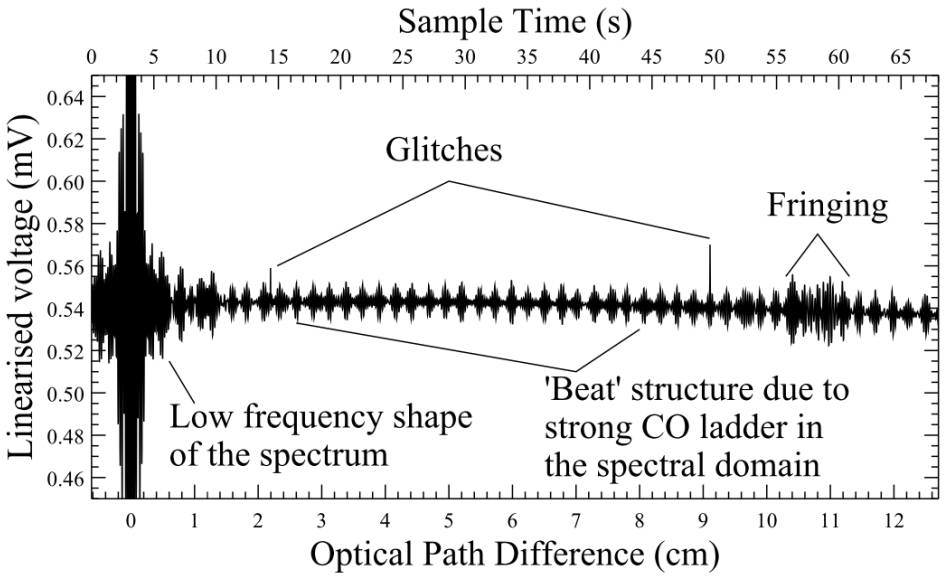
$B(\sigma) \otimes \sin(\pi\sigma/\Delta\sigma)/(\pi\sigma/\Delta\sigma)$

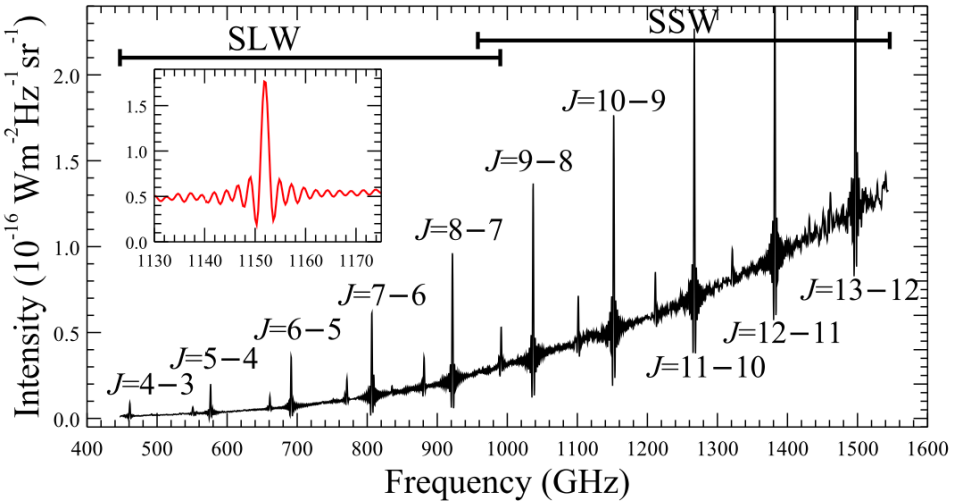
Multiplied by a top hat function



For an unresolved line:

- $I(\sigma) = I_0 \sin[\pi(\sigma-\sigma_0)/\Delta\sigma] / (\pi(\sigma-\sigma_0)/\Delta\sigma)$;
- Flux = $I_0\,\Delta\sigma$;
- FWHM = 1.207 $\Delta\sigma$, where $\Delta\sigma = 1/(2L)$; the resolution element





SPIRE/FTS Interferogram

Pipeline with calibration products

Spectrum

Observing Modes

Detector Setting:

- Nominal
- Bright-source (> 500 Jy)

Spectral resolution:

High Resolution (HR):

- 0.0395 cm^{-1} (or 1.1854 GHz)
- R = 1290 – 370
- ΔV = 230 – 800 km/s;

Suitable for line fluxes.

Low Resoltion (LR):

- 0.83 cm^{-1} (25 GHz)
- R = 62 – 18

Suitable for continuum.

High + Low:

- High & Low scans.

Spatial sampling using an internal jiggle mirror (BSM):

1 BSM position
Sparse (2 beam spacing)

4 BSM positions
Intermediate
(1 beam spacing)

16 BSM positions
Full (1/2 beam spacing)

Telescope pointing:

Single Pointing

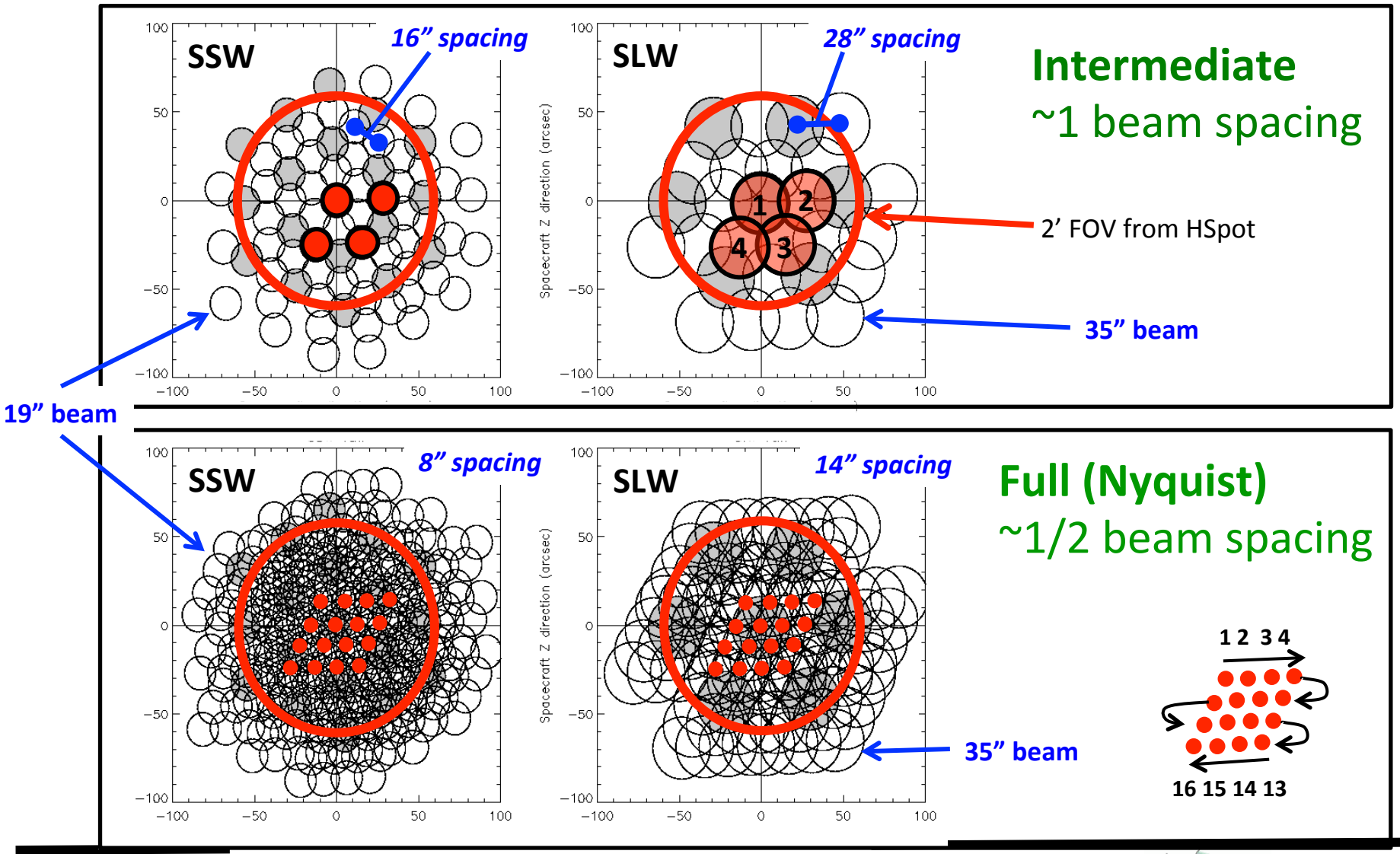
Raster
(for larger maps)

You get a map if any of these is used.

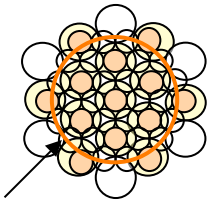
Spectral resolution, Δσ, depends on the maximum SMEC scan length L:

Δσ = 1/(2L), where L =12.8 cm for the High Res. mode

Mapping Observations



Larger maps via Raster



Overlapping spectrometer arrays projected on the sky

Image Sampling

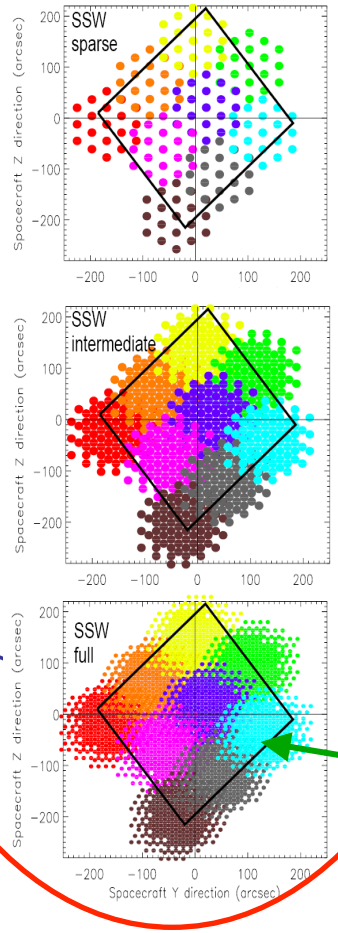
- Sparse
- Intermediate
- Full

Pointing Mode

- Single Pointing
- Raster Pointing

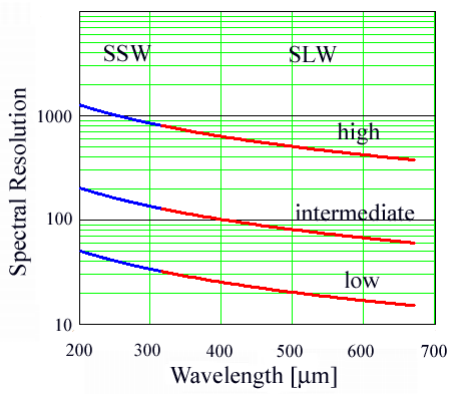
example 3 x 3 map

any combination allowed



Spectral Resolution

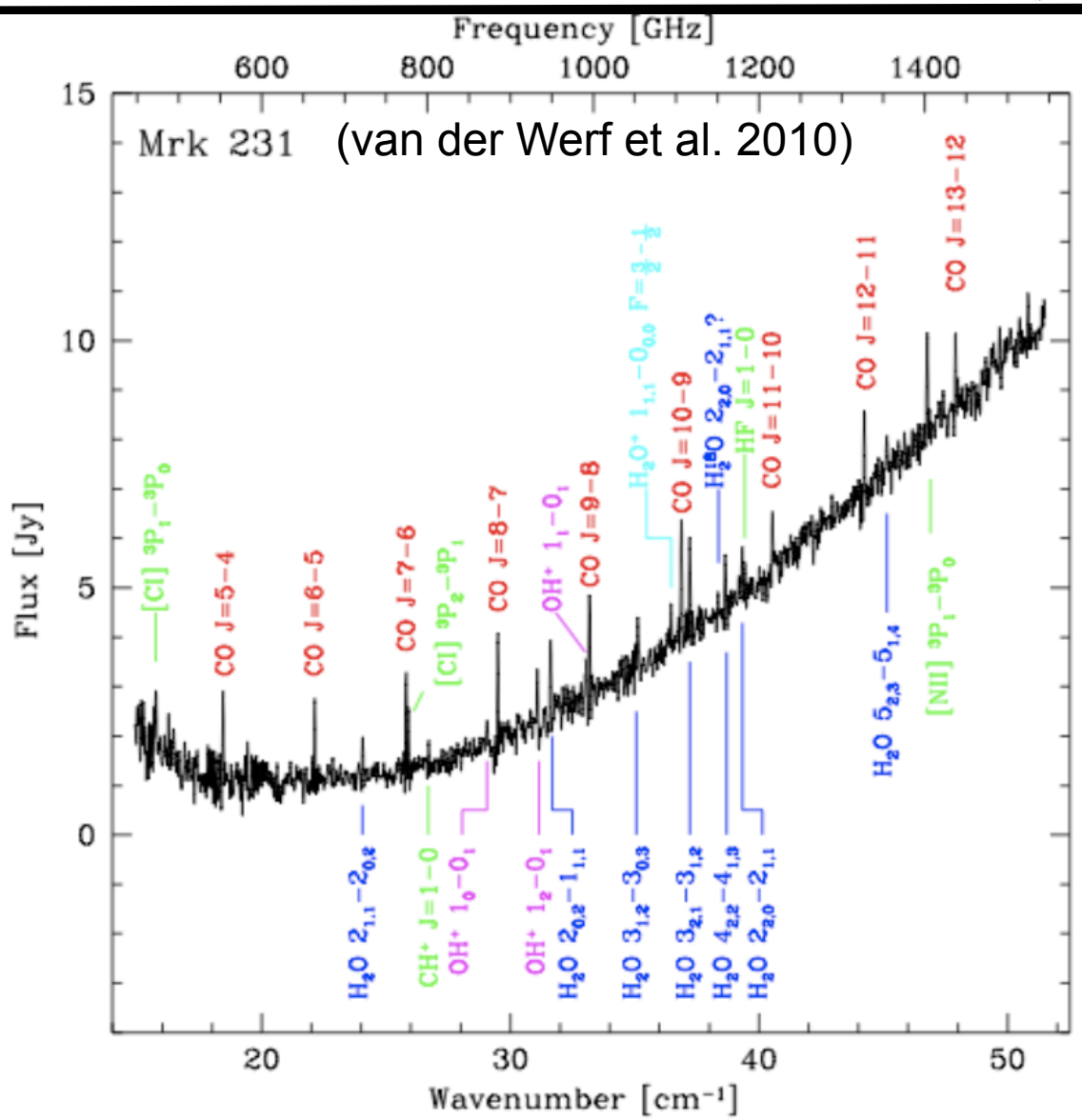
- High 0.04 cm^{-1}
- Medium 0.25 cm^{-1}
- Low 1.0 cm^{-1}
- High & Low 0.04/1.0 cm^{-1}



Each color shows the unvignetted beams of the same array for all sampling positions (jiggles) at one raster position.

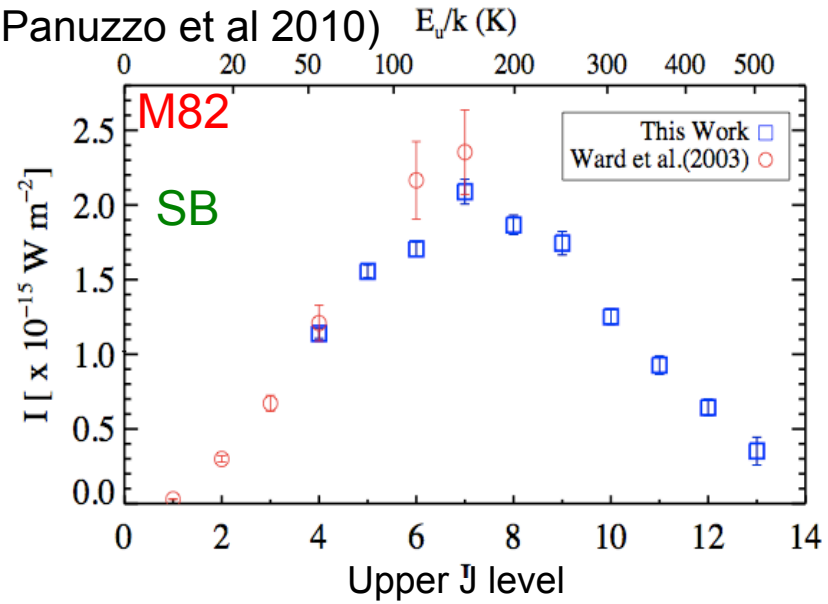
Science Application Examples

Probing molecular, atomic, and ionized gases via spectral lines:



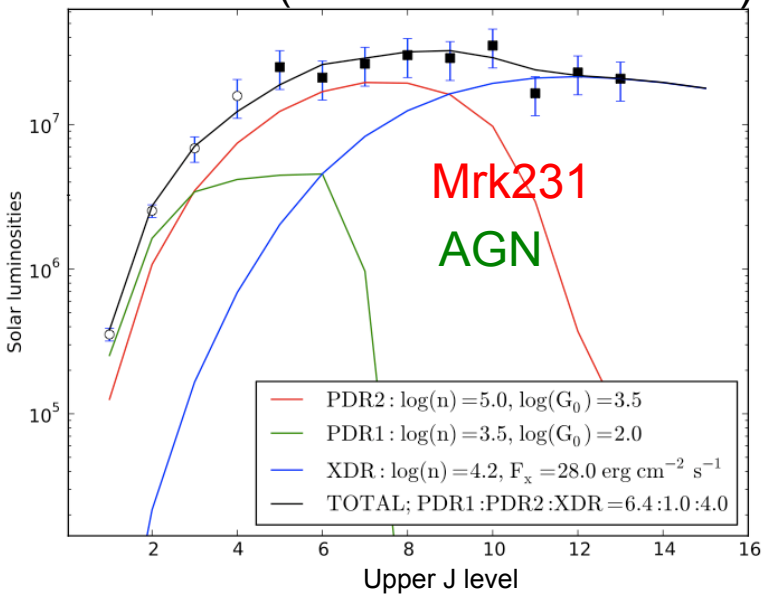
CO Spectral Line Energy Distribution (SLED): Starburst vs. AGN Gas Heating

(Panuzzo et al 2010)



- CO emission line ladder.
- Radiative transfer modeling.
- Warm gas ~500K in addition to known cold component.

(Van der Werf et al 2010)



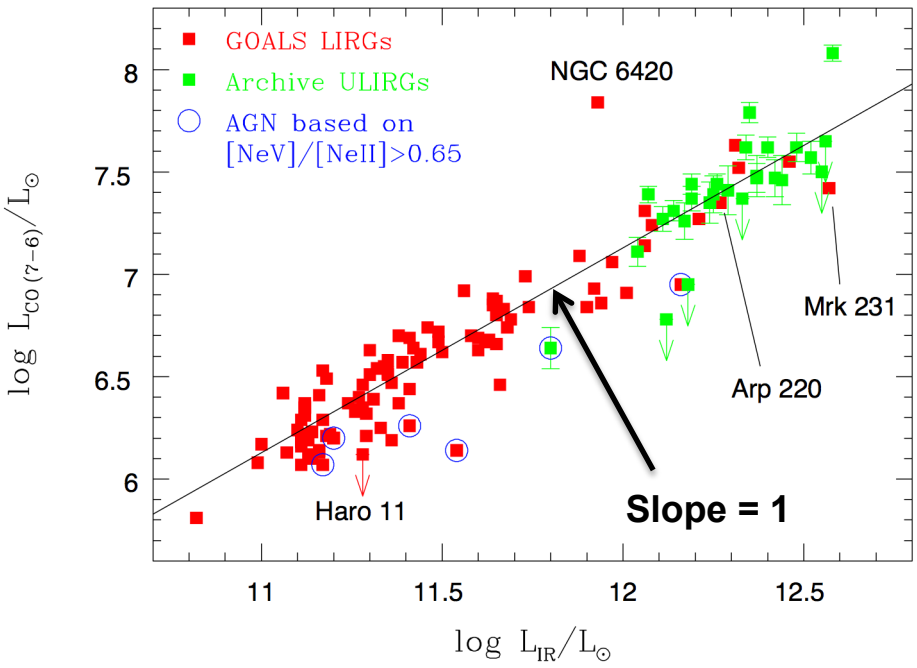
- Detected: CO ladder, H_2O, OH^+, H_2O^+, CH^+, HF
- X-ray driving excitation and chemistry out to 160pc.
- X-rays probably from central AGN.

Striking CO SLED difference between SB and AGN !

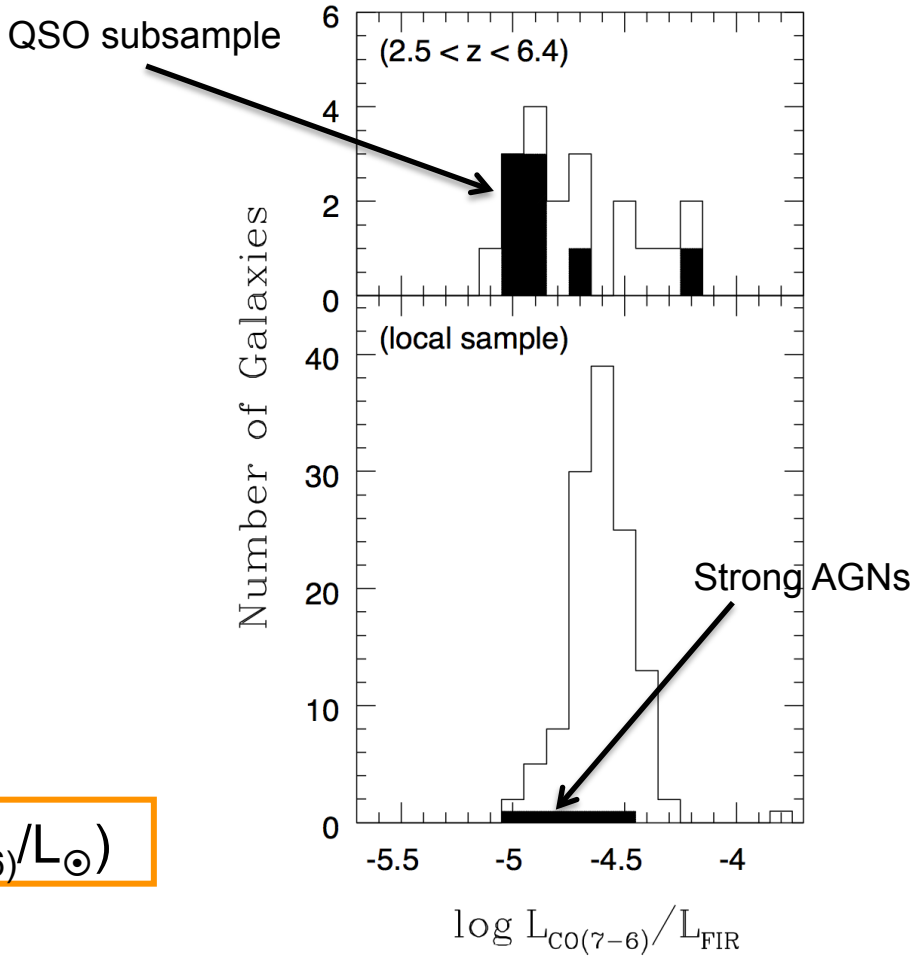
- Mid-J (5<J<10) CO lines are dominated by SB
- Higher-J CO line cooling is associated with AGN (see Lu et al 2014a)

Warm CO Gas Emssion as a SFR Tracer

(Lu et al. 2014a)



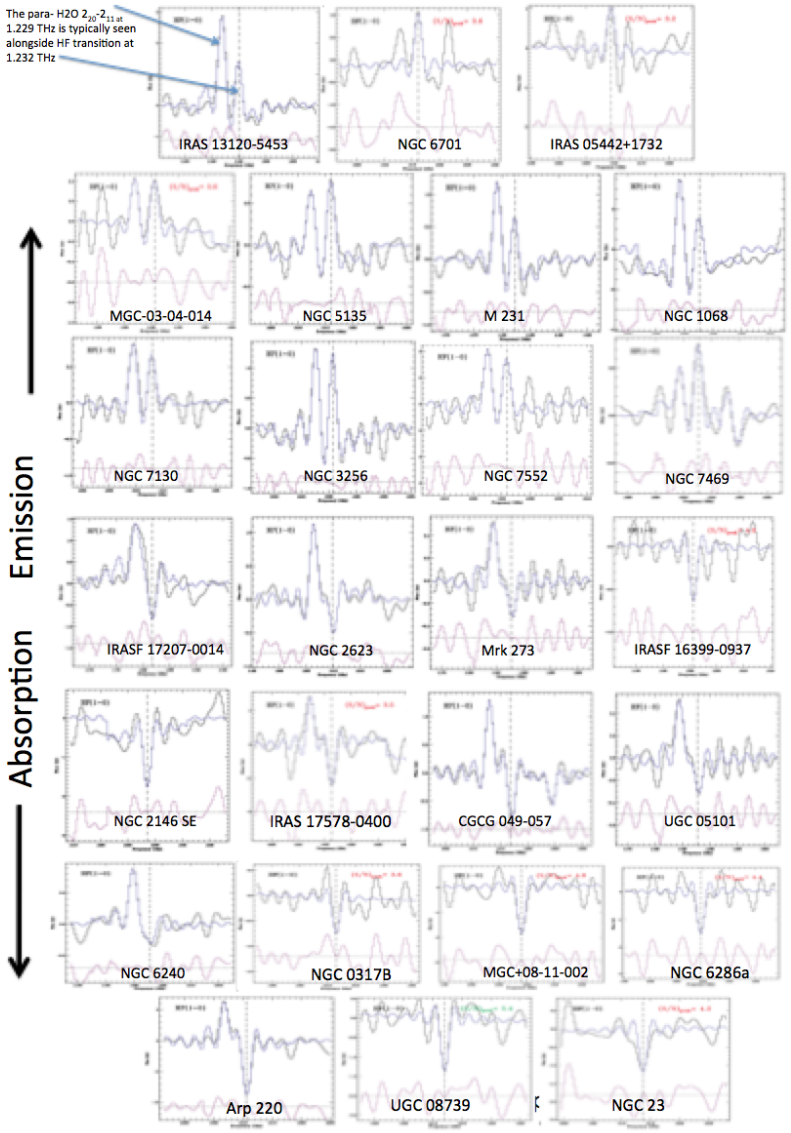
(Lu et al. 2014b)



$$SFR/(M_\odot\ yr^{-1}) = 1.34 \times 10^{(-5\pm0.12)}\ (L_{CO(7\text{-}6)}/L_\odot)$$

(based on Kennicutt 1988)

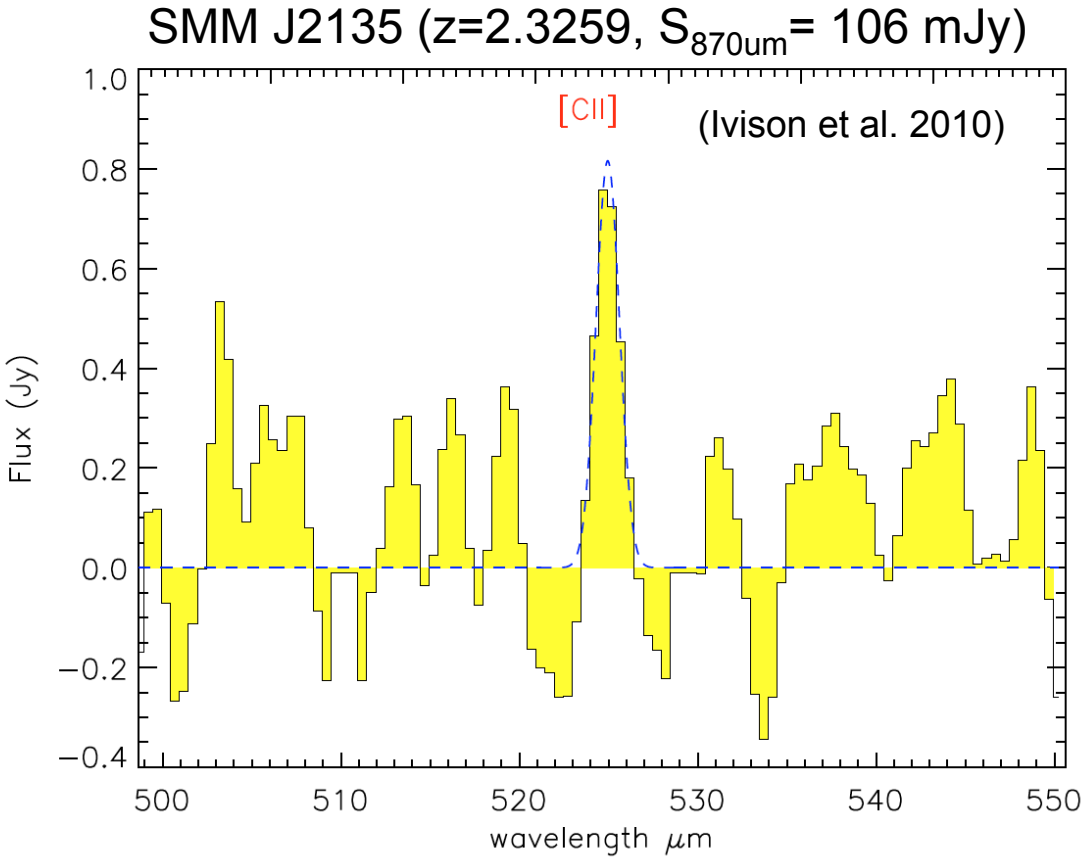
Hydrogen Fluoride HF (1-0)



- The HF (J=1-0) transition at 1.23 THz (243 um) is providing a new diagnostic probe of the molecular gas abundance, excitation, and column density toward infrared bright galaxy nuclei (Lord et al. 2014)

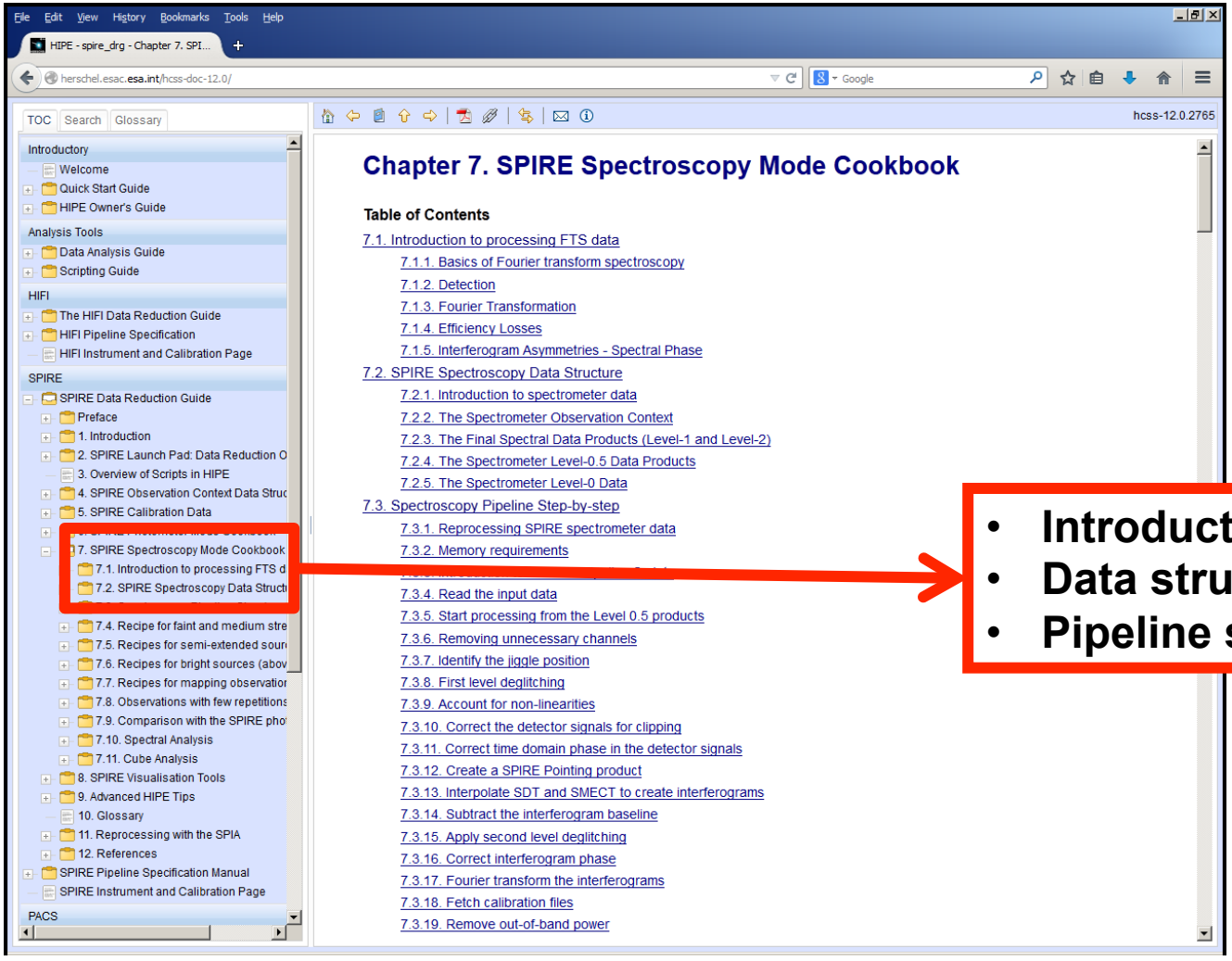
- SPIRE/FTS detected HF(1-0) in emission in some galaxies, but absorption in others in a flux limited sample of 125 LIRGs of Lu et al. (2014a)

[CII] 158um Line at High Redshift



Pipeline Data Products

SPIRE Data Reduction Guide (DRG)



Describes the data, pipeline, and analysis

- **Introduction to FTS**
- **Data structure**
- **Pipeline step-by-step**

The Pipeline

(cf. SPIRE DRG Sect. 7.3)

SPIRE Common Pipeline

1. Modify Detector Timeline V(t)

2. Create Interferogram V(x)

3. Modify Interferogram V(x)

4. Fourier Transform V(x)->S(σ)

5. Modify Spectra S(σ) to create Level-1 spectra of extended source flux calibration

6. Create ***Level-2 products***

Level 0.5 products:
- detector time lines
- scan mirror time line
- house keeping time lines

Interferograms (stored in Level 1)

Level 1 products:
(spectra in units of W/m^2/Hz/sr)
- average spectrum (unapodized)
- average spectrum (apodized)
- interferograms

Level-2 products:
- spectral cubes (*in W/m^2/Hz/sr*) if a mapping obs, otherwise
- a point-source spectrum (*in Jy*) for each of the unvignetted detectors.

Observation Context

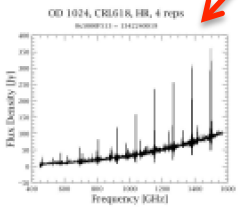
```
## SPIRE FTS observation of CRL618:
obs = getObservation(1342240019, useHsa=True)
```

Postage spectrum from the central detectors

ObservationContext for SPIRE data of observation 1342240019

Summary

AOR label:	Calibration_cycle60_1-SpireSpectroPointGen-CR-Rep4-CRL618		
Instrument:	SPIRE	**Obs. ID:**	1342240019
Object:	CRL618	**Obs. Date:**	2012-03-02T20:01:07Z
AOT:	Spectrometer	**Obs. Mode:**	Single Pointing
RA Nominal:	4h 42m 53.64s	**Dec. Nominal:**	36° 6' 53.4"
SPG Version:	SPG v12.1.0	**Operational Day:**	1024
Resolution:	CR	**Map Sampling:**	sparse
Bias Mode:	nominal	**Total Repetitions:**	4
LR Repetitions:	0	**HR Repetitions:**	4



Meta Data

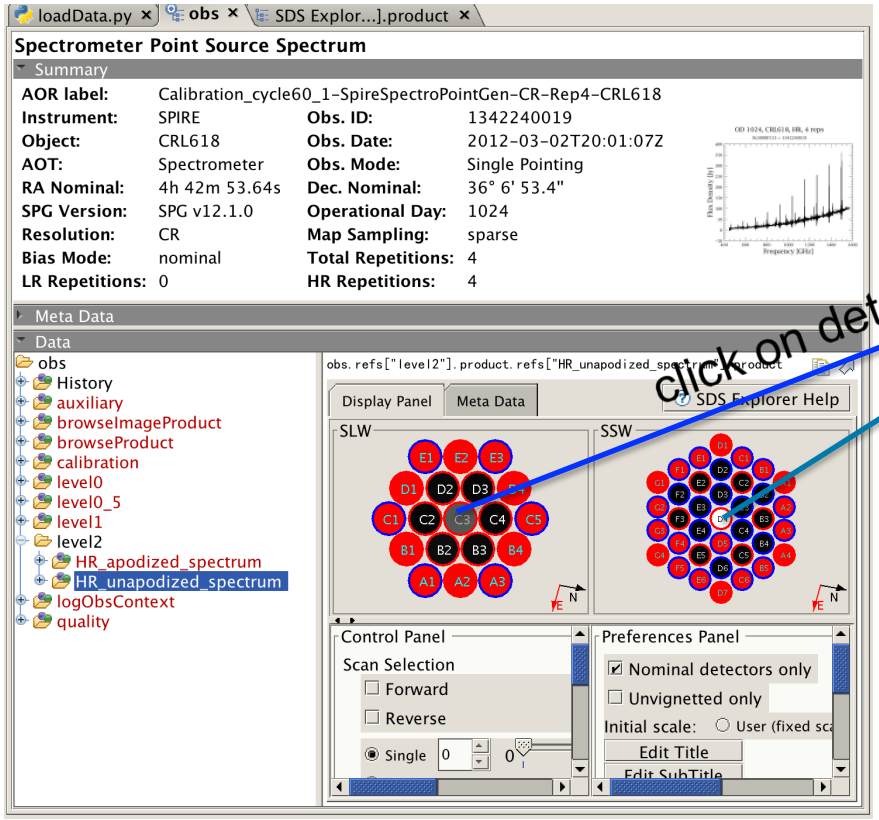
Data

- obs
  - History
  - auxiliary
  - browseImageProduct
  - browseProduct
  - calibration
  - level0
  - level0_5
  - level1
  - level2
  - logObsContext
  - quality

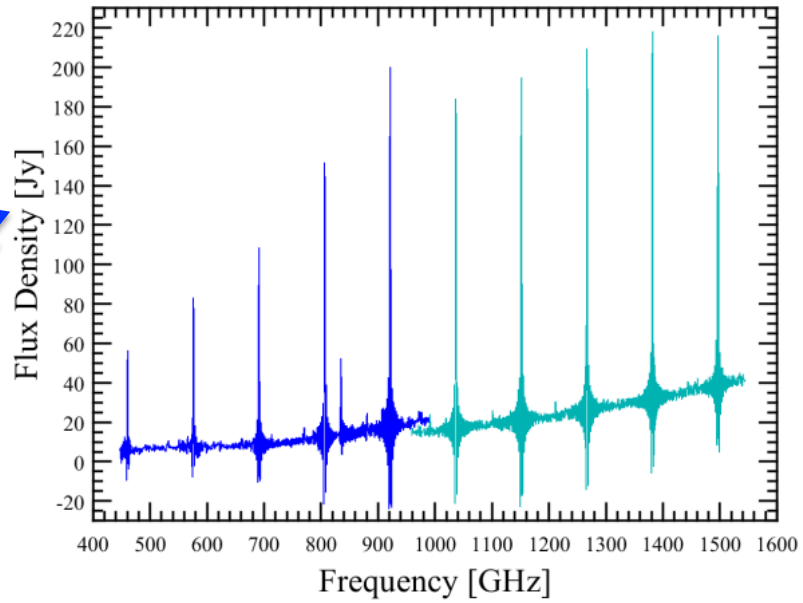
obs

Level-2 Products

Sparse Mode



click on detectors

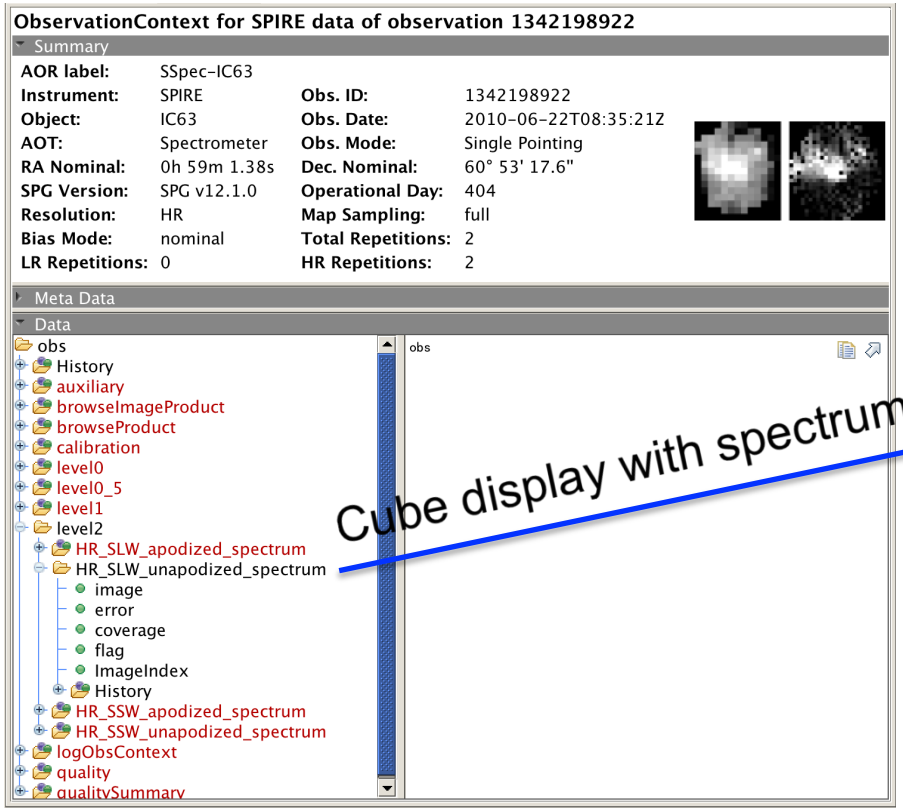


Apodized spectrum: convolved with a smoothing function so that line profiles are approximately Gaussian

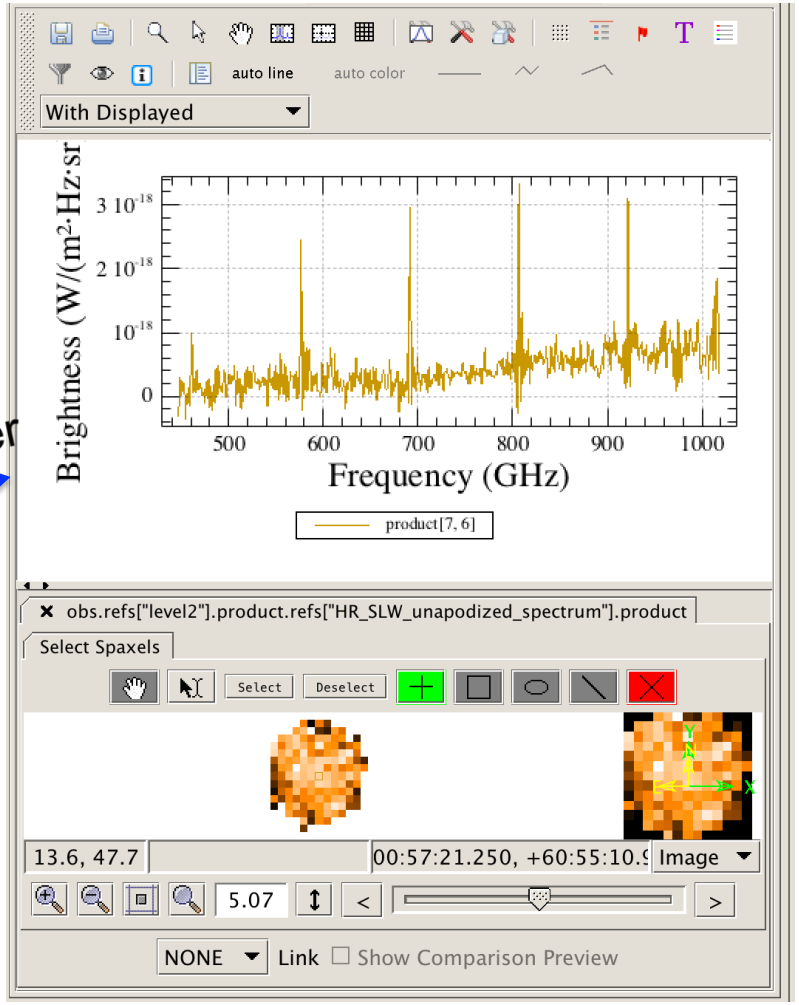
Heads up: the observation context structure will be changed in HIPE 13!!!

Level-2 Products

Mapping Observation



Cube display with spectrum explorer



What can you do next?

- If you have a point source, you can now work on deriving fluxes of spectral lines detected (see examples this afternoon and more on Thusrday morning)
- If you have a mapping observation, you can generate a line intensity map or extract a spectrum within an aperture (see talks/demos on Thusrday morning)
- Learn more about the calibration and special cases this afternoon