



SPIRE Spectroscopy: An Introduction

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





Topics Covered

- SPIRE spectrometer
- Pipeline data products



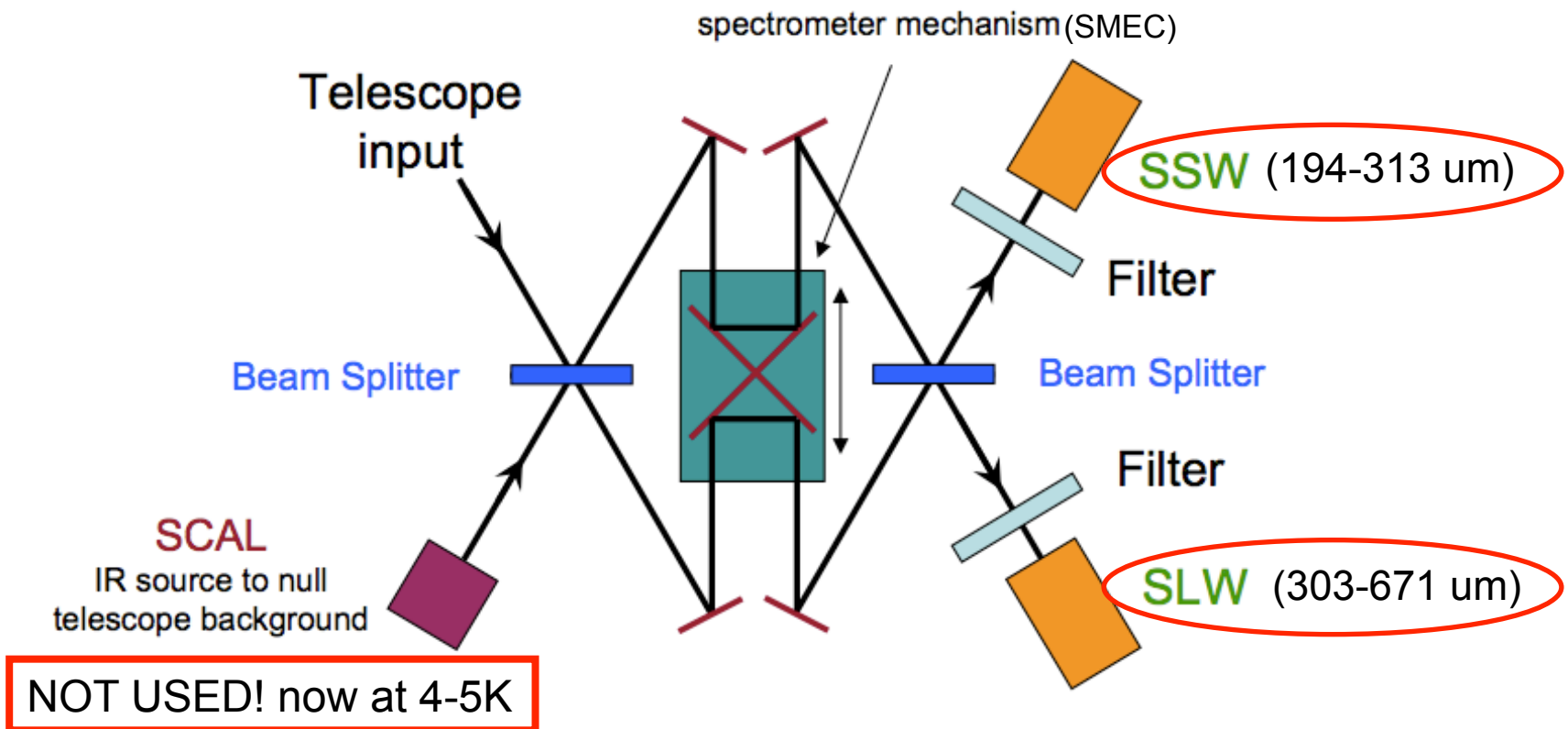
SPIRE Spectrometer





SPIRE Spectrometer

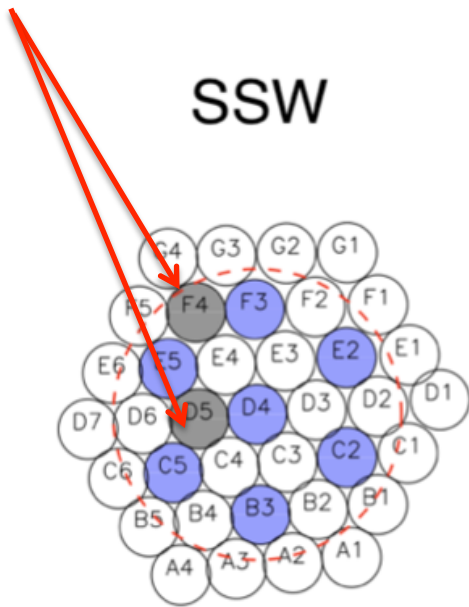
Fourier Transform Spectrometer (FTS): The entire spectral coverage of 194-671 micron is observed in one go!



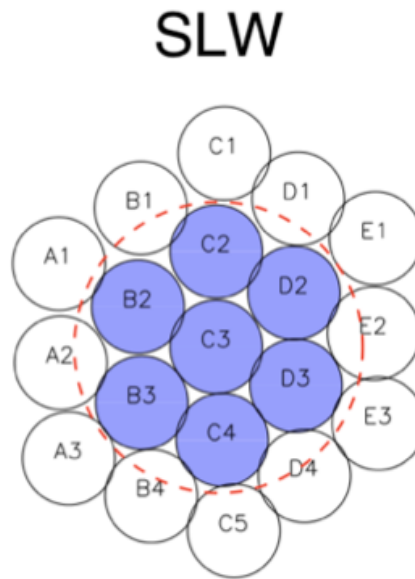


Two Bolometer Detector Arrays

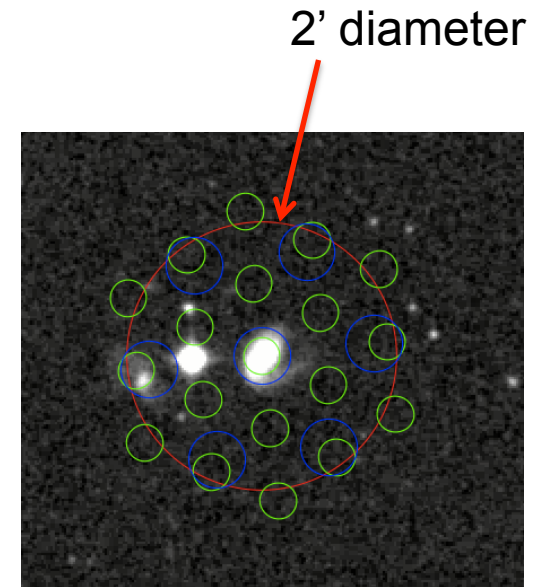
Two dead detectors



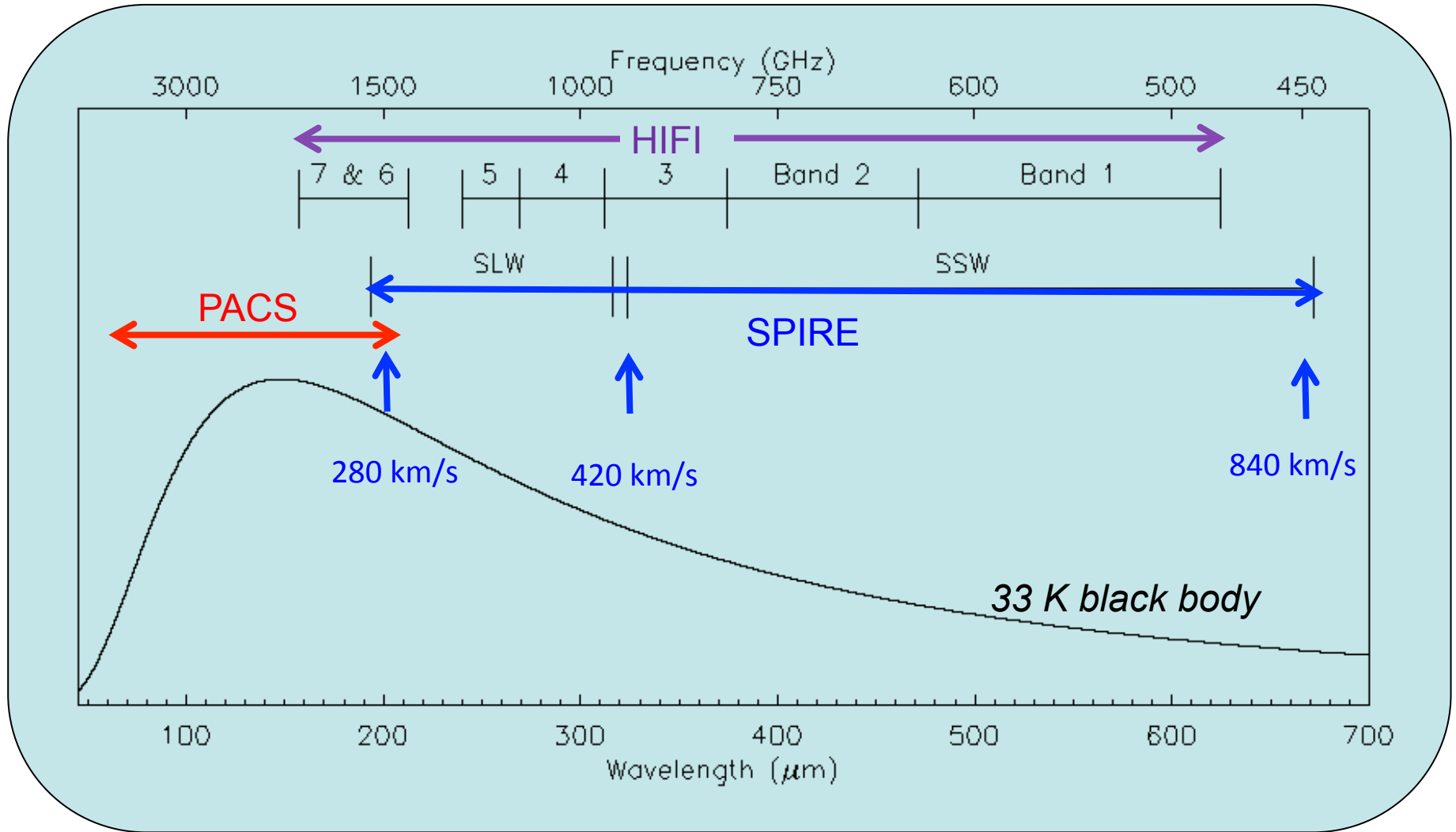
194 – 313 microns
Beam = 17" - 21"



303 – 671 microns
Beam = 29" - 42"

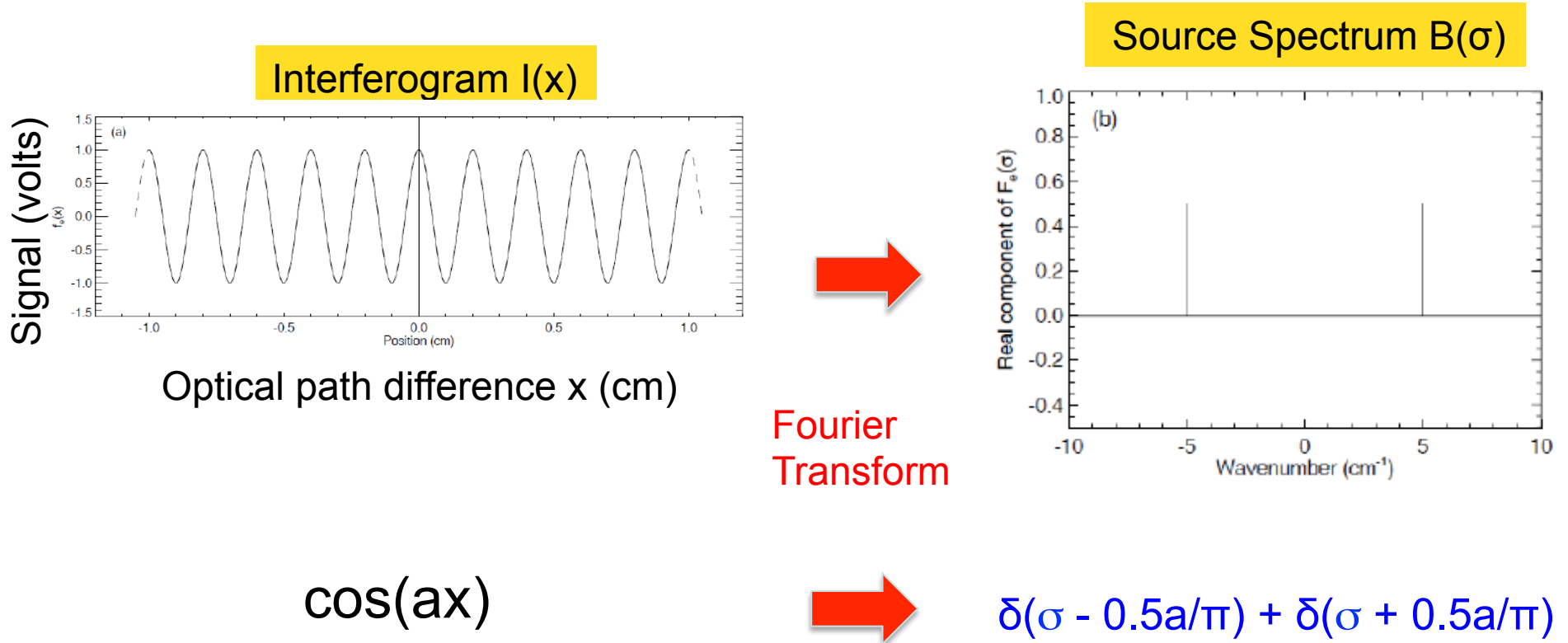


Foot print on sky



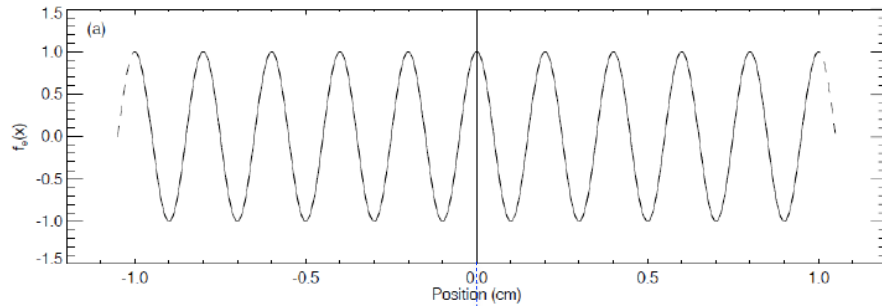


Fourier Transform: Interferogram to Spectrum

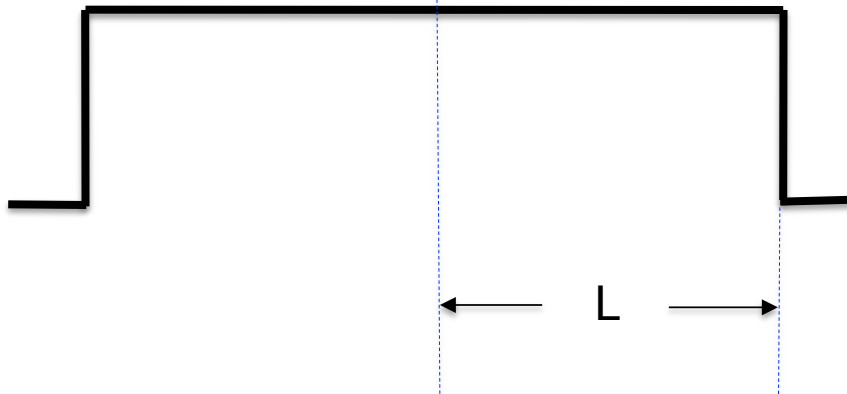




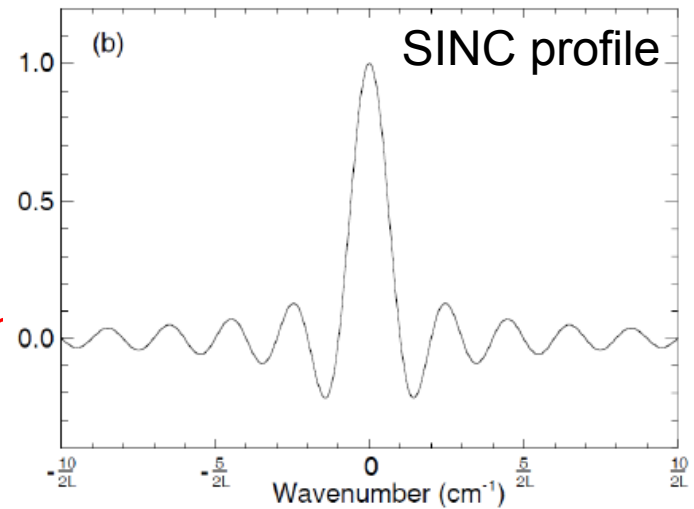
Real World: Finite Interferogram



Multiplied by a top hat function



Fourier Transform



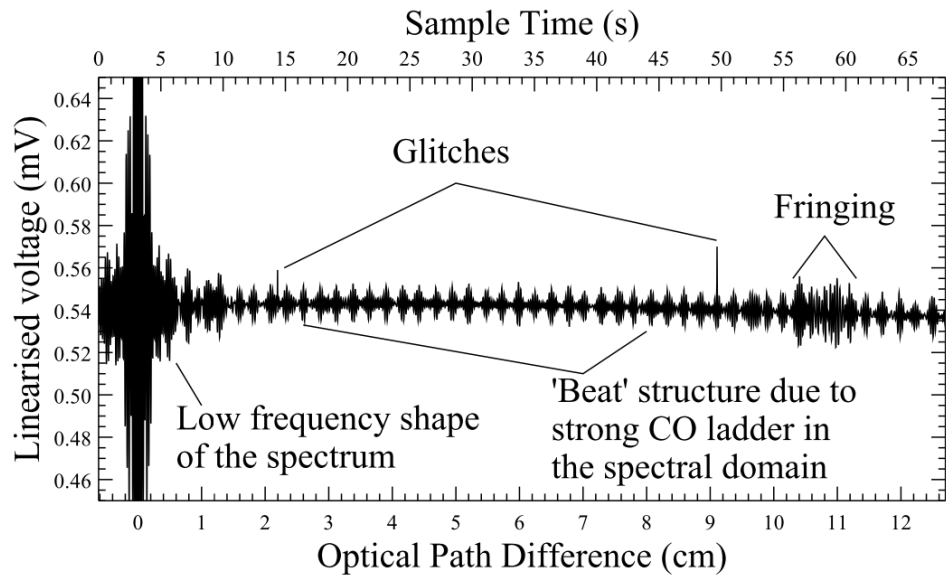
$$B(\sigma) \otimes \frac{\sin(\pi\sigma/\Delta\sigma)}{(\pi\sigma/\Delta\sigma)}$$

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

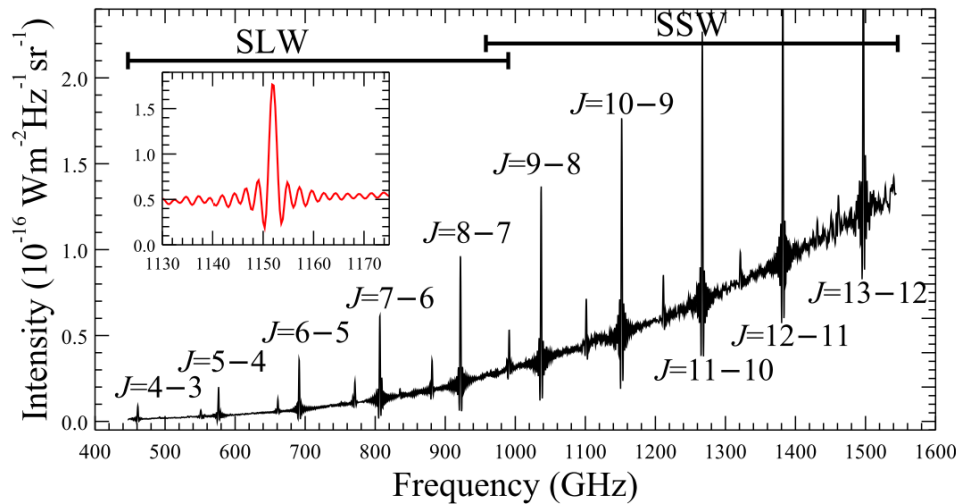


SPIRE/FTS Interferogram



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)
- $R = 1290 - 370$
- $\Delta V = 230 - 800 \text{ km/s}$;
Suitable for line fluxes.

Low Resolution (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

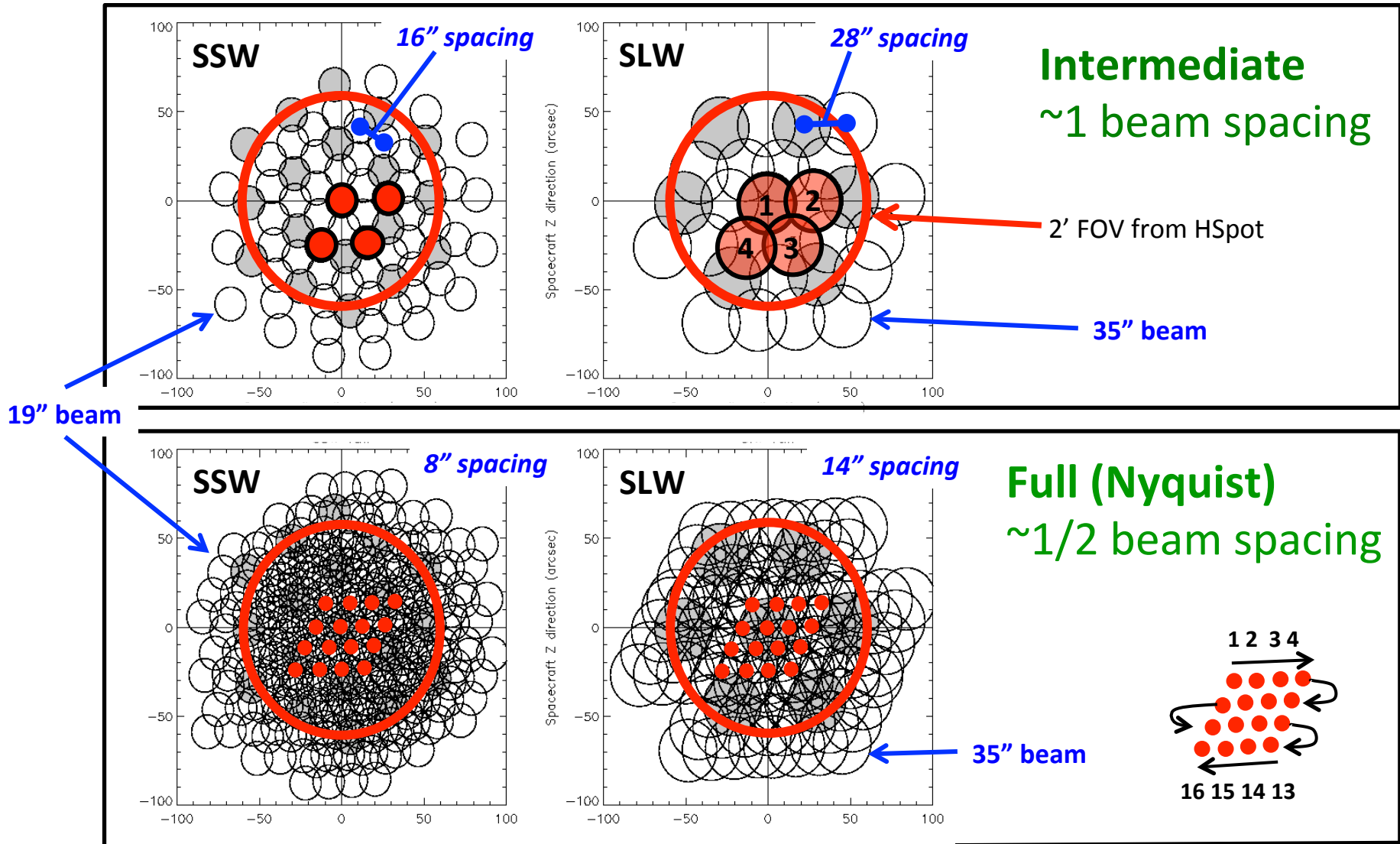
Raster
(for larger maps)

You get a map if any of these is used.

Spectral resolution, $\Delta\sigma$, depends on the maximum SMEC scan length L:

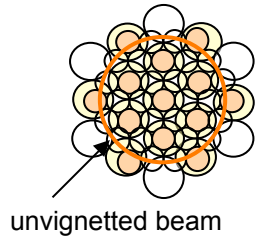
$$\Delta\sigma = 1/(2L), \text{ where } L = 12.8 \text{ cm for the High Res. mode}$$

Mapping Observations





Larger maps via Raster



Overlapping spectrometer arrays projected on the sky

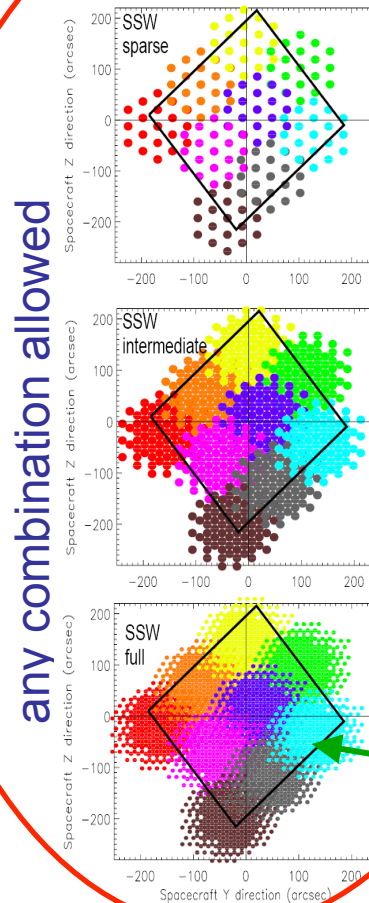
Image Sampling

- Sparse
- Intermediate
- Full

Pointing Mode

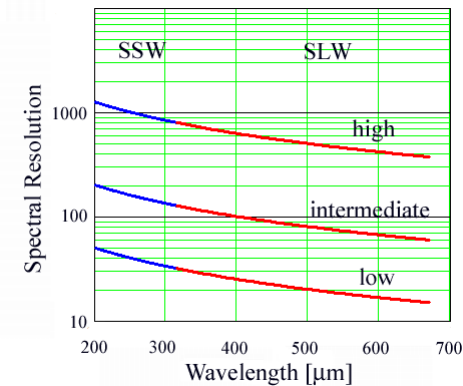
- Single Pointing
- Raster Pointing

example 3 x 3 map



Spectral Resolution

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



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

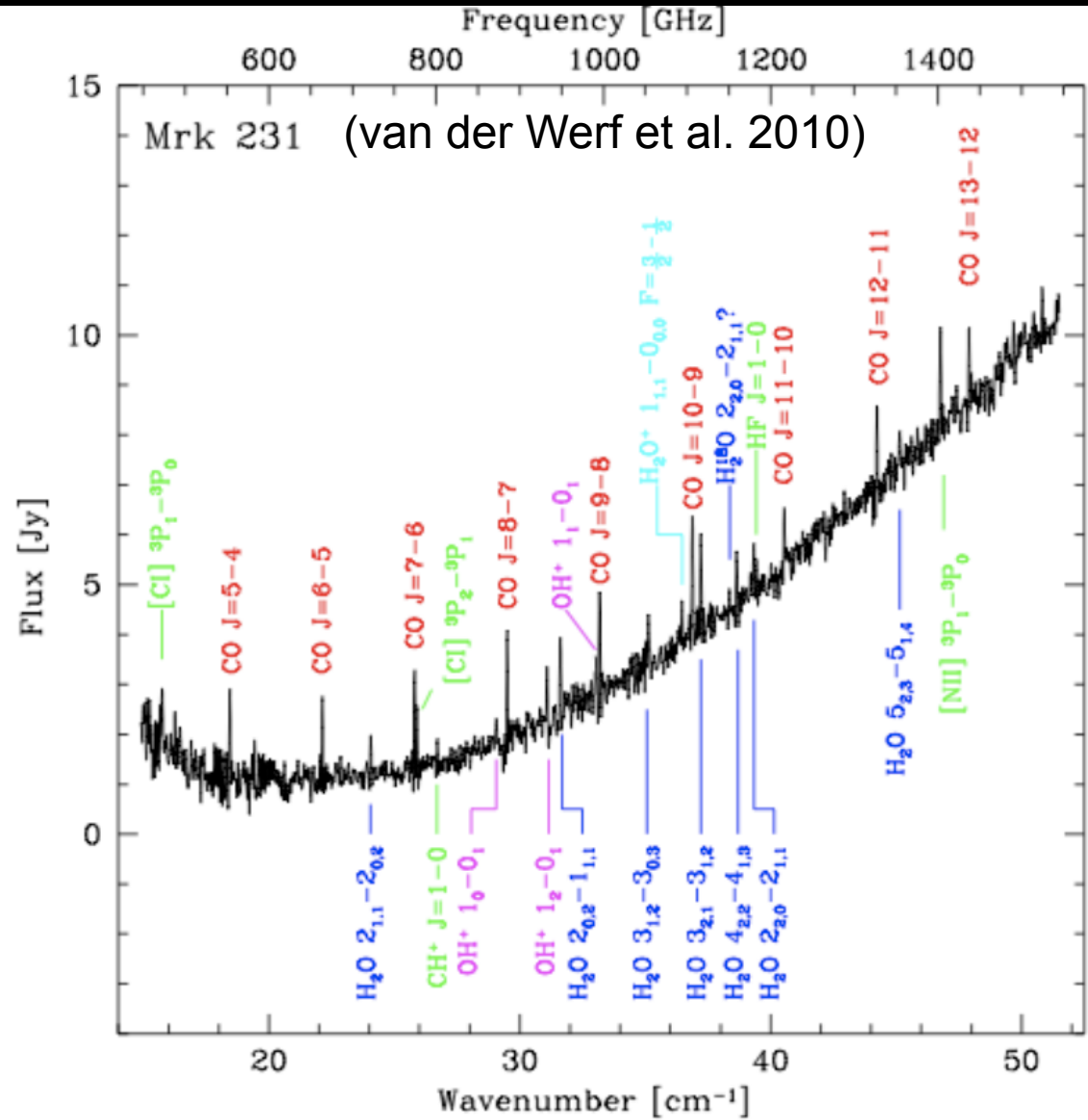


Science Application Examples



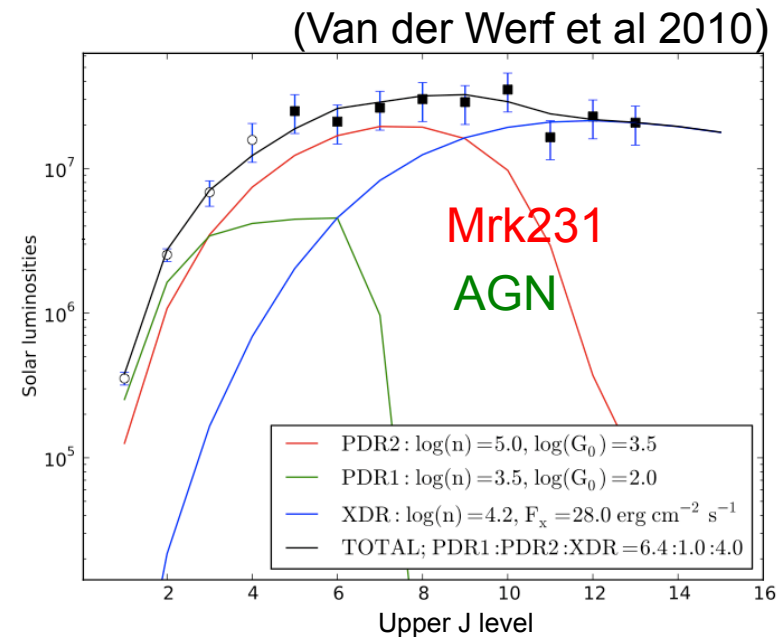
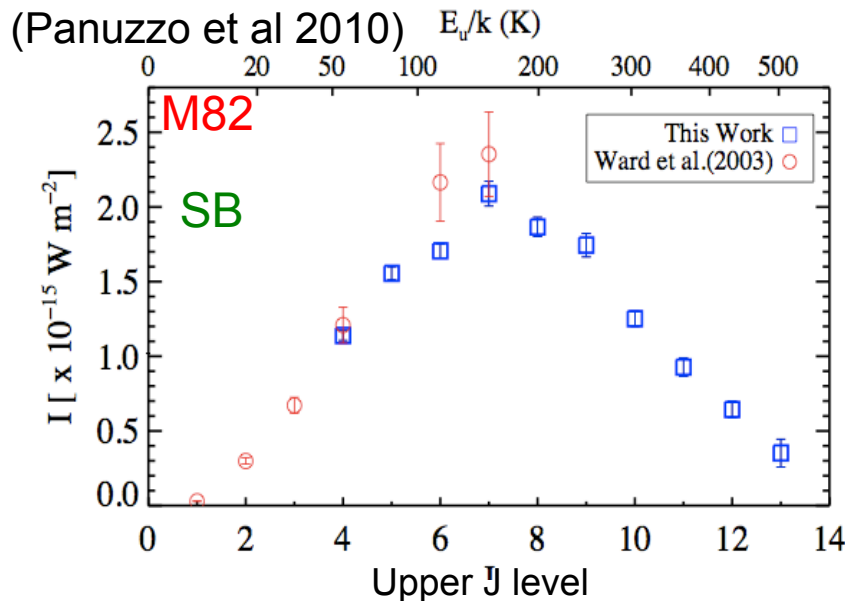


Probing
molecular,
atomic, and
ionized
gases via
spectral
lines:





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



- CO emission line ladder.
- Radiative transfer modeling.
- Warm gas $\sim 500\text{K}$ in addition to known cold component.

- 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.

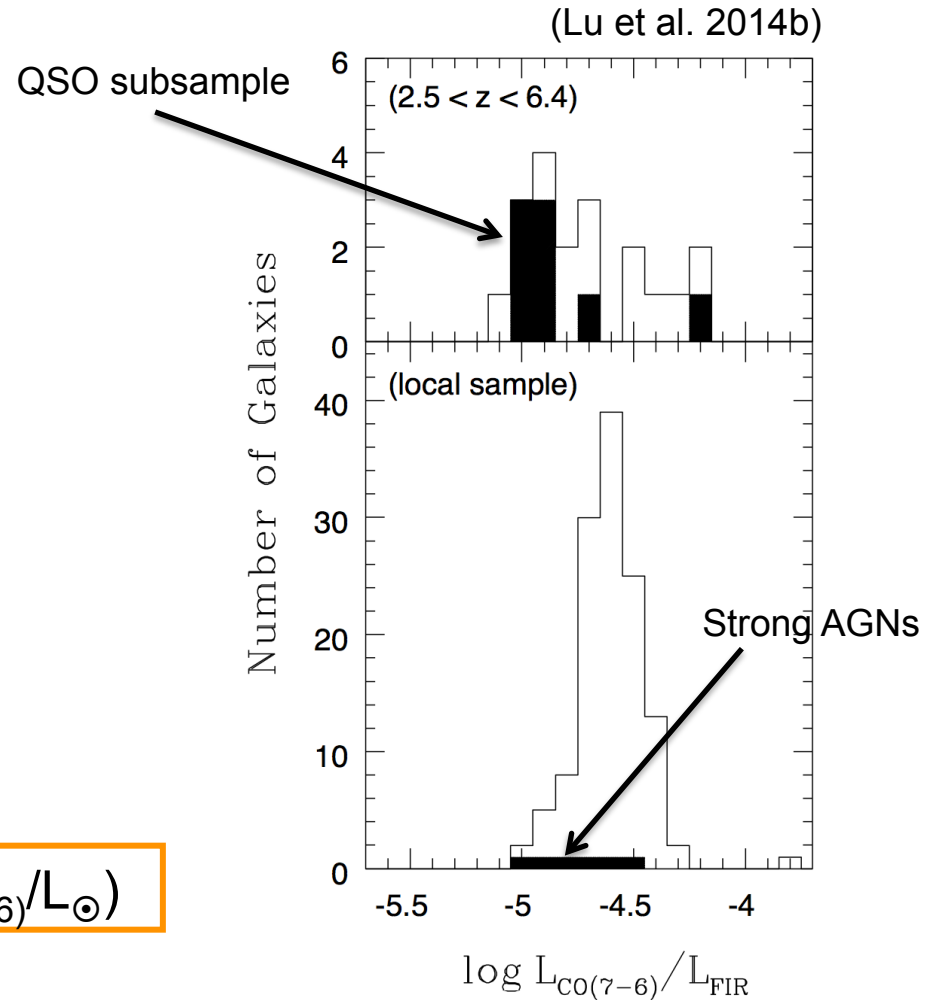
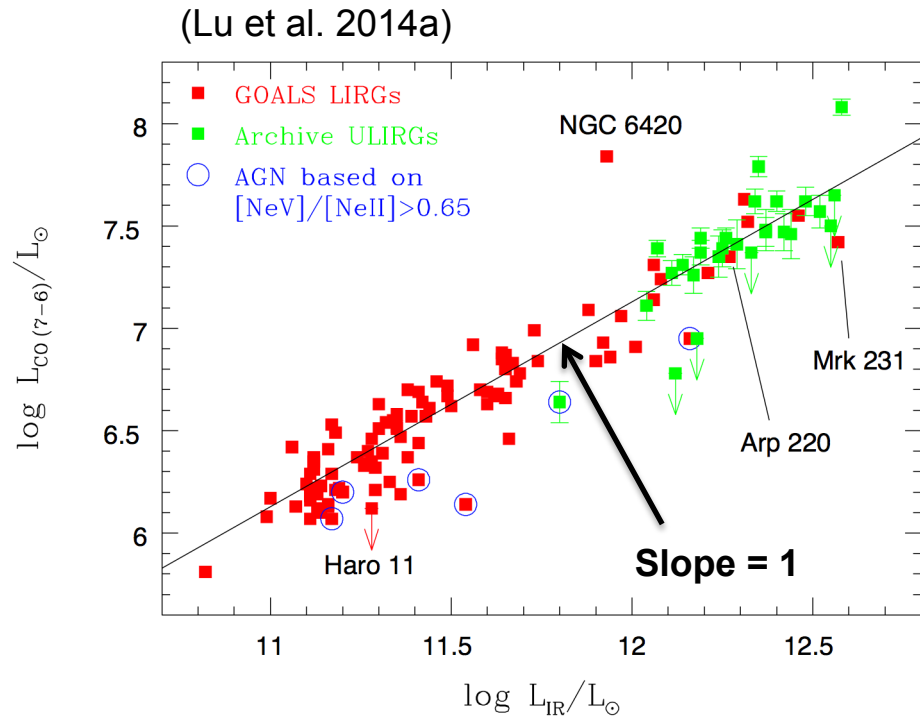
Striking CO SLED difference between SB and AGN !

- 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)

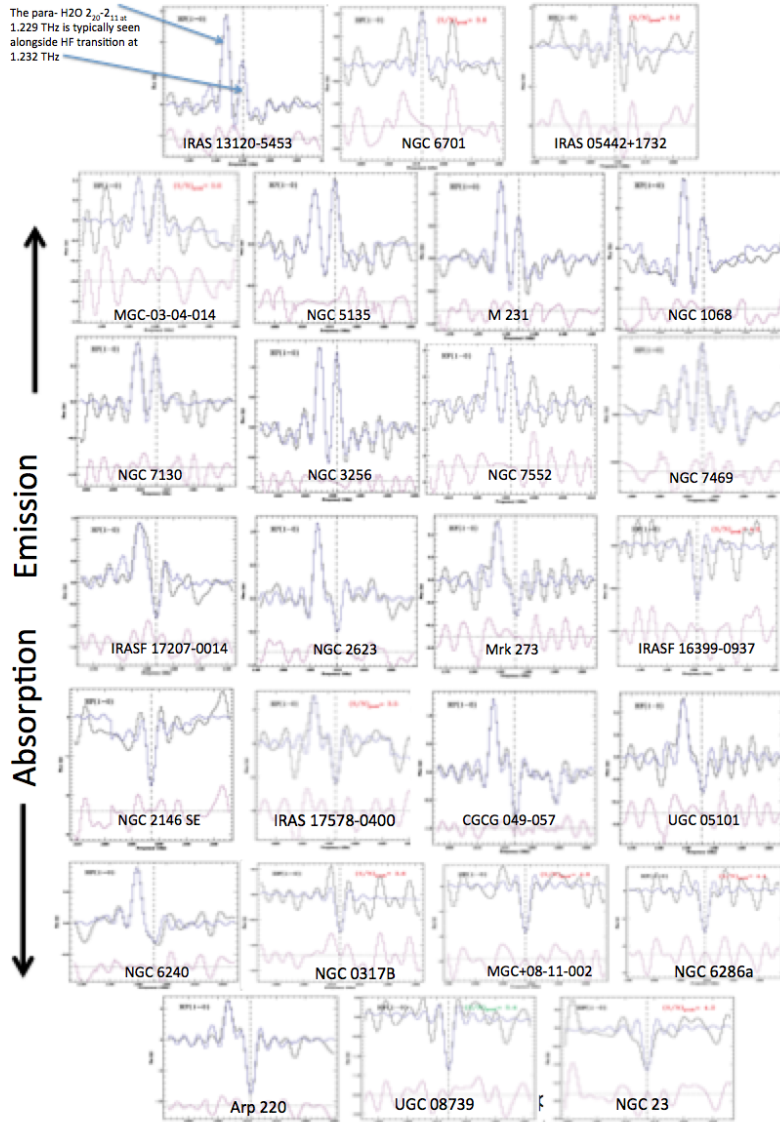


Warm CO Gas Emission as a SFR Tracer



$$\text{SFR}/(M_{\odot} \text{ yr}^{-1}) = 1.34 \times 10^{(-5 \pm 0.12)} (L_{CO(7-6)}/L_{\odot})$$

(based on Kennicutt 1988)



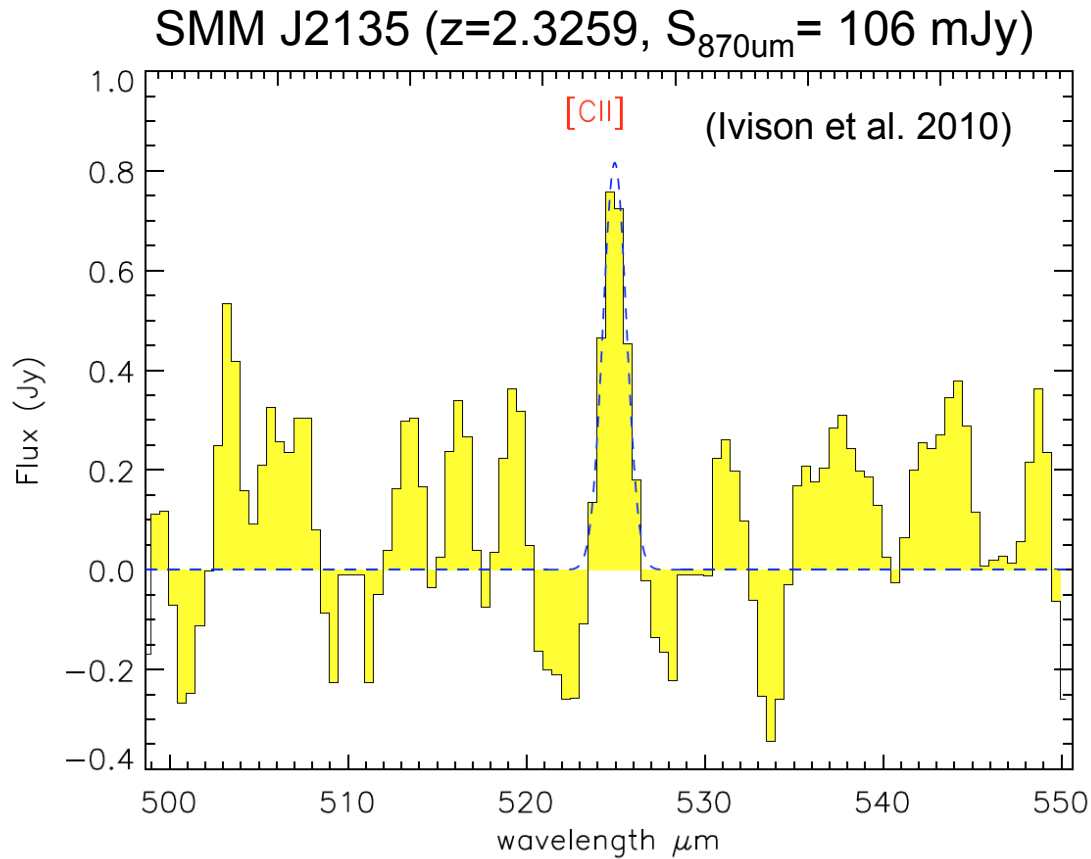
Hydrogen Fluoride HF (1-0)

- ✧ 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)

Chapter 7. SPIRE Spectroscopy Mode Cookbook

Table of Contents

- [7.1. Introduction to processing FTS data](#)
 - [7.1.1. Basics of Fourier transform spectroscopy](#)
 - [7.1.2. Detection](#)
 - [7.1.3. Fourier Transformation](#)
 - [7.1.4. Efficiency Losses](#)
 - [7.1.5. Interferogram Asymmetries - Spectral Phase](#)
- [7.2. SPIRE Spectroscopy Data Structure](#)
 - [7.2.1. Introduction to spectrometer data](#)
 - [7.2.2. The Spectrometer Observation Context](#)
 - [7.2.3. The Final Spectral Data Products \(Level-1 and Level-2\)](#)
 - [7.2.4. The Spectrometer Level-0.5 Data Products](#)
 - [7.2.5. The Spectrometer Level-0 Data](#)
- [7.3. Spectroscopy Pipeline Step-by-step](#)
 - [7.3.1. Reprocessing SPIRE spectrometer data](#)
 - [7.3.2. Memory requirements](#)
 - [7.3.4. Read the input data](#)
 - [7.3.5. Start processing from the Level 0.5 products](#)
 - [7.3.6. Removing unnecessary channels](#)
 - [7.3.7. Identify the jiggle position](#)
 - [7.3.8. First level deglitching](#)
 - [7.3.9. Account for non-linearities](#)
 - [7.3.10. Correct the detector signals for clipping](#)
 - [7.3.11. Correct time domain phase in the detector signals](#)
 - [7.3.12. Create a SPIRE Pointing product](#)
 - [7.3.13. Interpolate SDT and SMECT to create interferograms](#)
 - [7.3.14. Subtract the interferogram baseline](#)
 - [7.3.15. Apply second level deglitching](#)
 - [7.3.16. Correct interferogram phase](#)
 - [7.3.17. Fourier transform the interferograms](#)
 - [7.3.18. Fetch calibration files](#)
 - [7.3.19. Remove out-of-band power](#)

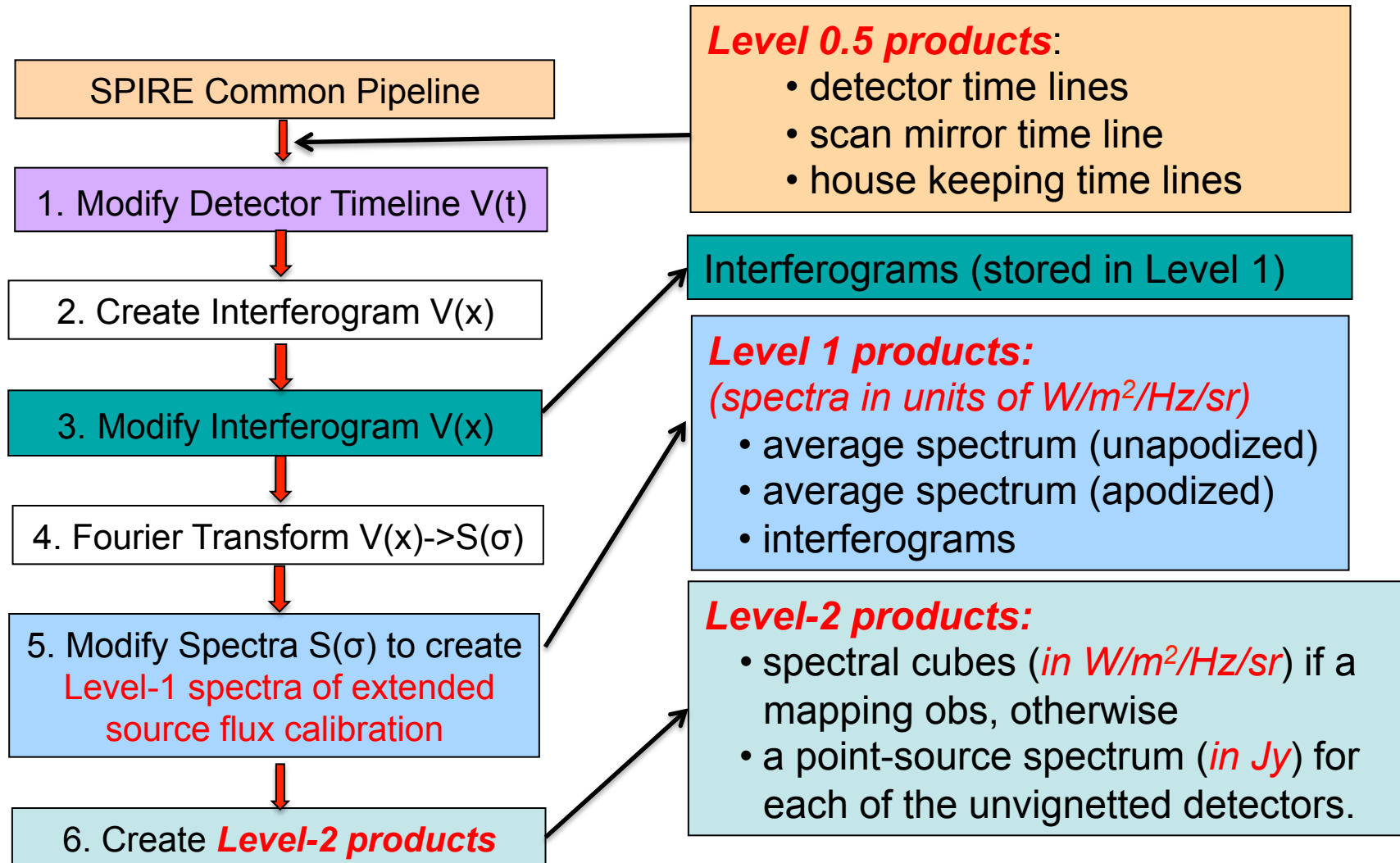
Describes the data,
pipeline, and analysis

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



The Pipeline

(cf. SPIRE DRG Sect. 7.3)





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



Level-2 Products

Sparse Mode

Spectrometer Point Source Spectrum

Summary

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

Meta Data

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

Control Panel

Scan Selection

Forward

Reverse

Single 0

Preferences Panel

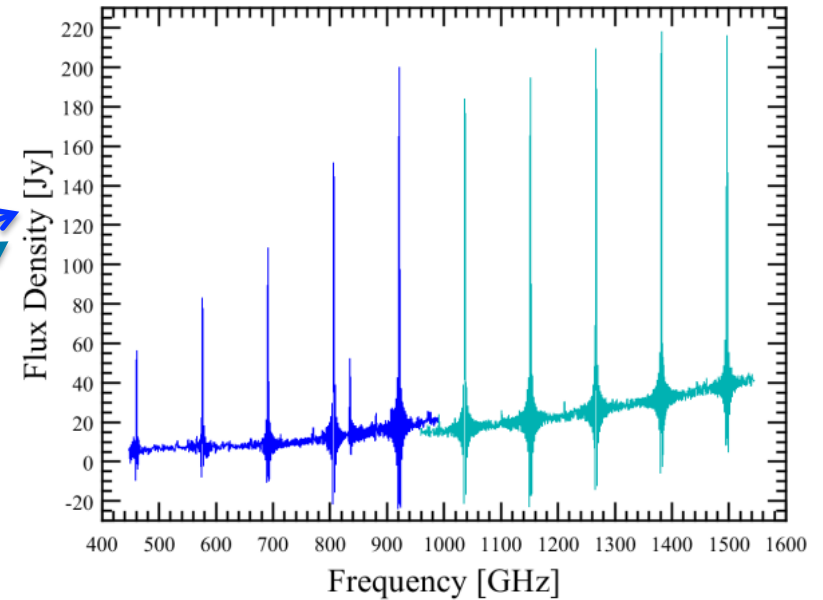
Nominal detectors only

Unvignetted only

Initial scale: User (fixed scale)

Edit Title

Edit SubTitle



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

ObservationContext for SPIRE data of observation 1342198922

Summary

AOR label:	SSpec-IC63	Obs. ID:	1342198922
Instrument:	SPIRE	Obs. Date:	2010-06-22T08:35:21Z
Object:	IC63	Obs. Mode:	Single Pointing
AOT:	Spectrometer	Dec. Nominal:	60° 53' 17.6"
RA Nominal:	0h 59m 1.38s	Operational Day:	404
SPG Version:	SPG v12.1.0	Map Sampling:	full
Resolution:	HR	Total Repetitions:	2
Bias Mode:	nominal	HR Repetitions:	2
LR Repetitions:	0		

Meta Data

Data

- obs
- History
- auxiliary
- browseImageProduct
- browseProduct
- calibration
- level0
- level0_5
- level1
- level2
 - HR_SLW_apodized_spectrum
 - HR_SLW_unapodized_spectrum
 - image
 - error
 - coverage
 - flag
 - ImageIndex
 - History
 - HR_SSW_apodized_spectrum
 - HR_SSW_unapodized_spectrum
 - logObsContext
 - quality
 - qualitySummary

Cube display with spectrum explorer

With Displayed

Brightness ($W/(m^2 \cdot Hz \cdot sr)$)

Frequency (GHz)

product[7, 6]

obs.refs["level2"].product.refs["HR_SLW_unapodized_spectrum"].product

Select Spaxels

13.6, 47.7 | 00:57:21.250, +60:55:10.5 | Image

5.07

NONE Link Show Comparison Preview



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 Thursday 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 Thursday morning)
- Learn more about the calibration and special cases this afternoon