SPIRE Spectrometer Products and Data Processing Pipeline

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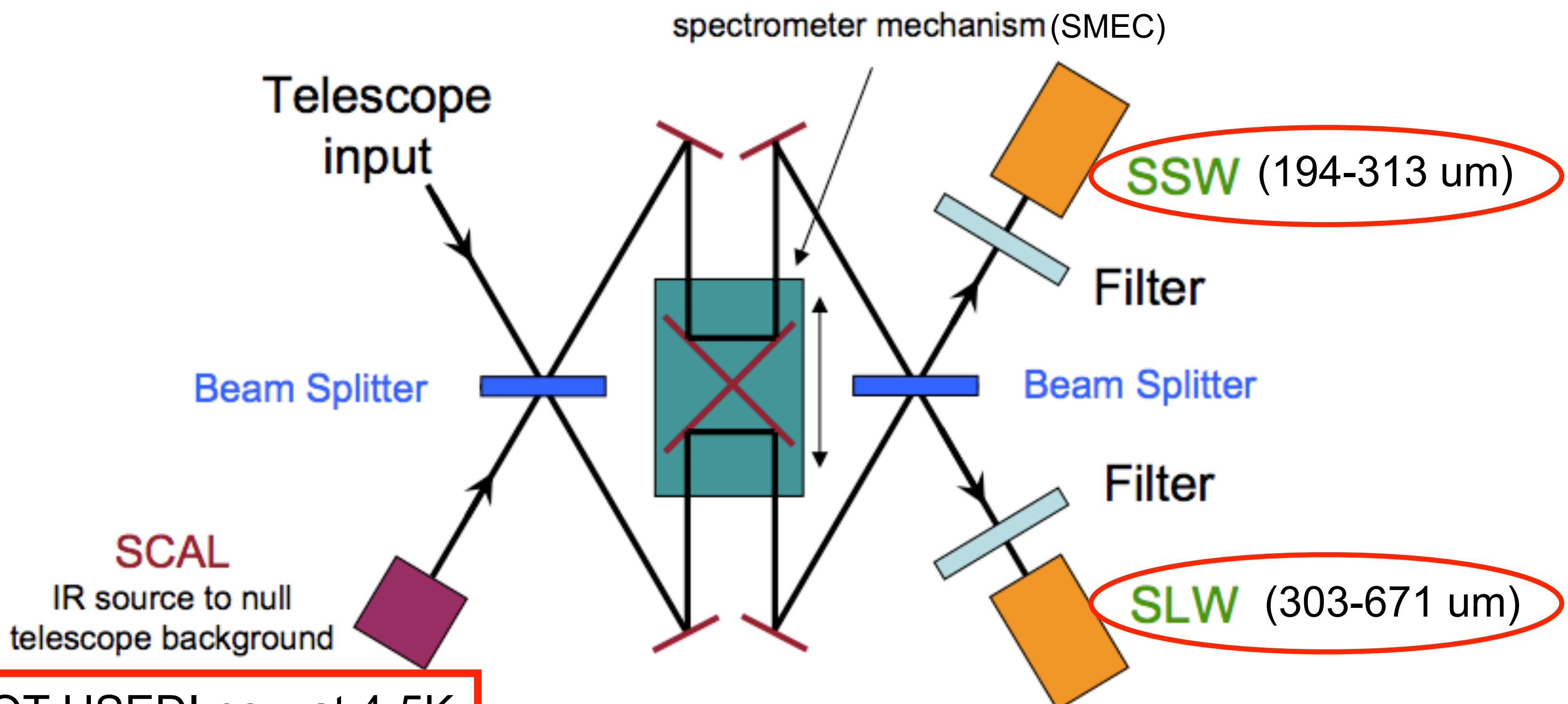
(on behalf of the SPIRE ICC, HSC & NHSC)

Outline

- Background
- Pipeline data products
  - What products are there?
  - Which ones are the most relevant to you?
- Pipeline calibrations
  - What are the standard calibration steps?
  - What calibration accurcies can you expect?

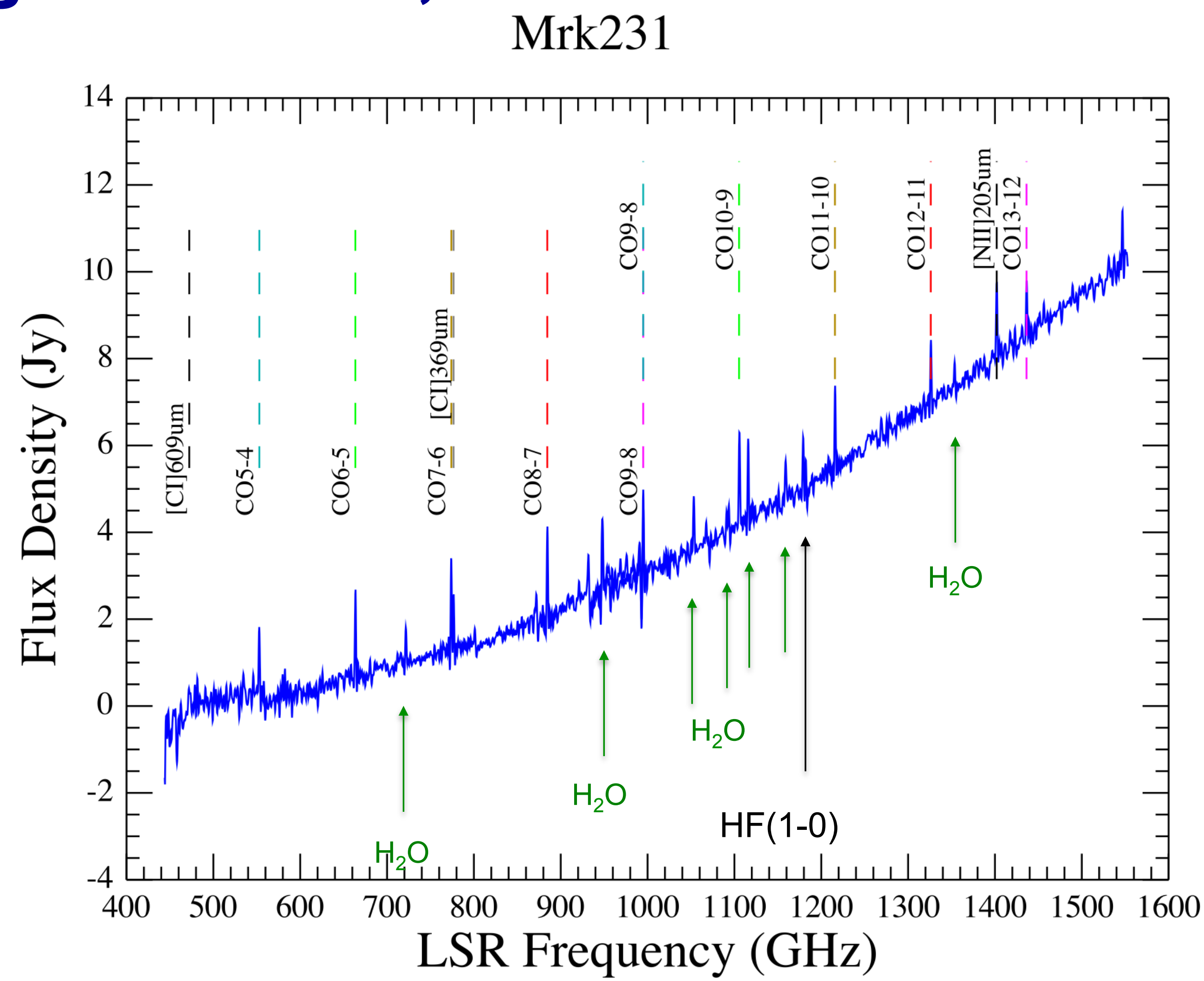
SPIRE Spectrometer

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



NOT USED! now at 4-5K

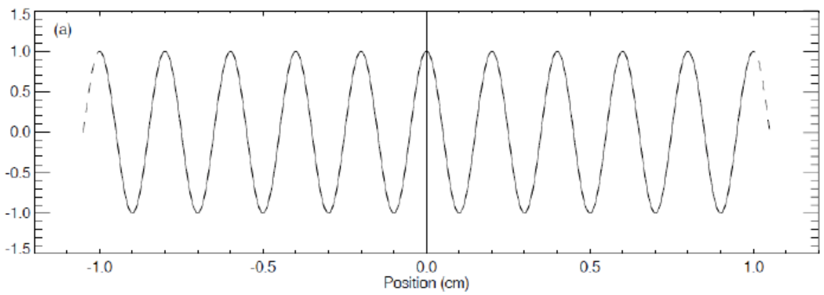
Probing Molecular, Atomic and Ionized Gases



Fourier Transform: Interferogram to Spectrum

Interferogram I(x)

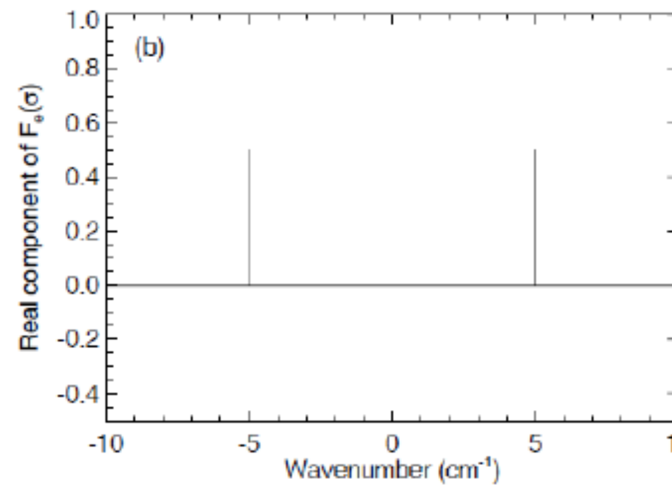
Signal (volts)



Optical path difference x (cm)

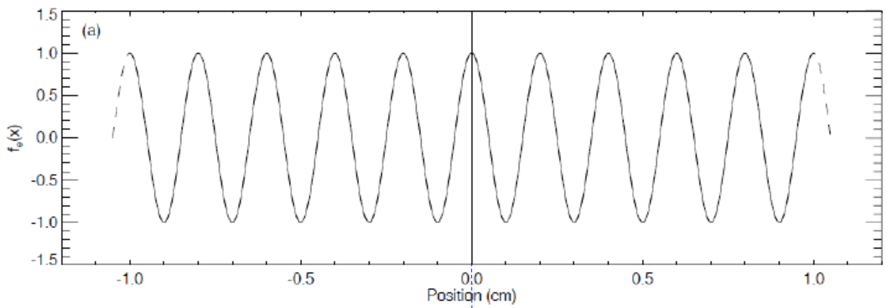
Fourier Transform

Source Spectrum B(σ)

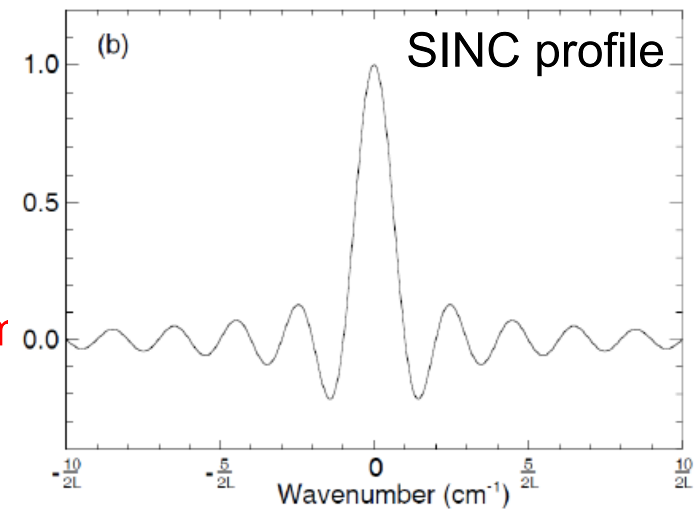


cos(ax) → $\delta(\sigma - 0.5a/\pi) + \delta(\sigma + 0.5a/\pi)$

Real World: Finite Interferogram

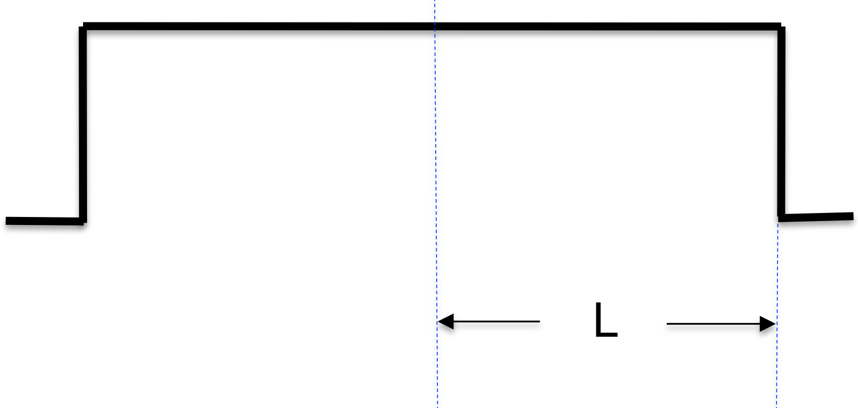


Fourier Transform



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

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

Background Documents

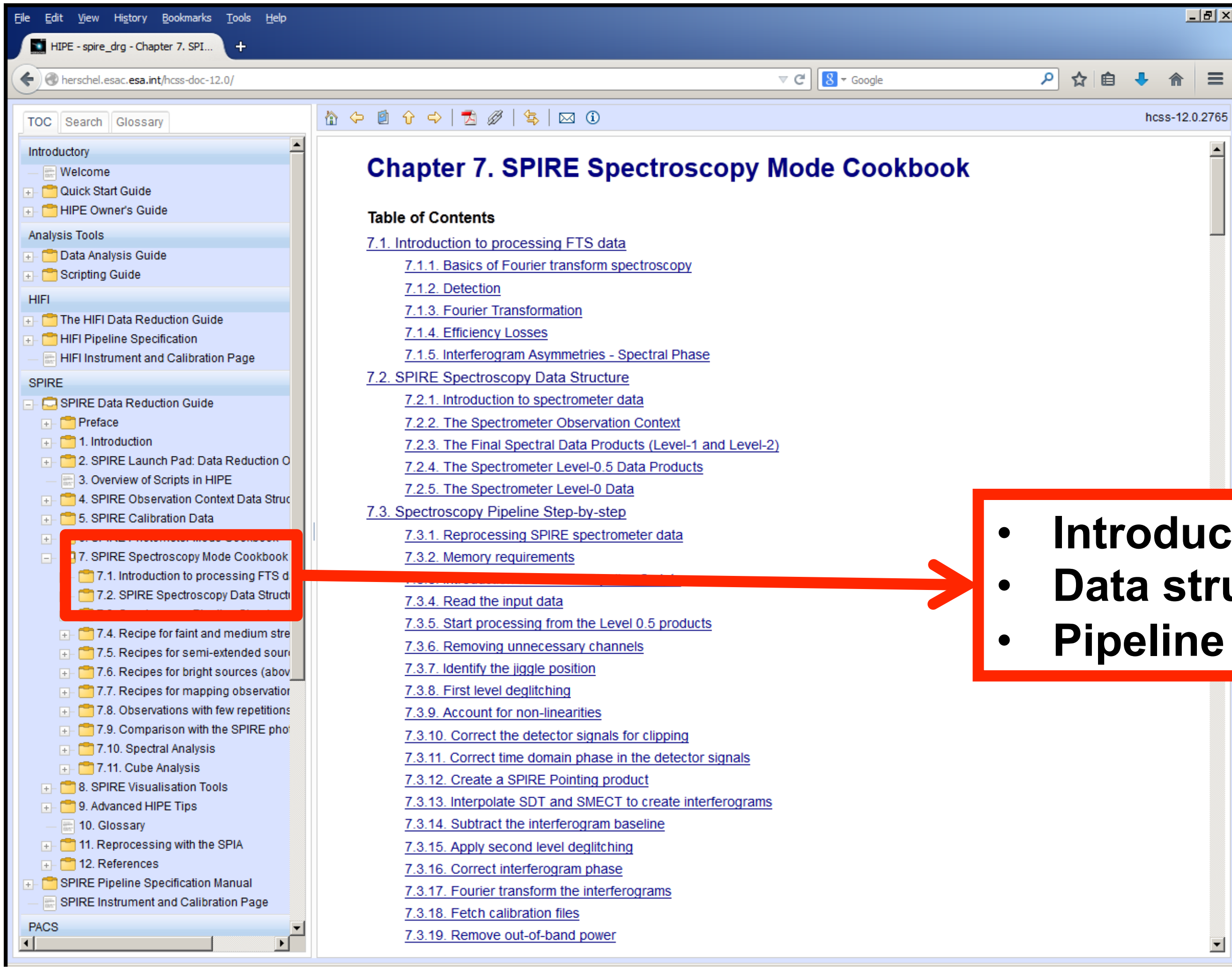
- **The SPIRE Data Reduction Guide** (DRG; data structure, processing, reprocessing, many details and cookbooks)
- **The SPIRE Handbook** (instrument observing modes, calibration…)

- Swinyard et al. 2014, MNRAS, 440, 3658 - **FTS calibration**
- Makiwa et al. 2013, Applied Optics, 52, 3864 - **FTS beams**
- Wu et al. 2013, A&A, 556, 116 - **Semi-extended sources**
- …

- Public wiki on SPIRE http://herschel.esac.esa.int/twiki/bin/view/Public/SpireCalibrationWeb

SPIRE Data Reduction Guide (DRG)

Describes the data, pipeline, and analysis



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

Pipeline Data Products

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)

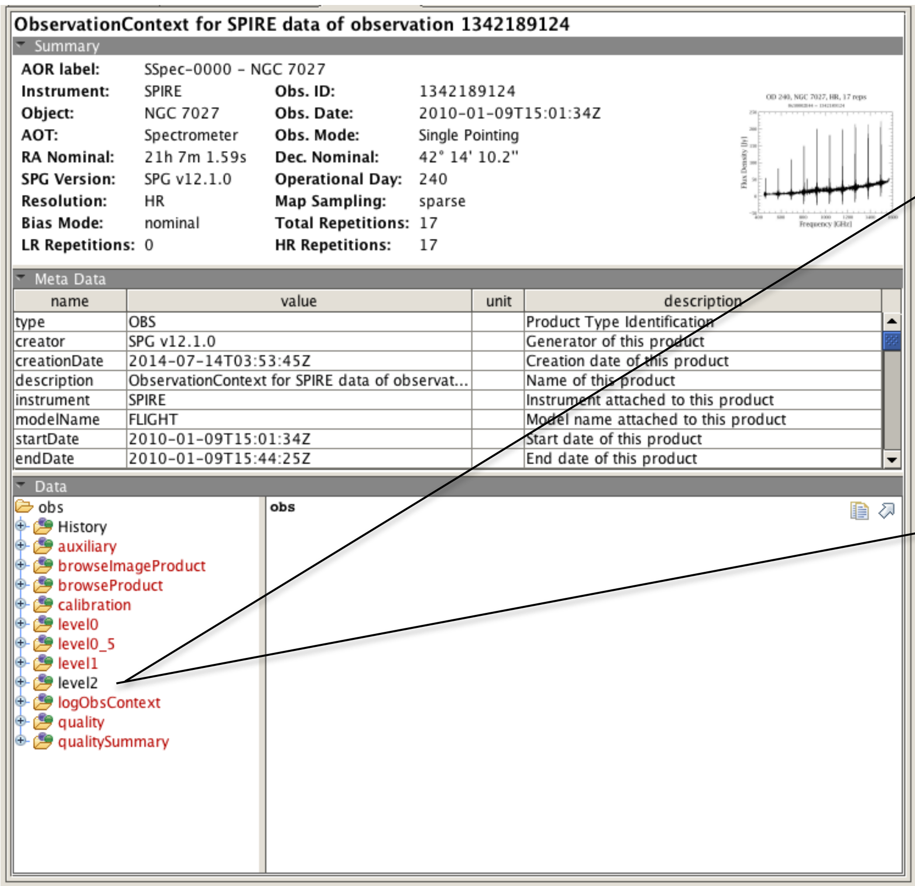
Level 1 products:
(spectra in units of W/m^2/Hz/sr)

- average spectrum (unapodized)
- average spectrum (apodized)
- interferograms

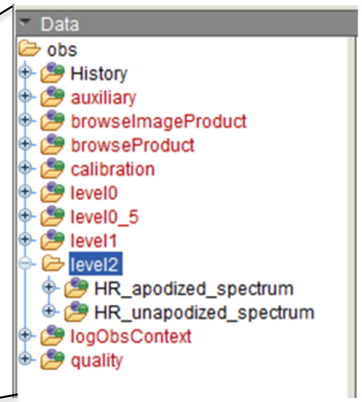
Level-2 products:

- 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.

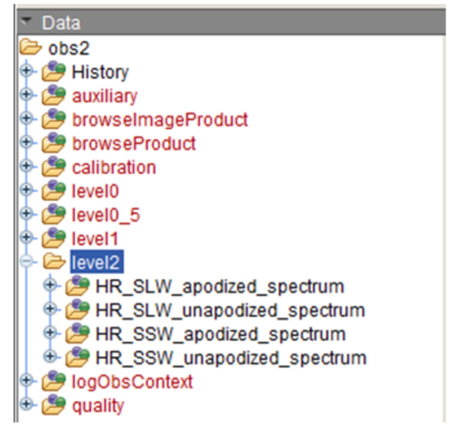
Observation Context



Sparse Mode



Mapping

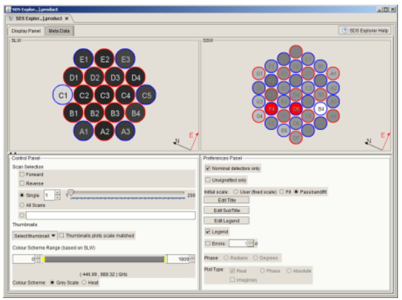


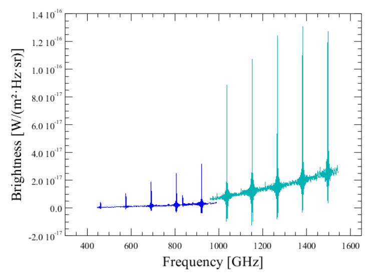
Apodization: spectrum convolve with a smoothing function so that line profiles are approximately Gaussian

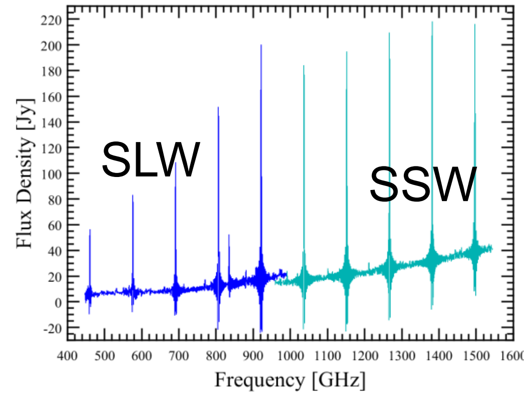
Note that the Observation Context structure will be changed in HIPE v13!!!

Spectrometer Level 2 (and Level 1)

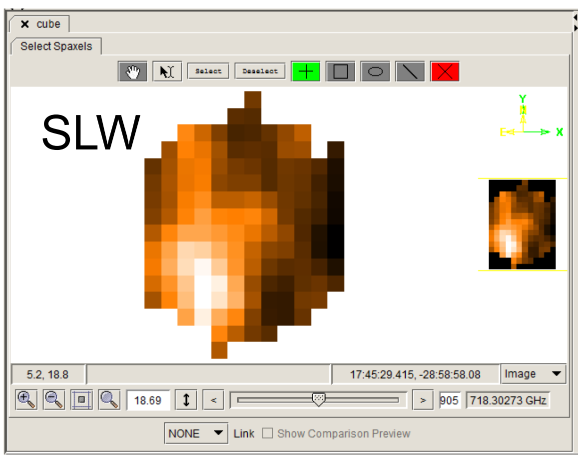
Sparse observations contain spectra calibrated in **W/m2/Hz/sr** (extended) and in **Jy** (point source)

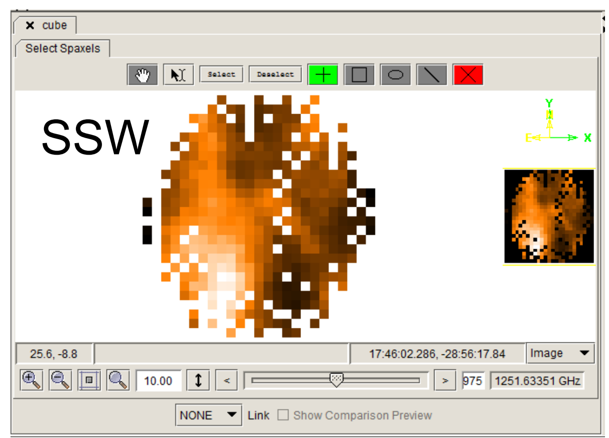






Mapping observations contain spectra and spectral cubes calibrated in **W/m2/Hz/sr** (extended):





Pipeline Calibrations

The Pipeline

(cf. SPIRE DRG Sect. 7.3)

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Level-2 products:
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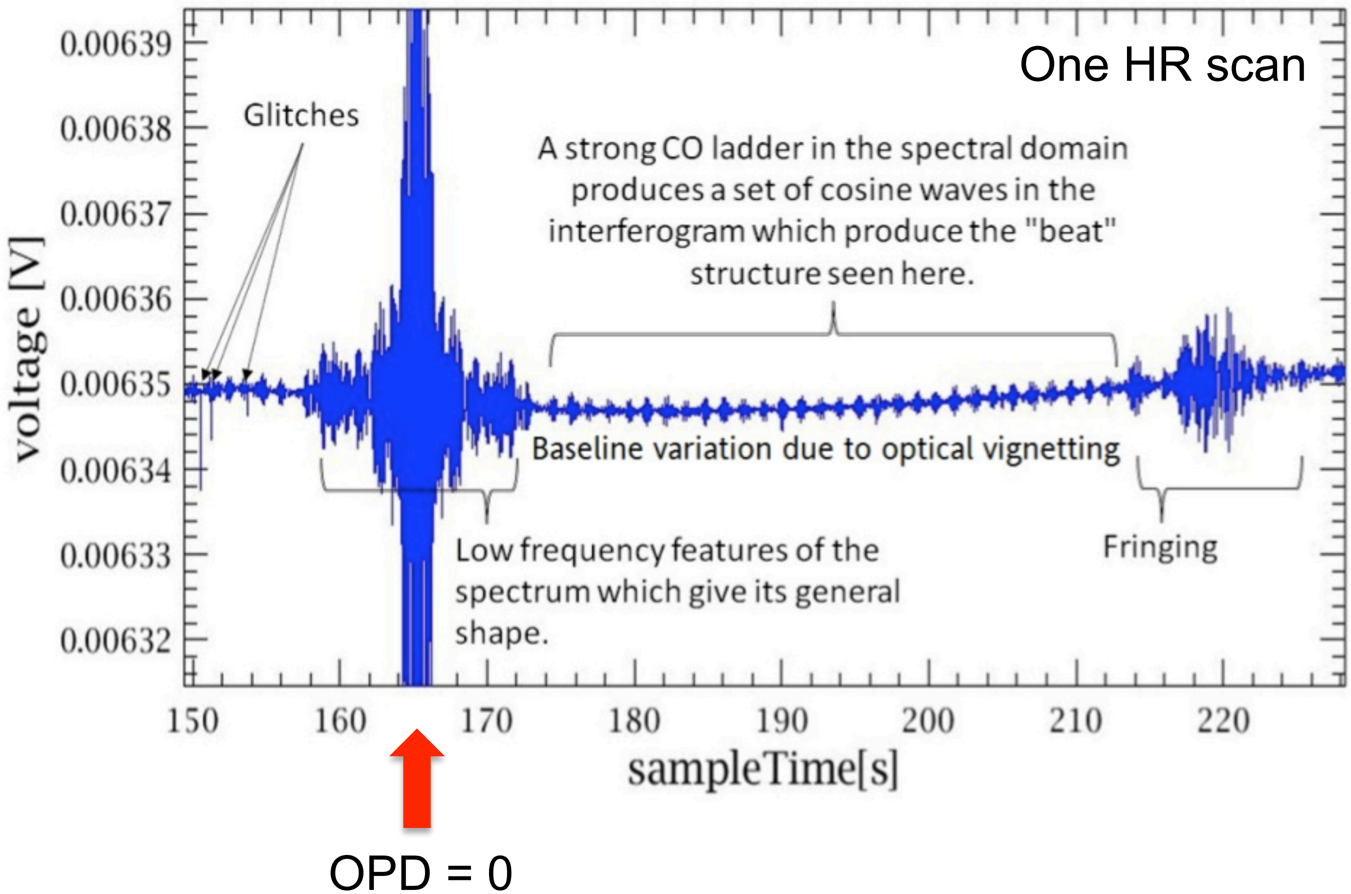
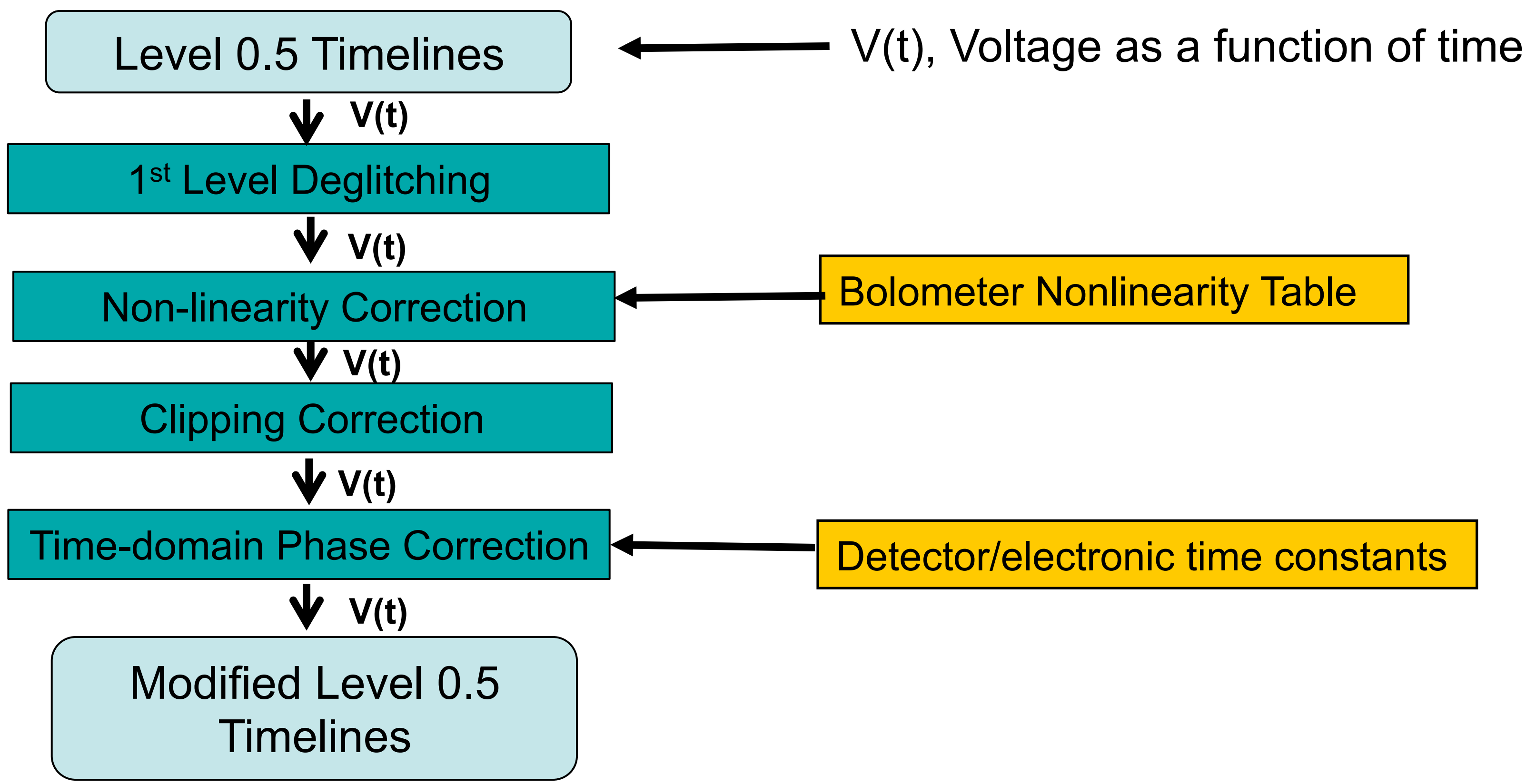
Spectrometer Detector Time Line



Pipeline Step 1: Modify Timelines



(cf. SPIRE DRG Sect. 7.3)

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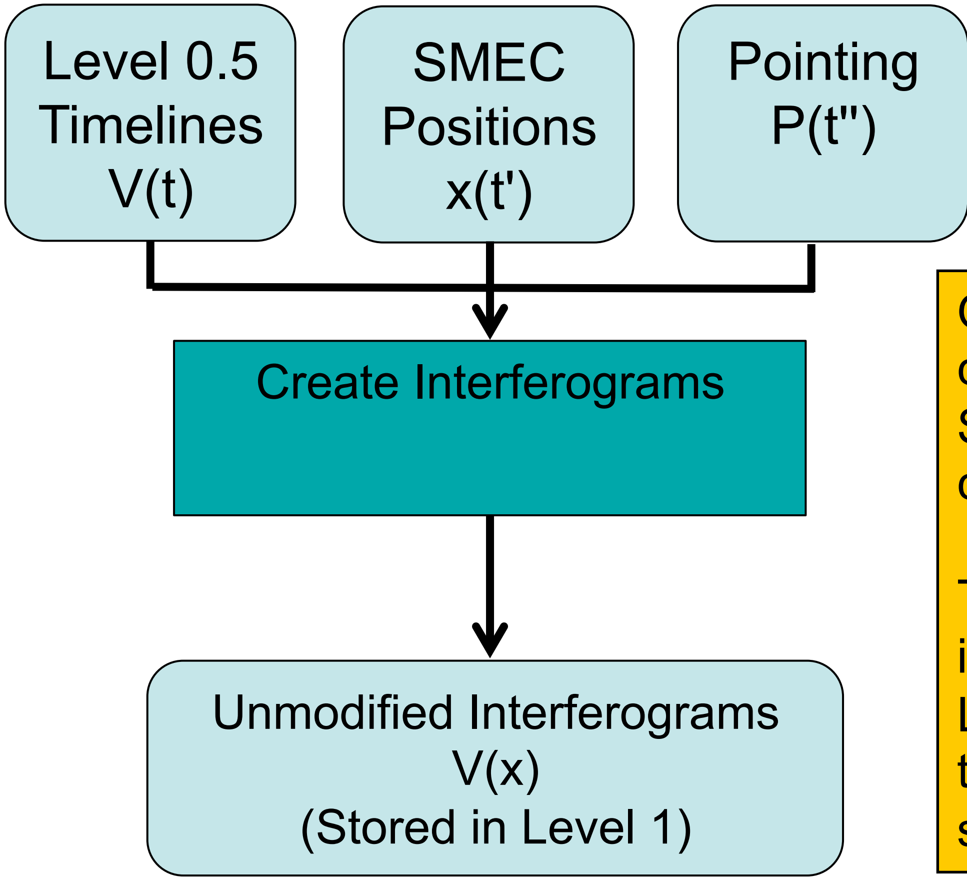
Pipeline Step 2: Create Interferograms

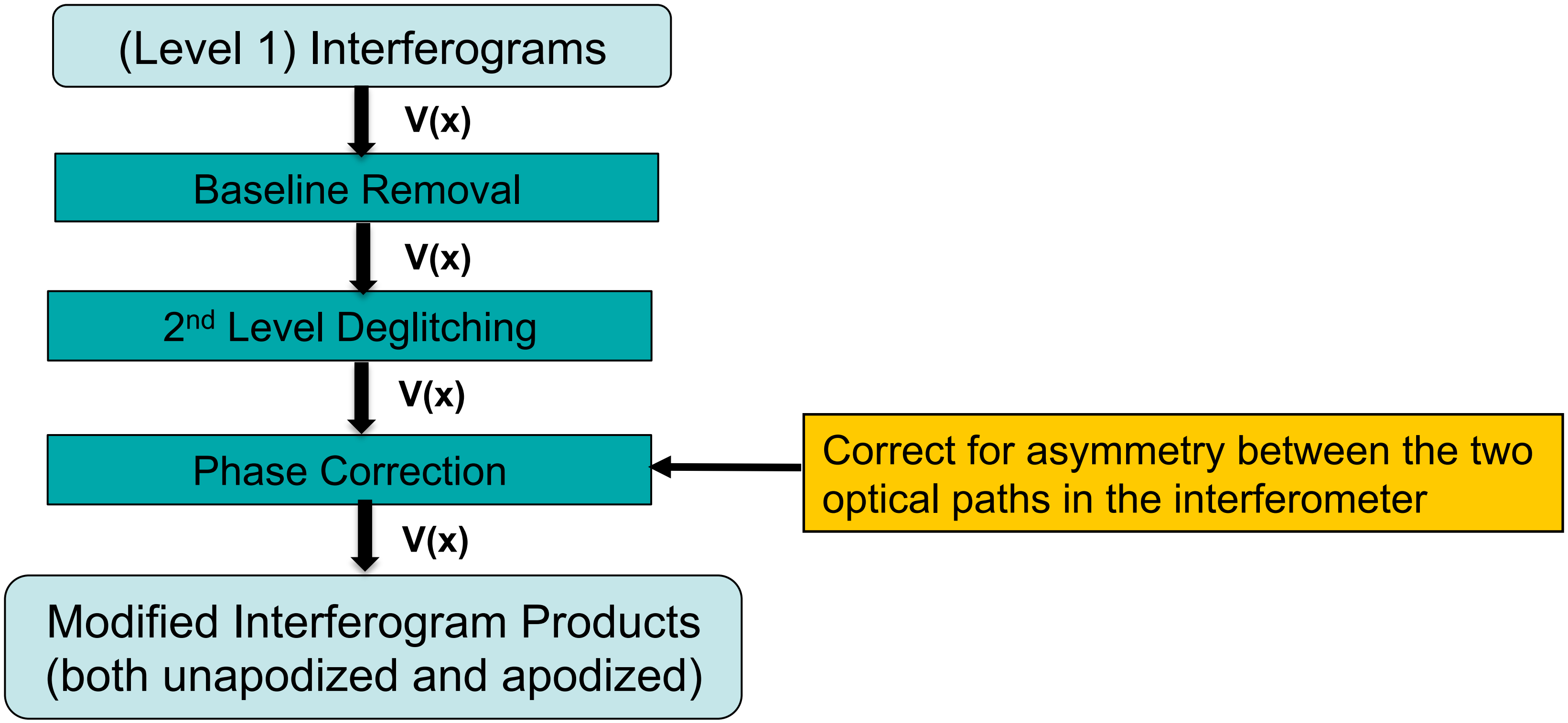


Once time domain processing is complete, the detector signals and SMEC positions can be merged to create interferograms.

The created "unmodified" interferograms are also stored in Level 1 in case users want to do their own interferogram-to-spectrum process.

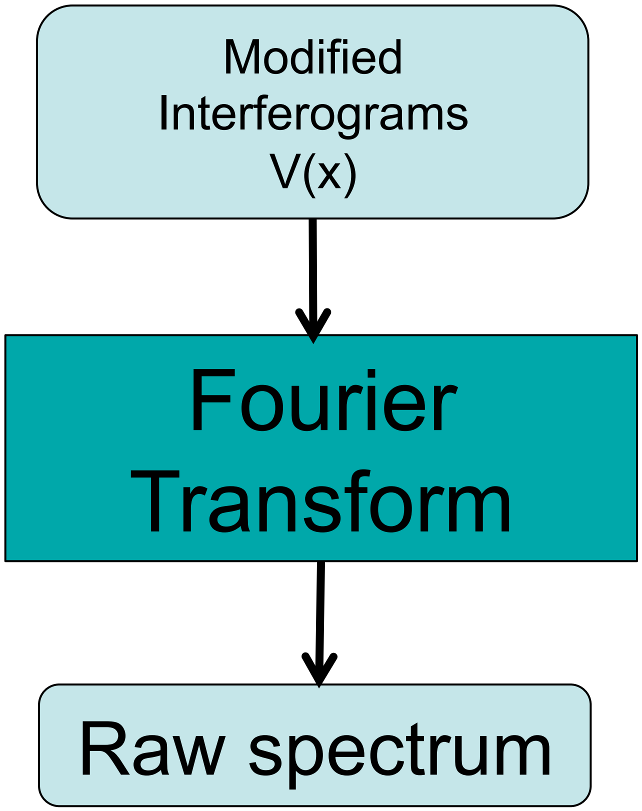
x = The difference between the 2 optical paths in the interferometer

Pipeline Step 3: Modify Interferograms



(cf. SPIRE DRG Sect. 7.3)

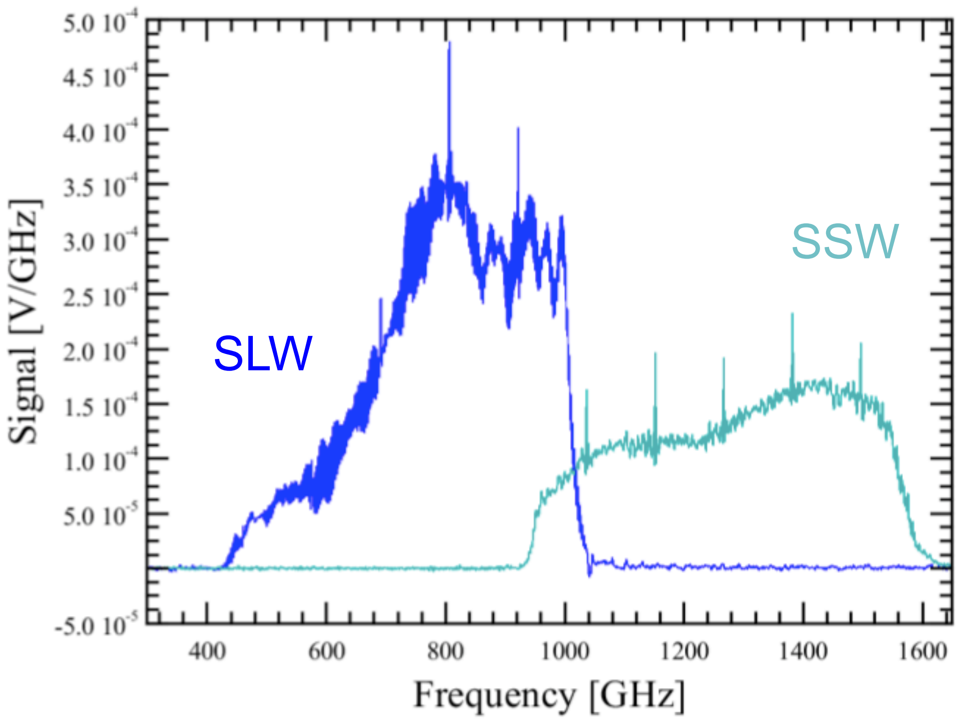
Pipeline Step 4: Fourier Transform



Apply the Fourier Transform to each interferogram to create a set of spectra for each spectrometer detector. The spectra are in units of V/GHz, not yet flux calibrated.

(cf. SPIRE DRG Sect. 7.3)

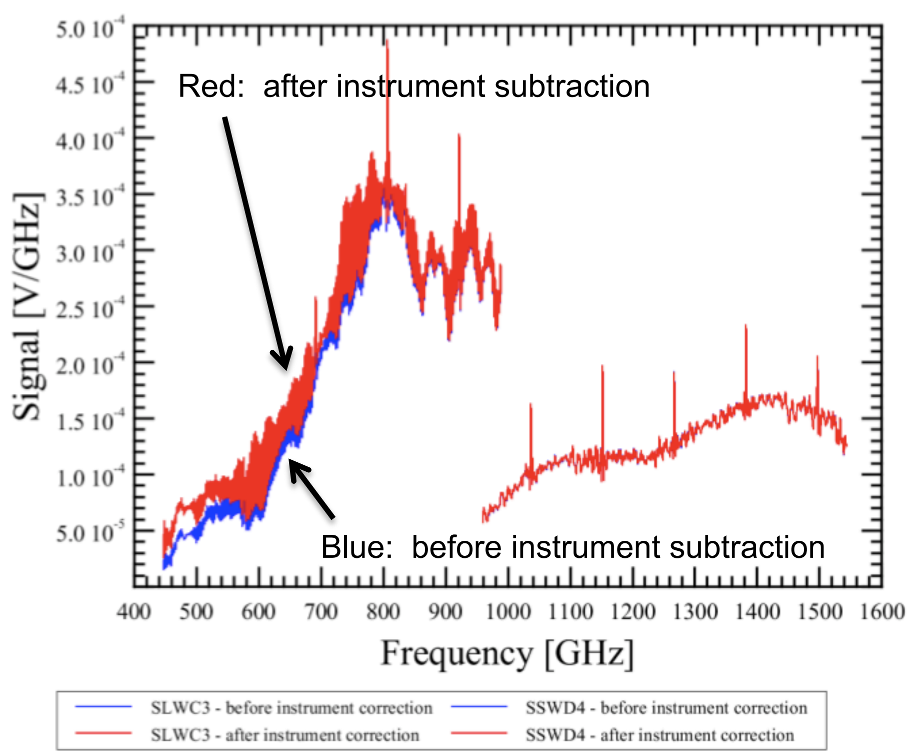
What is in the Raw Spectrum?



$$V_{Measured}(\sigma) = V_{Source}(\sigma) + V_{Telescope}(\sigma) + V_{Instrument}(\sigma)$$

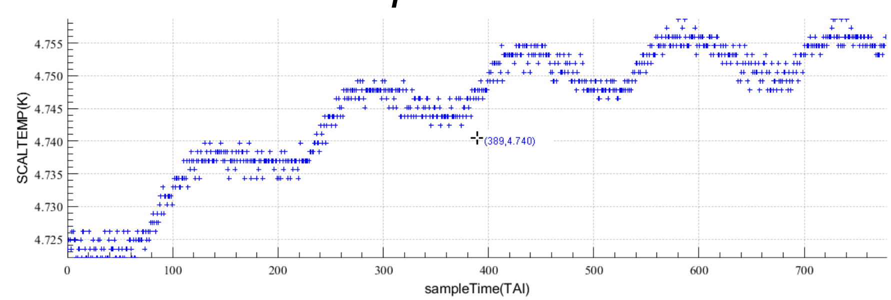
@80K @4-5K

Instrument Background Emission



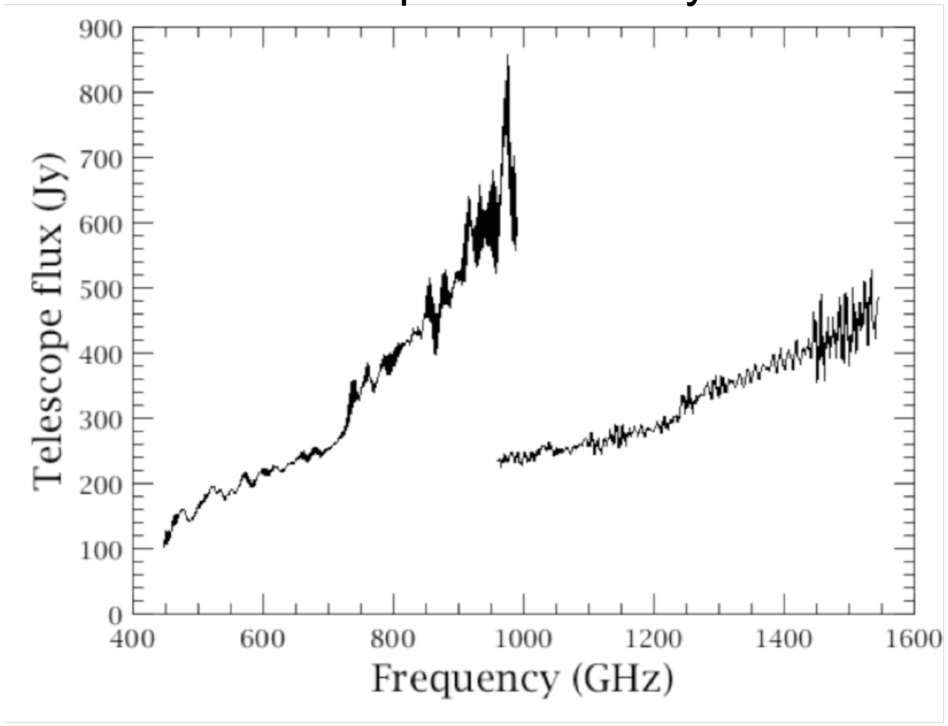
At about 4-5K, instrument emission is only significant at the long wavelength end of SLW.

Instrument temperature varies with time:



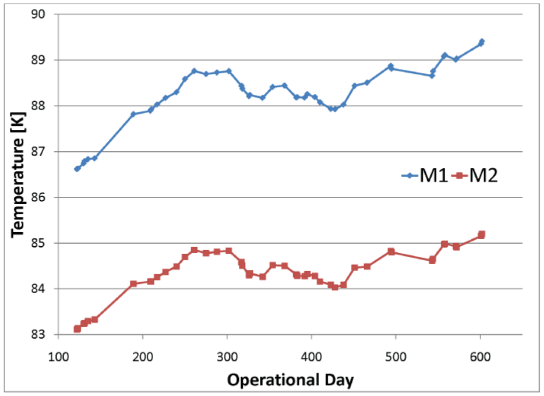
Telescope Background Emission

Point source-equivalent telescope model in Jy:

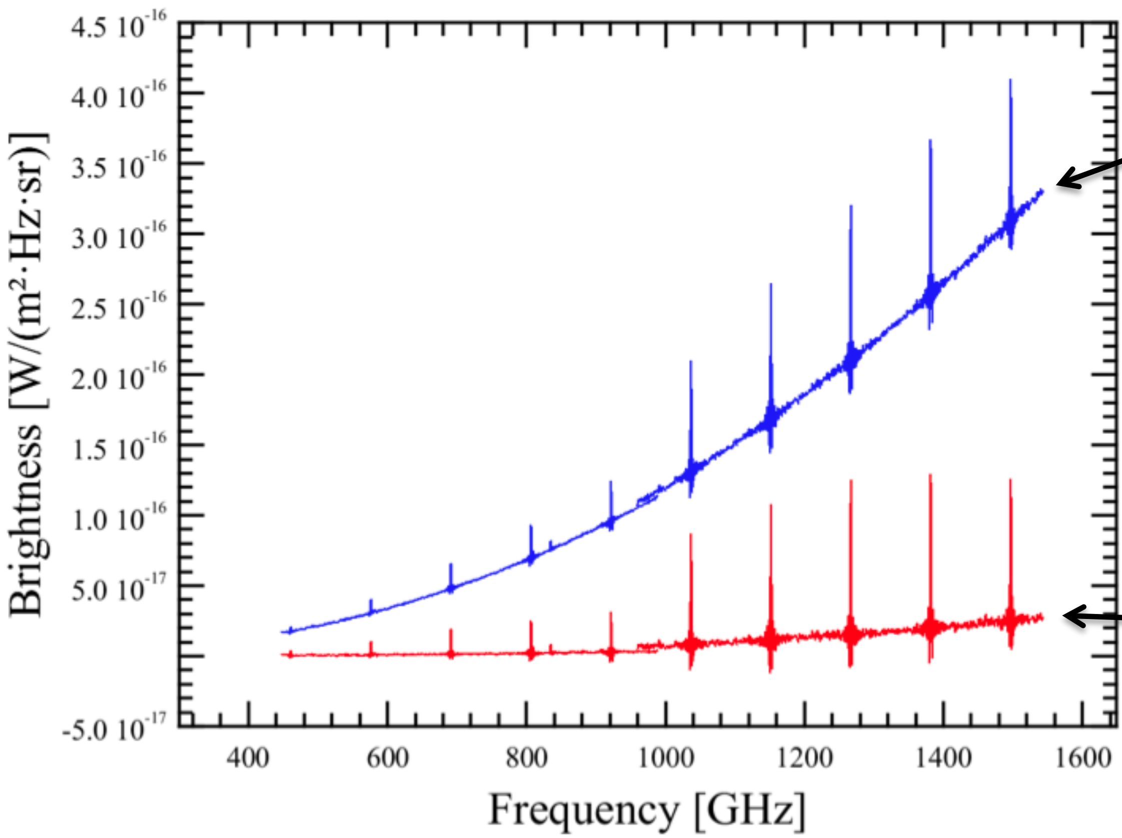


Your observations are most likely dominated by the telescope emission!

Telescope temperatures vary with time:



Telescope Background Emission: A Typical Case



Telescope + Source

Telescope model is good to ~ 0.1%, or ~0.5 Jy (as of HIPE 11)

Source only

Flux Calibration Scheme

Level-1 spectrum

Brightness in W/m²/Hz/sr
assumes extended emission

$$I = \frac{1}{R_{tel}} [S - R_{inst} M_{inst}] - M_{tel}$$

Telescope RSRF

Raw spectrum

Instrument model and RSRF important for SLW (T ~ 4-5 K)

Telescope model

Level-2 spectrum

Flux Density in Jy
assumes point-like emission

$$f = C_{point} \, I$$

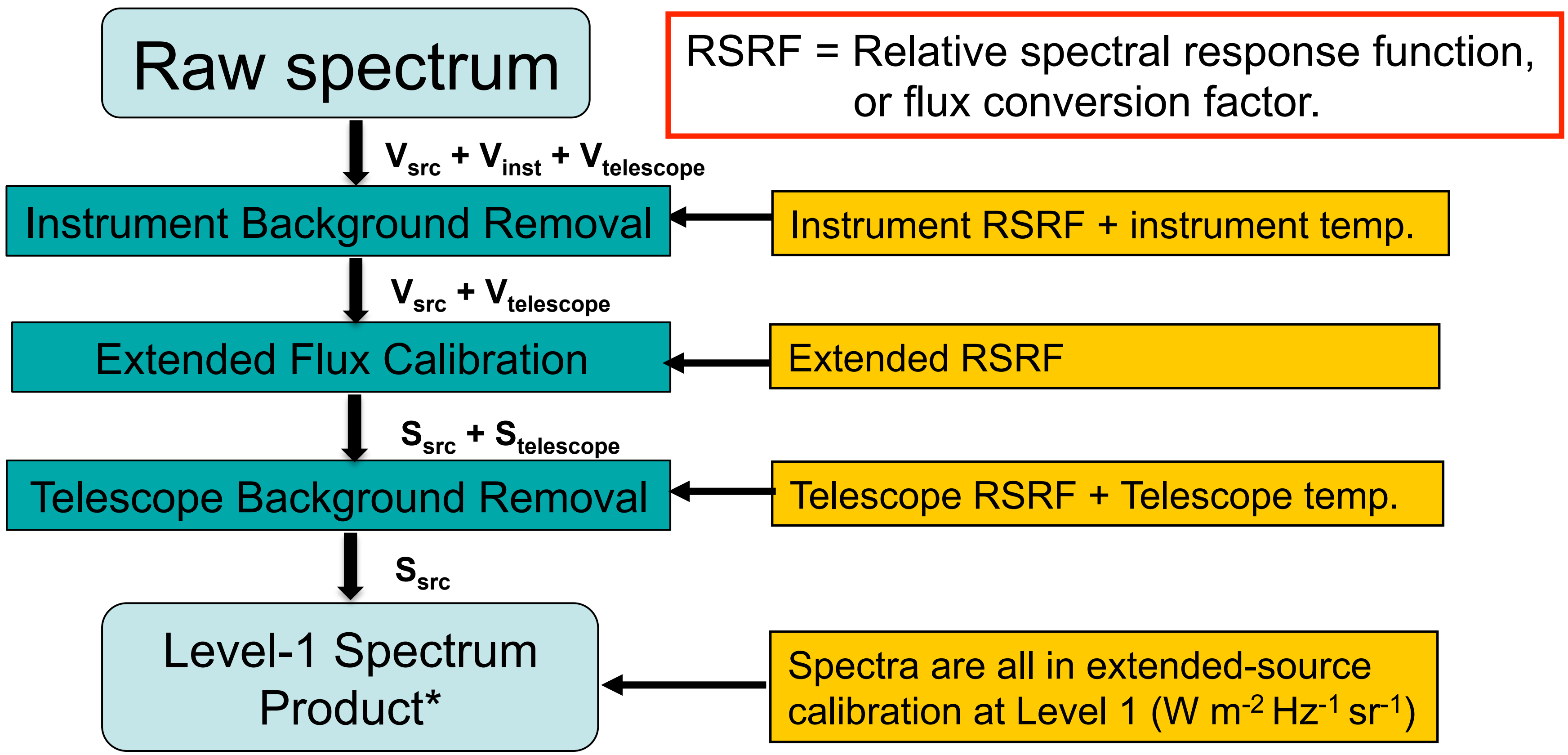
Point source conversion factor (= R_{tel}/R_{point})

RSRFs are empirically derived by observing a source with a known spectrum and dividing by a model:

R_{tel} : *Dark Sky (= the telescope)*
R_{point} : *Uranus*

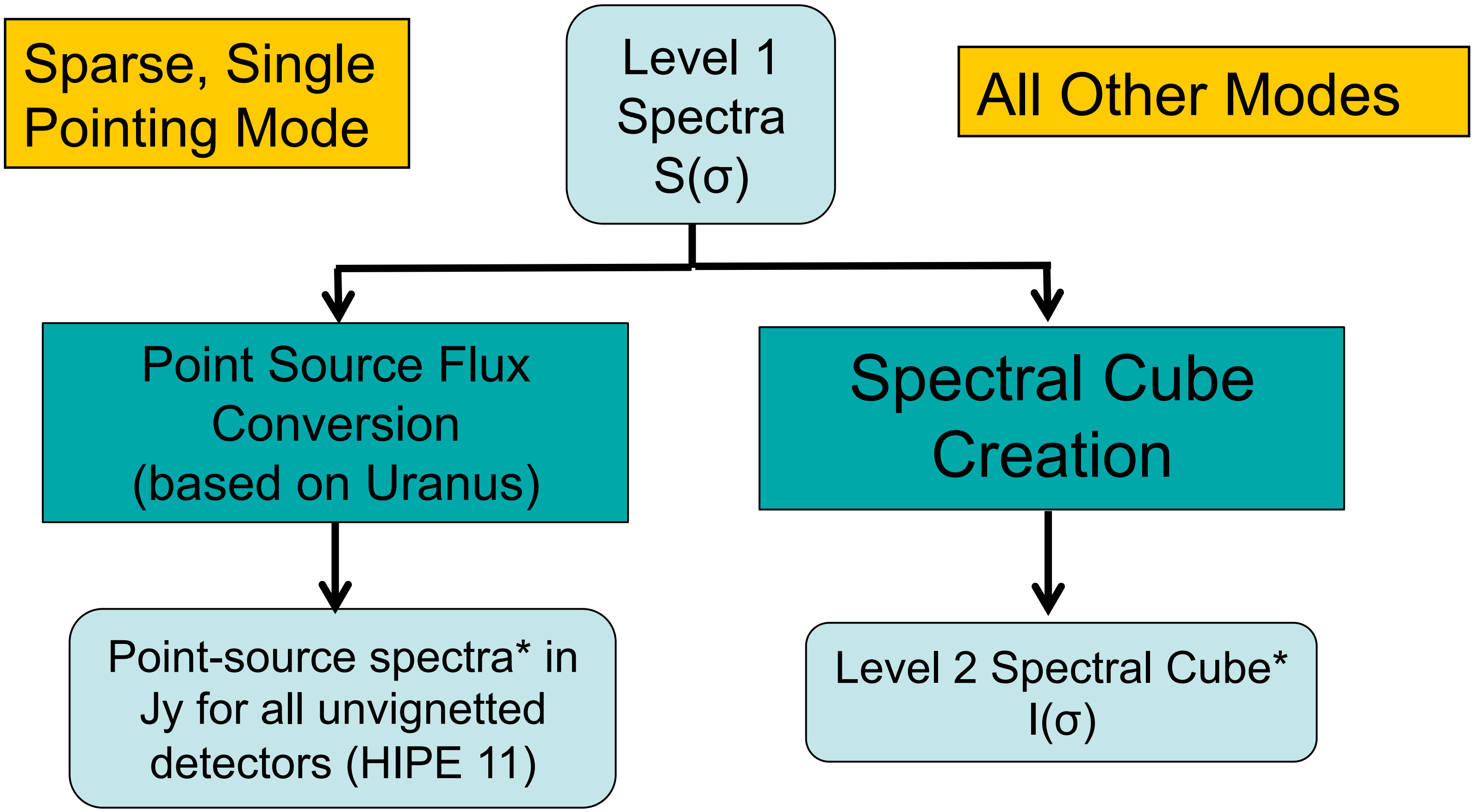
(See *Swinyard et al. 2014, MNRAS, 440, 3658*)

Pipeline Step 5: Modify Spectra



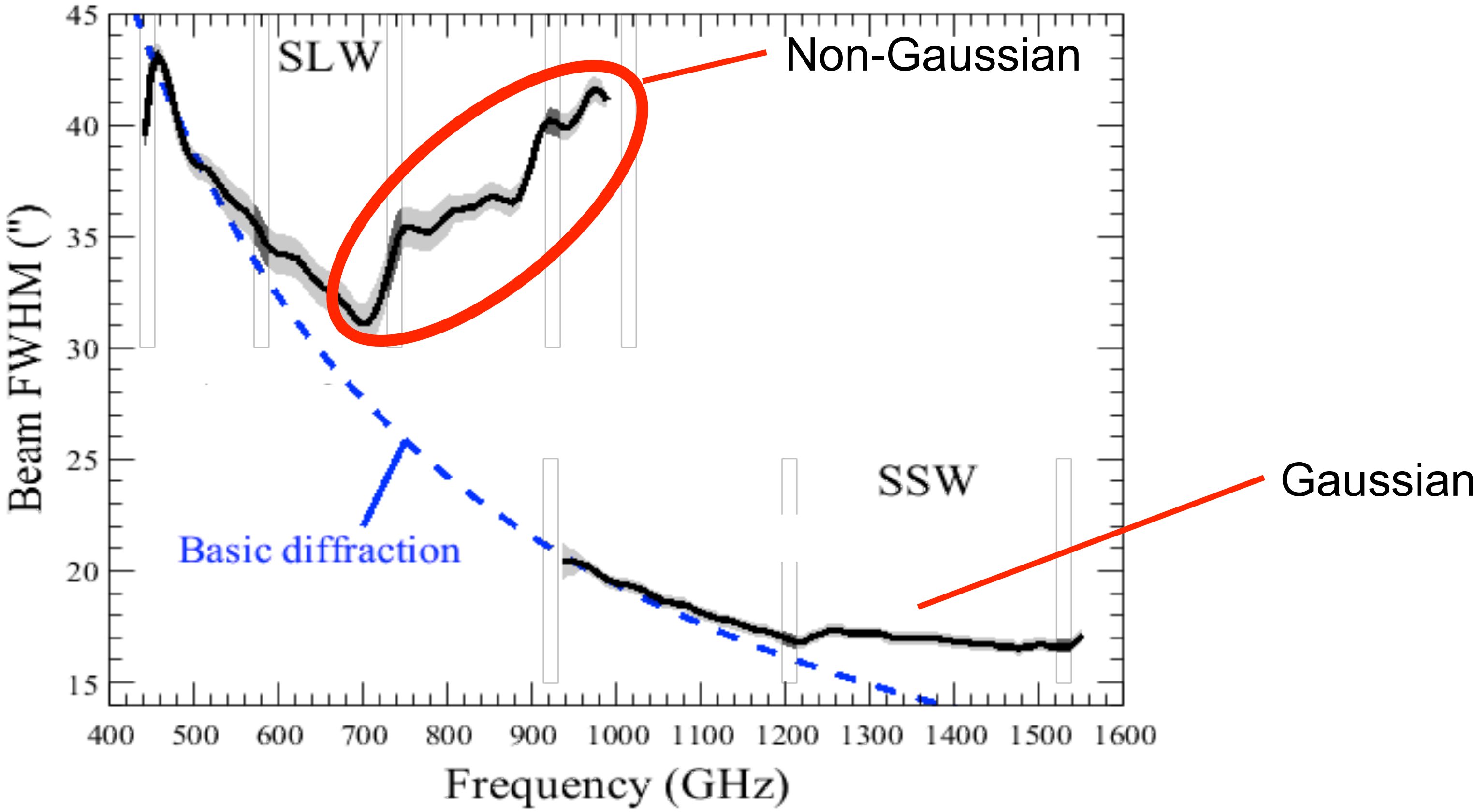
* Both unapodized and apodized spectra [using the default apodization func. NB(1.5)]

Pipeline Step 6: Create Level-2 Products



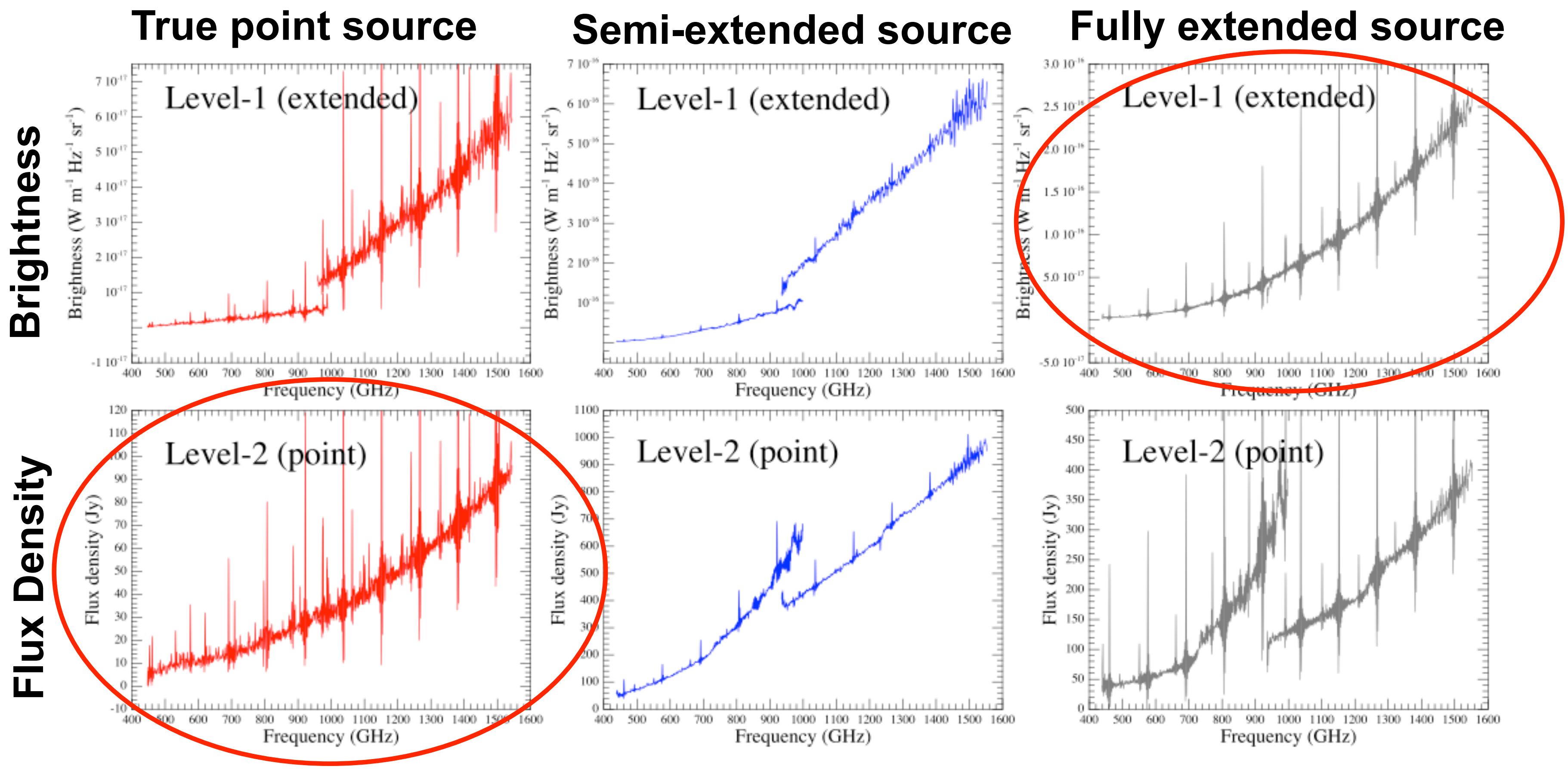
* Both unapodized and apodized data [using the default apodization func. NB(1.5)]

FTS beam profile



See [*Makiwa et al. 2013, Applied Optics, 52, 3864*]()

Extended vs. Point Source Flux Calibration



Both true point-source and fully extended-source cases are accurately Calibrated in the pipeline, but not so for the cases in between!

Calibration Uncertainties (HIPE v11 onwards)

- **Point sources observed on the centre detectors** (SSWD4 and SLWC3):
  - Absolute uncertainty **±6%**, with the following contributions:
    1. Systematic uncertainty in Uranus model: ±3%
    2. Statistical repeatability (pointing corrected): ±1%
    3. Uncertainties in the instrument and telescope model - additive continuum offset error of 0.4 Jy for SLW and 0.3 Jy for SSW
    4. The effect of the *Herschel* APE.
- **Sparse observations of significantly extended sources:**
  - Absolute uncertainty **±7%,** with the following contributions:
    1. Uncertainty comparing telescope and Uranus calibration: ±3%
    2. Systematic uncertainty in Uranus model: ±3%
    3. Systematic reproducibility of telescope model: 0.06%;
    4. Statistical repeatability estimated at ±1%
    5. Additive continuum offset of 3.4×10^{-20} W/m^2/Hz/sr for SLW and 1.1×10^{-19} W/m^2/Hz/sr for SSW.
- **Mapping mode:**
  - Overall repeatability **±7%**

- **Wavelength calibration:**
  - 5 - 7 km/s for line velocity.

(See *Swinyard et al. 2014, MNRAS, 440, 3658*)