



# SPIRE Spectrometer Products and Data Processing Pipeline

Nanyao Lu  
NHSC/IPAC

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





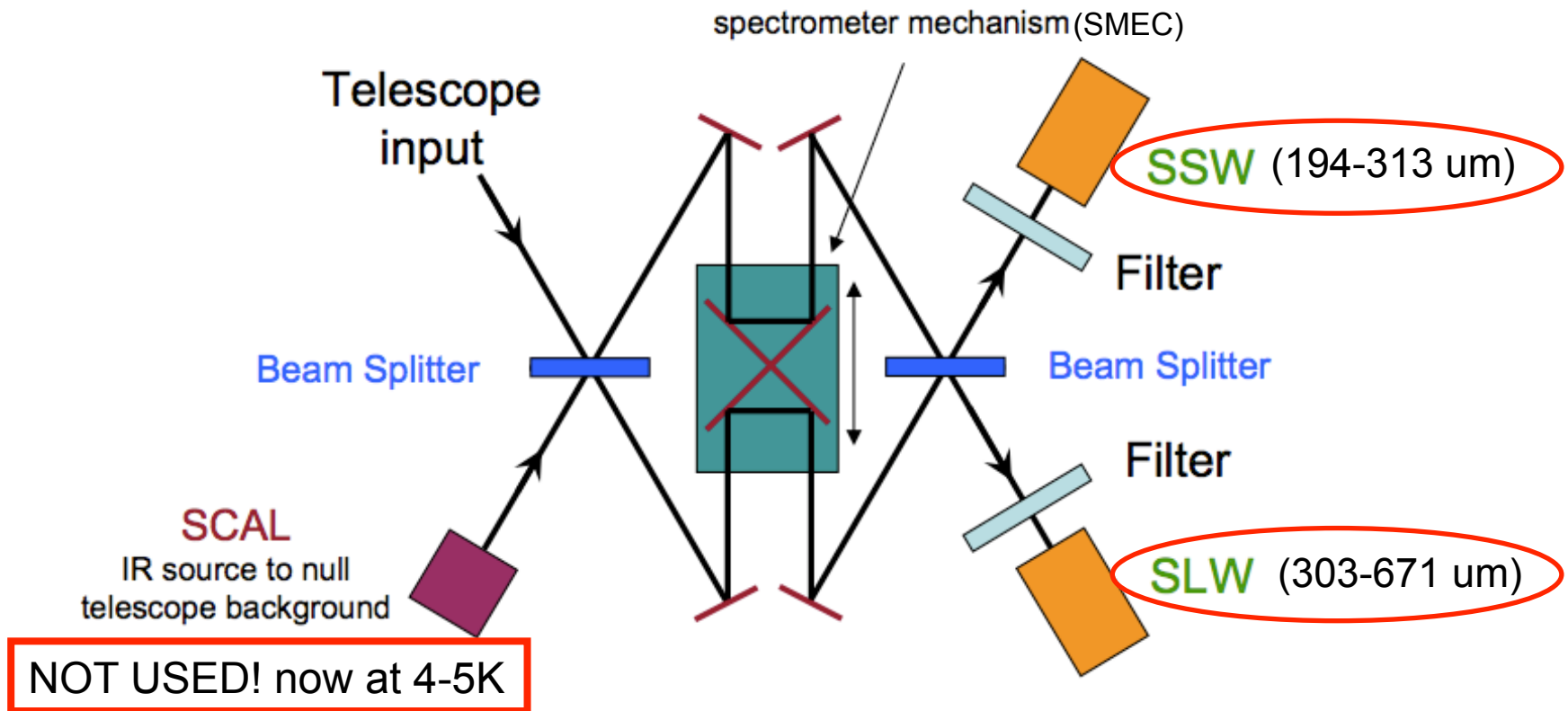
# Outline

- 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 accuracies can you expect?



# SPIRE Spectrometer

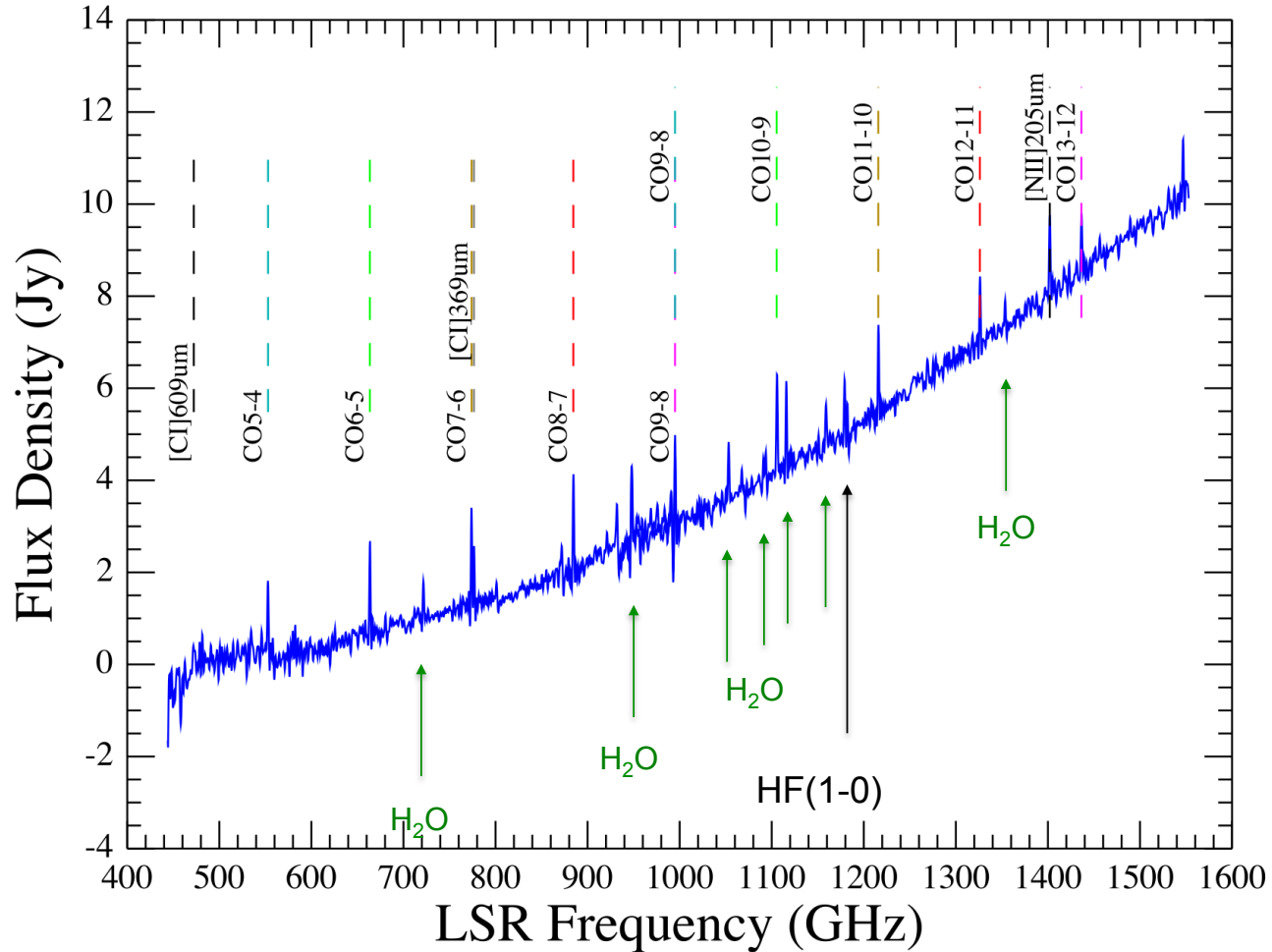
Fourier Transform Spectrometer (FTS): The entire spectral coverage of 194-671 micron is observed in one go!





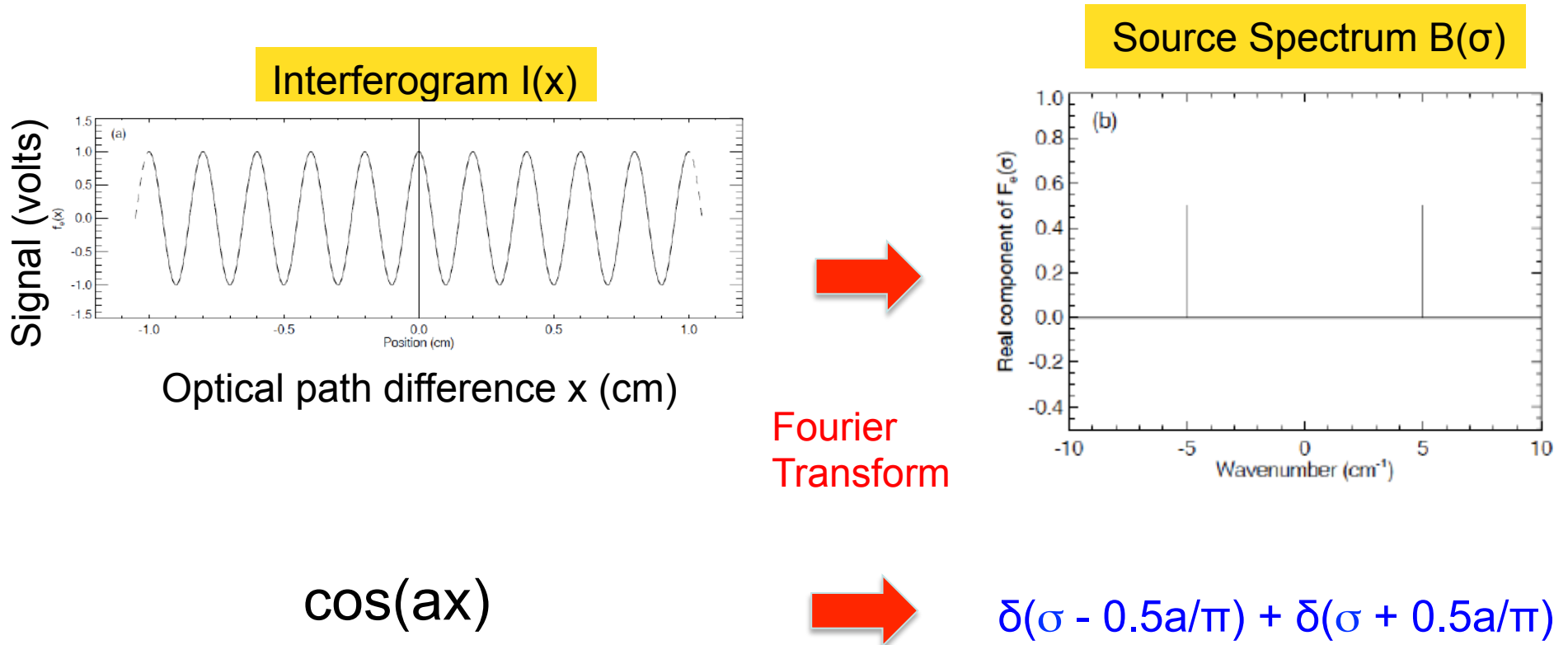
# Probing Molecular, Atomic and Ionized Gases

Mrk231



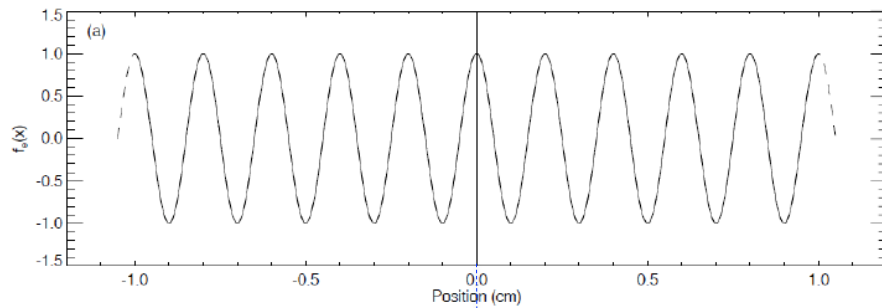


# Fourier Transform: Interferogram to Spectrum

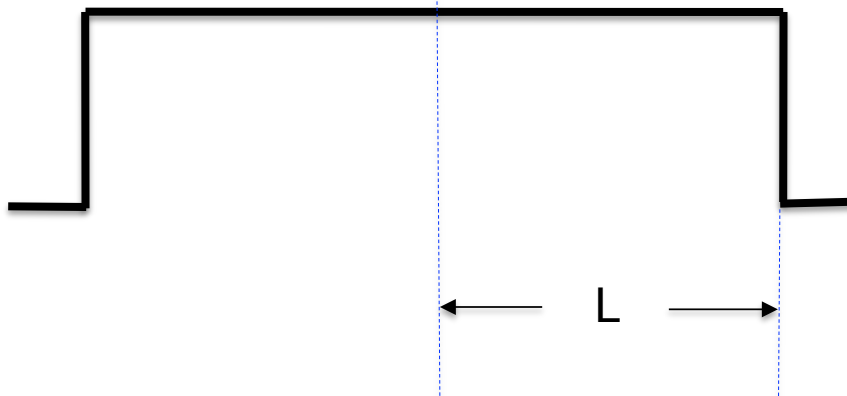




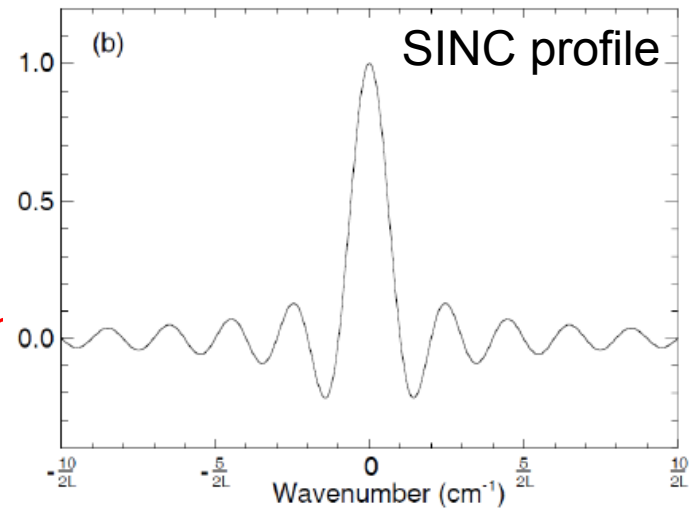
# Real World: Finite Interferogram



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



# 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

**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](#)
  - [7.3.3. Reprocessing SPIRE Level-0.5 products](#)
  - [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](#)

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







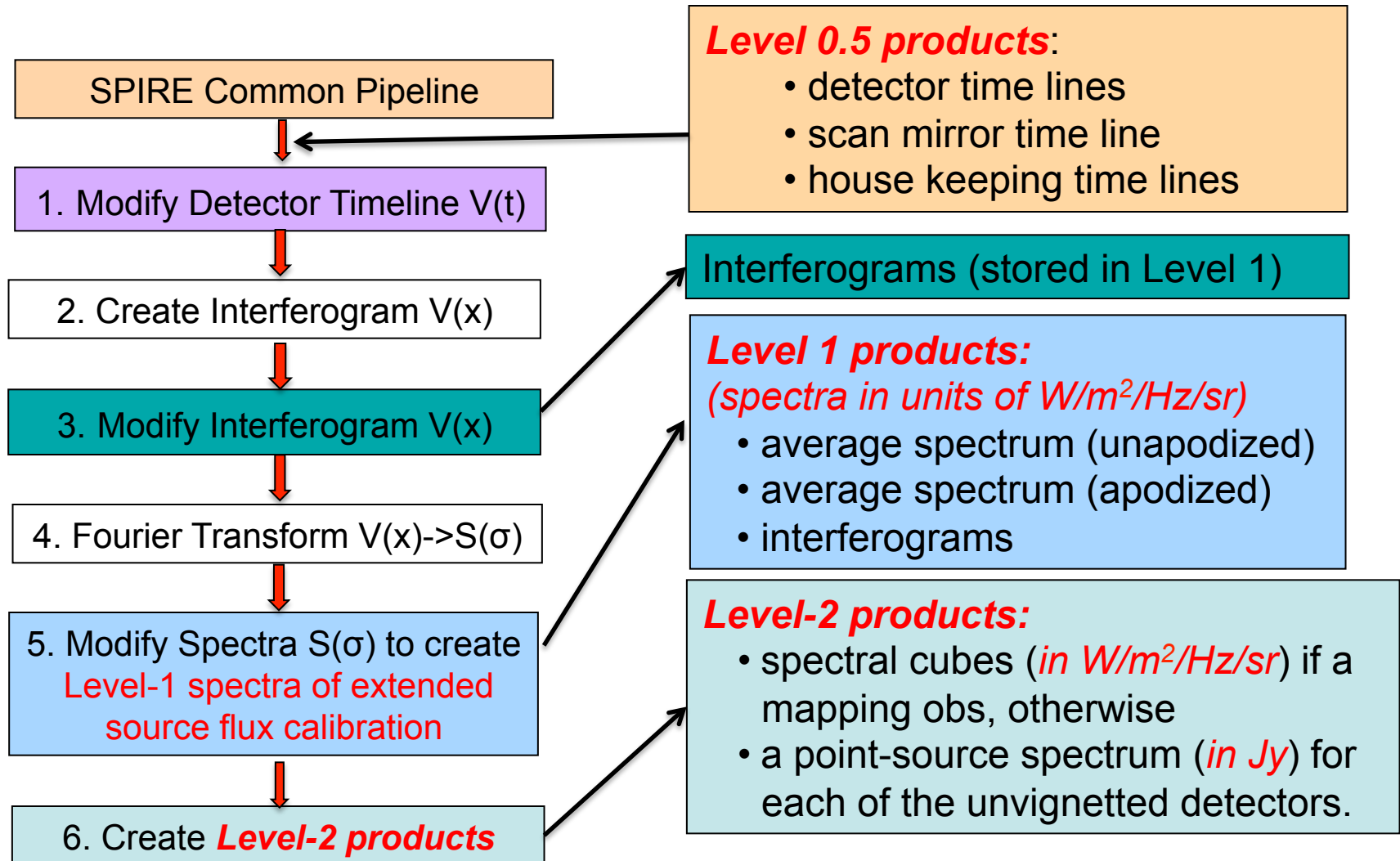
# Pipeline Data Products





# The Pipeline

(cf. SPIRE DRG Sect. 7.3)





# Observation Context

**ObservationContext for SPIRE data of observation 1342189124**

Summary

AOR label: SSpec-0000 - NGC 7027  
 Instrument: SPIRE    Obs. ID: 1342189124  
 Object: NGC 7027    Obs. Date: 2010-01-09T15:01:34Z  
 AOT: Spectrometer    Obs. Mode: Single Pointing  
 RA Nominal: 21h 7m 1.59s    Dec. Nominal: 42° 14' 10.2"  
 SPG Version: SPG v12.1.0    Operational Day: 240  
 Resolution: HR    Map Sampling: sparse  
 Bias Mode: nominal    Total Repetitions: 17  
 LR Repetitions: 0    HR Repetitions: 17

Meta Data

name	value	unit	description
type	OBS		Product Type Identification
creator	SPG v12.1.0		Generator of this product
creationDate	2014-07-14T03:53:45Z		Creation date of this product
description	ObservationContext for SPIRE data of observat...		Name of this product
instrument	SPIRE		Instrument attached to this product
modelName	FLIGHT		Model name attached to this product
startDate	2010-01-09T15:01:34Z		Start date of this product
endDate	2010-01-09T15:44:25Z		End date of this product

Data

- obs
- History
- auxiliary
- browseImageProduct
- browseProduct
- calibration
- level0
- level0\_5
- level1
- level2
- logObsContext
- quality
- qualitySummary

Sparse Mode

Mapping

Data

- obs
- History
- auxiliary
- browseImageProduct
- browseProduct
- calibration
- level0
- level0\_5
- level1
- level2
- HR\_apodized\_spectrum
- HR\_unapodized\_spectrum
- logObsContext
- quality

Data

- obs2
- History
- auxiliary
- browseImageProduct
- browseProduct
- calibration
- level0
- level0\_5
- level1
- level2
- HR\_SLW\_apodized\_spectrum
- HR\_SLW\_unapodized\_spectrum
- HR\_SSW\_apodized\_spectrum
- HR\_SSW\_unapodized\_spectrum
- logObsContext
- quality

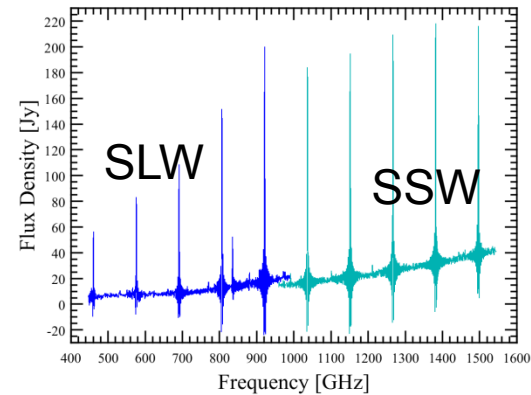
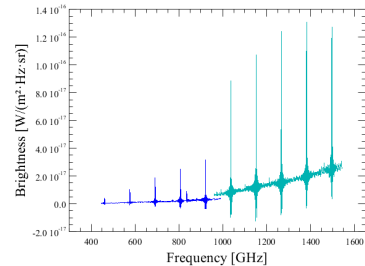
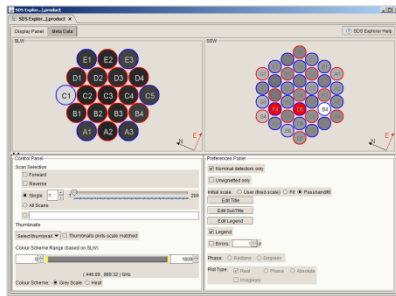
Apodization: spectrum convolve with a smoothing function so that line profiles are approximately Gaussian

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

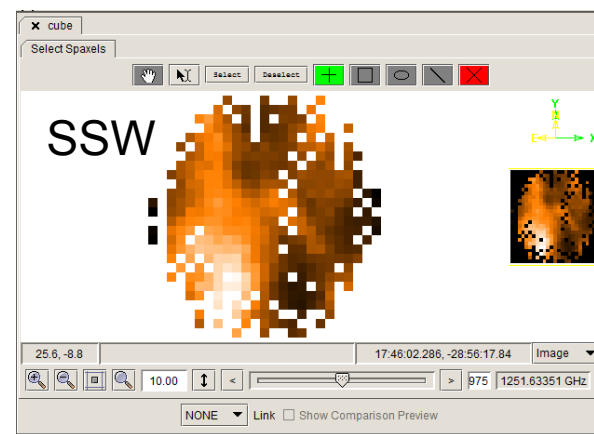
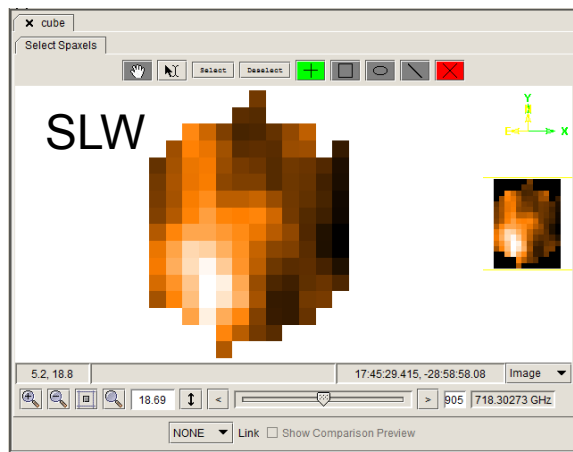


# Spectrometer Level 2 (and Level 1)

**Sparse** observations contain spectra calibrated in **W/m<sup>2</sup>/Hz/sr** (extended) and in **Jy** (point source)



**Mapping** observations contain spectra and spectral cubes calibrated in **W/m<sup>2</sup>/Hz/sr** (extended):





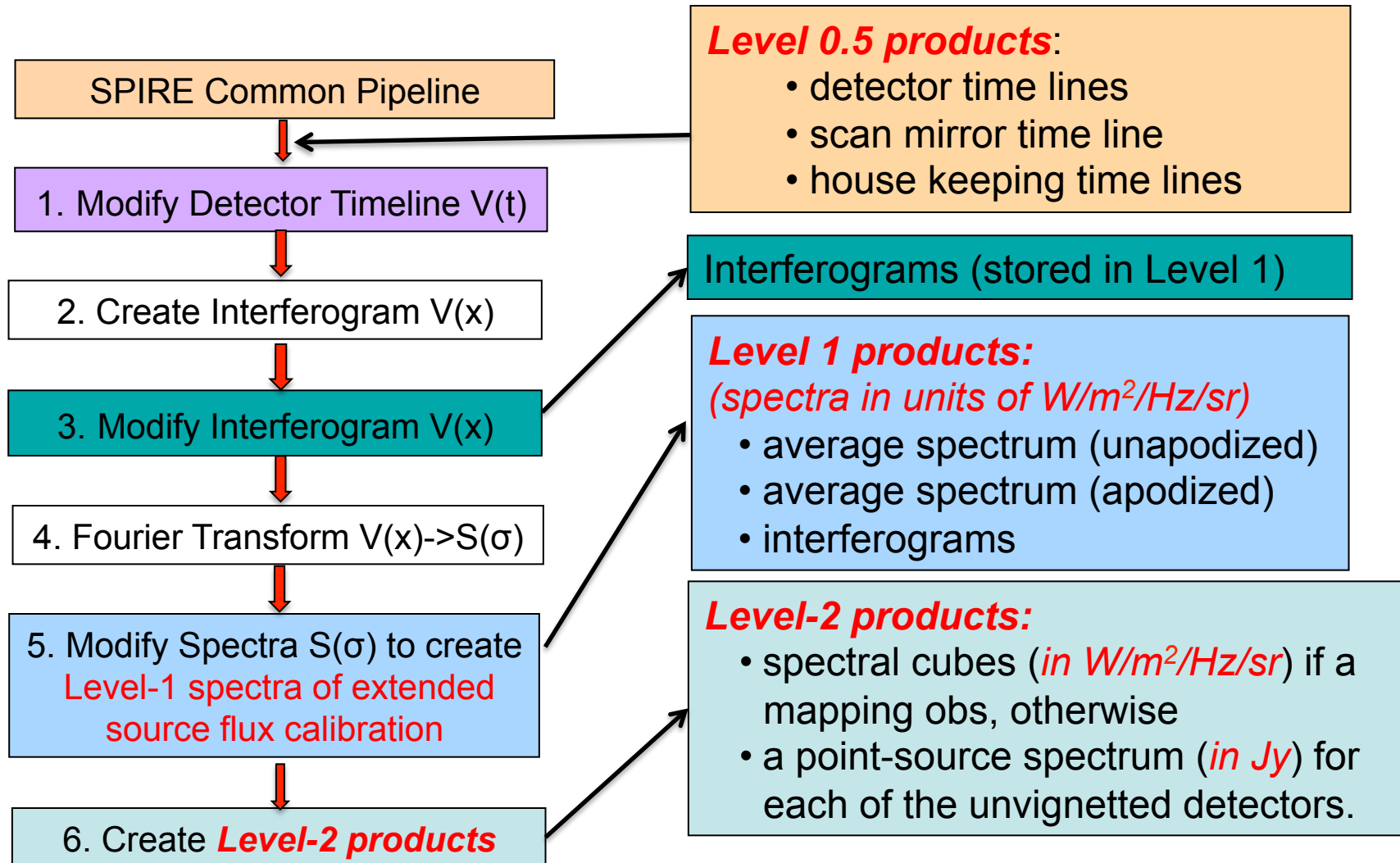
# Pipeline Calibrations





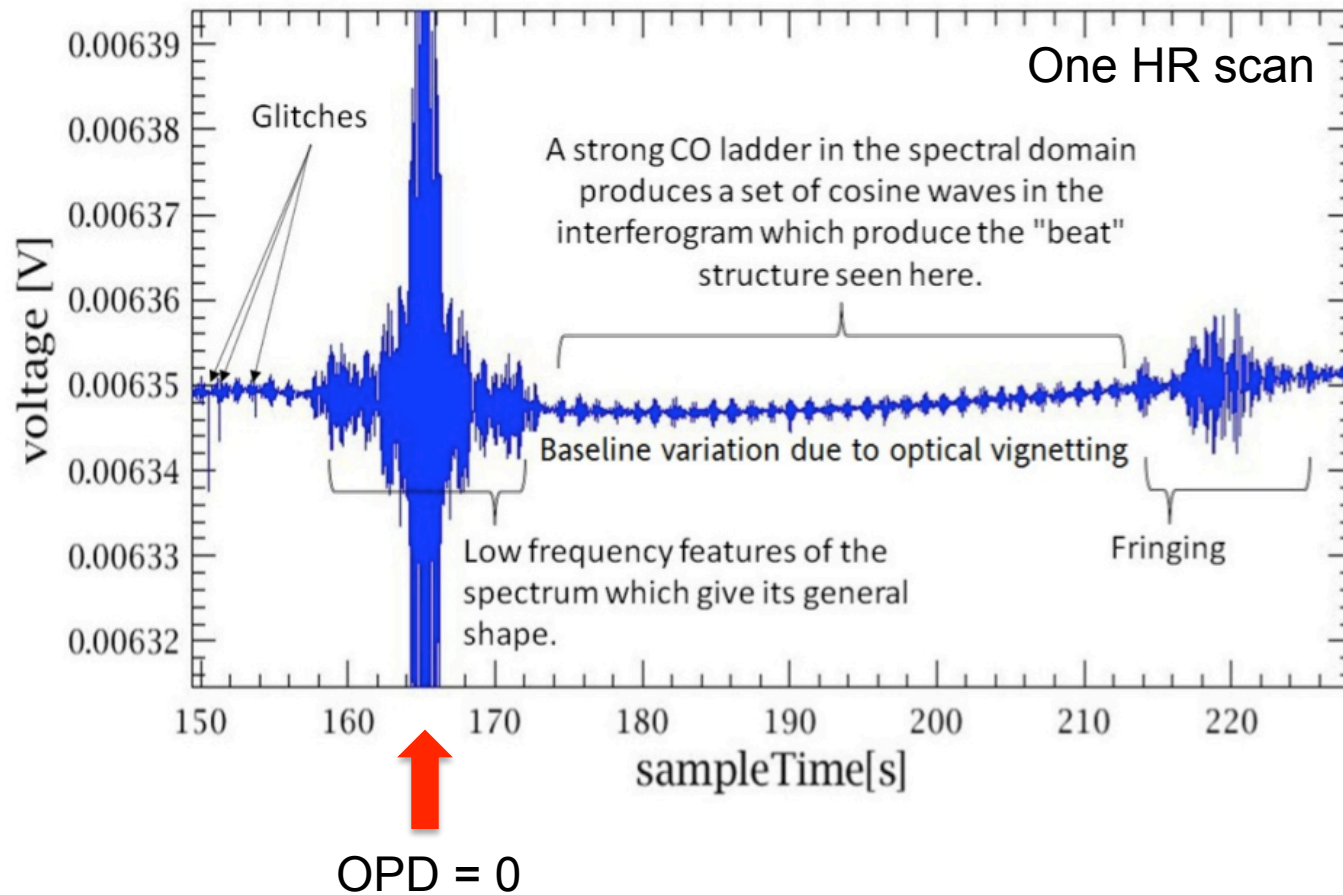
# The Pipeline

(cf. SPIRE DRG Sect. 7.3)



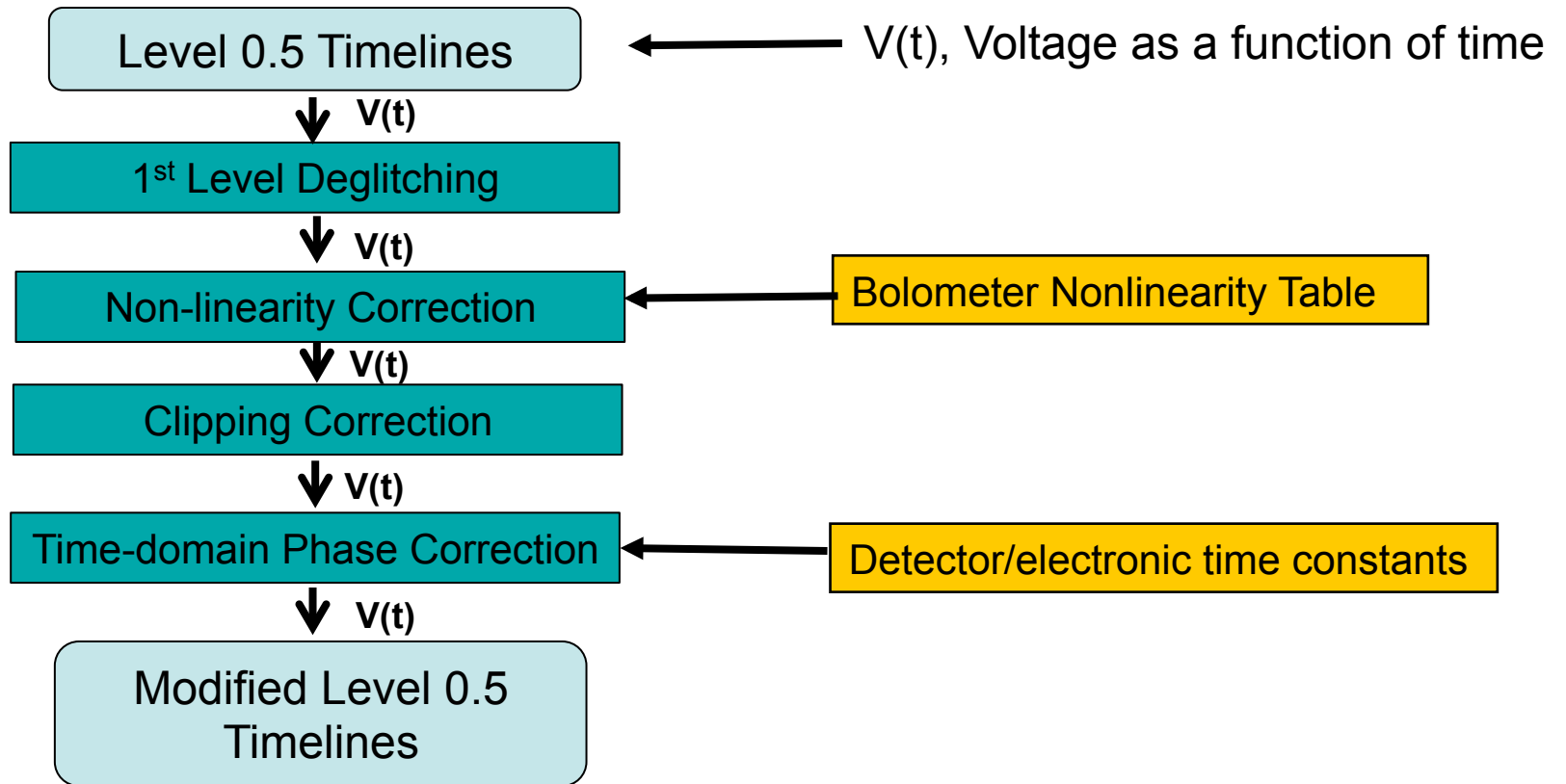


# Spectrometer Detector Time Line





## Pipeline Step 1: Modify Timelines



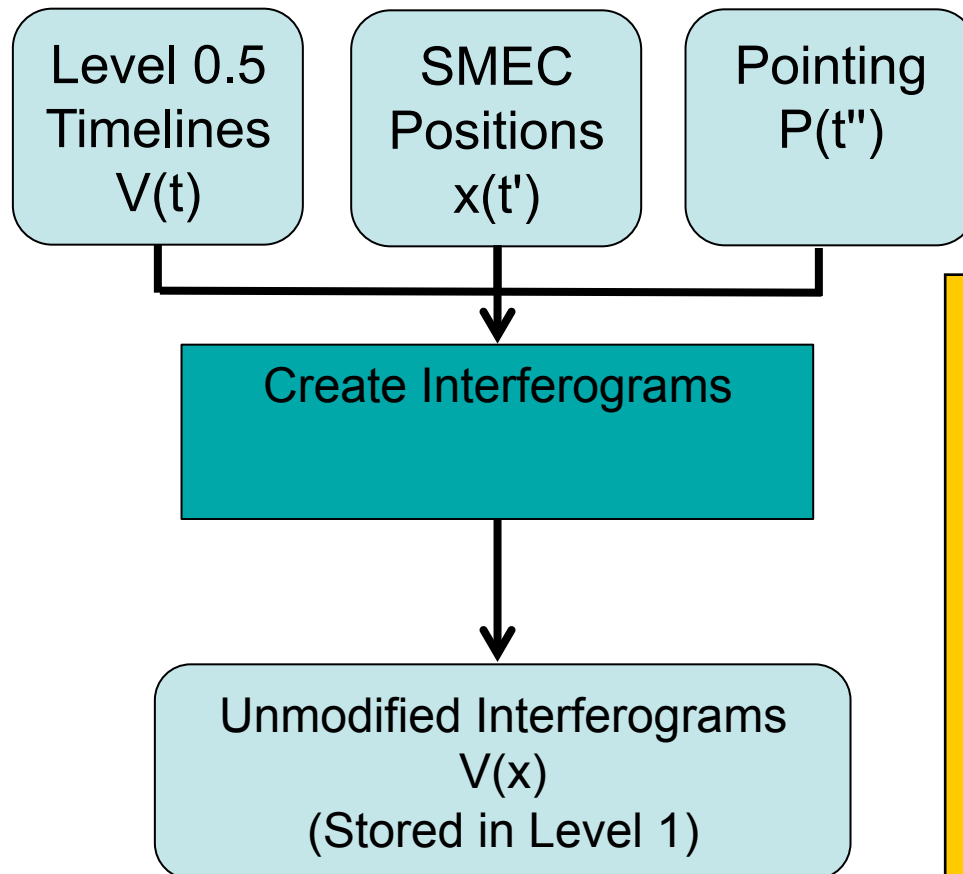
(cf. SPIRE DRG Sect. 7.3)





(cf. SPIRE DRG Sect. 7.3)

## Pipeline Step 2: Create Interferograms



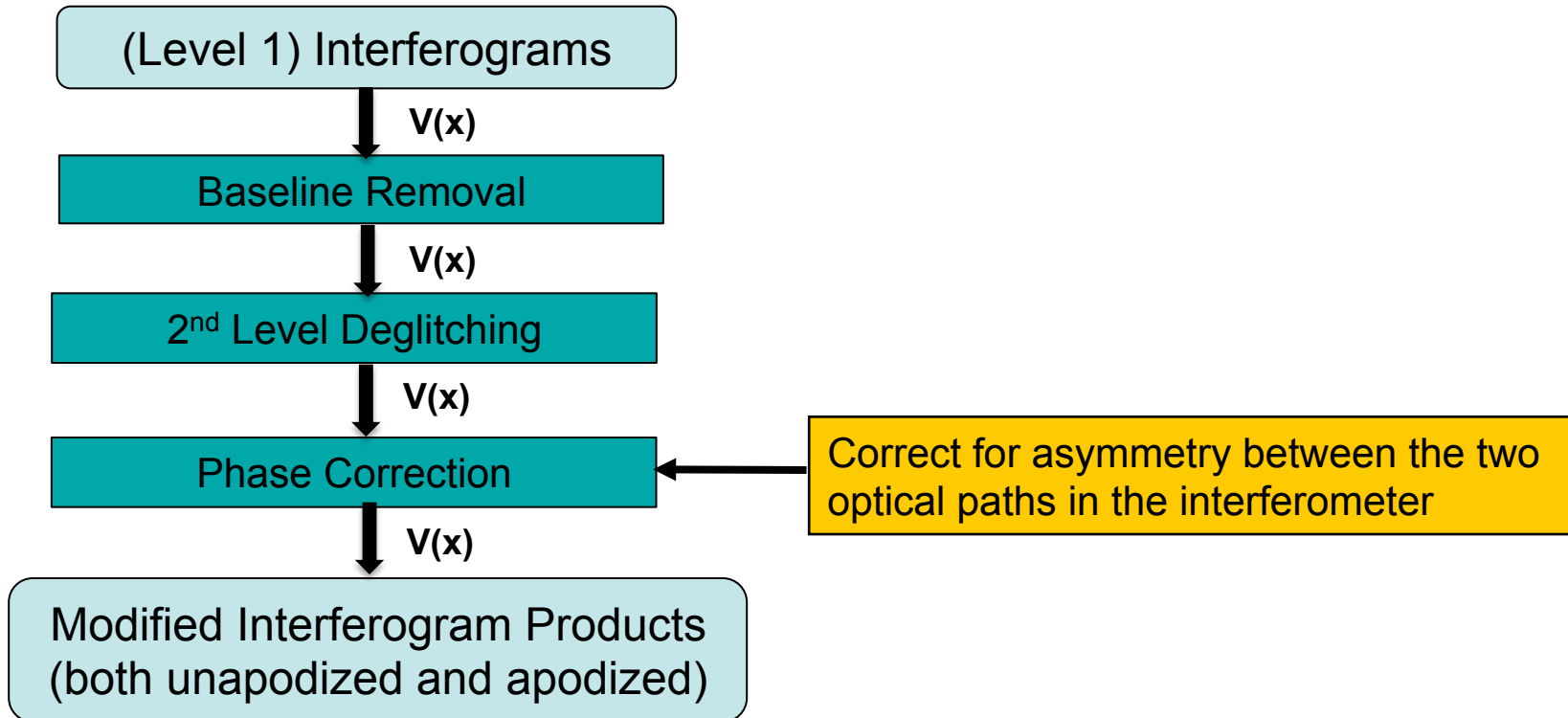
Once time domain processing is complete, the detector signals and SMEC positions can be merged to create interferograms.

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



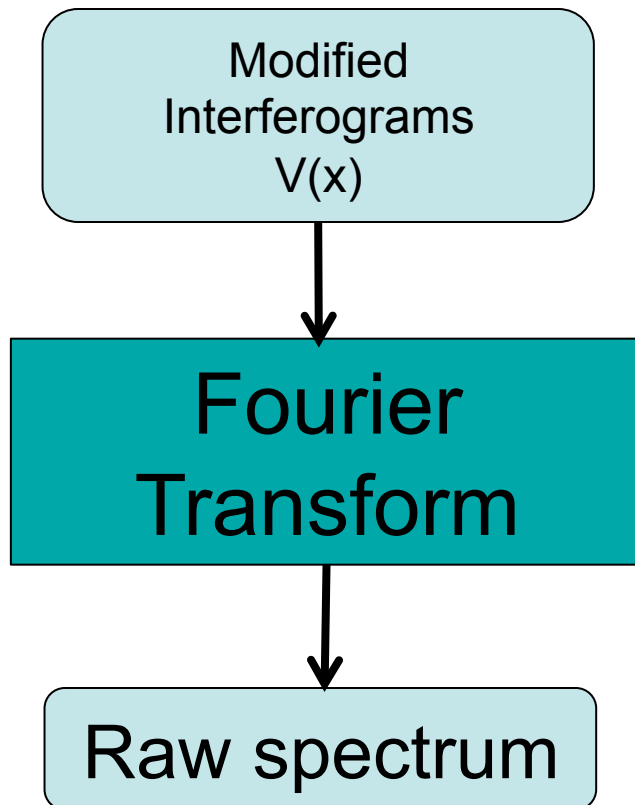
# Pipeline Step 3: Modify Interferograms



(cf. SPIRE DRG Sect. 7.3)



## Pipeline Step 4: Fourier Transform

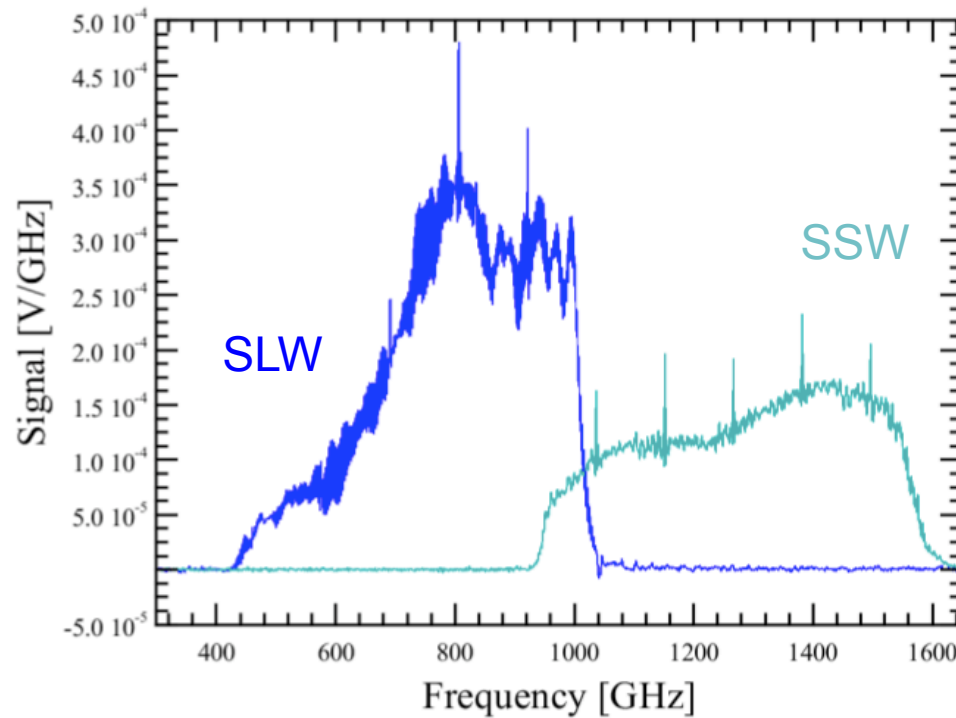


Apply the Fourier Transform to each interferogram to create a set of spectra for each spectrometer detector. The spectra are in units of  $V/\text{GHz}$ , not yet flux calibrated.

(cf. SPIRE DRG Sect. 7.3)



# What is in the Raw Spectrum?

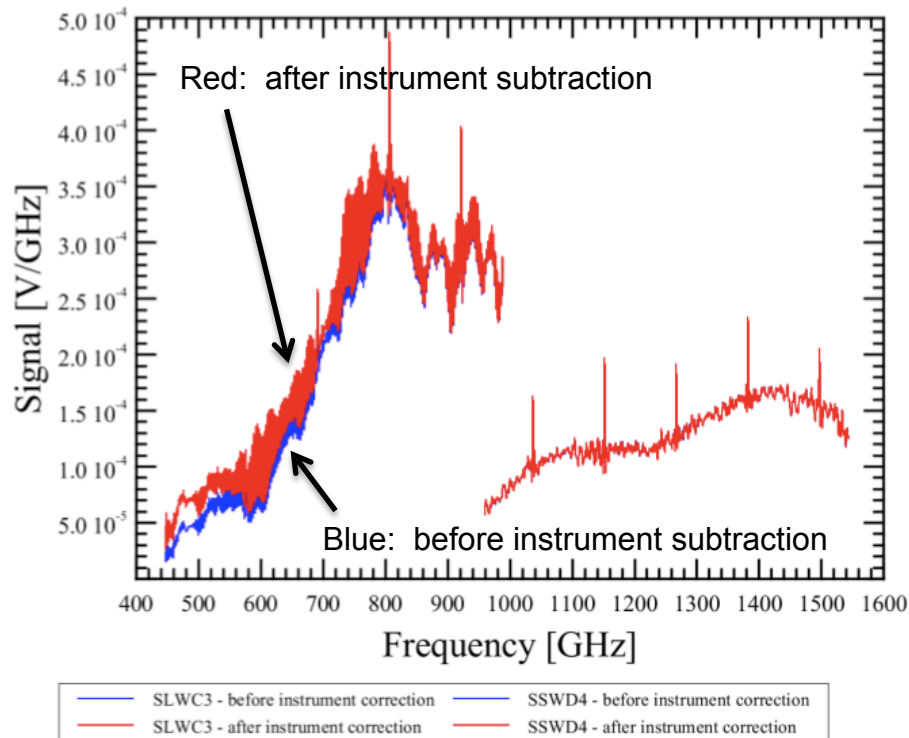


$$V_{Measured}(\sigma) = V_{Source}(\sigma) + V_{Telescope}(\sigma) + V_{Instrument}(\sigma)$$

@80K
@4-5K

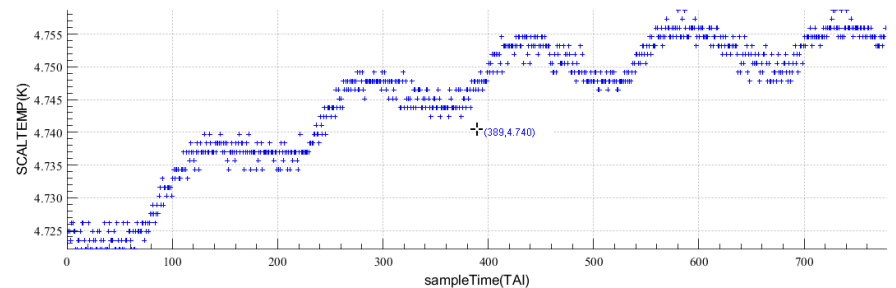


# Instrument Background Emission



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

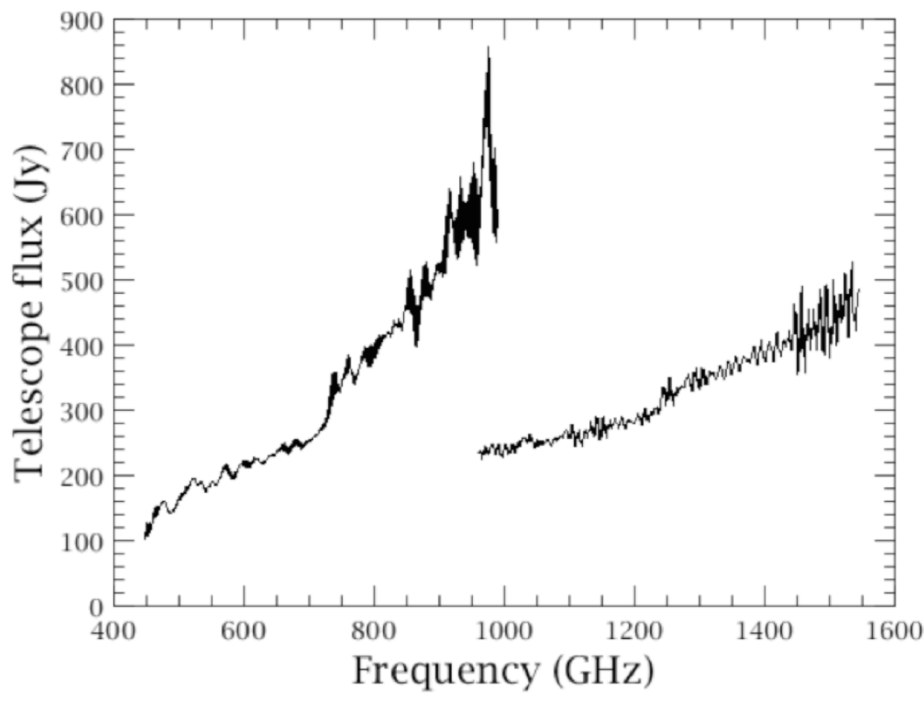
*Instrument temperature varies with time:*





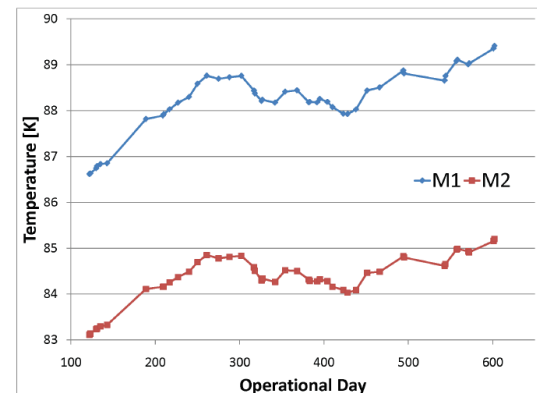
# Telescope Background Emission

Point source-equivalent  
telescope model in Jy:



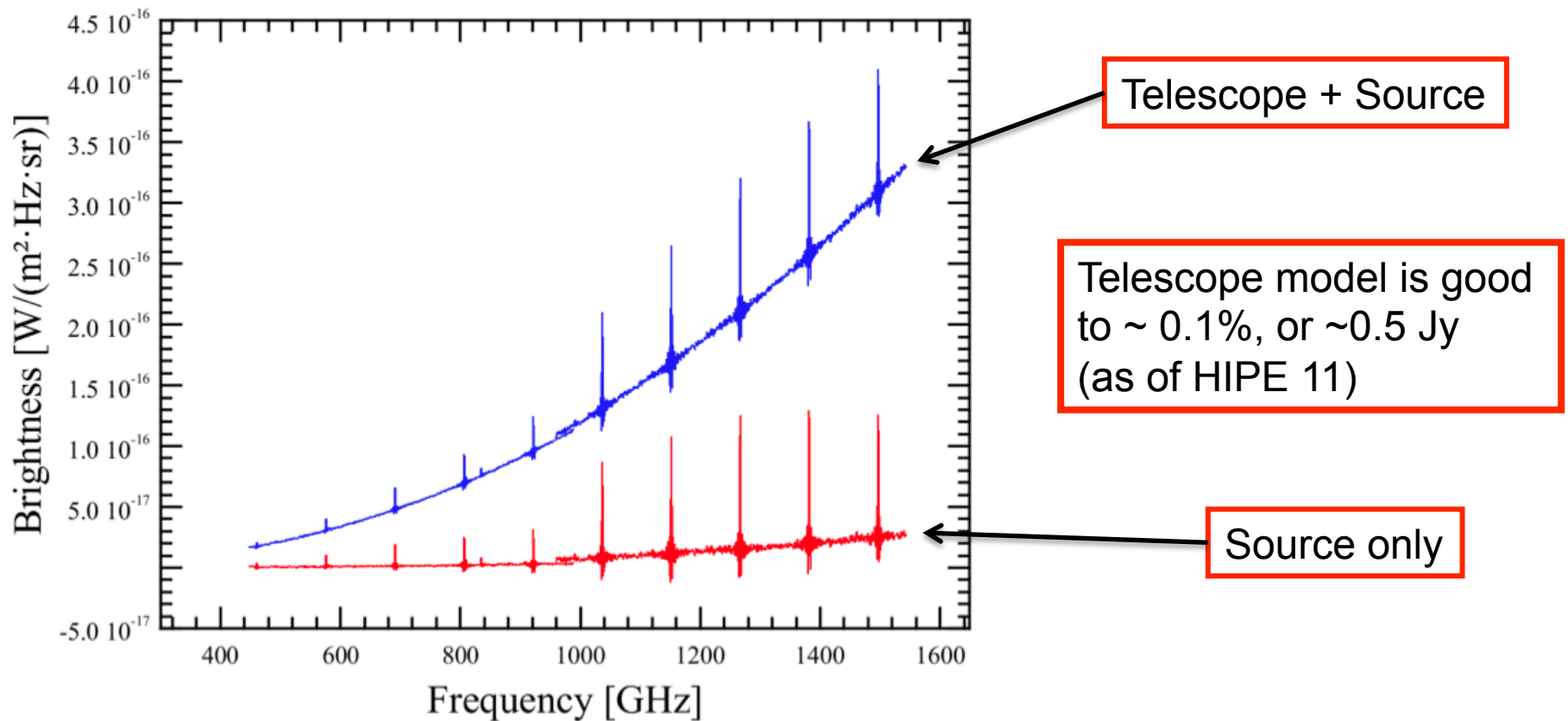
Your observations are most likely dominated by the telescope emission!

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  $W/m^2/Hz/sr$   
 assumes extended emission

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

Telescope RSRF (points to  $R_{tel}$ )  
 Raw spectrum (points to  $S$ )  
 Instrument model and RSRF important for SLW (T ~ 4-5 K) (points to  $R_{inst}$ )  
 Telescope model (points to  $M_{tel}$ )

## Level-2 spectrum

**Flux Density** in Jy  
 assumes point-like emission

$$f = C_{point} I$$

Point source conversion factor ( $= R_{tel}/R_{point}$ ) (points to  $C_{point}$ )

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

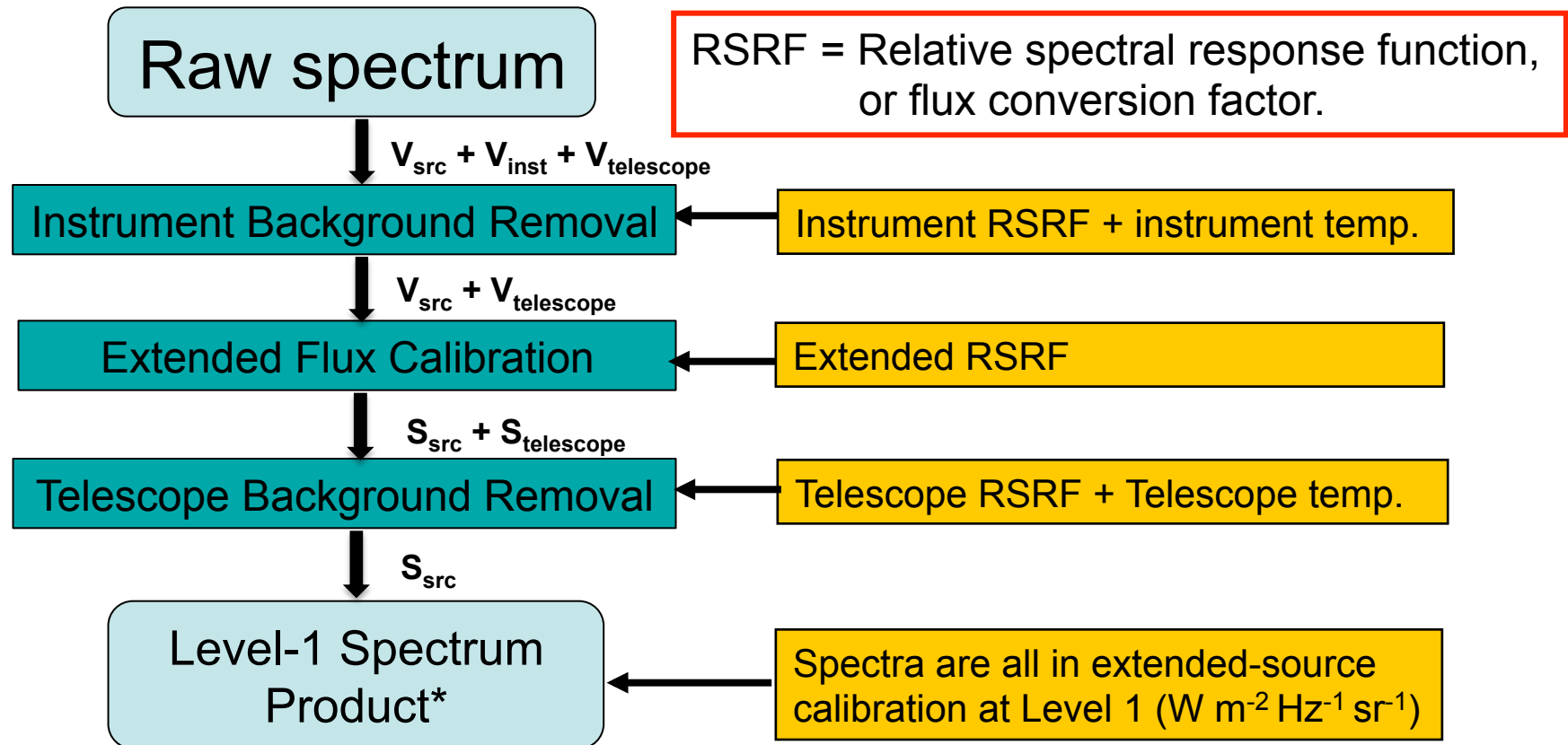
$R_{tel}$ : Dark Sky (= the telescope)  
 $R_{point}$ : Uranus

(See [Swinyard et al. 2014, MNRAS, 440, 3658](#))





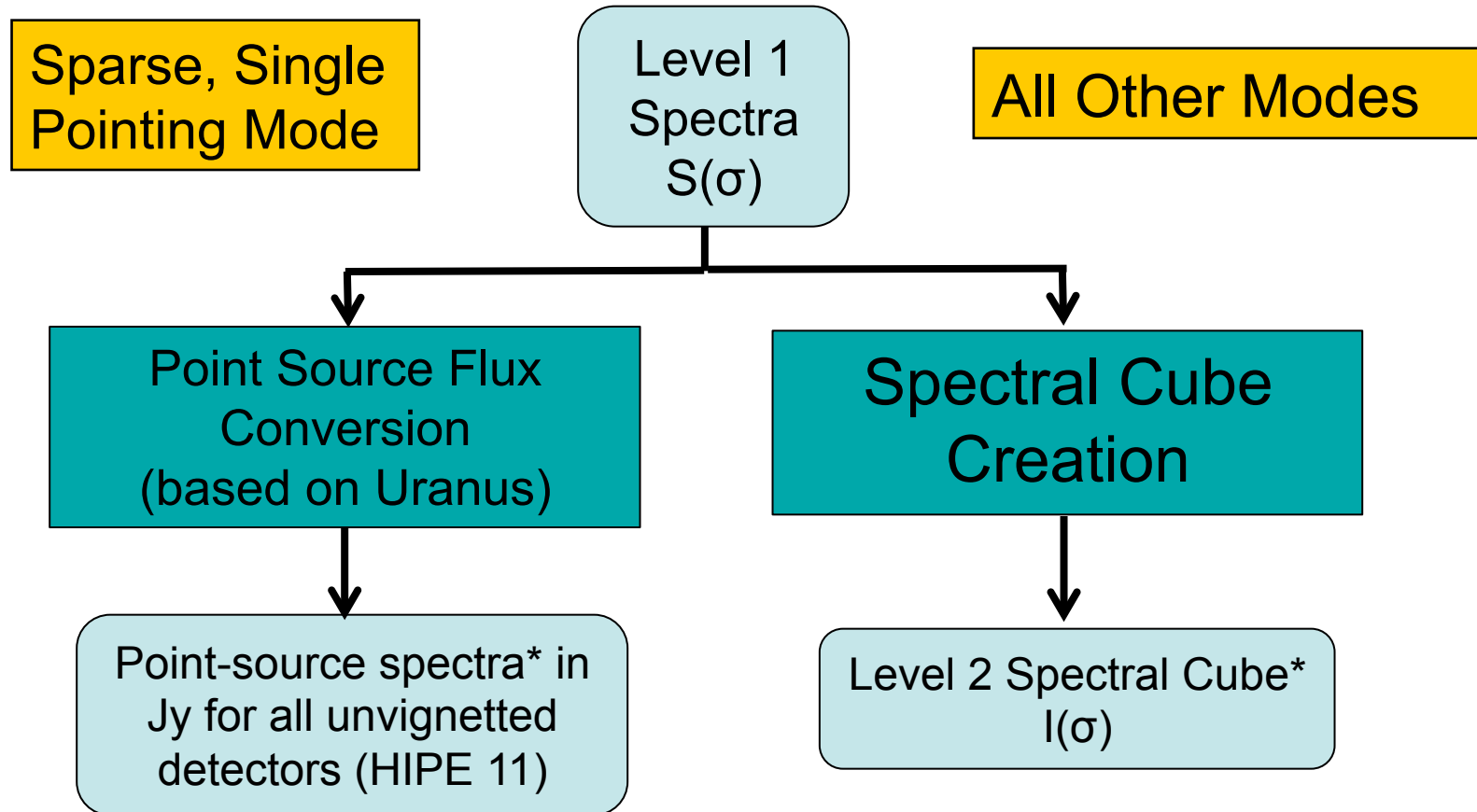
## Pipeline Step 5: Modify Spectra



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



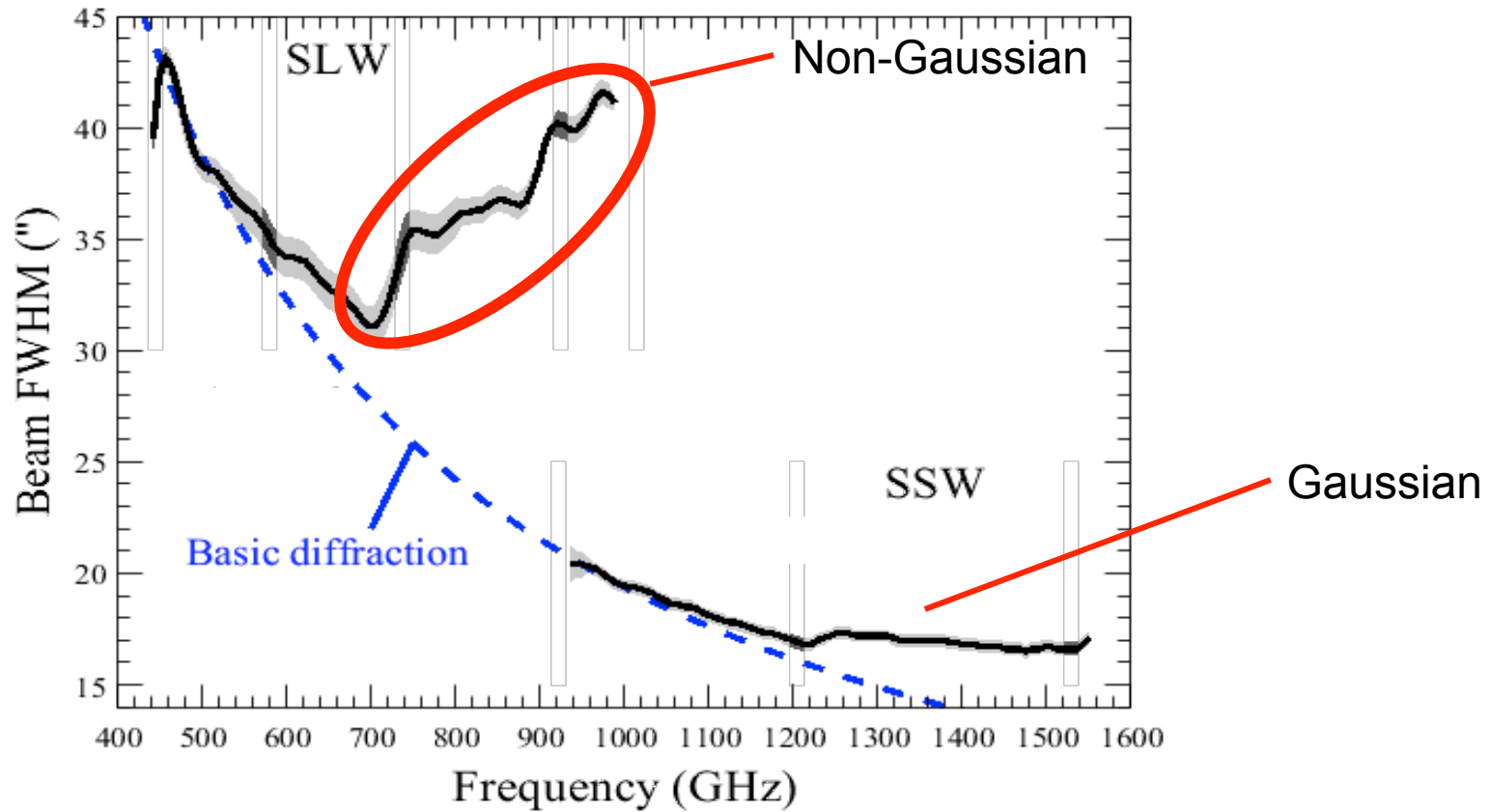
# Pipeline Step 6: Create Level-2 Products



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



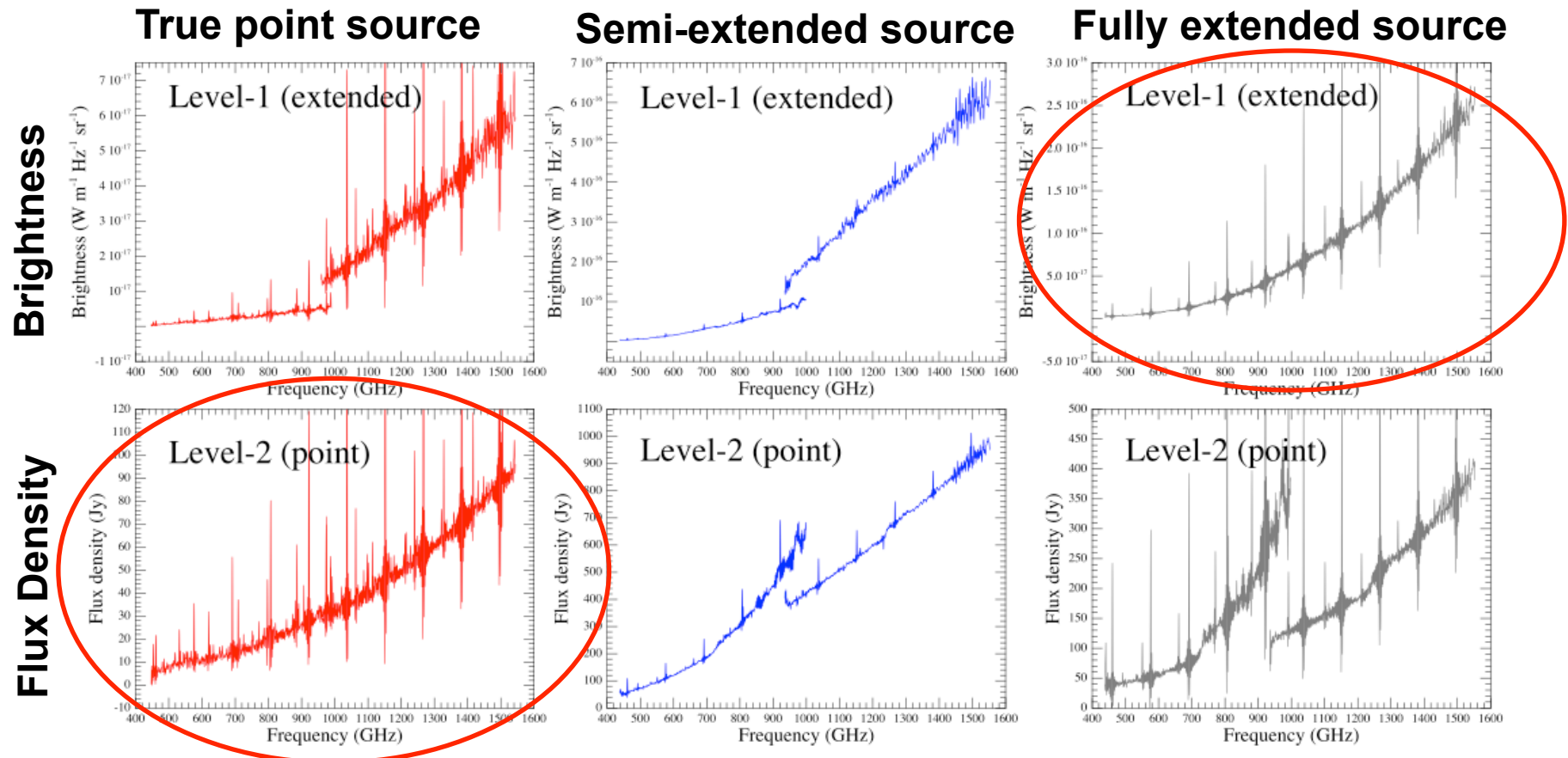
# FTS beam profile



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  $\pm 6\%$ , with the following contributions:
    - i. Systematic uncertainty in Uranus model:  $\pm 3\%$
    - ii. Statistical repeatability (pointing corrected):  $\pm 1\%$
    - iii. Uncertainties in the instrument and telescope model - additive continuum offset error of 0.4 Jy for SLW and 0.3 Jy for SSW
    - iv. The effect of the *Herschel* APE.
- **Sparse observations of significantly extended sources:**
  - Absolute uncertainty  $\pm 7\%$ , with the following contributions:
    - i. Uncertainty comparing telescope and Uranus calibration:  $\pm 3\%$
    - ii. Systematic uncertainty in Uranus model:  $\pm 3\%$
    - iii. Systematic reproducibility of telescope model: 0.06%;
    - iv. Statistical repeatability estimated at  $\pm 1\%$
    - v. Additive continuum offset of  $3.4 \times 10^{-20}$  W/m<sup>2</sup>/Hz/sr for SLW and  $1.1 \times 10^{-19}$  W/m<sup>2</sup>/Hz/sr for SSW.
- **Mapping mode:**
  - Overall repeatability  $\pm 7\%$
- **Wavelength calibration:**
  - 5 - 7 km/s for line velocity.

(See [Swinyard et al. 2014, MNRAS, 440, 3658](#))