SPIRE Spectrometer Data Analysis: An Introduction

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Outline

- Do you generally need to reprocess FTS data yourself?
- Data analysis examples with scripts and tasks available within HIPE.
  - Quick spectral noise assessment
  - Detector footprint on the sky
  - Faint source observations: further background subtraction and/or comparison with SPIRE photometer data
  - Deriving spectral line fluxes
  - Flux correction for a semi-extended target or a pointing offset
  - Mapping data analysis

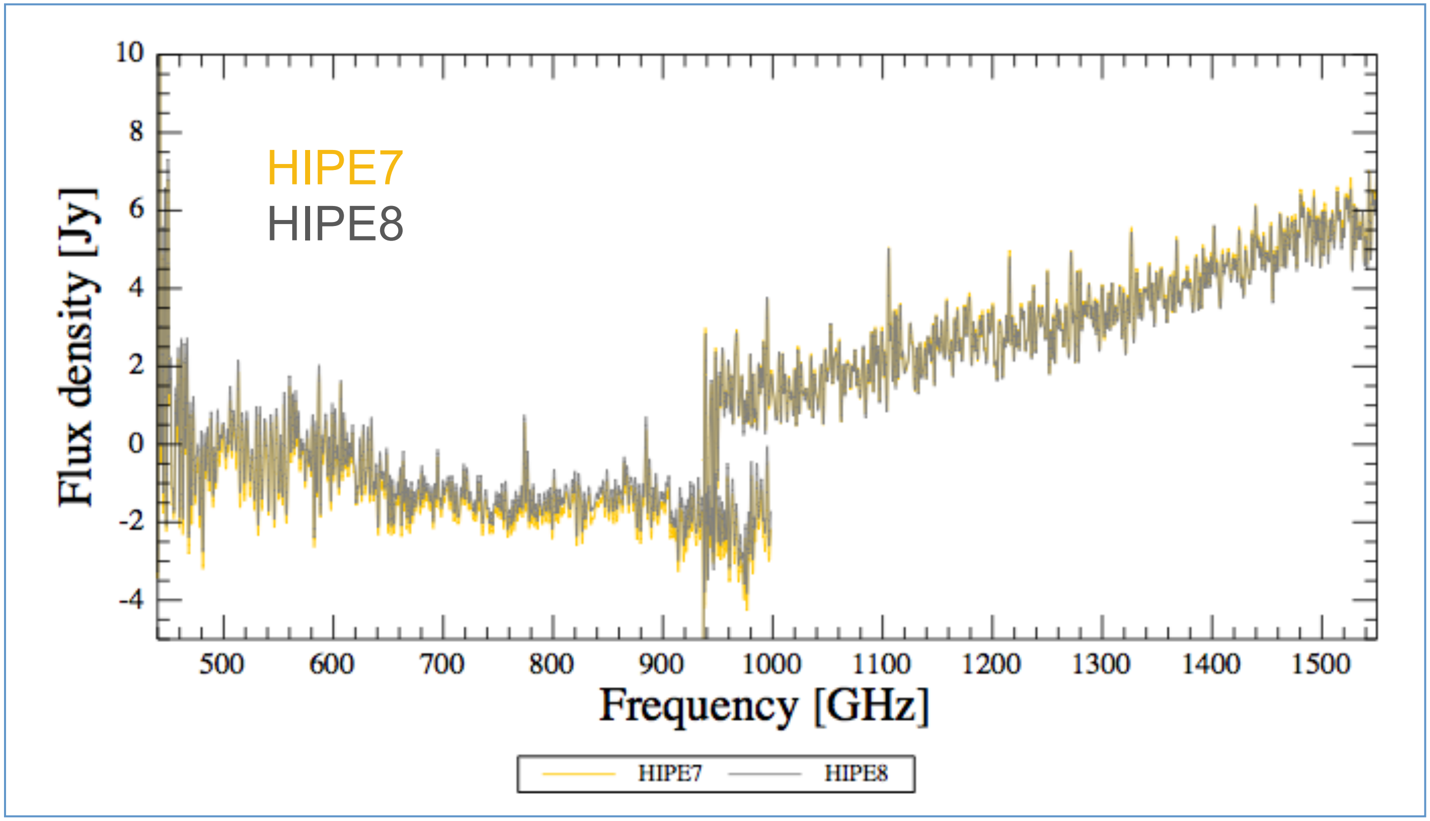
Do you need to reprocess your FTS data?

Normally, the answer is NO if you have data from HIPE 11 and onward. But,

- Both calibration and pipeline are still being improved at this point. There are times when you might want to reprocess your data with the latest calibration product.
  - For example, in HIPE 13 (~Jan 2015):
    - The nonlinearity correction will be upgraded to improve telescope background subtraction for those observations taken at the beginning of SPIRE cooler cycles (i.e., at lower detector temperatures than normal).
    - Some low-resolution observations will be better calibrated in HIPE 13 as well.
- At this point, HIPE 11 data are available in the Herschel science archive. To obtain HIPE 12 data, you can either
  - request on-demand data reprocess in the user interface of the Herschel science archive, or
  - reprocess HIPE 11 data to HIPE 12 using the reprocssing script in HIPE

FTS Spectra in Different HIPE Versions

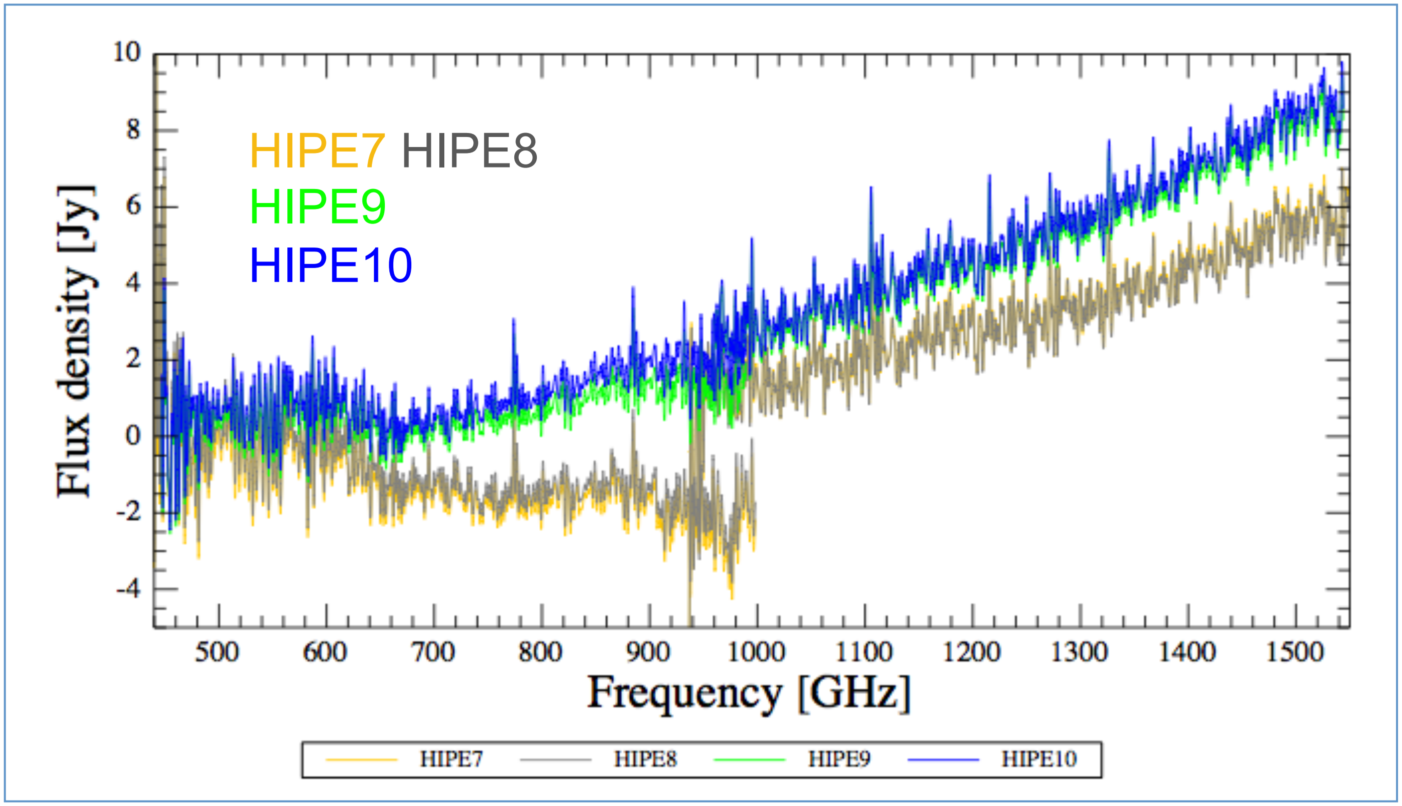
Mrk 231 observed on OD209



Standard pipeline Level-2 output

FTS Spectra in Different HIPE Versions

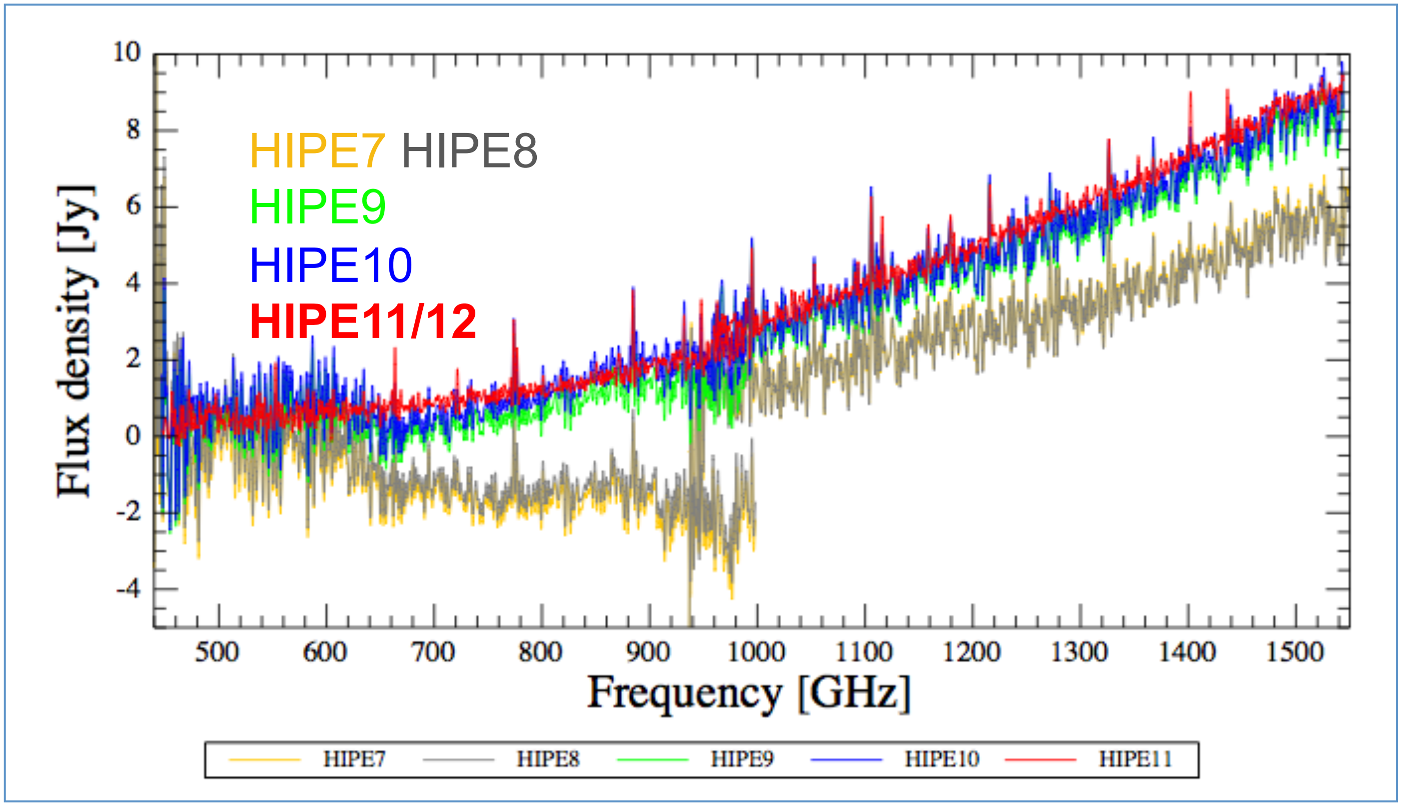
Mrk 231 observed on OD209



Standard pipeline Level-2 output

FTS Spectra in Different HIPE Versions

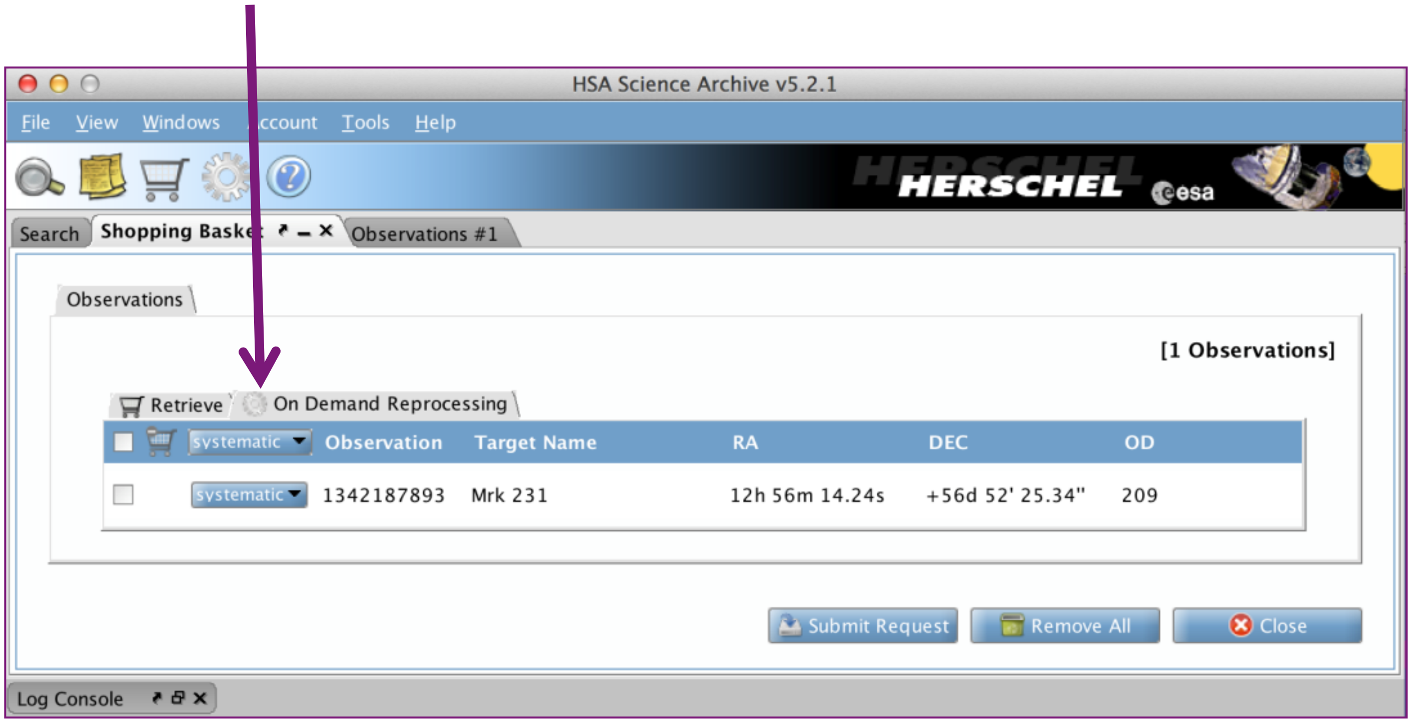
Mrk 231 observed on OD209



Standard pipeline Level-2 output

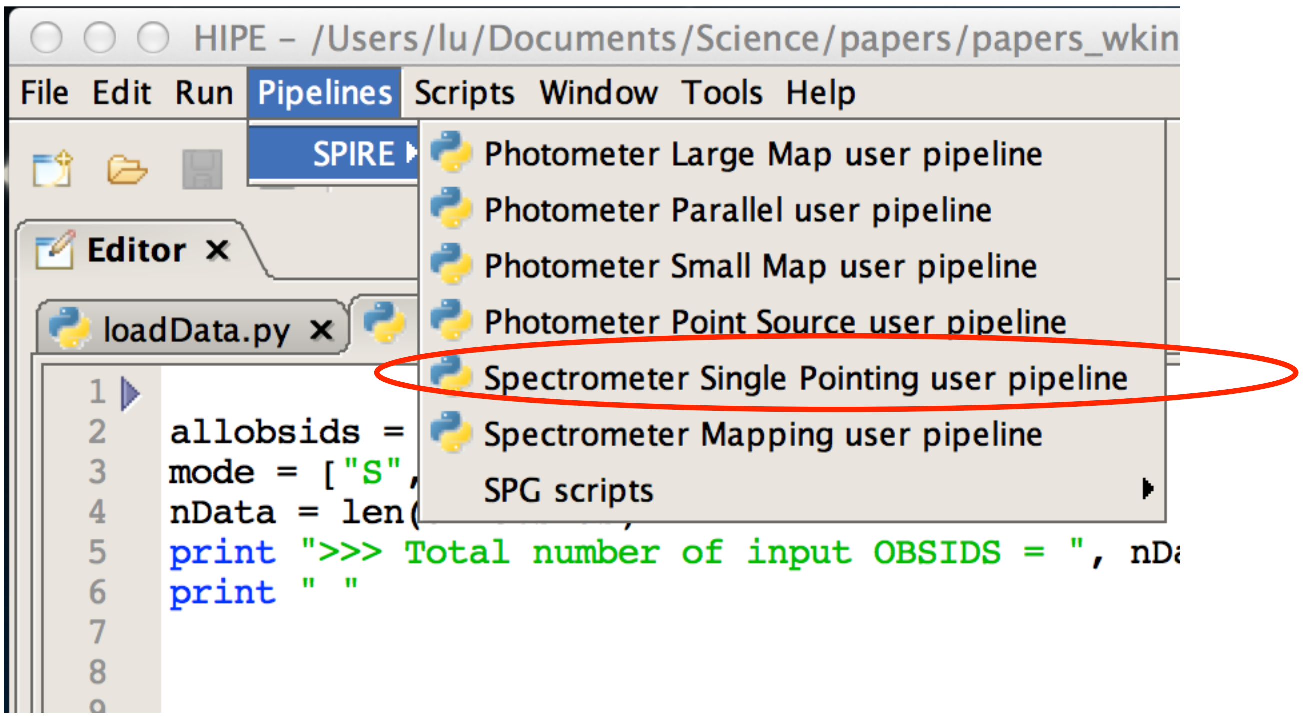
Getting HIPE v12 data

Option I: Elect the on-demand processing option in HSA



Getting HIPE 12 data

Option II: Alternatively, one can reprocess an observation of HIPE 11 to HIPE 12 using the reprocessing script that comes within HIPE.



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- Do you generally need to reprocess FTS data yourself?

- Data analysis examples with scripts and tasks available within HIPE.
  - Quick spectral noise assessment
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  - Faint source observations: further background subtraction, comparison with photometer data
  - Deriving spectral line fluxes
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Background Documents

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

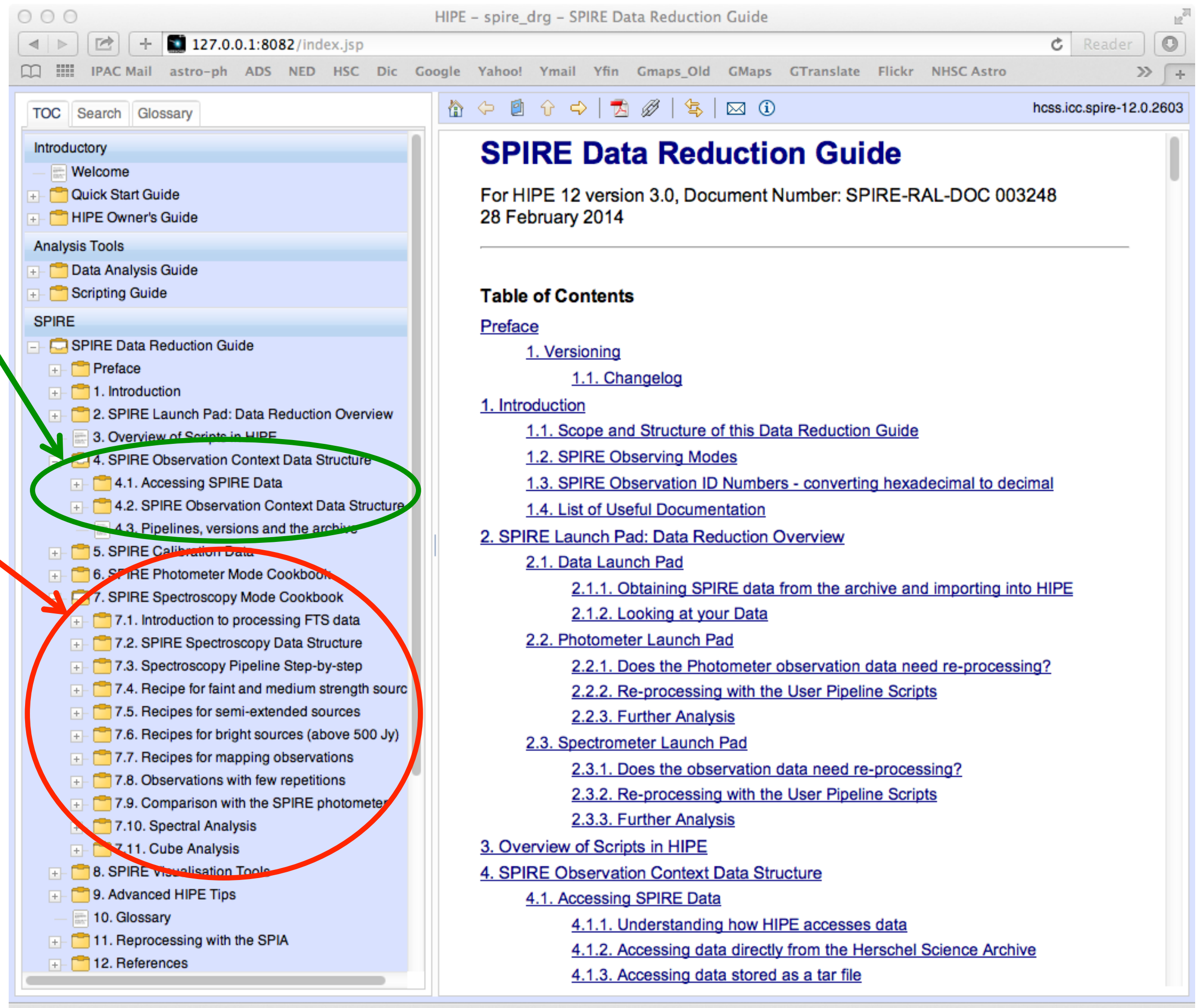
- Swinyard et al. 2014, MNRAS, 440, 3658 - **FTS calibration**
- Makiwa et al. 2013, Applied Optics, 52, 3864 - **FTS beams**
- Wu et al. 2013, A&A, 556, 116 - **Semi-extended sources**

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

SPIRE Data Reduction Guide (DRG)

General SPIRE data info

SPIRE/FTS data structure and processing, and data analysis receipes

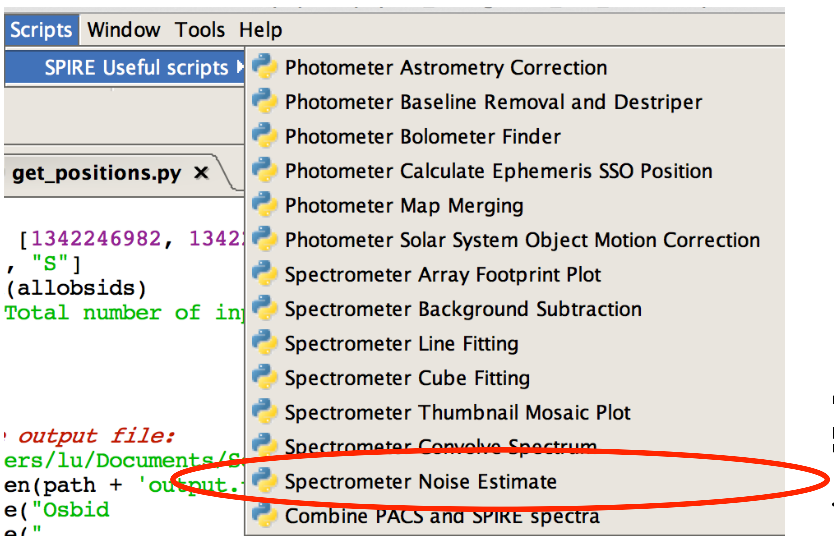


Spectrometer Useful Scripts

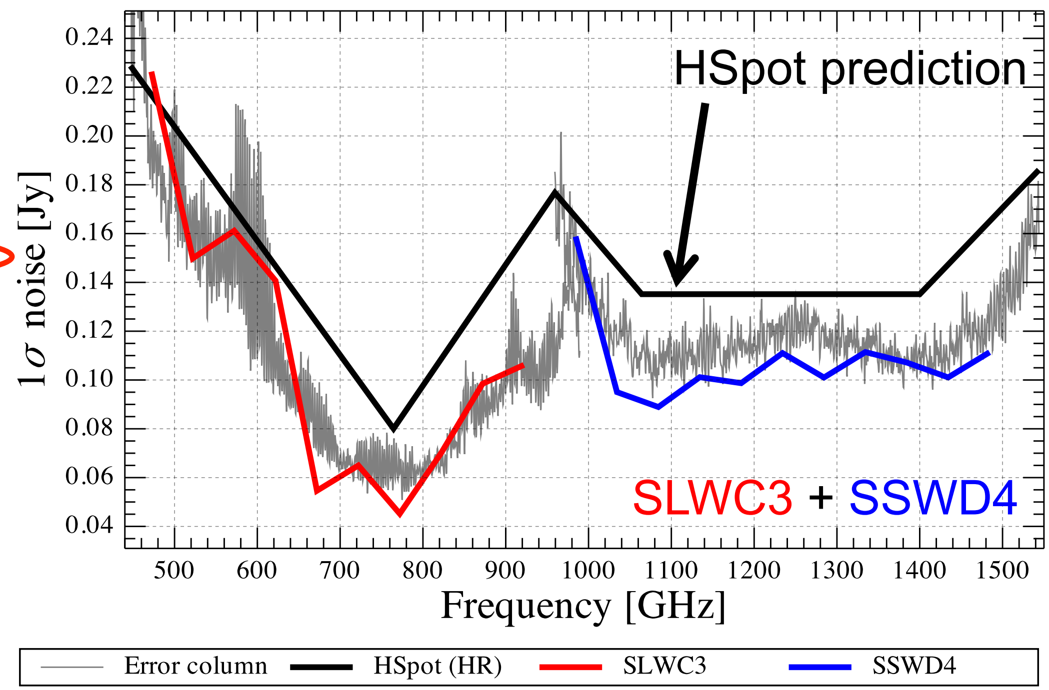
- Array Footprint Plot
- Background Subtraction
- Line Fitting
- Thumbnail Mosaic Plot
- Convolve Spectrum
- Noise Estimate
- Cube Fitting
- Combining PACS and SPIRE spectra

Available in HIPE!

Quick Noise Assessment

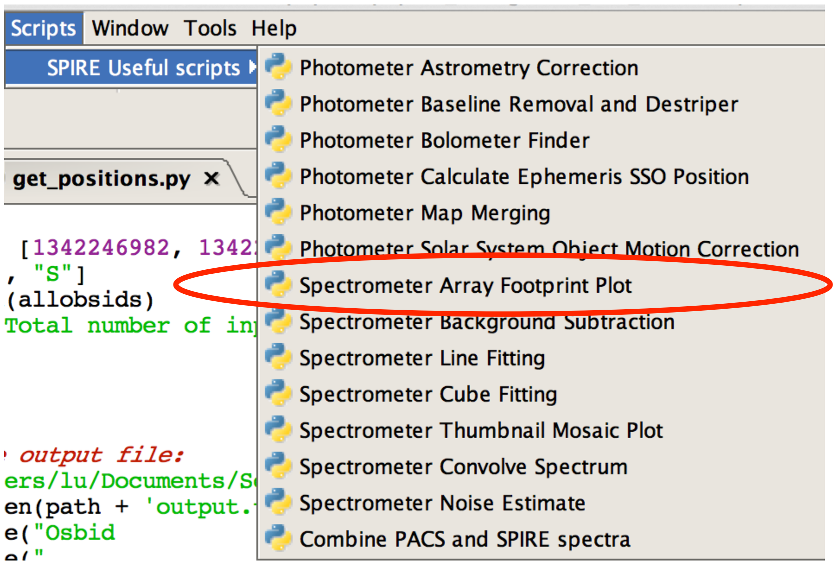


- Red and blue: Total rms noise (systematic + random)
- Gray spectrum: randon noise only
- Black curve: HSpot predicted total noise

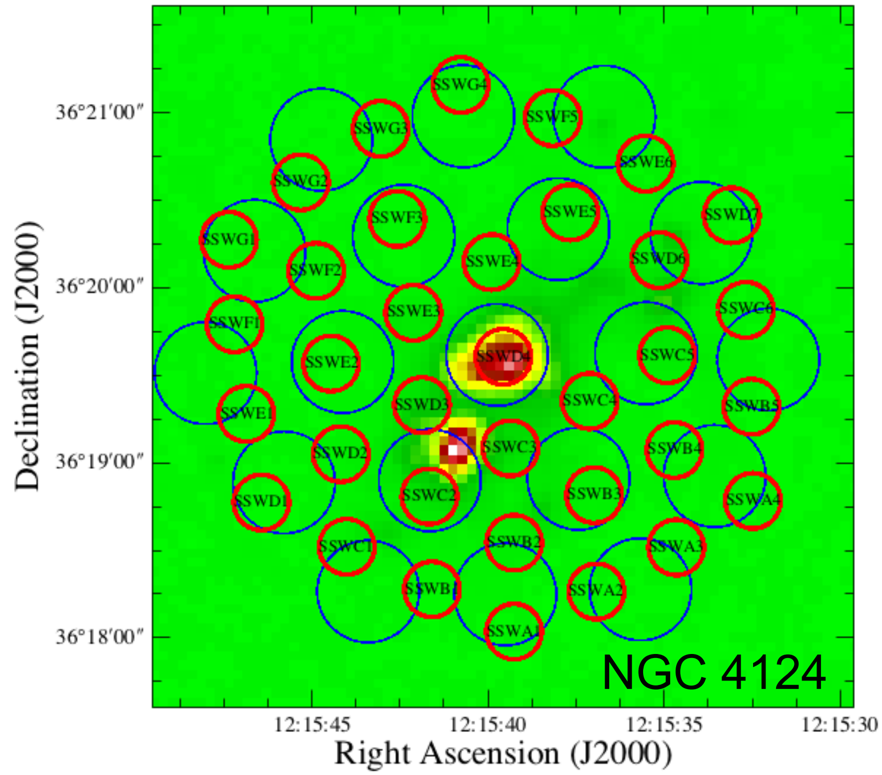


Useful to see if an observation suffers any significant systematics

Detector Footprint on Sky



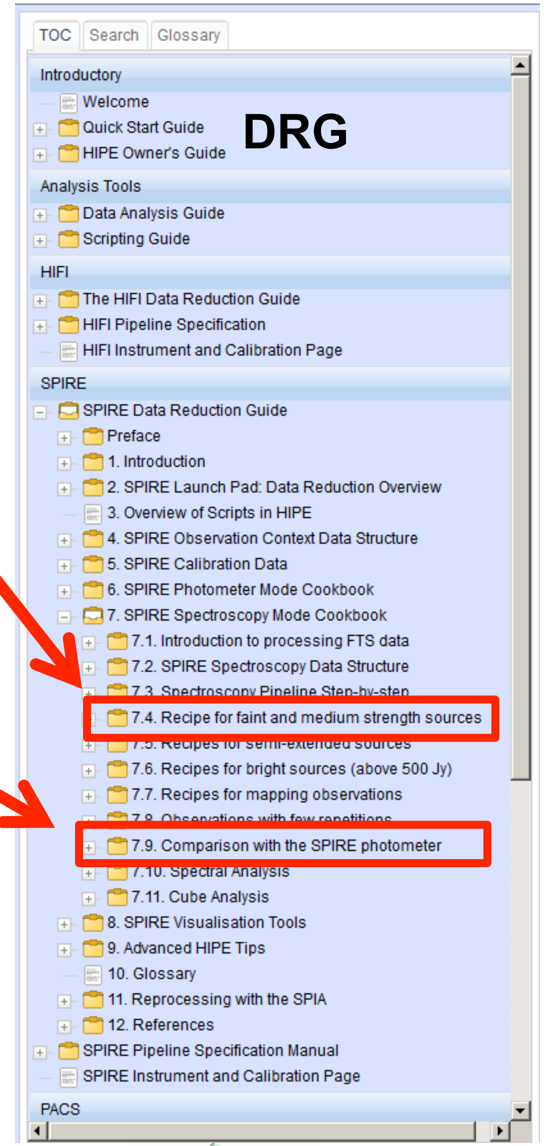
FTS footprint on PACS 70um image



Useful for visualization of the extent and relative location of the target w.r.t. the detector array.

Faint Point-like Targets

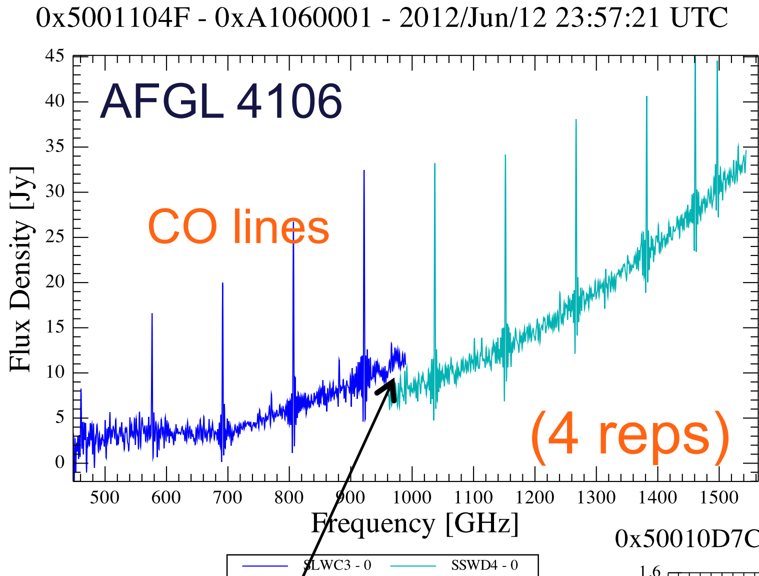
- Checking the source extent
  - To make sure it is a point source
- Further background subtraction
- Comparing with the photometer



Faint sources:	a few to < ~10 Jy;
Medium sources:	~10 to < ~100 Jy.

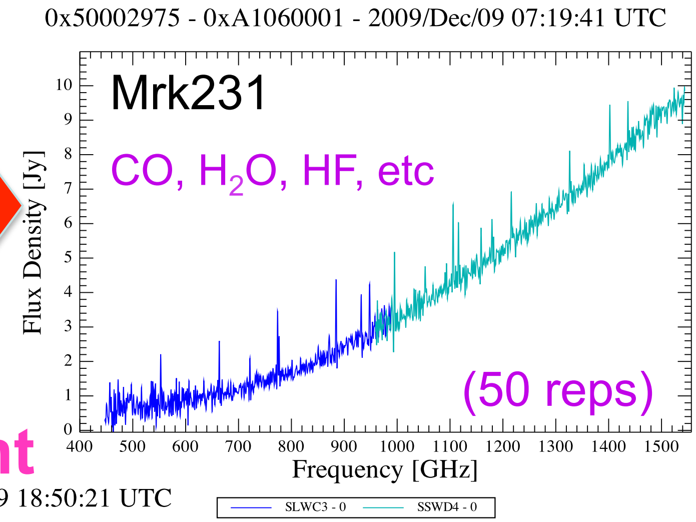
Examples of Point-source Spectra

Medium source

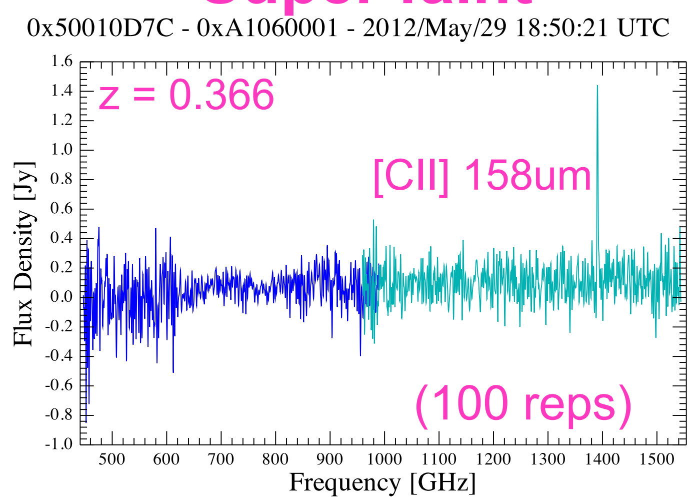


Gap: may indicate some residual telescope background, which can be further removed.

Faint

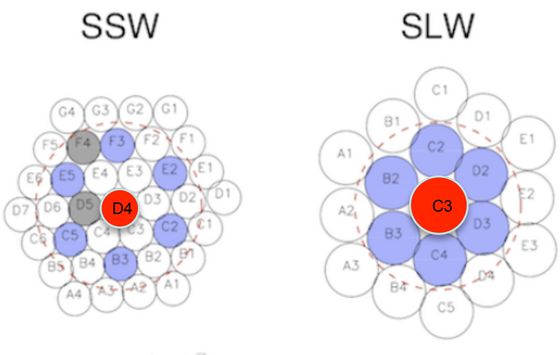


Super faint

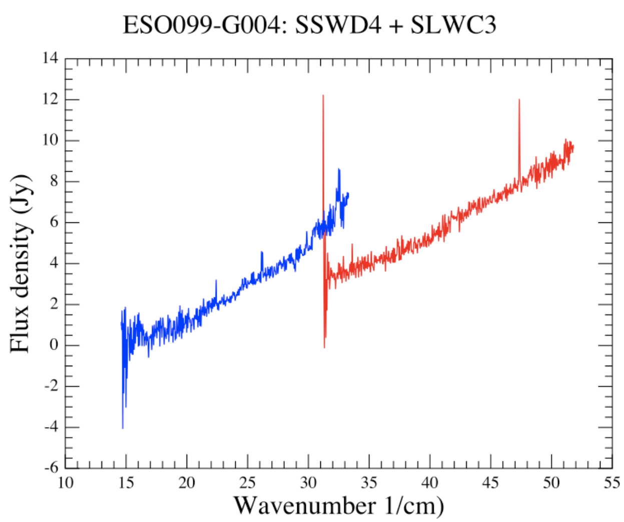


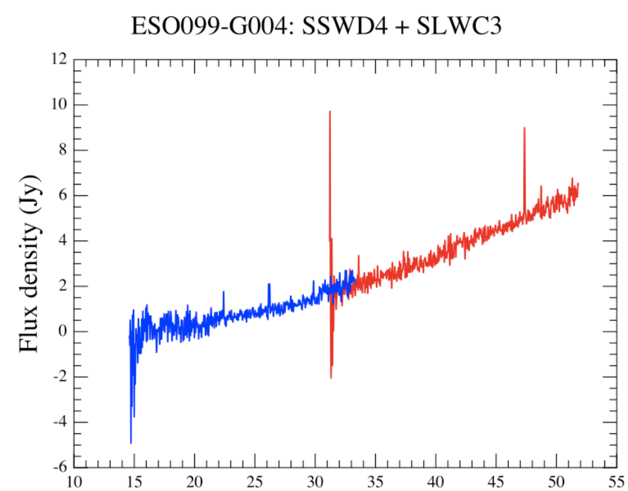
Level 2 pipeline products

Residual Telescope Emission Removal: Using Surrounding Channels

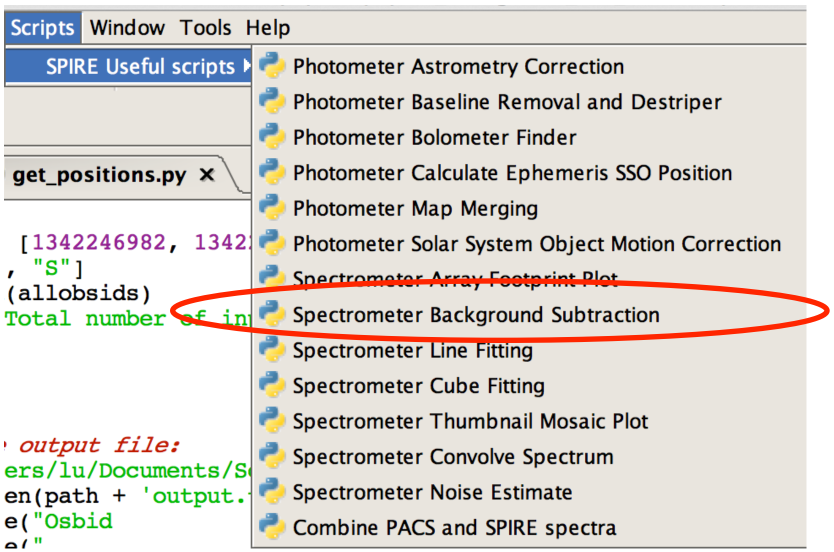


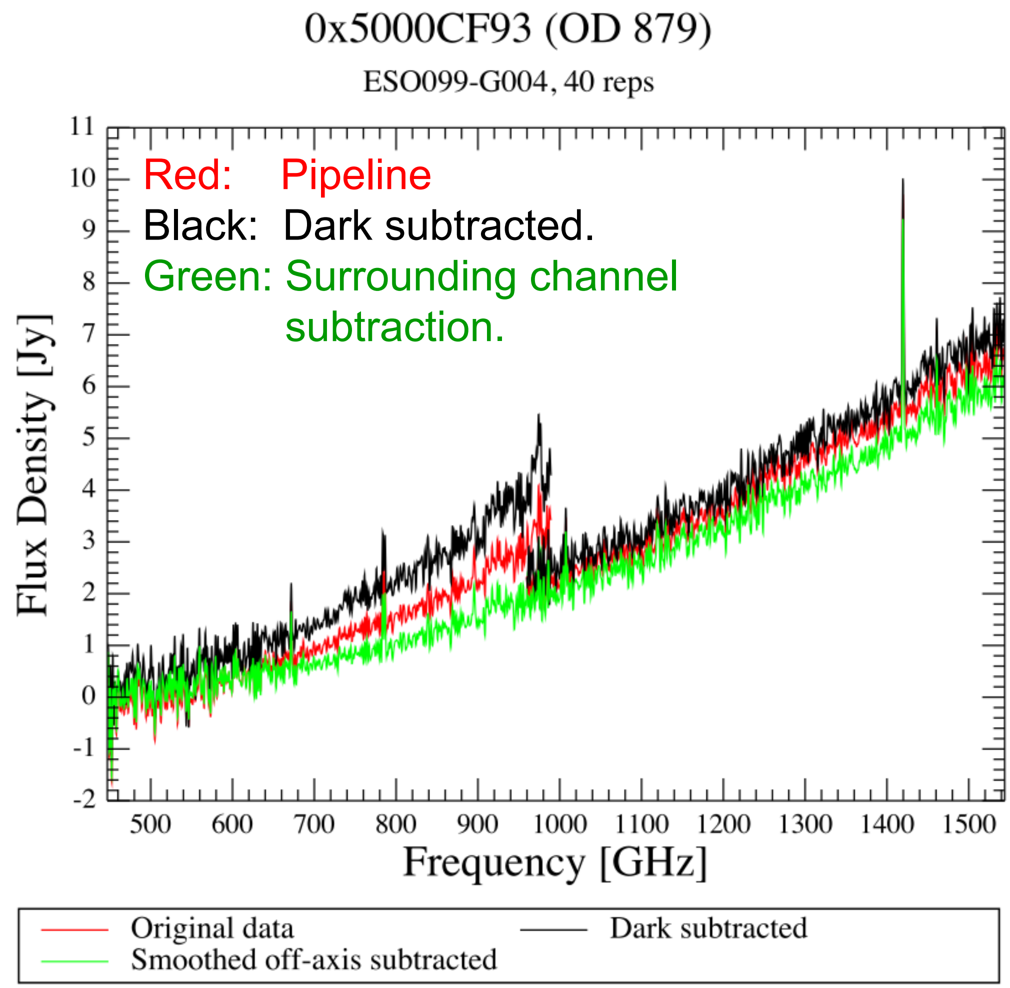
- Using a median spectrum from the co-aligned detectors as the residual telescope spectrum.
- This (or a polynominal fit to it) is then subtracted from the spectrum of the central detectors.





Background Subtraction

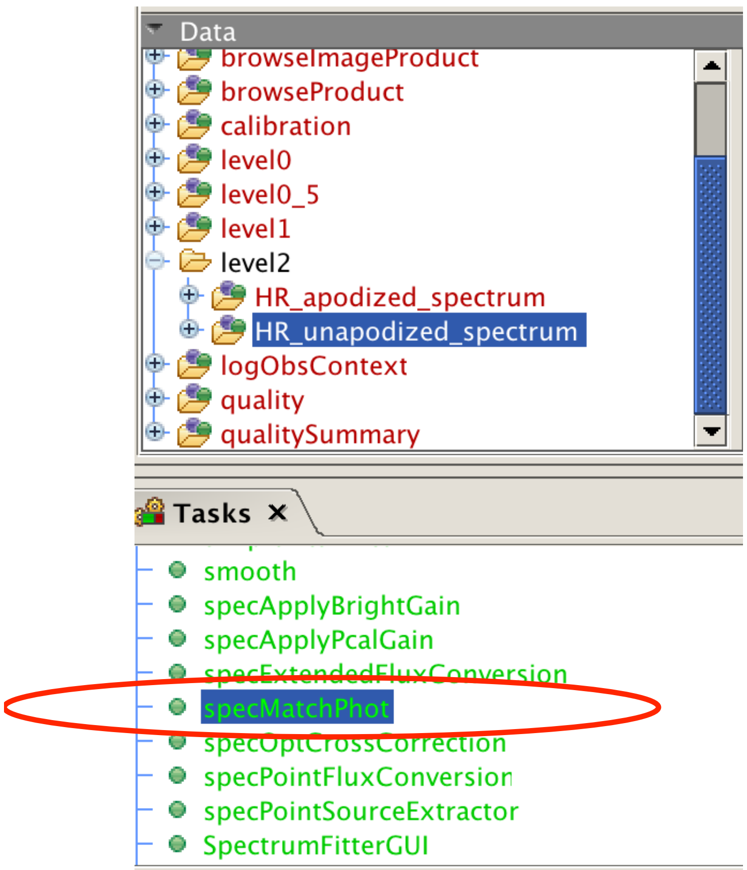


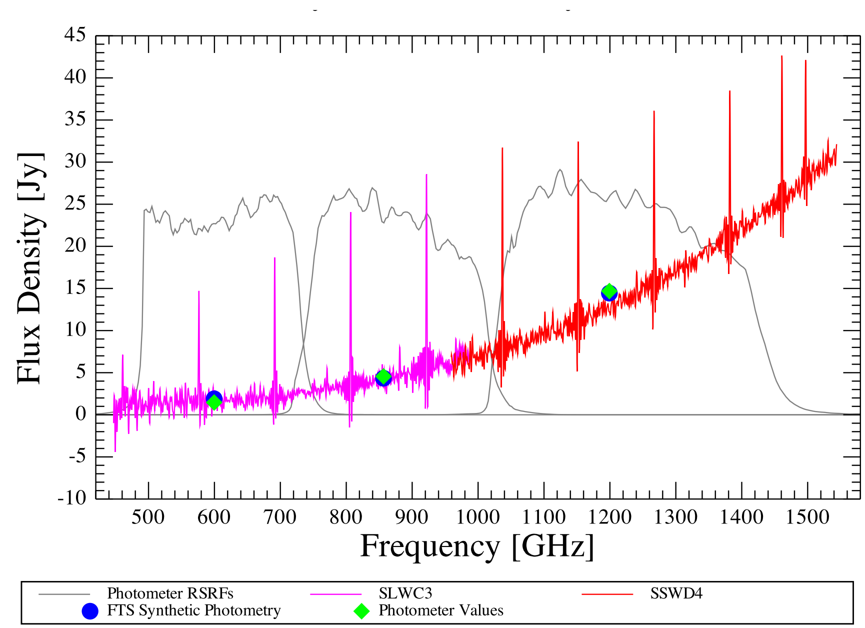


➡ Improves the continuum flux of a faint, point-like target.

Comparing with SPIRE photometer

HIPE task **SpecMatchPhot**





Synthetic photometry also output in a table:

Synthetic photometry results

Meta Data

None

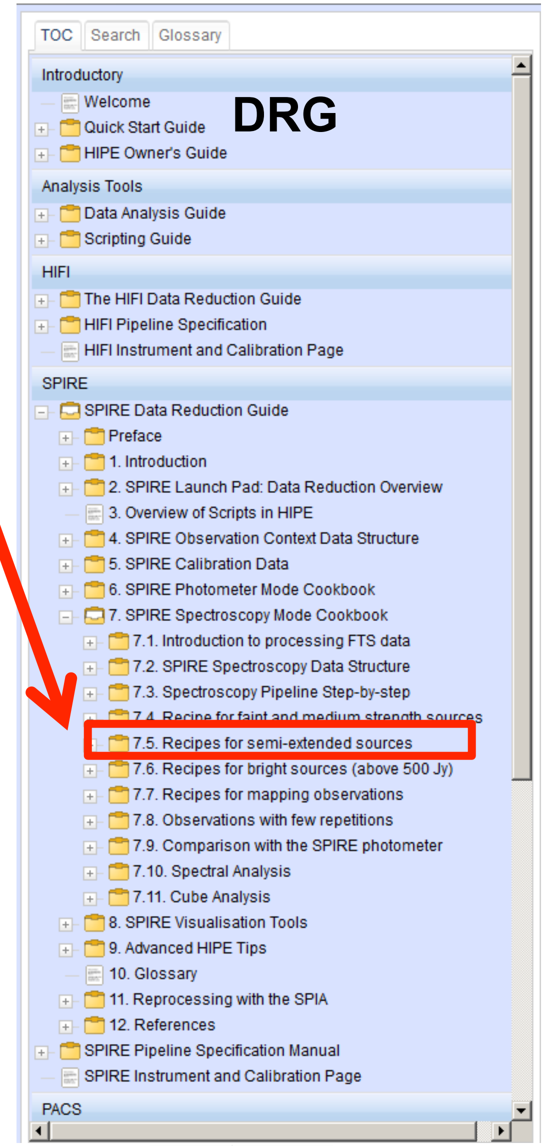
Table Data

Index	names []	spec250 [Jy]	spec350 [Jy]	spec500 [Jy]	phot250 [Jy/beam]	phot350 [Jy/beam]	phot500 [Jy/beam]
0	SLWB2	0.5524880934532026	2.2750690830393063	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
1	SLWB3	1.7079940700571916	2.900204401489005	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
2	SLWC2	0.7795710130592949	2.4846351262954545	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
3	SLWC3	3.5301211206430834	7.208739635225893	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
4	SLWC4	2.271641002463886	3.1913230785009703	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
5	SLWD2	1.910852171027807	3.147223386802127	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
6	SLWD3	2.4930847414696724	3.41185471573297	NaN	1.4595235477934987	4.5625949527907	14.688015400555697
7	SSWB2	NaN	NaN	1.7915315388884716	1.4595235477934987	4.5625949527907	14.688015400555697
8	SSWB3	NaN	NaN	1.5853857093619672	1.4595235477934987	4.5625949527907	14.688015400555697

Partially Extended Sources

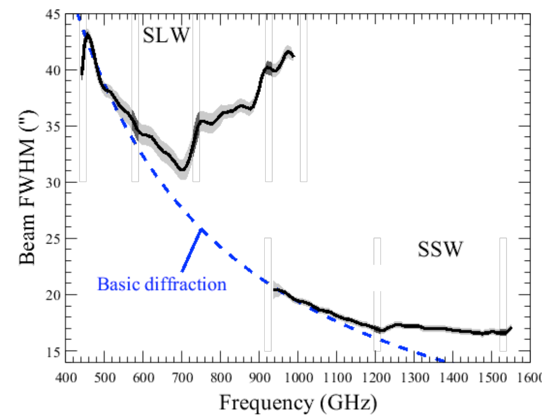
- Effect of a semi-extended source
- What correction is needed?

- Semi-extended (flux) correction tool (SECT) in HIPE



Identifying Possible Partially Extended Sources

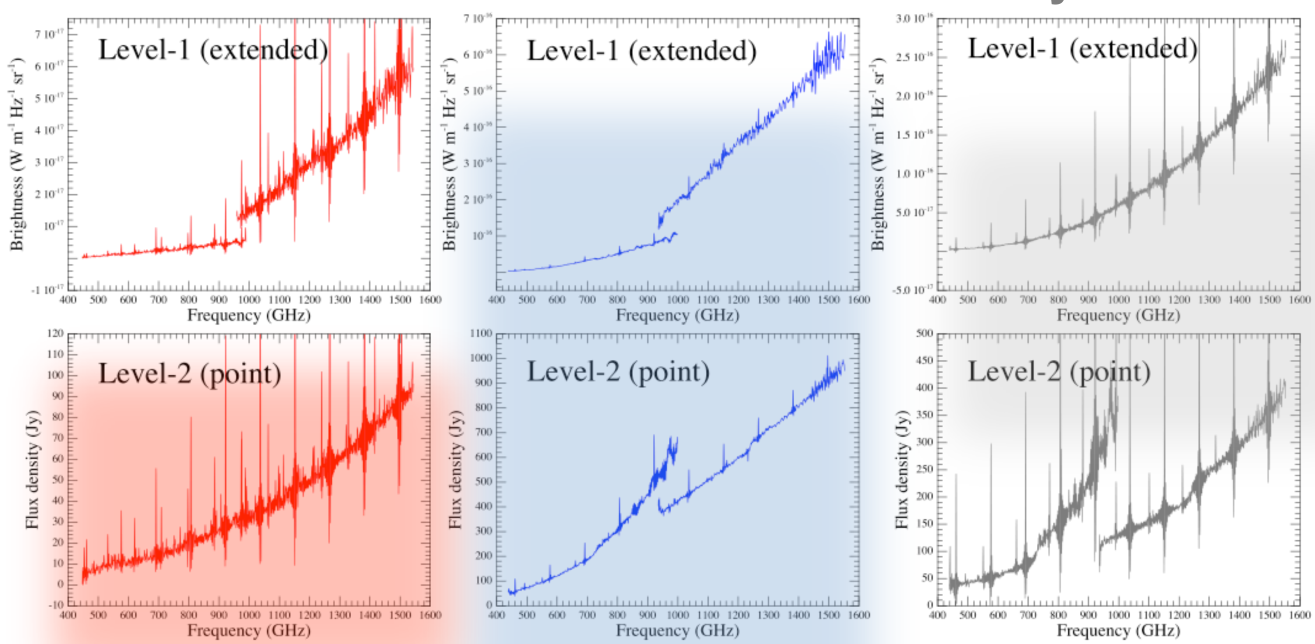
- The spectrum shows kinks and discontinuities where the beam size changes



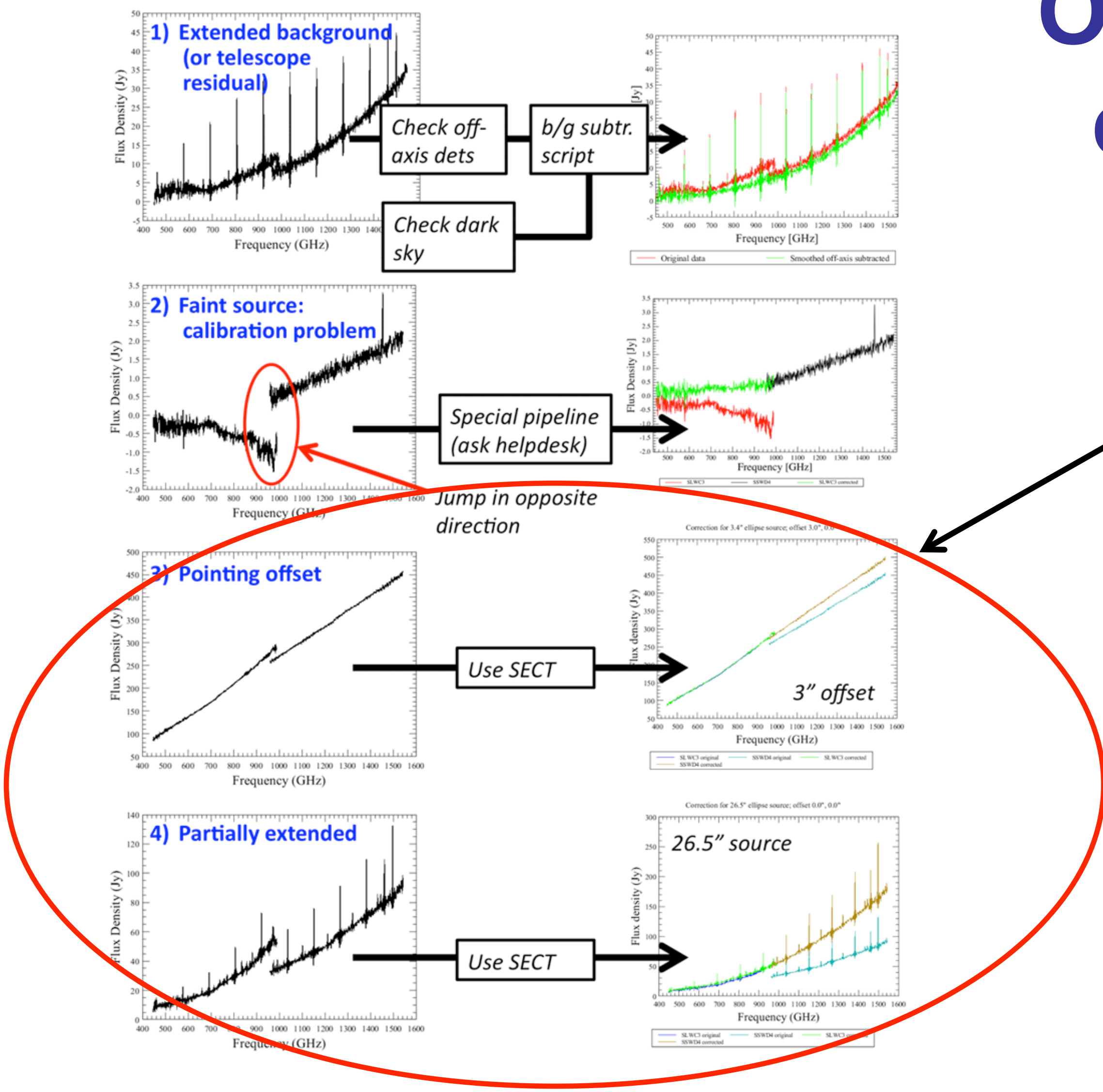
Point-like | **Partly extended** | **Fully extended**

Extended calibration →

Point-source calibration →



Other possible causes for a spectral gap



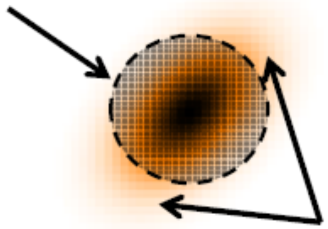
Cases appropriate for using SECT (the semi-extended source fluc correction tool) in HIPE.

(Caution: the CO lines, from warm/dense molecular gas, may arise from a more compact region than the cold dust contiuum.)

Semi-extended Correction Tool (SECT)

(cf. DRG Sect. 7.5)

Reference beam

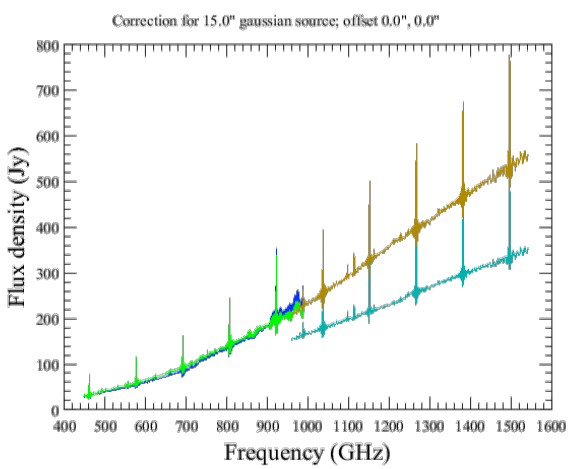


The final spectrum normalised to include only emission inside the reference beam

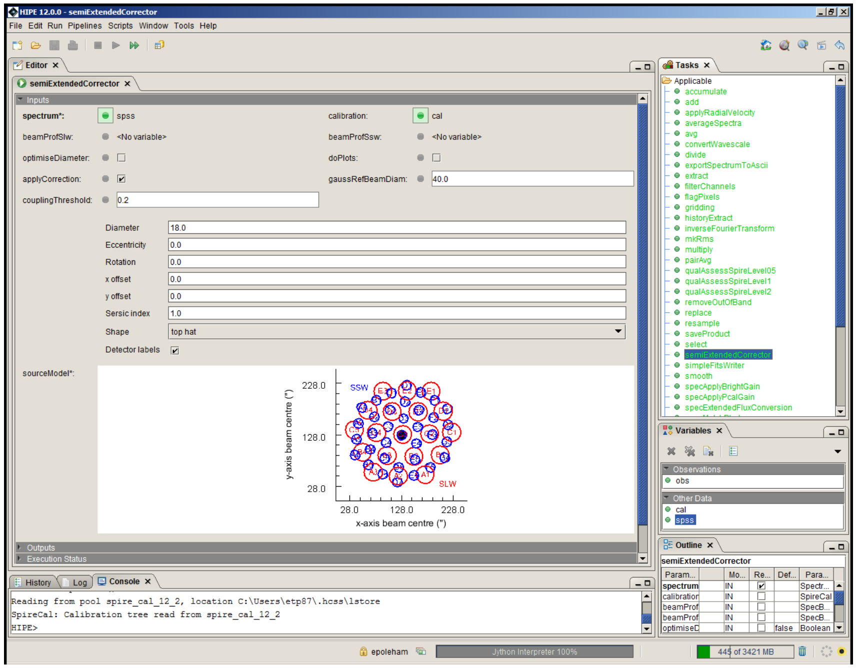
Emission excluded from final spectrum

Assumption: source distribution is independent of frequency

Source model

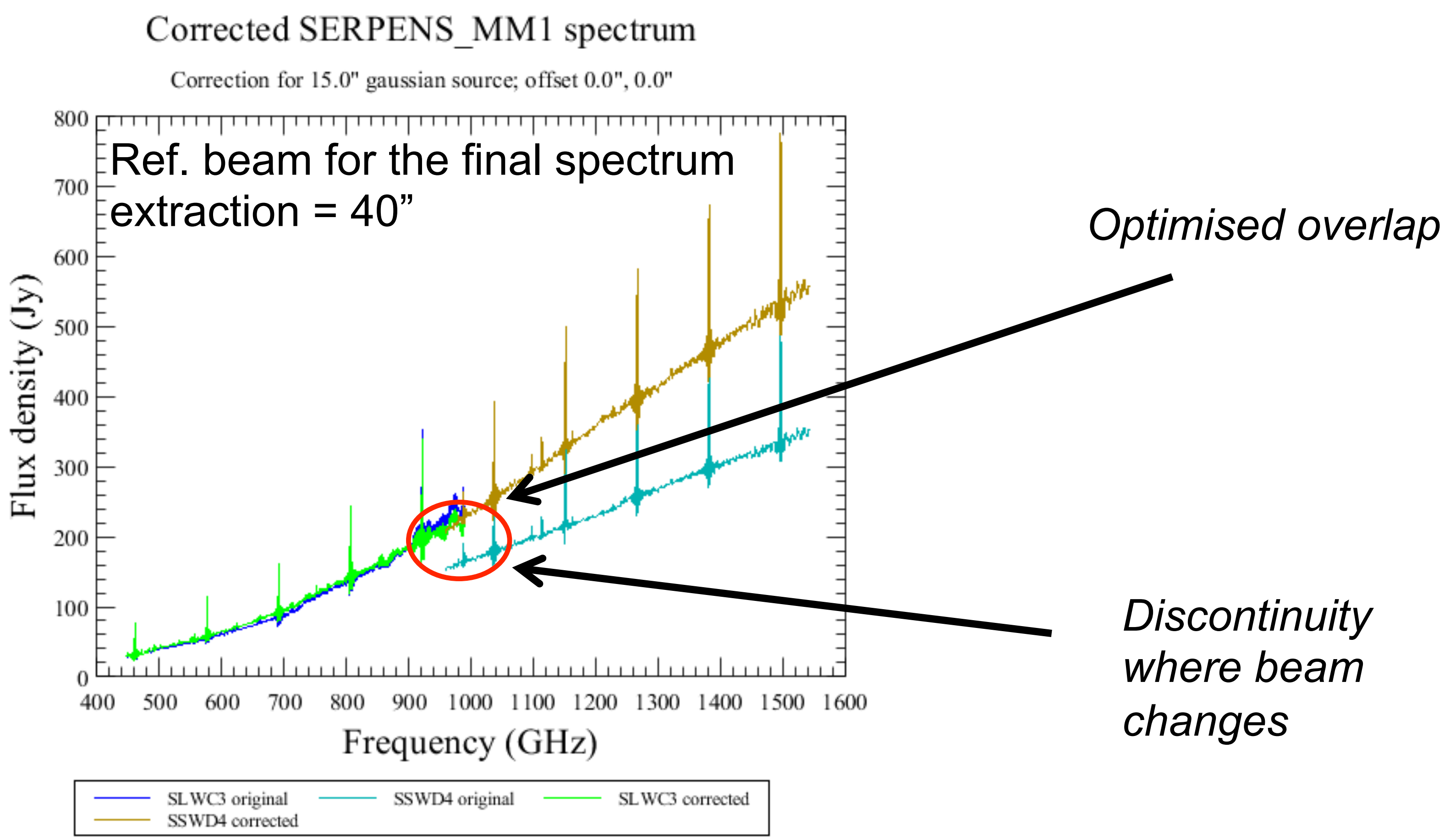


Units of output spectrum are Jy "in the reference beam"



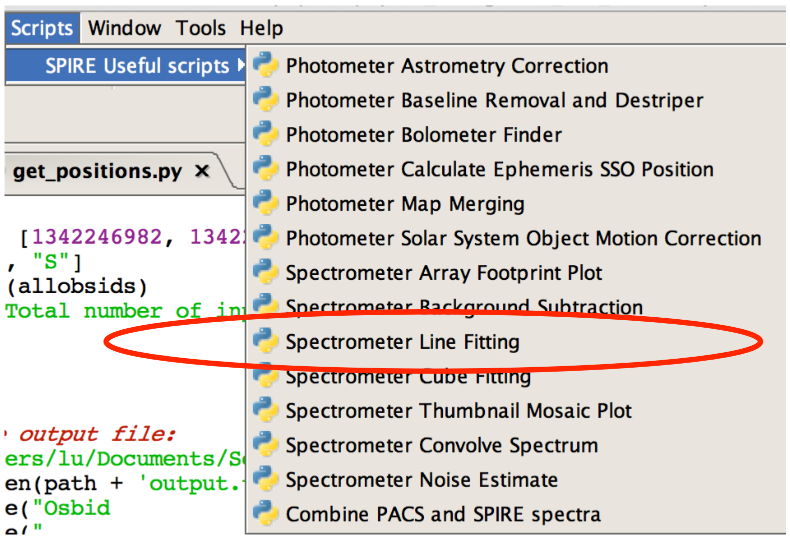
Theory is described in [*Wu et al., A&A, 556, 116 (2013*](#)

Serpens MM1 (1342216893)



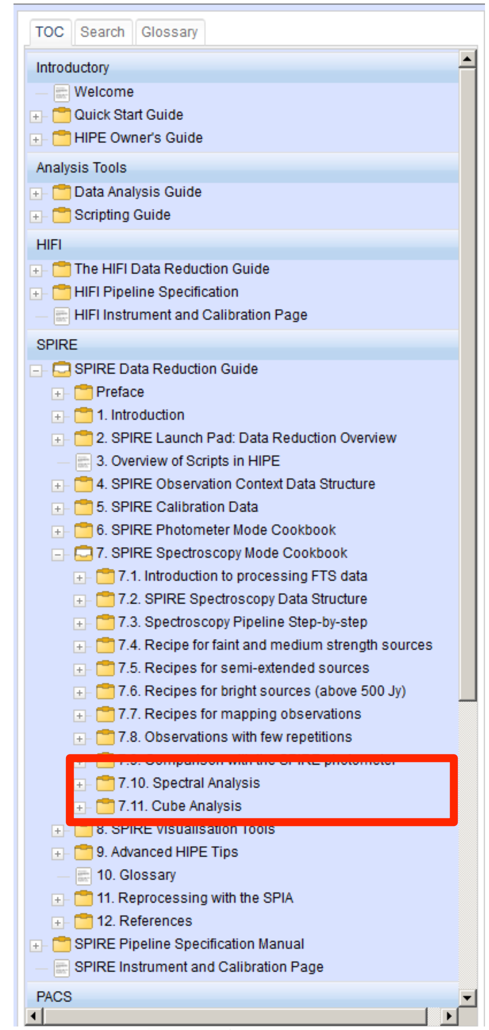
Spectral Line Fluxes

- Line fitting script (for unresolved lines):



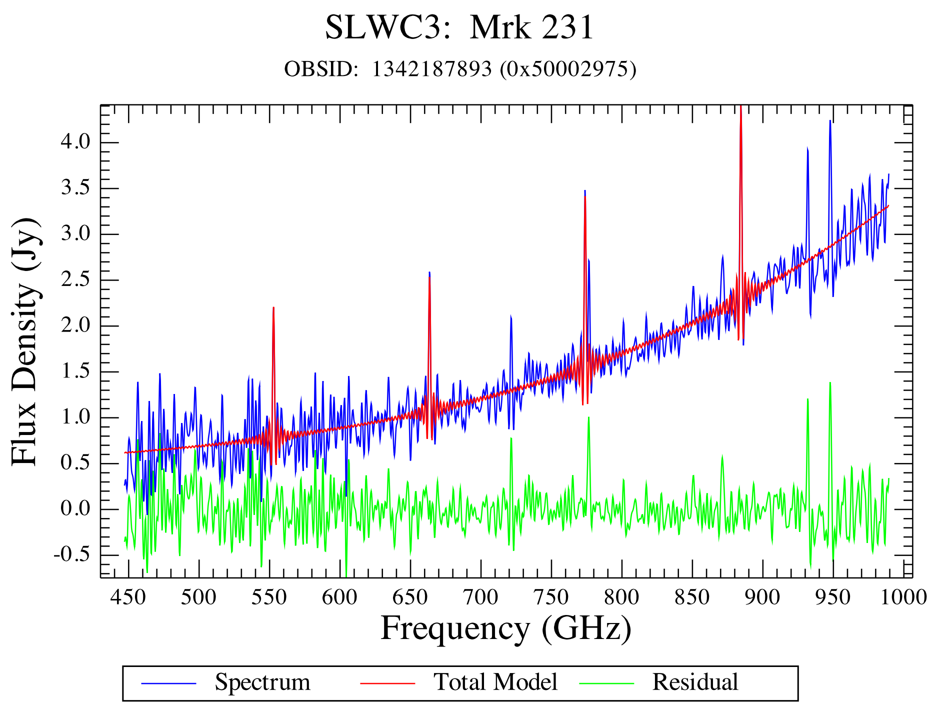
- Interactive line fitting (both unresolved & partially resolved lines)
- Cube fitting script (to fit one or more lines in a cube)

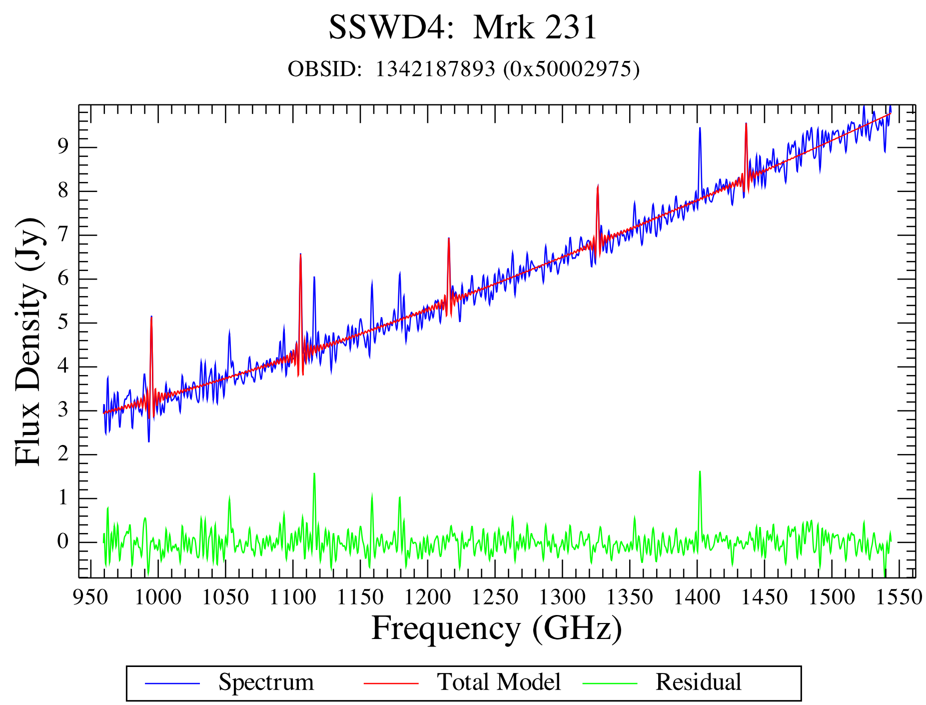
DRG



Line Fitting (for Unresolved Lines)

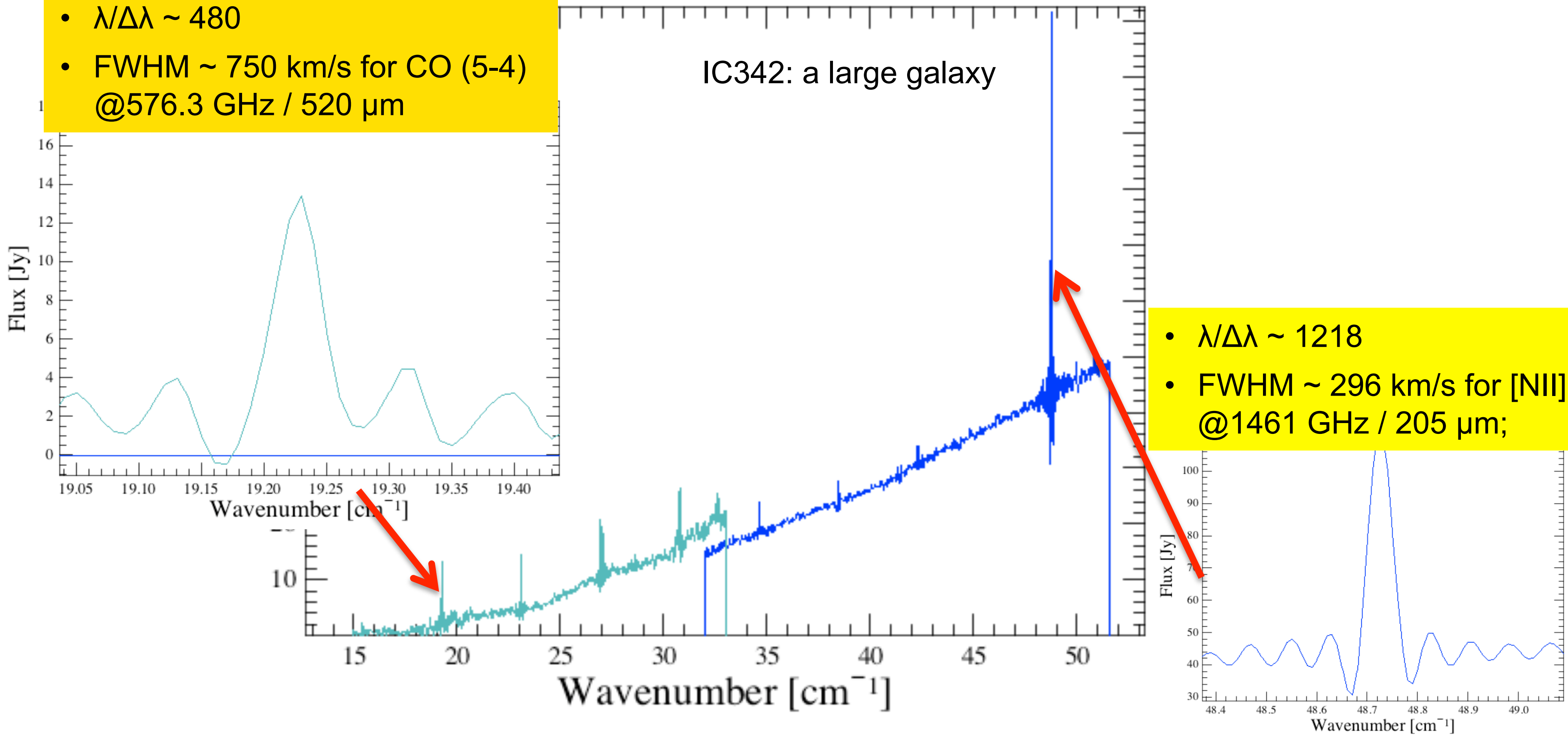
HIPE SPIRE useful script: **Spectrometer line fitting**





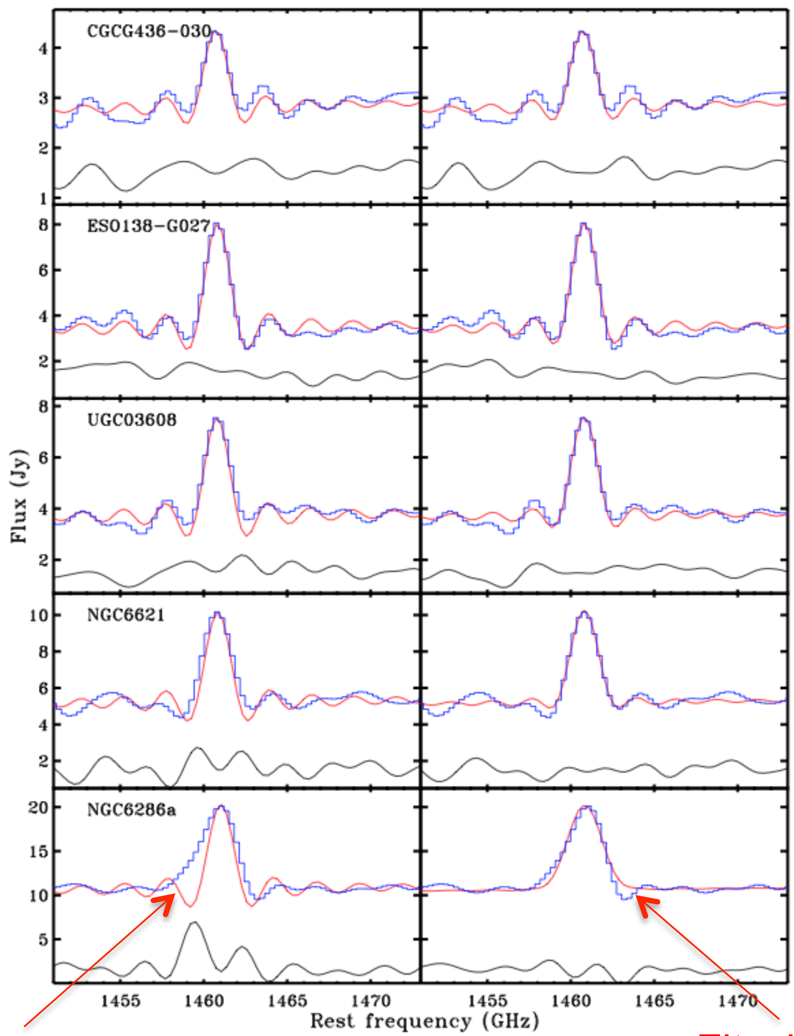
Spectral Resolving Power Depends on Wavelength

- λ/Δλ ~ 480
- FWHM ~ 750 km/s for CO (5-4) @576.3 GHz / 520 µm



- λ/Δλ ~ 1218
- FWHM ~ 296 km/s for [NII] @1461 GHz / 205 µm;

Partailly Resolved Lines

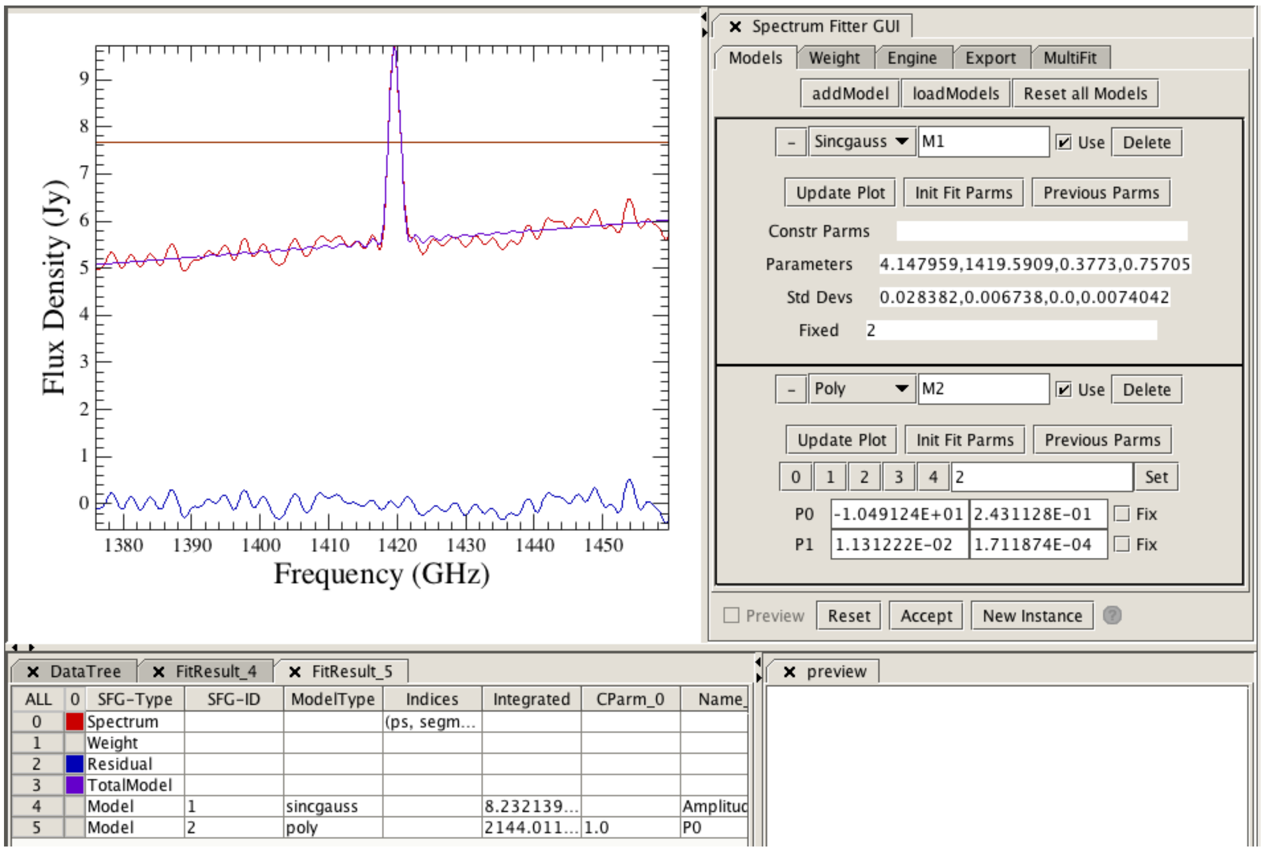


Fit with SINC only

Fit with SINC convolved with Gaussian (SincGauss model)

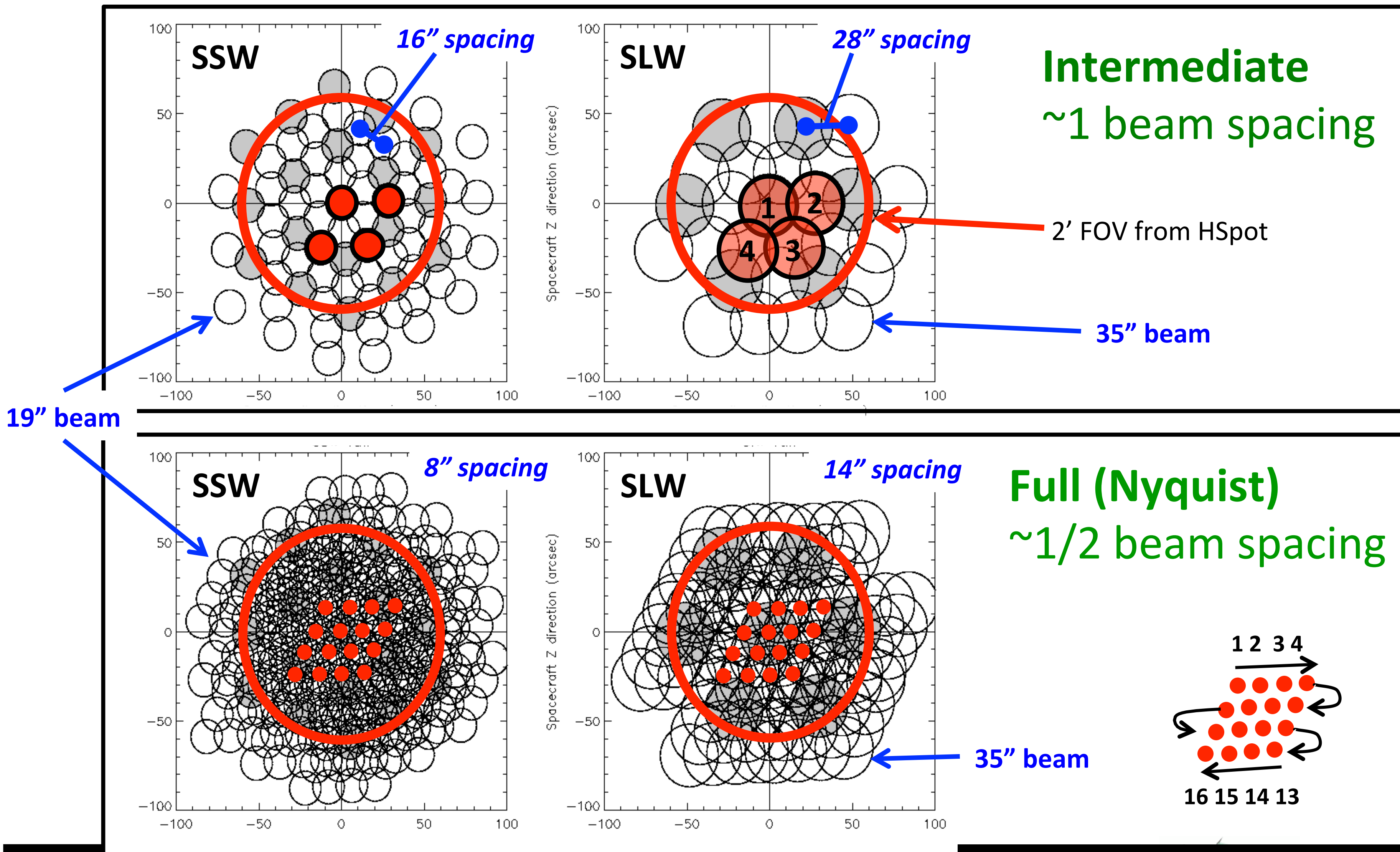
- The [NII] 205 μm line might be partially resolved if its intrinsic velocity is large enough (e.g., > 250 km/s)
- In this case, either use a SincGauss model to fit the line, or apply a correction factor to compensate for the flux underestimate in using a SINC-only line profile (see DRG Sect. 7.10.7)

Interacvtive Line Fitting: SincGauss Profile



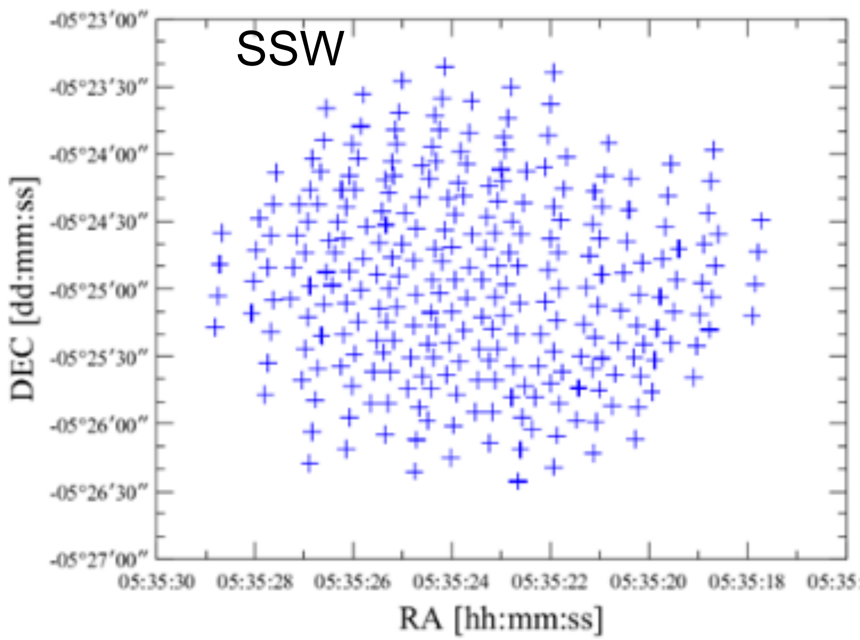
- Works best when S/N is high.
- For fainter lines, it might be better to use a SINC profile for fitting, and then correct the resulting flux for an estimated velocity width (see SPIRE DRG Sect. 7.10.7 for more info).

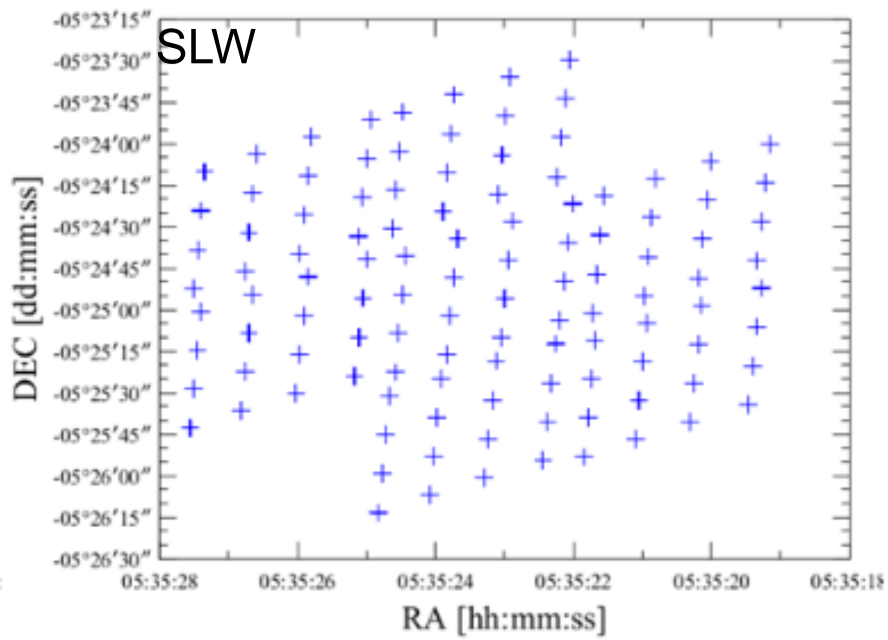
Mapping Observations



Sky Coverage

Actual positions observed on the sky for a fully sampled oobservation

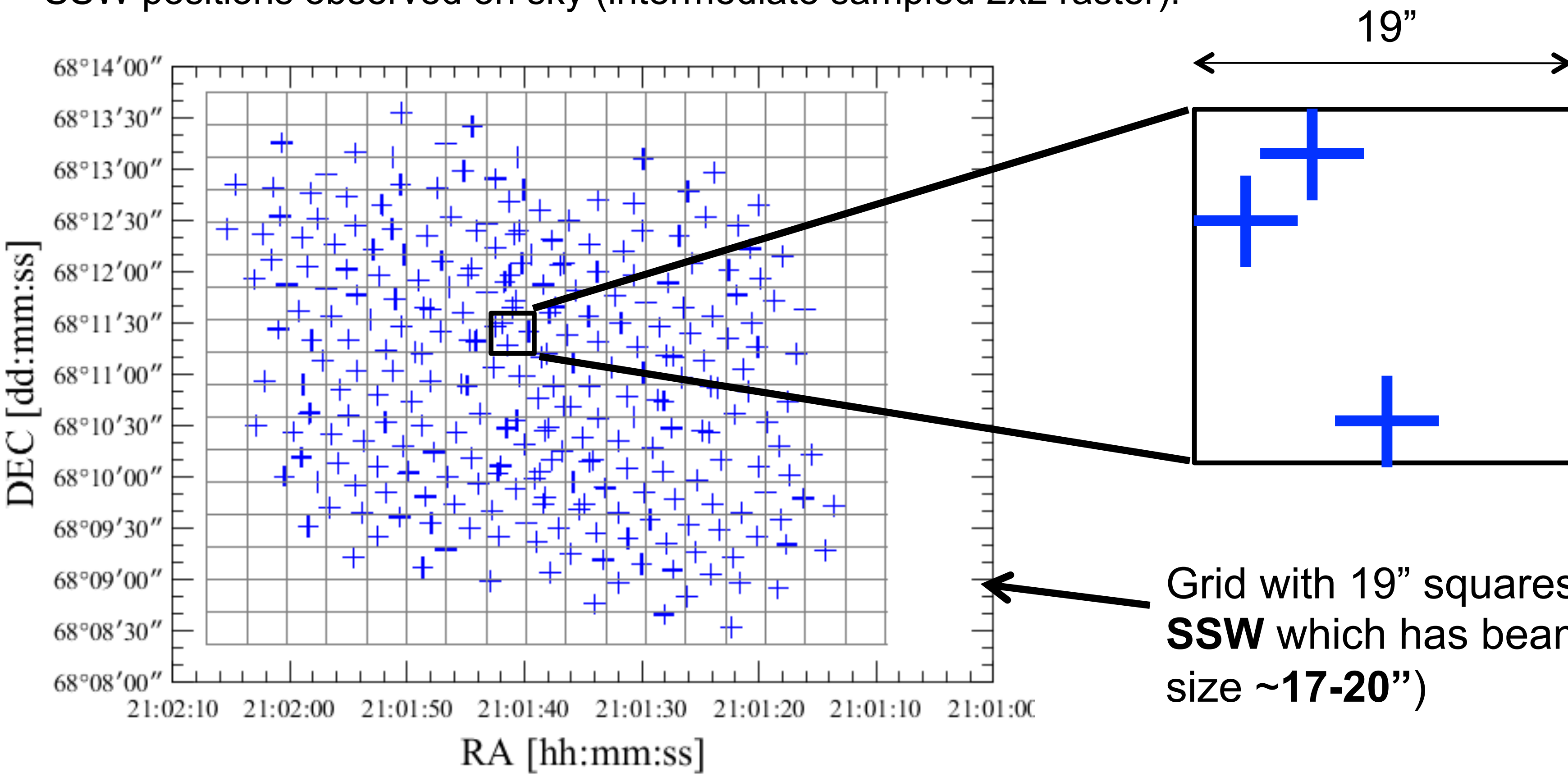




Naïve Projection

Naive Projection is the standard algorithm currently used in the pipeline

SSW positions observed on sky (intermediate sampled 2x2 raster):



Grid with 19” squares (for **SSW** which has beam size ~**17-20”**)

Mapping Observations: Investigation & Analysis

DRG

7.7. Recipes for mapping observations
- 7.7.1. Understanding the SPIRE beam and how it relates to mapping observations
- 7.7.2. Check clipping
- 7.7.3. Restricting the data made into the cube
- 7.7.4. Pointing Information
- 7.7.5. Gridding Algorithm
- 7.7.6. Combining several observations
- 7.7.7. Holes in the map: examining the coverage
- 7.7.8. Maps with faint continuum levels

Investigate the data before mapping:
- Exclude some data?
- Select a map maker (e.g., naïve)
- Grid size considerations
- ….

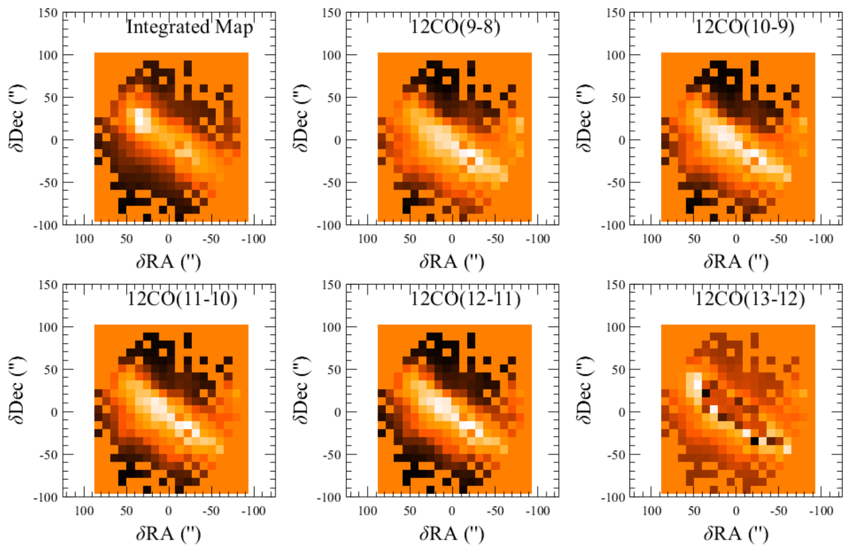
7.11. Cube Analysis
- 7.11.1. SPIRE cubes, general considerations
- 7.11.2. Extracting spectra from a SPIRE spectral cube
- 7.11.3. Extracting a point source from the map
- 7.11.4. Matching cube spectra from SSW and SLW
- 7.11.5. Convolving a cube to a different beam size
- 7.11.6. Cube fitting with the Spectrum Fitter GUI
- 7.11.7. Cube fitting and line intensity/velocity maps
- 7.11.8. Publication quality plots for mapping data
- 7.11.9. Comparison with photometer maps

Analyse the data in the final cube:
- Convolve to different beam sizes
- Fit spectral lines to produce line map
- ….

Cube Analysis Examples

- Line intensity maps:

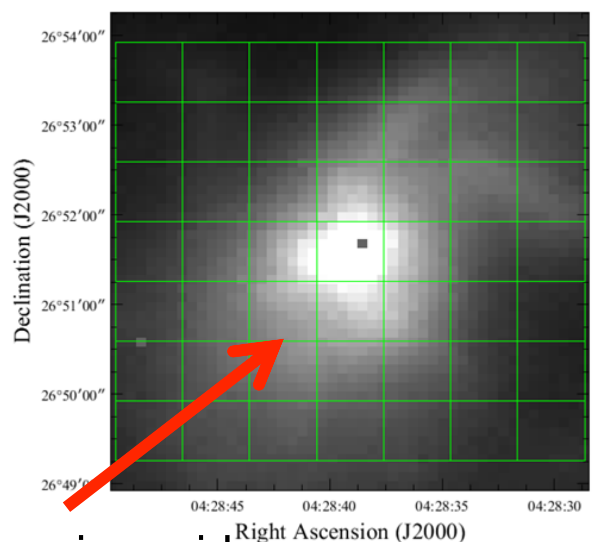
CO line intensity maps

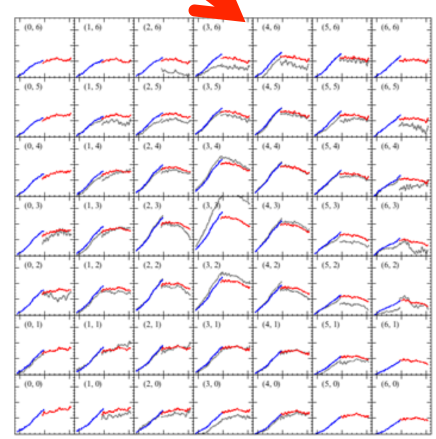


- Convolving a cube to a common beam size (i.e., independent of λ)

Grid of FTS spectra:

- Black curves: original data
- Blue/Red: convolved to a common beam of 80 arcsec





Photometer map of Orion Bar + FTS mapping grid