Line Spectroscopy from Herschel

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The Herschel spectrometers vs ALMA

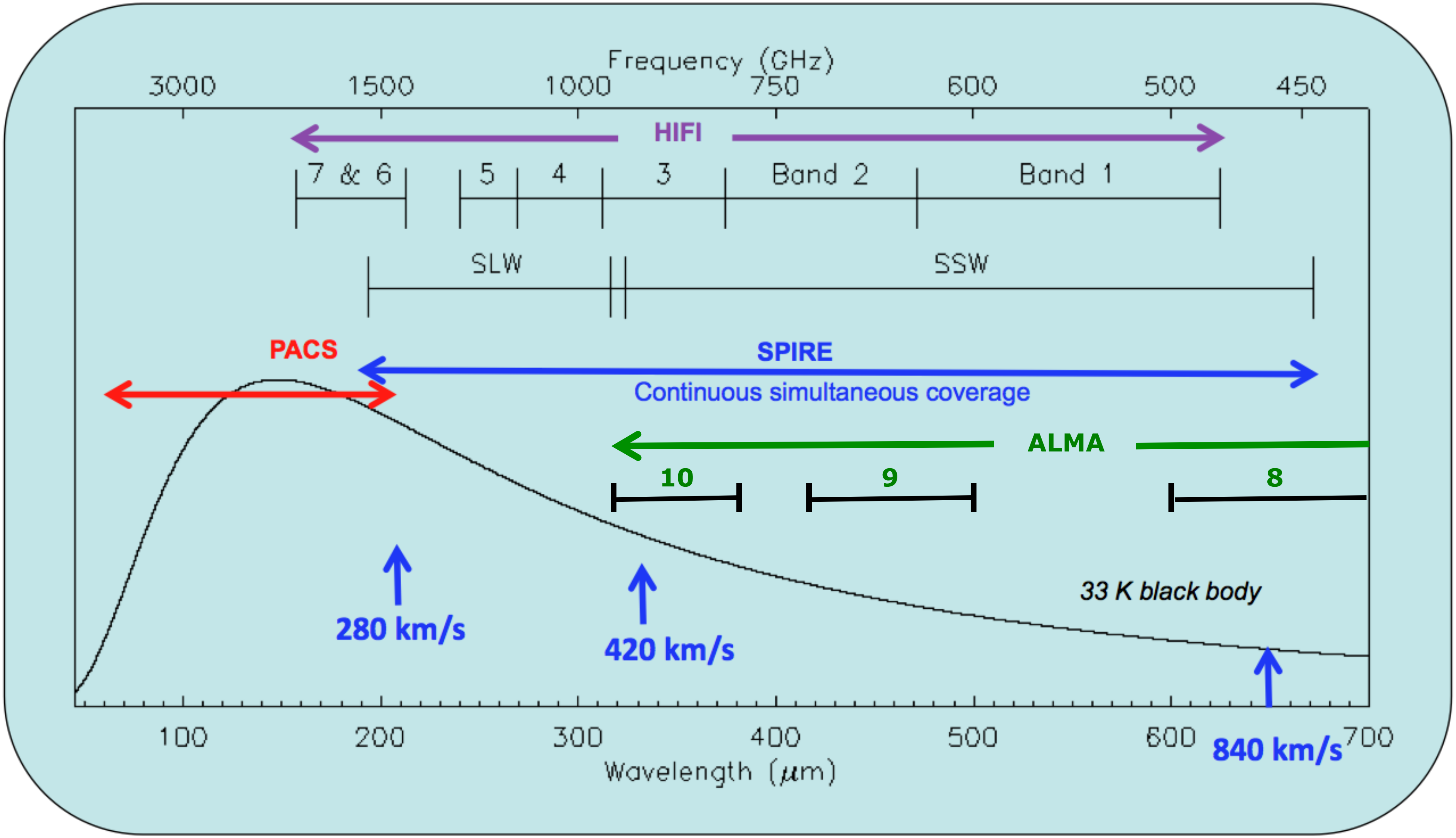
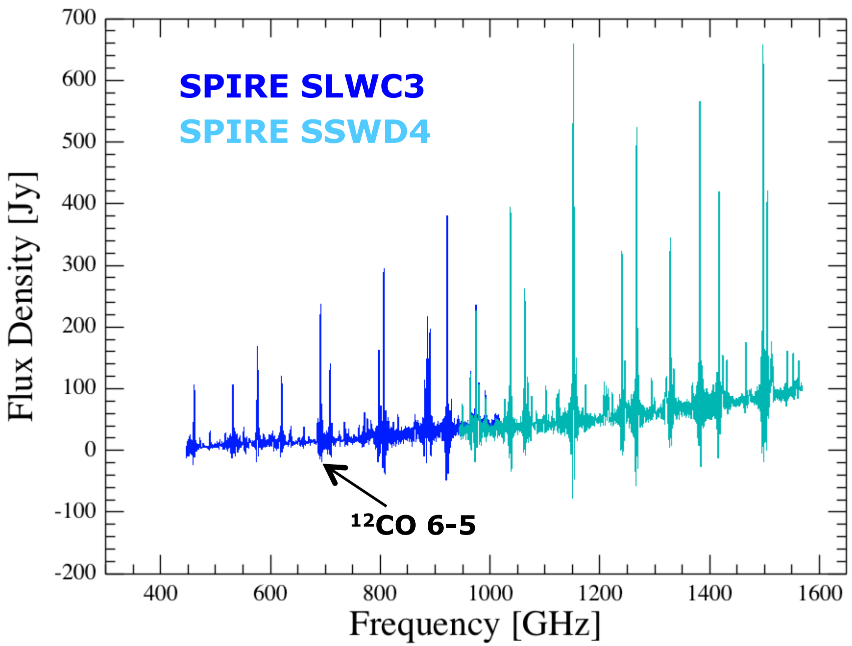
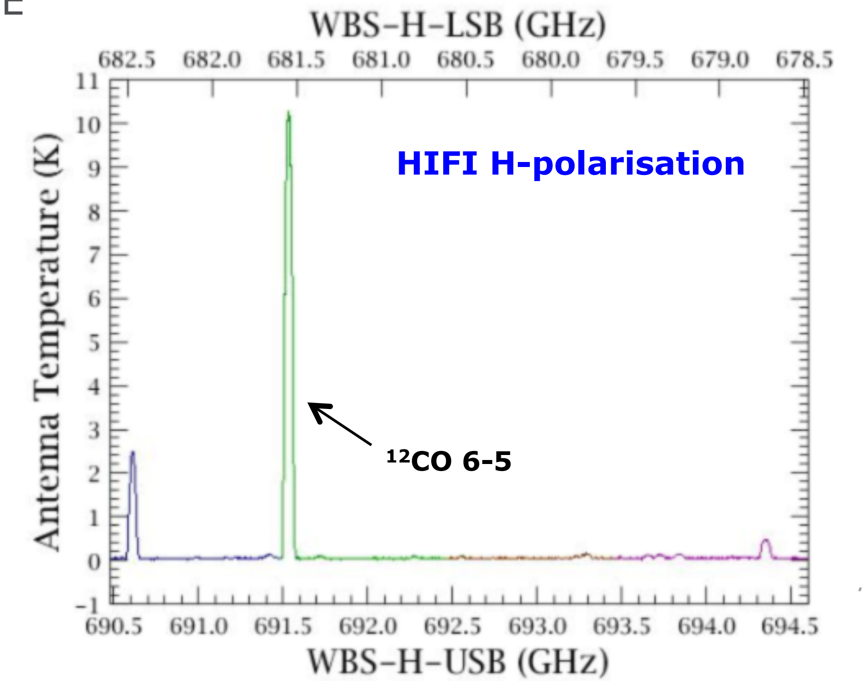


Image credit: C. Pearson (SPIRE ICC)

Science case: line flux extraction

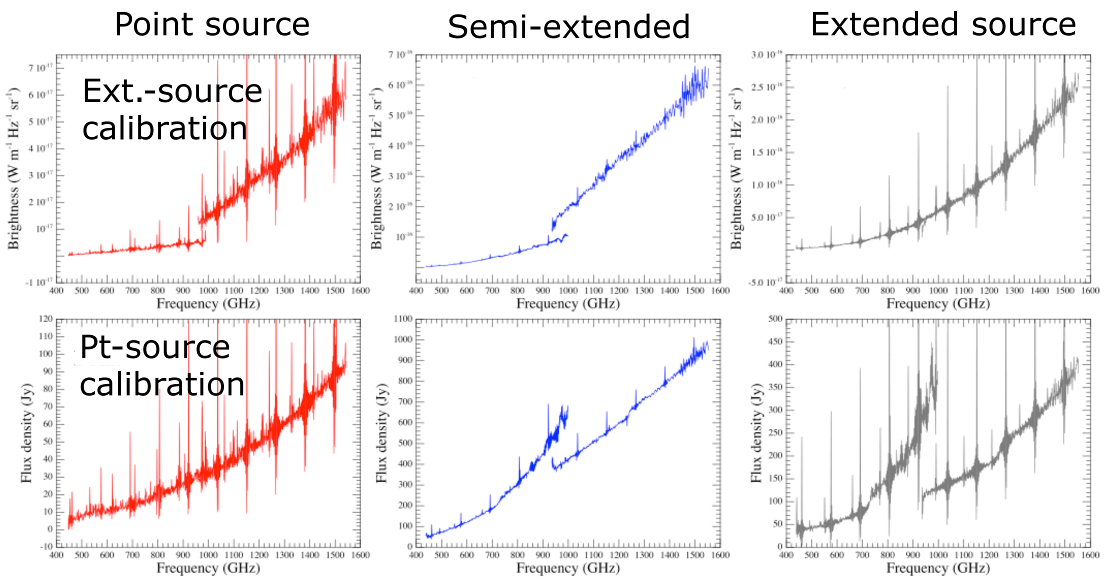
1. Considered science case: extract flux of the **^{12}CO(6-5)** line at 691 GHz (upper end of ALMA band 9) for both **HIFI** and **SPIRE** in the C-rich evolved star **IRC+10216**
   a. SPIRE data taken from ObsID 1342256105 (sparse mode)
   b. HIFI data taken from ObsID 1342196477 (single LO tuning)
   c. Work from stand-alone browse products downloaded from HSA (as of 12.1)
      – for SPIRE we will use the *point-source calibrated* spectra in Jy
      – For HIFI we will use the USB spectra calibrated in T_A^* (K)
   d. Flux extraction is performed in HIPE

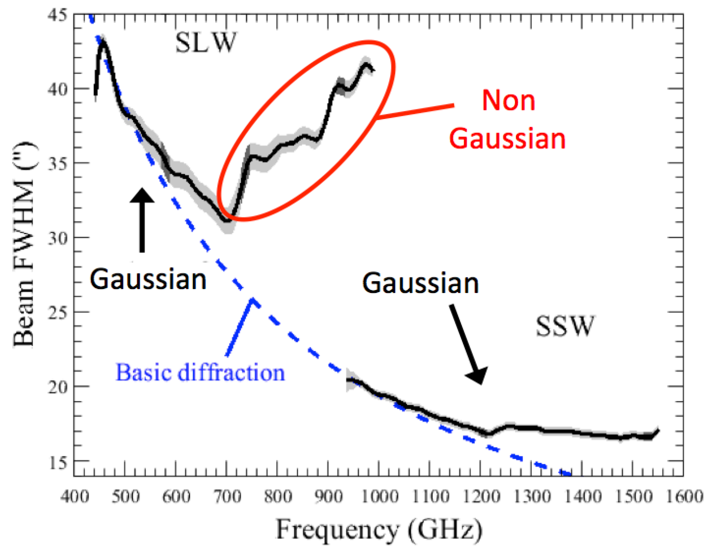




Semi-extended sources in SPIRE-S data

1. The FTS calibration is good for either point sources ("point-source calibrated" products) or extended sources ("extended-source calibrated" products).
2. For semi-extended sources an additional correction for the coupling of the beam to the source is needed
   a. Semi-compactness can be evidenced by a jump between SLW and SSW (!! Could also be mis-pointing or background contamination !!)
   b. A tool called **SECT** (Semi-Extended Correction Tool) is available for that in HIPE (see also Wu et al. 2013, A&A 556, 116)

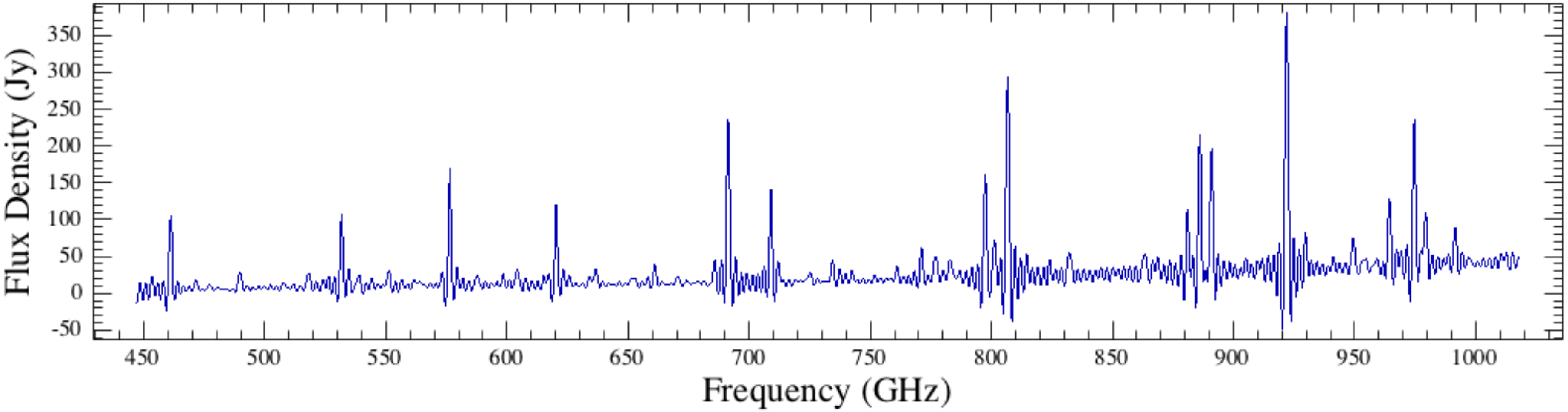




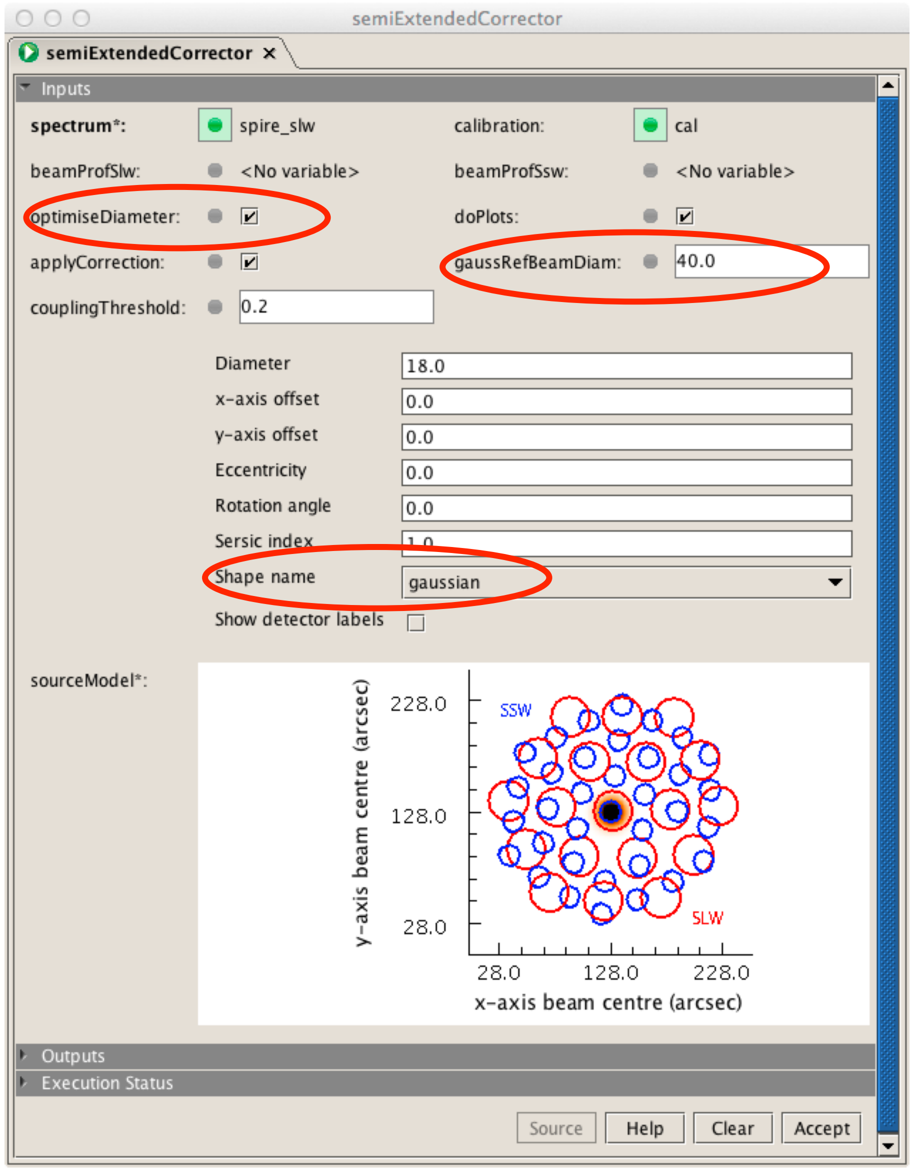
Line flux extraction in SPIRE data

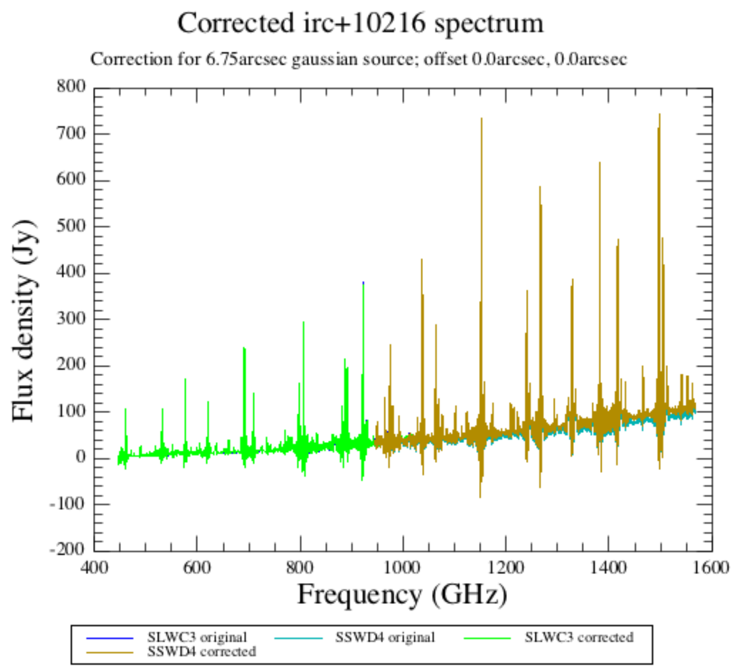
SPIRE line flux extraction work flow

1. If the source is semi-extended, run the **SECT** on point-source calibrated data to correct for the beam coupling (*!! Background emission correction can also be considered !!*)
2. For strictly point-like sources or extended sources, use the respective calibrated data from the level 1 or 2 (both at level 2 in HIPE 13) and go to step 3
3. Run cardinal sine (*sinc*) line fitting (**!! SPIRE provides unapodised spectra !!**)
   a. A useful script is available in HIPE ("***Spectrometer Line Fitting***")
   b. In case of high line density (like in our case), it is important to include more lines in the fitting than only the line of interest – flux from neighbouring lines can alter both the fitted continuum level and the fit to the line of interest



Semi-Extended Source Correction Tool

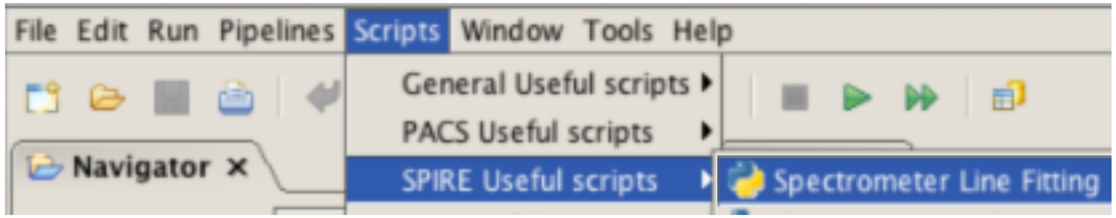




1. Various source shape models
2. Entire spectrum recalibrated to a common Gaussian beam size
3. Can account for mis-pointing
4. Can be used in automatic fashion to find the best source size based on the match at the SLW/SSW overlap (**here 6.5″**)

Unapodised SPIRE line fitting

1. SPIRE useful script available in HIPE



2. Fitting script uses 1) source velocity or redshift, 2) line list to be fitted (at rest frequency) – default provided, should be adapted to needs by user
3. Line list can be entered in the script or read from an external file

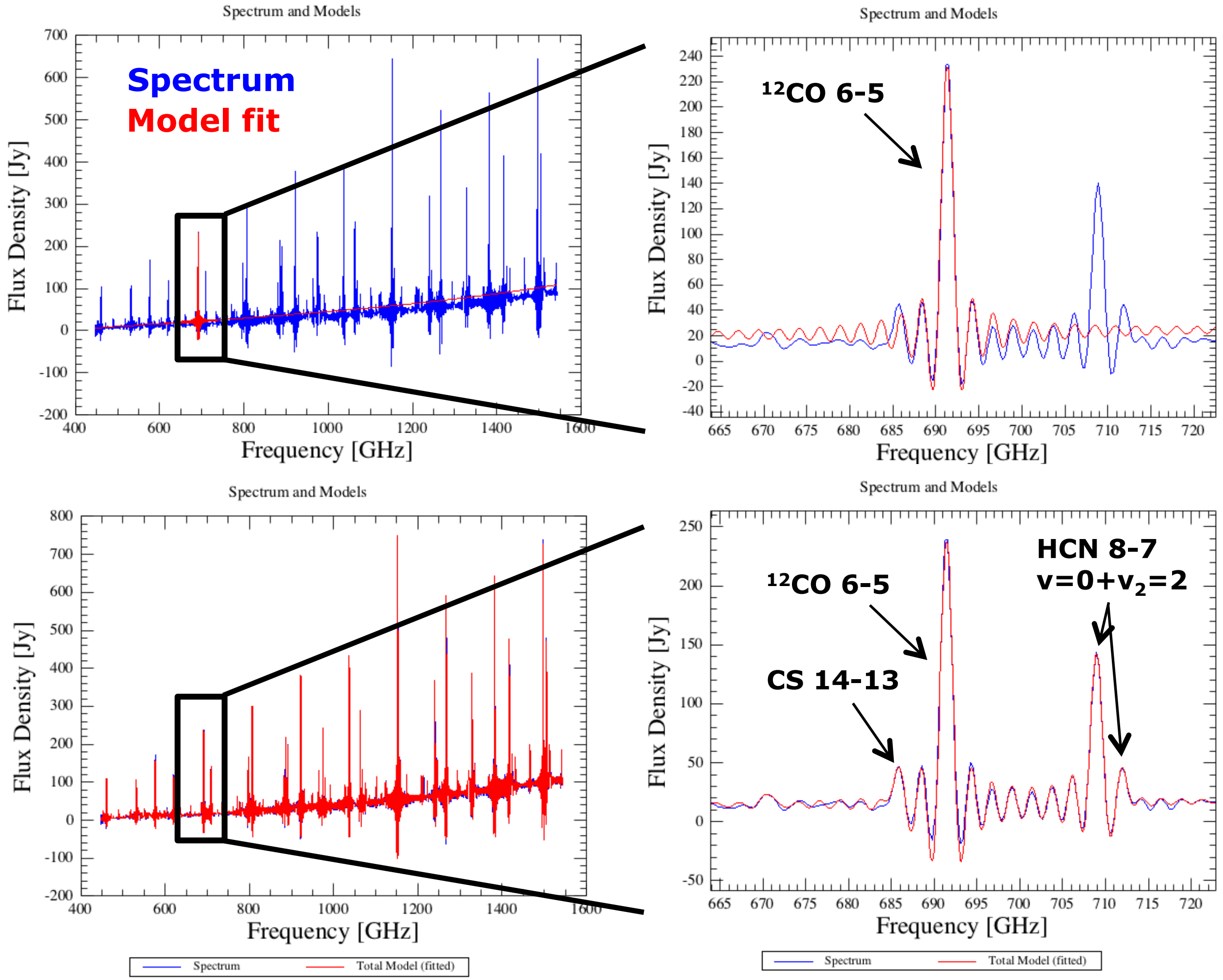
```
# the frequency range. Rest frame frequencies in GHz should be used.
# Below are the default set of lines that will be fitted, which are the 12CO
# ladder (The Cologne Database for Molecular Spectroscopy
# http://www.astro.uni-koeln.de/cdms/):
lineFreqs = Double1d([461.0407682,576.2679305,691.4730763,806.6518060,921.7997000,\
                      1036.9123930,1151.9854520,1267.0144860,1381.9951050,1496.9229090])

lineNames = String1d(['12CO(4-3)','12CO(5-4)','12CO(6-5)','12CO(7-6)','12CO(8-7)',\
                     '12CO(9-8)','12CO(10-9)','12CO(11-10)','12CO(12-11)','12CO(13-12)'])
```

4. The fit will consider a polynomial continuum baseline (default order is 3 – can be changed by user) and a **sinc** profile for each individual line (**fixed** pre-defined width according to SPIRE spectral response)

Unapodised SPIRE line fitting

Importance of multi-line fitting in high line density sources

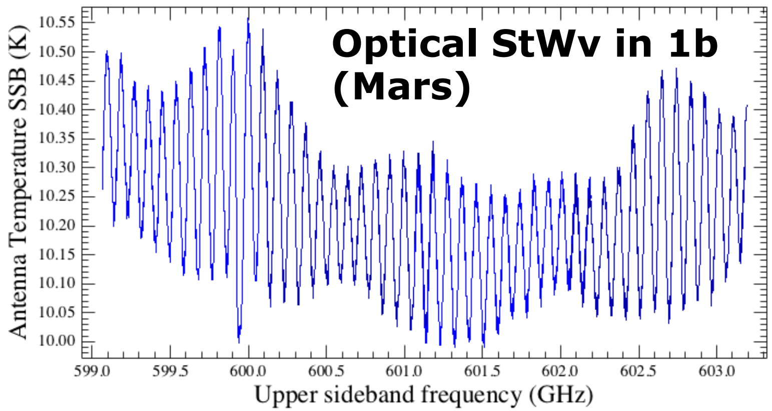


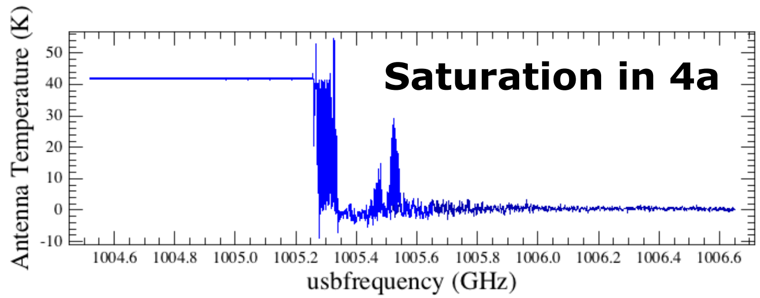
1. Single line model fit leads to inaccurate continuum fit
2. In these conditions the extracted flux is **1.0×10^5 Jy.km/s (2.4×10^{-15} W/m^2)**
3. Multi-line model fit accounts better for side-lobe ringing of the sinc profile due to neighbouring lines
4. In this second fit, the extracted flux is **1.1×10^5 Jy.km/s (2.6×10^{-15} W/m^2)**

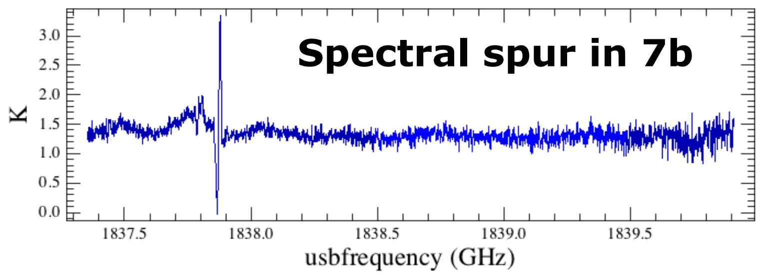
Line flux extraction in HIFI data

How good are the data from the stand-alone browse products ?

1. The pipeline end-products use a 3-point (hot/cold/off) "*chopper-wheel*" bandpass calibration method – means that residual baseline artifacts from fast gain drift can still affect the data
2. The most common residual artifacts in the final products are:
    a. Optical standing waves, showing up as (multiplicative) sine waves modulating the spectra
    b. Electrical standing waves (bands 6-7) that have not been optimally removed by the pipeline
    c. Spurious signals arising from the Local Oscillator (LO) – spectral purity issues, saturation, or LO excess noise, especially in diplexer bands 3/4/6/7







Line flux extraction in HIFI data

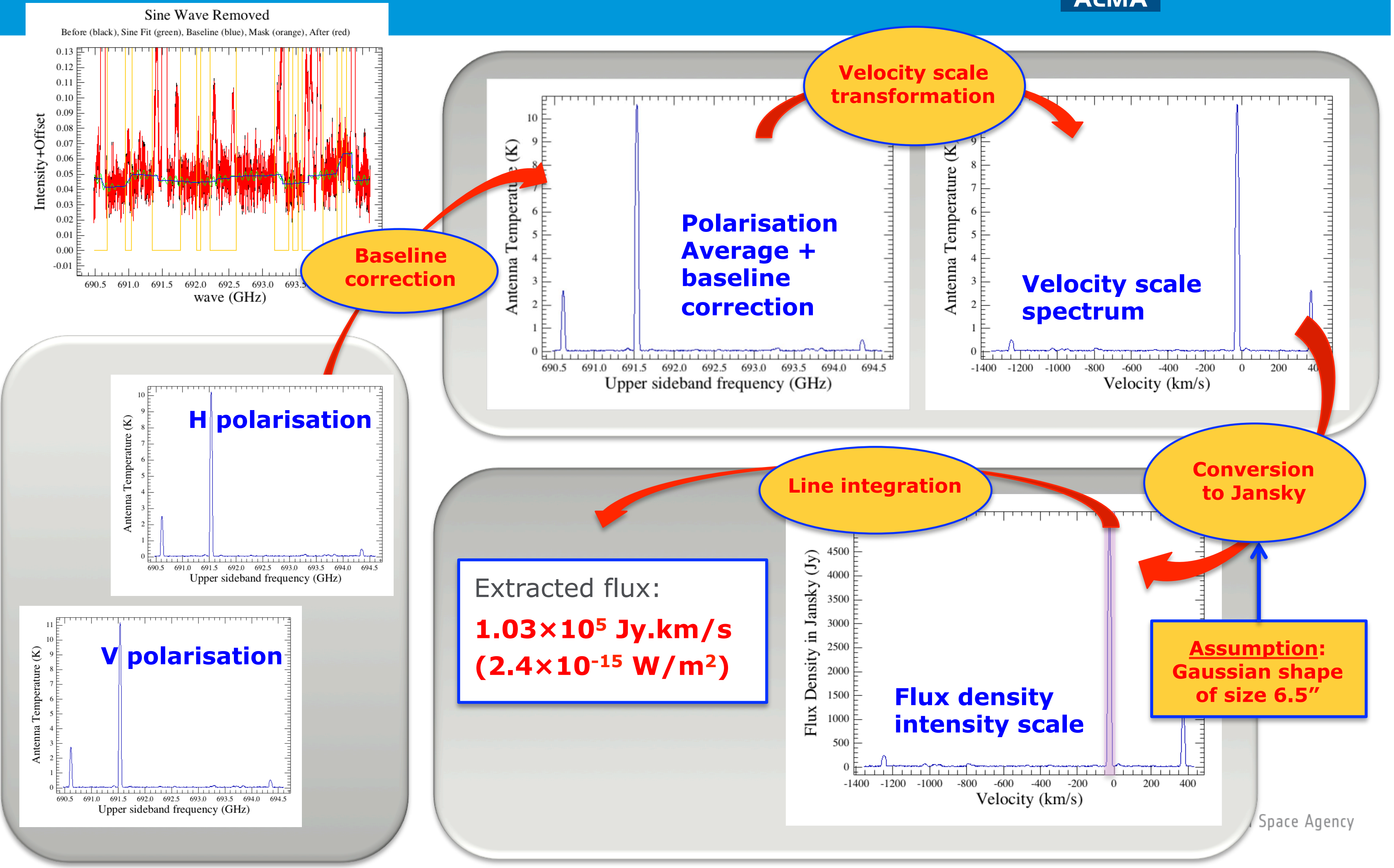
HIFI line flux extraction work flow

1. Depending on data quality, remove possible baseline artefacts – in HIPE use **flagTool** and **FitHifiFringe** (optimises fitted sine wave components to optical model of a given band)
2. If both H and V polarisations offer usable (and comparable) data, average spectra for improvement in signal-to-noise ratio – in HIPE use **polarPair**
3. If needed, turn frequency scale into velocity scale – in HIPE use **ConvertWavescale**
4. Convert spectrum into most adequate intensity scale
   a. Conversion to main beam temperature (T_{mb}) – in HIPE use **doMainBeamTemp** (will use the applicable HIFI coupling efficiencies)
   b. Conversion into flux density – in HIPE use **ConvertK2Jy**. Note that this task uses the detailed (non-Gaussian) HIFI PSF model in case of non pt-like sources
   c. Applicable coupling efficiencies can be found in the following report:

http://herschel.esac.esa.int/twiki/pub/Public/HifiCalibrationWeb/HifiBeamReleaseNote_Sep2014.pdf

5. Integrate line(s) of interest over applicable velocity/frequency interval

Line flux extraction in HIFI data



Space Agency

Epilogue

HIPE vs other data analysis packages

1. Many of the steps in the previous workflows are covered by other standard data analysis packages (e.g. Class, IDL, CASA), however unique built-in instrument models and algorithms are provided in **SECT** (SPIRE), **FitHifiFringe** and **ConvertK2Jy** (HIFI)

Cross-calibration and science interpretation

1. *Herschel* cross-calibration: the previous exercise shows excellent agreement between the HIFI and SPIRE extracted line fluxes (within 10%)
   a. Suggests proper assumption reg. the source size for conversion from antenna temperature to flux density and good understanding of the instrument PSF's
2. Comparison with ALMA –what can we learn ?
   a. At the ^{12}CO 6-5 frequency, the Herschel spatial resolution is ~30" and the ALMA primary beam is ~8"
   b. *Herschel* line fluxes very much in excess of the primary-beam-averaged ALMA flux will indicate significant extended emission being resolved out by ALMA
   c. As such the flux comparison can be used to gauge the compactness vs extended nature of a given line brightness distribution in the ALMA beam (see e.g. Decin et al. 2015)

References

For further information about the above tasks and workflows please refer to:

The SPIRE Handbook: http://herschel.esac.esa.int/Docs/SPIRE/spire_handbook.pdf

The SPIRE Data Reduction Guide:
http://herschel.esac.esa.int/hcss-doc-13.0/print/spire_drg/spire_drg.pdf#spire_drg

The HIFI Handbook: http://herschel.esac.esa.int/Docs/HIFI/pdf/hifi_om.pdf

The HIFI Data Reduction Guide: http://herschel.esac.esa.int/hcss-doc-13.0/index.jsp#hifi_um:hifi-um

or contact our helpdesk

https://herschel.esac.esa.int/esupport/