SPIRE Spectrometer Data Reduction: Spectral Line Fitting

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Goals

- Briefly discuss the SPIRE FTS instrumental line shape.
- Demos on how to fit lines and derive line fluxes in SPIRE FTS spectra:
  - Interactive line fitting with HIPE SpectrumFitter GUI.
  - Fit multiple lines using a HIPE line fitting script.

Instrumental Line Shape

The finite optical path difference (OPD ≤ L) leads to a truncated interferogram, which is equivalent to a convolution of the target spectrum with a SINC function in the spectral domain:

$S'(\sigma) = S(\sigma) \otimes \sin(\pi\sigma/\Delta\sigma)/(\pi\sigma/\Delta\sigma)$], where σ = wavenumber (or frequency);
$\Delta\sigma$ = 1/(2L), the resolution element.

Observed flux density

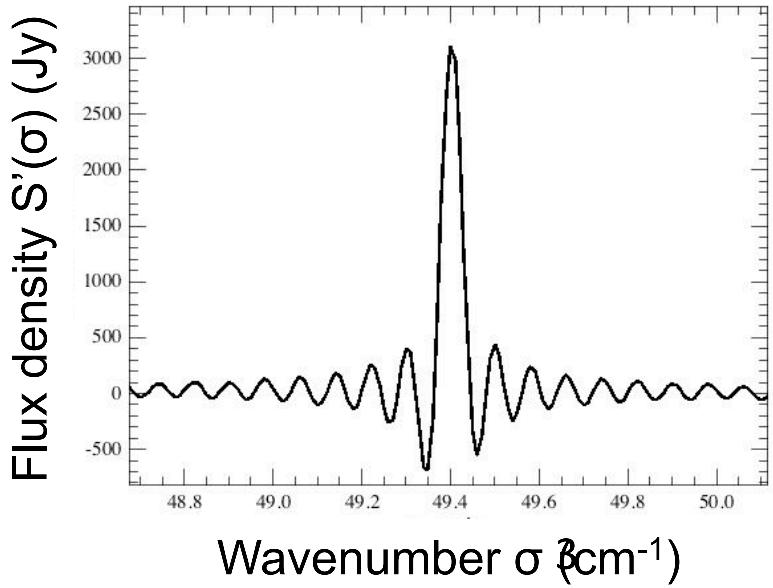
True flux density

SINC function

For an unresolved line:

- $S'(\sigma) = I_0 \sin[\pi(\sigma-\sigma_0)/\Delta\sigma]/[\pi(\sigma-\sigma_0)/\Delta\sigma]$;
- Flux $= I_0 \Delta\sigma$;
- FWHM = 1.207 $\Delta\sigma$.

($\Delta\sigma$ = 1.1854 GHz in the High Resolution Mode)



SINC Line Fitting in HIPE

6.9.6. Sinc model for unapodized lines

The natural FTS instrument line shape is given by the sinc fuction and the sinc model used by HIPE is:

$f(x{:}p) = p_0 \sin((x - p_1)/p_2) / ((x - p_1)/p_2)$

where p_0 is the amplitude at the central frequency of the line, p_1 is the central frequency, and p_2 is the width defined as

$p_2 = \Delta\sigma / \pi$ = 0.37733 GHz

where $\Delta\sigma$ is the width of one independent resolution element in the spectrum (see Section 6.1.1), equal to the distance between the peak and first zero. For high resolution mode, $\Delta\sigma$ = 1.18542 GHz and for unresolved lines p_2 can be fixed at $\Delta\sigma/\pi$ (0.37733 GHz).

Note that the full width at half maximum (FWHM) of a Sinc function can be calculated as 1.20671 * $\Delta\sigma$.

An example of the characteristic sinc shape for an unapodized line is shown in Figure 6.70

To calculate the integrated flux in W m^{-2} from the sinc fit to a point source calibrated spectrum, with flux density units of Jy, and line width in GHz, the following equation can be used,

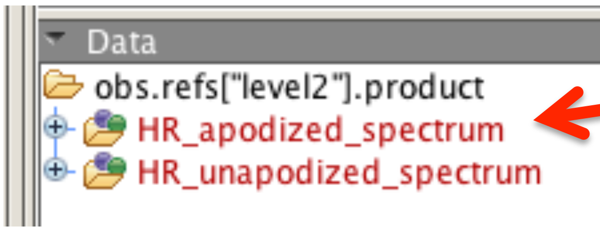
$I = \int f(x{:}p) = 10^{-26}\, p_0\, 10^9\, \pi\, p_2.$ (W/m^2)

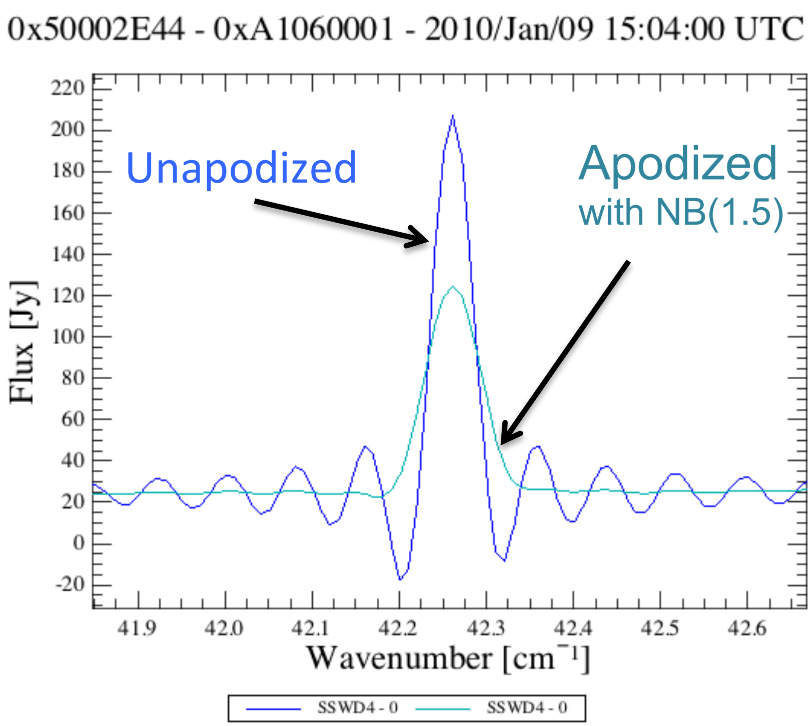
You might want to keep this as a fixed parameter

Reducing Side Lobes via Apodization

- The concept of Apodization is to further *multiply* an interferogram with some gradually tapering function to depress measurements at high optical path difference (OPD). The result is less side lobes from the SINC function at the cost of reduced spectral resolution.
- The best apodization function is such that it suppresses the side lobe the most for a given degree of line profile broadening. A family of such optimal functions is shown to be the so-called extended Norton-Beer (NB) functions (cf. Naylor & Tahic 2007 (*J. Opt. Soc. Amer, 24, 3644*)
- SPIRE FTS pipeline also provides a fully calibrated, apodized spectrum using the extended Norton-Beer function of order 1.5, or NB(1.5). The resulting line profile is about 50% wider in FWHM, appears similar to a Gaussian.

Pipeline Offers NB(1.5)-apodized Spectrum





- The pipeline provides both unapodized and NB(1.5)-apodized spectra, with proper flux calibration.
- NB(1.5) line profile is not too different from a Gaussian: a Gaussian fit to the NB(1.5) line profile may lead to a flux overestimate up to 5%.
- Most accurate line flux can be obtained by fitting a SINC function to the unapodized spectrum.

Summary Remarks

- Pipeline offers properly calibrated NB(1.5)-apodized spectrum with line profiles close to a Gaussian.
- Fit lines in the un-apodized spectrum for most accurate fluxes.
- The spectral resolution is fixed in frequency. Therefore, spectral resolving power ($R = \lambda/\Delta\lambda$) decreases as wavelength increases.
- In most cases, astronomical lines are unresolved (by SPIRE FTS). So a continuum plus one (or more) SINC functions is an adequate model to fit.
  - Possible exceptions: *[NII] 205um line in many galaxies, as well as some high-J CO lines in energetic objects, could be partially resolved. In these cases, line fitting with a Gaussian-convolved SINC profile (SincGauss model in HIPE) is more appropriate.*
- Various tools exist for fitting spectral lines and deriving line fluxes in SPIRE FTS spectra (see next slide).

Tools for SPIRE Spectral Line Analysis

- Use SpectrumFitter GUI in HIPE for interactive fitting:
  - See Herschel Data Analysis Guide, Chapter 7; and SPIRE Data Reduction Guide, Sect. 6.9.5 – 6.9.9.
- Using a script within HIPE:
  - Hipe → Scripts → SPIRE Useful scripts → Spectrometer Line Fitting
    (Also see SPIRE Data Reduction Guide, Sect. 6.9.10)

Also available:

- Use Cassis as plug-in in HIPE
  - see http://cassis.cesr.fr/ and the Cassis session at this workshop.
- An IDL based Fitter (FTFitter), via Herschel User Contributed Software at http://herschel.esac.esa.int/UserContributedSoftware.shtml

Demo on Line Fitting

- Sample data:
  - OBSID = 1342189124 (NGC7027, HR, 17 Repeats).