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The *Herschel*/SPIRE Spectrometer Useful Scripts

Edward Polehampton,[1,6] Rosalind Hopwood,[2] Ivan Valtchanov,[3] Nanyao Lu,[4] Nicola Marchili,[5] David Naylor,[6] Matthijs van der Wiel,[6] and Trevor Fulton[6]

[1]*RAL Space, Rutherford Appleton Laboratory, Didcot OX11 0QX, UK*

[2]*Imperial College London, South Kensington Campus, SW7 2AZ, UK*

[3]*ESAC, P.O. Box 78, 28691 Villanueva de la Cañada, Madrid, Spain*

[4]*NHSC/IPAC, 100-22 Caltech, Pasadena, CA 91125, USA*

[5]*Università di Padova, I-35131 Padova, Italy*

[6]*University of Lethbridge, Lethbridge, AB, T1K 3M4, Canada*

Abstract. In most cases, the Standard Product Generation (SPG) processing pipelines for the *Herschel* SPIRE Fourier Transform Spectrometer (FTS) produce well-calibrated spectra of high quality. However, some Astronomical sources, such as those with a faint continuum, require additional processing to achieve more meaningful spectra. In consultation with the astronomical community, a set of scripts were developed to assist in the post-pipeline analysis of the spectra.

1. Introduction

The final spectra produced by the Standard Product Generation (SPG) data processing pipelines for the *Herschel* SPIRE FTS (Pilbratt et al. 2010; Griffin et al. 2010) are in general of high quality (Swinyard et al. 2014). However, additional specialized processing steps may be required to maximize the scientific quality of the data, particularly for faint sources.

The SPG pipelines for the SPIRE FTS (Fulton et al. 2014) were developed to optimise results on a general basis, but were never intended to be a tool for specialized processing. In order to support interactive processing, the SPIRE FTS working group have developed a set of scripts and tasks for post-pipeline analysis within the Herschel Interactive Processing Environment (HIPE; Ott 2010). These scripts address issues such as the assessment and removal of background emission, determination of spectral noise and spectral line fitting. They are particularly useful for checking observations of very faint sources, for example. This paper briefly describes the scripts that are available.

2. Spectrometer array footprint

In order to provide information about the actual sky position of each SPIRE FTS detector, the "Spectrometer Array Footprint" useful script plots the array footprint onto an

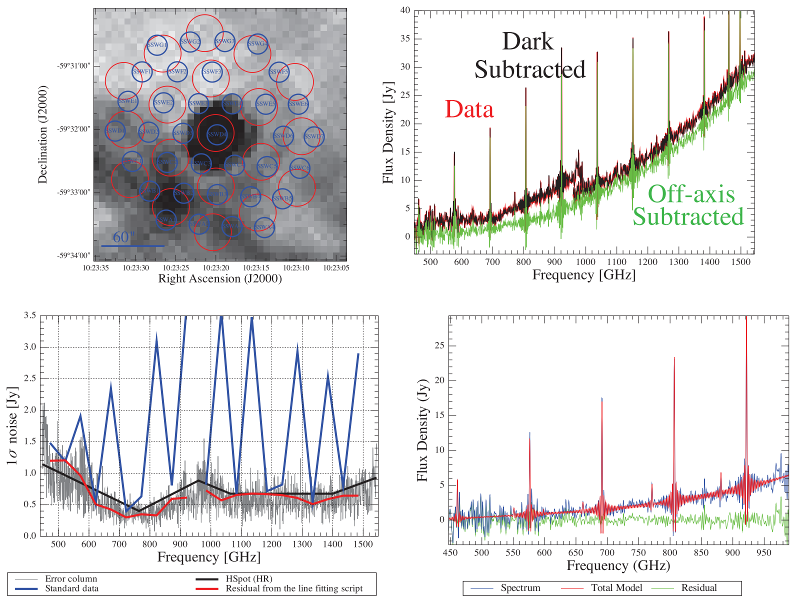

Figure 1. Example plots produced by the array footprint (top left), background subtraction (top right), noise (bottom left) and line fitting (bottom right) scripts for an evolved star spectrum. The noise plot shows both the original data which are affected by the lines (blue) and the residual after subtracting the line fit (red).

image of the source (e.g. a map from the SPIRE photometer if available) - see Fig. 1. This allows a check for extended source morphology, any extended astronomical background, or whether the telescope pointing for the observation was off target. Any of these issues can result in a discontinuity in the spectra between the two SPIRE spectral bands. Once the reason for the discontinuity has been identified, it may be possible to correct it, for example using the "Spectrometer Background Subtraction" script (see Section 3).

3. Spectrometer background subtraction

Extended background emission may be present in a SPIRE FTS observation due to astronomical background (e.g. galactic cirrus clouds), or from residual emission from the telescope or instrument. The standard pipeline subtracts the telescope and instrument emission using models based on measured temperatures. The telescope model generally reproduces the measured background spectrum to within 0.1% (Swinyard et al. 2014), but for faint sources, even this level of residual can be significant, leading to a discontinuity between the two SPIRE spectral bands and a distortion of the overall spectral shape.

The off-axis detectors can be used to estimate and remove the background from the central detectors. However, if there is unusually high systematic noise or the source is partially extended, it may be more appropriate to subtract an observation of a dark sky position instead. The "Spectrometer Background Subtraction" useful script applies both of these methods and compares the results.

The off-axis subtraction method has an option for visually examining the spectra observed by surrounding detectors to reject outliers. The selected spectra are then smoothed to give the wide-scale shape, averaged and subtracted. The "Spectrometer Array Footprint" useful script may be useful in rejecting off-axis detectors that contain neighbouring sources or uneven background emission. Dark sky observations were carried out on nearly every SPIRE FTS observing day. An appropriate observation must be selected that has the same resolution, at least as long integration time, and the same observing conditions (ideally from the same day) as the science observation.

Figure 1 shows the results of running the script on an example spectrum that is improved by the off-axis subtraction.

4. Spectrometer noise estimate

A good check of the final data quality is to examine the spectral noise achieved and compare this to the sensitivity predicted by the *Herschel* observation planning tool, HSpot (e.g. see the Valtchanov 2014). The "Spectrometer Noise Estimate" useful script estimates the spectral noise directly from the input spectrum over a specified frequency bin width. Within each bin, a baseline is subtracted and the standard deviation taken. The result is compared to the pipeline "error" column (the standard error of the mean calculated for each sample when averaging repeated scans; (Fulton et al. 2014) and the HSpot values. This is useful to compare the impact of the other useful scripts on the spectral noise - see Fig. 1.

5. Spectrometer line fitting

The "Spectrometer Line Fitting" useful script simultaneously fits the spectral lines and continuum of SPIRE FTS spectra. A default line list including only the ^{12}CO lines is included in the script, but for optimum results this should be edited to provide a full catalogue of all of the strong lines present in the spectrum. The script accepts a redshift for extragalactic sources or the intrinsic source velocity in order to improve the initial guess for the sinc parameters. It assumes that the spectral lines are unresolved, with a sinc profile (e.g. Swinyard et al. 2014) and a width fixed to the actual resolution of the detector spectrum. For each of the centre detectors, a plot of the input data, total model, and residual is produced (see Fig. 1) and the fitted line parameters and associated errors are printed to the HIPE console window. The script can be modified to customise the fit, and an extended version is available to fit all positions in a spectral cube (see Fig. 2).

6. Other scripts and tasks

Several other useful scripts are available in HIPE to demonstrate how to make a mosaic plot of the spectra from all detectors in the array, to convolve spectra from other telescopes or models to the SPIRE FTS spectral resolution, to combine spectra from SPIRE with those from the *Herschel* PACS instrument.

In addition, specialized HIPE tasks have been developed to correct sources which are partially extended in the beam (the "Semi-Extended Correction Tool"; Wu et al. 2013), to extract synthetic photometry from the spectra in order to compare with the

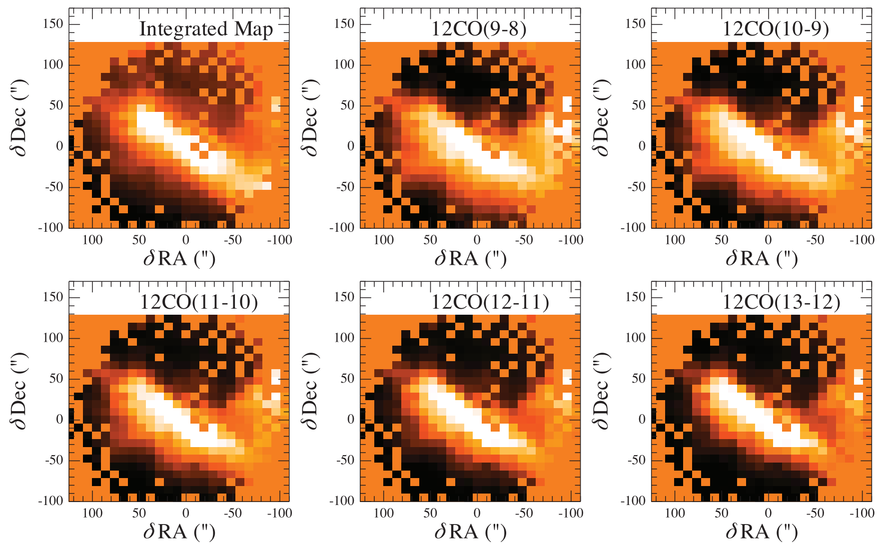

Figure 2. Continuum and Line flux maps resulting from the line fitting script that works with spectral cubes.

SPIRE photometer, and to extract point-source calibrated spectra from mapping observations. These tasks can either be called from a graphical user interface or from within a script.

Two of the useful scripts (background subtraction and noise) have also been wrapped into HIPE tasks to provide the functionality with a graphical user interface.

7. Conclusion

The SPIRE FTS useful scripts and tasks provide a complementary set of post-pipeline reduction and analysis tools. These scripts were written to present a solid basic method, and in such a way that any astronomer should find it straightforward to edit or expand on them for their specific requirements.

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