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DIGGING IN THE SPIRE FTS DIRT

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1. Introduction

The Spectral and Photometric Imaging Receiver (SPIRE; Griffin et al. 2010) operated aboard ESA's *Herschel* Space Observatory (Pilbratt et al. 2010). SPIRE's Fourier transform spectrometer (FTS) provided wide sub-millimetre coverage ~450-1550 GHz (194-671 μm), which allowed multiple lines to be simultaneously captured. Observations of FTS faint targets (<500mJy) present a strong challenge to reliably extract spectral lines, but exciting opportunities to probe high-z starforming galaxies. We present methods for improving S/N and continuum shape over standard pipeline products.

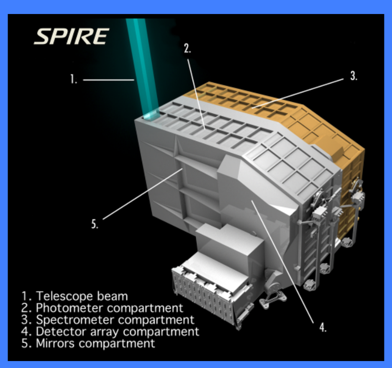


Figure 1: Artists impression of the SPIRE instrument. (credit: ESA)

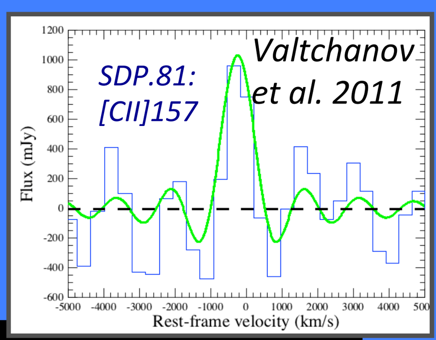
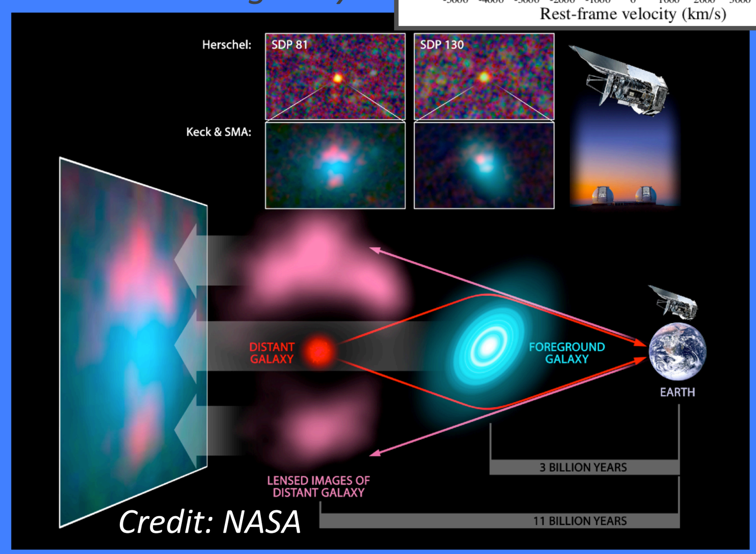


Figure 2: Valtchanov et al. 2011 identified several major ISM cooling lines in a high-z gravitationally lensed sub-millimetre galaxy.



2. Science

The ISM of mid-to-high-redshift starforming galaxies has been probed using the FTS, via important cooling lines (e.g. [CII], [OI], [OIII]), by Valtchanov et al. 2011, Ivison et al. 2010, Rigopoulou et al. 2013 and George et al. 2013. However a significant fraction of the whole FTS observing time was dedicated to faint targets and achieving the intended science goals for many of the observations is still in progress.

3. The Challenge: Noise

Three main contributing factors to FTS noise:
1) Random noise; 2) Instrumental noise;
3) Systematic noise from real signal.

1 and 2 dominate faint sources observations. When digging for faint lines (<5σ) the main challenge is to **reliably** distinguish real over noise peaks, as both manifest themselves on the same scale. Figure 3 shows three lines from science observations and three peaks from dark sky. Can you identify which is which? (Solution below).

Figure 3: Three plots show emission lines. Three show noise. All are fitted well with a sinc function + polynomial.
(See below for which "line" is which)

4. Bespoke RSRFs

One route to attempt to improve S/N (and shape) is by creating observation specific telescope RSRFs. Dark sky observations (after instrument correction) divided by the telescope model provide a daily RSRF. These RSRFs can be grouped by time or temperature and simply averaged and applied in the standard pipeline. Figure 4 shows an example in noise reduction using this approach, grouping by temperature.

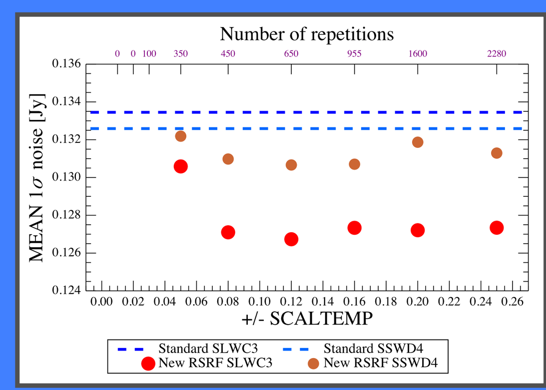


Figure 4: e.g. average noise comparison after applying the standard RSRF and RSRFs grouped by instrument temperature.

5. The Challenge: Flux Droop

During the SPIRE cooler recycle, detector temperature exhibits a steep rise, which leads to certain detectors (including the central SLW detector) suffering a droop in flux density. An empirical correction based on the correlation between detector temperature and flux density can be applied at the telescope model subtraction stage. Figure 5 shows an example of a faint source observation taken in the cooler recycle phase and the corrected spectrum.

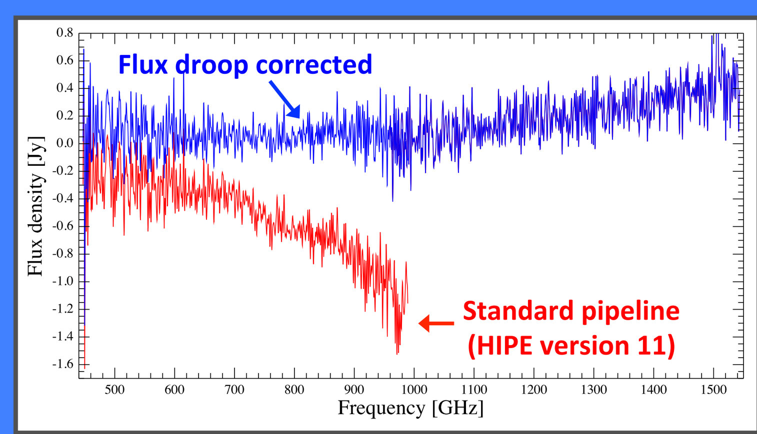
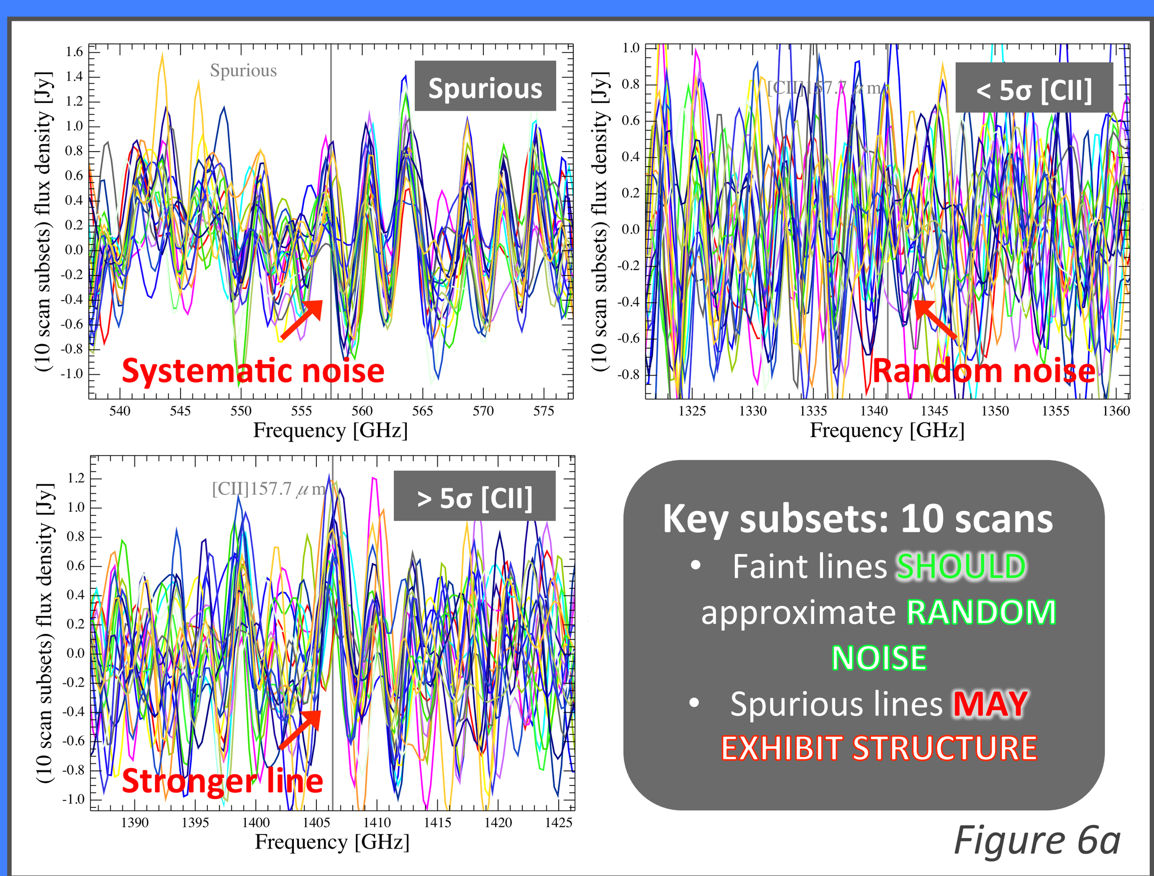


Figure 5: Faint target observation taken during a SPIRE cooler recycle, suffering SLW flux droop and the corrected spectrum. Continuum shape and fringing are improved.

6. Line Reliability

Visual assessment can be used to establish line reliability with a Jackknife approach. Using unaveraged point source calibrated data, the scans are split into groups of sequential subsets. Each scan subset is averaged and examined at expected line positions and compared to the results over all subsets. This process is repeated for subsets of decreasing numbers of scans, i.e. sets of 100, then sets of 50, down to sets of ten scans. Peaks due to real signal should show peak-like consistency throughout the scan sets, except for sets of ~10, where a more random distribution should be found. Figure 6 shows subset examples.



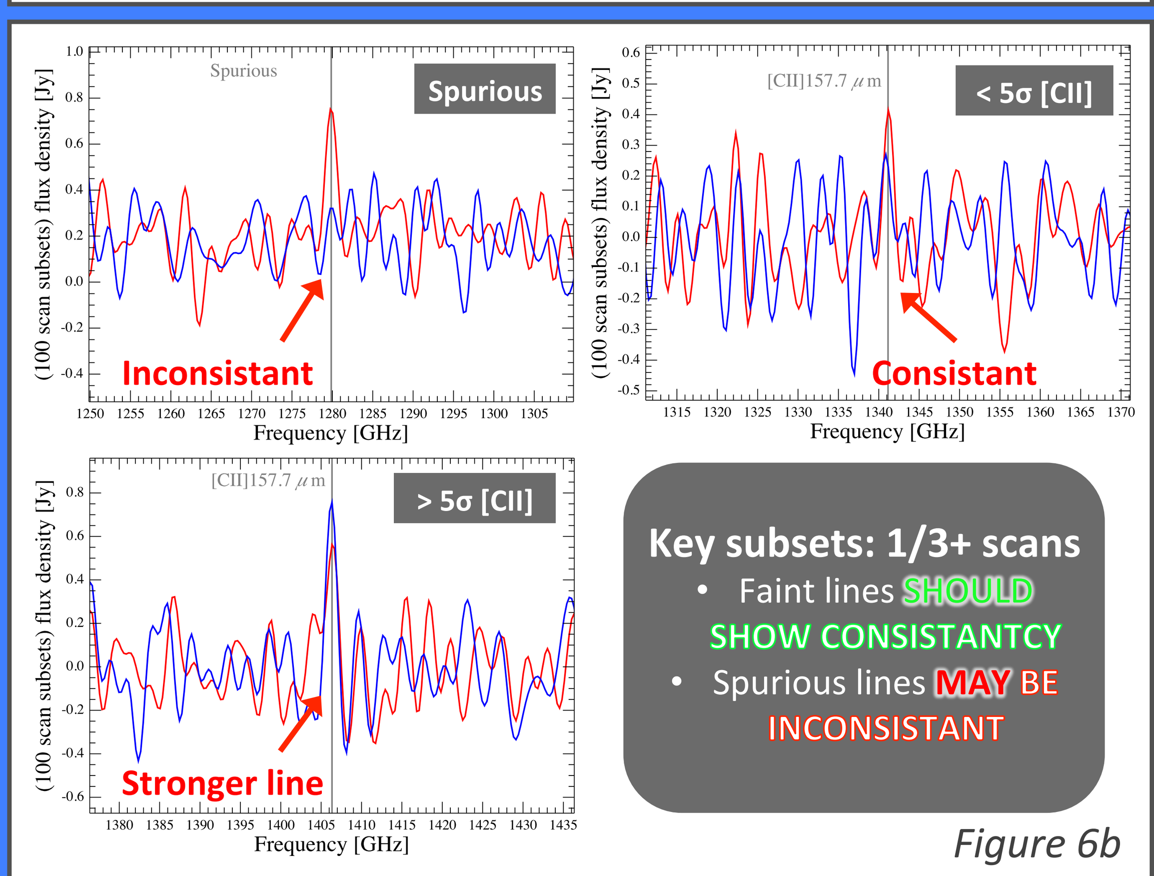


Figure 6: e.g. Jackknife scan subsets. 6a: 10 scan subsets identify one of the spurious lines in figure 3 as noise. 6b: 100 scan subsets show greater consistency for real lines (bottom left & top right) over noise (top left).

7. Line Measurements

Unresolved lines in an FTS spectra are well approximated by a sinc function. A sinc can be fitted to extract line measurements. For faint lines a statistical approach to measure line flux etc. can be made by bootstrapping the data. Unaveraged level-2 data is randomly sampled until the number in the parent population is reached. The scans are averaged and the line measurements taken from the best fit sinc. This process is repeated a statistically significant number of times (e.g. 10,000) and a Gaussian fitted to the resulting line measurement distributions to obtain the mean measurements and 1σ uncertainties. Random frequency positions can be generated and the same process applied for a reliability check. Due to the nature of FTS noise, the obtained distributions for random position are indistinguishable to those for faint lines, however, a background level can be established, above which a real spectral feature is strongly supported, as shown in figure 7.

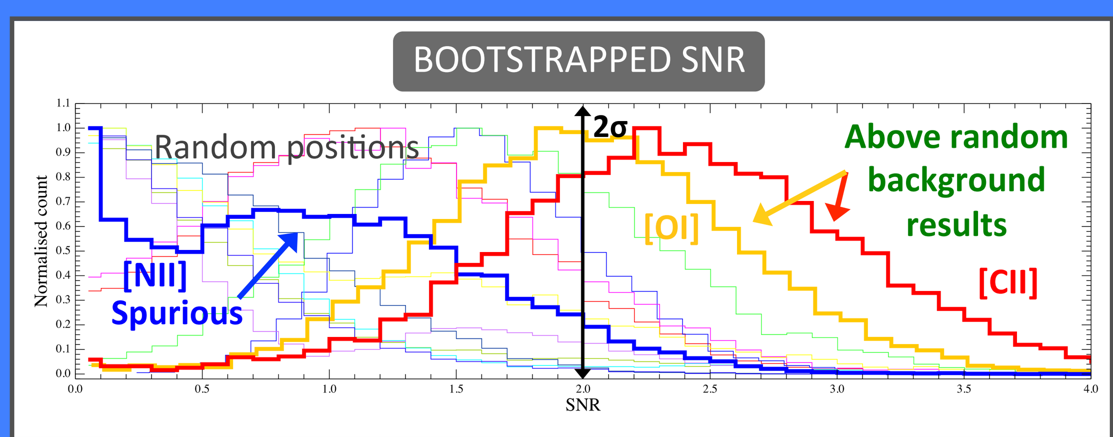


Figure 7: bootstrapped SNR distributions for three suspected lines in a faint source observation, compared to those obtained for several random positions. [CII] is well above the background and appears real, [OII] is marginal, [NII] is clearly spurious.

8. Conclusions

We have shown that by careful processing of SPIRE FTS spectra it is possible to reliably detected faint lines beyond the original expectations of the instrument. Figure 8 compares a standard pipeline product for a faint source observation, the SPIRE photometer photometry and the final best effort, after applying the methods presented in this poster (and Hopwood et al. in prep.).

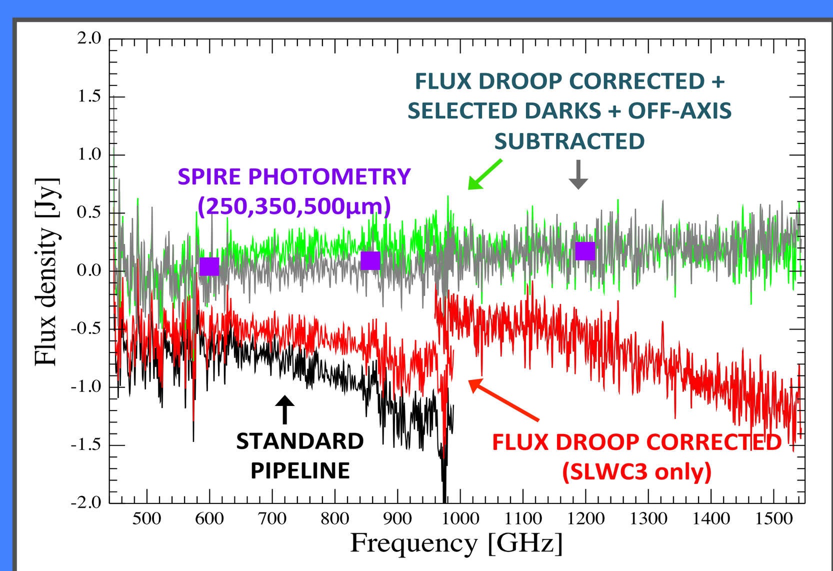


Figure 8: faint source observation corrected for high-noise and flux droop. A subtraction of the off-axis detectors was also performed. A 2.5σ line was reliably extracted.

References: *G. L. Pilbratt, et al., 2010 A&A, 518, L1; M. J. Griffin et al., 2010, A&A, 518, L3; I. Valtchanov et al., 2011 MNRAS, 415, 3473; Ivison et al., 2010 A&A, 518, L31; George et al., 2013 MNRAS, in press; Rigopoulou et al., 2013 submitted; Hopwood et al., 2013 in prep.*

SOLUTION FOR FIGURE 3 TL: dark sky, TR: [CII], ML: [CII], MR: dark sky, BL: dark sky, BR [OI]