SUBJECT:	SPIRE Spectrometer Point Source Observing Mode - Status		
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Change Record

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0.1	January 25, 2010	Original draft
0.2	January 27, 2010	Draft for feedback
0.3	January 28, 2010	Draft for submission to review board
1.0	January 29, 2010	Final version for ICC review

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Glossary

Acronym	***Description***
ADC	Analogue to Digital Converter
FTS	Fourier Transform Spectrometer
OD	Operational Day
PCal	Photometer Calibration source
PID	Proportional Integral Derivative
PV	Performance Verification
SCal	Spectrometer Calibration source
SLW	Spectrometer Long Wavelength array
SMEC	Spectometer Mirror Mechanism
SSW	Spectrometer Short Wavelength array

1. INTRODUCTION

1.1 Scope

This document summarizes the status of the point source observing mode for the SPIRE spectrometer (SOF1), which was released on December 4, 2009. This document does not report on the achieved sensitivity. Instead, this critical aspect of verifying the performance of the SPIRE spectrometer is presented in RD01.

1.2 Structure of Document

This document details

- the scope of the released observing mode (section 2),
- the most important considerations concerning instrument operations (section 3),
- the current calibration scheme (section 4),
- the achieved performance (section 5),
- and the data processing software (section 6).

1.3 Documents

1.3.1 Applicable Documents

AD01
AD02

1.3.2 Reference Documents

RD01 Flux Conversion and RSRF correction for the SPIRE FTS, SPIRE-BSS-REP-003243, issue 1.0, January 29, 2010
RD02 SPIRE Spectrometer Mapping Status (ICC Review), SPIRE-RAL-DOC-003242, issue 1.0, January 29, 2010
RD03 SPIRE Observer's Manual, HERSCHEL-HSC-DOC-0789, version 1.2, September 11, 2007

2. SCOPE OF THE RELEASED OBSERVING MODE

The release of the SOF1 observing mode covers single pointing observations of point sources of nominal brightness in sparse spatial sampling mode in high, low, and high+low spectral resolution. In order to complete the SOF1 release, we need to verify the capability of the SPIRE spectrometer to

- make raster observations with sparse spatial sampling. The calculation of the spectral map from sparsely sampled raster observations remains to be verified.
- observe extended, i.e. not point-like, sources. This depends on a robust calibration scheme for the off-axis detectors, which will have to relate calibration based on the telescope emission to the calibration based on an astronomical source. It also remains to be investigated whether a different set of instrumental parameters (SCal temperature) would significantly increase the data quality and warrant additional calibration efforts.
- observe bright sources, where bright is defined as a flux density greater than 50/150Jy for the SLW/SSW bands, which is equivalent to the flux density observed with Neptune (see Figure 1). Four calibration files explicitly depend on the bias settings for the detector arrays which are different between nominal and bright source mode and require updating and verification: nonlinearity correction, bath temperature correction, reference interferogram, flux conversion. Flux calibration of the bright source mode must be verified against the flux calibration of the nominal source mode.

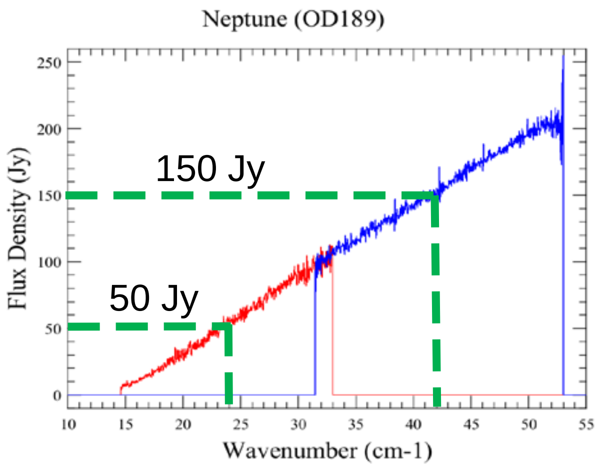

Figure 1: Neptune is the brightest object that has been observed successfully with nominal detector settings so far

- observe in medium spectral resolution. The reference interferograms to account for the instrument and telescope emission must be derived in medium resolution and verified. This work has been completed for nominal detector settings and the products will be released into the calibration context in the very near future.

RD02 reports the status of the release of the SOF2 observing mode for intermediate and full spatial sampling.

3. INSTRUMENT OPERATIONS

3.1 Spectrometer mirror mechanism

The spectrometer mirror mechanism is the most complex mechanical sub-system of the SPIRE instrument. The operation of this subsystem was based on the results of ground-based testing and optimized during the commissioning phase. Home position, scanning speed, and scan start and end positions were determined on the ground and verified but not changed during flight. The PID parameters for the servo-control system of the mechanism were optimized during the commissioning phase and there has been no indication since then that these parameters should be changed.

The initialization sequence for the stage mechanism underwent several significant changes during commissioning and performance verification (PV). Two of the parameters (the optical encoder signal offsets) are now being set in-situ based on a measurement of the actual signal offsets at the start of every observation, rather than being set once at the beginning of the

OD using a fixed value. This change was necessary because temperature variations of the optical bench of the SPIRE instrument significantly change the value of these parameters when the SMEC is not scanning (i.e. between observations – particularly during long slews). These temperature variations could be large enough to drive the parameters outside of the range suitable for controlling the mechanism and so performing the SMEC initialization prior to each observation ensures that it is kept under adequate control at all times.

3.2 Bolometric detector arrays

The detector bias settings were optimized for the two center detectors C3 and D4 of the two detector arrays SLW and SSW. The bias frequencies were optimized early on in the PV phase and the amplitude and phase were carefully selected to optimize the dynamic range available to the center detectors. The setting for SLW was kept at its optimal value from PV phase, but the setting for SSW was adjusted slightly to avoid clipping of the interferogram close to ZPD. Figure 2 shows the dynamic range set by the 16 bit ADC, with the measured interferogram (on dark sky) at a set of different detector bias amplitude settings. The final bias amplitude chosen for SSW moves the interferogram towards the center of the dynamic range.

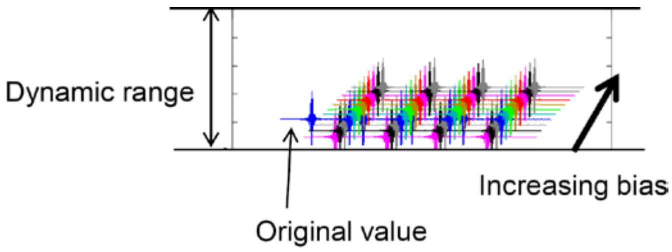

Figure 2: The dynamic range for the SSW center detector D4 with dark sky interferograms measured at a range of bias amplitude settings.

SPIRE's Photometer Calibration source PCal will be used to monitor the responsivity of the detectors throughout the mission. Currently, one PCal flash is executed at the beginning and end of each observation. In addition, one PCal flash is executed every 45 minutes throughout long observations. The change request SPIRE-2341 *Spectrometer PCAL flashes in Astronomer AOTs* has been issued to reduce the frequency of PCal flashes to maximize Herschel's useful observing time.

3.3 Spectrometer calibration source

SPIRE's Spectrometer Calibration source SCal was designed to reduce the dynamic range of the signal from SPIRE's interferometer by injecting power into the second input port to balance the signal of the warm telescope. After analyzing a comprehensive suite of observations during the PV phase, the decision was made not to actively control SCal and let its temperature float with the rest of the optical bench. The adjusted detector bias settings, described above, avoid clipping which was the original driver for including SCal. Furthermore, additional power would introduce additional noise and has the potential of complicating data processing as it may lead to the inversion of power within SLW's optical passband and introduce further contamination due to channel fringes.

3.4 Spacecraft environment

Based on a suite of raster observations early during PV, the Spacecraft Instrument Alignment Matrix was updated twice (OD82 and OD122) with new values for the center detectors of the two arrays. Subsequently, the pointing accuracy was confirmed to be accurate within <2arcsec. The pointing characteristics of the Herschel spacecraft satisfy the requirements of the SPIRE imaging spectrometer.

The seasonal variation in temperature of the primary and secondary mirrors of the Herschel Space Observatory complicate the calibration of the SPIRE spectrometer as they alter the dark sky reference measurements significantly for the detectors of the SSW array.

The temperature of the instrument bench varies by up to 1.5K across ODs (see Figure 3) which considerably affects the measurements made by the detectors of the SLW array. The calibration and data processing scheme must take these fluctuations of the instrument temperature into account.

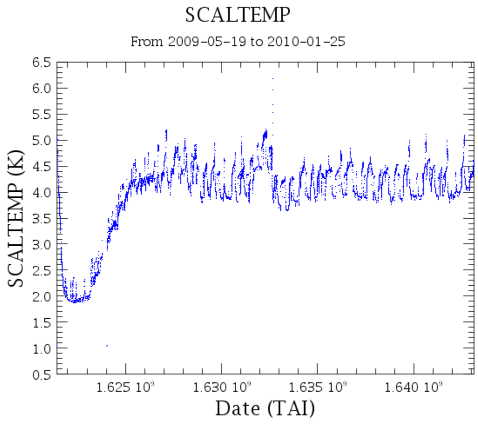

Figure 3: Temperature of the optical bench over the mission lifetime

The instrument temperature changes most strongly during and directly after switching to stand-by mode (see Figure 4) and a wait time of 10 minutes after this command has been implemented to avoid the strongest effects from switching the instrument on.

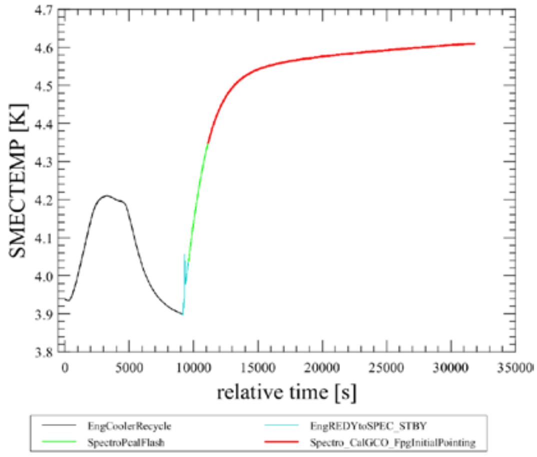

Figure 4: Evolution of the temperature of the optical bench after switching on the SPIRE spectrometer

4. INSTRUMENT CALIBRATION

In conjunction with the SOF1 release, four calibration data products were updated: nonlinearity correction, bath temperature correction, reference interferogram, and flux conversion. These updates have been made in HIPE version 2.1.0 RC1 and HIPE version 3.0.

A dark region in the sky has been observed since the start of the mission to characterize contributions from any non-astronomical source. The IRAC dark field at RA/DEC: 265.05/+69.00 degrees has been used throughout. This measurement is critical for the accurate flux calibration of the SPIRE spectrometer as the instrument and the warm telescope emit a significant amount of radiation in its optical passbands. In the near future we will further increase the consistency of the reference interferogram by co-adding more observations which were taken under comparable conditions.

The absolute flux calibration for point sources is based on measurements of the asteroid Vesta and a model of the asteroid provided by Thomas Müller for the observation time in question. The model has been adjusted by 20% in order to bring it in line with the measurements of the SPIRE photometer. The SOF1 flux calibration for extended sources will be based on the telescope emission.

As a Fourier transform spectrometer, the SPIRE imaging spectrometer provides an intrinsic frequency scale calibration starting at a frequency of 0 and incrementing in equal intervals up to the Nyquist frequency which is set by the smallest sampling interval of the optical path difference of SPIRE's interferometer. In the future, we will perform a more detailed analysis of systematic effects on the wavescale for on- and off-axis detectors.

5. ACHIEVED PERFORMANCE

5.1 Spectral range

The SPIRE observer's manual (see RD03) states the spectral range for the SPIRE spectrometer as 14.9 – 31.6 cm^{-1} and 30.9 – 51.5 cm^{-1} for the long and short wavelength ranges. The overall range has been successfully validated during flight with a slight shift of the overlap region to higher frequencies. The confirmed spectral ranges for the long and short wavelength arrays are 14.9 **– 33.0** cm^{-1} and **32.0 –** 51.5 cm^{-1} (see Figure 5). The overlap between the two SPIRE detector arrays and between the SPIRE and PACS spectrometer is still sufficient for cross-calibration.

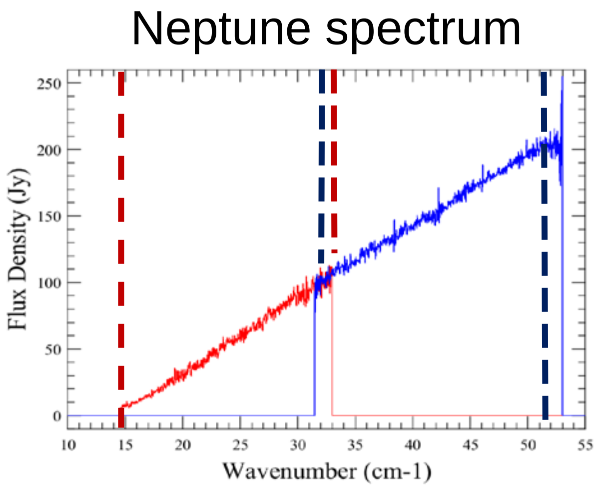

Figure 5: A Neptune spectrum shows the spectral ranges for the long and short wavelength detectors

5.2 Spectral resolution

The SPIRE observer's manual (see RD03) states the spectral resolution of the SPIRE spectrometer in high and low resolution mode as 0.04 and 1.0 cm^{-1}. The quoted resolution refers to the natural spectral resolution element of the SPIRE spectrometer, which is defined as $1/(2 \cdot OPD_{max})$. Measurements of strong CO lines (see Figure 6) confirm that the actual spectral resolution has been achieved for the high resolution mode at $\Delta\sigma = 0.0398 \pm 0.0002$ cm^{-1} and is slightly better than required for the low resolution at $\Delta\sigma = 0.83 \pm 0.04$ cm^{-1} mode. It has also been confirmed that the spectral resolution is identical for the two spectral ranges – as one would expect from Fourier theory.

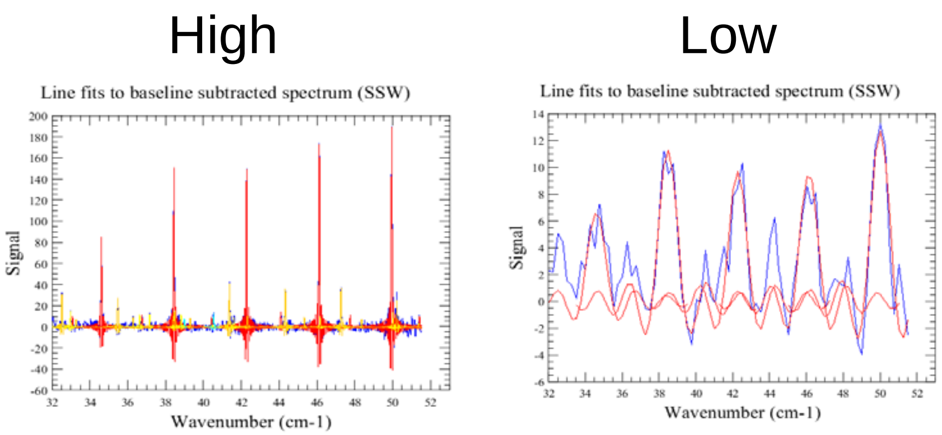

Figure 6: Measurements of the line width of strong CO lines

5.3 Wavescale accuracy

By following the standard procedure of setting the wavescale in Fourier transform spectroscopy (FTS)

$\sigma = i \cdot \Delta\sigma$, for an index i = 0, … , N, to reach the maximum Nyquist frequency $\sigma = 1/(2 \cdot \Delta OPD)$

the intrinsic calibration of the wavescale of the SPIRE spectrometer turns out to be accurate to within 1/10 of a resolution element $\Delta\sigma$ (see Figure 7).

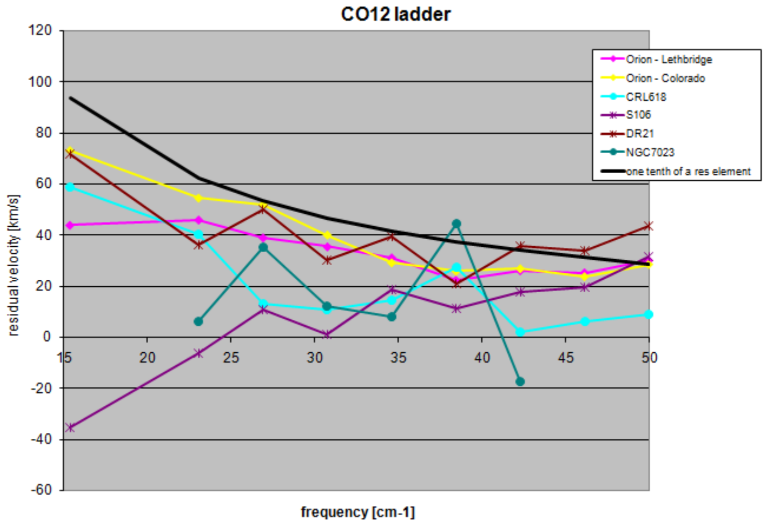

Figure 7: Residual velocity for five galactic sources from fitting to prominent CO lines

The systematic shift in the wavescale may be due to a slightly non-ideal Instrumental Line Shape for the center detectors. However, this remains to be verified. The wavescale accuracy for the off-center detectors has been explored and found to be consistent with expectations. However, a detailed verification of the wavescale for the off-center detectors is still outstanding. The calibration infrastructure is already in place to take these results into account.

5.4 Flux accuracy

Point source flux calibration is based on Vesta, the brightest asteroid observed so far. This calibration was then applied to measurements of Uranus and Neptune. A comparison between the measurements and the modified Griffin & Orton models (see Figure 8) shows good agreement of better than ~20%.

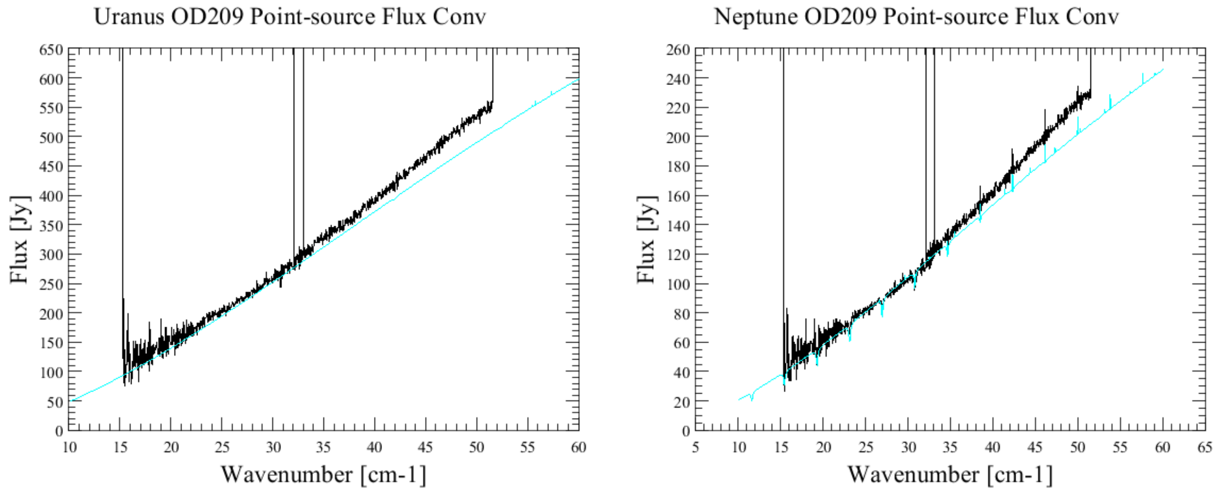

Figure 8: Measurements of Uranus and Neptune (black) in comparison to planetary models (blue)

The thermal variation of SPIRE's optical bench can introduce a systematic error on the flux calibration in the form of an additive term of up to ~20 Jy towards the long wavelengths. This systematic error will not affect the total power in spectral lines. For an example of this error, see Figure 9.

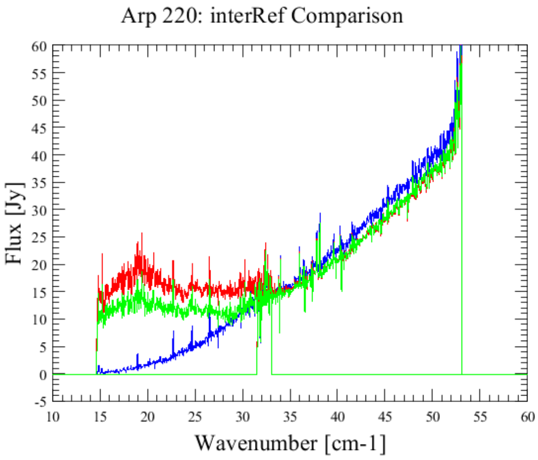

Figure 9: Example of systematic error at the long wavelength range due to thermal variation of the instrument

More details on the flux calibration scheme are given in RD01.

5.5 Noise

The noise in the data from the SPIRE spectrometer must decrease as the number of repeated measurements increases in order for SPIRE to achieve its sensitivity targets. In the presence of pure random noise, the noise should decrease proportional to the square root of the number of repeated measurements. This relationship holds in the interferogram domain but breaks down within the optical passband of the SPIRE detectors:

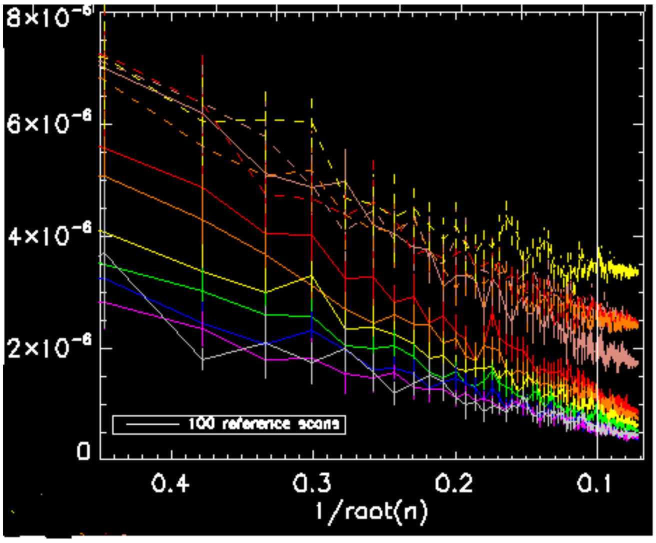

Figure 10: Standard deviation of the spectral signal inside (top four dashed line in yellow, orange, red, and mauve) and outside of the optical passband

This result suggests that further improvements of the consistency of the calibration will also improve the achievable sensitivity. The project team is currently undertaking considerable efforts in this area.

5.6 Sensitivity

The SPIRE spectrometer has already reached the line flux sensitivity advertised in the observer's manual (RD03). The line flux sensitivity was derived from a deep measurement of Fortuna as 1.38e-17 W m-2 above a 5-sigma flux limit in 3600s. The pre-launch estimate for this spectral region was 3.3e-17 W m-2. The equivalent results for the continuum sensitivity are still outstanding.

5.7 Beam size

The SPIRE observer's manual (see RD03) states that the FWHM of the beam size of the SPIRE spectrometer is 34 and 16arcsec in diameter for detectors of the long and short wavelength arrays. A measurement with fine scans across a bright source has confirmed the beam width for the center detector of the long wavelength detector array (SLWC3) at 35±1.5arcsec. The beam width of the center detector of the short wavelength detector array (SSWD4) is, at 19±1arcsec, slightly wider than anticipated. A 90 x 90arcsec raster observation of Neptune was performed on OD210 to determine the beam shape of the center detectors as a function of frequency. The analysis of this dataset is still on-going.

6. DATA PROCESSING SOFTWARE

The data processing software for SOF1 observing mode is available in HIPE and has been used on a routine basis during all flight phases so far (see Figure 8 for a schematic overview of the pipeline). In the current situation, where raster observations have not yet been released to the user community, data processing does not go beyond level 1 (the diagram in Figure 8 includes processing to level 2 only for future reference). Assuming an up-to-date calibration context, the pipeline provides high quality data to the users of the SPIRE spectrometer. All tasks set Quality Control parameters where applicable to flag observations with operational issues. A Trend Analysis procedure has been verified to provide the capability to monitor instrument performance throughout the mission. The software development team will continue to maintain the pipeline and its modules. From the already existing pipeline tasks, we expect to significantly improve phase correction once the non-linear phase has been characterized from in-flight data. The instrument team currently explores several aspects of processing the data from the SPIRE spectrometer, which will likely result in changes to the data processing pipeline. This includes tracking of solar system objects; correction for channel fringes which contaminate high resolution spectra; correction for thermal drifts of the telescope and the instrument itself; conversion from voltage into power based on a physical model of the bolometric detectors.

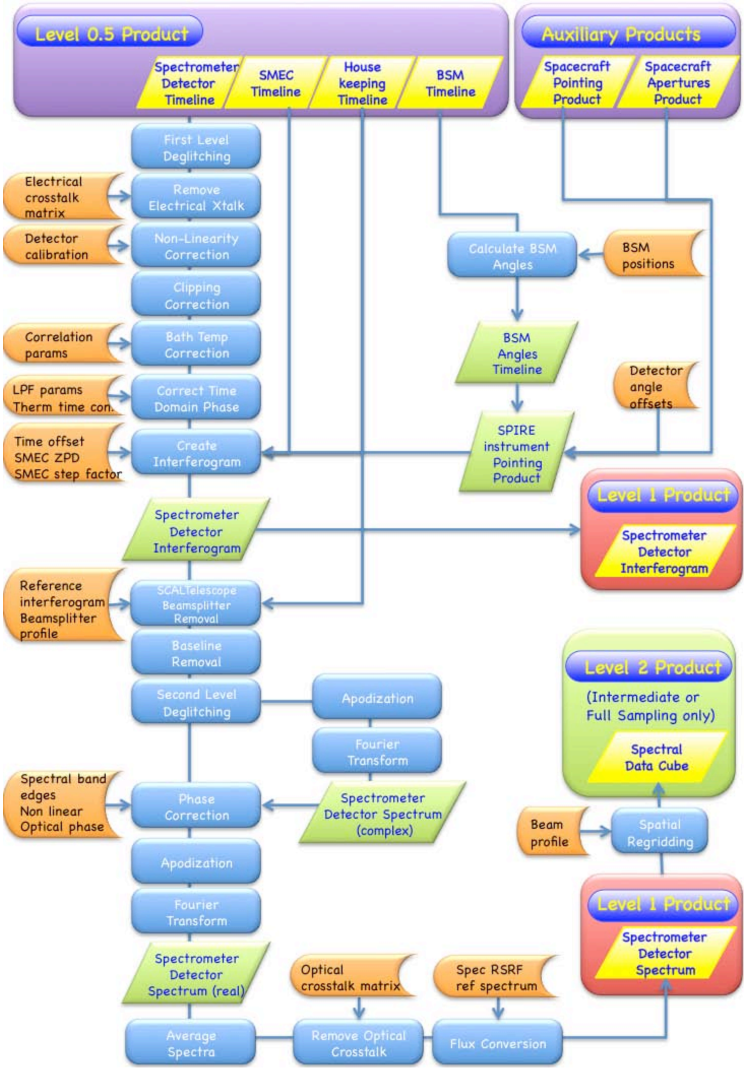

Figure 11: Diagram of the data flow through the spectrometer data processing pipeline