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Planck-HFI / Herschel-SPIRE Cross Calibration

Introduction

The data collected by the ISO and IRAS missions demonstrated convincingly the need for reliable photometric flux standards in the Far Infrared (FIR) beyond 100μm. Stars, asteroids, and planets are the usual candidates that have been used in the past. However, these objects are not without challenge.

Certain classes of stars are probably best understood from a photometric modelling point of view and accuracies claimed are at the 6% level and better. In Herschel's wavelength regime, however, stars become very faint. Dust envelopes and difficulties modelling non LTE conditions in stellar atmospheres impact the accuracy of predicted fluxes even further.

Some asteroids are brighter in the FIR and have been used successfully as photometric standards on IRAS, ISO and Spitzer. However, the high number of parameters associated with thermophysical models, and our limited means to determine those, typically prevent the achievement of accuracies better than 15%.

Planets are prime candidates as calibration standards, especially for their relative brightness at the long wavelengths reached by SPIRE. However, specific variabilities can be a problem. The impact of occasional Mars dust storms is still hard to model, and this particular source is in fact so bright that it will drive the bolometers of PACS and SPIRE into the non-linear operational regime. Other more suitable planetary sources would be the gas giants Uranus and Neptune, but most of our knowledge about their FIR emission is based on extrapolations of Voyager IRIS data, that reached only into the Mid-Infrared (MIR), and that would not take seasonal variations into account.

In addition, the data leading to the model descriptions of many of these standards are themselves interlinked in various, sometimes not easily traceable ways, until they can be tied to an absolute Blackbody standard, which is the fundamental radiometric standard. Blackbody standard sources have so far not been used very often on astronomical space missions for the FIR to Submm wavelength regime. The uncertainties remaining in available standard sources for the FIR, in particular any common biases introduced due to extrapolation, have been an issue for the preceding missions IRAS, ISO and Spitzer, where Herschel draws most of its heritage from.

General Concept

The contemporaneous missions of Planck and Herschel offer a unique opportunity to tie a network of celestial standards in the FIR to absolute Blackbodies in space. There are a number of instrumental similarities between both missions that will simplify cross calibration and will be of advantage to their respective calibration schemes. Both missions will launch on the same rocket, and will be located in similar positions within the solar system at L2. Planck-HFI and Herschel-SPIRE have two common filters that are almost identical in the 250 μm band, and overlapping by about three quarters in the 490/550 μm bands. The detector arrays have both been built by the same group at JPL and are based on Germanium spider-web bolometer technology that has been used in other ground based and balloon experiments like Bolocam and BLAST.

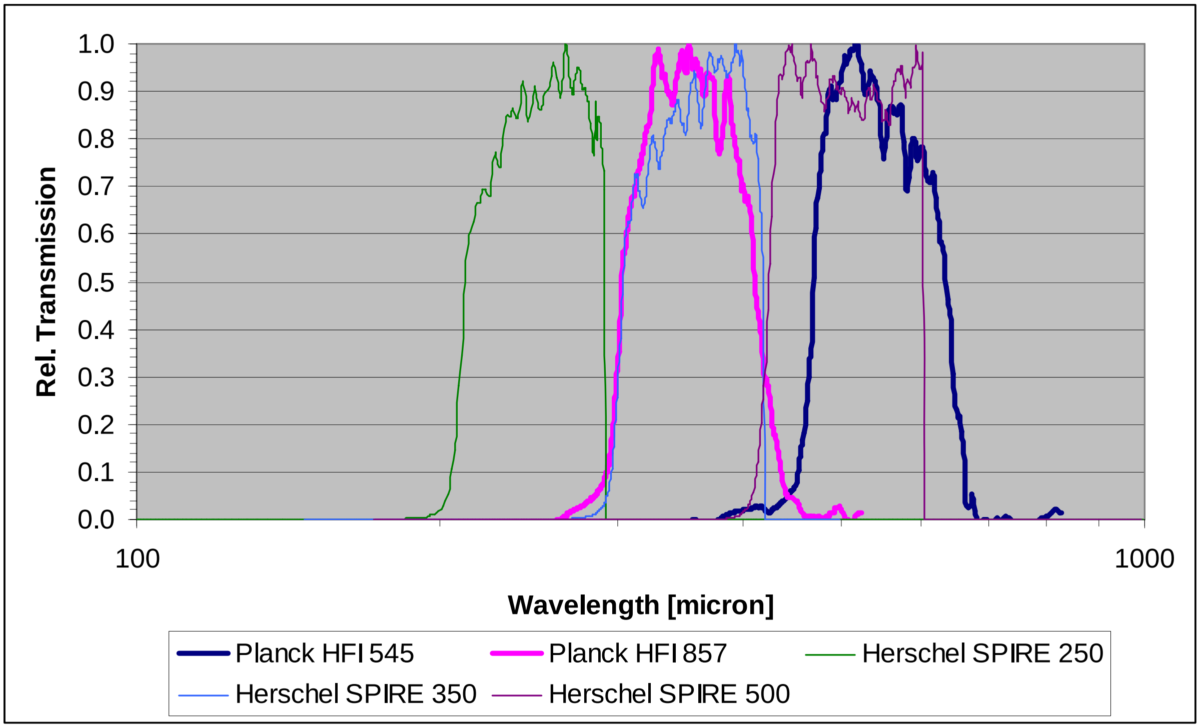

Figure 1: Planck HFI and Herschel SPIRE overlap of photometer bands.

Black Bodies

A known temperature and solid angle fully constrain the spectral energy distribution (SED) emitted by a good black body source, which is given by Planck's formula. Such a source constitutes an absolute radiometric calibration standard. Such a standard source located in space removes the need to make assumptions about, the transmission of the atmosphere, extrapolations of SEDs of celestial sources, or their physical properties.

There is one blackbody source, that in itself is quite fundamental, the cosmic microwave background (CMB), which has been measured by COBE to an accuracy of +/- 0.004 K). Since Planck will only do relative measurements, it will not be sensitive to the monopole moment of the CMB emission, but it will measure its modulation due to the dipoles formed by the relative motions of our Galaxy, the Sun, the Earth and the spacecraft. In particular, the photometric contributions of the dipole components due to the satellite motion, and more importantly, the orbital motion of the Earth, can be separated out, and are known from first principles.

The instrument on-board of COBE falling into our wavelength regime was FIRAS, and carried itself a very accurate blackbody source for calibration. The resulting maps of the FIR sky are of high quality and are calibrated to an absolute accuracy of <3% (Fixsen et al. 1994). The internal consistency of the instrumental calibration was even <0.1%, but a variation in amplifier gain could not be characterized to this accuracy. Strongly structured Cirrus fields on the sky should provide enough dynamic range, to be useful as differential flux standards.

Panck-HFI Calibration

Planck will be scanning the sky while rotating at a rate of 1 rpm along a polar circle with a radius of 85 degrees. Every hour the satellite will be re-pointed by 2.5 arcmin, so that 1 degree is covered every day.

According to current plans, Planck HFI will be calibrated primarily with extended source fluxes, using the FIRAS maps in both for SPIRE relevant filters at 545 and 857 GHz (550, 350 μm). This can be done by convolving the relevant HFI maps with a FIRAS beam profile, to achieve equal spatial resolutions in both maps and determine a calibration factor for HFI that minimizes the residuals between the maps of FIRAS and HFI.

The low frequency channels of HFI at 100 GHz, 143 GHz, and 217 GHz will be calibrated very accurately to 0.4% using the CMB dipole component due to the orbital motion around the Sun as absolute calibrator (Piat et al. 2002). In the 550 μm filter HFI is also expected to measure the CMB dipoles, which in principle offer an independent alternative calibration and consistency check. However, current estimates expect only accuracies of 15%, mainly due to galactic foreground dust contamination. It remains to be seen whether a wavelength cross calibration using objects with known relative SEDs can be performed to let higher frequency channels benefit from the superb accuracies achievable at long wavelengths.

Good knowledge of the Planck beams is an important ingredient to the calibration. These beam profiles will be characterized using bright quasi point sources (for HFI) like Mars, Jupiter, Uranus or Neptune. For these special observations, the rotational axis of the satellite will be re-pointed with a 1.25 arcmin/min shift. The beams are about 5 arcmin wide and are expected to be known to an accuracy of 3%. Expected point source sensitivities of the 545 and 857 GHz filters are 43 and 49 mJy respectively. Point source calibration accuracy is likely limited by this value.

Herschel-SPIRE Calibration

The SPIRE instrument consists of a spectrometer and a photometer. The photometer is expected to be the more accurate and stable part. In the following we will ignore the spectrometer part. The feedhorns form 3 detector arrays with broad-band filters at about 250 μm, 350 μm and 500 μm, that are arranged in hexagonal patterns. The feedhorn diameters are adapted to the telescope PSF at the respective wavelengths. All 3 detector arrays cover the same area on the sky and have 14 detectors per array with coincident feedhorn centers at all 3 wavelengths.

SPIRE offers 3 basic pointing modes: 7 point jiggle map, 64 point jiggle map, scan map.

The first mode is the most sensitive, and is dedicated to point source photometry. In this mode the point source is placed at the center of one of the positionally coincident detector feedhorns. The beam steering mirror (BSM) modulates (chops) the signal by regularly switching the beam to a second position on the array with 3 coincident feedhorns. To account for inaccuracies in centering the point source and to compensate for the low filling factor of the array, the BSM sequentially displaces the image to 6 closely surrounding positions in addition to the central position (jiggling). In addition the source is moved periodically into the other beam to correct for radiative offset from the telescope.

The 64 point jiggle map chops with a +/-2’ throw. It covers a total of 64 positions on and around each detector position in the same way as for the 7 point jiggle map. This produces a 4’x4’ area which is fully mapped on the sky.

The third mode doesn't use the BSM for signal modulation, but rather uses the movement of the entire spacecraft across the sky. The slew direction is limited to certain magic angles towards the orientation of the detector arrays to achieve Nyquist sampled coverage of the sky by the detector beams.

The system is thermally stabilized and residual thermal variations are measured by additional thermistor pixels. These are detector pixels that lack the optical absorber (spider-web) and measure directly to the temperature of the thermal base-plate. In addition changes of the system response on longer time scales of 30 min to 1 hour will be monitored by performing regular highly reproducible flashes by an internal calibration source (P-Cal).

The baseline calibration of SPIRE will be performed with a well known bright point source, which doesn't drive the detectors yet too much into the non-linear regime, most likely Neptune. Other point-like sources, like bright stars and asteroids are under consideration to provide cross checks at different brightness levels. However, given the difficulties extrapolating these source SEDs to longer wavelengths and the lack of calibrations of these sources against absolute radiometric blackbody standards in space, leaves doubts whether the ultimately absolute achievable calibration accuracy can be improved beyond 10% in this way.

SPIRE/HFI Cross Calibration

An interesting alternative could be the transfer of the prospective much higher absolute calibration accuracy of Planck to the two overlapping SPIRE filter bands (Figure 1), which can be traced very well to an absolute photometric blackbody standard. There are two tracks, one for extended source photometry, the other for point sources. These are schematically illustrated in Figure 2.

The extended source photometry can be transferred in the same way as the FIRAS map calibration is transferred to Planck maps. SPIRE maps of strongly structured regions in the galactic plane with large dynamic range are reduced to the spatial resolution of Planck HFI by convolution with the respective Planck beam profiles. The calibration factor for SPIRE is then determined by minimizing the residuals between the maps of HFI and SPIRE. This exercise is useful for both instruments, as it could identify potential issues with the HFI beam profiles. For this purpose useful regions on the sky can potentially be drawn from the data of various scientific programs, and it appears ulikely at this point, that dedicated cross-calibration time will be needed for this matter.

The point source calibration is probably best done with contemporaneous observations of a planet. A good compromise between linearity and sensitivity requirements could be again Neptune. The Planck team is interested in variability monitoring while doing beam profile scans. Discussions within the HCalSG which included Raphael Moreno lead to the conclusion that flux variability of Uranus and Neptune would be unlikely to have a measurable effect, even on timescales of a month. However, simultaneous observations could still be helpful to increase accuracy, as the background around those sources will vary with time. Also the expected closeness of Jupiter to Uranus in 2010 can become an important factor for the observed background.

These simultaneous observations could be the basis for a point source cross calibration between both experiments. In this case dedicated observations of a few hours per object, that are coordinated with Planck, would be required. The comparison of the resulting point and extended source calibrations of SPIRE will give another useful consistency check.

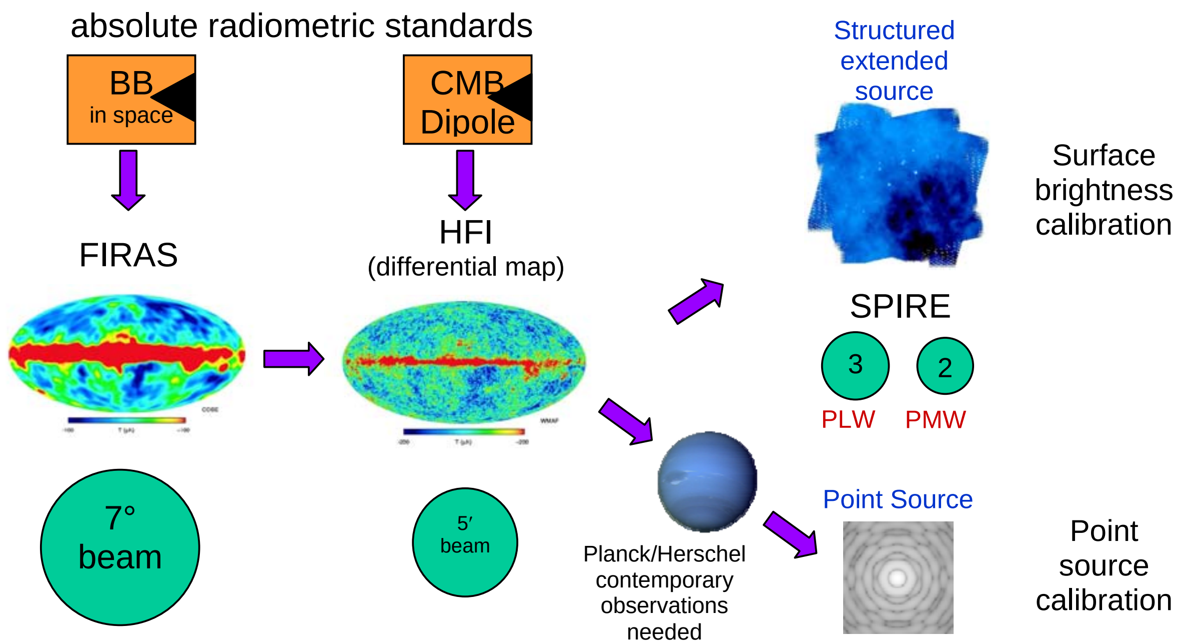

Figure 2: The traceability of HFI and SPIRE cross calibration to fundamental blackbody standards.

Coordinated Observations

According to the current understanding, only coordinated observations of SPIRE and HFI will be needed for observations of the bright standards Uranus and Neptune. The purpose of the observations is rather than monitoring short term variability in the sources, mapping the source and enough of the surrounding background at the time of the HFI observations, so that the HFI beam diameter is covered several times. To verify the assumption of the short term stability of the sources, a staring variability monitoring measurement should be performed at least once over the time it takes for HFI to do a complete point source scan.

It is still TBD, how much of the far field of the HFI beam profile will need to be covered by the SPIRE map. The 5’ beam of HFI will be covered within 4 minutes in the special HFI scan mode for bright point sources. At this rate a distance of 15 beam diameters, corresponding to 75 arcmin on the sky will be covered within one hour. A corresponding single square scan map with SPIRE to a 1 sigma level of 10.5 mJy in the 350 micron band will take 2.85 h. If cross scanning is required this time will double to 5.71 h. This exercise already shows the practical limitations of beam coverage possible within a given timeframe, but also the general feasibility of the approach.

Summary of Expected Accuracies

A great deal of modelling work was undertaken to understand the relative accuracies achievable with HFI (Piat et al. 2002) and SPIRE (Griffin 2004). However a full analysis of the expected absolute errors resulting from the proposed cross calibration would require additional extensive modelling. This is unlikely to occur before the start of the mission.

TBW

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