ZeroPoint Correction for Herschel-SPIRE Maps via Planck-HFI Cross Calibration

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with special thanks to

Guilaine Lagache, Pedro Gomez, Steve Guest, Gabriele Mainetti, the Planck Team, the SPIRE team, and the HCalSG

Overview

- Zero-point correction:
  - Objective, Plan, Change of Plan
- Algorithm for comparison
- Color correction
- Derivation of beam profiles
- HIPE 10 implementation
- New HIPE 10 products

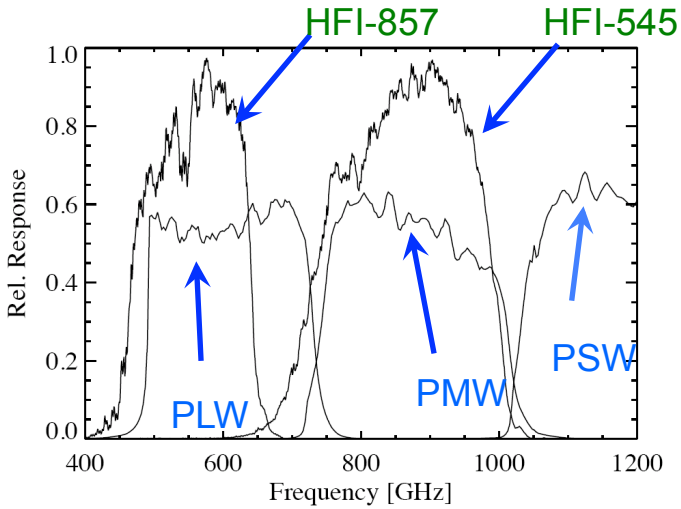
SPIRE/HFI Cross-Calibration

The Opportunity

- Herschel-SPIRE 350mm and 500mm filters have strong overlaps with Planck-HFI 857GHz and 545GHz respectively
- Planck-HFI use COBE-FIRAS maps (3% accuracy) to flux-calibrate their maps in these two filters in offset and scale.
- The COBE-FIRAS calibration for the overlapping filters is based on two on-board blackbodies operated in space.
- The FIRAS beam is 7°, the HFI beam is 5', the SPIRE beams are 25" and 36".

The Plan

- Take accurate blackbody calibrated COBE-FIRAS all-sky maps with 7° beam and cross calibrate Planck-HFI 545 and 857 GHz maps with ~5' beams.
- Take Planck-HFI 545 and 857 GHz maps, make sure photometric gains match, and correct zero-point of SPIRE maps with 18, 25, 36" beams.

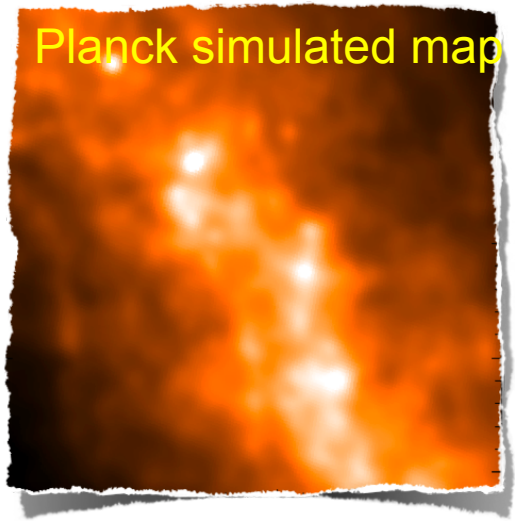


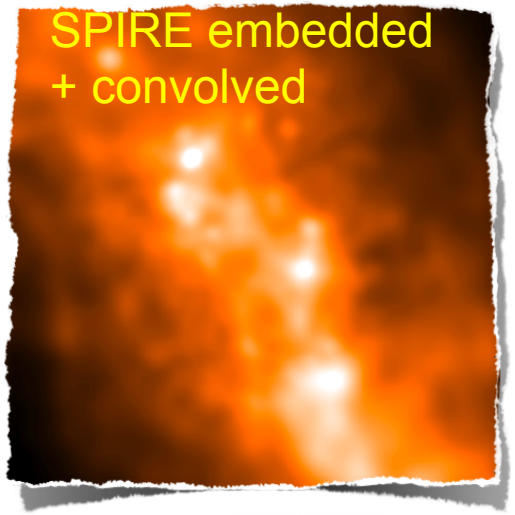
Change of Plans

- In our first comparisons we found the photometric gains of the FIRAS based HFI maps were considerably higher than those of the SPIRE maps.
- Because of this and other inconsistencies the Planck team decided to change the calibration scheme for the 545 and 857 GHz channels.
- Change of calibration scheme for Planck-HFI 545 and 857 GHz maps
  - Derive photometric gain from observations of Uranus and Neptune.
  - Derive zero levels from correlation of HI (21cm) gas column density and add CIB mean level.
  - See talk by Guilaine Lagache (Planck Collaboration VIII. 2013, In preparation)

Map Comparison (Algorithm)

- Derive a color corrected HFI map at the reference wavelength of the SPIRE band based on the flux ratio of both HFI bands.
- Convolve SPIRE maps assuming an 8' Gaussian beam.
- Determine first offset estimate and embed SPIRE map into HFI map that is set to SPIRE offset estimate to reduce edge effects.
- Repeat convolution and comparison.
- Comparison (for photometric verification)
  - Plot HFI and SPIRE maps pixel by pixel and fit gain and offset.
  - Determine median and scatter in difference map.
- Correction (for SPIRE pipeline)
  - Determine median and scatter in difference map.
  - Add median difference to SPIRE map





Color Correction

- Objective: From 857 and 545 GHz maps construct a map as if measured with SPIRE.
- The HFI and SPIRE maps are defined at the reference wavelengths/frequencies and a standard reference spectrum.
- The actual spectrum is a cold galactic dust spectrum characterized by a temperature.
- Color correction factors are tabulated for a range of temperatures.
- Ratios of monochromatic flux densities in the HFI map are tabulated for the same list of temperatures.

with $F_{std}(\nu 0)\cdot K = F_{sky}(\nu 0)$,

$$\frac{F_{std}(\nu 0_2)\cdot K_2}{F_{std}(\nu 0_1)\cdot K_1} = \frac{F_{sky}(\nu 0_2)}{F_{sky}(\nu 0_1)} \quad \text{and} \quad K_{12} = \frac{K_1}{K_2}\cdot\frac{F_{sky}(\nu 0_2)}{F_{sky}(\nu 0_1)}$$

the color correction factor becomes

$$K_{12} = \frac{\nu 0_1 \cdot \int_{\nu_0}^{\nu_{N-1}} \frac{T_1(\nu)}{\nu}\, d\nu \cdot \int_{\nu_0}^{\nu_{N-1}} F_{sky}(\nu)\cdot T_2(\nu)\, d\nu}{\nu 0_2 \cdot \int_{\nu_0}^{\nu_{N-1}} \frac{T_2(\nu)}{\nu}\, d\nu \cdot \int_{\nu_0}^{\nu_{N-1}} F_{sky}(\nu)\cdot T_1(\nu)\, d\nu}$$

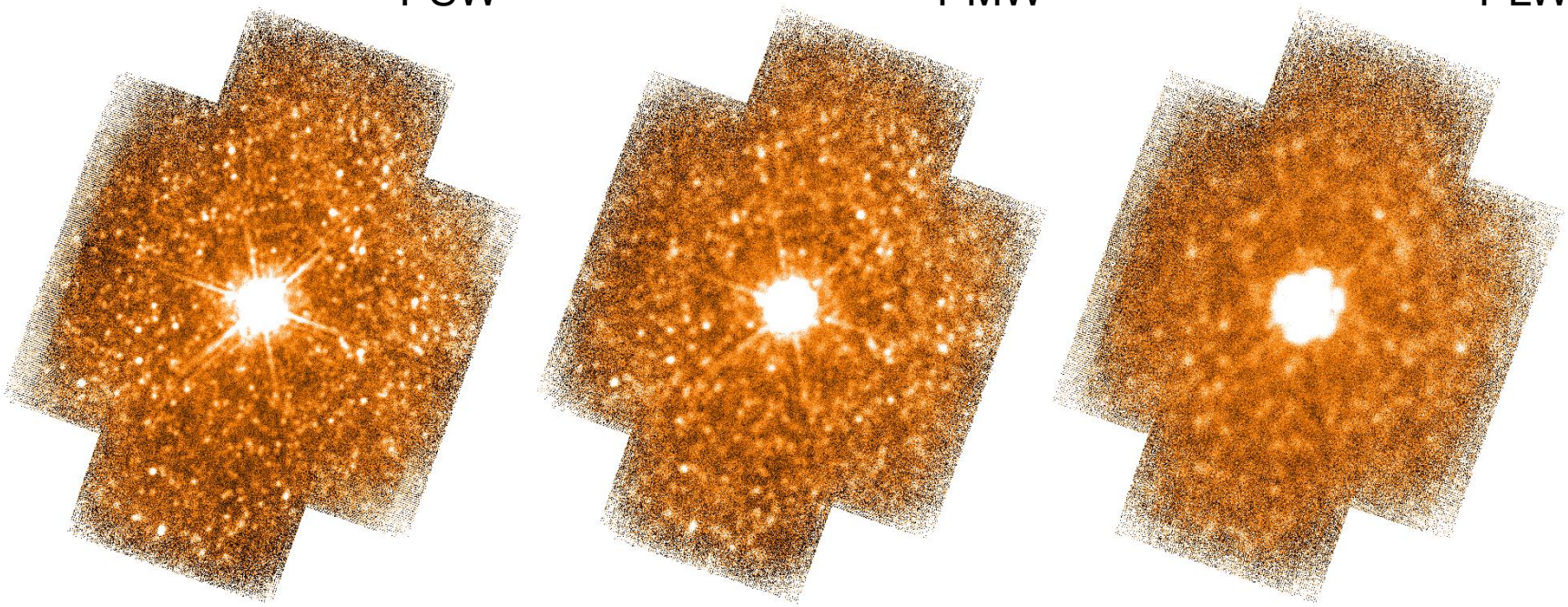
The sky SED is

$$F_{sky}(nu, T) := B(nu, T)\cdot\left(\frac{nu}{GHz}\right)^{1.8} \quad \text{with} \quad B(nu, T) := \frac{2\cdot h\cdot nu^3}{c^2\cdot\left(e^{\frac{h\cdot nu}{kb\cdot T}} - 1\right)}$$

and the flux ratio is $\frac{F_{std}(\nu 0\ )}{F_{std}(\nu 0\ )}$

Neptune Fine Scan Maps

PSW PMW PLW

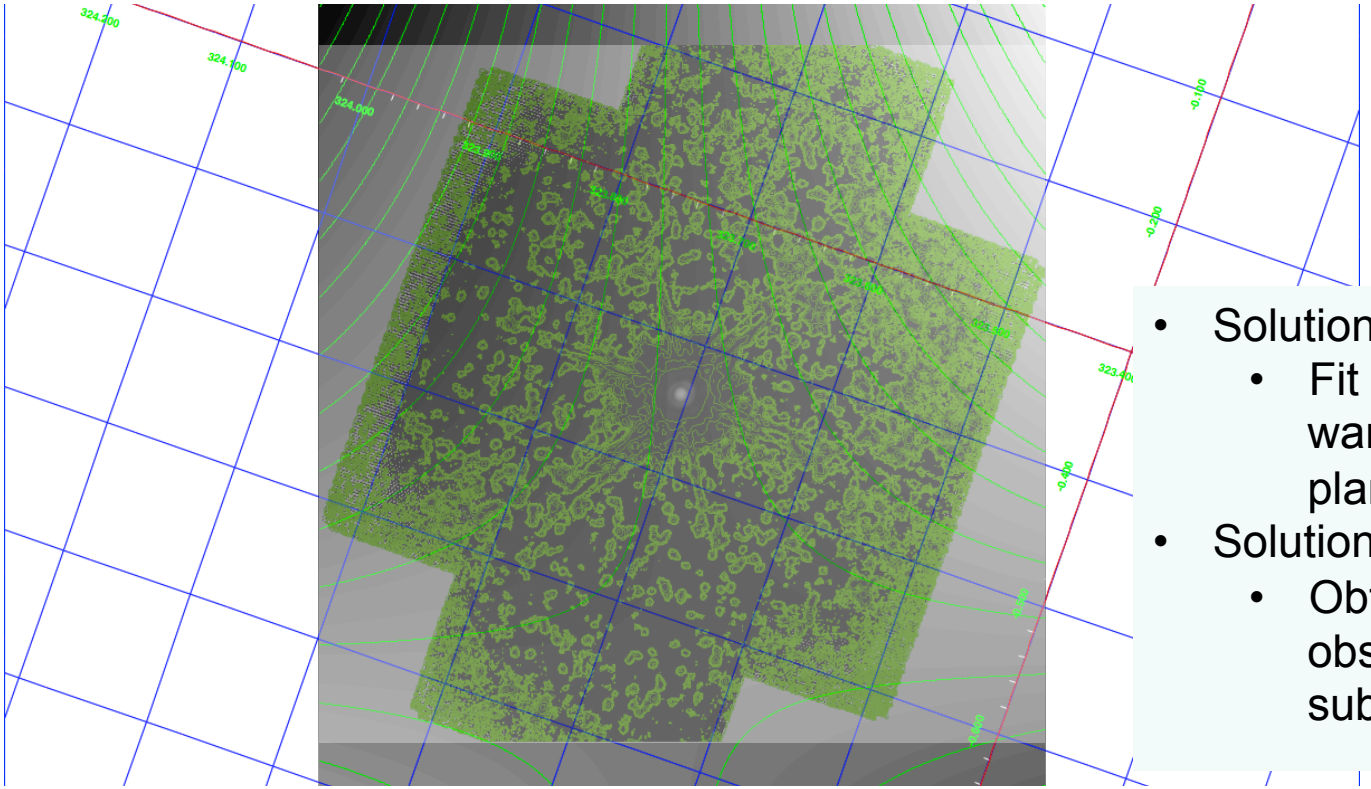


- With background sources.

Fitted Background

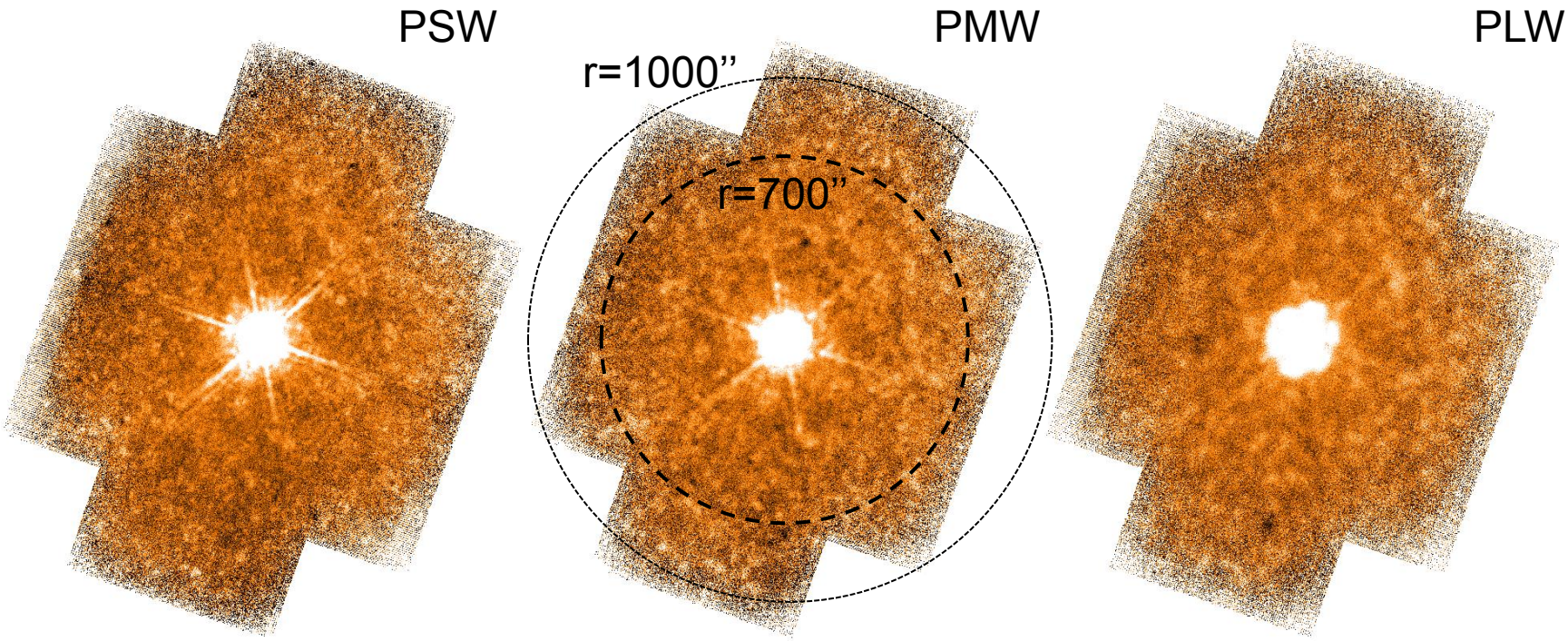
Direction of tilt and strength of gradient are compatible with using a Zodiacal light model by Reach et al. (1996) and extrapolating it to submm wavelengths.

Ecliptic coordinate grid



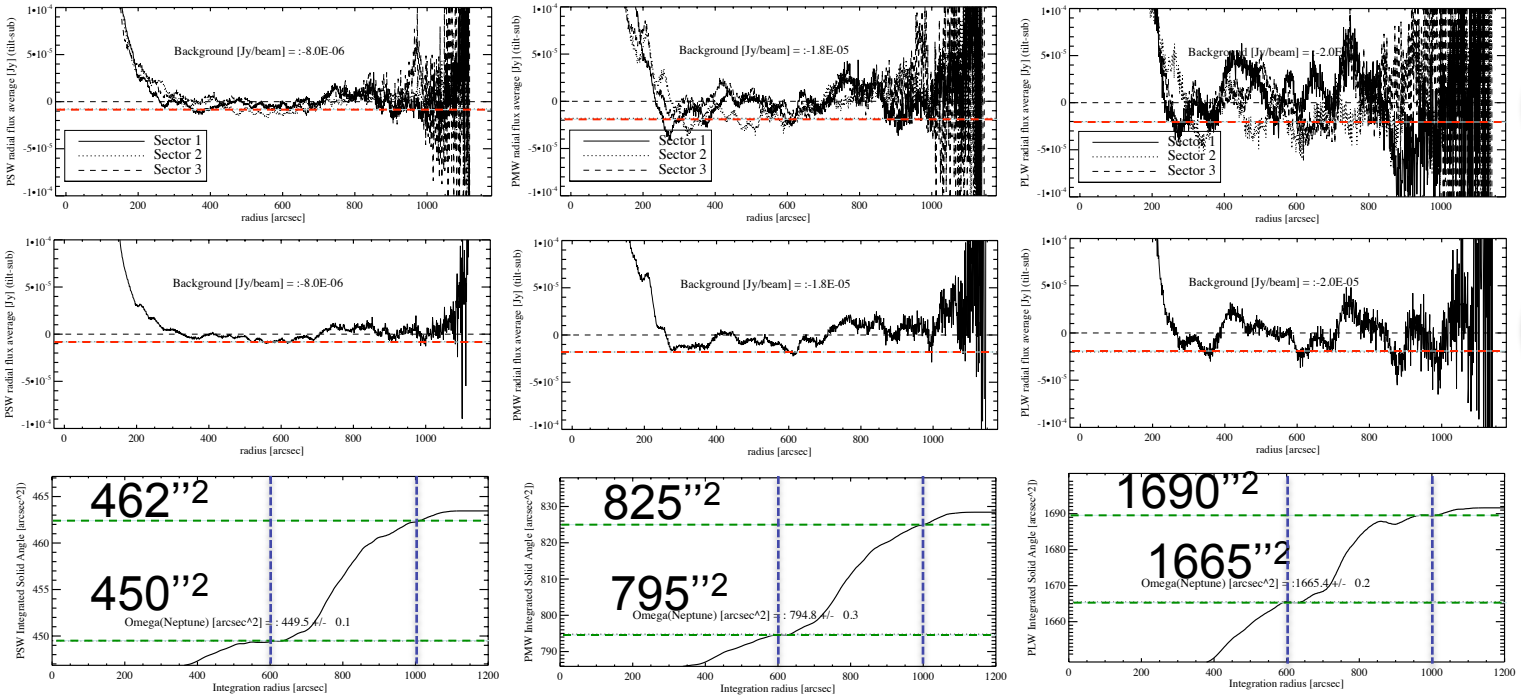
- Solution 1:
  - Fit and subtract a warped background plane (implemented).
- Solution 2:
  - Obtain “shadow” observation and subtract (next version).

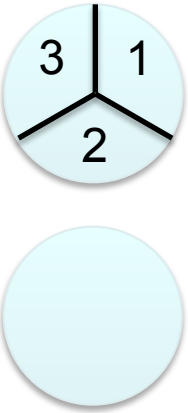
Neptune Fine Scan Maps



- Maps after removal of background sources.
- Coverage beyond 700” radius is low and reliability is questionable.

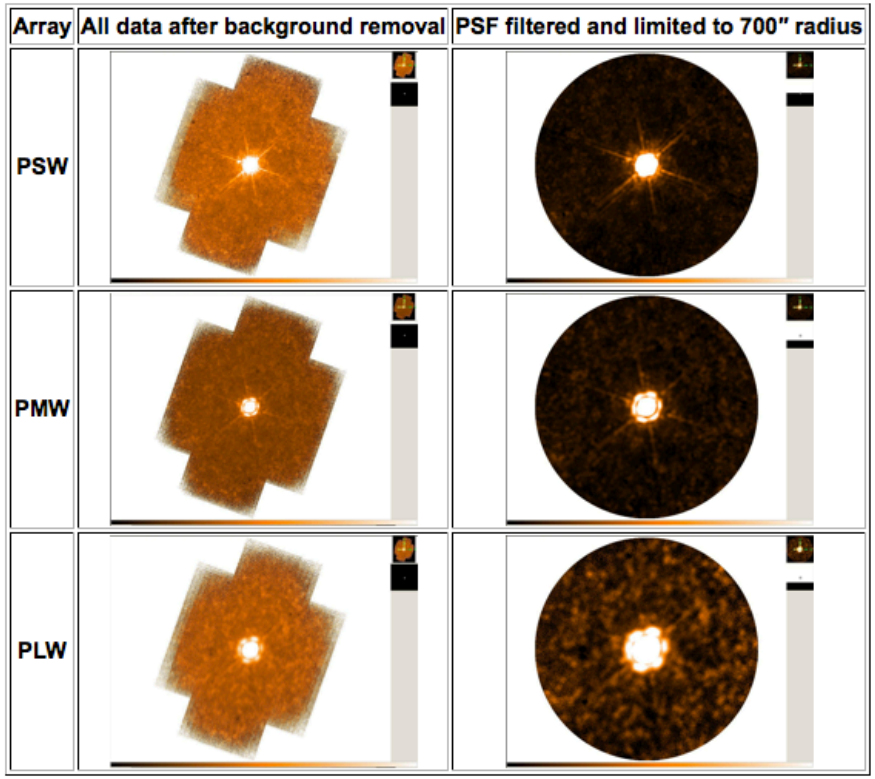
After Source and Background Removal





- Removed sources and warped plane improves consistency between three beam sectors.
- Background estimates similar to previous estimates before source removal.
- Integration out to 600’’ results in 450”^{2}, 795”^{2}, 1665”^{2} respectively for PSW, PMW, PLW.
- Integration out to 1000’’ results in 462”^{2}, 825”^{2}, 1690”^{2} respectively for PSW, PMW, PLW.
- Integrated solid angles smaller again.

SPIRE Extended Source calibration



- Re-built fine scan map of Neptune with 1 arcsec pixel size.
- Removed sky background structure (tilt and galaxies)
- Integrated solid angle to 600" radius.
- Estimated uncertainty is +/- 4%.
- Recently (Nov 2012) obtained "shadow" observation of the same region should improve accuracy further.
- Monochromatic extended source fluxes are quoted assuming the standard $\nu * F_\nu$=const. reference spectrum.

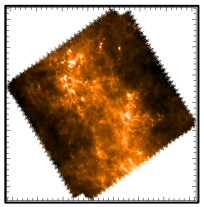
Solid angles in [arcsec^2]	PSW	PMW	PLW
Measured with Neptune spectrum	450	795	1665
SPIRE photometer reference spectrum (nu*F_nu = const.)	465	822	1768

HIPE 10 Implementation

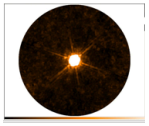
- New Healpix Library to read HFI 545 GHz and HFI 857 GHz maps.
- Interpolator for irregularly distributed data points.
- HIPE task “zeroPointCorrection()”
- Input parameters:
  - Level 2 context with three extended source maps
  - Two HFI Healpix maps at 545 GHz and 857 GHz.
  - A table with pre-calculated relative color correction factors based on relative HFI flux ratios and a simple dust model.
  - Photometric gains (1.0) SPIRE/HFI for 545 GHz and 857 GHz.
  - SPIRE photometer solid angles (hard coded 465, 822, 1768”^2)
  - Effective Gaussian FWHM of HFI maps (8’’)

Comparison in Detail I

PMW or PLW



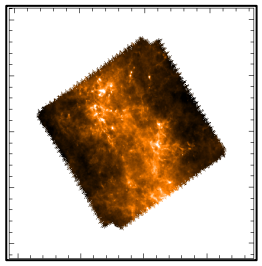
SPIRE

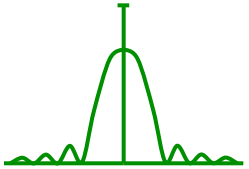


Solid Angle from Beam Profile

Convert to MJy/sr
multiply by $K4_{ext}/K4_{pnt}$
divide by Solid Angle

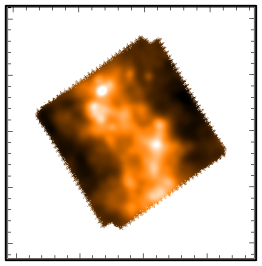
Expand Map

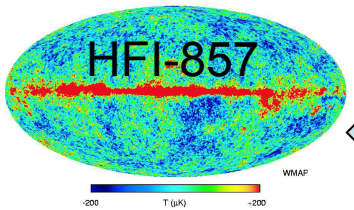




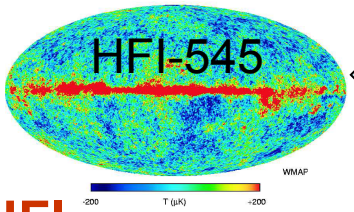
Convolve
Kernel is convolution of 8' Gaussian and HFI Beam model (Smaller ~3.5' Gaussian)

Convolved SPIRE map



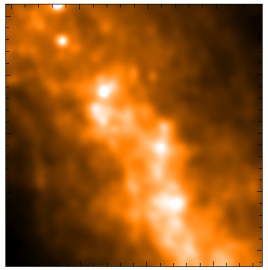


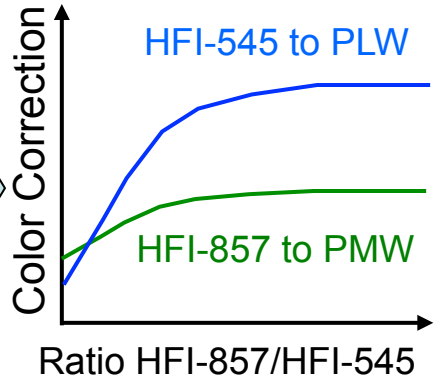
All sky Healpix maps



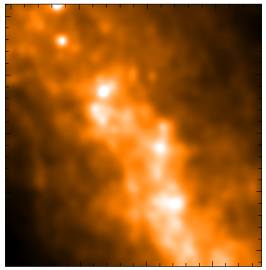
HFI

Ratio map





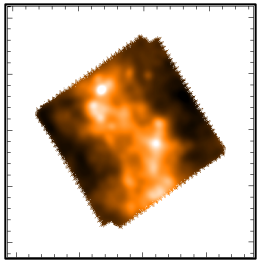
Color corrected HFI map



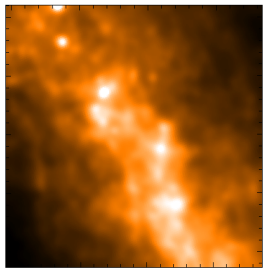
Color correct HFI map to SPIRE filter bands PSW or PLW based on fit of Grey-Body dust model with β=1.8 to HFI fluxes.

Comparison in Detail II

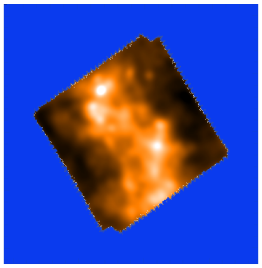
Convolved SPIRE map



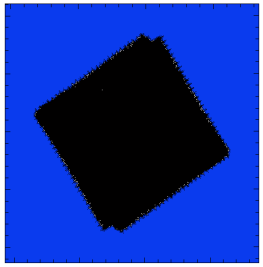
Color corrected HFI map



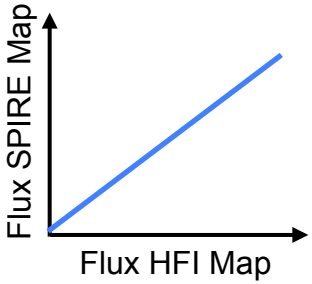
Compare within mask



Mask where edge effects <0.1%



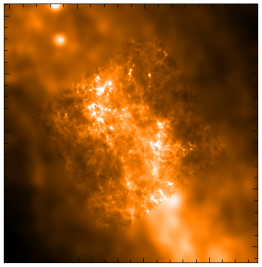
Determine median difference. Fit Offset and Scale.



1st Scale
1st Offset
1st Median Offset

Embed SPIRE map into median adjusted HFI map

Embedded SPIRE map



Embedding reduces edge effects in the subsequent SPIRE map convolution

Comparison in Detail III

Embedded SPIRE map

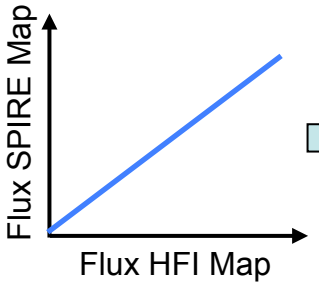
Convolve

Convolved SPIRE map

Color corrected HFI map

Compare within mask

Determine median difference. Fit Offset and Scale.



2nd Scale
2nd Offset
2nd Median Offset

Pipeline Output

SPIRE map with corrected zero-point using median difference

Median and standard deviation of the difference map in FITS header

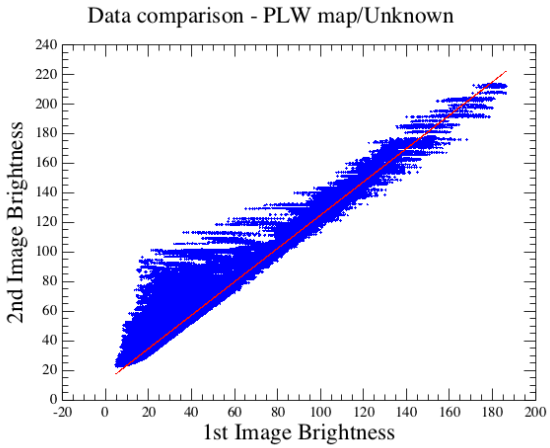
Mask for entire SPIRE map

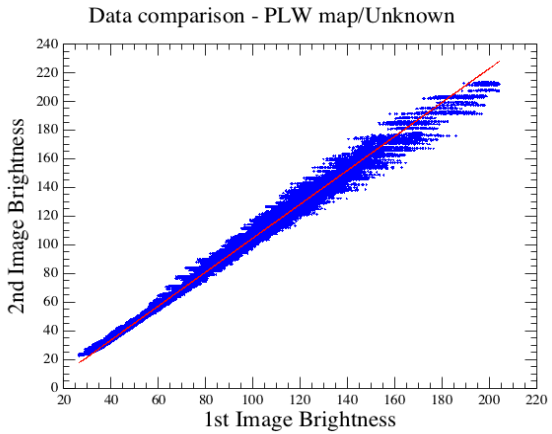
Map Correlations

First Comparison

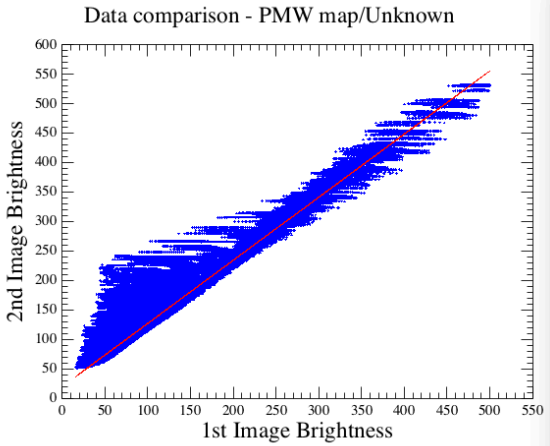
Second Comparison (embedded map)

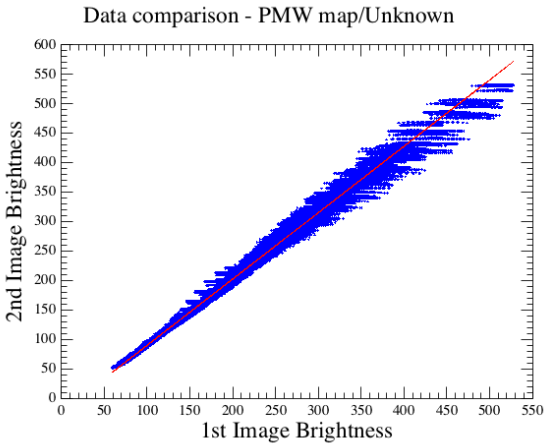
PLW

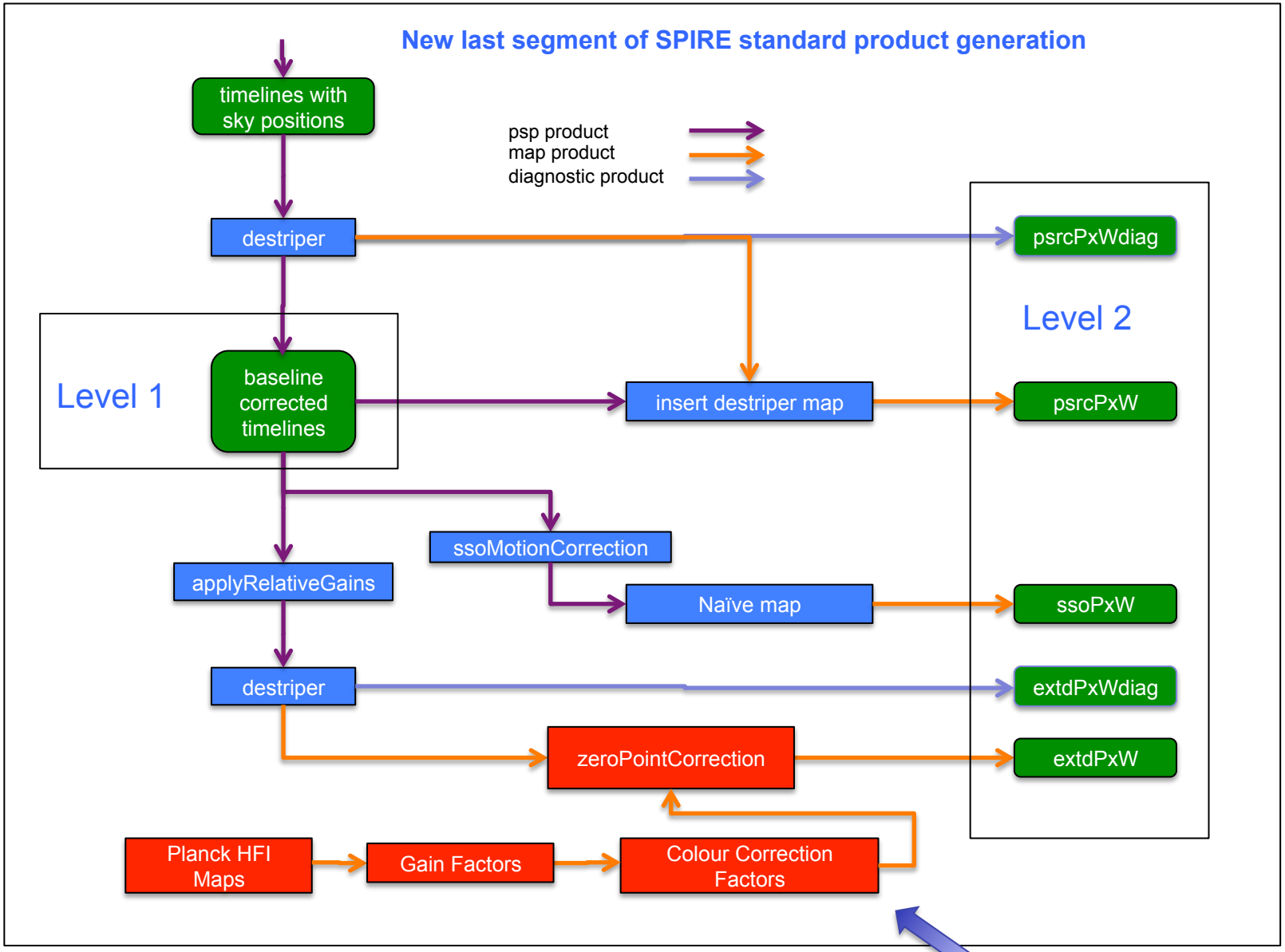




PMW



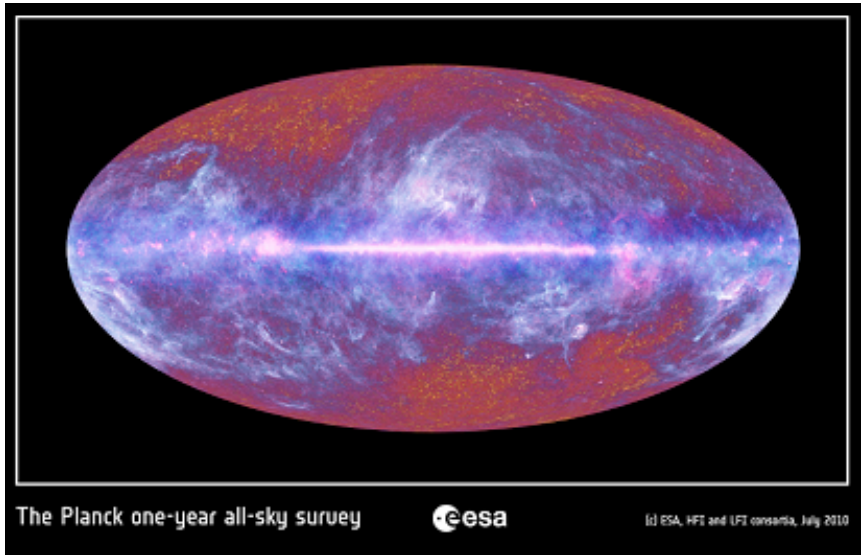



New last segment of SPIRE standard product generation
timelines with sky positions
psp product
map product
diagnostic product
destriper
psrcPxWdiag
Level 2
Level 1
baseline corrected timelines
insert destriper map
psrcPxW
ssoMotionCorrection
applyRelativeGains
Naïve map
ssoPxW
destriper
extdPxWdiag
zeroPointCorrection
extdPxW
Planck HFI Maps
Gain Factors
Colour Correction Factors

New Level 2 Products

- Point source maps [Jy/beam] renamed to psrcP?W.
- Associated diagnostic products named psrcP?Wdiag.
- (for SSOs) Proper motion corrected maps ssoP?W.
- Extended source maps [MJy/sr] with FIRAS/HFI absolute sky background levels extdP?W.
- Associated diagnostic products named extdP?Wdiag.

Planck-HFI Maps



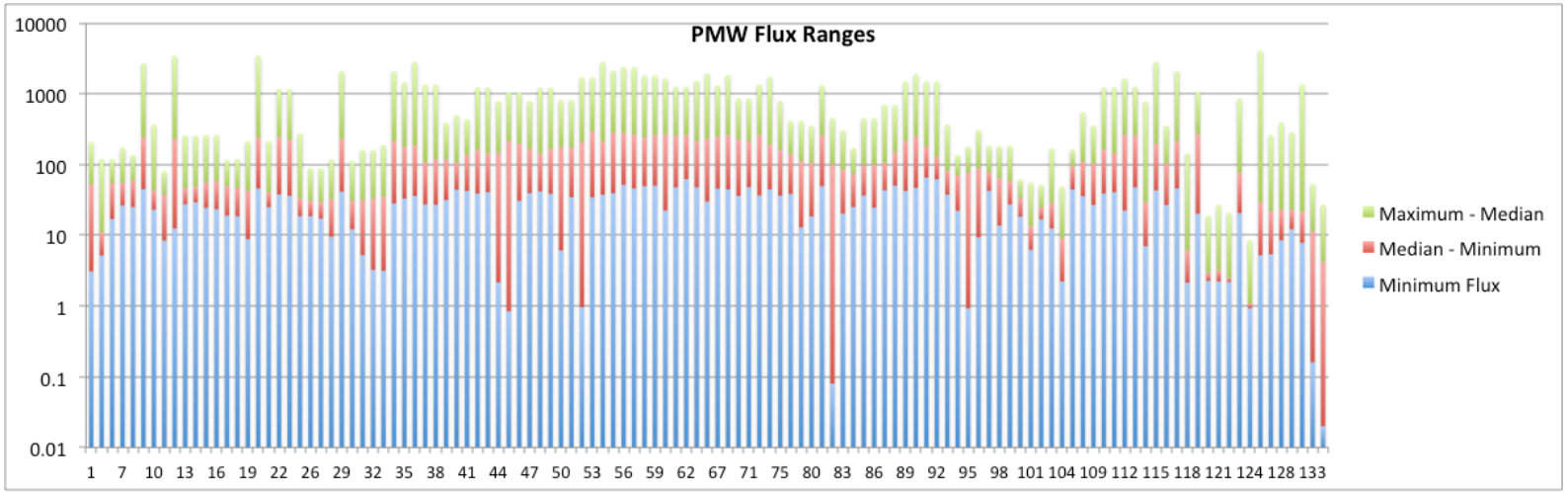
In March 2011 the Planck team kindly agreed to make a confidential release of HFI 545 and 857 GHz maps before the official release date to enable zero-point correction of SPIRE maps in the data reduction pipeline at the Herschel Science Center only.

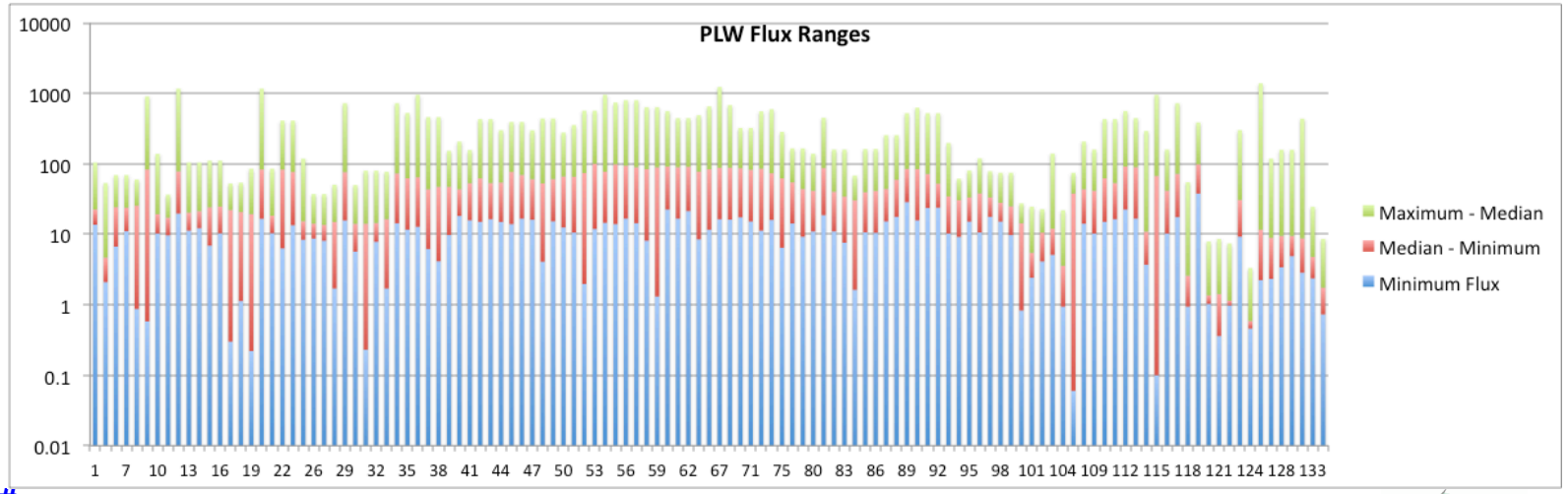
- Subsequently four different internal releases for the HFI 545 GHz and HFI 857 GHz filter bands were received and evaluated
  - (DR2, DX7, DX9, re-calibrated DX9).
- Relative photometric gains, consistency and beam profile verifications were conducted.
- HFI photometry of planets was compared with planet flux models.
- Regular telecons/meetings of the HFI/SPIRE cross calibration team were held to clarify matters, agree on policies, and to provide feedback to the Planck project.

Gain Verification

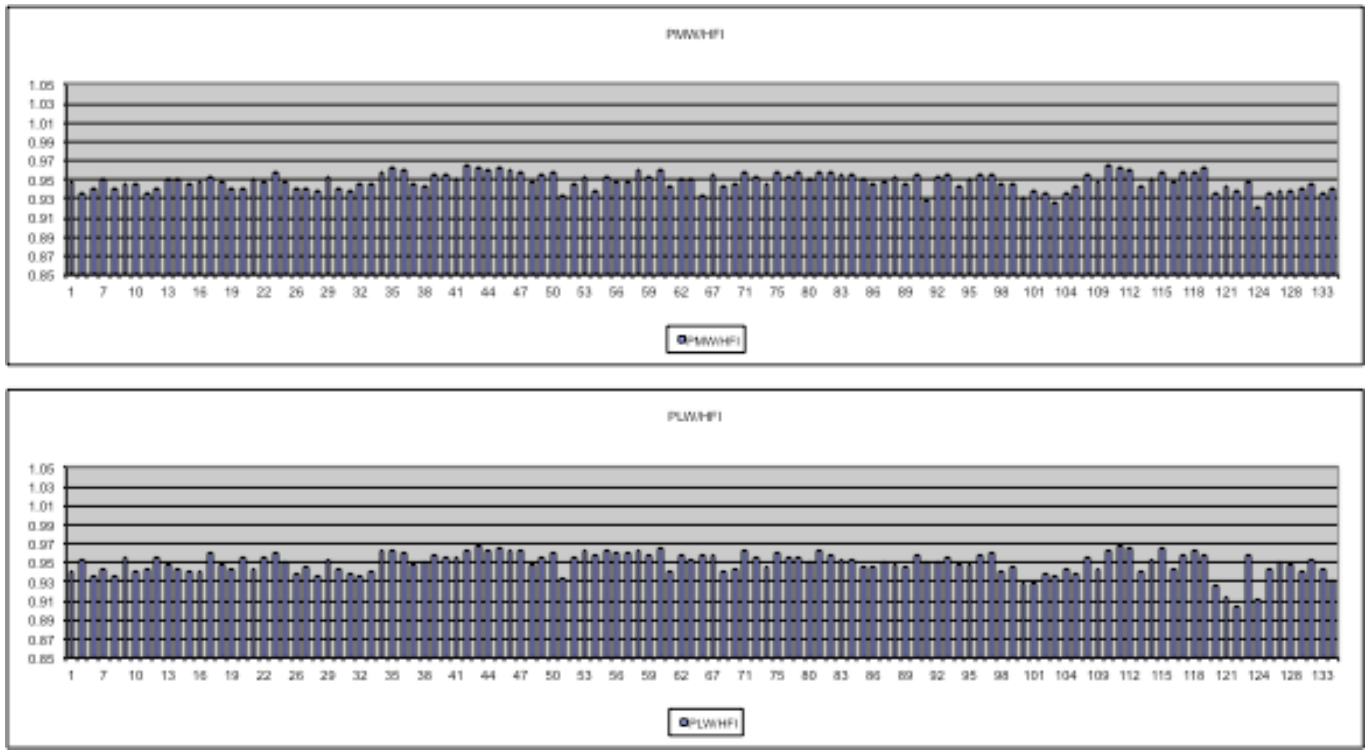
- Verification of the photometric gain is a prerequisite for the zero-point correction of SPIRE photometer maps.
- Select large SPIRE photometer maps, re-reduce to Level 1 and construct de-striped maps.
- Exclude smaller fields, fields with low flux dynamic range, fields with strong saturated sources close to the edge.
- Run comparison procedure.
  - There are one IDL and two HIPE implementations for cross checking.
- Determined ratio of photometric gains for SPIRE and HFI maps from pixel to pixel plots of SPIRE and HFI data.
- The scatter of the difference maps is at a few per cent of the respective background flux level.

Map Flux Ranges





Gain Verification

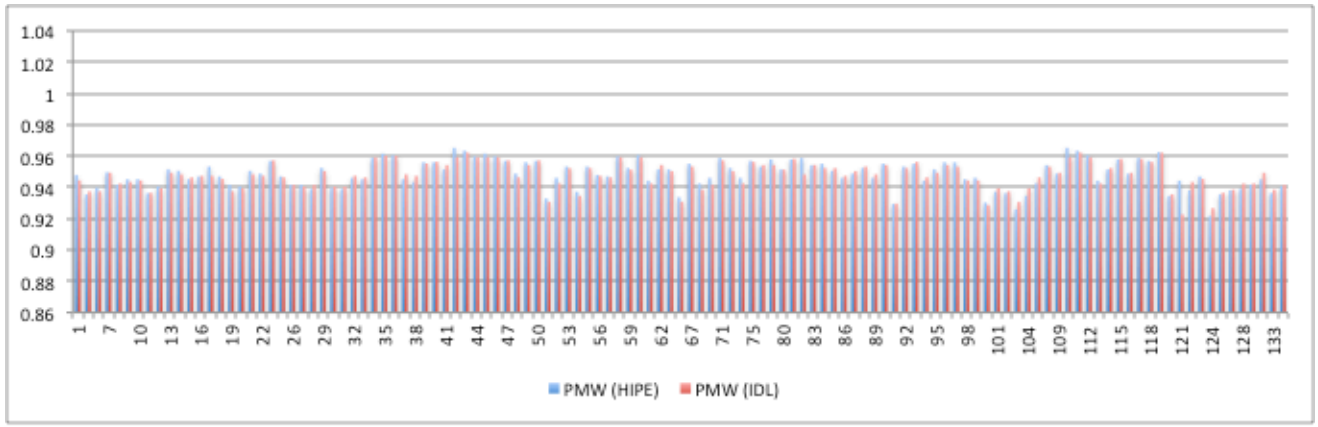


- A total of 119 large SPIRE maps were included in the comparison.
- We plot the flux ratios PMW/HFI-857 (top) and PLW/HFI-545 (bottom).
- The median ratios are 0.949 and 0.951 with standard deviations 0.009 and 0.011 for PMW/HFI-857 and PLW/HFI-545 respectively.

Gain Verification

- The HFI fluxes are about 5% brighter than the SPIRE fluxes in both channels.
- A similar comparison of several maps by the Planck team yields an average of 2% and 7% brighter HFI fluxes at 545 and 857 GHz (Planck Collaboration VIII. 2013, In preparation).
- Although the correspondence between the HFI and SPIRE calibrations is very good, the relative difference between the gains both teams found is significant and we are looking for the reason.

HIPE and IDL Results



HIPE and IDL gains agree well, on average within 0.4% and 1.7% for PMW and PLW.

Summary

- The new zero point calibration implementation into HIPE 10 is complete and operational.

- The new maps fit into the new Level 2 product structure adopted by SPIRE for HIPE 10.
- The new Level 2 product structure contains zero-point corrected SPIRE maps in [MJy/sr] and keywords specifying the median and the standard deviation of the difference map.
- New solid angles for the conversion to extended source fluxes have been determined to an accuracy of 4%.
- New “shadow” observations will improve the accuracy further and are being analyzed.
- The current HFI maps are photometrically consistent with the SPIRE maps within the quoted 10% absolute photometric accuracy of the HFI maps.
- The HFI photometry seems to be biased towards slightly higher fluxes and both teams find different photometric ratios.
- A more refined analysis is ongoing.