SPIRE Broad-Band Photometry Extraction

Bernhard Schulz (NHSC/IPAC)

on behalf of the
SPIRE ICC, the HSC and the NHSC

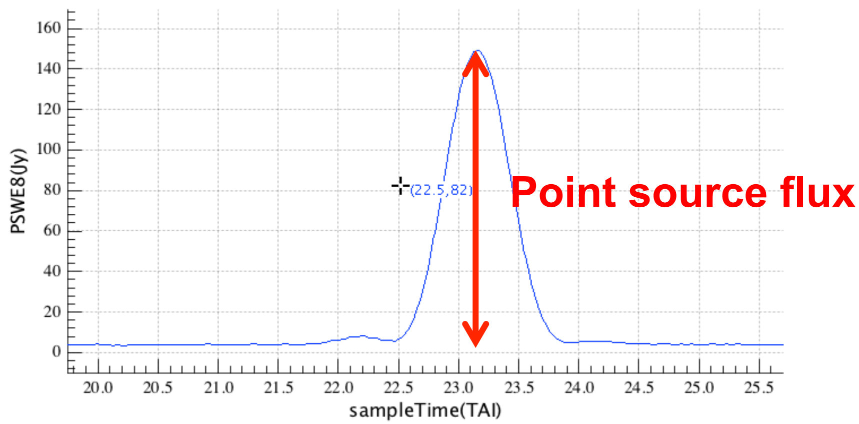
Contents

- Point Source Photometry
- Choices
- Extended gain correction factors
- Zero-point corrected extended flux maps
- Convert point source map to extended source fluxes.
- Correction factors to take into account
  - Color correction
  - Omega correction
  - Aperture correction
  - Background correction
- Derive aperture correction factors for semi extended sources
- Uncertainties

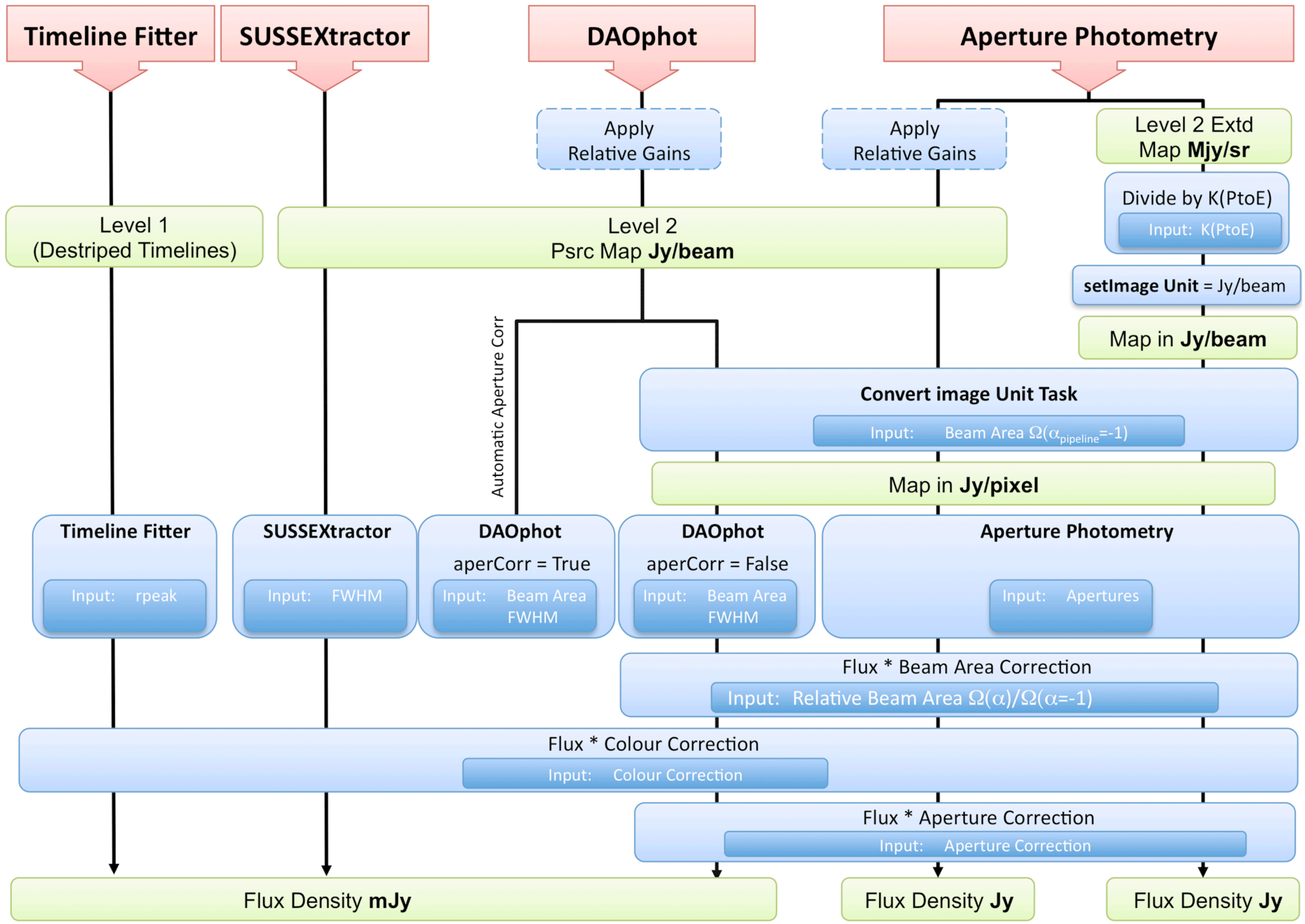
Point Source Photometry

- The SPIRE calibration is based on point source photometry (Prime calibrator: Neptune)
- Standard SPIRE unit is Jy/beam
- When a detector is scanned centrally over a point source, the peak deflection of the signal timeline equals the brightness of the source.
- The spire broad-band photometry is quantified as monochromatic flux density at a reference wavelength (250, 350, 500μm) assuming a reference spectrum of νF_ν = const.
- For a different reference spectrum a color correction must be applied.

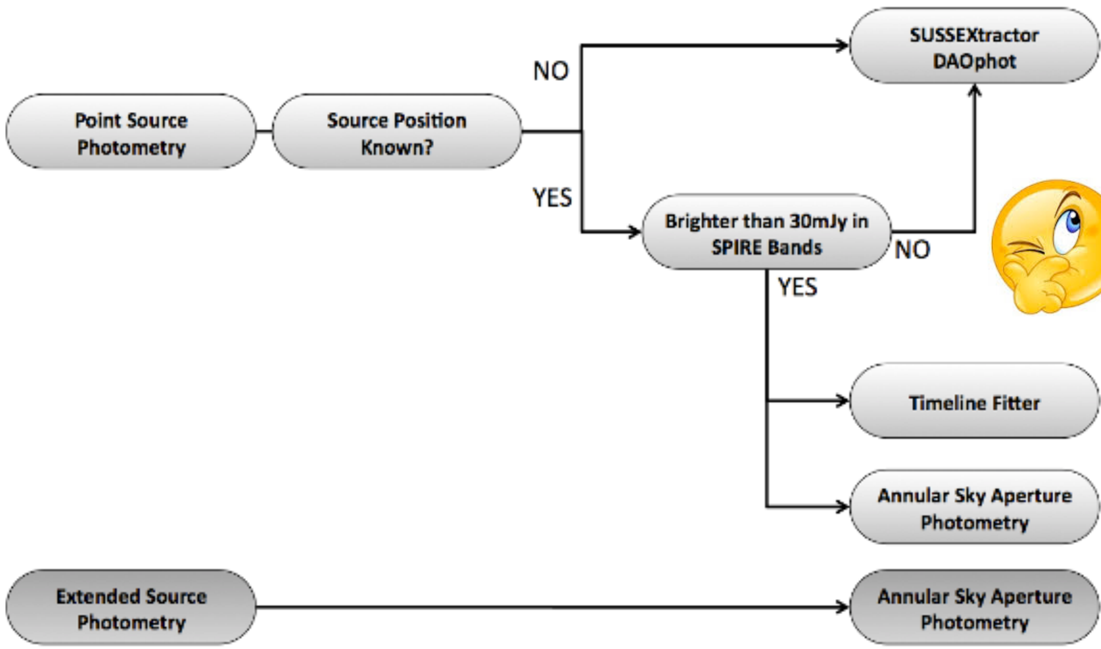
Scan of detector PSWE8 over Neptune, obsid 1342187440



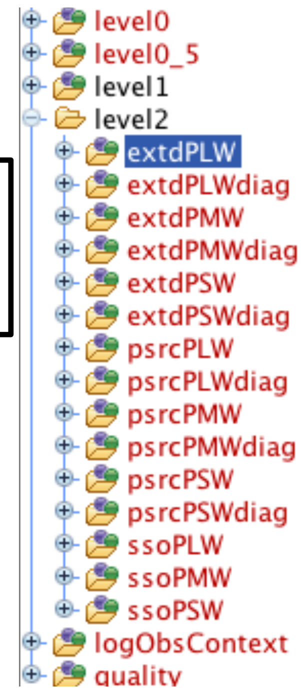
RECIPES FOR **SPIRE POINT SOURCE** PHOTOMETRY



The Right Photometry Choice

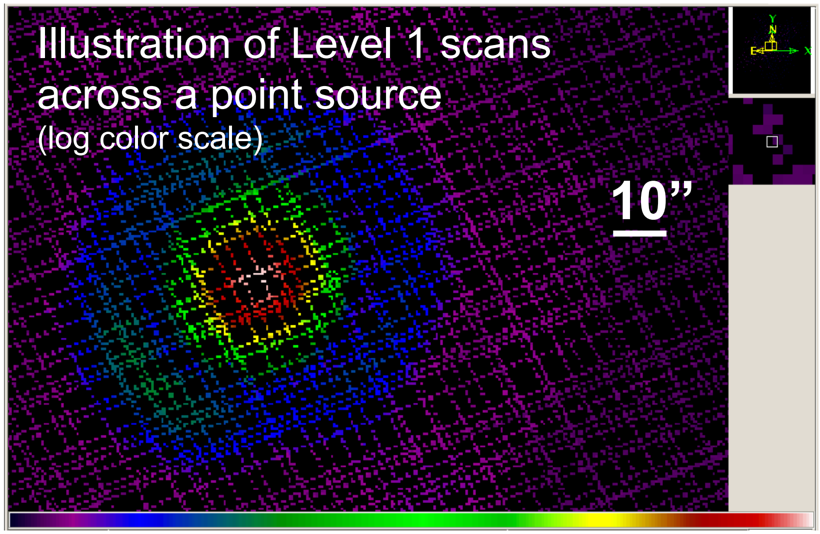


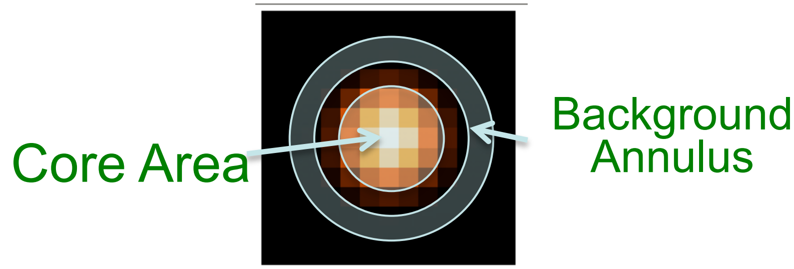
Be aware of the confusion limit



- For point sources there are several choices and it depends a bit on the task at hand. Generally the Timeline Fitter gives the most accurate results.
- For large and small extended sources there is only aperture photometry.
- The SPIRE Level 2 products fortunately already contain a product that comes in extended source units MJy/sr, ready for aperture photometry.

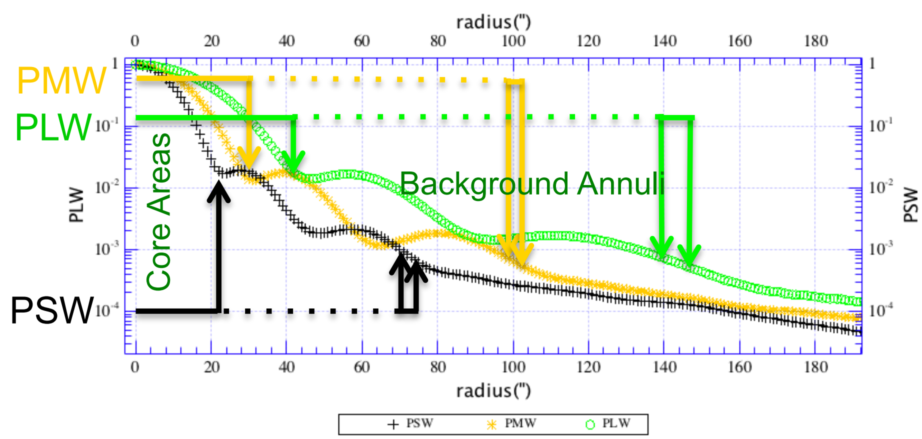
Timeline Fitter for Point Sources





Optimal Parameters	PSW	PMW	PLW
Core radius [“]	22	30	42
Inner radius [“]	70	98	140
Outer radius [“]	74	103	147

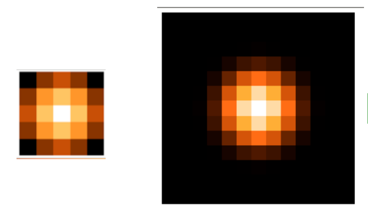
- Level 1 scan grid is fitted by 2D Gaussian
- Only readouts from core area and the background annulus are used for the fit.
- Annuli begin after 2nd Airy ring and cover an area comparable to core area.
- It is good to allow the background level to vary and to use the background annulus in the fit.
  - Example:
    - sourceList2 = sourceExtractorTimeline(input=obs.level1, array='PSW', rPeak=22.0, inputSourceList=sourceList1, allowVaryBackground=True, useBackInFit=True, rBackground=Double1d([70,74]))



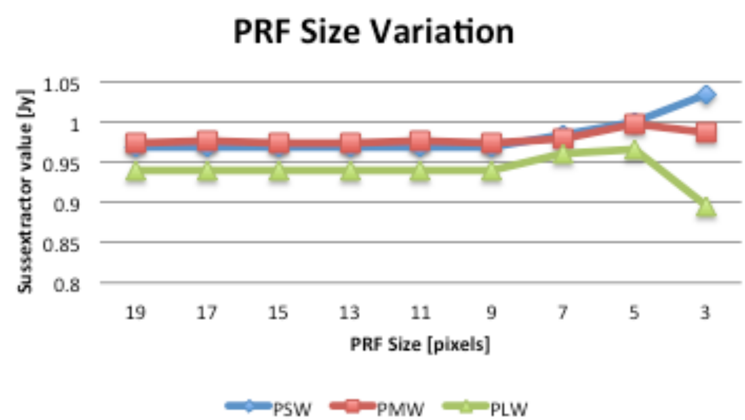
Sussextractor for Point Sources

- Source detector and extractor based on Bayesian model selection and information criterion (Savage & Oliver 2007, ApJ 661, 1339).
- The tool performs both, source detection, background estimation, and photometric evaluation.
- Uses Gaussian PRF model that is either internally generated or user-supplied.
- The default PRF size was increased from 5x5 to 13x13 pixels in HIPE 12.
- New studies suggest that the optimum may be at 9x9 pixels, based on the photometric consistency of results obtained in simulations with different PRF sizes.

HIPE 11
5x5

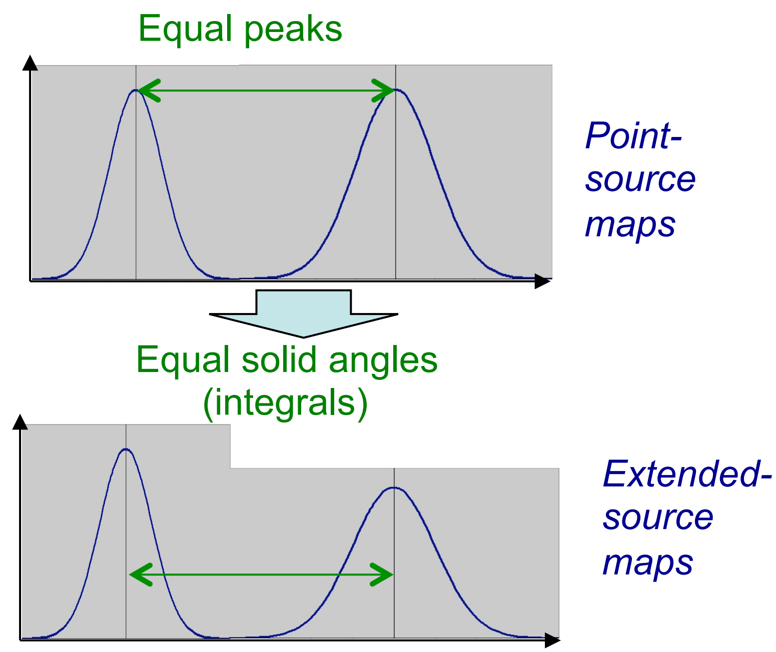


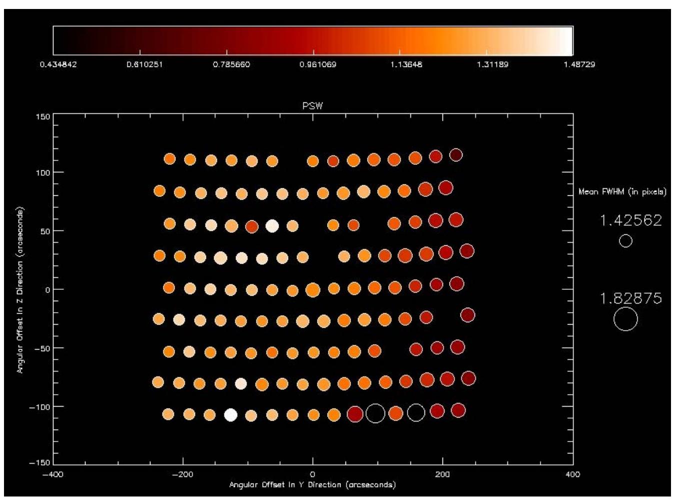
HIPE 12
13x13



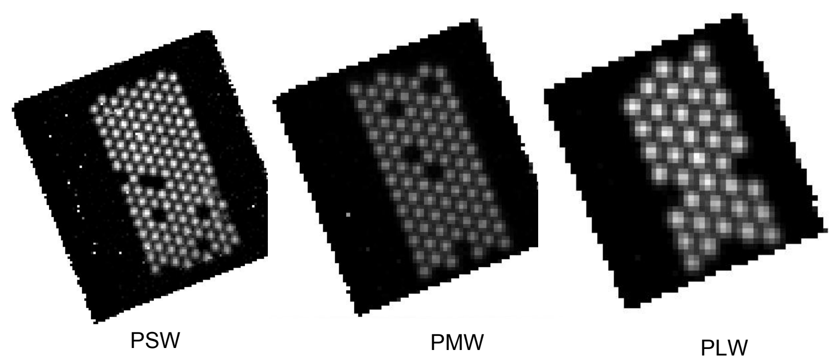
Extended Gain Correction

- Not all detector beam-profiles have the same width.
- Applying the Extended Gains equalizes the detector areas (instead of the peaks).
- The numbers are provided in the SPIRE calibration tree.
- These gain factors should be applied before median subtraction, or destriping, and map-making.



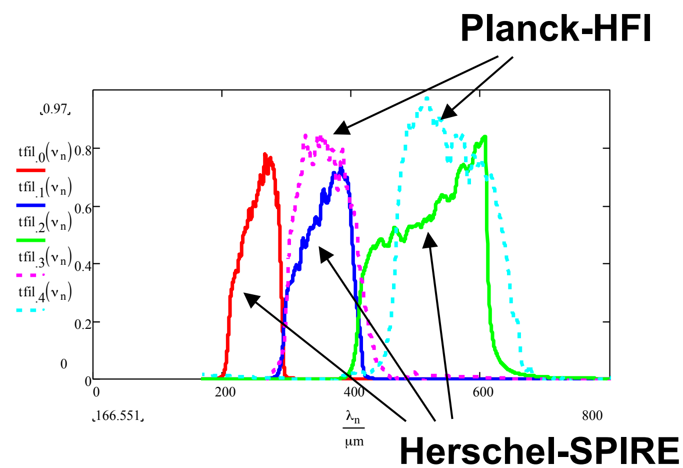


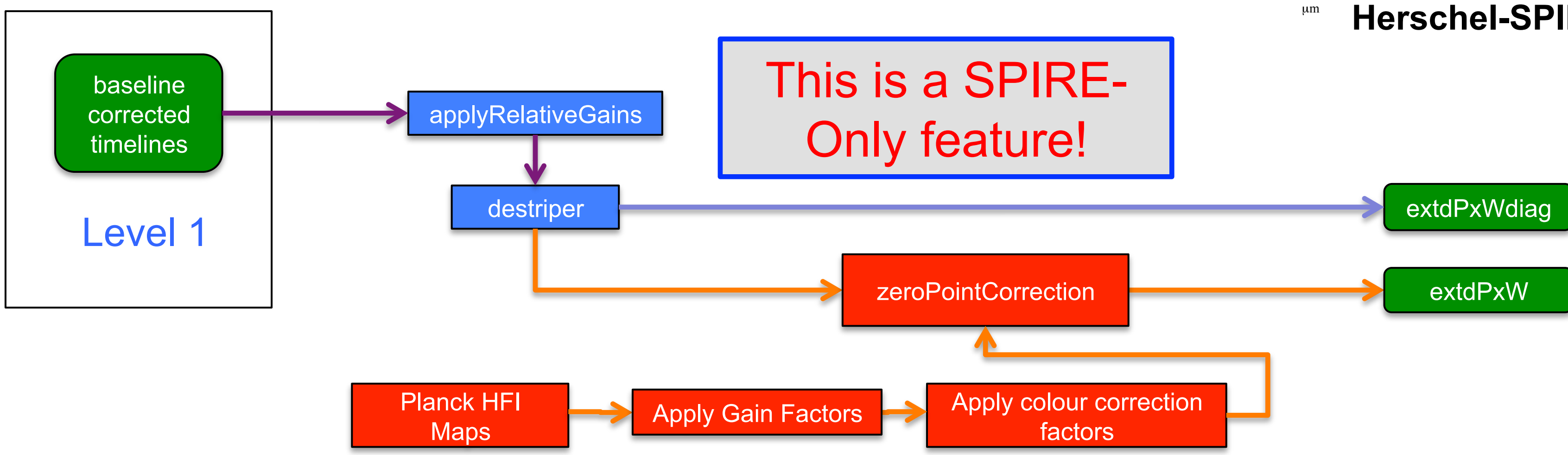
PSW: FWHMs are exaggerated



Zero-Point Correction of Extended Source Maps

- SPIRE and Planck-HFI overlap in SPIRE filters at 350 and 500mm (HFI 857 and 545 GHz filters).
- Planck HFI is using photometric gains from Uranus and Neptune radiative models and zero-levels from correlation of HI (21cm) gas column density with CIB mean level added (Planck Collaboration VIII. 2013, In prep.)
- Latest analysis shows very good correspondence of SPIRE and HFI photometric gains. We still multiply the HFI 545GHz map by 0965 for consistency.
- The SPIRE standard pipeline uses fits to gain and color corrected HFI maps to provide absolute flux offsets in the extended flux map products
  - one offset value added to a map.



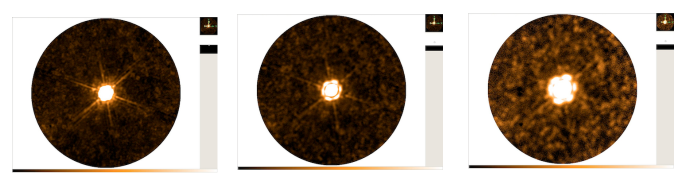


Aperture Photometry

- Aperture photometry sums up map pixels, i.e. expects the map signal in extended source units like MJy/sr, Jy/’’□, or Jy/pixel.
- The solid angle needed for the conversion is color dependent and was derived from large fine scan maps (1” pixels) of Neptune that go out to 700” radius.
- The extended flux source maps in the HSA are converted for a νF_ν=const. spectrum and corrections need to be applied to aperture photometry.

- Color correction:
  - Source SED different from assumed reference spectrum νF_ν=const.
- Aperture correction
  - Correction for Flux lost outside of integration aperture.
- Background correction
  - Correction for flux of the beam still inside of the annulus where backround is determined.
- Omega correction
  - Correction for change in effective solid angle when source SED is different from νF_ν=const.

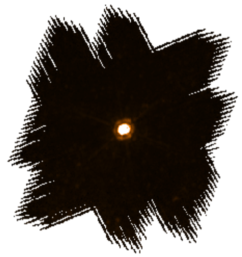
Solid angles in [arcsec^2]	PSW	PMW	PLW
Measured with Neptune spectrum	450	795	1665
SPIRE photometer reference spectrum (nu*F_nu = const.)	465	822	1768



See: http://herschel.esac.esa.int/twiki/bin/view/Public/SpirePhotometerBeamProfile

Aperture Photometry on Point Sources

extdPxW
[MJy/sr]



Best to start with extended source map

Convert Image Unit Task

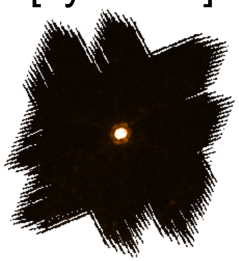
[Jy/pixel]

Aperture Photometry Task

[Jy/pixel]

Convert Image Unit Task

psrcPxW
[Jy/beam]



Aperture Correction

alpha	Perfect BG PSW	Perfect BG PMW	Perfect BG PLW	BG annulus 60"-90" PSW	BG annulus 60"-90" PMW	BG annulus 60"-90" PLW
-4.0	1.277	1.227	1.216	1.282	1.234	1.236
-3.5	1.275	1.226	1.214	1.280	1.234	1.234
-3.0	1.274	1.226	1.213	1.279	1.234	1.232
-2.5	1.273	1.226	1.212	1.277	1.233	1.231
-2.0	1.272	1.225	1.210	1.276	1.233	1.229
-1.5	1.271	1.225	1.209	1.276	1.232	1.227
-1.0	1.270	1.224	1.208	1.275	1.232	1.226
-0.5	1.269	1.224	1.207	1.274	1.231	1.224
0.0	1.269	1.223	1.205	1.273	1.231	1.222
0.5	1.268	1.223	1.204	1.272	1.231	1.221
1.0	1.267	1.222	1.203	1.272	1.230	1.219
1.5	1.267	1.222	1.202	1.271	1.230	1.218
2.0	1.266	1.222	1.201	1.270	1.229	1.216
2.5	1.265	1.221	1.200	1.269	1.229	1.215
3.0	1.264	1.221	1.199	1.269	1.229	1.213
3.5	1.264	1.220	1.198	1.268	1.228	1.212
4.0	1.263	1.220	1.197	1.267	1.228	1.211
4.5	1.262	1.219	1.196	1.266	1.227	1.209
5.0	1.262	1.219	1.195	1.266	1.227	1.208

Color Correction

Table 5.12. Color Corrections for Point Sources and Extended Emission

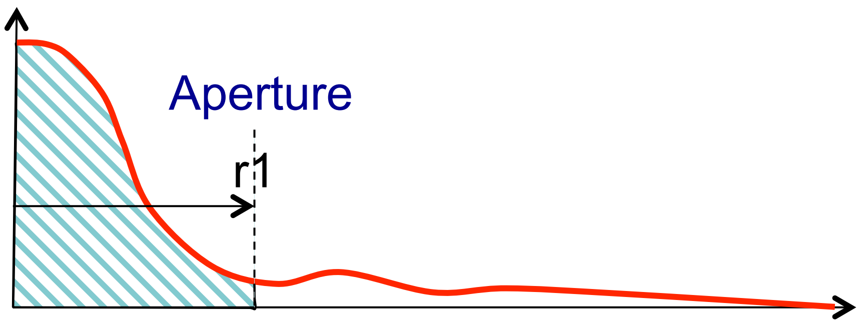
Spectral Index ($F_{nu}=nu^{alpha}$)	Point Source Colour Correction PSW	Point Source Colour Correction PMW	Point Source Colour Correction PLW	Extended Emission Colour Correction PSW	Extended Emission Colour Correction PMW	Extended Emission Colour Correction PLW
-4	0.9800	0.9791	0.9333	0.9407	0.9405	0.8703
-3.5	0.9884	0.9875	0.9525	0.9549	0.9547	0.8982
-3	0.9948	0.9940	0.9687	0.9675	0.9673	0.9239
-2.5	0.9992	0.9986	0.9817	0.9784	0.9783	0.9472
-2	1.0016	1.0011	0.9913	0.9875	0.9874	0.9679
-1.5	1.0019	1.0016	0.9974	0.9948	0.9947	0.9855
-1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
-0.5	0.9960	0.9963	0.9990	1.0032	1.0033	1.0111
0	0.9899	0.9906	0.9945	1.0043	1.0046	1.0187
0.5	0.9818	0.9829	0.9864	1.0034	1.0038	1.0227
1	0.9716	0.9732	0.9751	1.0003	1.0009	1.0230
1.5	0.9594	0.9615	0.9606	0.9951	0.9960	1.0197
2	0.9454	0.9481	0.9432	0.9878	0.9890	1.0128
2.5	0.9296	0.9329	0.9231	0.9784	0.9800	1.0025
3	0.9121	0.9161	0.9005	0.9671	0.9691	0.9889
3.5	0.8930	0.8978	0.8758	0.9538	0.9563	0.9721
4	0.8725	0.8780	0.8492	0.9388	0.9418	0.9526
4.5	0.8507	0.8571	0.8210	0.9220	0.9255	0.9304
5	0.8278	0.8350	0.7916	0.9036	0.9077	0.9059

For aperture photometry, starting with a point source map is not recommended but possible.

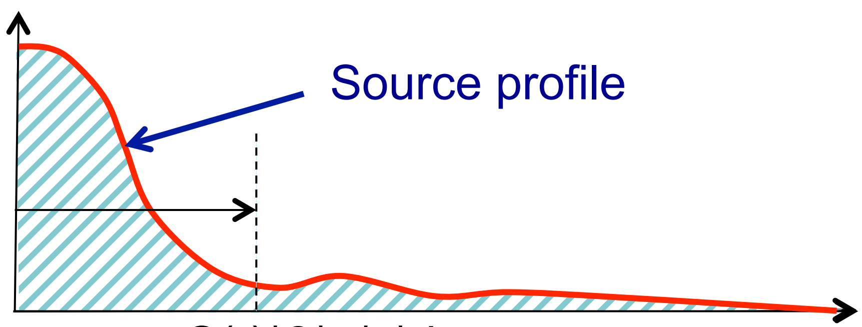
Solid angles in [arcsec^2]	PSW	PMW	PLW
SPIRE photometer reference spectrum (nu*F_nu = const.)	465	822	1768

Aperture Correction Factors

If background was perfectly known and subtracted.

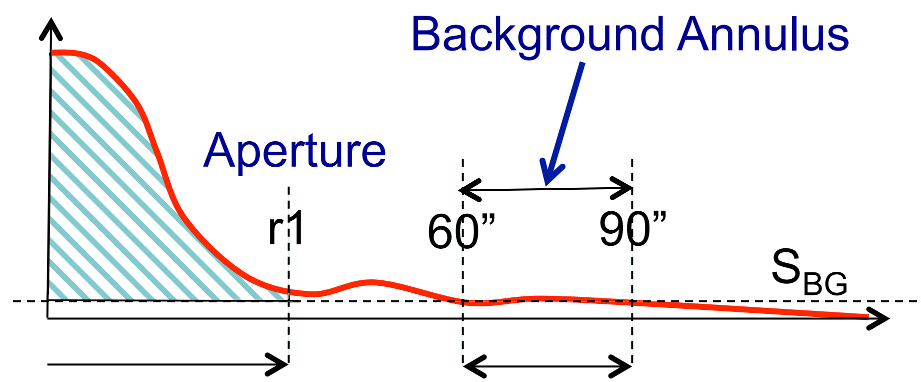


$\Omega_{aper}=\Sigma_{0..r1}$ S(r)*2*π*r*dr



$\Omega_{total}=\Sigma$ S(r)*2*π*r*dr

Take into account error due to beam residual in background estimation.



$\Omega_{aper}=\Sigma_{0..r1}$ (S(r)-S_{BG}) *2*π*r*dr

aperCorr = Ω_{total} / Ω_{aper}

The same principles apply for both, point, and extended sources.

Parameters for Point Source Photometry

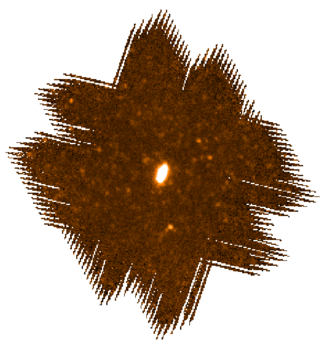
Algorithm	FWHM (arcsec)	Beam^1 Area (arcsec²)	Detection Threshold	Rpeak (arcsec)	Torus (arcsec)	Aper Corr	
SUSSEXtractor	17.6 23.9 35.2	N/A	✔	N/A	N/A	N/A	use with point source map
DAOphot	18.4 25.1 36.9	465 823 1769	✔	default or 22 30 42	60-90	Auto or 1.2620 1.2197 1.1897	use with extended source map
Timeline Fitter	N/A	N/A	N/A	22 30 42	70-74 98-103 140-147	N/A	use with Level 1 data of point source map
Aperture Photometry	N/A	465 823 1769	N/A	22 30 42	60-90	1.2620 1.2197 1.1897	use with extended source map

The Useful script "Photometer_Photometry.py" is a good example how to do point source photometry in a practical case.

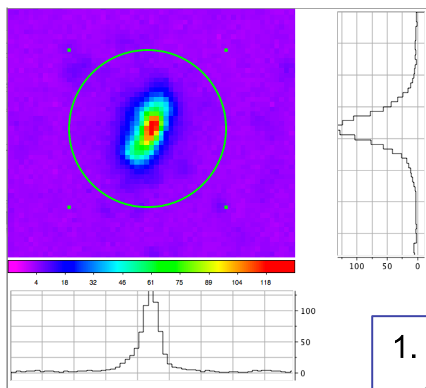
Note that the script does not yet reflect some of the optimized parameters in this table.

Aperture Photometry on Extended Sources

extdPxW
[MJy/sr]



Aperture Correction



Convert Image Unit Task

[Jy/pixel]

Aperture Photometry Task

1. For a large bright source the aperture can be large and aperture correction is negligible.

2. For a small faint source the aperture can not be too large and the aperture correction must be derived by modeling the source flux distribution to obtain precise results.

Color+Omega Correction

Table 6.13. Color Corrections for Point Sources and Extended Emission

Spectral Index	Point Source Colour Correction			Extended Emission Colour Correction		
($F_{nu}=nu^{alpha}$)	PSW	PMW	PLW	PSW	PMW	PLW
-4	0.9800	0.9791	0.9333	0.9406	0.9409	0.8696
-3.5	0.9884	0.9875	0.9525	0.9550	0.9551	0.8977
-3	0.9948	0.9940	0.9687	0.9677	0.9676	0.9236
-2.5	0.9992	0.9986	0.9817	0.9786	0.9785	0.9471
-2	1.0016	1.0011	0.9913	0.9877	0.9876	0.9678
-1.5	1.0019	1.0016	0.9974	0.9948	0.9948	0.9855
-1	1.0000	1.0000	1.0000	1.0000	1.0000	1.0000
-0.5	0.9960	0.9963	0.9990	1.0031	1.0032	1.0111
0	0.9899	0.9906	0.9945	1.0041	1.0044	1.0187
0.5	0.9818	0.9829	0.9864	1.0031	1.0035	1.0226
1	0.9716	0.9732	0.9751	0.9999	1.0006	1.0229
1.5	0.9594	0.9615	0.9606	0.9945	0.9955	1.0195
2	0.9454	0.9481	0.9432	0.9871	0.9885	1.0126
2.5	0.9296	0.9329	0.9230	0.9776	0.9794	1.0022
3	0.9121	0.9161	0.9005	0.9661	0.9684	0.9885
3.5	0.8930	0.8978	0.8757	0.9527	0.9555	0.9717
4	0.8725	0.8780	0.8492	0.9375	0.9409	0.9521
4.5	0.8507	0.8571	0.8210	0.9206	0.9245	0.9298
5	0.8278	0.8350	0.7916	0.9020	0.9067	0.9053

Uncertainties

- Uncertainty in the derived flux
  - Includes the instrument
  - Confusion noise
    - (minimum of about 5 mJy for point sources)
  - Background estimate
- Point Sources (based on peak photometry with Timeline Fitter)
  - 2% statistical reproducibility
  - 4% absolute level of Neptune model
    - (systematic)
- Extended Sources (assuming aperture correction is understood)
  - 2% statistical reproducibility
  - 4% absolute level of Neptune model
    - (systematic)
  - 4% uncertainty in solid angle determination
    - (systematic)
    - This one will be substantially reduced in the next version.

Point Source Photometry Notes

- Point source maps are calibrated to produce equal peak signals for the same point source brightness.
- Extended flux maps are calibrated to produce equal signals for the same flux density filling the entire detector beam.

- Timeline Fitter, Sussextractor and a Gaussian Fit are estimates of the peak and should be applied to point source calibrated maps [Jy/beam].
- Daophot, or any other form of aperture photometry, regardless of whether it is applied to a real point source or extended source, should be used with extended flux calibrated maps [MJy/sr].
- The important difference between both types of maps is the Extended Gain Correction, not the units.