SPIRE Photometry

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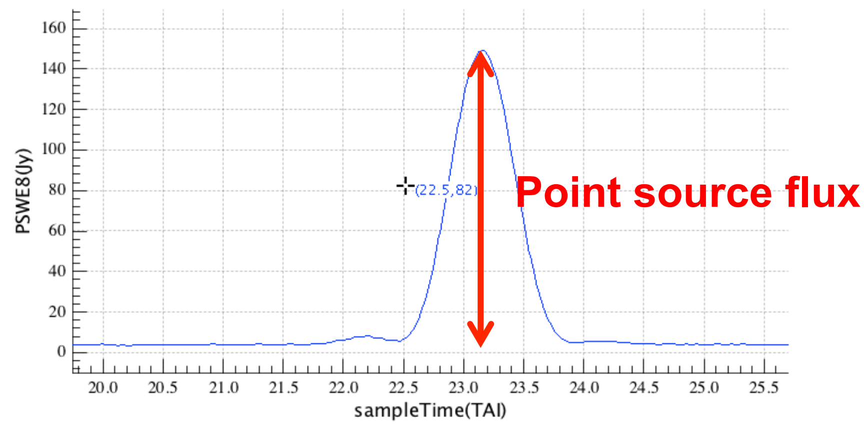
on behalf of the
SPIRE ICC, the HSC and the NHSC

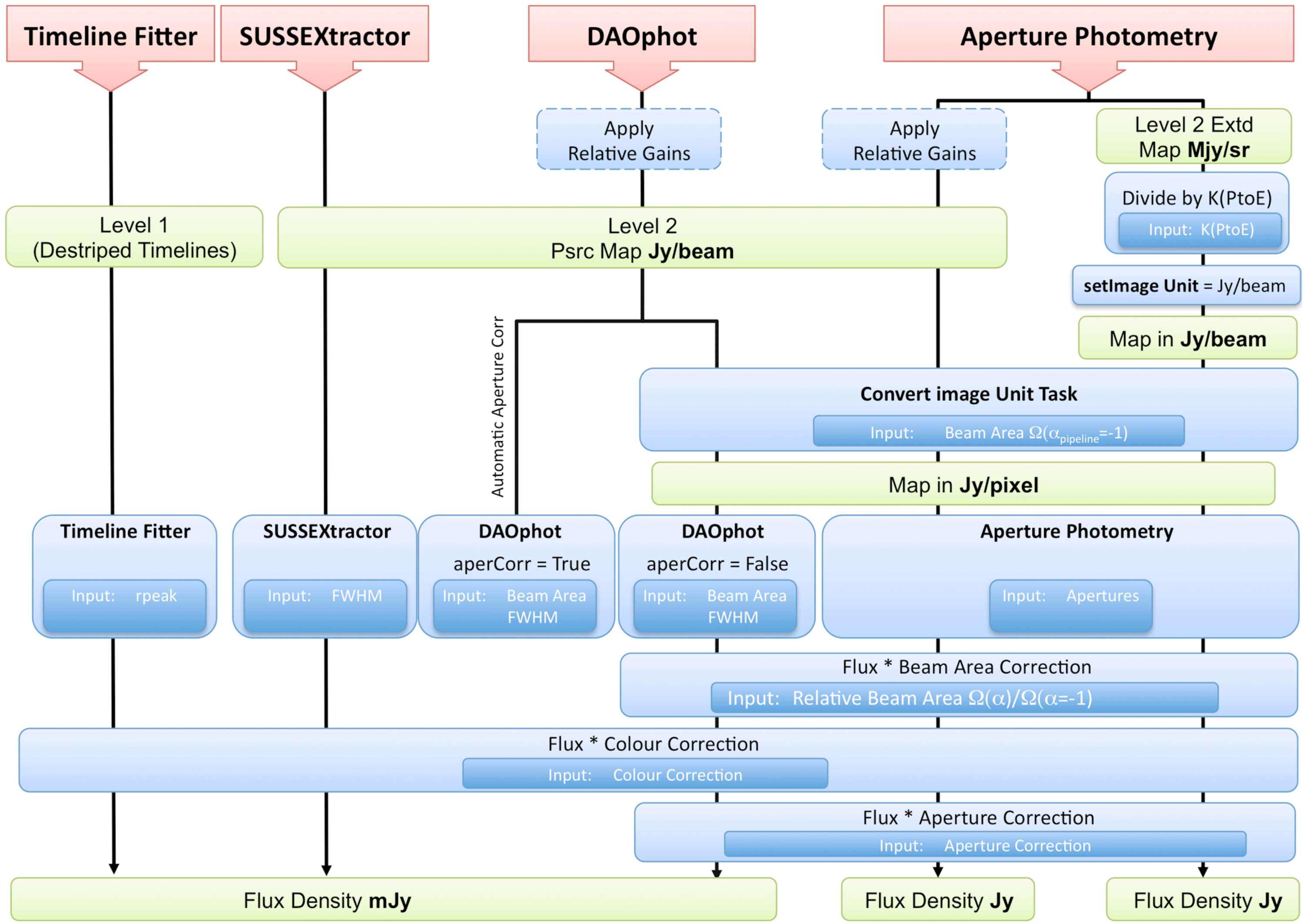
Point Source Photometry

- 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.

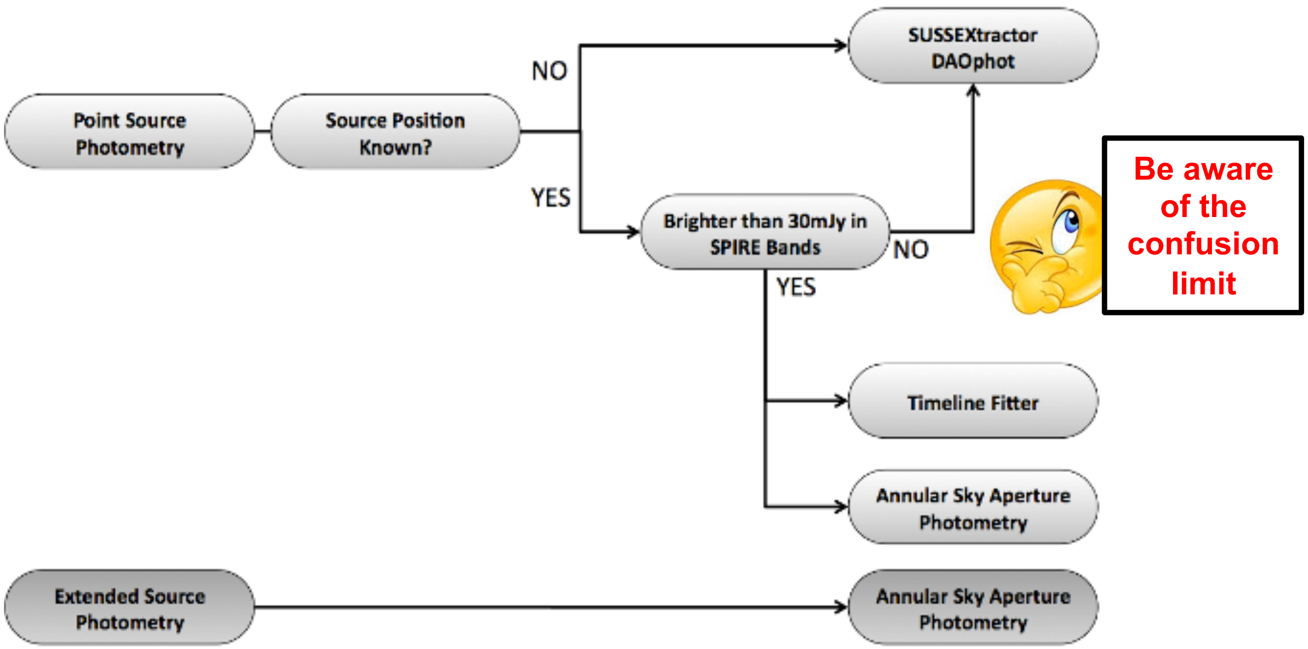
Scan of detector PSWE8 over Neptune, obsid 1342187440

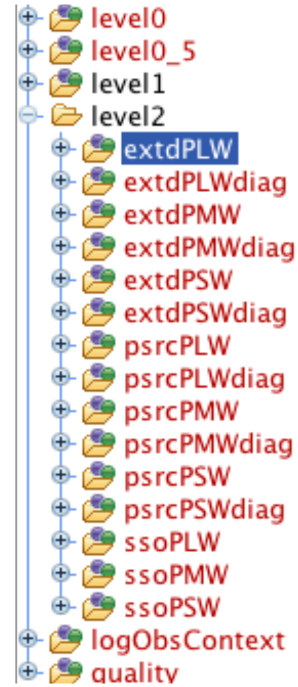


RECIPES FOR **SPIRE POINT SOURCE** PHOTOMETRY



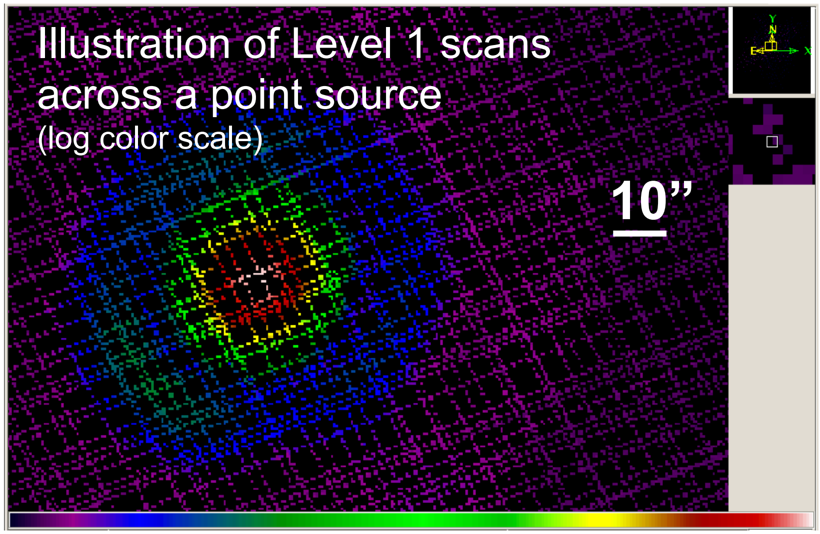
The Right Photometry Choice

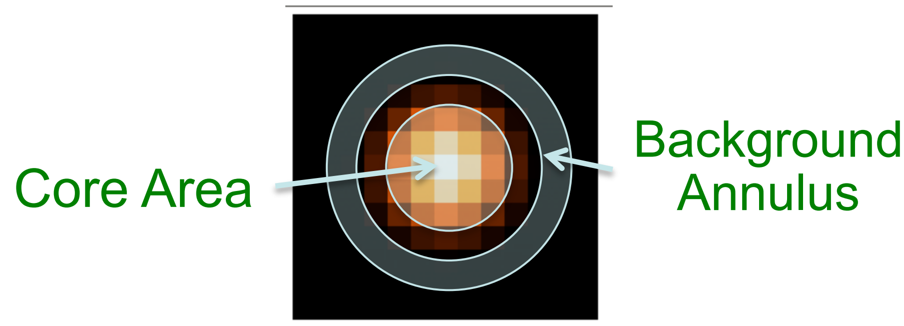




- For point sources there are several choices and it depends a bit on the task at hand. Generally the Timeline Fitter gives the most accurate results.
- For large and small extended sources there is only aperture photometry.
- The SPIRE Level 2 products fortunately already contain a product that comes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

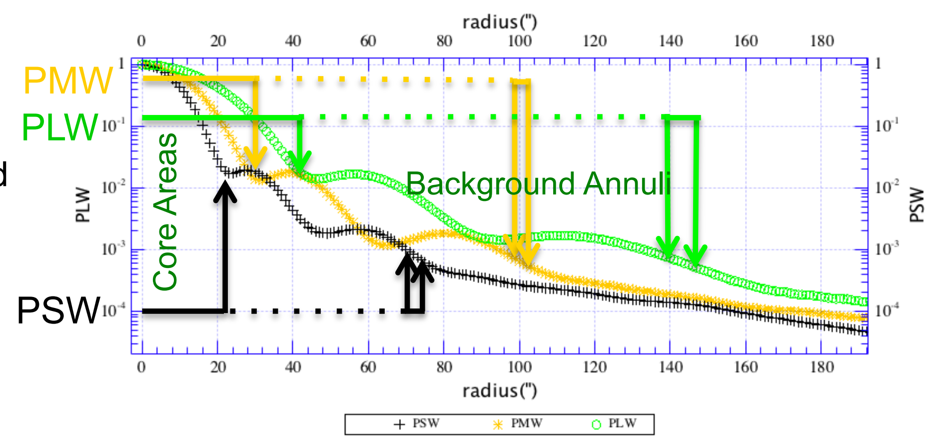
Timeline Fitter





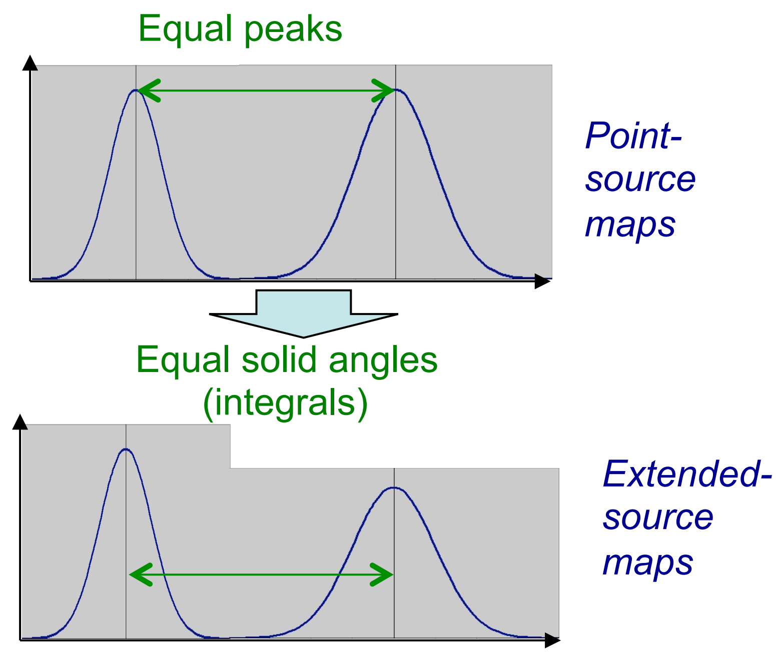
	PSW	PMW	PLW
Core radius ["]	22	30	42
Inner radius ["]	70	98	140
Outer radius ["]	74	103	147

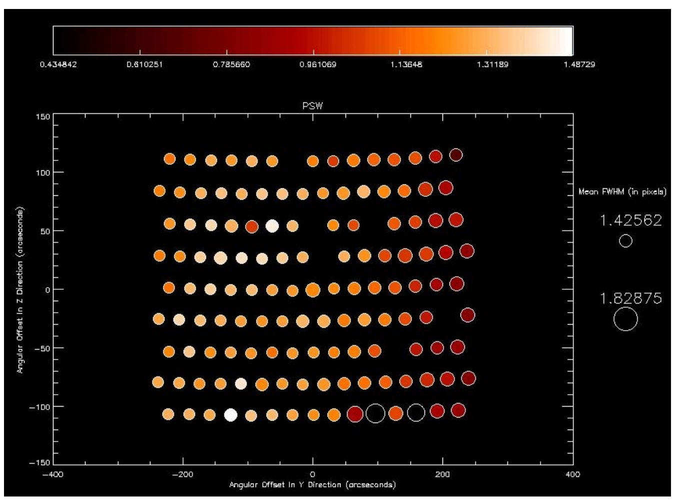
- Level 1 scan grid is fitted by 2D Gaussian
- Only readouts from core area and the background annulus are used for the fit.
- Annuli begin after 2nd Airy ring and cover an area comparable to core area.
- It is good to allow the background level to vary and to use the background annulus in the fit.
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



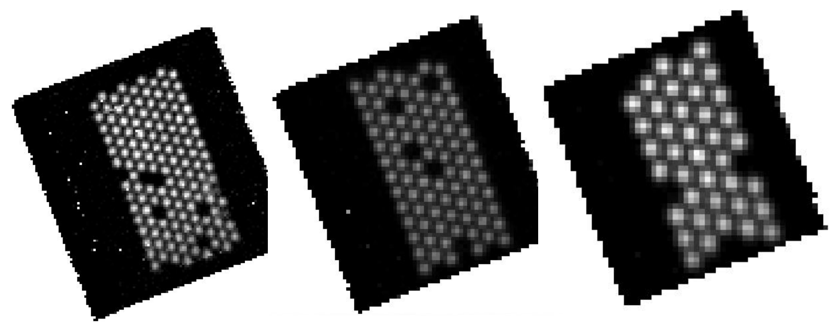
Extended Gain Correction

- 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 destriping, and map-making.





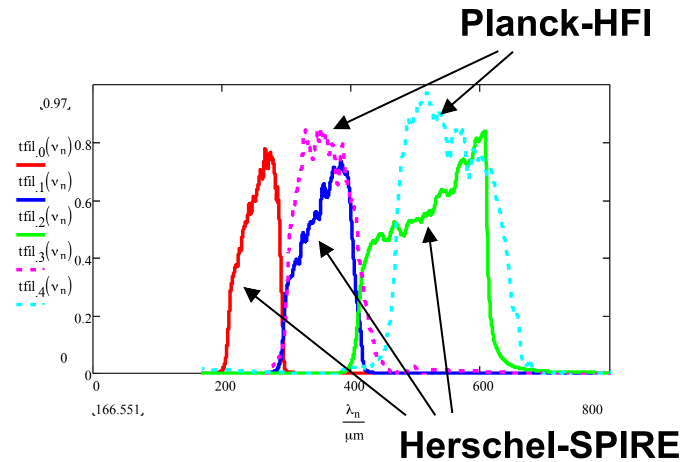
PSW: FWHMs are exaggerated

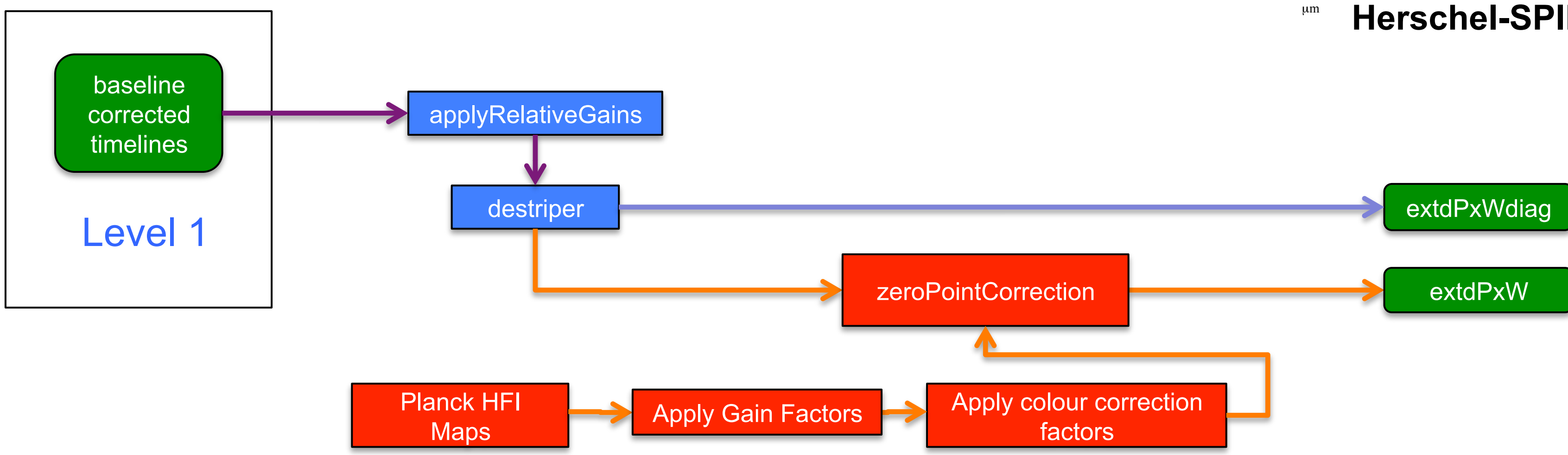


PSW PMW PLW

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.



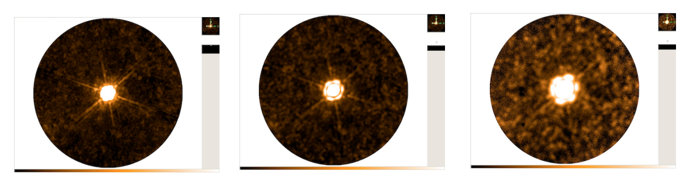


Aperture Photometry

- 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.

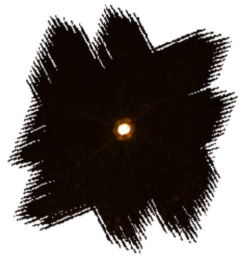
Solid angles in [arcsec^2]	PSW	PMW	PLW
Measured with Neptune spectrum	450	795	1665
SPIRE photometer reference spectrum (nu*F_nu = const.)	465	822	1768



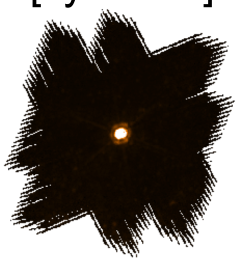
See: http://herschel.esac.esa.int/twiki/bin/view/Public/SpirePhotometerBeamProfile

Aperture Photometry on Point Sources

extdPxW
[MJy/sr]



psrcPxW
[Jy/beam]



Best to start with extended source map

Convert Image Unit Task

[Jy/pixel]

Aperture Photometry Task

[Jy/pixel]

Convert Image Unit Task

BG perfectly removed

BG removed using annulus 60"-90"

Aperture Correction

Table 6.12. Aperture Corrections for Annular Aperture Photometry

Spectral Index ($F_{nu}=nu^{alpha}$)	Background included PSW	PMW	PLW	Case of background removed PSW	PMW	PLW
-4	1.2715	1.2298	1.2227	1.2690	1.2222	1.1956
-3.5	1.2694	1.2294	1.2205	1.2669	1.2218	1.1946
-3	1.2680	1.2290	1.2183	1.2655	1.2214	1.1936
-2.5	1.2669	1.2286	1.2160	1.2645	1.2210	1.1926
-2	1.2660	1.2282	1.2146	1.2636	1.2206	1.1916
-1.5	1.2651	1.2279	1.2133	1.2628	1.2201	1.1907
-1	1.2645	1.2275	1.2116	1.2620	1.2197	1.1897
-0.5	1.2637	1.2271	1.2104	1.2613	1.2192	1.1887
0	1.2629	1.2267	1.2088	1.2605	1.2188	1.1877
0.5	1.2622	1.2263	1.2071	1.2598	1.2183	1.1868
1	1.2615	1.2258	1.2048	1.2591	1.2179	1.1858
1.5	1.2607	1.2254	1.2042	1.2583	1.2175	1.1849
2	1.2599	1.2250	1.2011	1.2576	1.2170	1.1840
2.5	1.2592	1.2246	1.2009	1.2569	1.2166	1.1831
3	1.2584	1.2242	1.1975	1.2561	1.2161	1.1822
3.5	1.2577	1.2238	1.1968	1.2554	1.2157	1.1814
4	1.2570	1.2234	1.1956	1.2547	1.2152	1.1805
4.5	1.2563	1.2230	1.1945	1.2540	1.2148	1.1797
5	1.2555	1.2226	1.1936	1.2533	1.2144	1.1789

Color Correction

Table 6.13. Color Corrections for Point Sources and Extended Emission

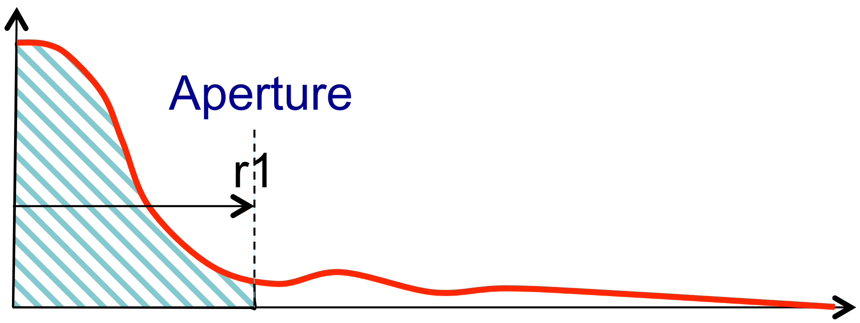
Spectral Index ($F_{nu}=nu^{alpha}$)	Point Source Colour Correction PSW	PMW	PLW	Extended Emission Colour Correction PSW	PMW	PLW
-4	0.9800	0.9791	0.9333	0.9406	0.9409	0.8696
-3.5	0.9884	0.9875	0.9525	0.9550	0.9551	0.8977
-3	0.9948	0.9940	0.9687	0.9677	0.9676	0.9236
-2.5	0.9992	0.9986	0.9817	0.9786	0.9785	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

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

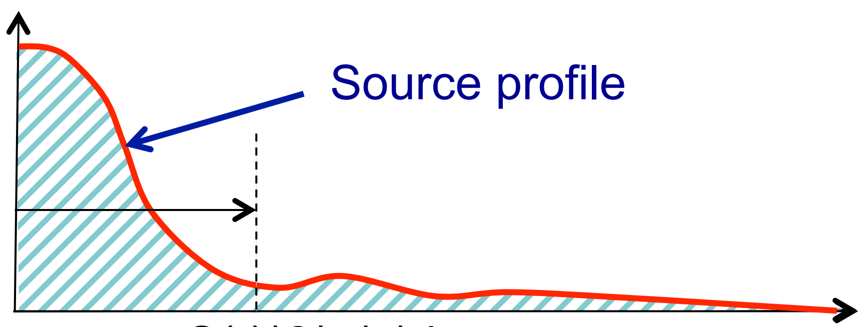
Solid angles in [arcsec^2]	PSW	PMW	PLW
SPIRE photometer reference spectrum (nu*F_nu = const.)	465	822	1768

Aperture Correction Factors Explained

If background was perfectly known and subtracted.

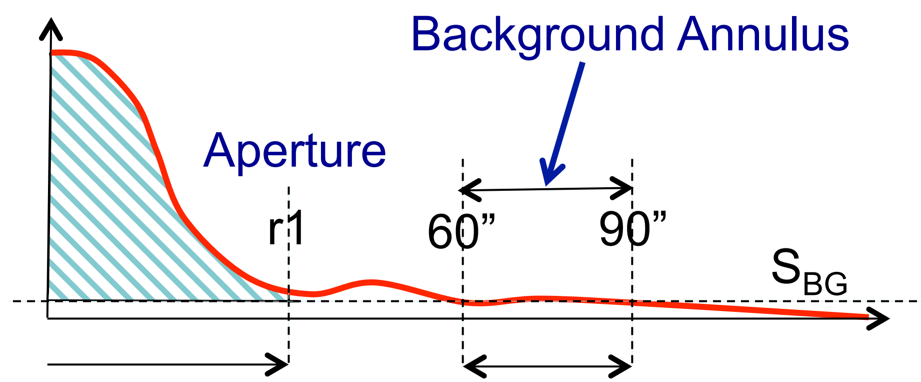


$\Omega_{aper}=\Sigma_{0..r1} S(r)*2*\pi*r*dr$



$\Omega_{total}=\Sigma S(r)*2*\pi*r*dr$

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



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

aperCorr = $\Omega_{total} / \Omega_{aper}$

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

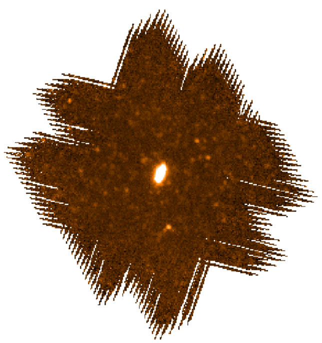
Parameters for Point Source Photometry

Algorithm	FWHM (arcsec)	Beam^1 Area (arcsec^2)	Detection Threshold	Rpeak (arcsec)	Torus (arcsec)	Aper Corr
SUSSEXtractor	18.2 24.9 36.3		✔			
DAOphot		465 822 1769	✔	1*FWHM	1.25-3 *FWHM	Auto or 1.2750 1.1933 1.2599
Timeline Fitter			N/A	22 30 42	300,350	
Aperture Photometry			N/A		60-90	1.2750 1.1933 1.2599

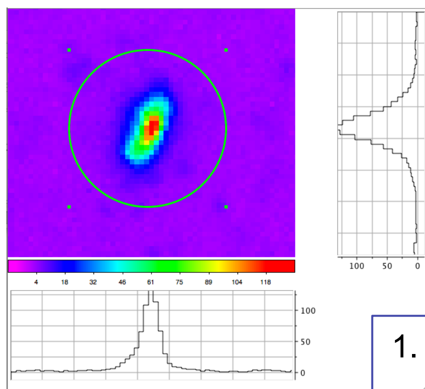
The Useful script "Photometer_Photometry.py" is a good example how to do point source photometry in a practical case.

Aperture Photometry on Extended Sources

extdPxW
[MJy/sr]



Aperture Correction



[Jy/pixel]

Convert Image Unit Task → **Aperture Photometry Task**

Color+Omega Correction

Table 6.13. 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	0.9406	0.9409	0.8696
-3.5	0.9884	0.9875	0.9525	0.9550	0.9551	0.8977
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-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
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5	0.8278	0.8350	0.7916	0.9020	0.9067	0.9053

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.

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 may go away as it can in principle be bootstrapped out.

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.