TITLE: **SPIRE calibration files: Photometer beam profiles**

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CHANGE RECORD

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CONTENTS

APPLICABLE AND REFERENCE DOCUMENTS

RD1 M.Griffin, MoM SDAG meeting n^{o}20 (RAL, 13/06/2007)

1. Introduction

This note reports on the generation of SPIRE photometer beam profiles for the calibration files.

From RD1, the specifications of the beam profiles files are as follows:

	PSW	PMW	PLW
Grid size (in " on-sky)	**72"x72"**	**100"x100"**	**144"x144"**
Grid size (in samples)	**36x36**	**50x50**	**72x72**
Grid sampling (in ")	**2"**	**2"**	**2"**

2. General process

The general procedure developed to generate the Phot beam profiles from the optical model is detailed step by step below.

- **Step 1:** Setting up the simulation tool

The official ASAP model of SPIRE Phot optics and HSO telescope design & prescription design labelled "*spire_tel4.inr*", delivered back to RAL by Astrium, is used. An extra script is added is for the simulations of the PSF. The new ASAP file is "*spire_tel4_testPSF.inr*" and was run under ASAP2006 v1R3.

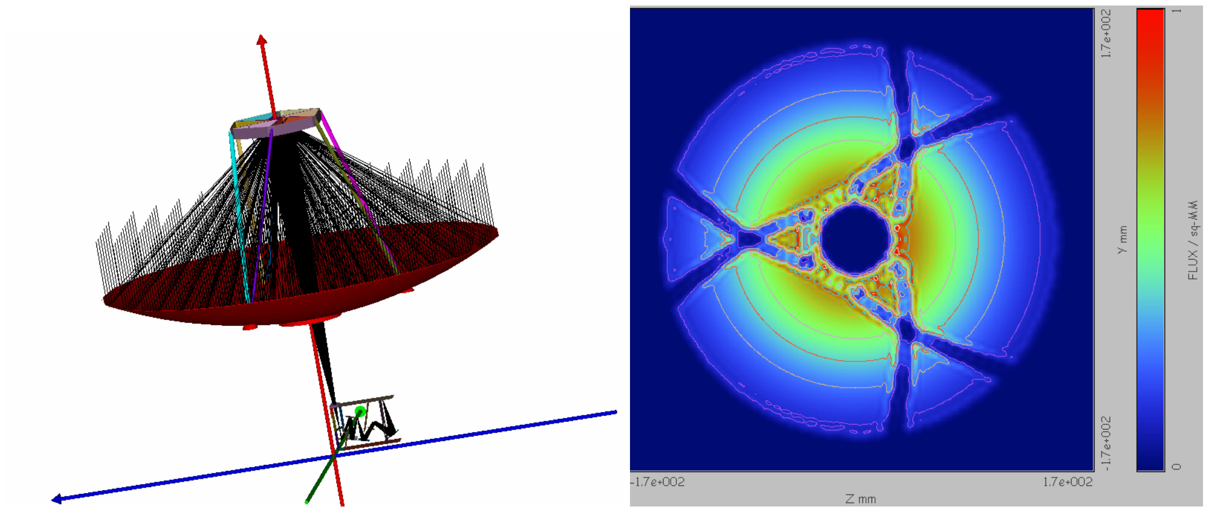

Figure 1: 3D layout with forward ray-trace through the ASAP HSO telescope and SPIRE models (left) and example of M2 pupil illumination at 350um with adapted Gaussian apodisation (right)

The simulations are performed for the Phot chief ray i.e. for central field position, and in forward sequential direction. At first, one would have thought that backward towards sky (as in SPIRE-RAL-NOT-002881 v1.3) would be more relevant but this needs high sampling of the last surface (M1) which is very large so computationally very demanding in order to reach a sufficient accuracy. More the starting point, near-field pattern of the detector feedhorn, is not known accurately. This leads to the choice of the forward propagation which includes all the effect from the as-prescribed SPIRE optical design (verified independently by alignment measurements on the STM, CQM, PFM and FS) but with scattering from the filters and dichroics assumed negligible here. In order to simulate the supplementary quasi-single mode behaviour (see the distributed spreadsheet "*SPIRE Photometer: cut-*

off of the waveguide & associated propagating modes", Marc Ferlet, 19/07/06) of the detector system, a Gaussian pupil apodisation is added.
Source simulated is point source, unpolarised and monochromatic, the wavelength of which is varied across the different array spectral bands as discussed further below.

- Step 2: Comparison/matching of the ILT optical performances results

For the SPIRE PFM, the following results in terms of beamsize (individual focal plane pixel beam pattern FWHM) when measured with a broadband source (HBB at 1200degC so in RJ regime for Phot bands) have been found:

Source is HBB in all cases	**PSW**	**PMW**	**PLW**
From average of PFM1-2-3-4 beamscans and peak-ups over entire Phot FoV, usually at respective "best focus"	**18.6"**	**24"**	**35.2"**
Associated estimated average wavelength of the end-to-end spectrum	**250um**	**350um**	**492.5um**
From PFM4 aperture tests, central part of the Phot FoV, at best all-bands average focus	**20.8"**	**24.6"**	**35.6"**
Associated estimated average wavelength of the end-to-end spectrum	**250um**	**350um**	**485um**
Average beamsize from ILT measurements (including some weighting due to relative change of instrumentation focus)	**19.4" @ 250um**	**24.4" @ 350um**	**36.1" @ 500um**

Measured beamsizes are given with an uncertainty of ~+/-5% typically. The additional central wavelength was obtained from the first moment (see for example spreadsheet "SPIRE PFM4: Average wavelength for Phot bands from broadband measurements", Marc Ferlet, Feb 07) of the end-to-end spectral response (i.e. including source, instrumentation and SPIRE spectral response, atmosphere, …) as measured with SPIRE and the Test FTS in the end-to-end PFM ILT configuration.
This is actually used to fine-tune the model described in step 1 above. Simulations are run at the specific central wavelengths for each band and the pupil Gaussian apodisation edge-taper level is adjusted iteratively until the resulting simulated beam pattern match the respective measured averaged beamsizes. The difference in edge-taper level from one band to another is also indication of the relative as-built defocus effect.

Within the bands itselves, PFM ILT also provides data from the narrow line measurements with FIR laser source.

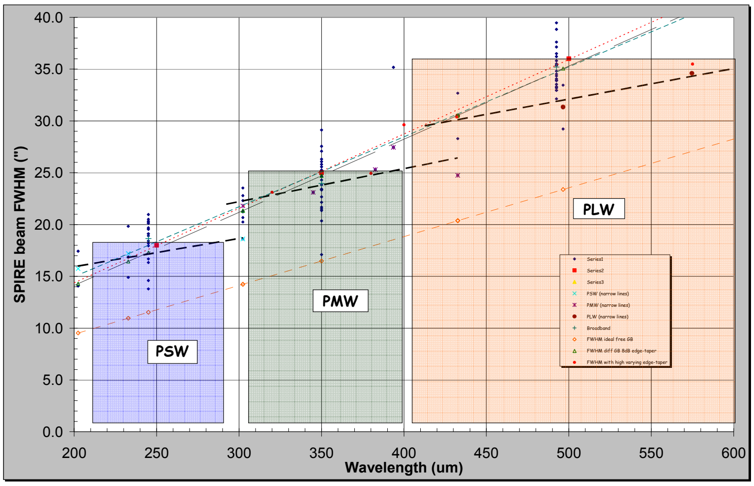

Figure 2: Summary of PFM ILT Phot beam pattern size measurements (broadband and spectral)

Matching an analytical model to the in-band measured spectral variations (linear fit in bold black dashed in above figure) of beamsize, taking into account the fact that they were actually measured at respective "best-focus" which turns out to be wavelength-dependent, allows to retrieve the apparent spectral variations of an effective edge-taper.

Remarks: The forward propagation approach means that the beam profiles are actually obtained at the focal plane of the SPIRE optics, image of the sky object. Therefore it is projected in linear local dimensions expressed in mm. The translation into arcsec on-sky is done via the plate-scale as found by running independent geometric ray-trace simulation to derive the sky (angular) to focal plane (linear) local conversion. At the restricted scale of the file grid size specified in section 1 above, the local variations of plate-scale (from imagery distortion inducing slight change in f-number) are below 1% so negligible here for all bands when compared to the final relative accuracy of typically of one grid sampling (2") over the respective beamsize (~18" for PSW so ~11% and ~5.5% for PLW).

- Step 3: Combination of spectral pattern and reconstruction of broadband spatial responses

About 12 beam patterns (not normalised) at different equally spaced wavelengths and with adequate respective edge-taper level are generated under ASAP for each Phot band. Two combinations, manually (script) implemented under ASAP (see files: "*PHOT_beampatterncombiner_xyz.inr*" where xyz has to be replaced by psw, pmw or plw respectively) are applied:

- the flat spectrum case where they are all summed with equal weight w_i (actually w_i=1) except the ones at the edge of the band (defined by the 50% level approximate wavelengths in the Phot spectral bands) which get a weight of 0.5 to take into account the wings/transition regions of the in-band spectral response;
- the Rayleigh-Jeans (RJ) case with an overall distribution of spectral weights following a $1/\lambda^2$ variation law and still with the extra modulation of factor 0.5 for the edge wavelengths in each band;

This is illustrated in the figure below. The shift of PDIC2 shortwave edge (seen since in PFM4 so relevant for the actual PFM configuration) makes PMW and PLW less spectrally separated and is approximately taken into account here.

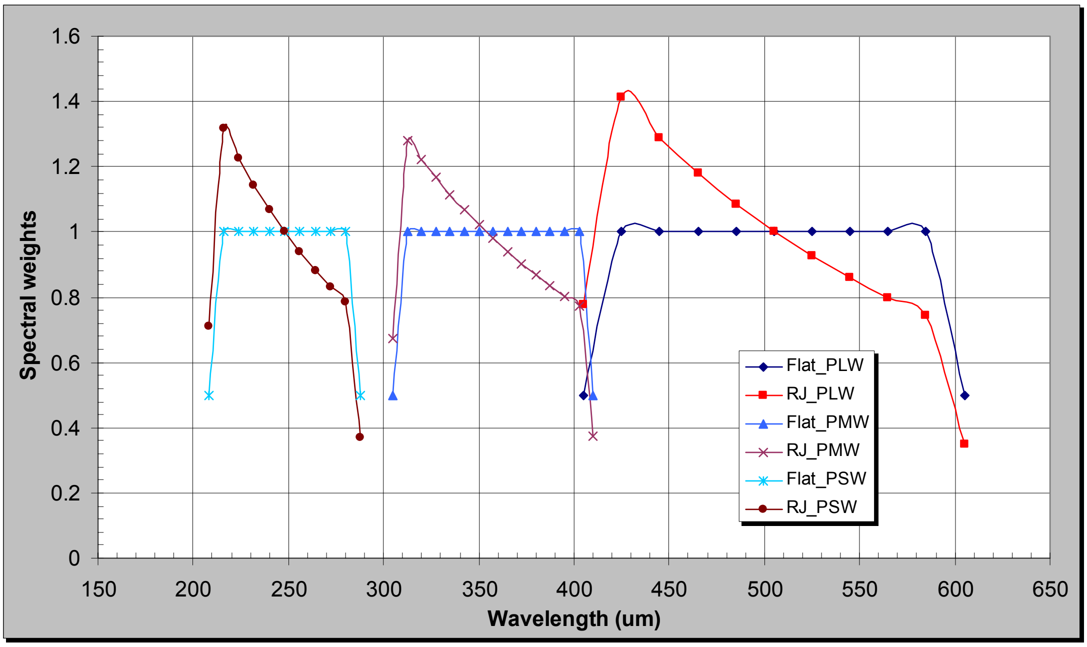

Figure 3: Spectral weights in the different Phot bands used for the recombination of spectral beam patterns to generate the broadband responses for 2 different types of spectrum

As illustration the case of flat spectrum for PMW is illustrated below, after final normalisation by the max of the beam profile. The display window size and sampling is as per the specifications of section 1.

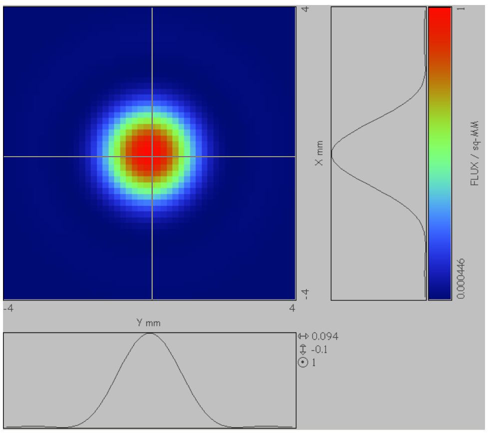

Figure 4: Example of reconstructed broadband PMW beam pattern in the case of flat spectrum

The table below summarises the beamsizes of the final beam profiles in each band for the 2 spectrum cases. They are in agreement with the measured broadband values (although differences maybe due to slightly different spectrum). The flat spectrum case gives slightly larger values than RJ case, but by less than a grid sampling element size. The difference RJ and flat spectrum may be even reduced in reality for PLW as the shortwave edge shift of PDIC2 widens the PLW spectral band in the domain where the second mode of the detector becomes more dominant, which, as seen on the Spectrometer side, increases against diffraction the beamsize at short in-band wavelength. This, when RJ weighted, would increase the broadband beamsize, but not expectedly more than a sampling element size here.

Reconstructed broadband beam profiles	PSW	PMW	PLW
FWHM in case of flat spectrum	**18.76”**	**24.6”**	**35.6”**
FWHM in case of RJ spectrum	**18.47”**	**24.3”**	**34.9”**

For final comparison, the figure below shows in the case of PMW the results of PFM4 ILT (measured data), along side the one obtained by the above process (simulated, reconstructed) under ASAP, the output of which is a general readable ASCII data file. This last fact is demonstrated by the last plot on the right being obtained simply by reading the ASAP output data file with a basic IDL script, reproduced here in Appendix.

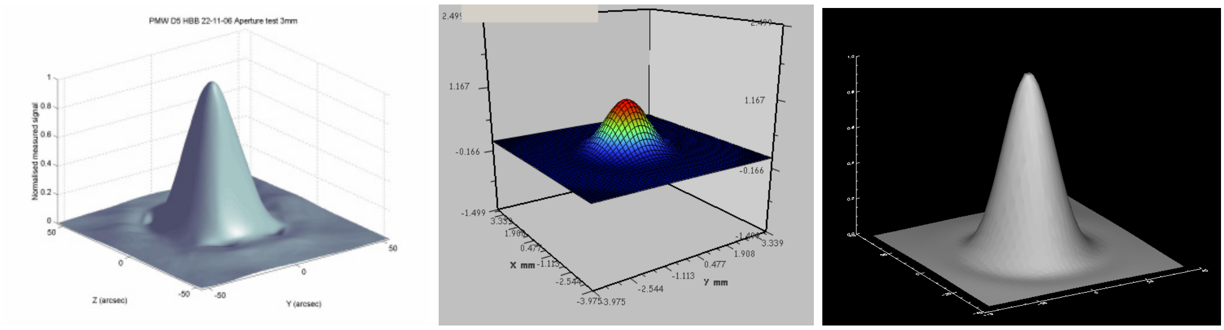

Figure 5: PFM4 ILT results for PMW D5 with quasi point-source (diameter ~F.λ) and HBB (left), beam pattern for PMW FoV centre from ASAP simulations (centre), ASAP final PMW pattern re-opened in IDL (right).

3. List of attached files

A total of 6 files are attached to this note. They stand for the representative peak-normalised broadband Phot beam profiles obtained from the process described in section 2 of this note with extent & sampling defined by the specifications in section 1. There are 2 files per Phot bands. The details are as follows:

List of file names	**PSW**	**PMW**	**PLW**
Flat spectrum case	***Phot_psw_flat.din***	***Phot_pmw_flat.din***	***Phot_plw_flat.din***
RJ spectrum case	***Phot_psw_rj.din***	***Phot_pmw_rj.din***	***Phot_plw_rj.din***

Their format is the standard ASCII output (".din" extension) of data distribution from the ASAP software. Import to general processing tool/language such as IDL can be done via the suggested basic IDL script listed in Appendix.

Remarks: The given files are intended to represent the spatial response of any pixel for a given Phot spectral band. Different measurements during PFM Performances ILT have indicated that the beamsize spread over the Phot FoV for any band is limited and that the beam pattern ellipticity (when measured with broadband source) is within the higher level specifications defined by the SPIRE IRD. These effects as well as some embedded in the simulations like the particular symmetry of the beam pattern sidelobes due to diffraction by the complex telescope pupil obscuration (see figure 1 above) is sufficiently local and small to be assumed presently negligible compared to the specified grid sampling size.
Effect of source size extent (i.e. larger than the pure point source case) are discussed elsewhere (see for example *Aperture test & source size effect* section in "*Herschel-SPIRE: Optical aspects of performances tests*", presentation at SDAG meeting n°19, Marc Ferlet, 13/06/07)

Appendix IDL script to read the Photometer beam ASAP ".din" files

```
; IDL file:   read_asap.pro
; by Marc Ferlet (STFC, RAL/SSTD), July 07
; & based on similar general scripts used for MSG/GERB and others
;
; this scripts  reads the ASAP ".din" ascii file format and
; uses the header info to generate the absicca values
; and returns a 2-d array of values v for v=f(x,y) plotting
;

name='D:\phot_pmw_flat.din'  ; this is an example

 openr,unit,name,/get_lun

  title='abcdefghijk'
  readf,unit,format='(a12)',title
  print,title

  ztitle='abcdefghijk'
  valtitle='abcdefghijk'
  readf,unit,format='(a11,f8,a30)',ztitle,zpos,valtitle
  print,ztitle,' ',zpos,' ',valtitle

  xtitle='abcdefghijk'
  nxpts=intarr(1)
  ;readf,unit,format='(a20,f10,f15,i10)',xtitle,xmin,xmax,nxpts
   readf,unit,format='(a20,g15,g13,i10)',xtitle,xmin,xmax,nxpts
  print,xtitle,' ',xmin,' ',xmax,' ',nxpts

  ytitle='abcdefghijk'
  nypts=intarr(1)
  ;readf,unit,format='(a20,f10,f15,i10)',ytitle,ymin,ymax,nypts
  readf,unit,format='(a20,g15,g13,i10)',ytitle,ymin,ymax,nypts
  print,ytitle,' ',ymin,' ',ymax,' ',nypts

   dum='abcdefghijk'
   readf,unit,format='(a20)',dum
   print,dum

   arrsiz=intarr(1)
   arrsiz(0)=abs(round(nxpts)*round(nypts))  ; size of data grid

   array=fltarr(nxpts(0),nypts(0))
   readf,unit,array

  close,unit
  free_lun,unit

print,'************ read asap data *************'
print,'data read from ',name,' is :',nxpts,' by ',nypts

  x=fltarr(nxpts(0),nxpts(0))
  y=fltarr(nxpts(0),nxpts(0))

for i=0,nxpts(0)-1 do begin
  x(i,*)=(xmin+i*(xmax-xmin)/(nxpts(0)-1))*12.57887
  y(*,i)=(ymin+i*(ymax-ymin)/(nxpts(0)-1))*12.57887
endfor

v=transpose(array)

shade_surf, v, x, y   ; this is just for visu check
```