Photometric Calibration and Accuracy of the Herschel/PACS Photometer Camera

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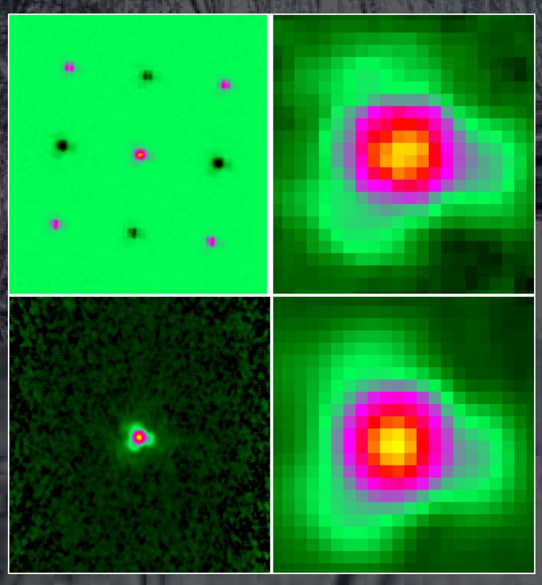
Abstract

The *Herschel Space Observatory* is comprised of 3 instruments, of which PACS is a combined photometer camera and photo-conductor spectrograph. A wide range of objects like stars, asteroids and planets have been used to derive a photometric calibration of the imaging camera for its three bands with nominal reference wavelengths at 70, 100, and 160 micron. Based on some 300 individual observations executed in the two PACS photometer AOT modes (chopped point source and scan map), we find a photometric accuracy of currently better than ±10% in the blue and green bands, and better than ±20% in the red band. Furthermore, there is no indication of NIR filter leaks. The photometric calibration appears to be linear between 1 mJy and 200 Jy in all bands. Colour correction terms are small for source temperatures > 20 K.

Observing Details

We use the two recommended PACS AOTs for compact sources, i.e. chopped photometry and mini scan-maps. We aim for nominal S/N ratios of at least 30. Some of the faintest targets were observed with a lower precision in order to reduce the execution time. The data reduction was done with HIPE (V 4.0) running optimised interactive pipeline scripts.

The figure to the right shows the PACS maps of γ Dra at 70 µm observed with the chopped point source (up) and the scan map AOT (down). The right images are enlargements of the left images.



Target List

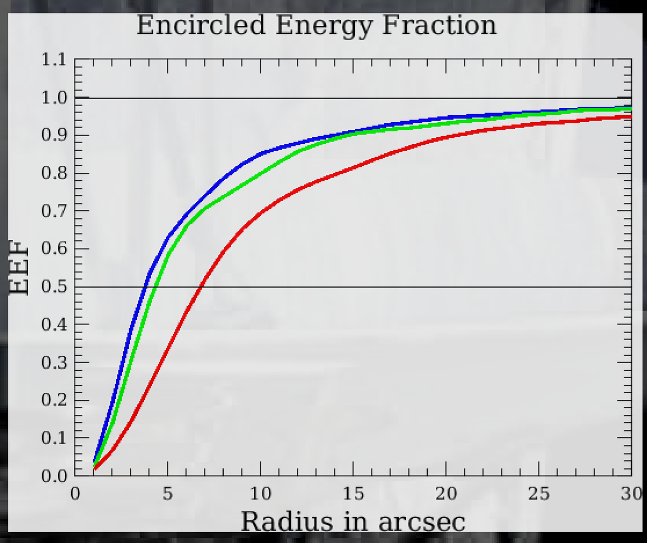
The target list contains three types of flux calibrators covering large temperature and flux ranges between a few tens mJy and several hundred Jy. The prime fiducial stars are considered most reliable. Their fluxes are extracted from detailed stellar modelling (Dehaes et al. 2010). The secondary stars are mostly taken from the ISO Groundbased Preparatory Programme (IGBPP), Cohen et al. (1996), and Spitzer/MIPS 70 µm calibration stars (Gordon et al. 2007). Flux predictions of the asteroids are derived from thermophysical models (e.g. Müller et al. 2005) that take into account physical parameters like albedo, absorptivity, emissivity, surface structure, and rotation leading to time-dependent predictions. Planet flux models are taken from Moreno (2010). Cross calibration using planets and asteroids will be done with synchronous observations obtained with the Planck satellite.

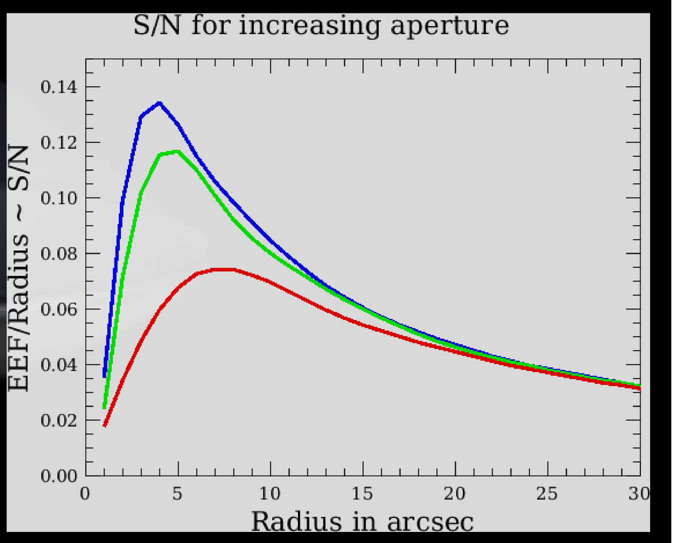
Prime Fiducial Stars	Secondary Stars	Asteroids/Planets
α Boo (Arcturus)	α Ori (Betelgeuse)	Neptune
α Cet (Menkar)	β And (Mirach)	1 Ceres
α CMa (Sirius)	β UMi (Kochab)	2 Pallas
α Tau (Aldebaran)	δ Dra (HD 180711)	3 Juno
β Peg (Scheat)	δ Hyi (HD 15008)	4 Vesta
γ Dra (Etamin)	ε Car (HD 71129)	6 Hebe
	ε Lep (HD 32887)	10 Hygiea
	θ UMi (HD 139669)	18 Melpomene
	HD 41047	19 Fortuna
	HD 138265	20 Massalia
	HD 148387	21 Lutetia
	HD 152222	47 Aglaia
	HD 159330	52 Europa
	HD 161796	54 Alexandra
		65 Cybele
		88 Thisbe
		360 Carlova
		423 Diotima

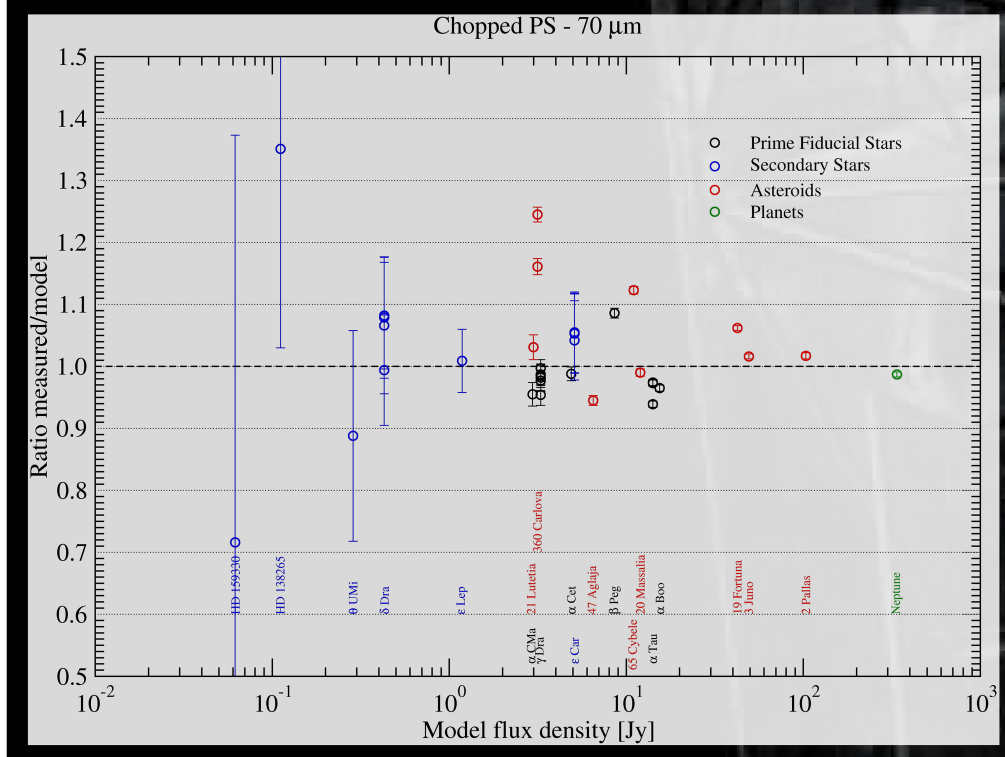
Aperture Photometry

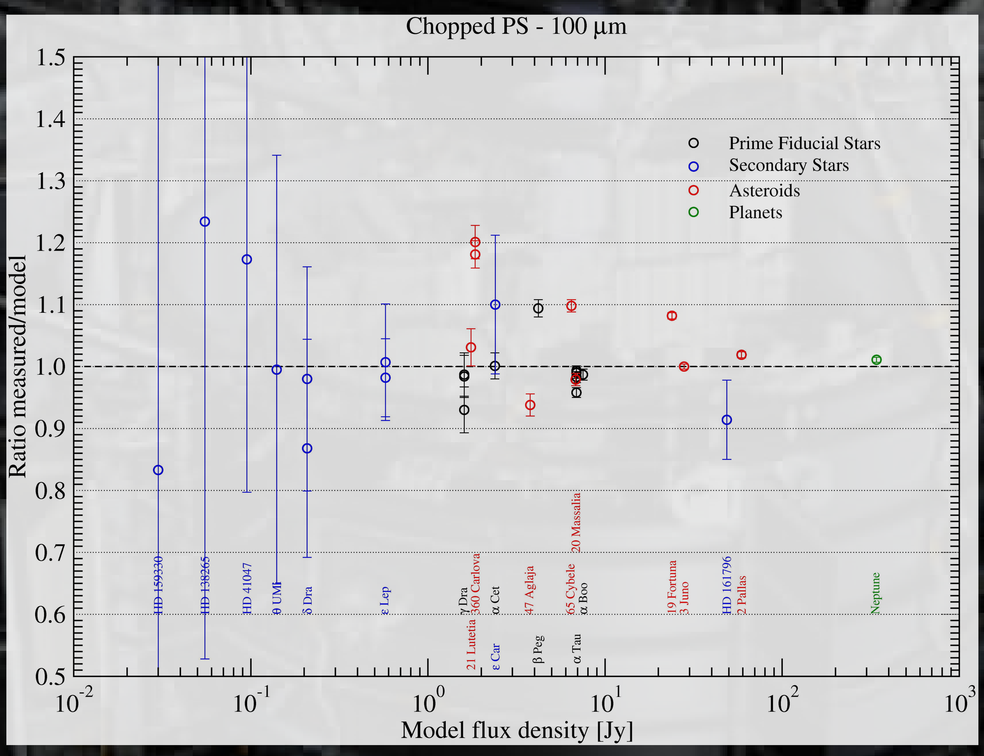
The source flux densities were measured by aperture photometry which turned out to be highly reliable for the isolated point sources used for our calibration purposes. The necessary aperture corrections were applied according to the encircled energy fraction as represented by the figure to the right. It depicts the radially averaged flux growth curve of a point source for the three photometric bands. In practice, the flux measured in varying apertures proved to be highly reproducible.

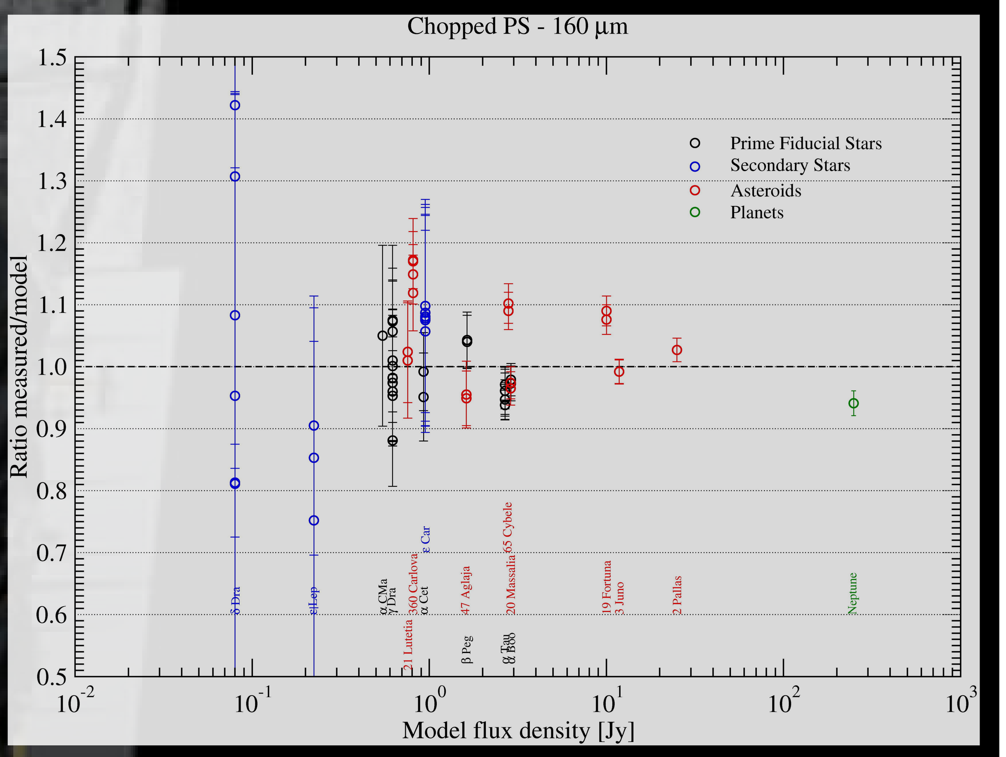
The optimal aperture radius in terms of the resulting S/N ratio is in the range between 5″ and 10″. The entire relation between aperture radii and the resulting S/N ratios is reflected in the second figure to the right.





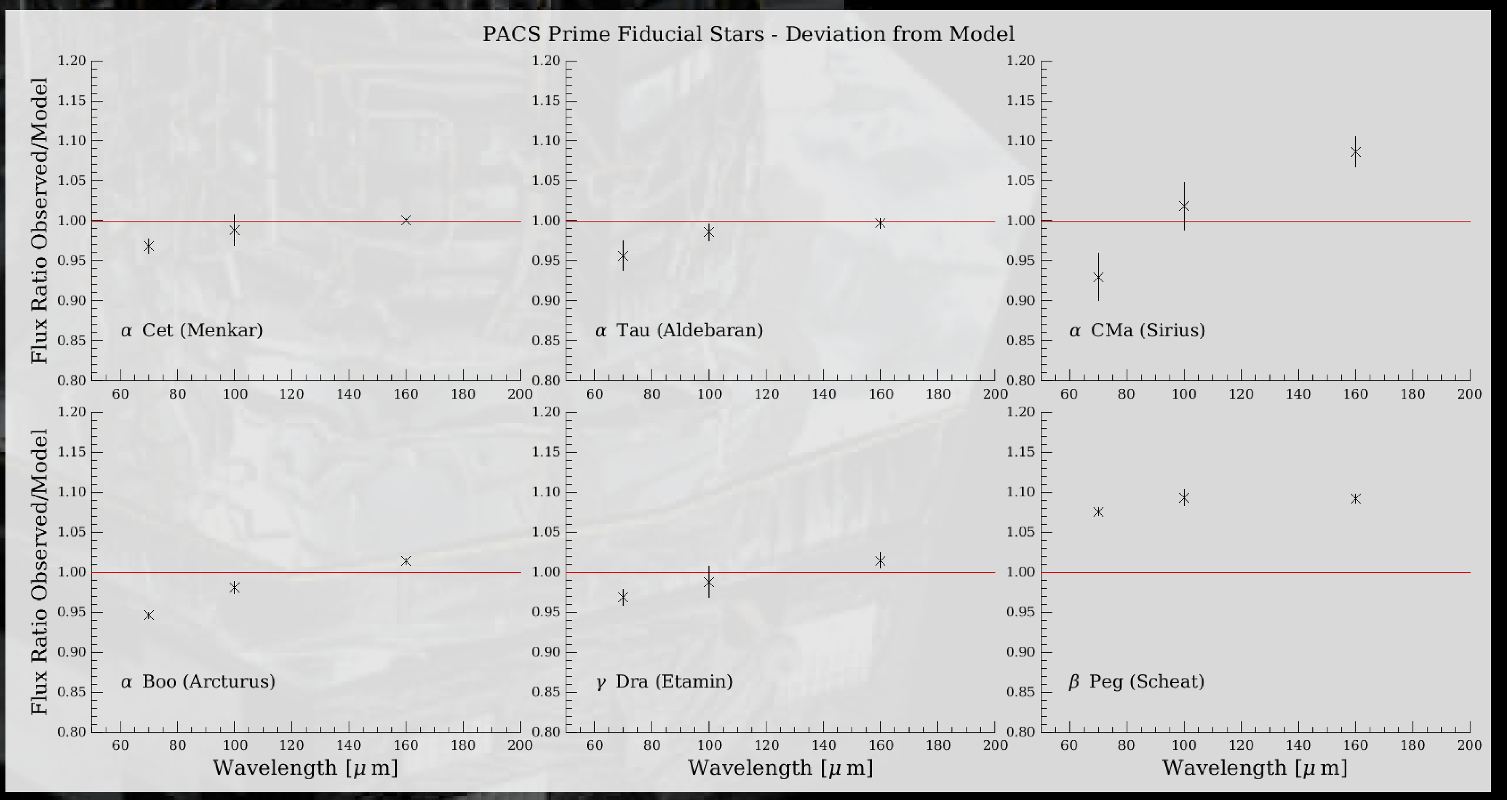


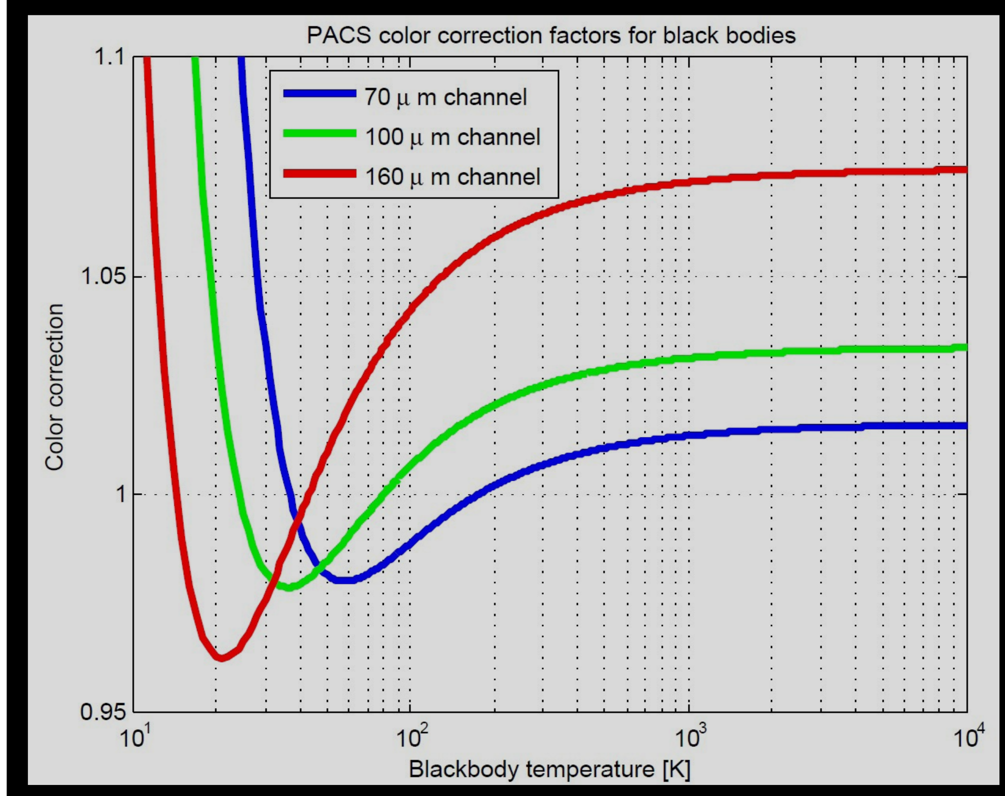




Results

1. Based on all reliable calibrators, the current standard flux calibration is accurate to better than 10% at 70 and 100 µm and better than 20% at 160 µm.
2. If only the prime calibrators are used, the accuracy improves to below 5% in all bands. Further improvement is possible.
3. The calibration is consistent for the two PACS imaging observing modes.
4. This high precision allows identifying outliers (e.g. β Peg) and providing feedback to improve the models of the calibrators.
5. The agreement between the various source types having a wide range of temperatures indicates the absence of NIR filter leakages.
6. Non-linearity effects seem to be important for point sources that have a few 100 Jy.
7. Colour correction terms are small for temperatures above 20 K.





Correlated Noise

The pixels of the final maps do not reflect the detector geometry of the PACS bolometers. They are produced artificially during the algorithm of the map reconstruction, during which the drizzle method is applied. This leads to a correlation of the noise behaviour of the physical detector pixels in the virtual map pixels. As a result, the measured map pixel-to-pixel noise strongly underestimates the true detector noise. Thus, there can be a large discrepancy between the apparent and true S/N ratio. The figure to the right provides an empirical relation between the noise ratio and the virtual map pixel size.