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DOCUMENT

Release notes: Herschel Stellar Calibrator models

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1 INTRODUCTION

This release note provides a short description of the stellar atmosphere models were used as prime calibrators during the Herschel mission. These models were used a primary calibrators for the PACS photometer and spectrometer.

The following note is expanded on in the calibration model website[1] where additional detailed information on cross-comparison between stellar and planetary models (the latter being used as prime calibrators for the SPIRE instrument). All files provided in the framework of this Ancillary Data Product can also be fetched from the Herschel long-term repository area at http://archives.esac.esa.int/hsa/legacy/ADP/StellarModels/.

2 MODEL OVERVIEW

2.1 Introduction

Prior to the launch of Herschel, in collaboration with Leen Decin (KU Leuven), a set of MARCS stellar atmosphere models were obtained for some of the brightest infrared stars in the sky. Several of these had previously been used as calibrators for the Spitzer Space Telescope instruments.

The following is a list of the stars for which stellar model atmospheres were calculated and for which MARCS model outputs were determined. The full description of this is contained within Dehaes et al (2011; A&A, 533, A107). Models were created for the following stars:

- Alpha Boo
- Alpha Cet
- Alpha Tau
- Beta And
- Beta Peg
- Beta Umi (Note: no extension beyond 200 microns. Early measurements indicated chromospheric emission excesses into the SPIRE wavelengths. Considered a less trustworthy calibrator)

[1] http://www.cosmos.esa.int/web/herschel/calibrator-models

- Gamma Dra
- Sirius

It should be noted that the spectra were normalised to accurate K band fluxes as measured by Selby et al (1988; A&AS, 74, 127). For one case, β UMi, it was shown that the original normalisation was incorrect and this was dropped as a prime calibrator during the Herschel mission -- although it was possible to find the correction factor during operations.

The following tables give the standard star fluxes in the PACS wavebands:

Primary calibrator stars

HR	HD	HIP	ID	Name	RA (J2000)	Dec (J2000)	Sp Type	Model flux [mJy]		
								70 µm	100 µm	160 µm
337	6860	5447	β And	Mirach	01:09:43.92388	+35:37:14.0075	M0III	5594	2737	1062
911	18884	14135	α Cet	Menkar	03:02:16.77307	+04:05:23.0596	M1.5IIIa	4889	2393	928
1457	29139	21421	α Tau	Aldebaran	04:35:55.23907	+16:30:33.4885	K5III	14131	6909	2677
5340	124897	69673	α Boo	Arcturus	14:15:39.67207	+19:10:56.6730	K1.5III	15434	7509	2891
6705	164058	87833	γ Dra	Etamin	17:56:36.36988	+51:29:20.0242	K5III	3283	1604	621

Secondary calibrator stars

HR	HD	HIP	ID	Name	RA (J2000)	Dec (J2000)	Sp Type	Model flux [mJy]		
								70 µm	100 µm	160 µm
2491	48915	32349	α CMa	Sirius	06:45:08.91728	-16:42:58.0171	A1V	2955	1427	545
5563	131871	72607	β UMi	Kochab	14:50:42.32580	+74:09:19.8142	K4III	3200	1572	607
8775	217906	113881	β Peg	Scheat	23:03:46.45746	+28:04:58.0336	M2.5II-IIIe	8585	4208	1635

Overall errors on the stellar calibrator models are quoted as +/- 5%.

Comparisons between SPIRE photometer measurements (where planetary models were the prime calibrators) and the PACS photometer measurements suggest that calibration across the two instruments is consistent to less than 1% (see Lim et al, in preparation, and the Herschel Explanatory Legacy Library: http://www.cosmos.esa.int/web/herschel/legacy-documentation).

3.1 Data format

Each stellar calibrator has a FITS file plus a README note provided within the Ancillary Data Product repository (http://archives.esac.esa.int/hsa/legacy/ADP/StellarModels/).

The README gives details of the MARCS model inputs and the fundamental assumed parameters of each of the calibrator stars. The FITS file format is a basic table containing two columns, one with the wavelength in microns and the second with the stellar flux in Janskys.

3 MODEL DETAILS

3.1 Alpha Boo

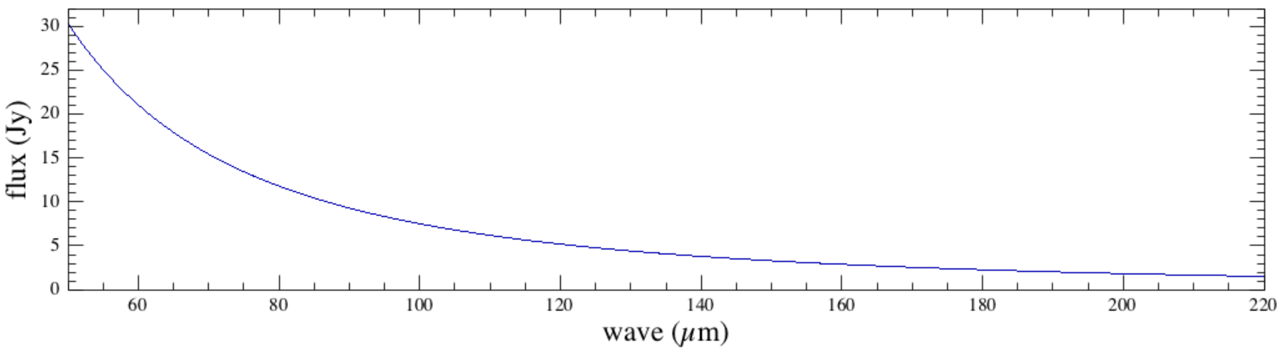

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used α Boo as a prime calibrator.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda$ = 5000 applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).

For $\lambda > 200$ μm, the temperature T of the flux forming region where $\tau_\lambda=1$ is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of α Boo, the following stellar parameters are used:

- Effective temperature T_{eff} = 4320 K
- Gravity log g[cm/s^2] = 1.50
- Mass M = 0.75 $M_\odot$
- Microturbulent velocity = 1.7 km/s
- Metallicity [Fe/H] = -0.50
- Carbon abundance: C = 7.96
- Nitrogen abundance: N = 7.61
- Oxygen abundance : O = 8.68
- Magnesium abundance : Mg = 7.33
- Silicon abundance: Si = 7.20
- $^{12}C/^{13}C$ ratio = 7
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at $\log(\tau_\lambda) = -7.2$ with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -3.075 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 20.74 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.2 Alpha Cet

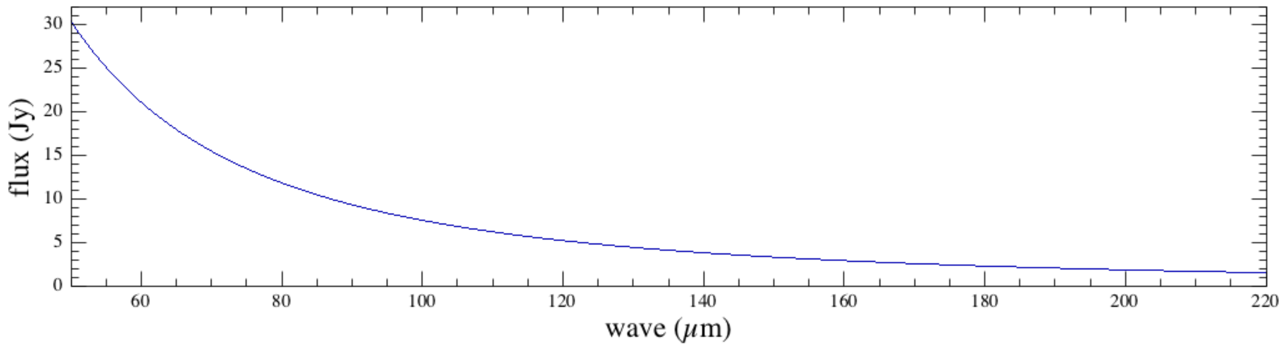

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used α Cet as a prime calibrator

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda = 0.5$ Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda = 5000$ applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For $\lambda > 200$ μm, the temperature T of the flux forming region where $\tau_\lambda=1$ is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of α Cet, the following stellar parameters are used:

- Effective temperature Teff = 3740 K
- Gravity log g[cm/s^2] = 0.95
- Mass M = 2.69 $M_\odot$
- Microturbulent velocity = 2.3 km/s
- Metallicity [Fe/H] = 0.0
- Carbon abundance: C = 8.20
- Nitrogen abundance: N = 8.26
- Oxygen abundance : O = 8.93
- $^{12}C/^{13}C$ ratio = 10
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -1.760 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 12.34 milli-arcsec. The estimated absolute flux uncertainty is 1%

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3.3 Alpha Tau

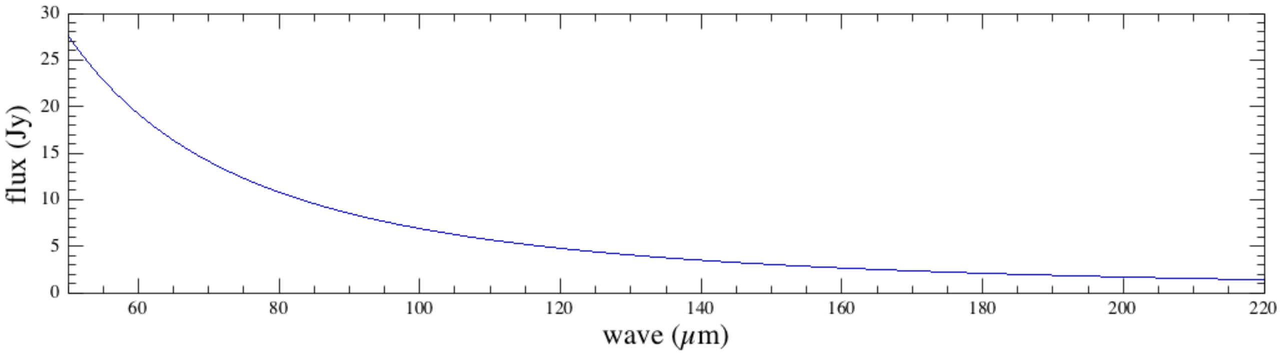

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used α Tau as a prime calibrator.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda$ = 5000 applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For λ > 200 μm, the temperature T of the flux forming region where τ_λ=1 is determined for each wavelength point, based on the logarithmic extrapolation of T(τ_λ=1) in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of α Tau, the following stellar parameters are used:

- Effective temperature T_{eff} = 3850 K

- Gravity log g[cm/s^2] = 1.50
- Mass M = 2.30 $M_\odot$
- Microturbulent velocity = 1.7 km/s
- Metallicity [Fe/H] = -0.15
- Carbon abundance: C = 8.35
- Nitrogen abundance: N = 8.35
- Oxygen abundance : O = 8.93
- $^{12}C/^{13}C$ ratio = 10
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -2.940 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 20.89 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.4 Beta And

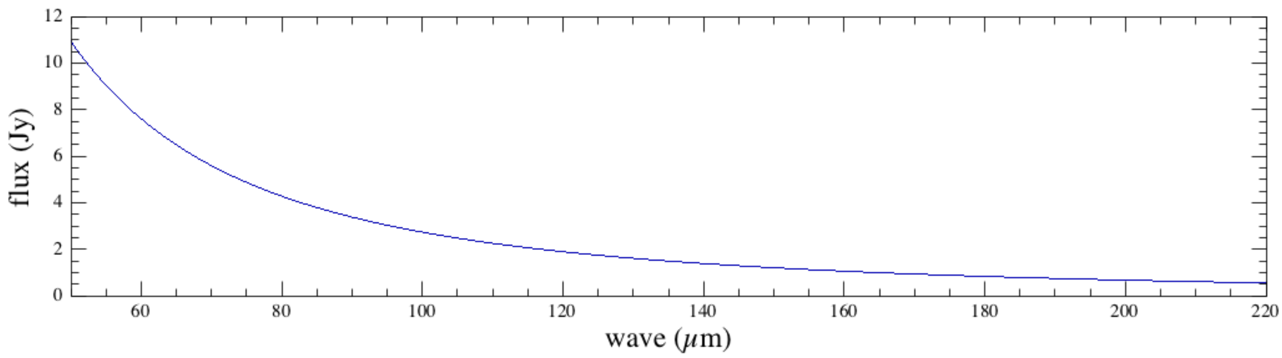

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used β And as a prime calibrator.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda = 5000$ applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For $\lambda > 200$ μm, the temperature T of the flux forming region where $\tau_\lambda=1$ is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of β And, the following stellar parameters are used:

- Effective temperature T_{eff} = 3880 K

- Gravity log g[cm/s^2] = 0.95
- Mass M = 2.49 $M_\odot$
- Microturbulent velocity = 2.0 km/s
- Metallicity [Fe/H] = 0.0
- Carbon abundance: C = 8.12
- Nitrogen abundance: N = 8.37
- Oxygen abundance : O = 9.08
- $^{12}C/^{13}C$ ratio = 9
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -1.930 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 13.03 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.5 Beta Peg

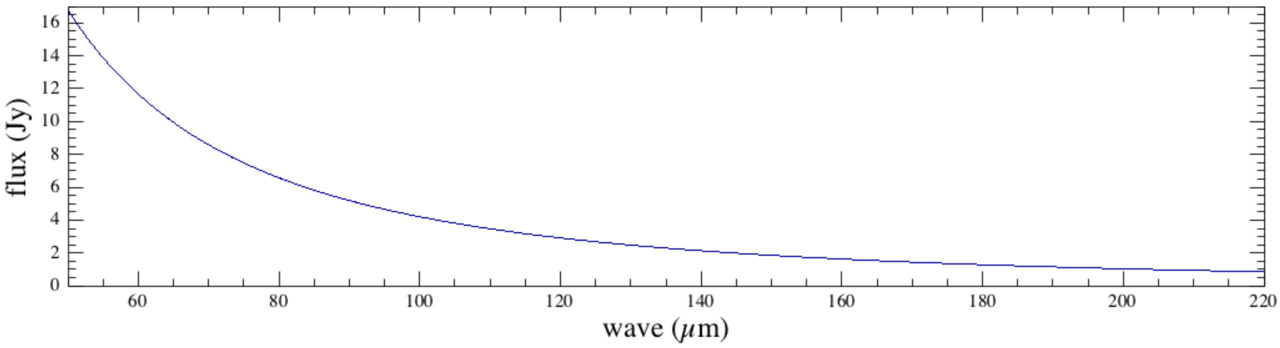

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used β Peg as a prime calibrator.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda$ = 5000 applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For λ > 200 μm, the temperature T of the flux forming region where τ_λ=1 is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of β Peg, the following stellar parameters are used:

- Effective temperature T_{eff} = 3600 K

- Gravity log g[cm/s^2] = 0.65
- Mass M = 1.94 $M_\odot$
- Microturbulent velocity = 2.0 km/s
- Metallicity [Fe/H] = 0.0
- Carbon abundance: C = 8.20
- Nitrogen abundance: N = 8.18
- Oxygen abundance : O = 8.93
- $^{12}C/^{13}C$ ratio = 5
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -2.330 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 16.43 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.6 Beta Umi

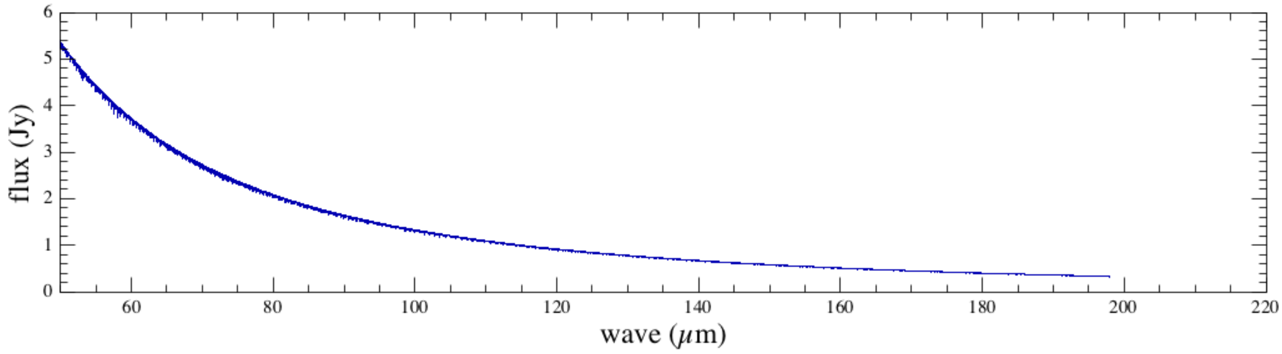

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used β Umi as a prime calibrator. Note that no model was produced that went beyond 200 μm for β Umi.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.001 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda$ = 5000 applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For $\lambda > 200$ μm, the temperature T of the flux forming region where $\tau_\lambda=1$ is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of β Umi, the following stellar parameters are used:

- Effective temperature T_{eff} = 4085 K

- Gravity log g[cm/s^2] = 1.6
- Mass M = 2.49 $M_\odot$
- Microturbulent velocity = 2.0 km/s
- Metallicity [Fe/H] = -0.15
- Carbon abundance: C = 8.25
- Nitrogen abundance: N = 8.16
- Oxygen abundance : O = 8.83
- $^{12}C/^{13}C$ ratio = 9
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on the K-band magnitude (Johnson) by Faucherre et al., 1983, A&A 120, 263 : Kmag = -1.22 Using the appropriate conversion factor (Selby et al)., this corresponds to a K-band magnitude of **Kmag = -1.280 in the Selby system (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 9.35 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.7 Gamma Dra

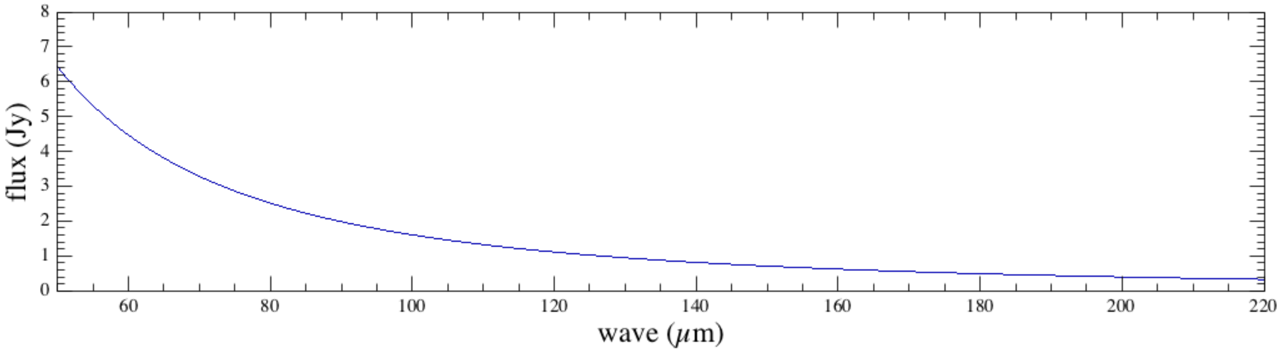

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used γ Gra as a prime calibrator

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda$ = 0.5 Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda$ = 5000 applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For λ > 200 μm, the temperature T of the flux forming region where τ_λ=1 is determined for each wavelength point, based on the logarithmic extrapolation of T(τ_λ=1) in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of γ Dra, the following stellar parameters are used:

- Effective temperature T_{eff} = 3960 K

- Gravity log g[cm/s^2] = 1.30
- Mass M = 1.72 $M_\odot$
- Microturbulent velocity = 2.0 km/s
- Metallicity [Fe/H] = 0.0
- Carbon abundance: C = 8.15
- Nitrogen abundance: N = 8.26
- Oxygen abundance : O = 8.93
- $^{12}C/^{13}C$ ratio = 10
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on Selby K-band photometry. **Kmag = -1.370 (Selby et al., 1988, A&AS, 74, 127)**

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 9.94 milli-arcsec. The estimated absolute flux uncertainty is 1%

3.8 Sirius (Alpha CMa)

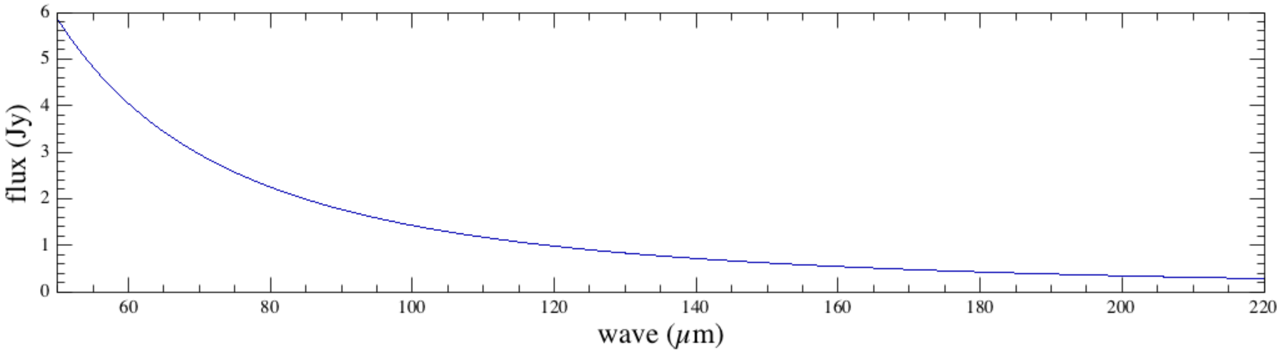

Figure 1: Plot of 50 to 220 μm part of the computed stellar atmosphere model used for the stellar flux calibrator α Boo. This covers the full wavelength range of the PACS instrument, which used Sirius as a prime calibrator.

The model is based on the following assumptions:

Un-blanketed atmosphere's spectrum, covering 0.5 μm - 7 cm at a resolution of 0.1 μm. It consists of the MARCS generated model up to 200 μm and an extrapolation at the longer wavelengths.

The original theoretical spectrum was calculated at a resolution of $\Delta\lambda = 0.5$ Angstrom, and then degraded to a resolution of $\lambda/\Delta\lambda = 5000$ applying a gaussian convolution.

Stellar atmosphere model and theoretical spectrum are generated using the MARCS theoretical stellar atmosphere code (Gustafsson et al. 1975, A&A, 42, 407 and further updates; Gustafsson et al. 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002) and the TURBOSPECTRUM synthetic spectrum code (Plez et al, 2003, *Modelling of Stellar Atmospheres*, Poster Contributions. Proceedings of the 210th Symposium of the International Astronomical Union held at Uppsala University, Uppsala, Sweden, 17-21 June, 2002). Stellar parameters (and uncertainties thereon) have been derived by Decin et al. (2003, A&A, 400, 709).
For $\lambda > 200$ μm, the temperature T of the flux forming region where $\tau_\lambda=1$ is determined for each wavelength point, based on the logarithmic extrapolation of $T(\tau_\lambda=1)$ in the 50 to 200 μm wavelength range.

The flux density at each wavelength point is then approximated by the black-body flux at that temperature T (Dehaes et al 2011, A&A, 533, A107).

For the theoretical spectrum of Sirius, the following stellar parameters are used:

- Effective temperature $T_{eff} = 10150$ K

- Gravity log g[cm/s^2] = 4.3
- Mass M = 2.0 $M_\odot$
- Microturbulent velocity = 2.0 km/s
- Metallicity [Fe/H] = 0.50
- Carbon abundance: C = 7.97
- Nitrogen abundance: N = 8.15
- Oxygen abundance : O = 8.55
- other atomic abundances are solar scaled with metallicity

The outermost depth point of the theoretical atmosphere model was taken at log(τ_λ) = -7.2 with λ being 2.2 μm. The atmosphere model was calculated with a spherically symmetric geometry, under the assumption of radiative and hydrostatic equilibrium, local thermodynamic equilibrium (LTE) and homogeneous layers.

Uncertainties on the theoretical spectrum predictions are discussed in depth in Decin & Eriksson (2007, A&A, 472, 1041).

Absolute flux calibration is based on TCS photometry (**Kmag = -1.388**)

The Zero-point is determined on the basis of an ideal 'Vega', i.e. the K-band photometry of Vega is corrected for a flux excess of 1.29% (cf Absil et al. 2006, A&A, 452, 237). The determined Selby et al. K-band zero-point is 4.0517 x 10^{-10} W/m^2/μm. The derived angular diameter based on the K-band photometry is 6.24 milli-arcsec. The estimated absolute flux uncertainty is 1%