Stellar calibrators for Herschel and their models

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Herschel Calibration Workshop
Madrid, 7 February 2008

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Introduction

in orbit spectrophotometric calibration of PACS
$\longrightarrow$ need fiducial standards with accurate atmosphere models

we will present a set of stellar sources and models appropriate for this task

Theoretical atmosphere models

Requirements on the theoretical models

- up to 250 μm
- accuracy $\leq 5\%$

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Status of the MARCS models

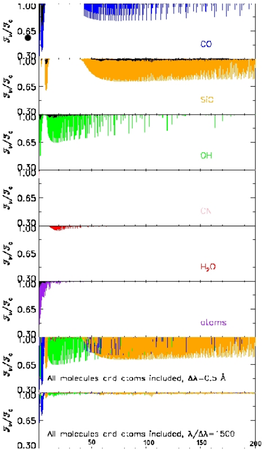
- tested and evaluated for $\lambda \leq 25\mu m$ with high accuracy data
- modelling up to 200μm (Decin et al 2007), no accurate observational data available for verification

Marcs models

Assumptions

1. spherical stratification in homogeneous stationary layers
2. hydrostatic equilibrium
3. energy conservation for radiative and convective flux
4. local thermodynamic equilibrium (LTE)

Example: α Boo



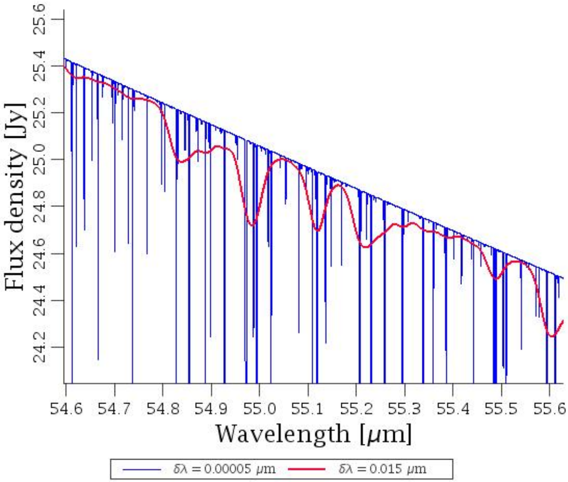
parameters

- T_{eff} = 4320 K, log g = 1.50 cm/s^2, M = 1.1 M_{sun}
- ξ_t=2km/s, [Fe/H]=-0.50
- $\epsilon(C)$=7.96, $\epsilon(N)$=7.61, $\epsilon(O)$= 8.68, $\epsilon(Mg)$= 7.33, $\epsilon(Si)$=7.20
- $^{12}C/^{13}C$=7

important features

- CO and SiO absorption lines
- absorption lines up to 30% in high resolution
- absorption reduced to $\leq$ 3% in PACS resolution

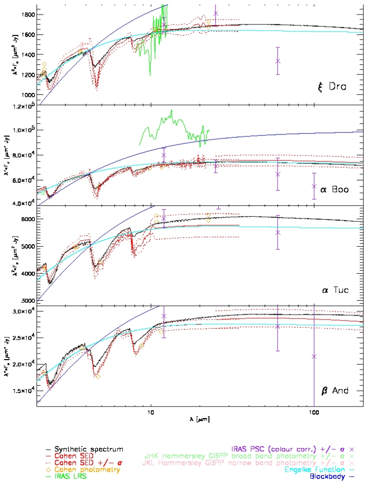
Example : α Boo



Overview accuracy

Description	Uncertainty	Type	λ region
• dependency on stellar parameters			
$\rightarrow$ molecular features	up to 8%	G-K	around 2.3, 4.0, 4.2, 8 μm
$\rightarrow$ continuum	up to 4%	A-M	2-200 μm
• uncertainties on T(τ)			
$\rightarrow$ continuum flux (without high-res data)	3.5%	A-M	2-200 μm
$\rightarrow$ continuum flux (with high-res data)	1-2%	A-M	2-200 μm
• presence of chromosphere/ionised wind	10%	G-M	$\lambda > 100$ μm
presence of circumstellar dust	10%	A-M	$\lambda > 2$ μm
• continuous opacity by H -ff	1%	A-M	2-200 μm
• line lists	3%	A0-M0	2-200 μm
OVERALL BUDGET:	1-2%	A0-M0	near-IR
for approved standards with	~3%	A0-M0	mid-IR
high-resolution data constraints	~5%	A0-M0	far-IR

Different models



- no constrains from observations (IRAS: 1σ errors, should be 20%)
- black body not suitable
- Engelke function + Cohen templates: significant difference
- theoretical models: consistent and known what is incorporated

The Sources

First candidate list

16 candidate calibration sources presented in the Herschel Calibration Steering Group (2005)

- 14 ISOPHOT standard stars, 2 A stars with ISOPHOT minimap mode observations

Selection criteria:

- brightness: from 100mJy up to $\leq$ 10 Jy from 90 μm onwards
- different spectral types (A,G, K, M)
- check for cirrus confusion noise
- well documented stellar parameters to construct accurate models
- sky visibility: at least 1 object at any time

Observational constrains

Needed to rule out flux excess
SEST, IRAM, CSO and VLA data obtained

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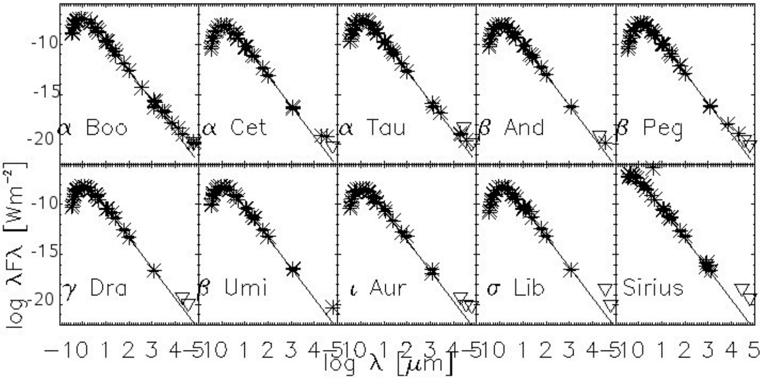
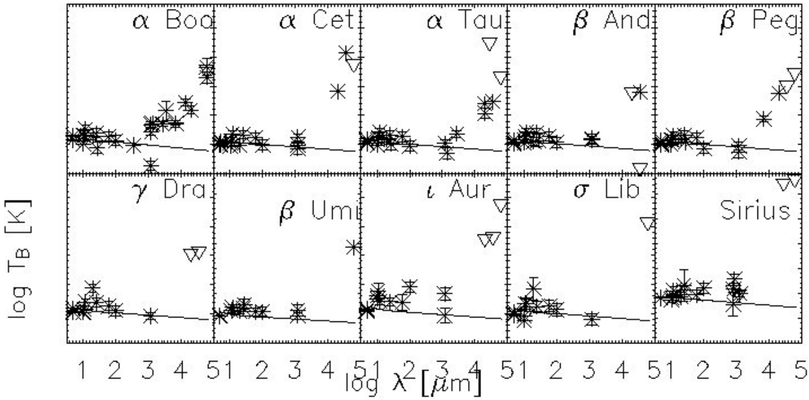


In terms of brightness temperature



Legend: $\bigtriangledown$= upper limit, $\star$= measurement with error bars

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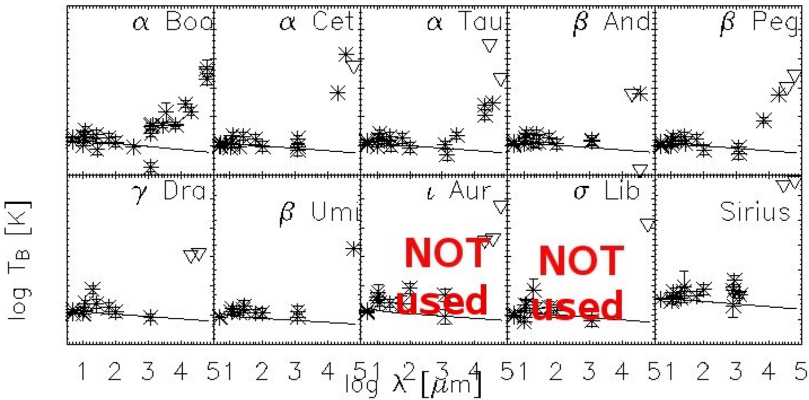
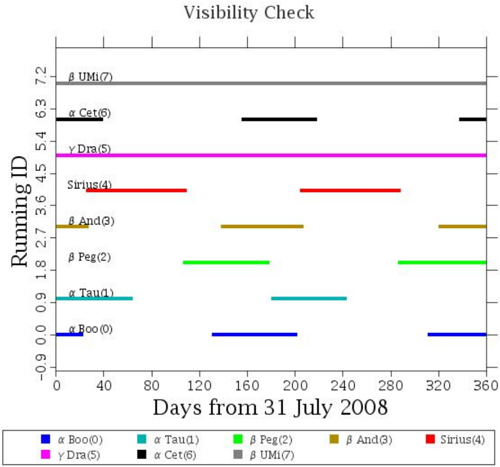


Legend: ▽= upper limit, ⋆= measurement with error bars

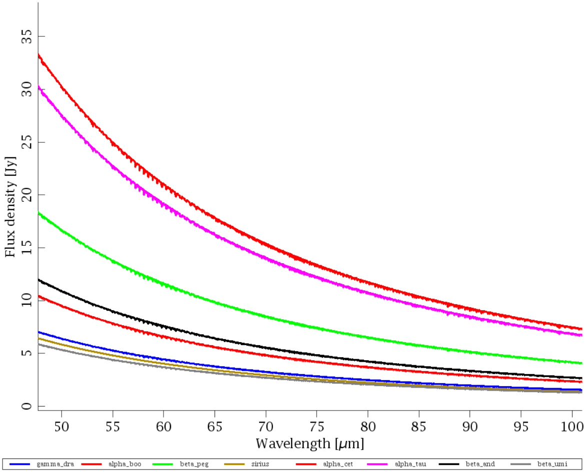
Reduced list of sources

- 8 fiducial standards:
  - α Boo
  - α Tau
  - β And
  - β Peg
  - γ Dra
  - Sirius
  - α Cet
  - β UMi
- spectral types: A, K, M
- all have ISO SWS, IRAM and/or SEST, MIPS observations and high resolution optical spectra

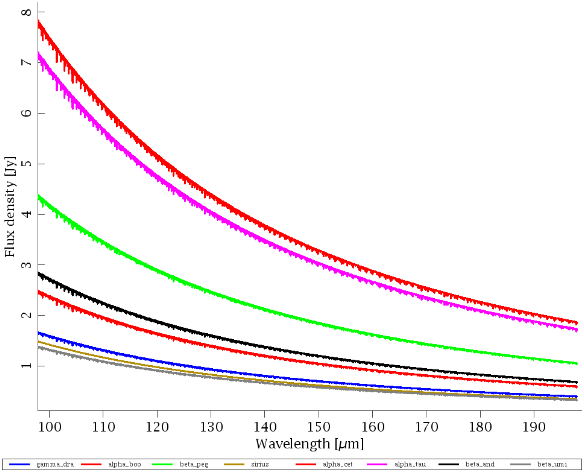
Visibility


Visibility Check
β UMi(7)
α Cet(6)
γ Dra(5)
Sirius(4)
β And(3)
β Peg(2)
α Tau(1)
α Boo(0)
Running ID
−0.9 0.0 0.9 1.8 2.7 3.6 4.5 5.4 6.3 7.2
0 40 80 120 160 200 240 280 320 360
Days from 31 July 2008
α Boo(0) α Tau(1) β Peg(2) β And(3) Sirius(4)
γ Dra(5) α Cet(6) β UMi(7)

Fiducial stars at blue PACS wavelength



Fiducial stars at red PACS wavelength



Absolute flux calibration

2 possibilities:

- based on an ideal ‘Vega’ theoretical spectrum
- based on a spectrum of the K2III giant Alpha Boo

1. Calibration based on ‘Vega’ (Rieke et al. 2008)

- theoretical (Kurucz) 'ideal' Vega model
- absolute flux measurements at 10.6μm: 35.07 ± 0.3 Jy
- extrapolated via SED to 2.22 μm (649$\pm$10Jy) – compare to direct measurements at 2.2μm corrected for disk excess (1.29 %) (645$\pm$15Jy)

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Question:

Why still use Vega as fundamental calibrator?

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Advantage:

completely independent from Vega
Expected accuracy $\leq 5\,\%$

Delivery

Now:

For the 8 fiducial PACS standards:

- absolute calibrated spectra using 'Vega' and Selby K-band photometry
- wavelength range: 2 - 200 μm
- computed at resolution of $\Delta\lambda = 0.5\,\text{Å}$, delivered at resolution $\lambda/\Delta\lambda = 4000$

Delivery

note: 5 fiducial PACS standards have S/N $>$ 10 in all 3 SPIRE bands

$\longrightarrow$ should be used for cross-calibration

$\longrightarrow$ opportunity to connect planet calibration to stellar calibrators

May – June 2008

- computation of model atmosphere spectra up to 700 μm

Summary

- MARCS models meet the accuracy and wavelength requirements
- set of 8 fiducial calibrators is presented
- suggestions given for absolute calibration:
  - 'Vega'
  - Arcturus
- delivery of models up to 200 μm

Vacancy

2 vacancies PACS instrument team in Leuven:

- PACS calibration scientist
- PACS data analysis scientist