Prime stellar calibrators - models and observations

Joris Blommaert,
Leen Decin, Eva Bauwens, Bart Vandenbussche
(IvS, KU Leuven)
PACS ICC

Herschel Calibration Workshop #5

25 March 2013, ESAC

Special thanks

- PACS Photometry group: Zoltan Balog, Thomas Mueller, Markus Nielbok, PACS ICC

  who will present more details on the PACS observations

Outline

- Description of the models
- Absolute calibration
- Selection of the stars
- Comparison with observations

State of the art of 'used' model atmospheres

MARCS

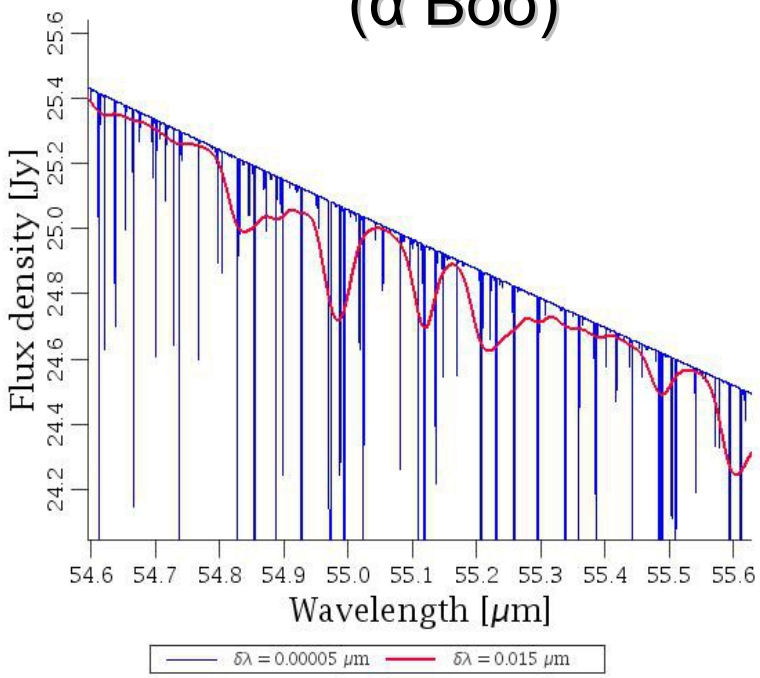
- **assumptions:**
  - spherical stratification in homogeneous stationary layers
  - hydrostatic equilibrium
  - energy conservation for radiative and convective flux
  - local thermodynamic equilibrium (LTE)

- **tested and evaluated intensively for $\lambda < 30\mu m$:**
  accuracies: < 2% for $T_{eff} > 3500$ K (H_2O)
  based on high-resolution optical + medium-resolution NIR data
  (numerical accuracies: 50 K)

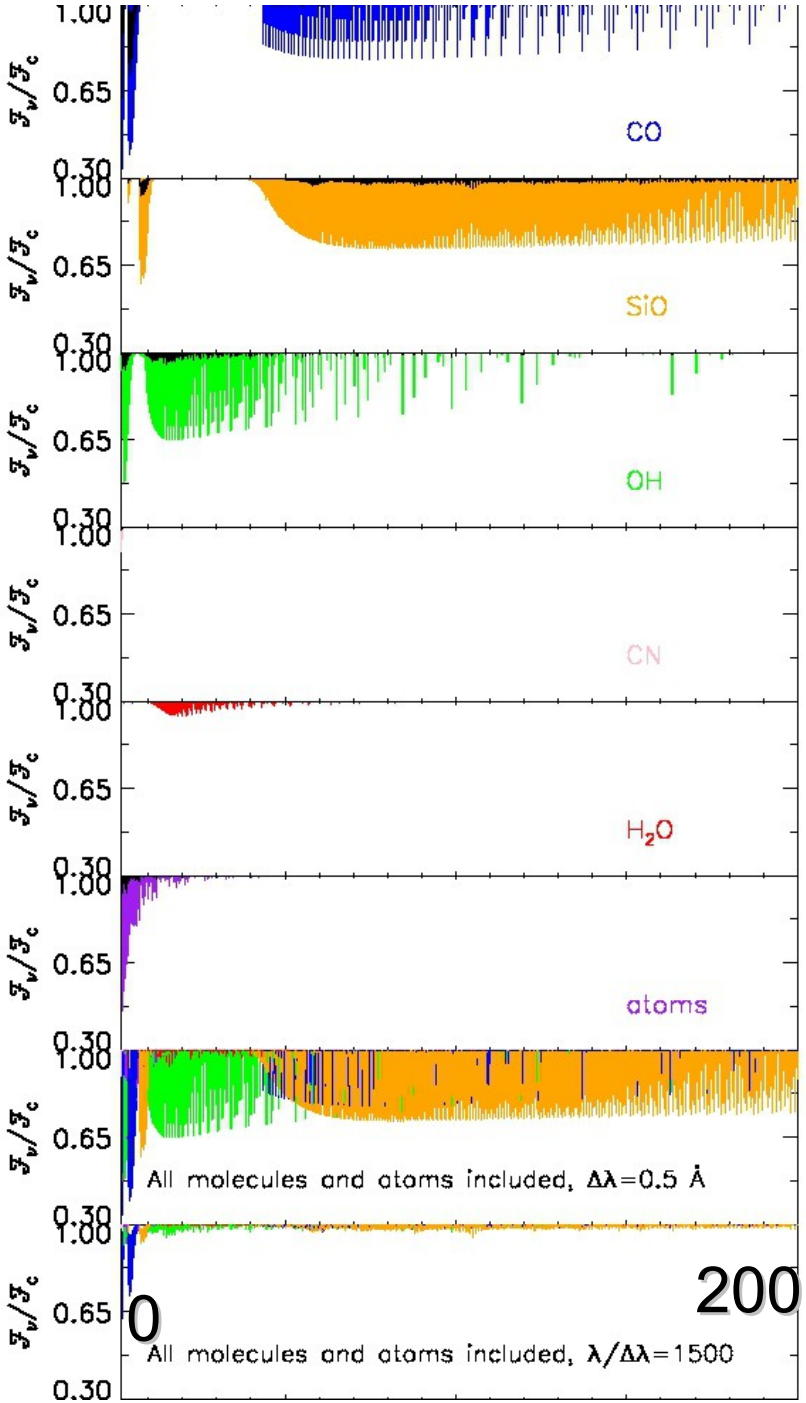
- **computed + evaluated till 200 μm (Decin & Eriksson, 2007)**

uncertainty study on: model parameters, temperature distribution, effect of chromosphere or circumstellar dust, continuous opacity H^-_{ff}, assumptions, linelists

Theoretical spectrum for K2 III (α Boo)



- CO and SiO absorption lines
- Absorption up to 30% in high resolution
- Absorption up to 3% in PACS resolution



State of the art of 'used' model atmospheres

Uncertainties of the models

Description	Uncertainty	Spectral Type	Wavelength Region
• dependency on stellar parameters			
→ molecular features	up to 8 %	G–K	around 2.3, 4.0, 4.2, 8 μm
→ continuum	up to 4 %	A–M	2–200 μm
• uncertainties on $T(\tau)$			
continuum flux (without high-resolution data constraints)	$\lesssim$3.5 %	A–M	2–200 μm
continuum flux (with high-resolution data constraints)	1–2 %	A–M	2–200 μm
• presence of chromosphere/ionized wind	$\gtrsim$10 %	G–M	$\lambda > 100$ μm
presence of circumstellar dust	$\gtrsim$10 %	A–M	$\lambda > 2$ μm
• continuous opacity by H^-_{ff}	1 %	A–M	2–200 μm
• line lists	$\lesssim$3 %	A0-M0	2–200 μm

Overall: ~5% in the FIR

Decin & Eriksson 2007

State of the art of 'used' model atmospheres

- *Can the models be improved?*

  At the moment, not really.

  - 3D hydrodynamical modelling
  - Improved line lists. This is being worked on, but takes a long time and for our photometry, likely to be small effect.

Standards in the FIR

Aspects that need to be checked in the FIR:

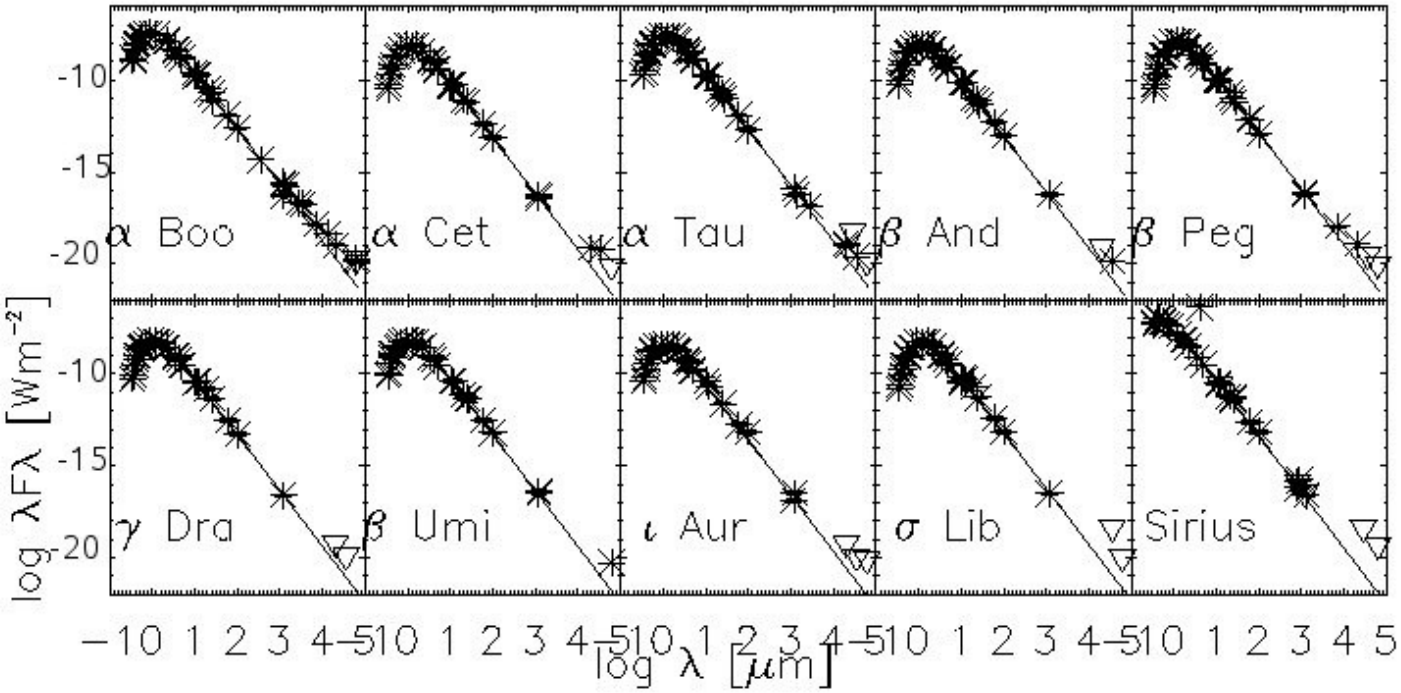
- M III: CS dust, non-photospheric molecular layers, non-LTE effects
- G-K III-V: chromosphere – ionic wind
- AV: Vega phenomenon (debris disk)

- In preparation of Herschel we started a program to investigate possible FIR excess (Dehaes et al 2011)

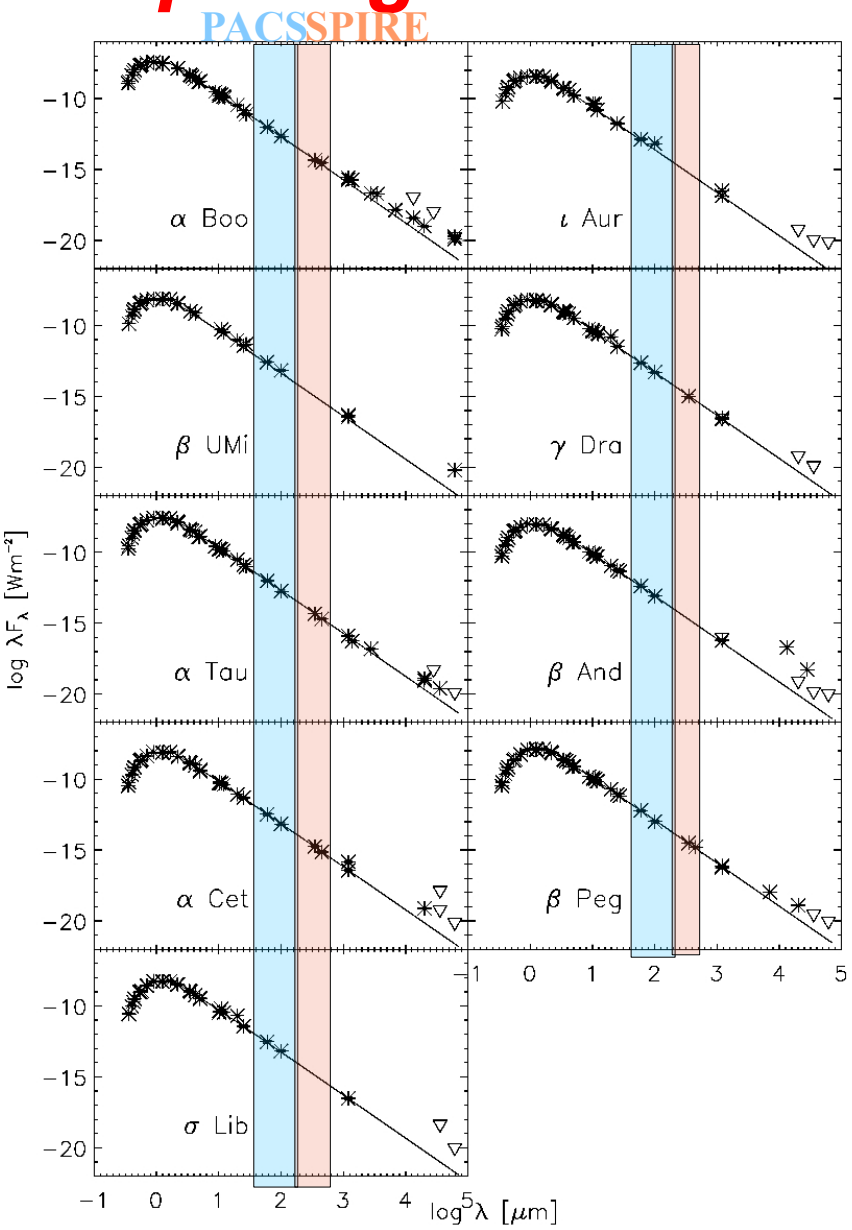
Searh for FIR excess

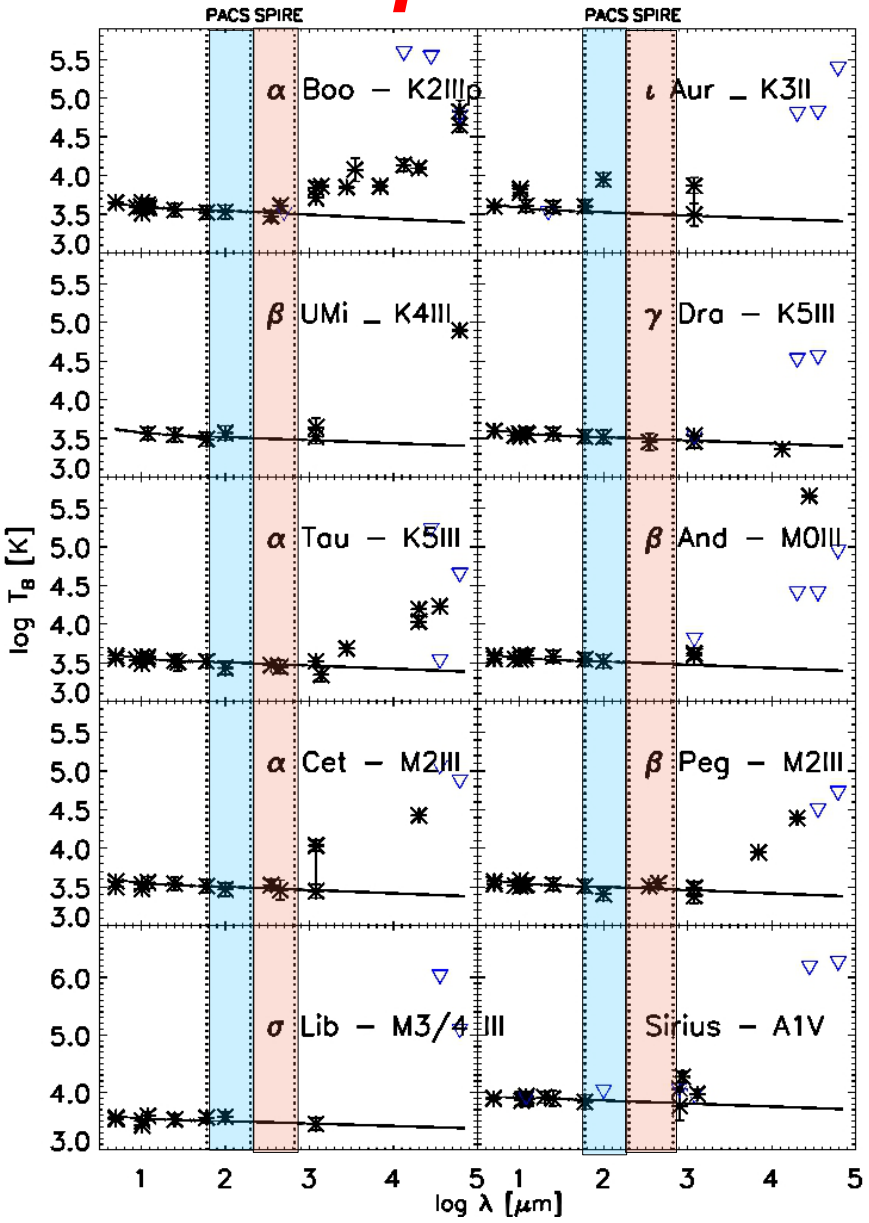
- SEST, IRAM, CSO and VLA mm and cm data obtained
- Models compared to photometry from the literature

Dehaes et al 2011:

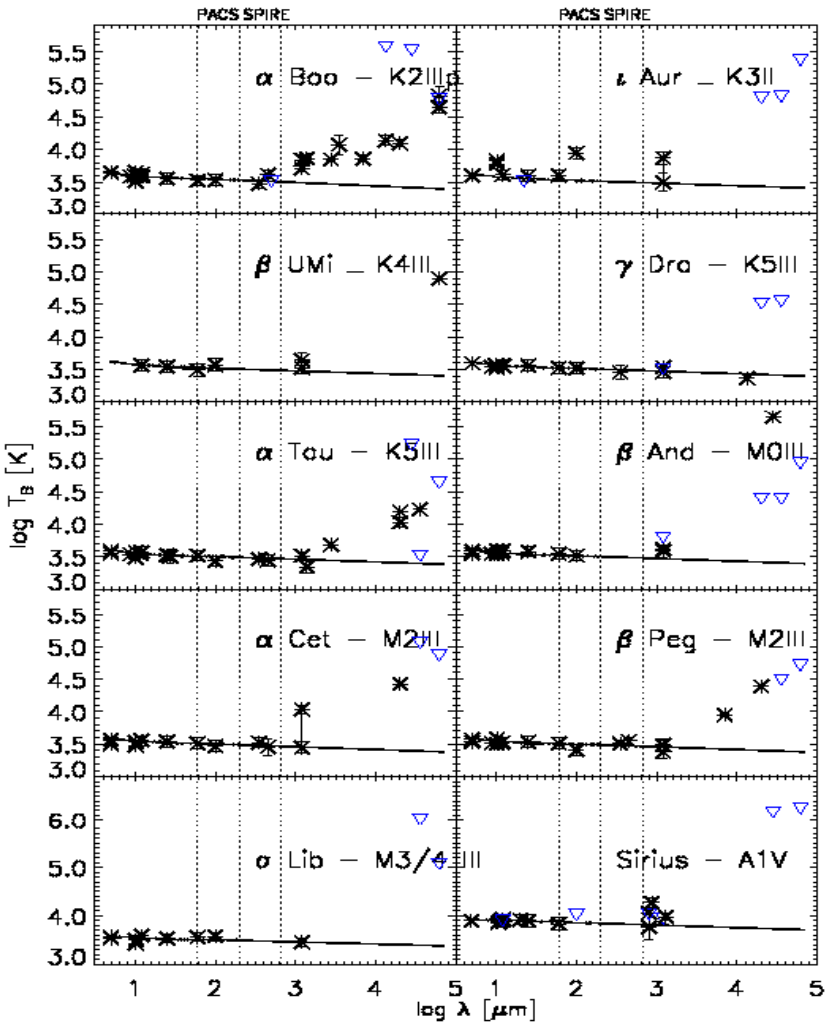


Comparing SED and theoretical predictions





Status of the fiducial stars HCalSG#24



Dehaes et al. 2011

- α Boo: OK PACS; NOT SPIRE
- α Cet: OK PACS, maybe OK SPIRE
- α Tau: OK PACS, OK SPIRE
- β And: unclear
- β Peg: OK PACS, OK SPIRE
- β UMi: recalibrated, possibly OK but needs TBC
- γ Dra: OK PACS, OK SPIRE
- Sirius: OK PACS, OK SPIRE

List of 8 stars in 2009. Almost all are K or early M type Giants

Absolute calibration – determination θ_D

- Absolute calibration tied to (Selby 1988) K band photometry (when it exists)
- Claimed accuracy 0.01 – 0.02 mag
- zeropoint: using Kurucz Vega model + *correction for Vega near-IR excess of 1.29% (Absil et al. 2006)*

From this *angular diameters* are determined at 2.2 μm

Comparisons of the angular diameter

Target	Dehaes et al	Piau et al	Engelke et al
α Boo	20.74 ± 0.10	20.84 ± 0.03	21.06 ± 0.21
β Umi	10.15 ± 0.42	10.09 ± 0.08	10.00 ± 0.20
α Tau	20.89 ± 0.10	20.57 ± 0.02	20.75 ± 0.21
ϒ Dra	9.94 ± 0.05	9.90 ± 0.09	10.17 ± 0.11
β And	13.03 ± 0.06		13.65 ± 0.27
α Cet	12.34 ± 0.06		12.94 ± 0.26

Piau et al 2011: K band interferometry

Engelke et al 2006: from models and photometric and spectroscopic observations (not specific K band)

Fiducial stars – models

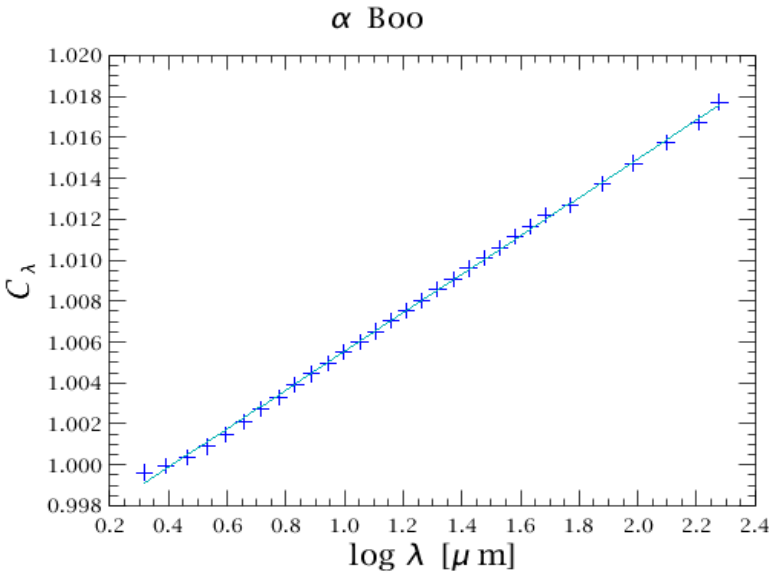
- SED fits files are available on the HCalSG ftp site (ftp.sciops.esa.int)
  - MARCS model, R=5000, wvl range = 2 to 200 μm
  - *_cont.fits: MARCS model with BB extension (Temp. determined from 50 - 200 μm part), wvl range = 0.5 μm to 7cm, at a resolution of 0.1 μm

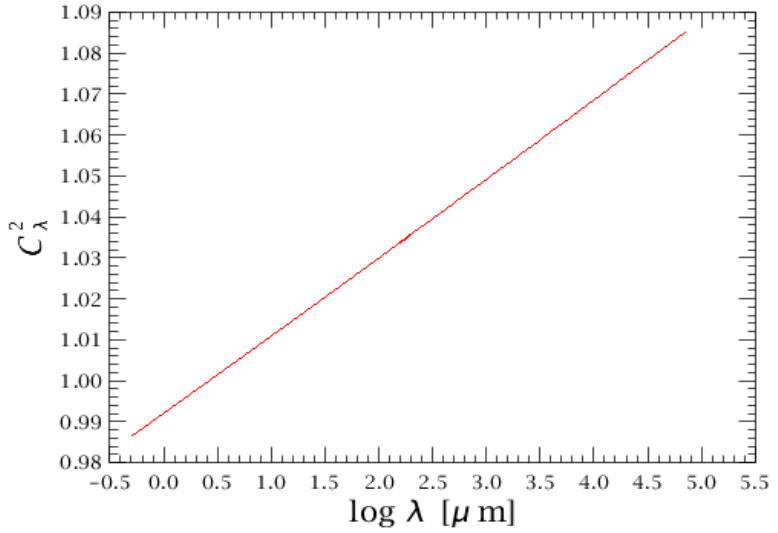
Since last year – proposed refinement

- So far, the angular diameter was kept constant for the whole wvl range (i.e. the K band a.d.)

=> Now, determine angular diameter as function of wavelength (radius at which τ_λ =1) and adapt flux density accordingly: 1 – 4% effect

Usage of this correction gives a slight improvement (see Zoltan's presentation)





Fiducial stars used for ...

- PACS photometer: primary calibrators
- PACS spectrometer: part of the set of flux calibrators: stars, asteroids and Planets

- SPIRE photometer: used as secondary calibrators (absolute flux calibration based on Neptune)

- Finally 5 stars selected as prime calibrators for the PACS photometer:

α Boo, α Cet, α Tau, β And and γ Dra

β UMi degraded

- β UMi has no K(Selby) available => calibrated with Faucherre et al (1983)
- From PACS PV photometry it was found to be deviating from the other fiducials.

New calibration: Johnson K band (Ducati 2002)
but less accurate (~10%)

Not a primary standard (still useful for comparison, it is always visible)

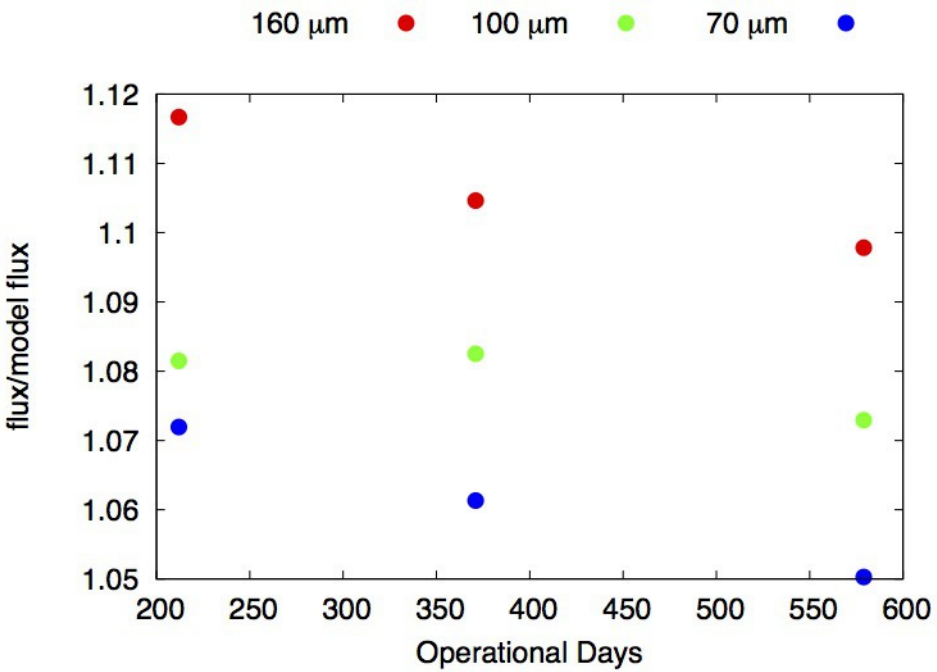
New/old: 18% higher flux

Results – PACS photometer

- based on latest results, including all corrections (see Markus and Zoltan's talks)
- Absolute flux calibration based on the stars, so only useful to look at internal differences, deviating colours

- First, 2 more stars that didn't make it: β Peg and Sirius

PACS results – β Peg



M2.5 III

F70 = 8.5Jy

F160=1.6Jy

F250= 662mJy

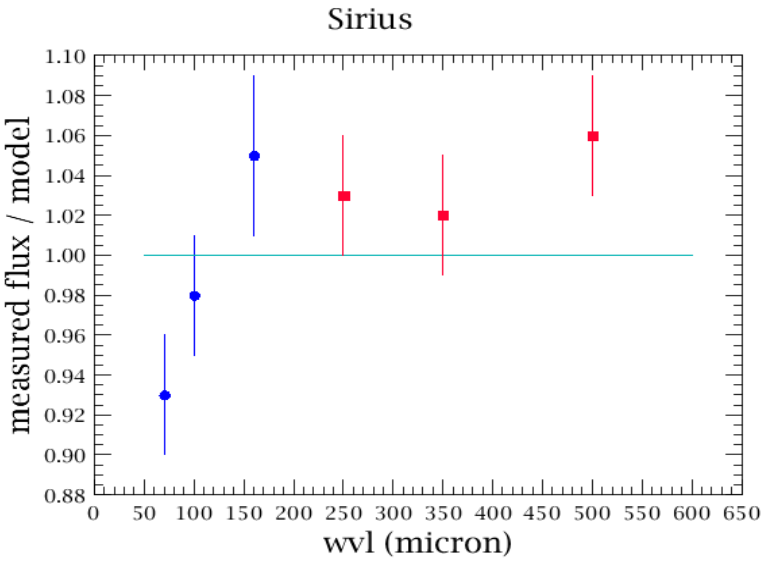
F500 = 161mJy

variable in the mid-infrared (~10%, Price et al 2004)

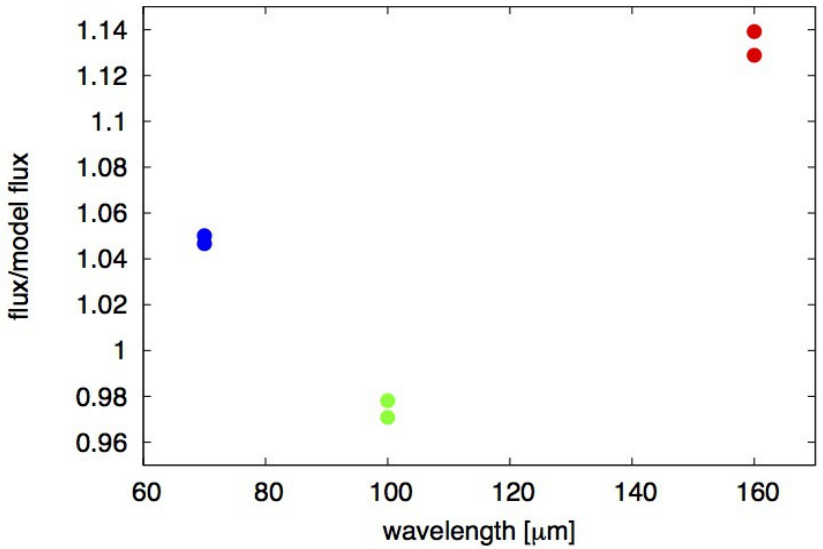
PACS repeatability ≤ 2%

Sirius

From Cal_Wkshp#3:



Most recent:



A1 V !

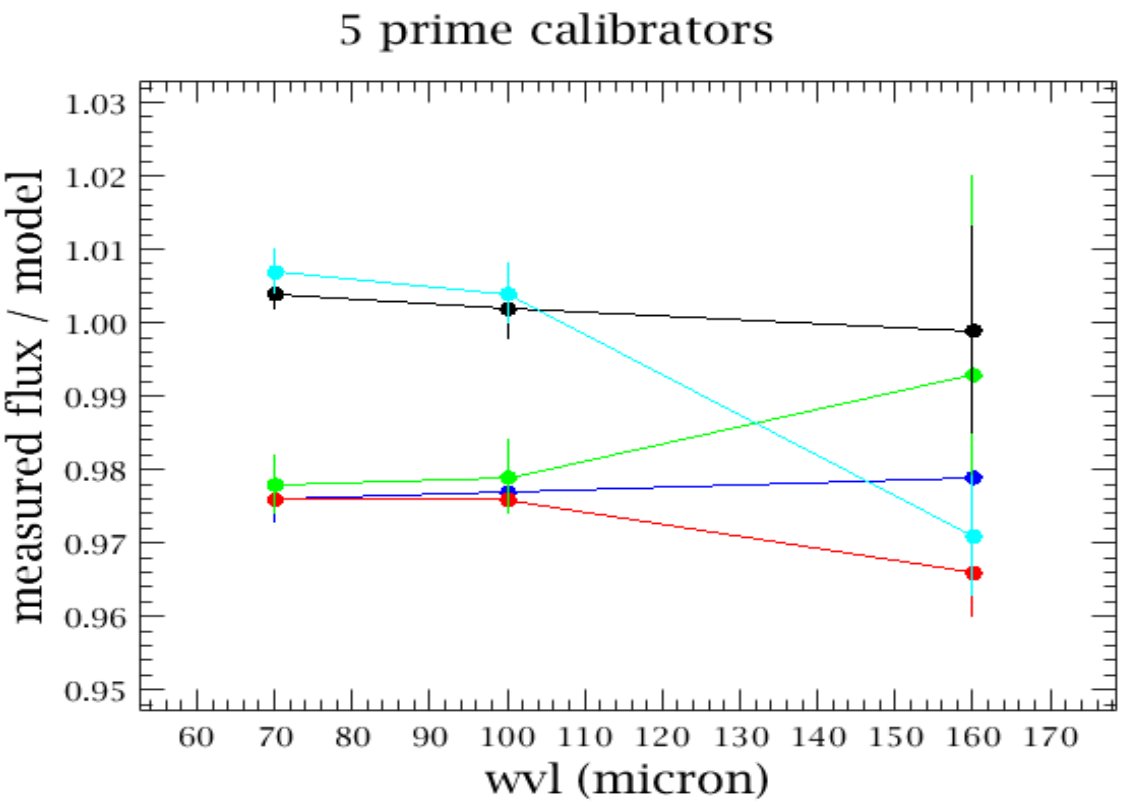
F70 = 3Jy, F160= 0.5Jy

F250= 219mJy, F500 = 53mJy

PACS photometer – prime calibrators

Latest results (based on all measurements of prime calibrators):

- $\sigma < 2\%$
- *Intriguing 3% difference between K and M giants is it real?*



β And M0
α Cet M2
γ Dra K5
α Boo K2
α Tau K5