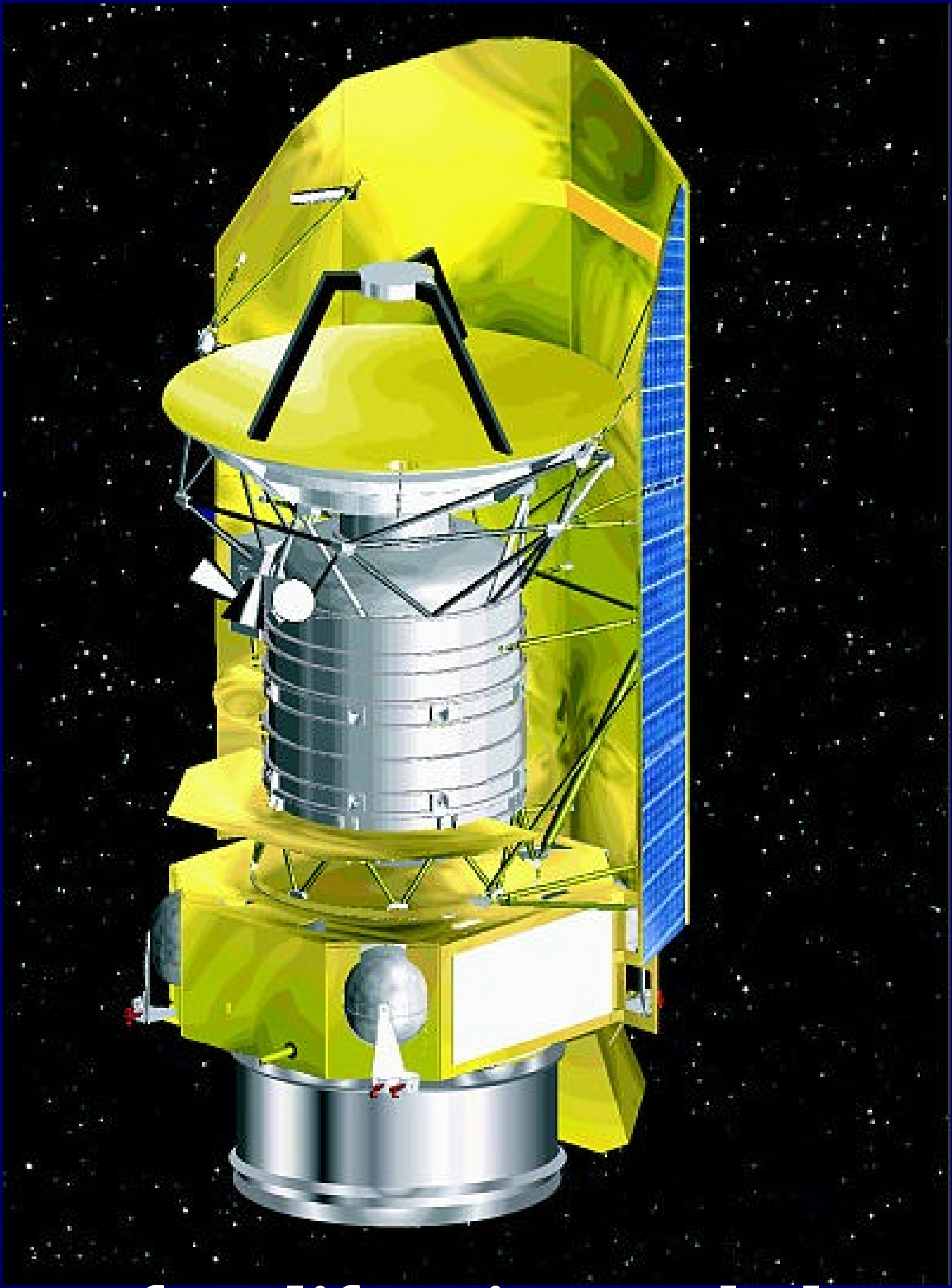
Stellar calibrators for HERSCHEL SPIRE & PACS



Herschel Calibration Workshop: Models and Observations of Astronomical Calibration Sources

1-3 December 2004, Leiden

Martin Cohen, University of California, Berkeley

Outline

- Strategies for FIR calibration by stars
  - Building on the MSX absolute calibration
  - Extrapolating K0-M0III spectra to the FIR
  - Uncertainties of model atmospheric spectra
  - Closure of ISO FIR calibration: LWS/PHOT
  - Testing bright K-giants with LWS & BIMA
  - Mm observations of cool giants: a new view
  - PACS/SPIRE calibration stars: suggestions
  - “Real” stellar models? too soon, too simple

Absolute calibration by MSX

(S. D. Price et al. 2004, AJ, 128, 889)

- Response of the 6 MSX MIR bands precisely (<0.5% rms) tied to Cohen-Walker-Witteborn (CWW) fluxes for α CMa
- Absolute MSX calibration by the emissive reference spheres averaged over 6 bands is within 1.1% of CWW 0-magnitude flux scale, well within the 1.5% assigned uncertainties
- The MSX calibration experiments thus confirm the scale of zero-magnitude fluxes proposed by Cohen et al. (1992a)
- MSX validates use of spectral templates based on composite spectra of the secondary standards for the energy distributions of fainter stars of the same spectral type
- The zero-magnitude absolute fluxes proposed by Cohen et al. are validated if the flux from Sirius is increased by 1%

Ratio of MSX Measured to CWW Predicted Irradiances

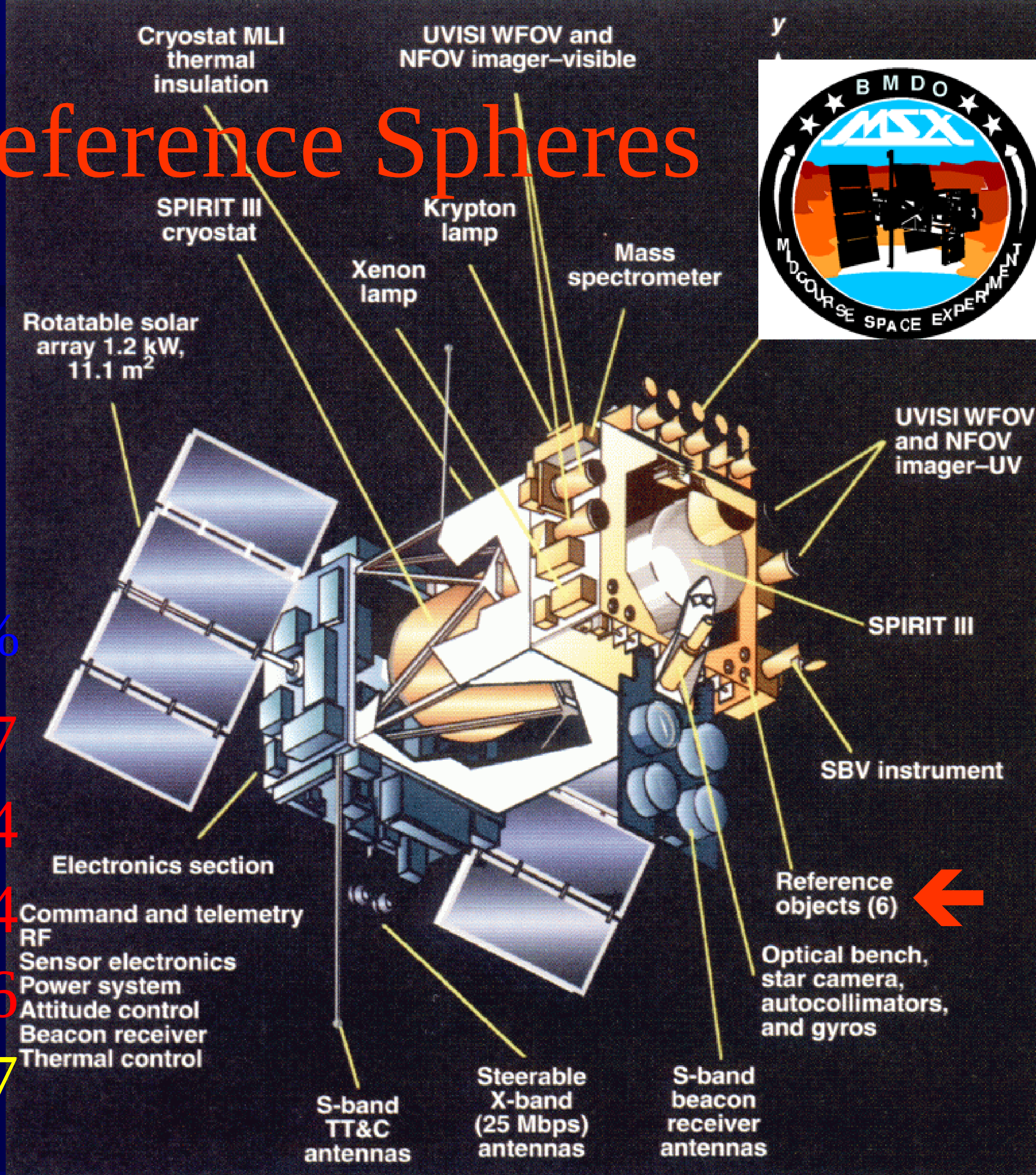
μm	8.28	4.29	4.35	12.13	14.65	21.34
Star	A	B1	B2	C	D	E
α CMa	1 def.	1	1	1	1	1
α Boo	1.0015	1.0057	.9907	.9908	.9907	.9838
α Tau	.9795	1.0294	1.0060	.9903	.9942	.9962
α Lyr	.9893	1.0164	.9954	1.0479	1.0378	1.172
β Gem	.9800	.9786	.9487	.9907	.9909	1.088
γ Cru	.9449	.9812	.9654	.9989	.9975	1.005
γ Dra	.9738	1.012	1.001	.9987	.9976	1.005
Ave.	.986	1.014	.990	.991	.988	1.023
$s\ N^{-0.5}$	±0.004	±0.009	±0.010	±0.0005	±0.003	±0.020

Average MSX/CWW is 0.991⇒ brighten α CMa by 1%

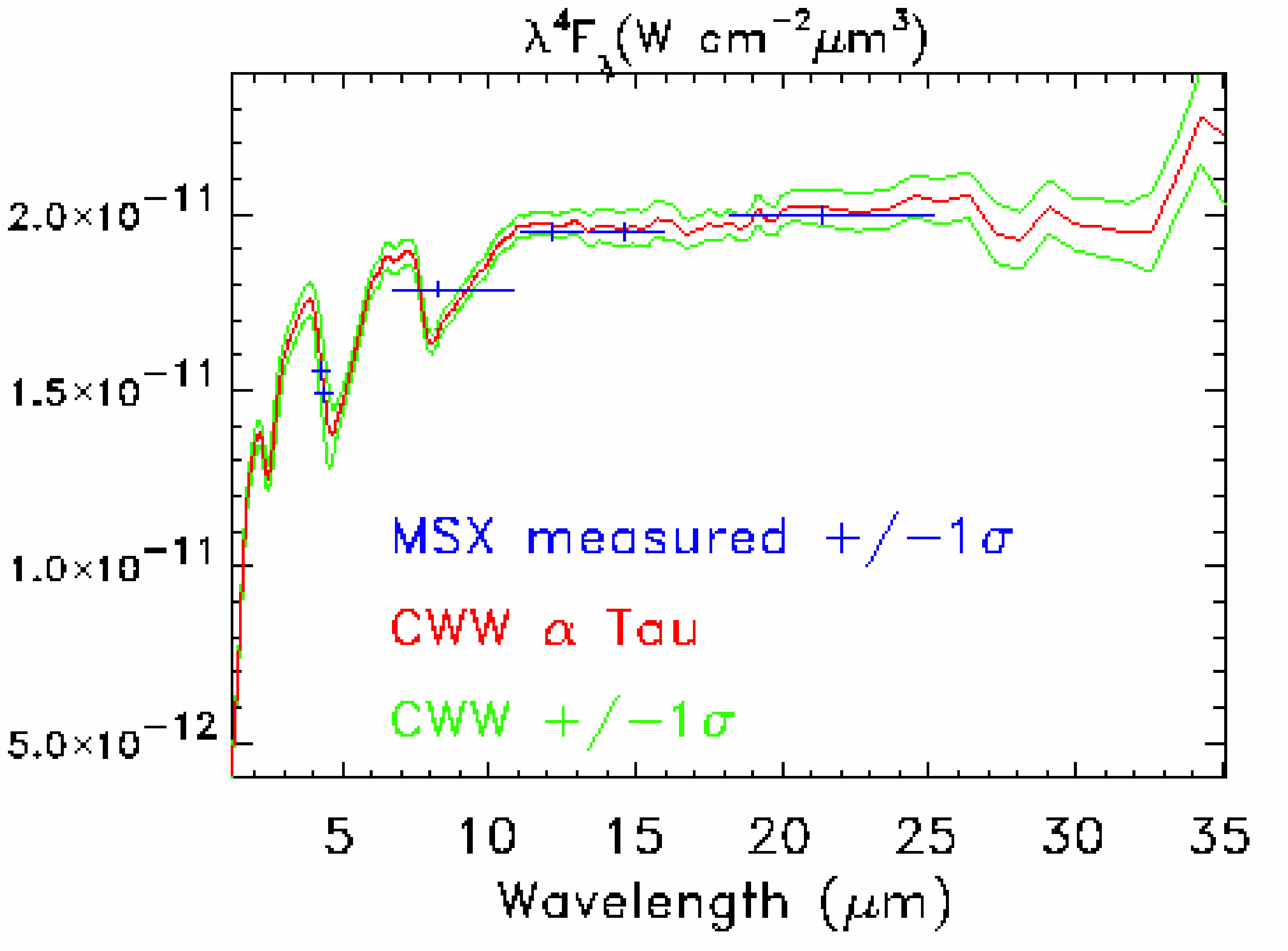
Emissive Reference Spheres

CWW absolute flux biases in 4 MSX bands

BAND	BIAS %
Band A	0.4±0.7
Band C	–0.4±0.4
Band D	–1.9±0.4
Band E	–2.5±0.6
<MIR>	–1.1±0.7



MSX absolute validation of a Tau



Advantages to Herschel of the common absolute scheme

- Direct comparison with other missions: DIRBE, ISO, MSX, 2MASS, Spitzer, ASTRO-F, WISE
- 1.2–35μm absolute spectra of normal K0-M0IIIs extrapolated to 300μm for ISOPHOT by NASA-Ames model SEDs (Duane Carbon), assuming all single-component atmospheres=pure photospheres
- Absolute accuracy of FIR stellar spectra made for ISOPHOT was estimated to be better than ±6%
- ISOPHOT products validated by Cray/Columbia stellar spectra; K/MIIIs explored in 1-3 mm region

Criteria for Walker-Cohen Atlas

- All-sky, originally 1 source per 50 sq. degrees
- High quality IRAS F12 & F25, with F25>1 Jy
- Normal stars: F12/F25>=3.19; F25/F60>=4.28
- No variable, carbon, emission-line, nebulous, dusty stars, nor with IRAS VAR>90%
- Total flux of known sources within a 6´ radius contributes <5% to calibrator flux at 12/25μm
- Limit cirrus contamination: CIRR3<6.3*F12
- Spectral types K0-M0III to minimize potential stellar variability in the MIR (92 DIRBE 'BCC' calibrators; have <2% ΔMIR with ΔV~1 mag)

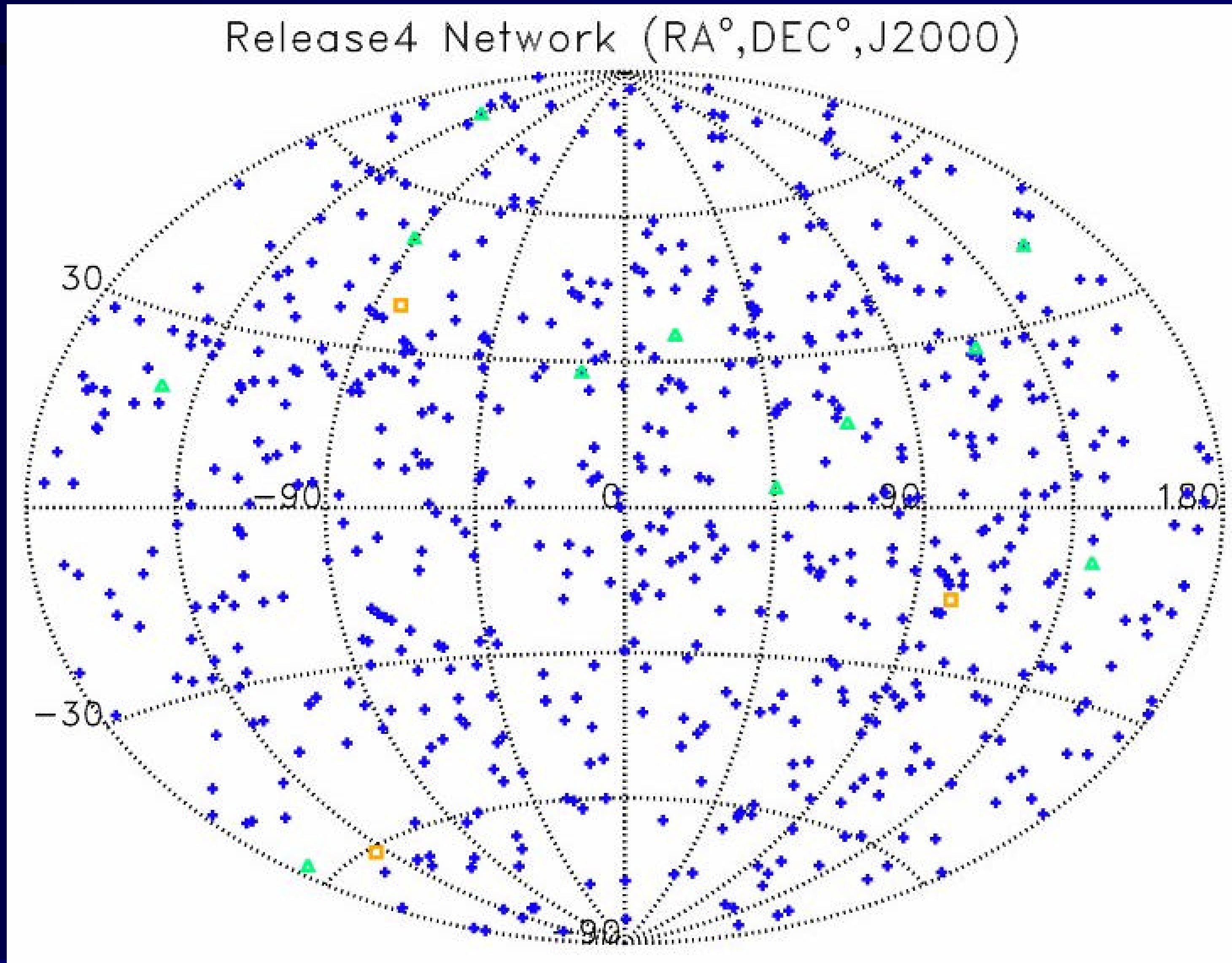
Current bright calibrator network

(610 K0-M0IIIs with 1.2–35μm absolute spectra)

Kurucz models (a CMa)

Composites bright giants (a Tau)

Faint template (HD) stars



Selection of FIR calibration stars

- Isolated predictable point sources, in clean sky
- Not extended objects (PNe,HII) due to spatio-spectral variations seen at Herschel resolution
- Bright enough for good SNR measurements
- Normal K/M-giants difficult to model but bright, well-observed & brightest are known not to vary in MIR>2% from 1.2-25μm (DIRBE BCC): αBoo, α Cet, αHya, αTau, βAnd, βPeg, βUMi,γCru, γDra…
- Early-type stars problematic (O,B: winds; A: faint or debris disks; F,G: models + debris?)
- MIRAs: photospheric + dust modeling ⇒ spectral time variation very difficult to predict
- Well-characterized empirical spectra best

Testing model synthetic spectra of K/M giants in the FIR

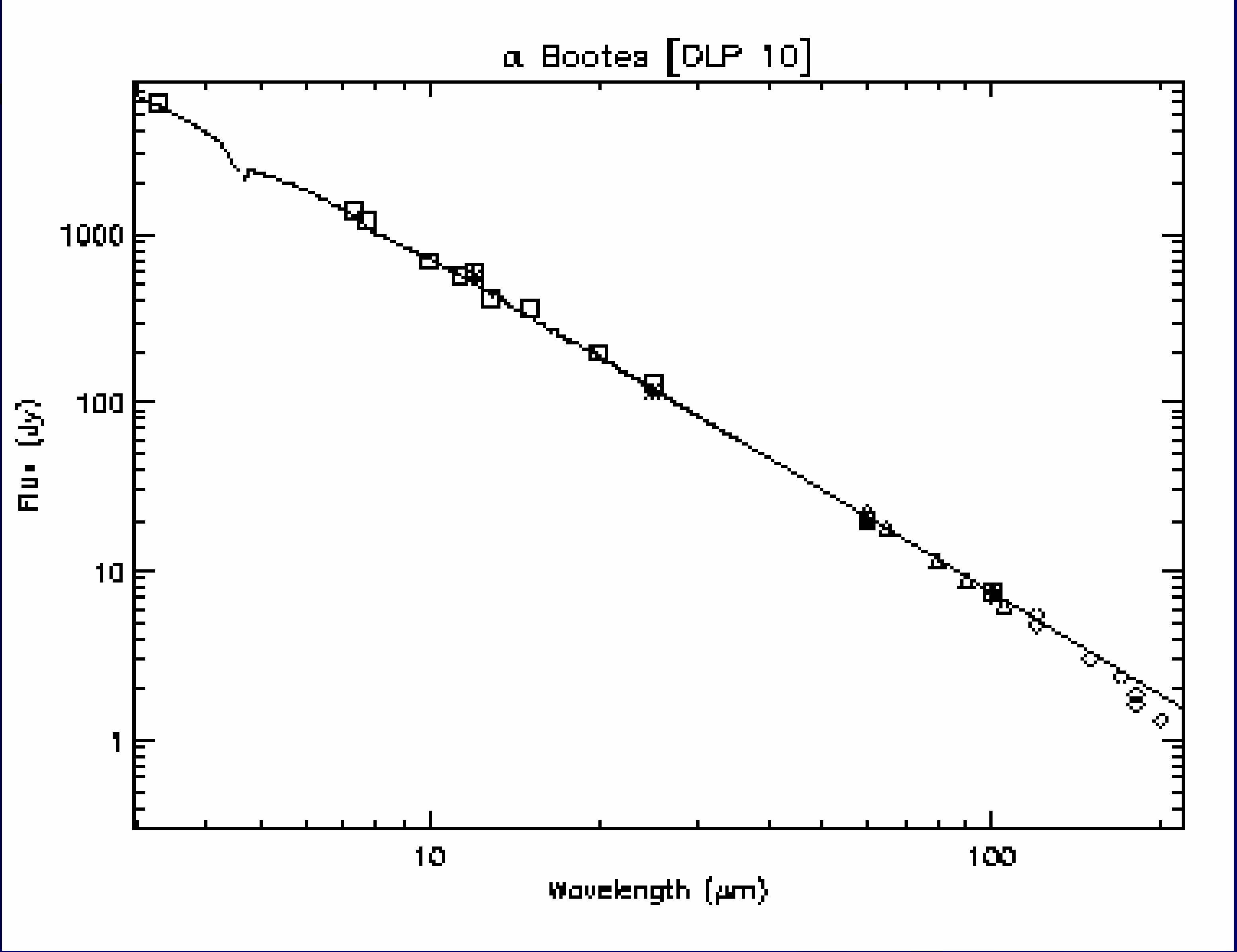
TABLE 6. Ratios of *IRAS* flux densities synthesized by integration of the *IRAS* passbands over our observed composite spectra (12,25 μm), extrapolated by model atmospheres (60,100 μm), to those actually observed by *IRAS*.*

AJ, 112, 2274, 1996

IRAS data	12 μm	σ	25 μm	σ	60 μm	σ	100 μm	σ
FSS	0.961	0.012	0.946	0.013	0.997	0.015	1.038	0.040
PSC	0.961	0.010	0.943	0.010	0.985	0.029	1.015	0.026

Validated by ISOPHOT using planets, asteroids, & stars (Schulz et al. 2002, A&A, 381, 1110)

Testing a Boo vs. ISOPHOT calibrators

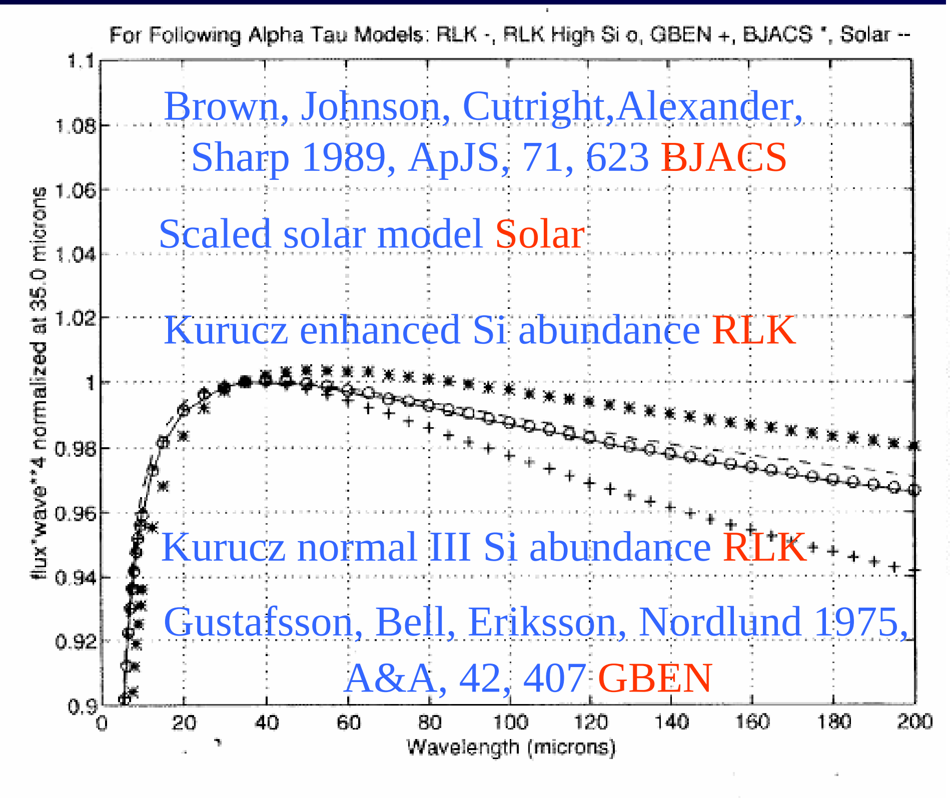


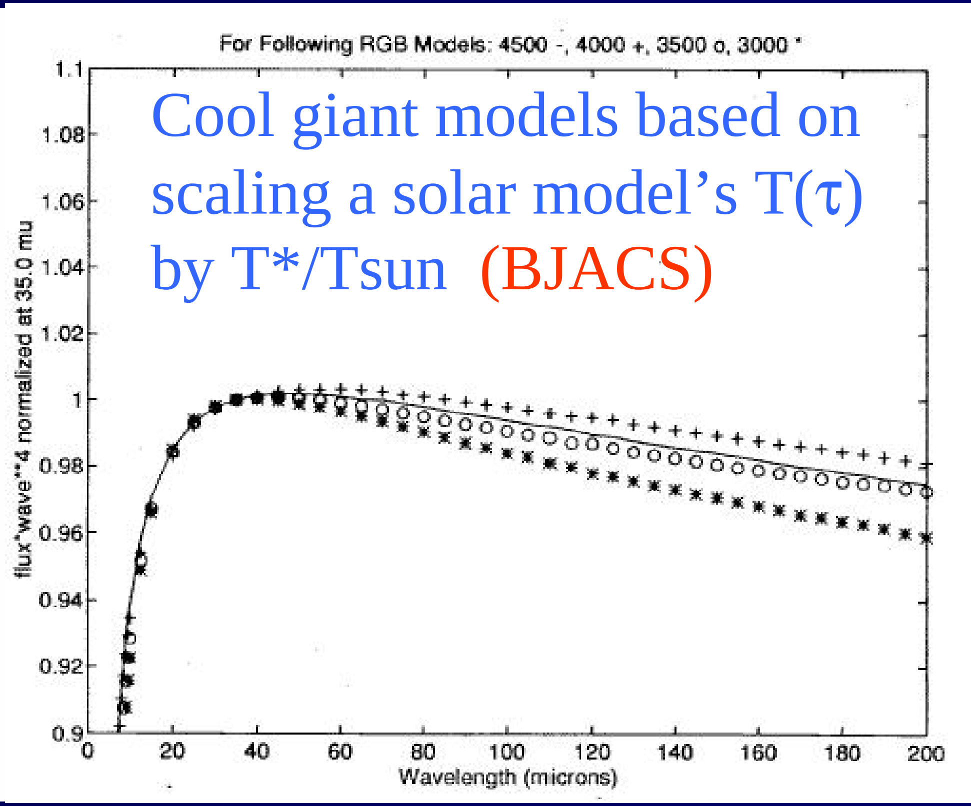
K/MIII models: error sources >100μm

van der Bliek, N. S., Gustafsson, B. & Eriksson, K. 1996, A&A, 309, 849

- Effective temperature: ±100K
- Gravity: ±0.5 dex
- Metallicity: ±0.2 dex
- Total from fundamental parameters: 4%
- Total from temperature structure: 1.5%
- H-minus opacity & CS dust: 2%
- RSS all these errors: 4.8%
- In 1996 we added 3% for errors of including the many molecules & their isotopes: total ±6%

Comparing model synthetic spectra





Five different models for one star (α Tau) ⇒ 4% spread in spectra at 200μm when normalized at 35μm

A single model grid for effective temperatures 3000 to 4500K ⇒ only 2% spread in spectra at 200μm when normalized at 35μm

Cautions about stellar models (D. Carbon)

• Just because models agree does not mean any are correct Issues of opacities used and the routines that implement them, numerical accuracy, and precision of calculations arise

• Disagreements between modelists arise due to different treatments of line lists, convection, and line blanketing

• If everybody was allowed to vary their parameters probably all models could be made to agree, but would not reflect EXACTLY the same calculations for the same star

• Which is correct? Probably no-one using an LTE, static model, with homogeneous layers is correct

• Computational facilities are finally available to do the problem roughly correctly; it will be some years before this approach is standard (NASA's 10,240-processor Columbia, 20 SGI® Altix™ 3700 superclusters each of 512 Intel Itanium2s)

Bright K/MIIIs: physics & tests

- Wiedemann (1994): temperature bifurcation; material at common altitude has 2 temperatures: chromosphere & radiative equilibrium mediated by molecules (CO)
- Contributions from the two regions to overall stellar radiation varies greatly between stars of same type
- Bright IIIs used as calibrators are the "quiet" stars: radiatively-cooled regions dominate surfaces so single component models valid (a Boo, a Hya, a Tau, ? Dra)
- Map a Tau & a Boo in 1-/3-mm continuum: sample temperature minimum; probe outer atmospheres
- Do these stars radiate as expected ⇒ stellar FIR calibration is viable, or have long-? chromospheres?
- Connect mm & FIR absolute flux calibrations

Using LWS on faint objects

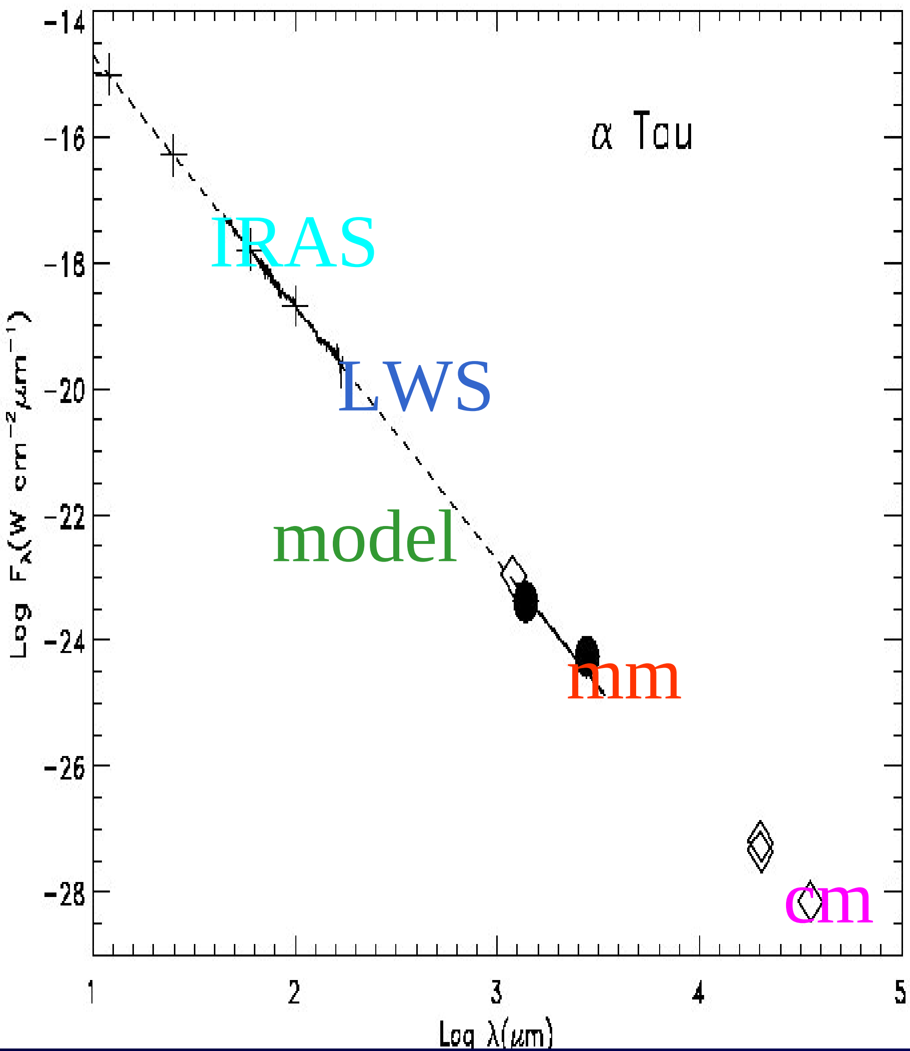
- OLP10 used the "fixed dark currents" that are essentially measurements of dark backgrounds
- Dark current signals were constant through mission
- High cirrus: need an "off" spectrum to remove sky
- COBE-predicted sky flux in dark regions is large % of the LWS dark signal but is deemed undetected as no signal is seen over the signal from the blank
- Corrections for off-source emission in LWS are not appropriate for faint normal stars in low-cirrus sky* to subtract off-source sky ⇒ subtract dark twice!
- If measured sky backgrounds near the KIIIs at time observed < fixed darks then no "off" spectra needed

Sky measured near α Tau & α Boo

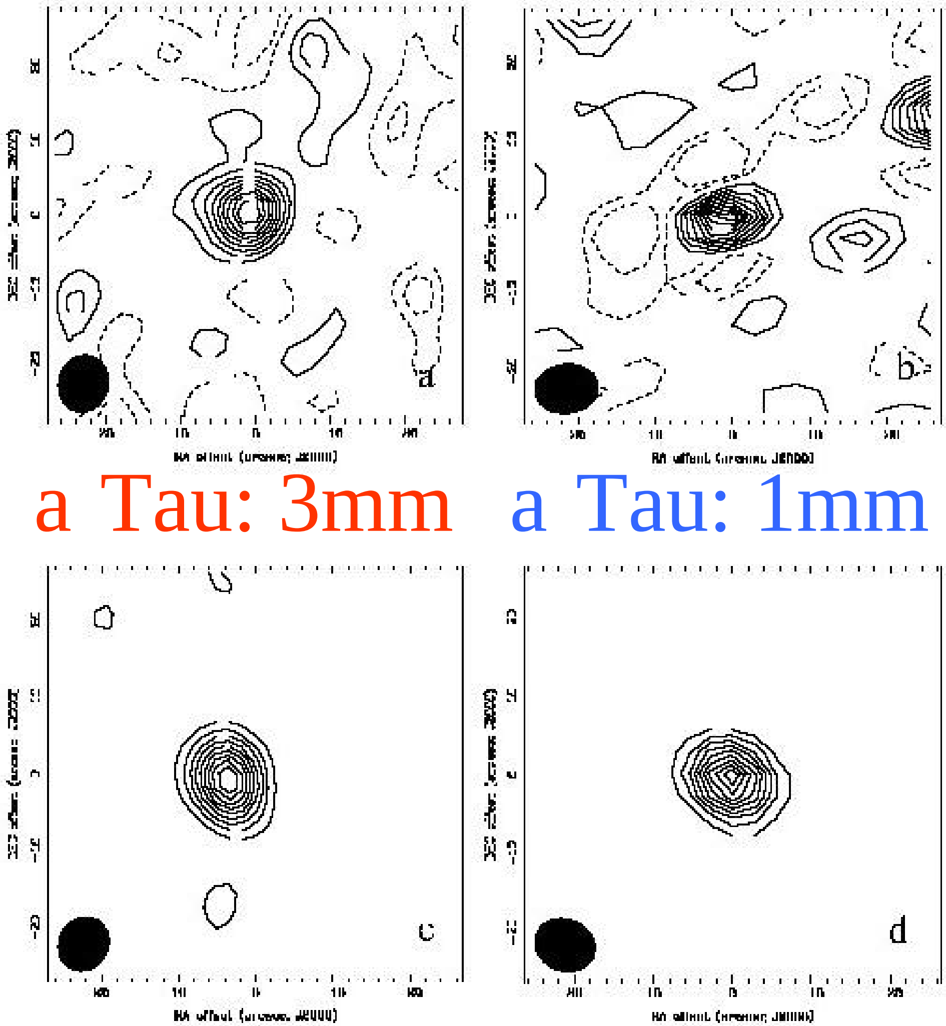
Star	ISOPHOT	LWS	Dark	Sky	Zodi
α Tau	C1-60	SW2	4.2E-18	4.5E-19	3.8E-19
α Tau	C1-100	LW1	8.0E-19	1.3E-19	1.1E-19
α Tau	C2-160	LW4	9.1E-20	4.5E-20	5.9E-20
α Boo	C1-50	SW2	4.2E-18	2.0E-19	>1.3E-19
α Boo	C1-90	SW5	3.2E-18	8.7E-20	---
α Boo	C1-105	LW1	8.0E-19	5.2E-20	2.4E-20
α Boo	C2-120	LW2	7.7E-21	3.2E-20	---
α Boo	C2-135	LW3	2.0E-20	1.7E-20	---
α Boo	C2-160	LW4	9.1E-20	1.5E-20	1.8E-20
α Boo	C2-200	LW5	4.4E-19	8.6E-21	---

Dark: LWS. Sky: Schulz. Zodi: DIRBE/MSX

BIMA mm-continuum imaging of stars



a Tau radiates like a photosphere to 170 mm



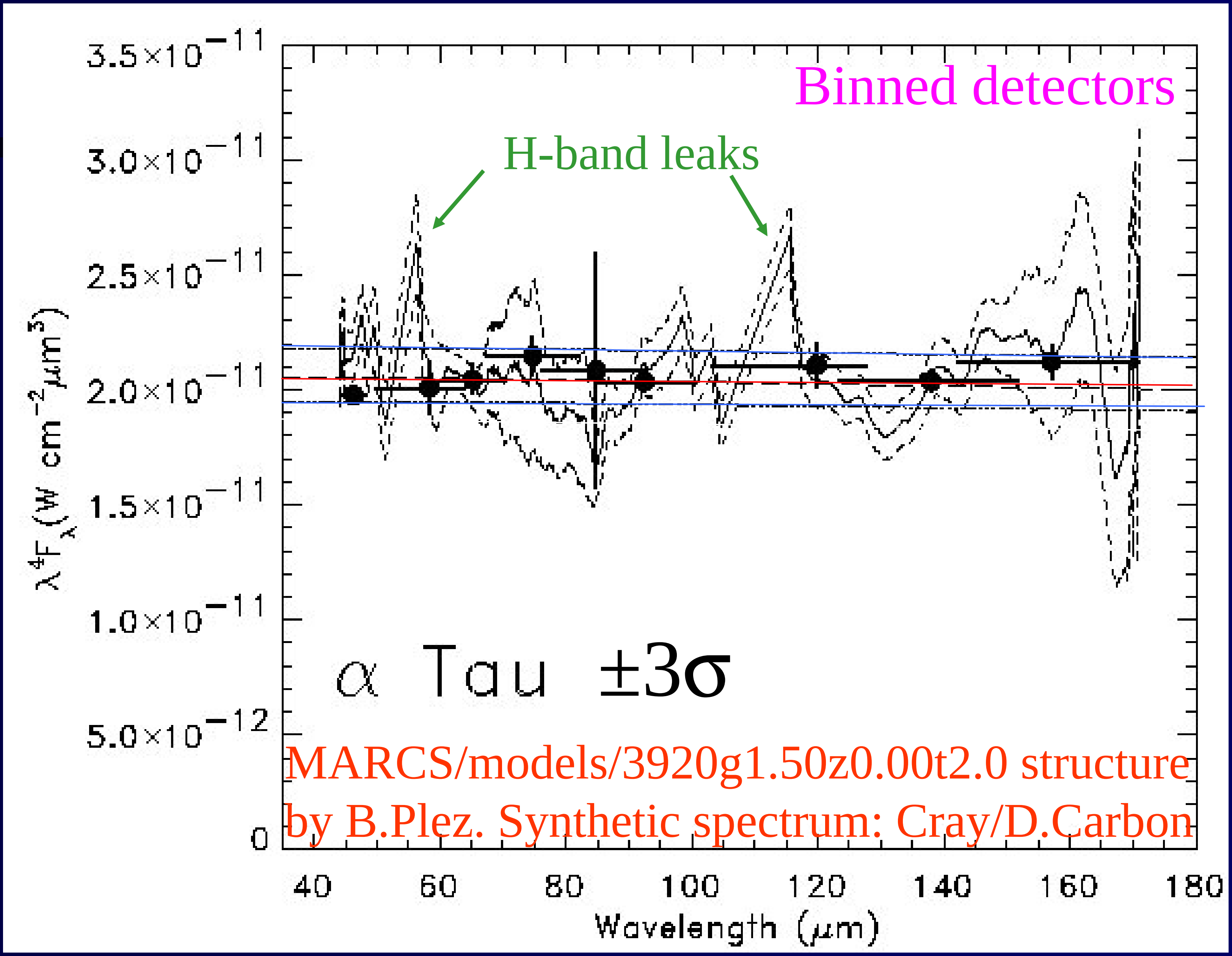
a Tau: 3mm

a Tau: 1mm

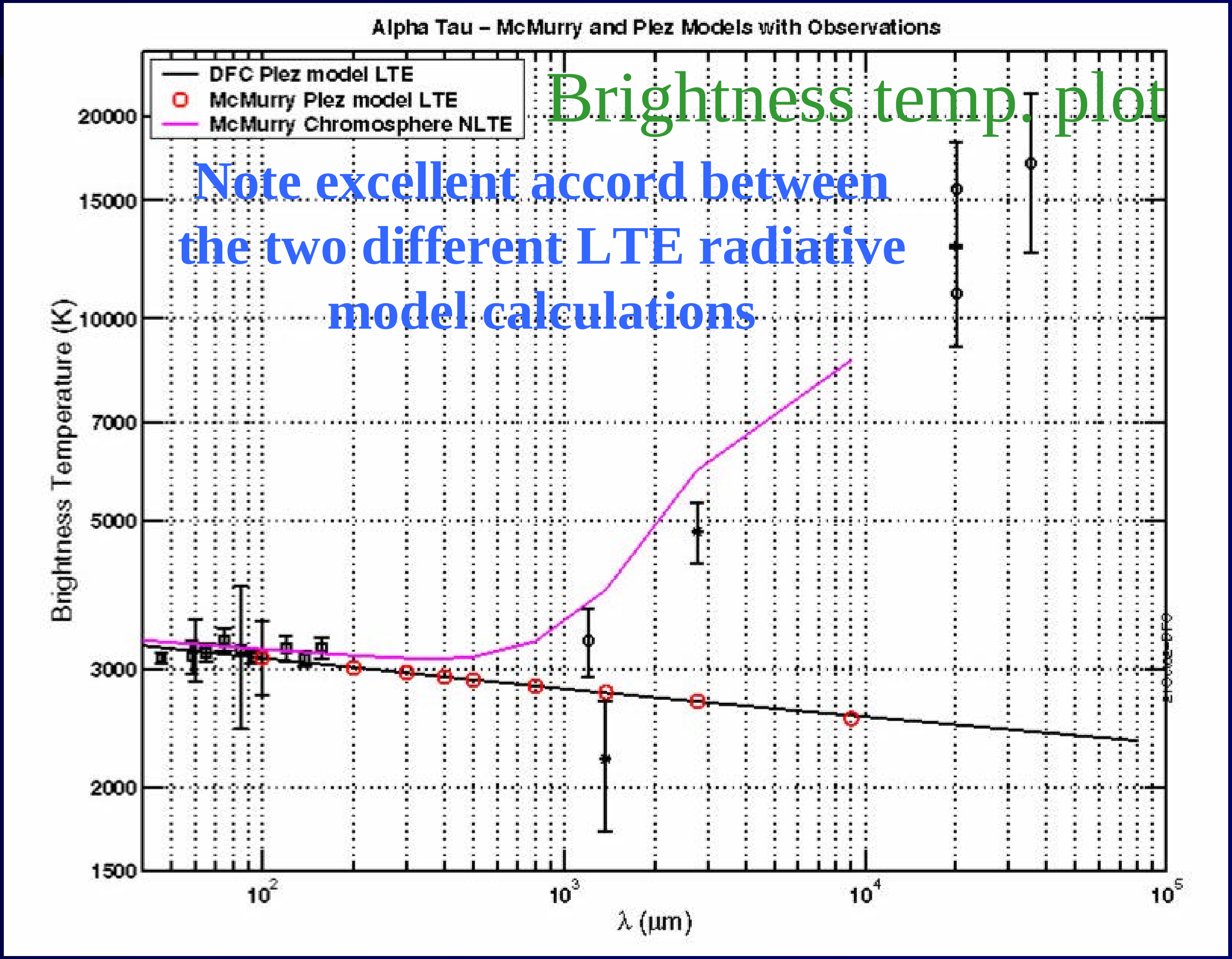
a Boo: 3mm

a Boo: 1mm

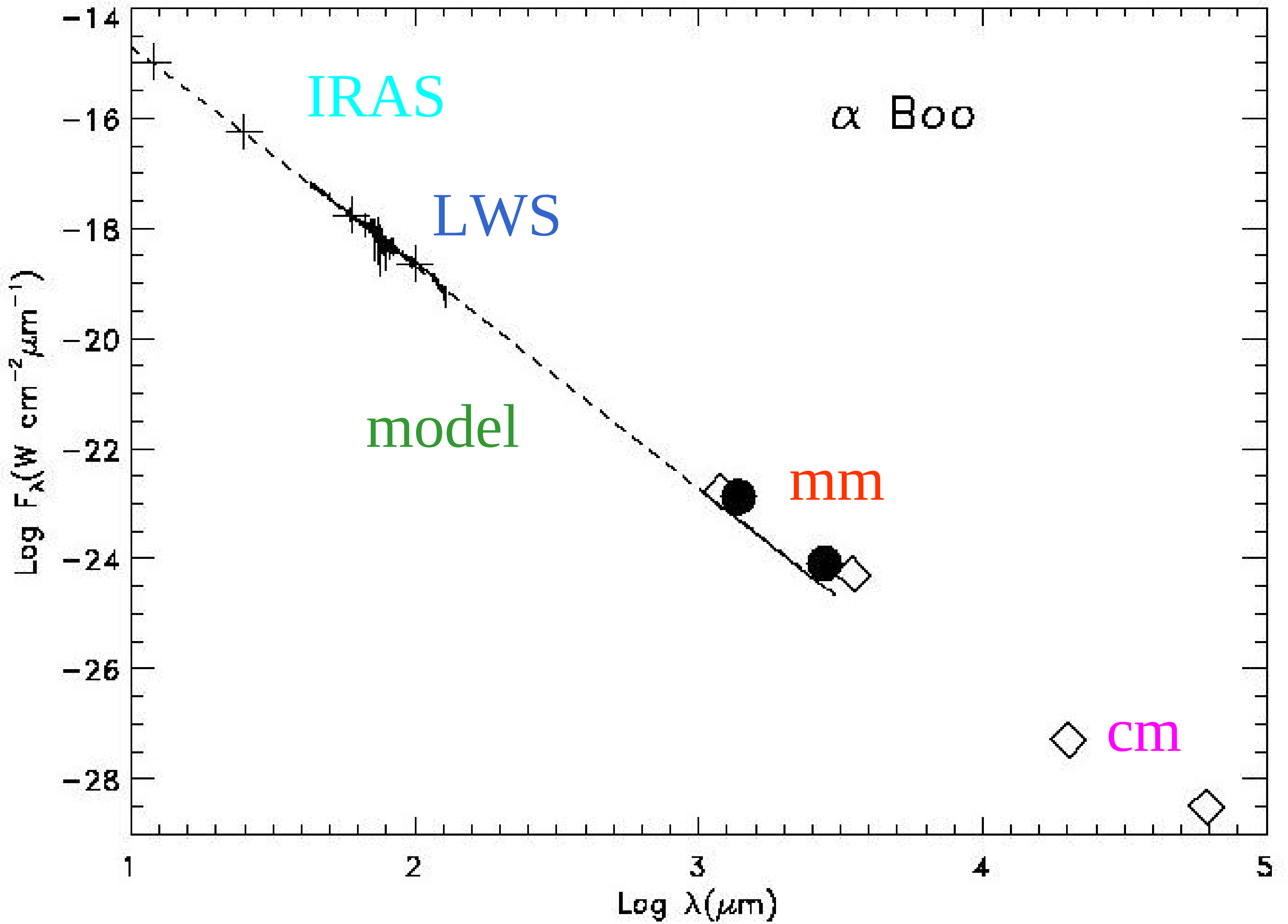
LWS, 2004 model, 1996 PHOT delivery



What NLTE chromospheres do: α Tau's mm-flux densities (A.D. McMurry, Oslo)

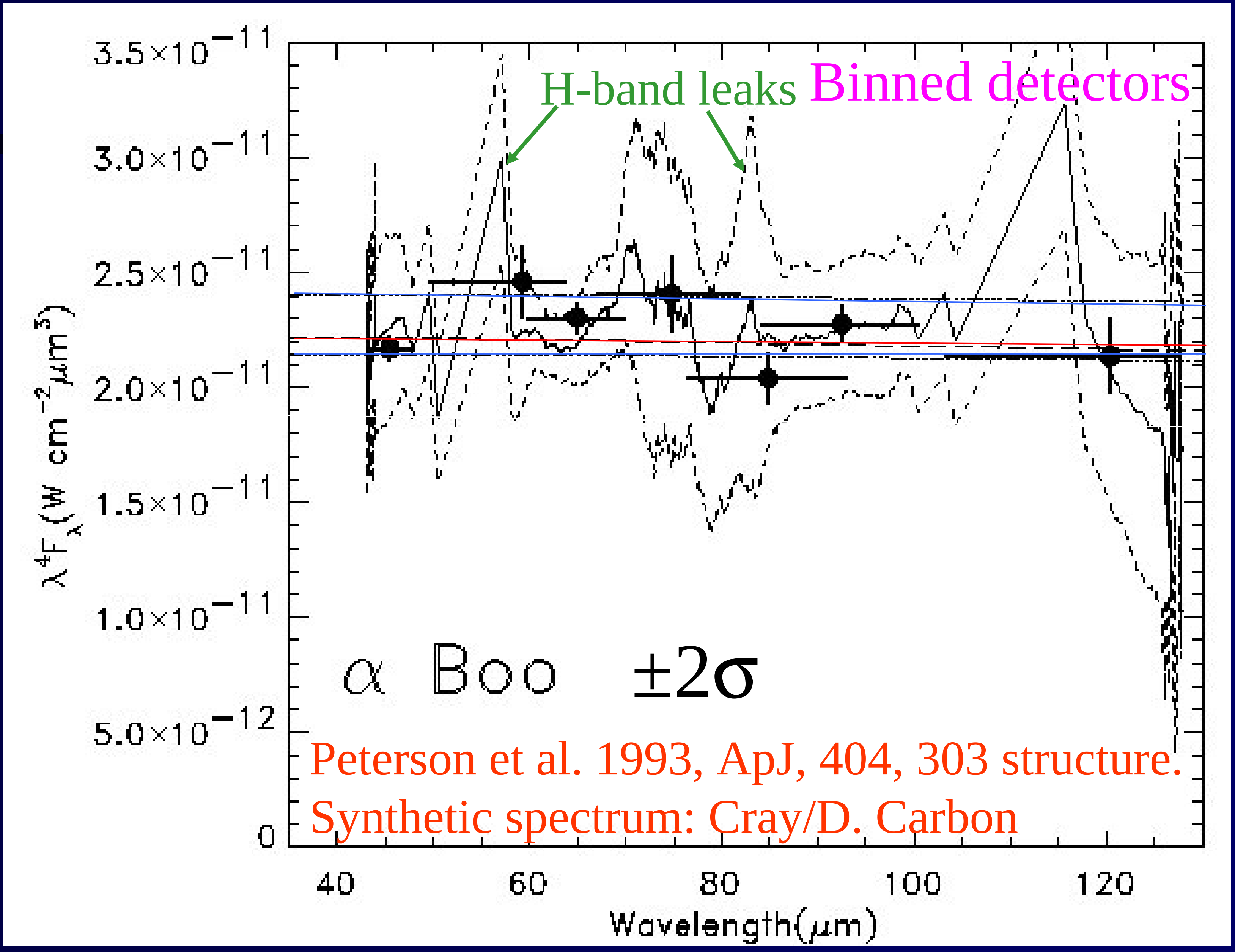


BIMA mm-continuum imaging of stars



a Boo radiates like a photosphere to 125 mm

LWS, 2004 model, 1996 PHOT delivery



More BIMA mm-images obtained

- β Peg M2.5II-III at 1.4 & 2.7 mm
- β And M0III at 1.4 & 2.7 mm
- α Cet M1.5III at 2.7 mm
- γ Dra K5III at 2.7 mm
- α Hya K3II at 2.7 mm
- μ UMa M0III at 2.7 mm

Try to tie planets to stars: Mars, Venus, Jupiter, Uranus, Neptune, MWC349A

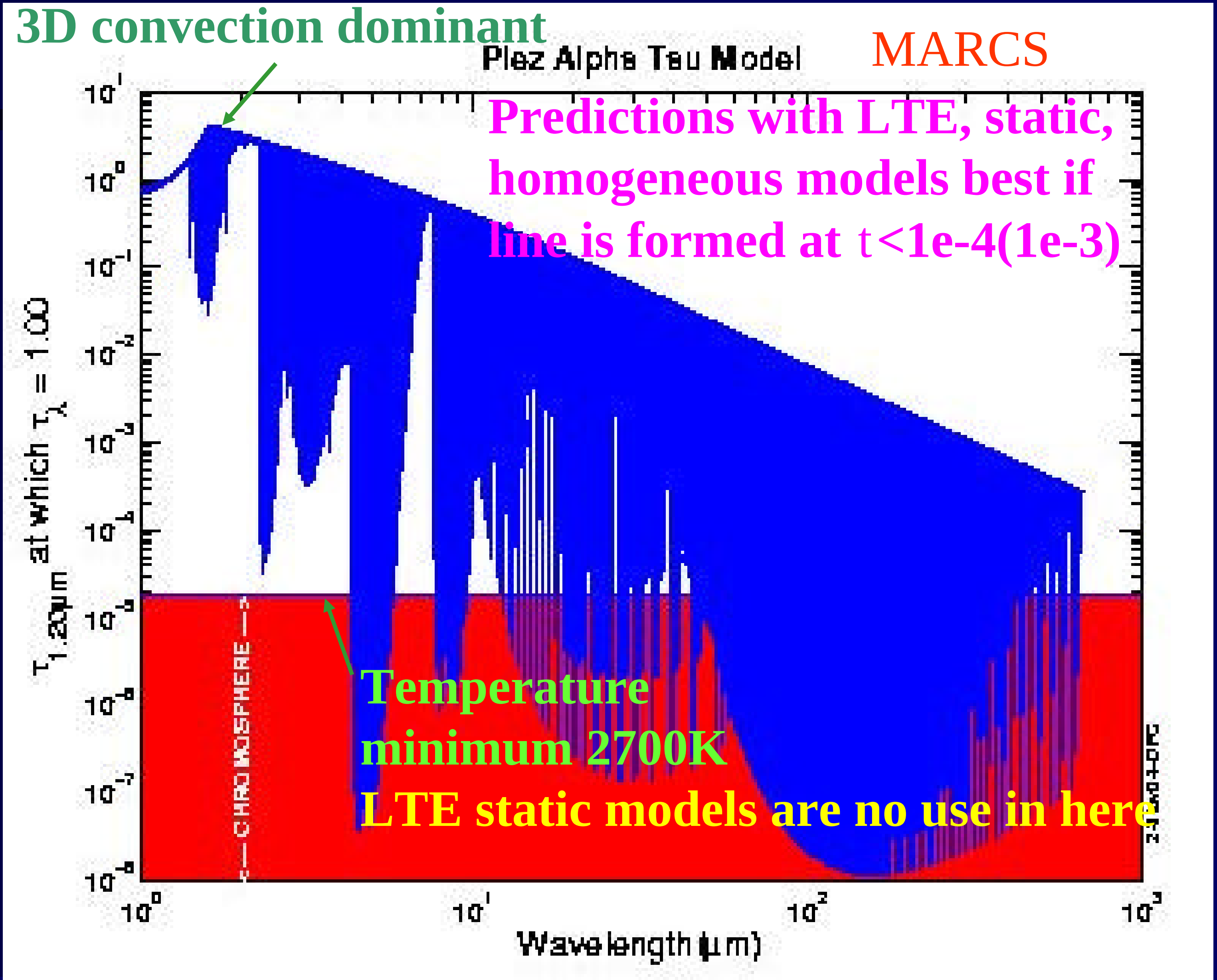
BIMA - SCUBA - CARMA - ALMA

- Sub-mm data are essential on potential calibrators!
- CARMA = 6x10m OVRO + 9x6m BIMA dishes

5-6x more sensitive than BIMA at 3mm (>6 at 1mm)

- CARMA will enable many more normal K/MIIIs to be observed at mm wavelengths
- Remove dependence on Mars, link planets to, & replace by, fiducial stars in mm region
- Upgrade heterogeneous calibrators in the sub-mm
- Lead the way for stellar calibration with ALMA
- Stars that fail as calibrators are “science”
- Jack Welch & Jim Gibson: new calibrations at 1cm & 3mm to ±1% ⇒ unified calibration 1μm-1cm

$\tau_{1.2\mu m}$ for $\tau_{\lambda}=1$ in α Tau: 1-1000μm



Approximate flux densities for the 614 K/M-giant network, for PACS/SPIRE

- Start with Carbon SEDs to 300μm for ISOPHOT
- Extended all 1.2-35μm templates as composites
- These can support PACS broadbands (& spectra)
- Selected monochromatic F_ν at 70,110,170μm
- Extended 300μm-3mm using new Carbon spectra (average of α Tau and α Boo models) as approx'n.
- These can support SPIRE broadband (& spectra)
- Selected monochromatic F_ν at 250, 360, 520μm
- Must replace by integrals over broadband RSRs when the accurate complete RSRs are measured

Utility of 614 K/MIIIs for PACS, SPIRE

BAND	Max. Jy	Min. mJy	Limit mJy	No.
70μm	19	4.2	100	585
110 μm	7.5	1.7	100	241
170 μm	3.1	0.7	100	114
250 μm	1.4	0.32	100	50
360 μm	0.67	0.15	100	19
520 μm	0.31	0.07	100	5

Also 400 mostly faint Spitzer KIIIs & AVs