Max-Planck-Institut für extraterrestrische Physik

MAX-PLANCK-GESELLSCHAFT

MPE

The Asteroid Preparatory Programme for HERSCHEL, ASTRO-F and ALMA

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& HERSCHEL Calibration Steering Group

& ASTRO-F calibration team

Instrument requirements → asteroid selection → asteroid models[1] → instrument calibration

[1]**TPM: characteristics, capabilities, verification, limitation**

Instrument Requirements

- **HIFI:** $>$40 Jy at 150 μm or $>$3 Jy at 600 μm for frequent 5-10 min observations (aperture efficiency calib.); accuracy better 10 %
- **PACS:** 5-15 asteroids (between U&N and stars) for flux calibration; spatial calibration aspects, instrument footprint, leaks, ...; 2-5 sources available at any time; accuracy 5-15 %
- **SPIRE:** $>$20 mJy at 250 μm for non-linearity, flux calibration, as backup for U&N, for monitoring, spatial distortion, footprint characterisation, RSRF checks; accuracy $<$5 %
- **ASTRO-F/FIS:** FIS survey flux calib.; spatial calib. aspects, instrument footprint, leak, colour correction, ...; accuracy 5-15 %
- **ALMA:** Flux calibrators at flux levels below U&N (?), ???

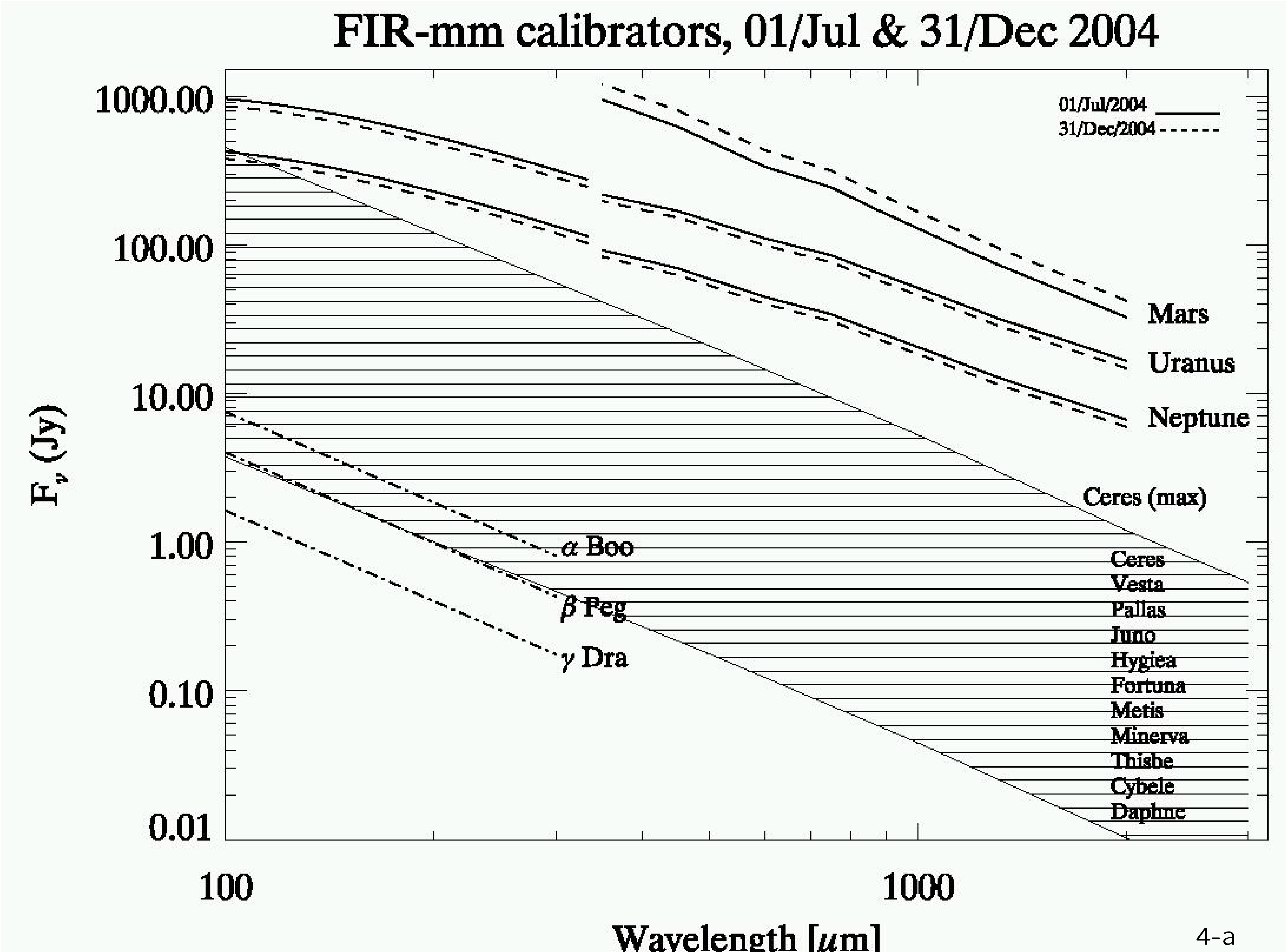
Asteroid Selection Process

- Starting list: all known large main-belt asteroids
- high quality, smooth, low amplitude lightcurves (visible)
- good quality spin vector and shape solutions (lc inversion method)
- large main-belt asteroids with diameters $>$ 100 km
- independent diameter and albedo information (occultation, speckle, HST, flybys, ...)
- multiple thermal observations (N-/Q-band, submm/mm, IRAS/ISO)
- exclusion of binaries, M-types, poor spin vectors, elongated objects
- **New:** availability of "Kaasalainen" shape models (lc inversion complemented by radar, adaptive optics, occultations, HST, ...)

49 Selected Asteroids

- no extreme thermal lightcurve variations expected (up to max. 10-20 % over several hours; typically $< 5\,\%$; many $< 1\,\%$)
- thermal behaviour depends mainly on the observing and illumination geometry, the albedo and the dust regolith; very little influence of the surface material;
- 46 asteroids have IRAS, 15 ISO and 4 MSX observations;
  40 asteroids have N-/Q-band and 15 submm/mm observations
- "Kaasalainen" shape models exist currently for 27 (+12) asteroids

Note: The target list is very inhomogeneous with respect to the physical asteroid description and with respect to the available thermal data. The list will be extended/shortened, depending on new information.



FIR-mm calibrators, 01/Jul & 31/Dec 2004
01/Jul/2004
31/Dec/2004
1000.00
100.00
10.00
1.00
0.10
0.01
100
1000
F_ν (Jy)
Wavelength [μm]
Mars
Uranus
Neptune
Ceres (max)
Ceres
Vesta
Pallas
Juno
Hygiea
Fortuna
Metis
Minerva
Thisbe
Cybele
Daphne
α Boo
β Peg
γ Dra

IRAS Number Statistics

		1-10 Jy	10-100 Jy	>100 Jy
All sky	60 μm	62 260	23 537	3 308
	100 μm	146 241	69 760	27 730
$\|b\| > 5^\circ$	60 μm	16 400	1 189	176
	100 μm	125 566	16 797	456
$b\| > 10^\circ$	60 μm	11 168	852	137
	100 μm	94 353	5 394	294

Thermophysical Modelling (TPM)

- Energy balance between solar insolation, reflected light and thermal emission: $sS_{\odot}r^{-2} = F_r + F_e$
- Size (D_{eff}) and shape (ellipsoid, radar, lc inversion, ...)
- Spin vector and rotational behaviour (+ abs. timing and positioning)
- Thermal behaviour (1-dim heat conduction, thermal inertia, diurnal temperature variation)
- Albedo p_V and direction and wavelength dependent emissivity ϵ_d
- Modelling of surface (regolith, craters, roughness, multiple scattering, ...): beaming model with hemispherical segment craters (f: fraction of the surface covered by craters; ρ: r.m.s. of surface slopes)
- Observing and illumination geometry (distances and angles)
- TPM can be applied to NEOs, MBAs, TNOs, cometary nuclei or planetary satellites

TPM Capabilities and Applications

A. Thermal Lightcurve: Based on shape, rotation, illumination geometry and thermal behaviour

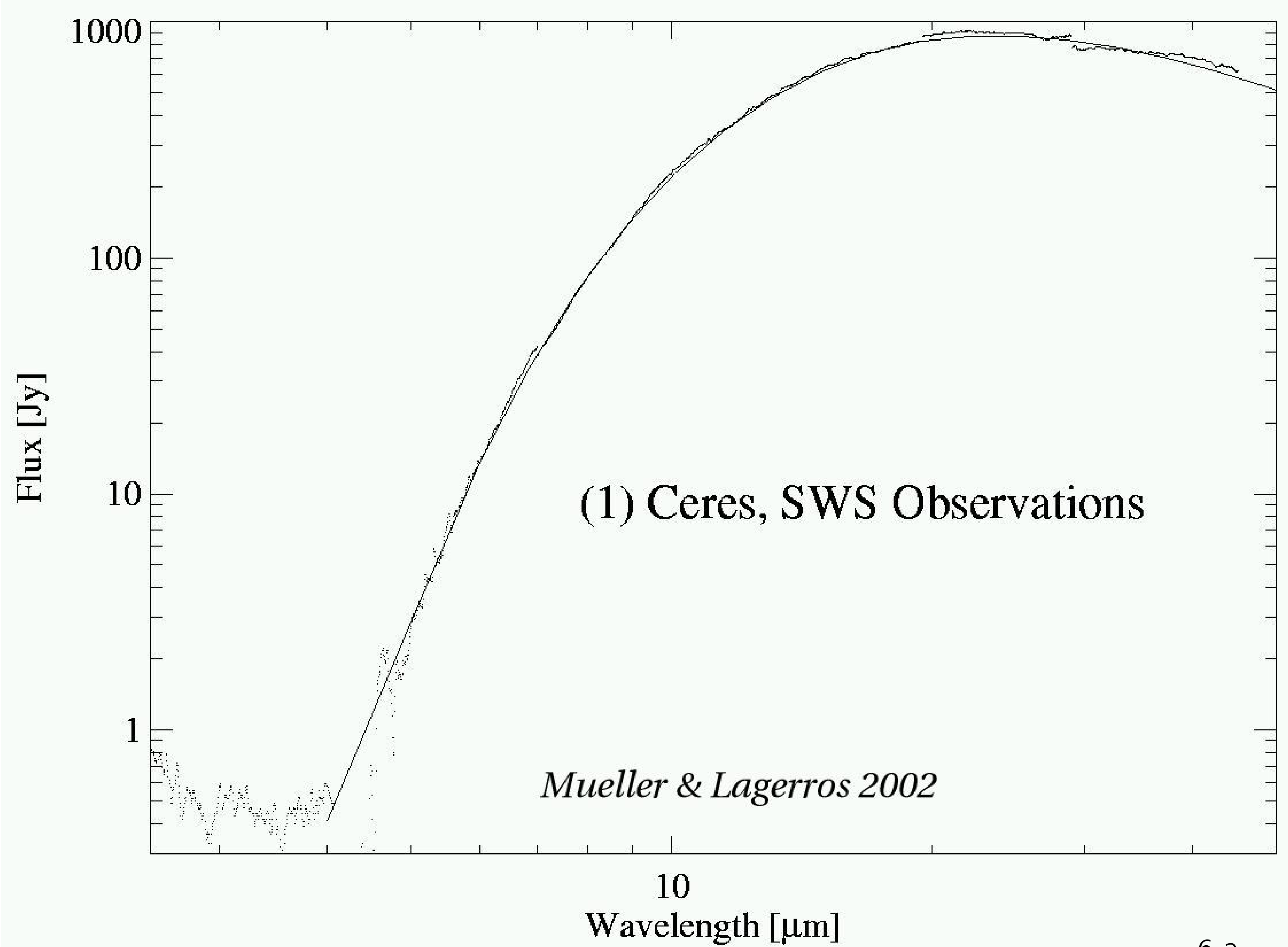
B. Spectral Energy Distribution: TPM predictions between $\approx 5\,\mu m$ and mm-range, absolute accuracy for well-known asteroids: **5-10%**

C. State of Polarization: State of polarization of the thermal emission from MIR to mm wavelengths, degree of linear polarization π_L and orientation angle ψ

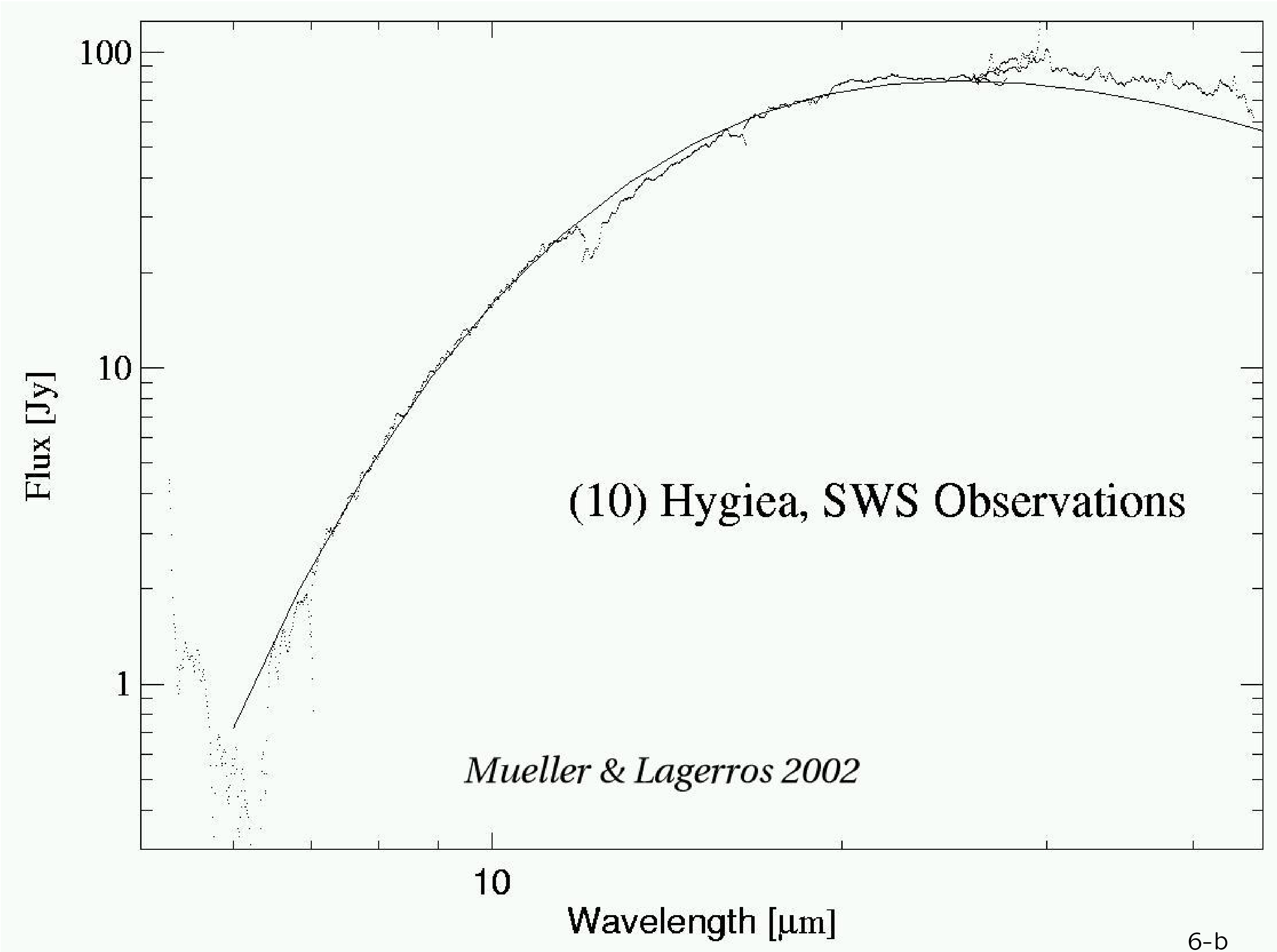
D. Interpretation of Spectra: Identification of mineralogic features, comparison with laboratory spectra of minerals and meteorites, direct implementation of material emissivities, optical constants and refractive index in TPM code

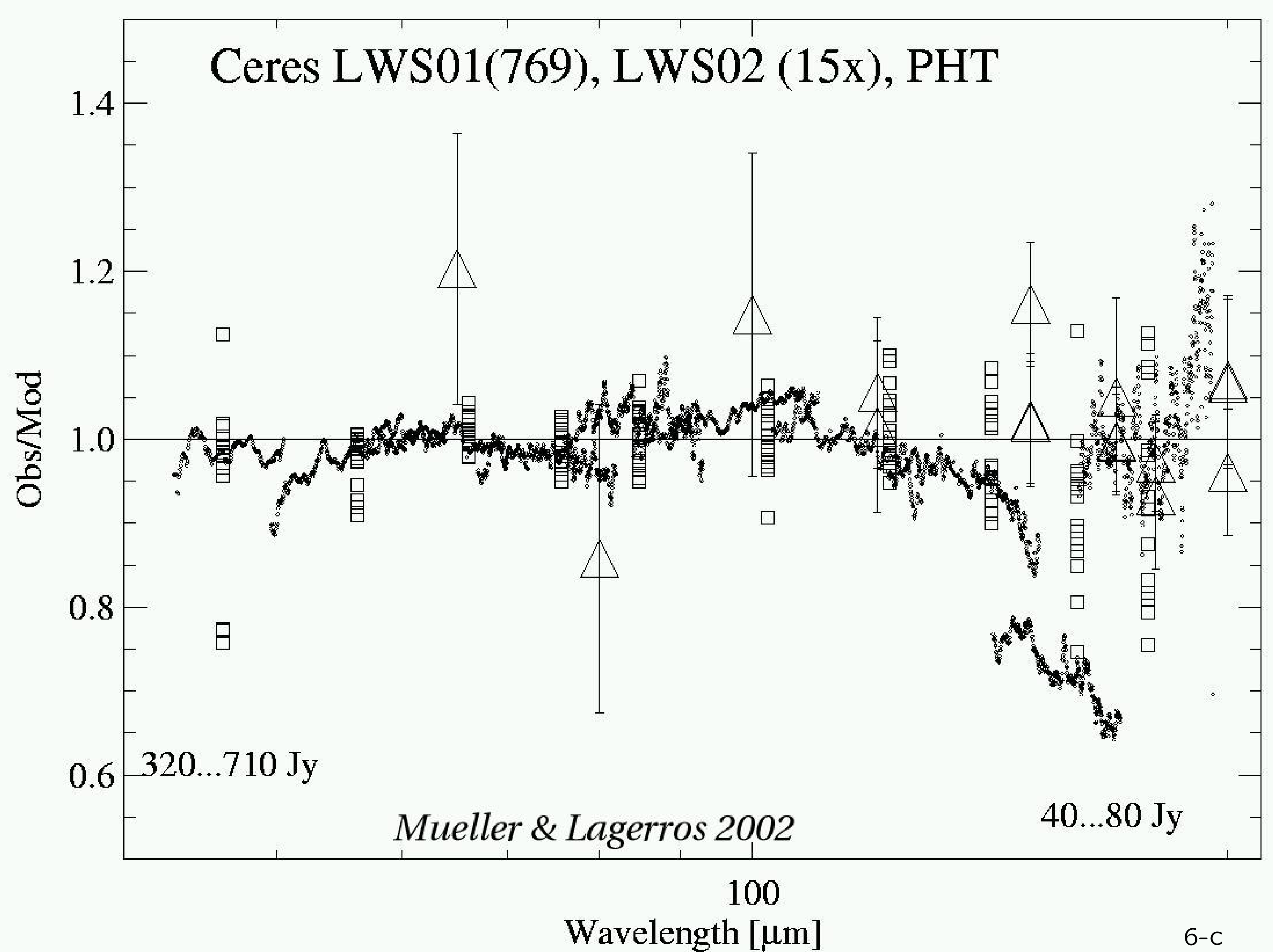
- References:

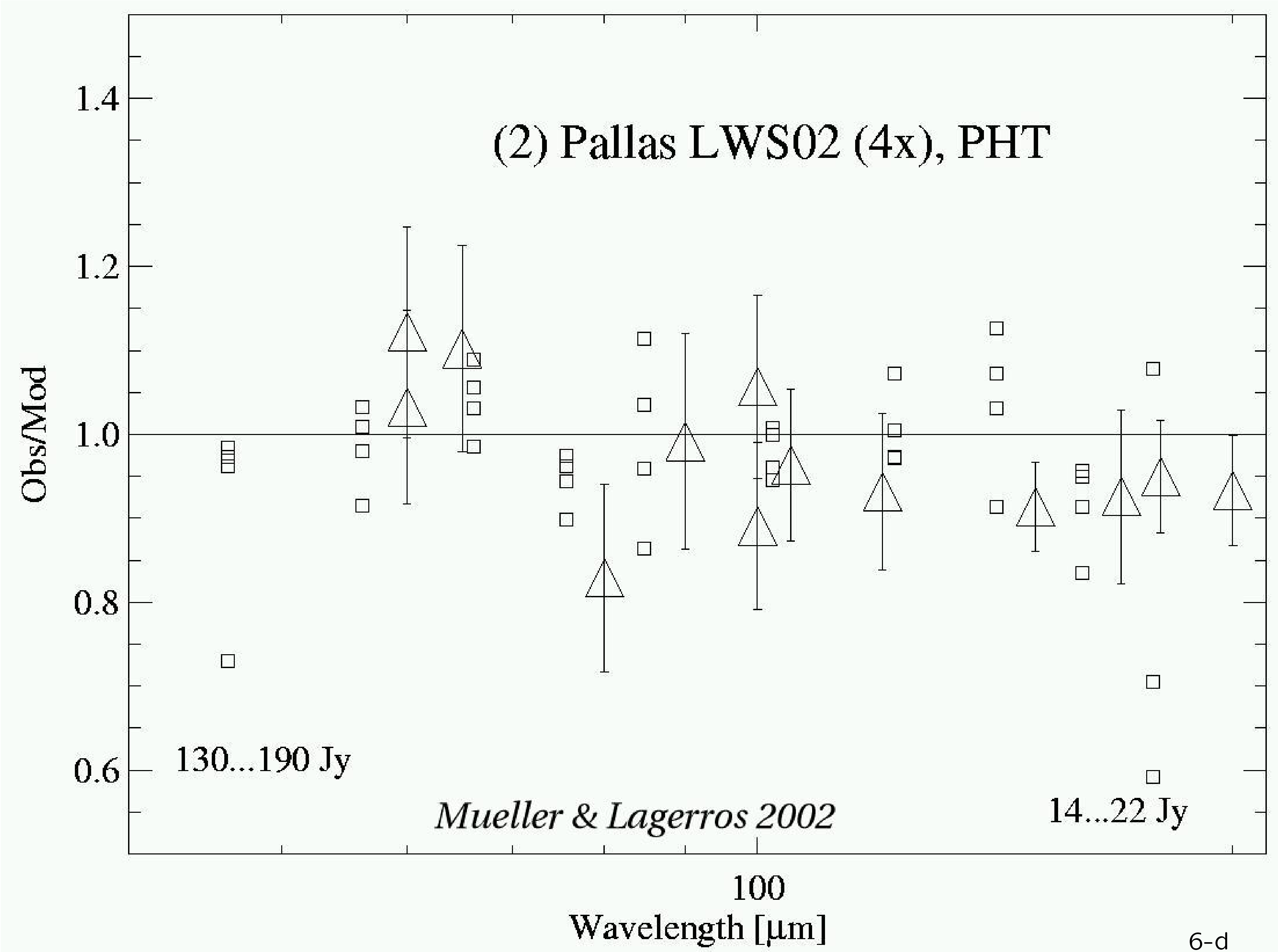
Lagerros, J. S. V. 1996, A&A 310, 1011
Lagerros, J. S. V. 1997, A&A 325, 1226
Lagerros, J. S. V. 1998, A&A 332, 1123



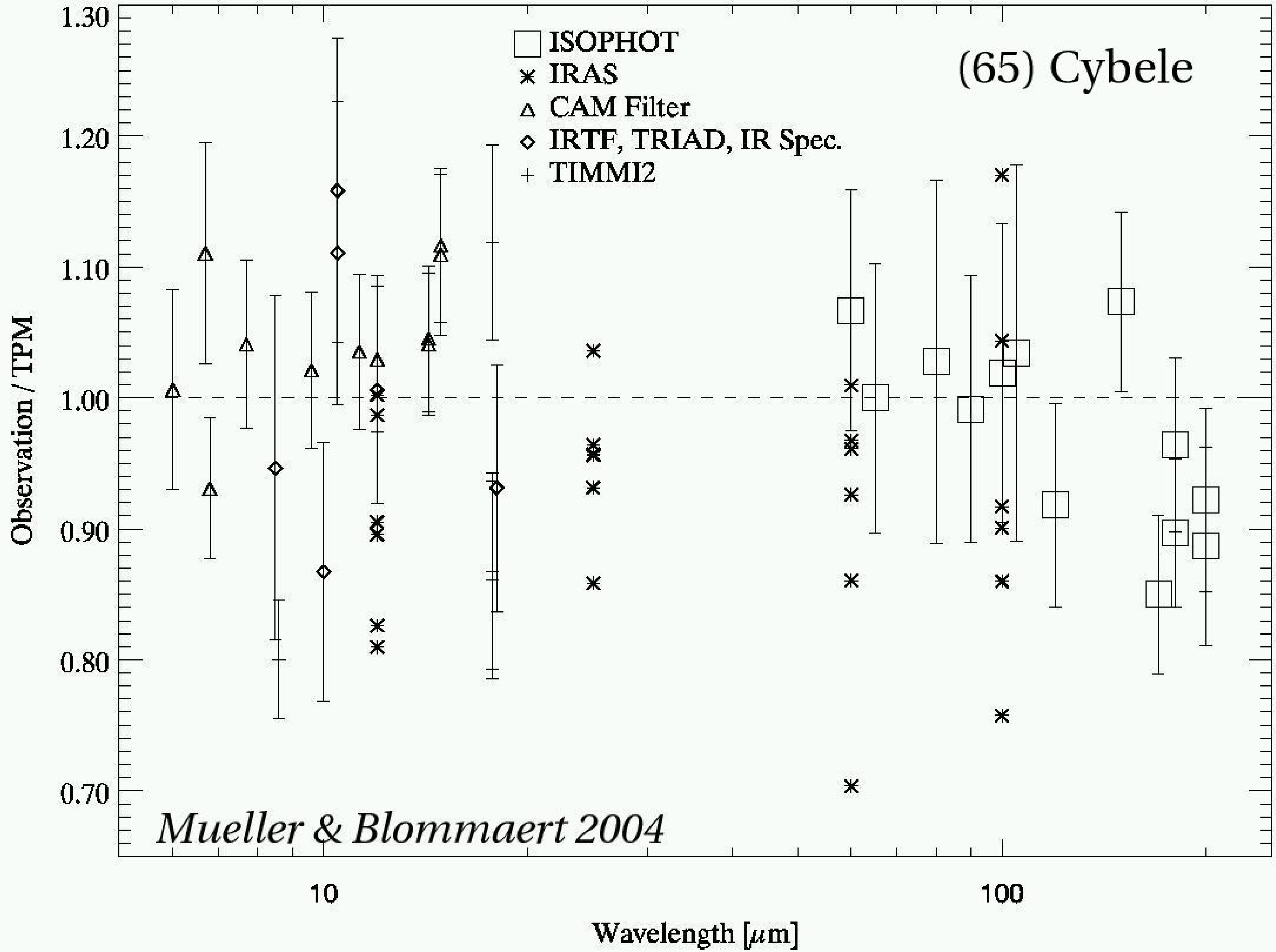
1000
100
10
1
Flux [Jy]
(1) Ceres, SWS Observations
Mueller & Lagerros 2002
10
Wavelength [μm]


100
10
1
Flux [Jy]
(10) Hygiea, SWS Observations
Mueller & Lagerros 2002
10
Wavelength [μm]

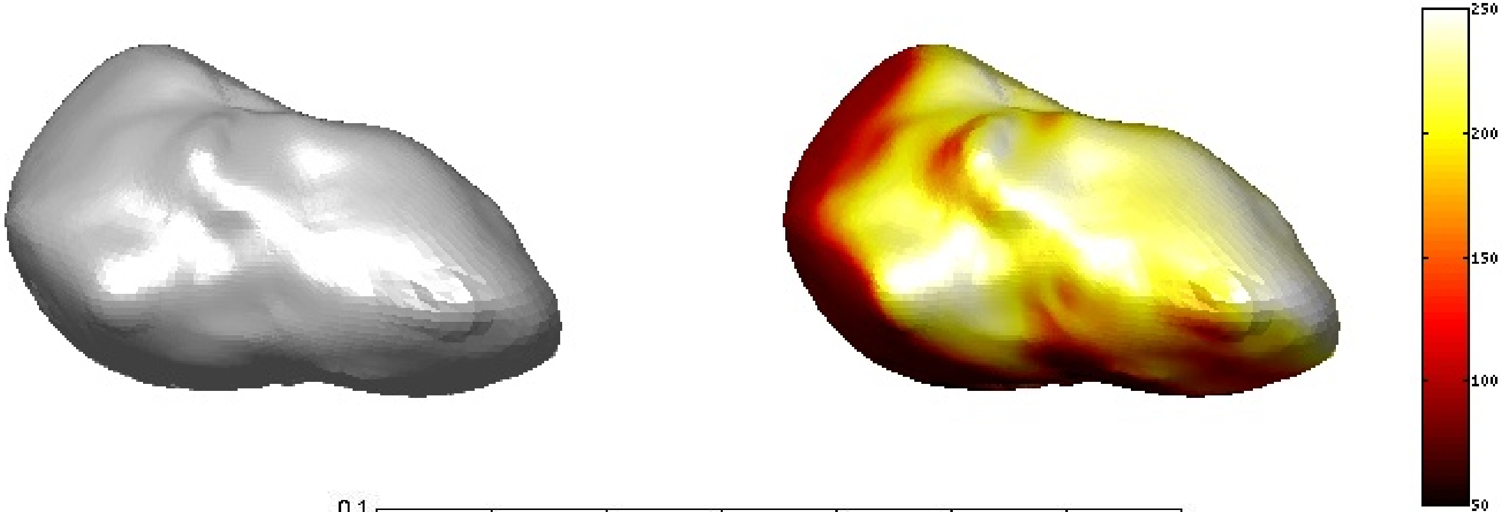

Ceres LWS01(769), LWS02 (15x), PHT
1.4
1.2
1.0
0.8
0.6
Obs/Mod
320...710 Jy
40...80 Jy
Mueller & Lagerros 2002
100
Wavelength [μm]

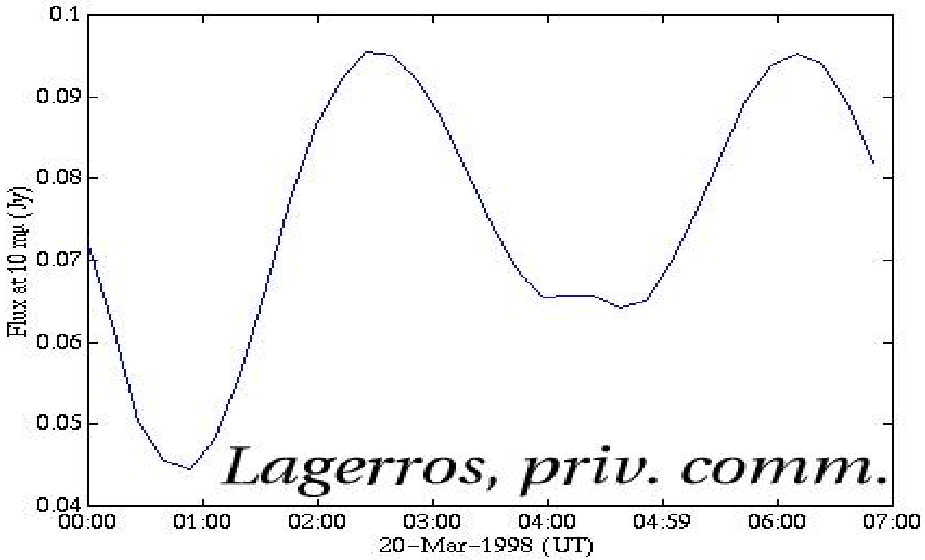


(2) Pallas LWS02 (4x), PHT
Obs/Mod
1.4
1.2
1.0
0.8
0.6
130...190 Jy
Mueller & Lagerros 2002
14...22 Jy
100
Wavelength [μm]


ISOPHOT
IRAS
CAM Filter
IRTF, TRIAD, IR Spec.
TIMMI2
(65) Cybele
Observation / TPM
1.30
1.20
1.10
1.00
0.90
0.80
0.70
Mueller & Blommaert 2004
10
100
Wavelength [μm]

Thermophysical Model of 951 Gaspra





Asteroids as IR Standards

- Individual TPMs for all 49 asteroids
- "Kaasalainen" or ellipsoidal shape + spin vector solutions
- thermal behaviour description derived from ISO data on several large main-belt asteroids (Müller et al. 1999)
- Effective size and albedo values derived from available thermal observtions (based on the individual shape/SV model)
- Wavelength-dependent emissivity (Müller & Lagerros 1998)
- TPM in well-tested regime: main-belt temperatures; mid-IR to mm wavelengths; phase angles $< 30^\circ$; large objects with regolith, ...
- Expected absolute accuracy, monochromatic, one epoch: 5-10(15) % for primaries, 5-20 % for secondaries
- **References:** Müller & Lagerros 1998, A&A 338, 340; Müller et al. 1999, ESA SP-427, 141; Müller & Lagerros 2002, A&A 381, 324; Müller & Lagerros 2002, ESA SP-481, 157

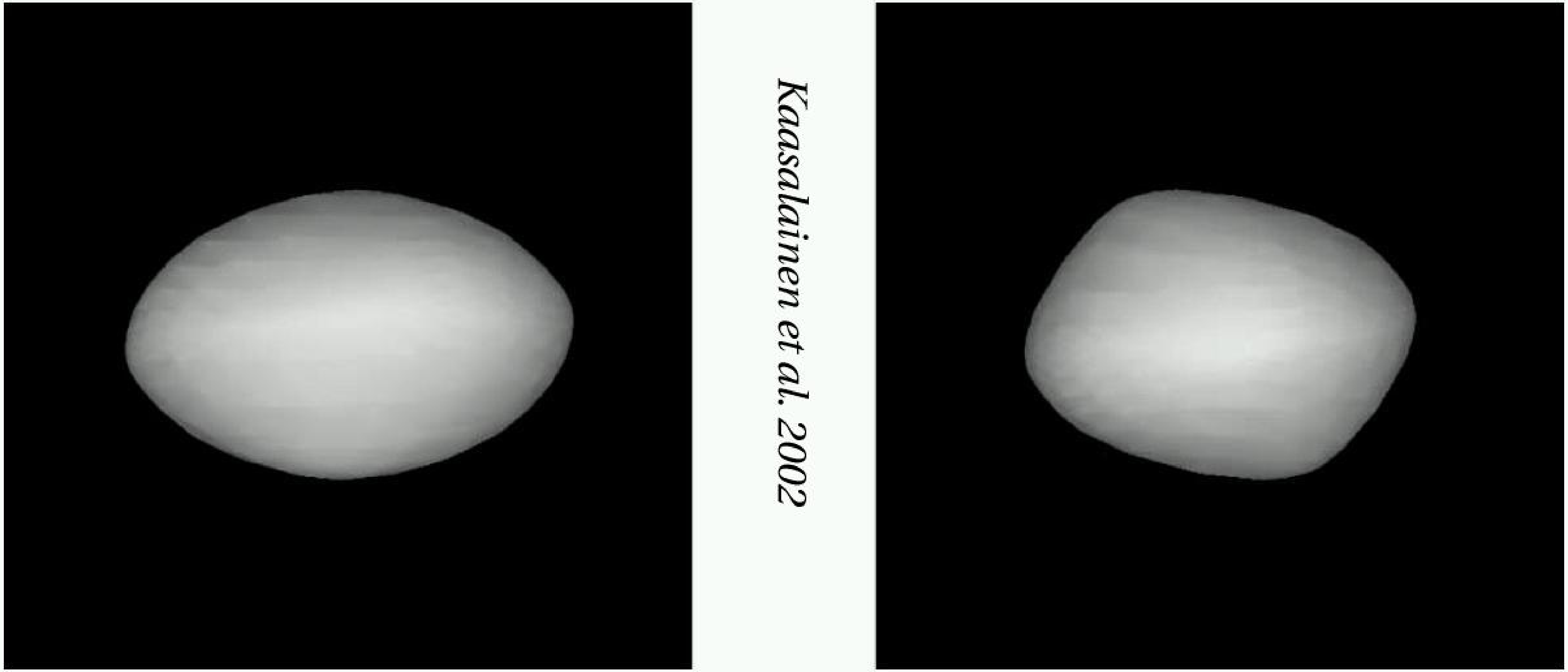


FIG. 1. The shape model of 3 Juno, shown at equatorial viewing/illuminaton geometry, with rotational phases 90° apart.

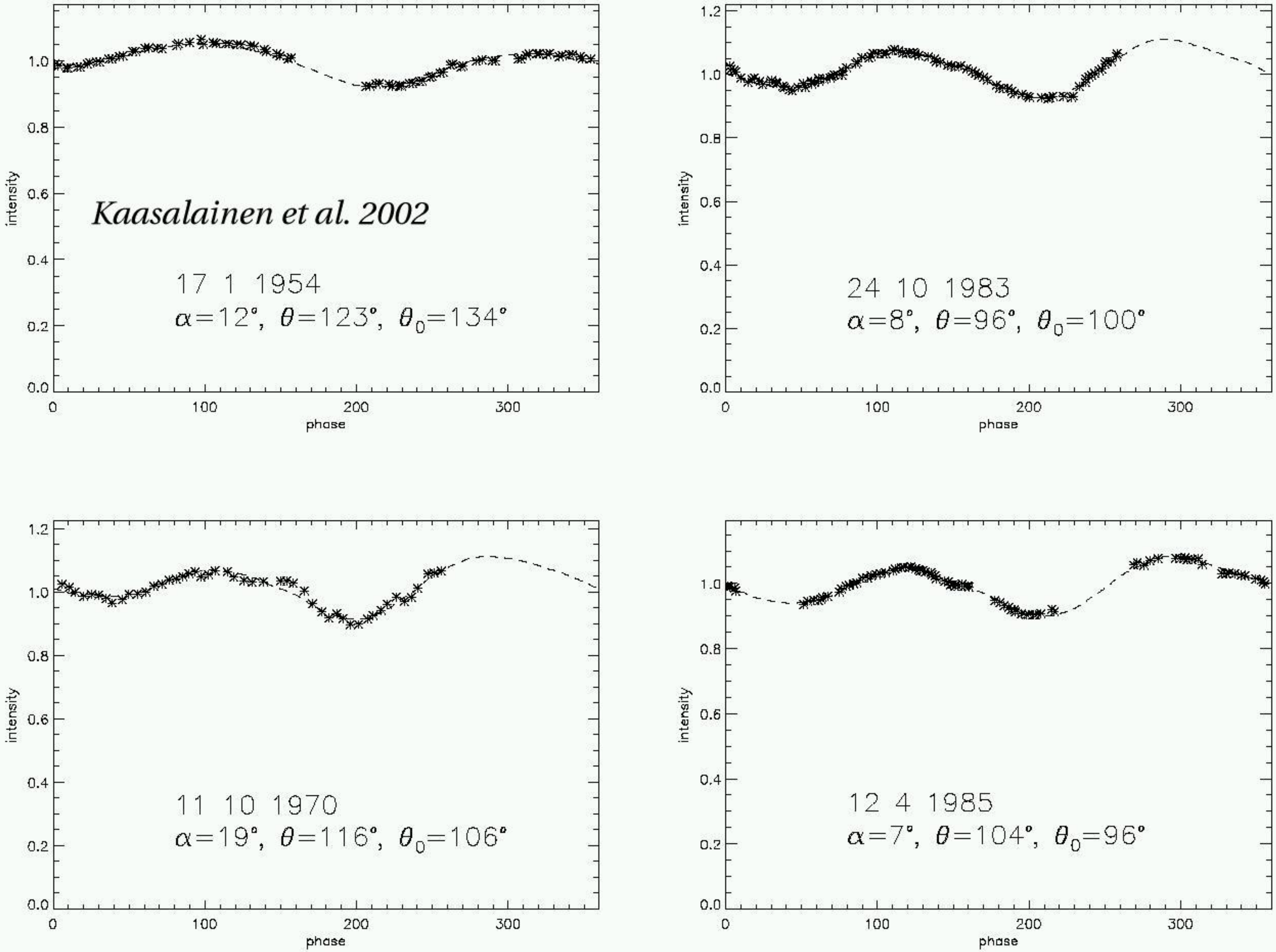
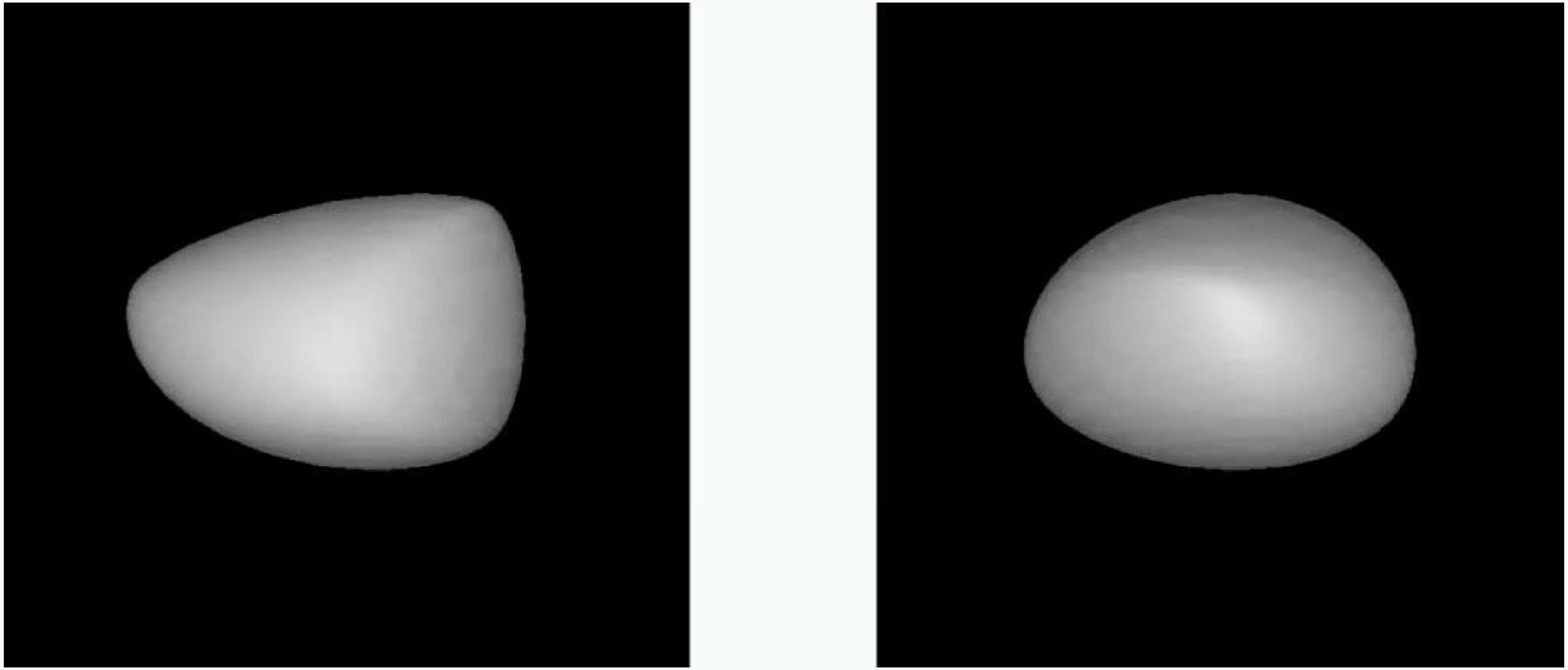
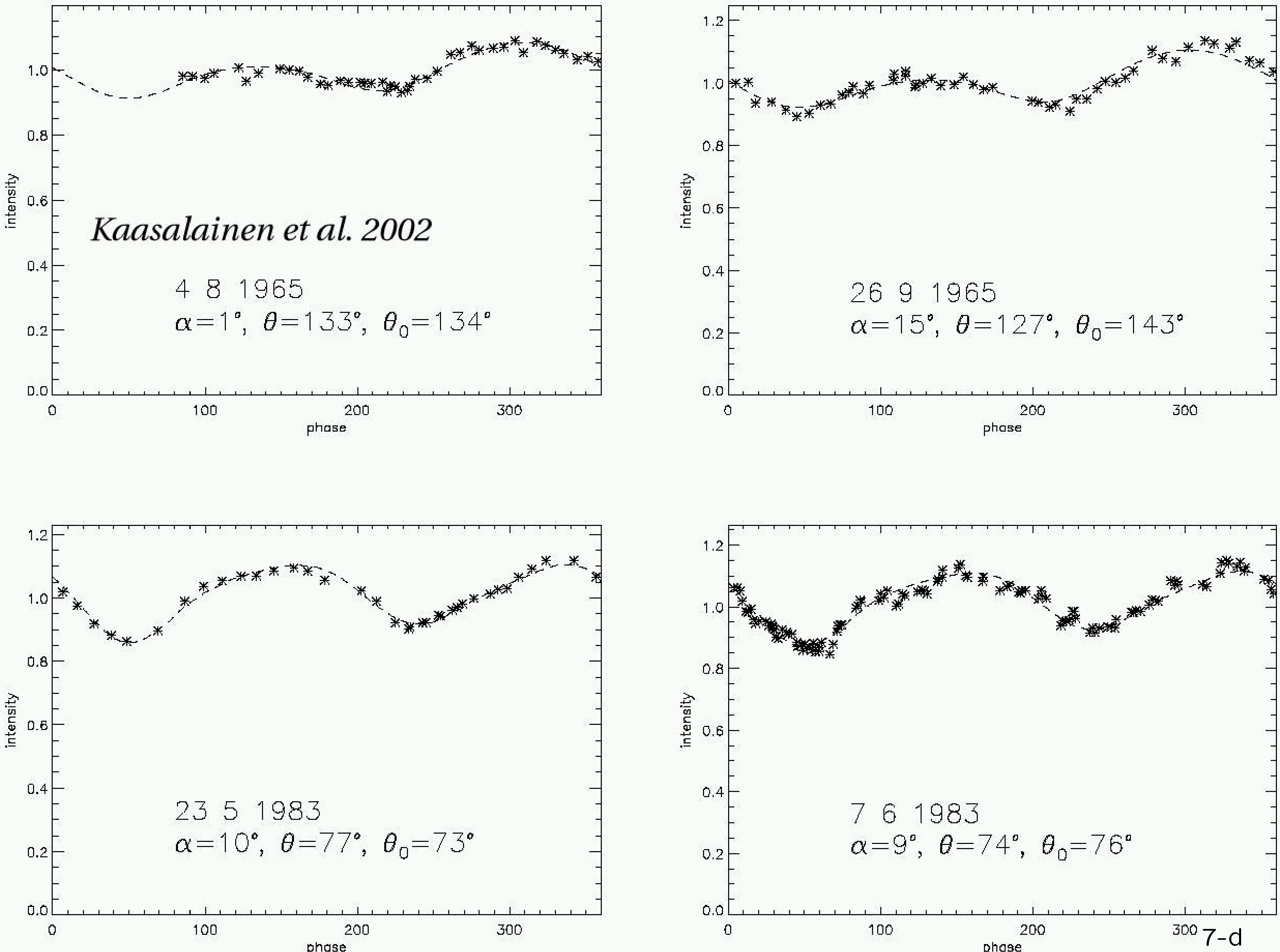


FIG. 2. Four lightcurves (asterisks) and the corresponding fits (dashed lines) for 3 Juno. The rotational phase is given in degrees, and the brightness in units of relative intensity. The aspect angle of the Earth (measured from the North pole) is given by θ, and that of the Sun by θ_0. The solar phase angle is given by α.



Kaasalainen et al. 2002

FIG. 31. The shape model of 354 Eleonora.


Kaasalainen et al. 2002
4 8 1965
α=1°, θ=133°, θ0=134°
26 9 1965
α=15°, θ=127°, θ0=143°
23 5 1983
α=10°, θ=77°, θ0=73°
7 6 1983
α=9°, θ=74°, θ0=76°
intensity
phase

References "Kaasalainen shape model"

- Optimisation methods for asteroid lightcurve inversion:
  - Kaasalainen & Torppa 2001, Icarus 153, 24:
    Shape determination
  - Kaasalainen, Torppa & Muinonen 2001, Icarus 153, 37:
    The complete inverse problem
- Models of individual asteroids:
  - Kaasalainen et al. 2002, Icarus 159, 369: **20 Asteroids**
  - Torppa et al. 2003, Icarus 164, 346: **30 Asteroids**
  - Michalowski et al. 2004, A&A 416, 353: **3 Asteroids**
- **http://www.rni.helsinki.fi/~mjk/**

Asteroid Parameter Space for HERSCHEL

- visibility periods: twice a year, each time about 10±2 weeks
- maximum apparent diameter: $< 0.7''$ (Ceres)
- Min./max. distance from Sun/Earth: 2.0...3.5 AU/1.4...4.0 AU
- Apparent movements (during visibility periods): 0...80$''$/hour

Flux densities [Jy] during visibility periods in 2007...2010:

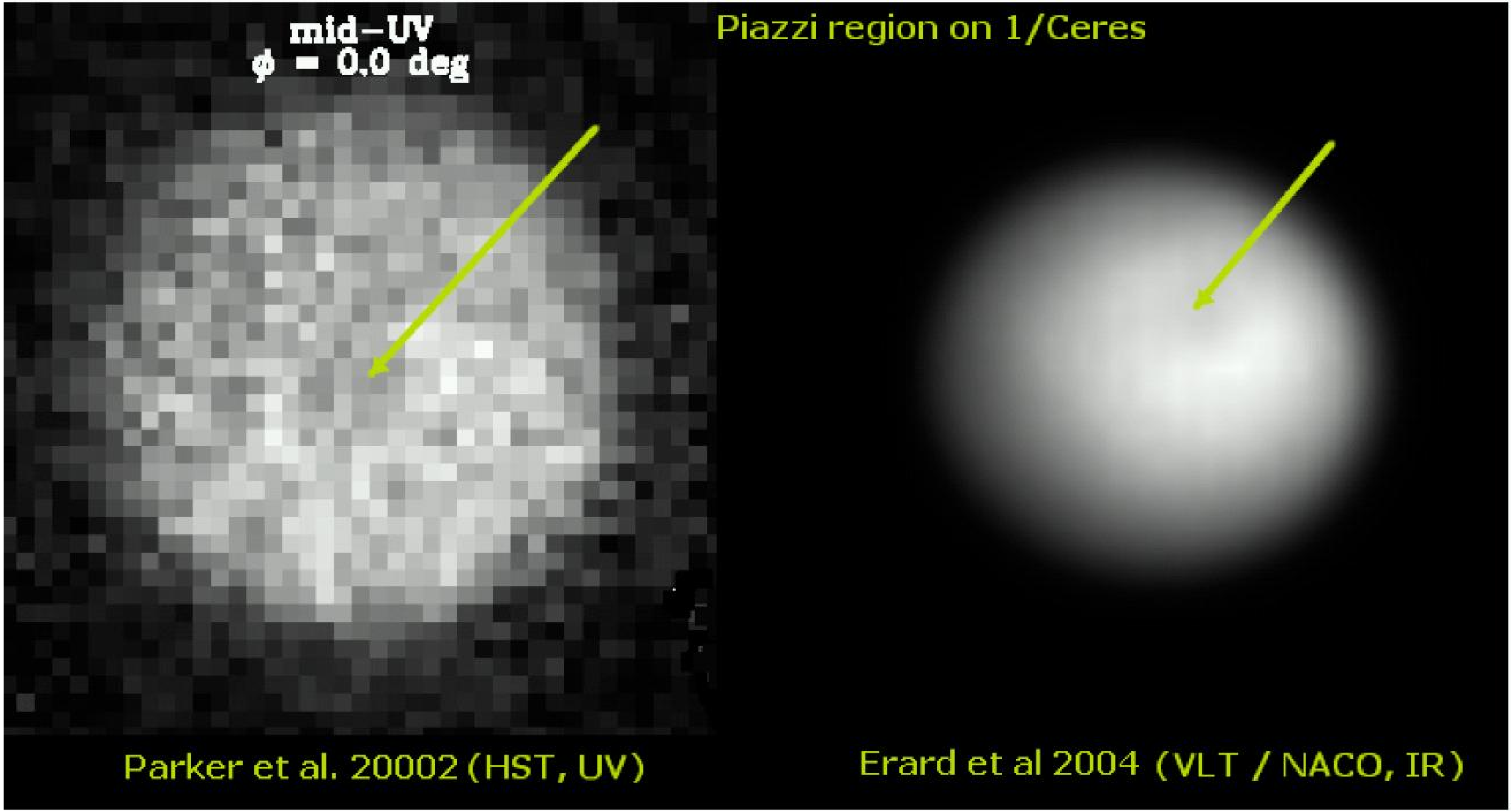
	60 μm		100 μm		200 μm		500 μm	
Ast.	min	max	min	max	min	max	min	max
1	200	750	90	340	25	100	5	20
2	40	390	18	170	5	50	1	10
3	8	200	4	90	1	26	0.2	4.5
4	75	400	35	180	10	50	2	10
10	20	70	10	30	3	10	0.6	1.7
65	8	33	3.5	15	1	5	0.2	0.8
532	8	60	3.5	28	1	8	0.2	1.5

Ongoing Projects

- Filling and maintance of the observation data base (currently 1840 entries for the 49 asteroids): Analysis of recent observations, search for published data, recalibration of old data, identification of missing and/or critical observational data
- Implementation of Kaasalainen shape models and extensive tests with available observations
- Determination of radiometric solutions for size and albedo
- Documentation of the TPM input parameters
- Proposal writing for mid-IR/submm/mm observations
- Iterations on the asteroid list, establishment of individual TPMs for the selected calibrators
- Support of Spitzer IRS and MIPS calibration

Open Points

- Tool for HERSCHEL-centric position calculation (implementation of preliminary orbit file into the JPL HORIZON system?)
- More submm-data are required
- Clean calibration of asteroid data (against stars and planets)
- Agreement on calibrators for asteroid observations in the mid-IR and the submm/mm range
- ...


mid-UV
ϕ = 0.0 deg
Piazzi region on 1/Ceres
Parker et al. 20002 (HST, UV)
Erard et al 2004 (VLT / NACO, IR)

Appendix

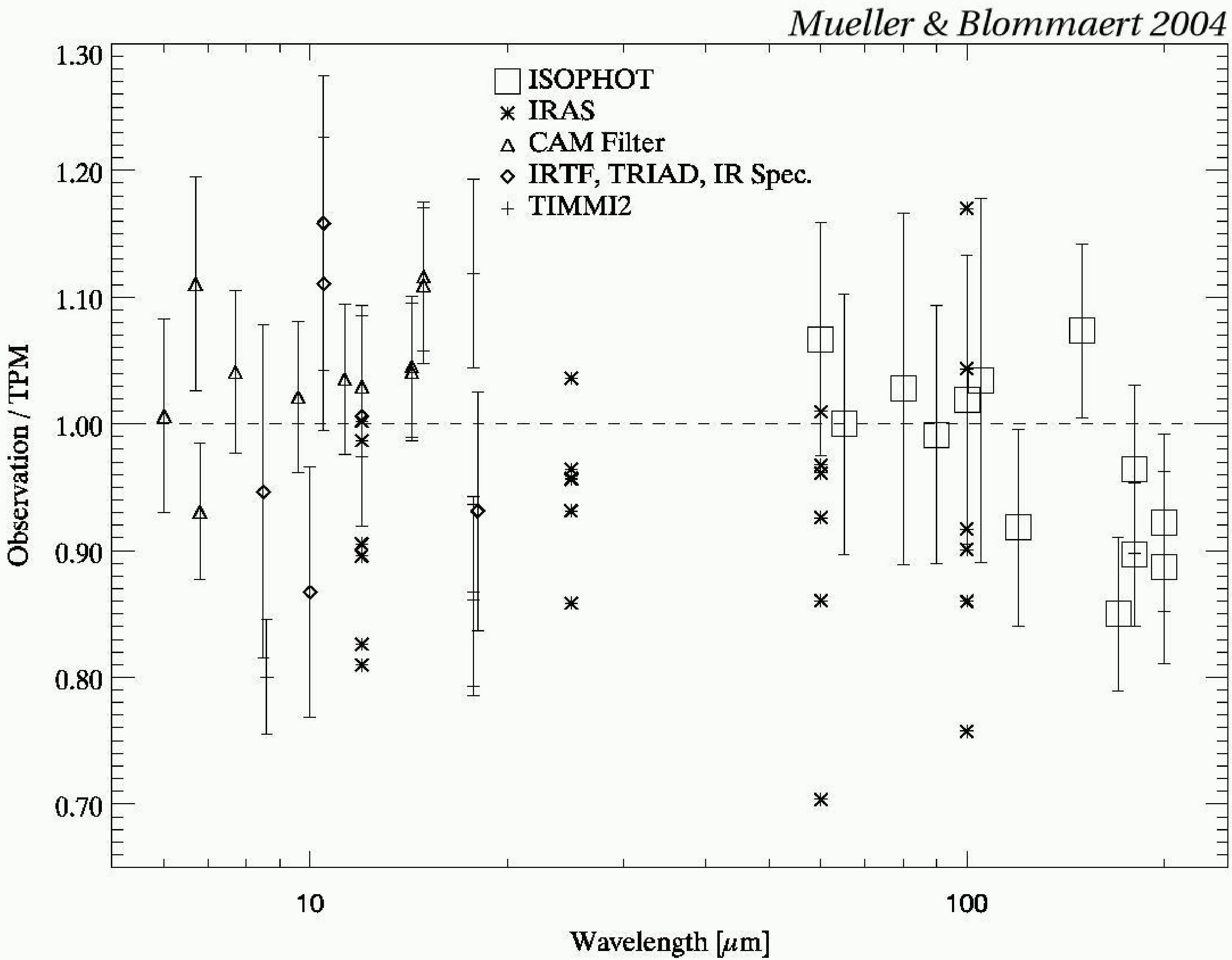
No.	SV qual.	shape	occ.	LC qual.	IRAS	ISO	MSX	other therm. obs.	Remarks
1	I	y	5	3	y	y	n	nq/NQ/submm mm	primary calibrator, HST, adaptive optics, extensive thermal observations, ...
2	I	y	5	4	y	y	n	nq/NQ/mm, CSO	ISOPHOT calibrator
3	I	y	5	4	y	y	n	nq/NQ	ISOPHOT calibrator
4	I	y	4	4	y	y	n	nq/NQ/submm/ mm/radar, ATCA	ISOPHOT calibrator; optical shape model by HST; adaptive optics; thermal LC
5	I	h	-	4	y	n	n	nq/radar	
6	I	h	3	4	y	y	n	submm/radar	
7	I	y	1	4	y	n	n	nq/submm/radar	
9	I	y	4	4	n	y	y	nq/radar, ATCA	
10	I	h	1	4	y	y	n	nq/NQ/mm	ISOPHOT calibrator, HST, speckle
12	II	y	1	4	y	n	n	nq/radar	
17	I	y	-	4	y	n	n	nq	IRAS diam. 90.04 km
18	I	h	5	4	y	n	n	nq/submm/radar	
19	I	y	4	4	y	n	n	nq/radar	
20	I	h	-	4	y	y	n	nq/radar	
21	I	h	1	4	y	n	n	nq/radar	IRAS diam. 95.76 km; M-type, radar size/shape/SV
23	I	h	-	4	y	n	y	nq	
24	I	h	-	3	n	n	n		
28	I	h	-	4	y	n	y	nq	
29	I	y	-	4	y	n	n	nq, CSO	
31	I	h	-	4	y	n	n		
37	I	h	2	4	y	n	n	nq	
40	I	y	-	4	y	n	n	nq	
41	I	y	1	4	y	n	n	nq/radar	
42	I	n	1	3	y	n	n	nq, CSO	

bold face:
Kaasalainen shape model

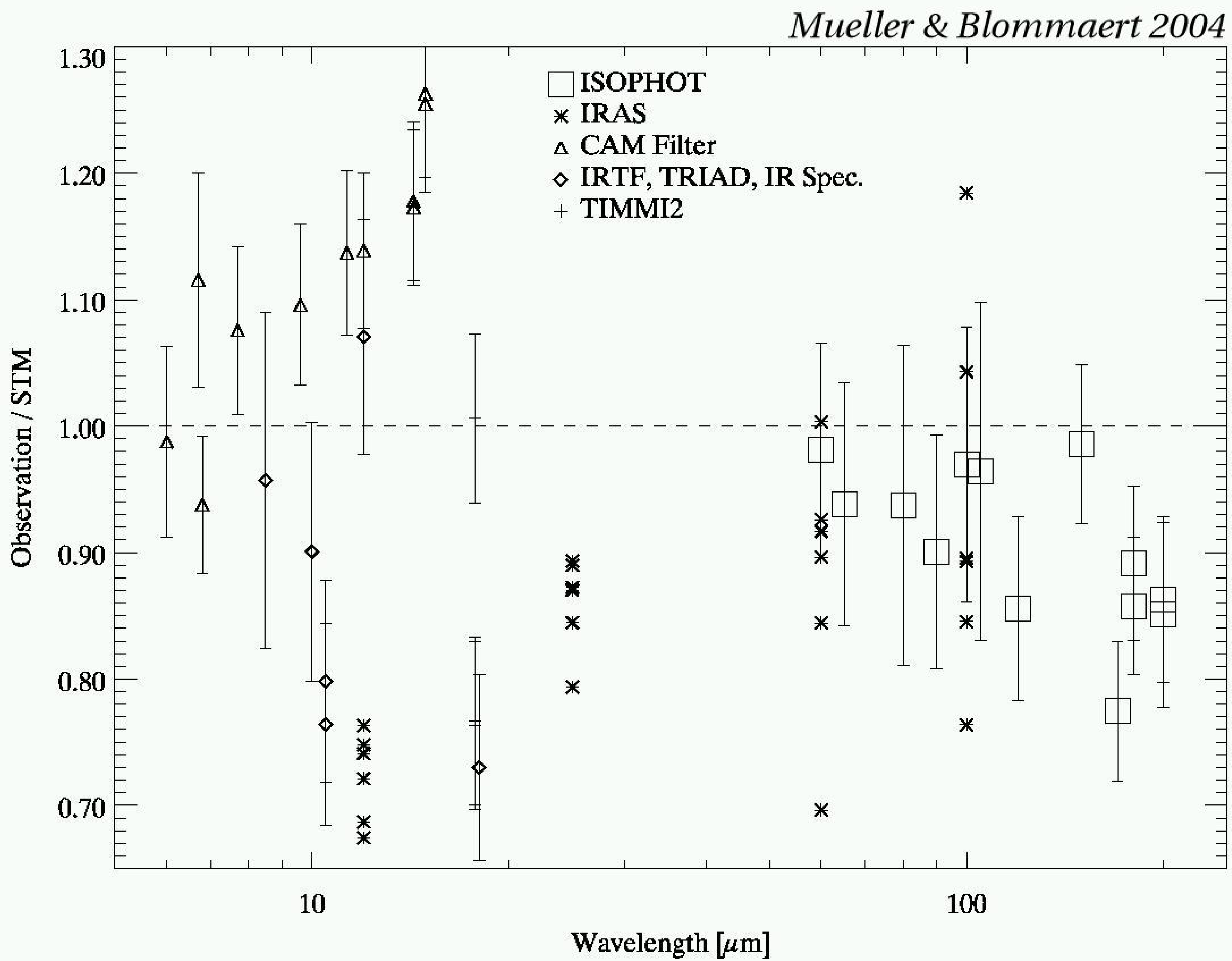
No.	SV qual.	shape	occ.	LC qual.	IRAS	ISO	MSX	other therm. obs.	Remarks
47	I	y	4	4	y	n	n	nq	
48	I	n	2	3	y	n	n		
51	I	n	5	4	y	n	n	nq	
52	I	y	2	4	y	y	n	nq, CSO	
54	II	n	-	4	y	y	n	nq/NQ	ISOPHOT calibrator
56	II	h	-	2	y	y	n	nq	
65	II	y	4	4	y	y	n	NQ, CSO	ISOPHOT calibrator
69	I	y	-	4	y	n	n		
85	I	h	4	4	y	n	n	nq, CSO	
88	I	y	5	4	y	n	n		
93	II	y	4	4	y	n	y		
94	I	y	-	3	y	n	n	nq	
196	II	y	-	4	y	n	n	nq	
241	I	y	-	3	y	n	n	nq	
313	II	y	1	2	y	y	n	nq/NQ/mm	IRAS diam. 96.34 km; ISOPHOT calibrator
354	I	y	-	4	y	n	n	nq	
360	I	y	-	4	y	n	n	nq	
423	I	h	1	2	y	n	n		
451	II	y	-	4	y	n	n	nq	
471	II	h	4	3	y	n	n	nq	
505	I	y	-	3	n	n	n		
511	I	y	1	4	y	y	n	nq	
532	I	y	3	4	y	y	n	nq/NQ/mm/radar	ISOPHOT calibrator
704	I	y	4	4	y	n	n	nq	
776	I	y	-	2	y	n	n		

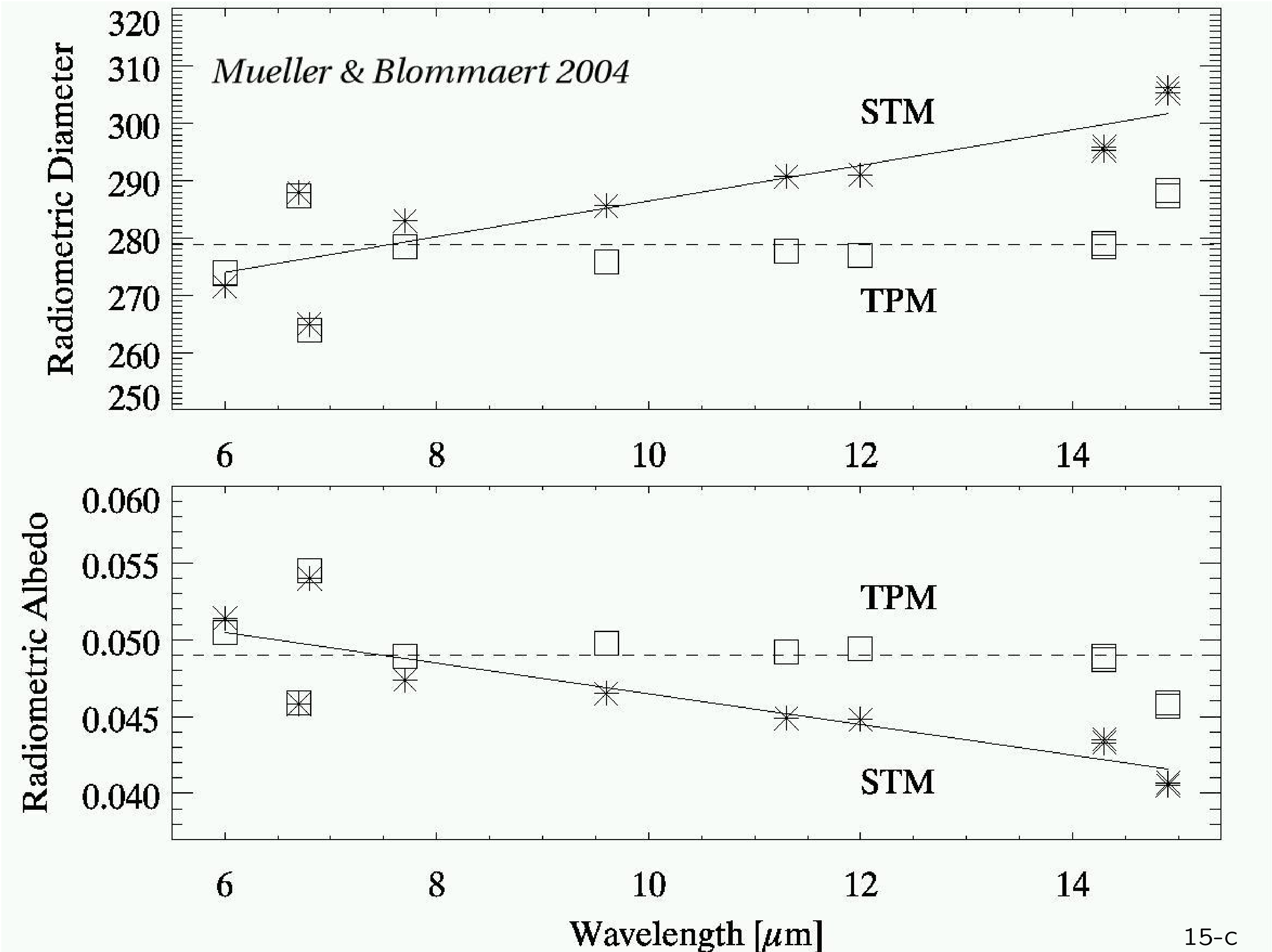
Observational Programmes

- **JCMT-SCUBA:** 24-27 Nov 2003, D. Hughes
- **CSO—SHARC-II:** 8-11 Oct 2003, D. Teyssier, 2, 29, 42, 52, 65, 85
- **IRAM–30m/PdB:** accepted for spring 2004, but not executed, T. Müller
- **SUBARU-COMICS, UKIRT-Michelle:** Several campaigns, presentation by T. Ootsubo
- **Others:**
  — BLAST: D. Hughes;
  — VLT, Jan 2004, Erard et al.: Ceres
  — ASTE: asteroid observations at sub-mm, planned;
  — ESO-3.6/TIMMI2: ongoing, T. Müller: Cybele
  — ATCA: executed in Oct 2004: Vesta, Metis



Mueller & Blommaert 2004
ISOPHOT
IRAS
CAM Filter
IRTF, TRIAD, IR Spec.
TIMMI2
Observation / TPM
1.30
1.20
1.10
1.00
0.90
0.80
0.70
10
100
Wavelength [μm]


Mueller & Blommaert 2004
ISOPHOT
IRAS
CAM Filter
IRTF, TRIAD, IR Spec.
TIMMI2
Observation / STM
1.30
1.20
1.10
1.00
0.90
0.80
0.70
10
100
Wavelength [μm]


Mueller & Blommaert 2004
Radiometric Diameter
STM
TPM
320
310
300
290
280
270
260
250
6
8
10
12
14
Radiometric Albedo
TPM
STM
0.060
0.055
0.050
0.045
0.040
6
8
10
12
14
Wavelength [μm]