Herschel Calibration Workshop, ESAC/Spain:
Asteroids as Prime Calibrators

T. Müller, MPE, Mar 25, 2013

Idea:

to establish 3-5 asteroids as truly primary calibrators based on object properties derived from flyby and/or in-situ measurements.

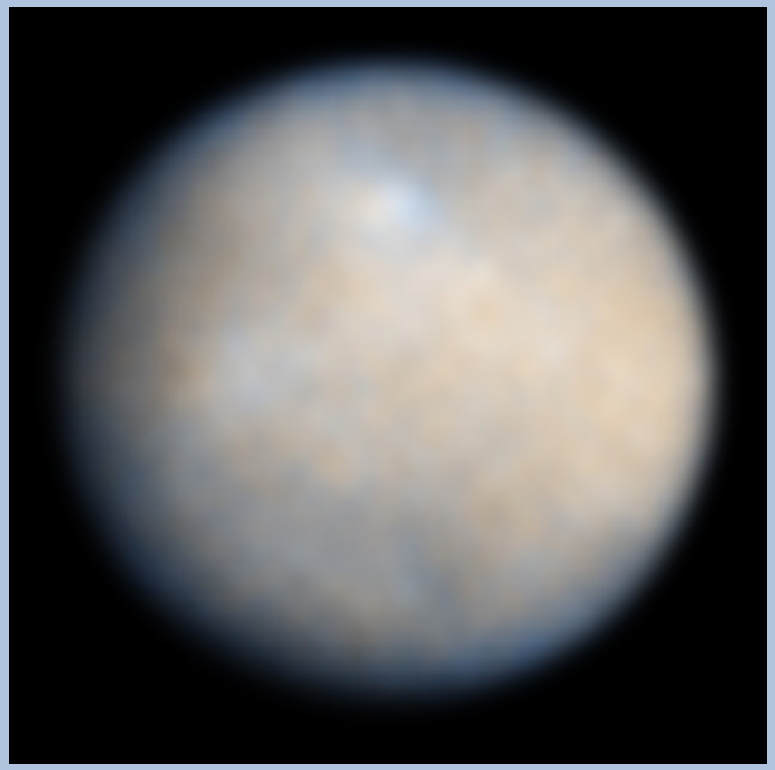
Potential candidates:

(1) Ceres, (2) Pallas, (4) Vesta, (21) Lutetia

General Aspects

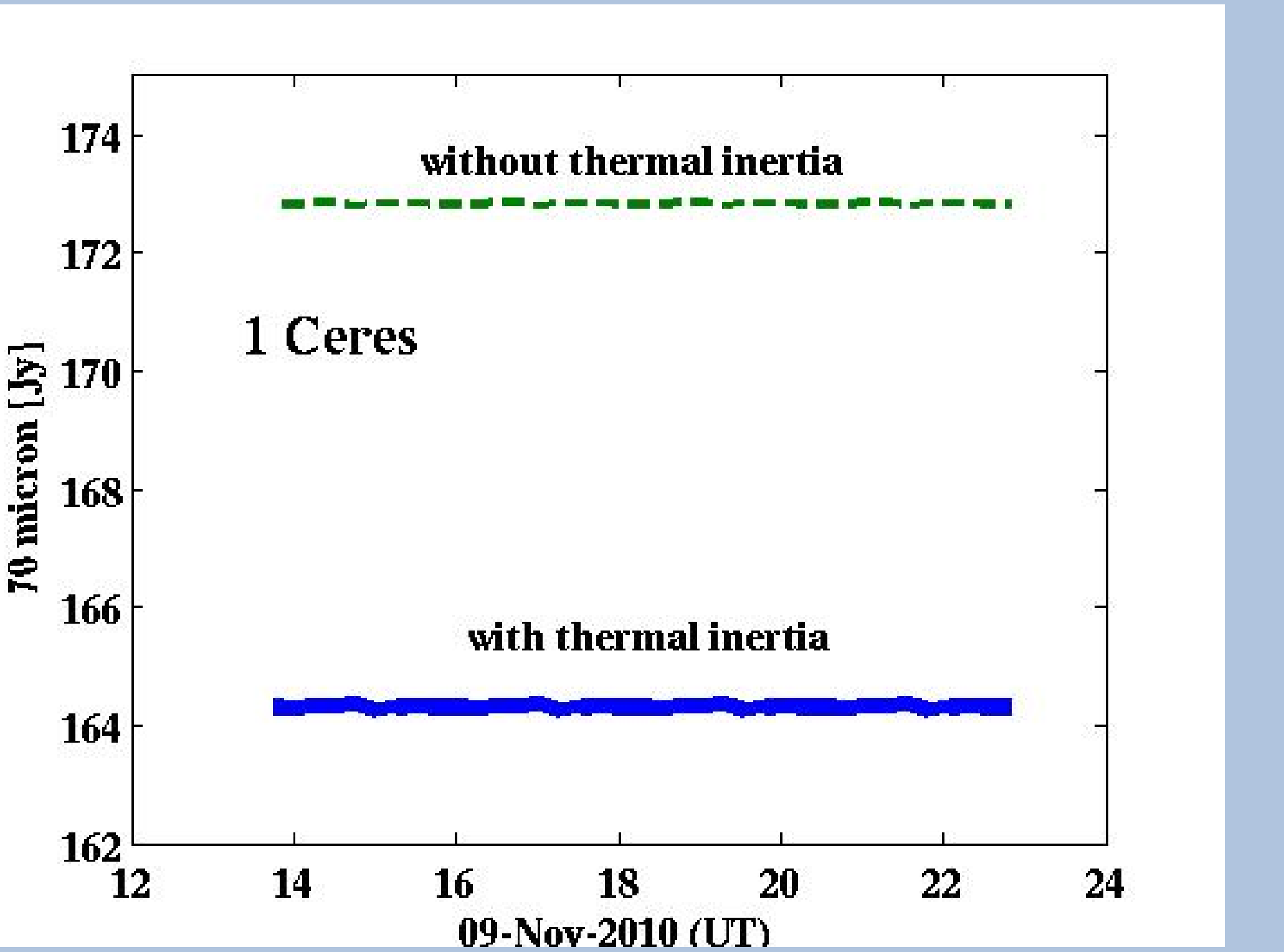
- Data reduction:
  - HIFI data: David Teyssier, March 2013
    prime flux calibrator: Mars
  - SPIRE data: Tanya Lim, December 2012
    prime flux calibrators: Uranus, Neptune (model version?)
  - PACS chop-nod data: Markus Nielbock, February 2013
    prime flux calibrators: 5 fiducial stars (new models)
  - PACS single scan-map data: Zoltan Balog, March 2013
    prime flux calibrators: 5 fiducial stars (new models)
- PACS corrections for primary asteroids
  - non-linearity correction: 0 ... 6%
  - evaporator temperature correction: -0.3 ... 3.2%
  - chop-nod flux correction: 4 ...8%
  - colour-correction: 0 ... 7%

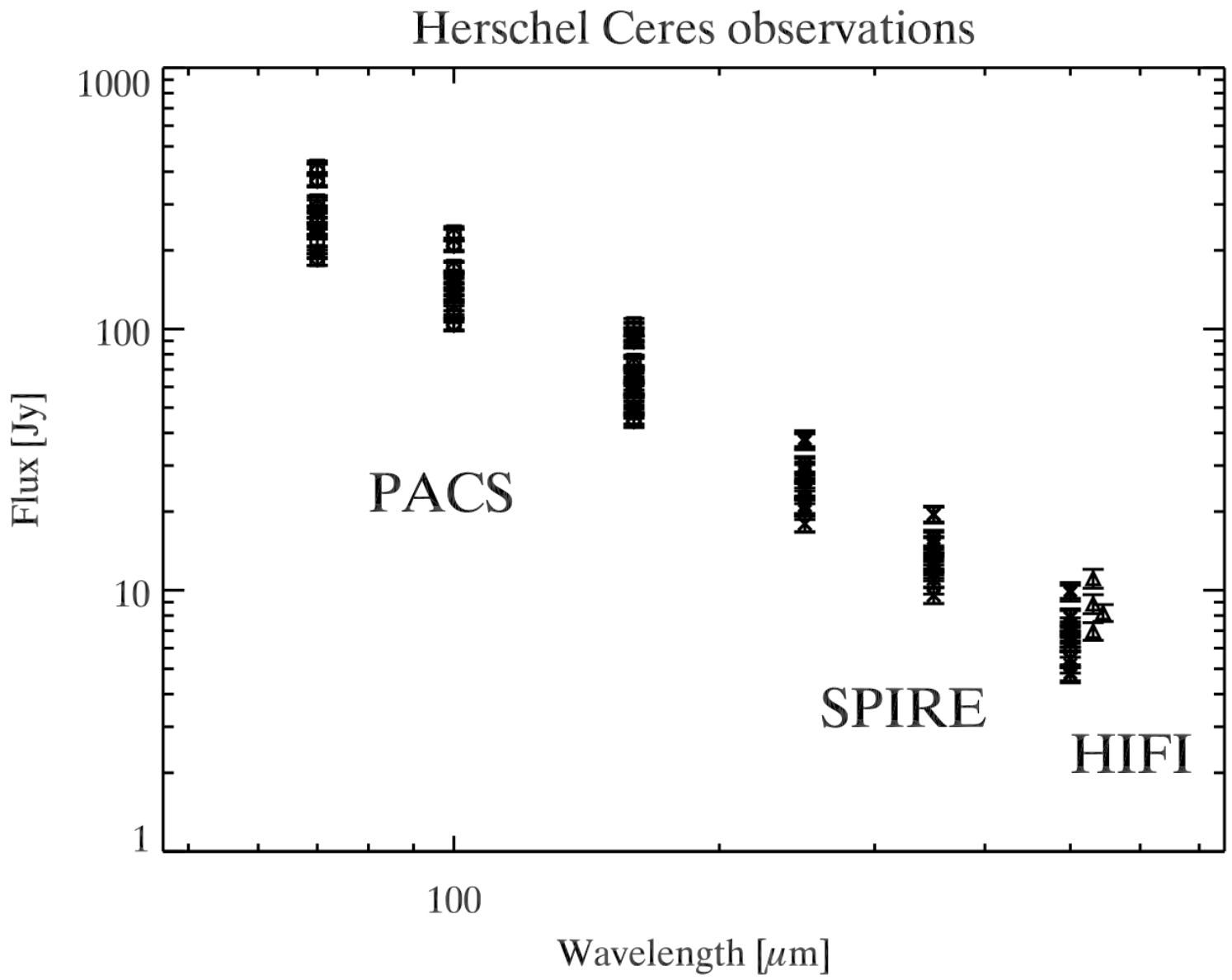
Prime calibrator (1) Ceres

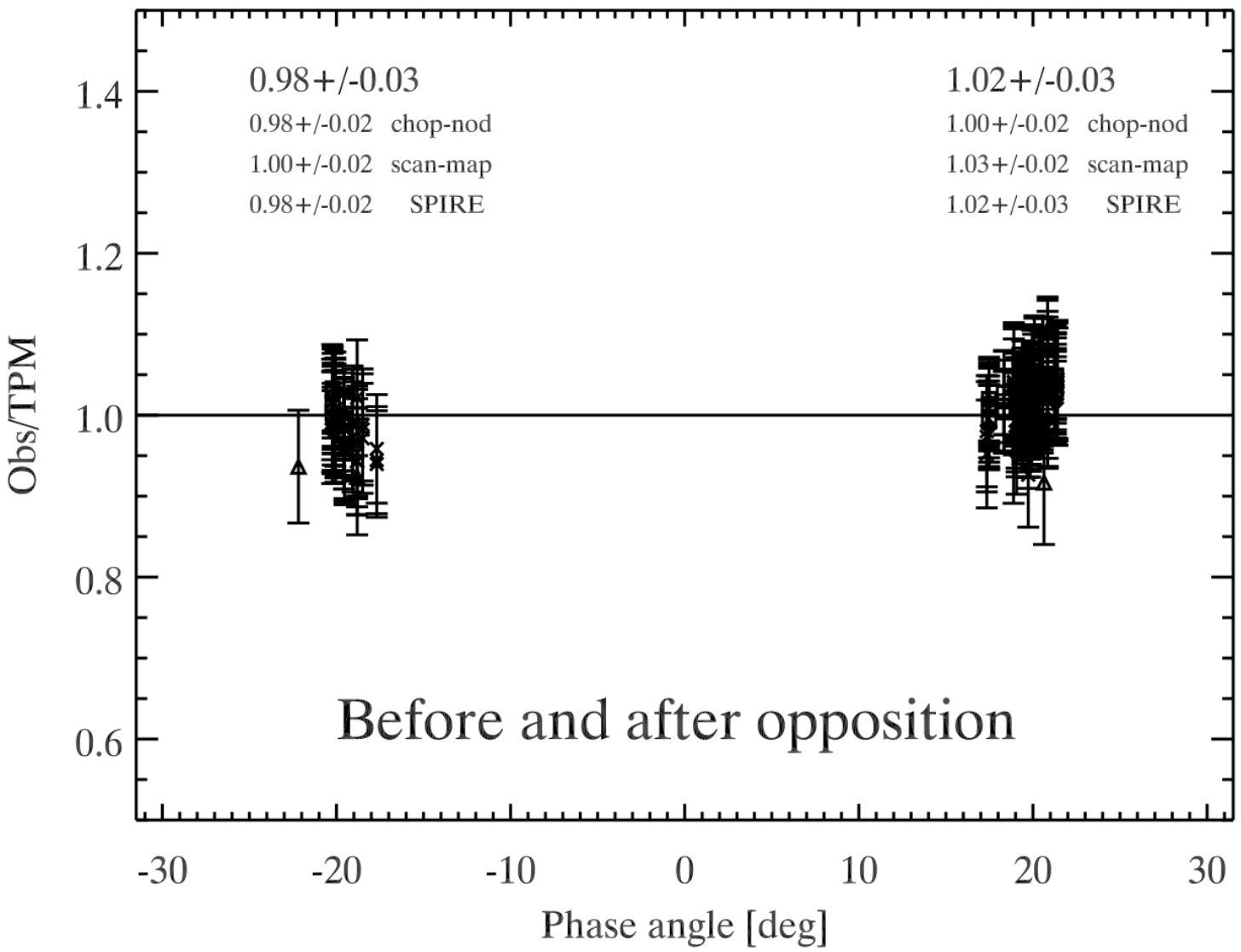


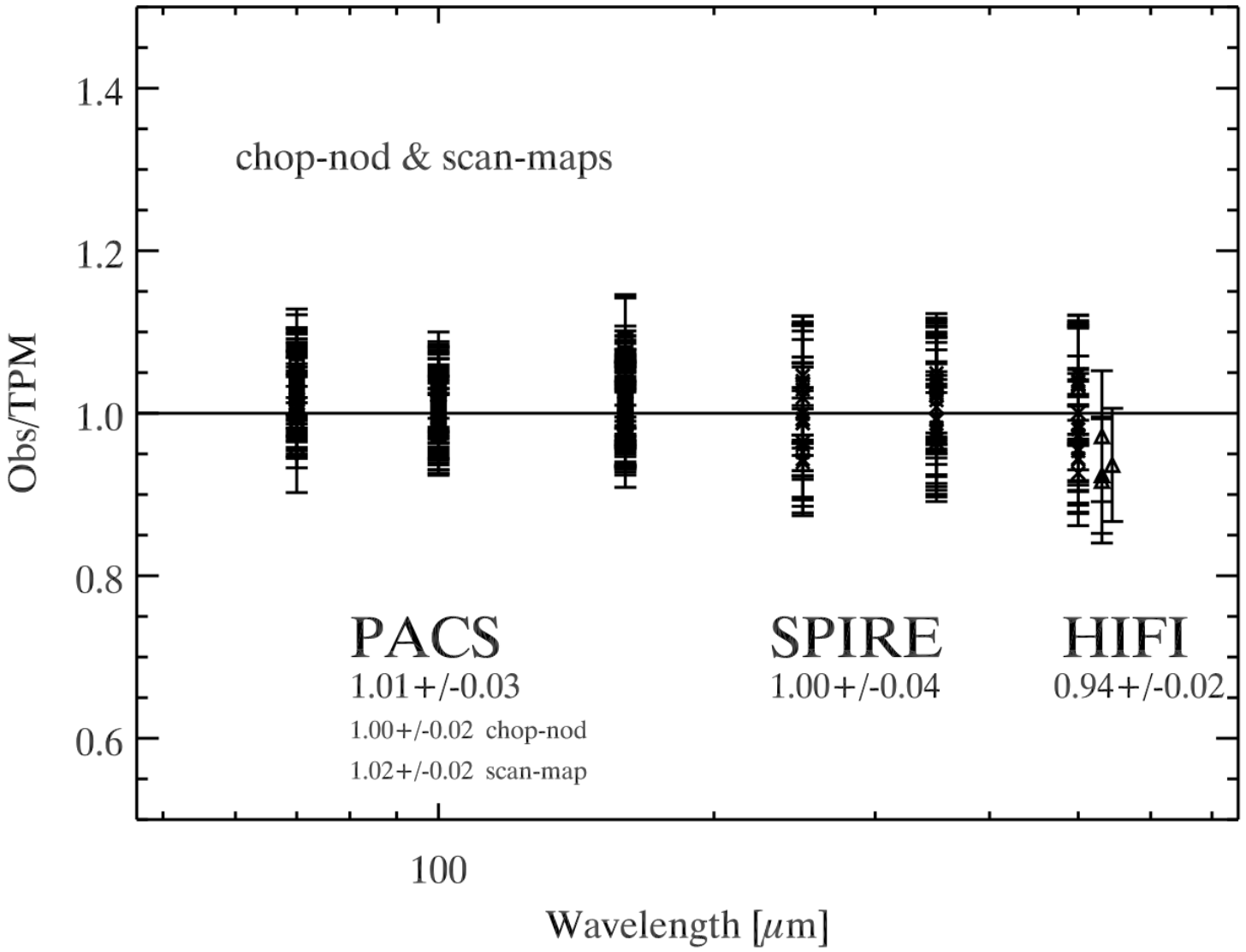
1 Ceres (HST)

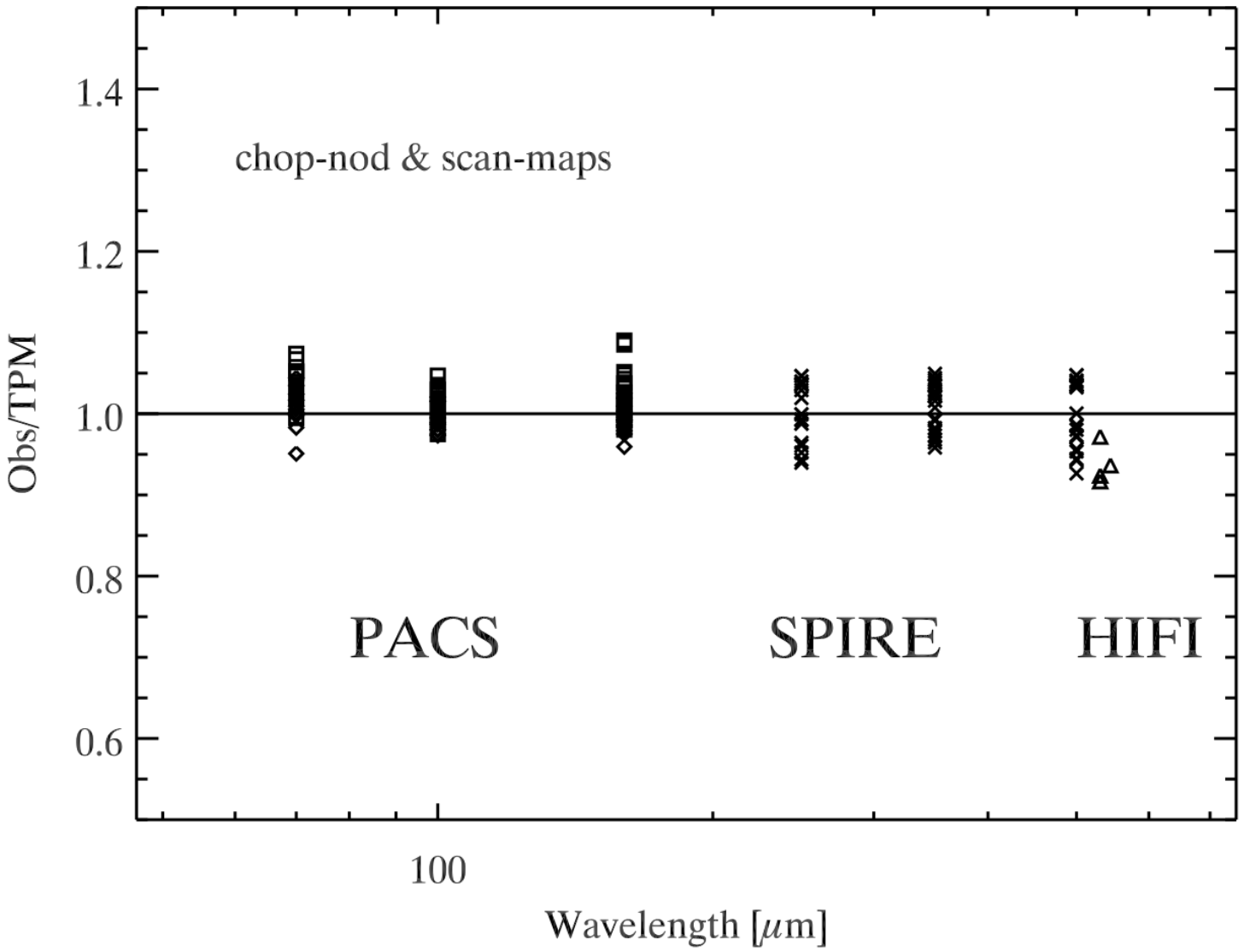
- Ellipsoidal shape model derived from HST (Thomas et al. 2005, Nature 437)
- Spin-axis and rotation period (Chamberlain et al. 2007, Icarus 188)
- H-G values: reflected light (Lagerkvist et al. 1992, A&A)
- Size from HST (Thomas et al. 2005, Nature 437)
- geometric albedo from HST (Li et al. 2006, Icarus 182)
- default thermal properties & roughness MBAs (Müller & Lagerros 2002, A&A)

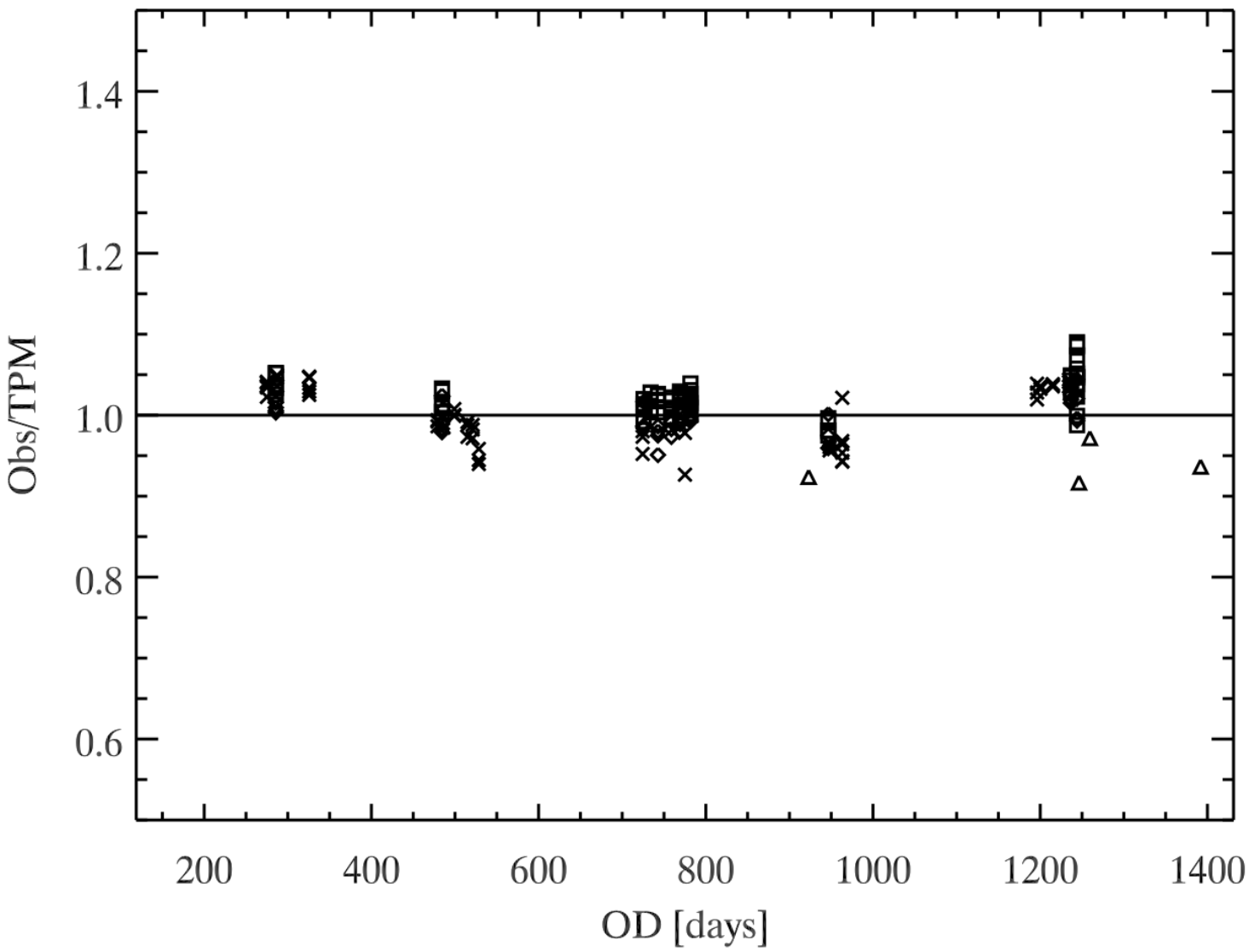

without thermal inertia
1 Ceres
with thermal inertia
70 micron [Jy]
174
172
170
168
166
164
162
12
14
16
18
20
22
24
09-Nov-2010 (UT)


Herschel Ceres observations
1000
100
10
1
Flux [Jy]
PACS
SPIRE
HIFI
100
Wavelength [μm]

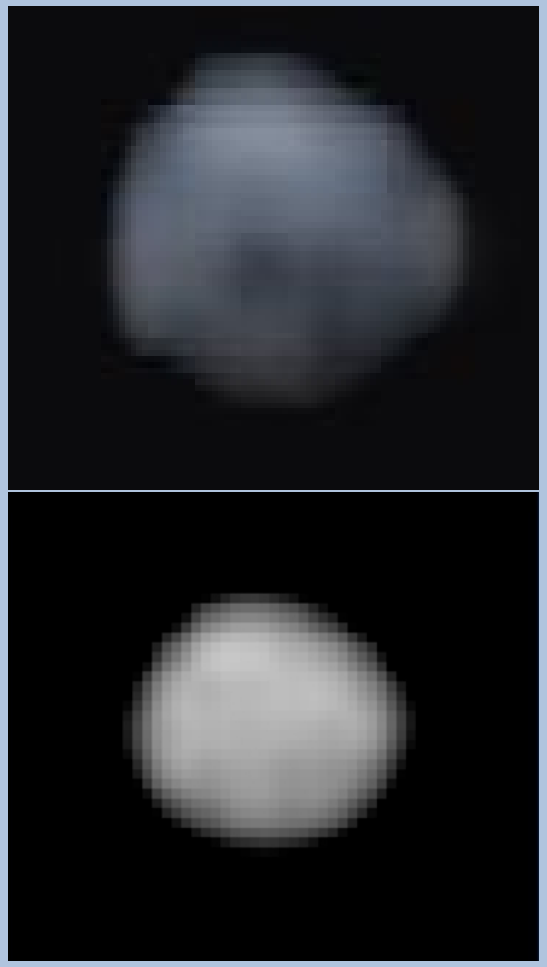

0.98+/-0.03
0.98+/-0.02 chop-nod
1.00+/-0.02 scan-map
0.98+/-0.02 SPIRE
1.02+/-0.03
1.00+/-0.02 chop-nod
1.03+/-0.02 scan-map
1.02+/-0.03 SPIRE
Before and after opposition
Obs/TPM
1.4
1.2
1.0
0.8
0.6
-30
-20
-10
0
10
20
30
Phase angle [deg]


chop-nod & scan-maps
Obs/TPM
1.4
1.2
1.0
0.8
0.6
PACS
1.01+/-0.03
1.00+/-0.02 chop-nod
1.02+/-0.02 scan-map
SPIRE
1.00+/-0.04
HIFI
0.94+/-0.02
100
Wavelength [μm]


chop-nod & scan-maps
1.4
1.2
1.0
0.8
0.6
Obs/TPM
PACS
SPIRE
HIFI
100
Wavelength [μm]

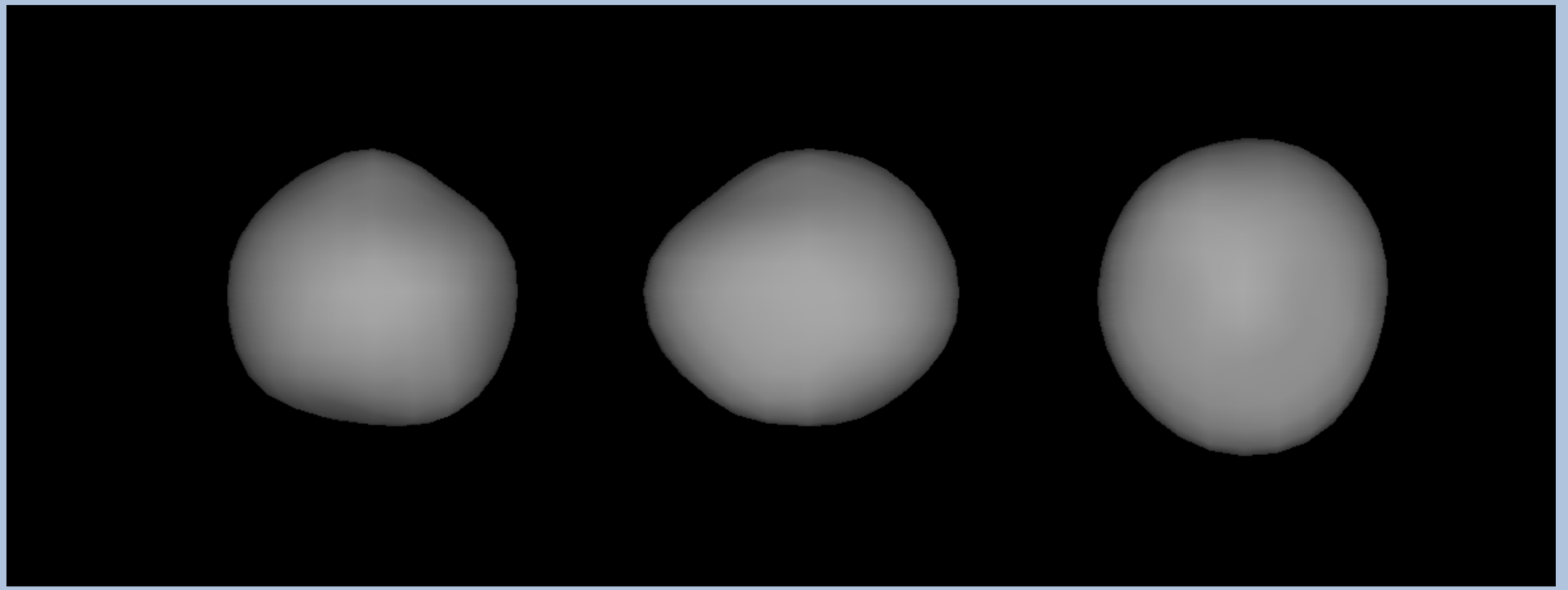

1.4
1.2
1.0
0.8
0.6
Obs/TPM
200
400
600
800
1000
1200
1400
OD [days]

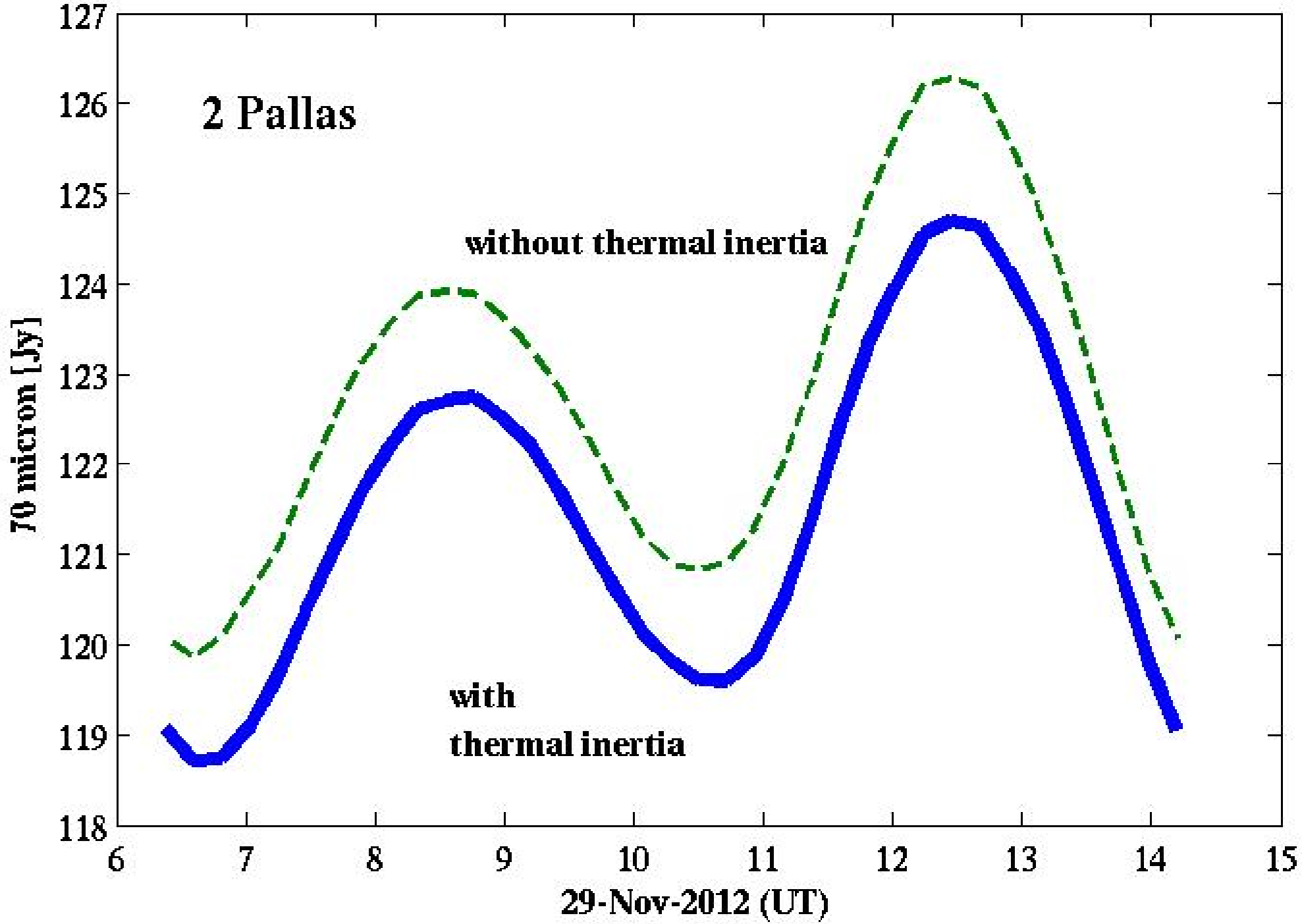
Prime calibrator (2) Pallas

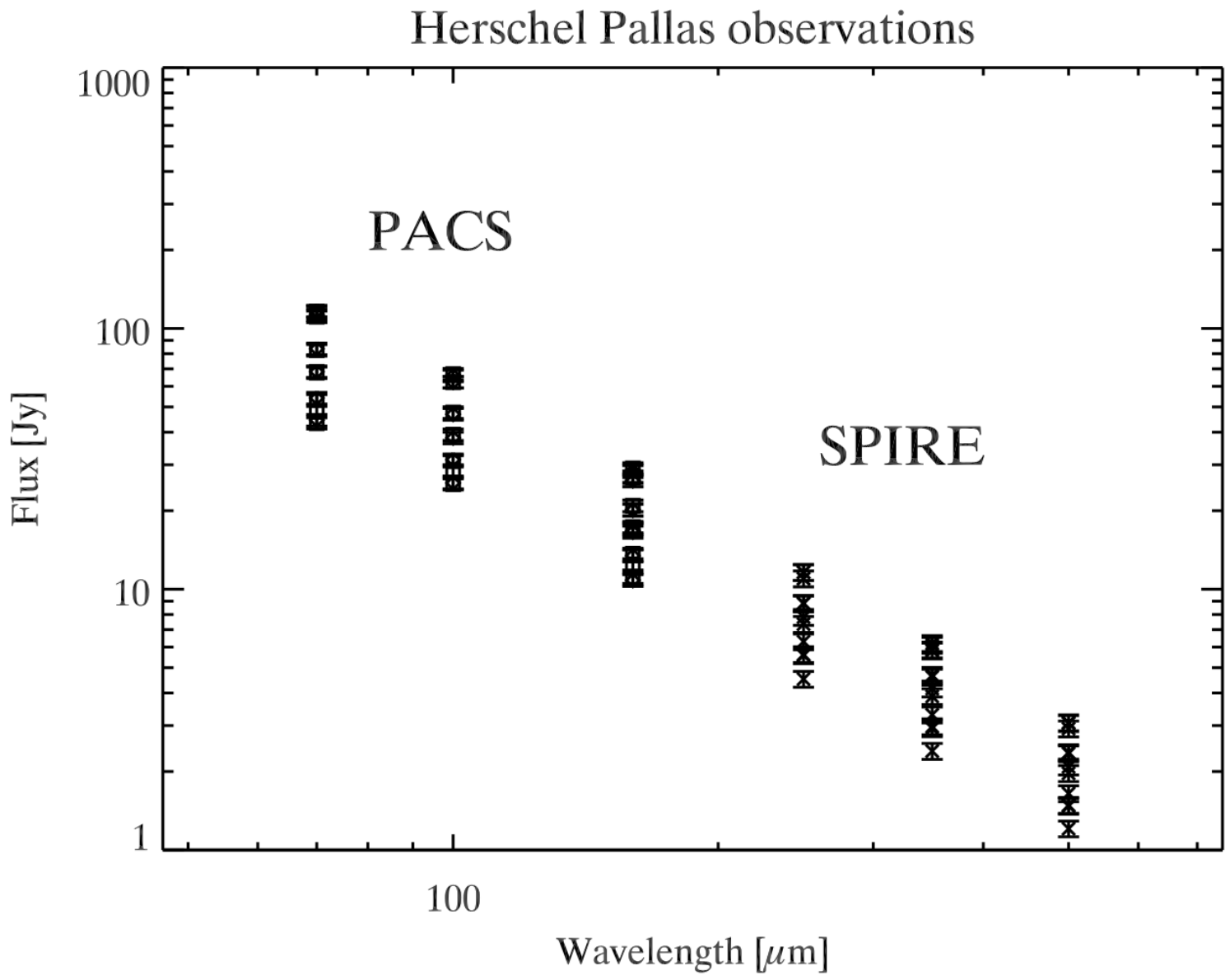


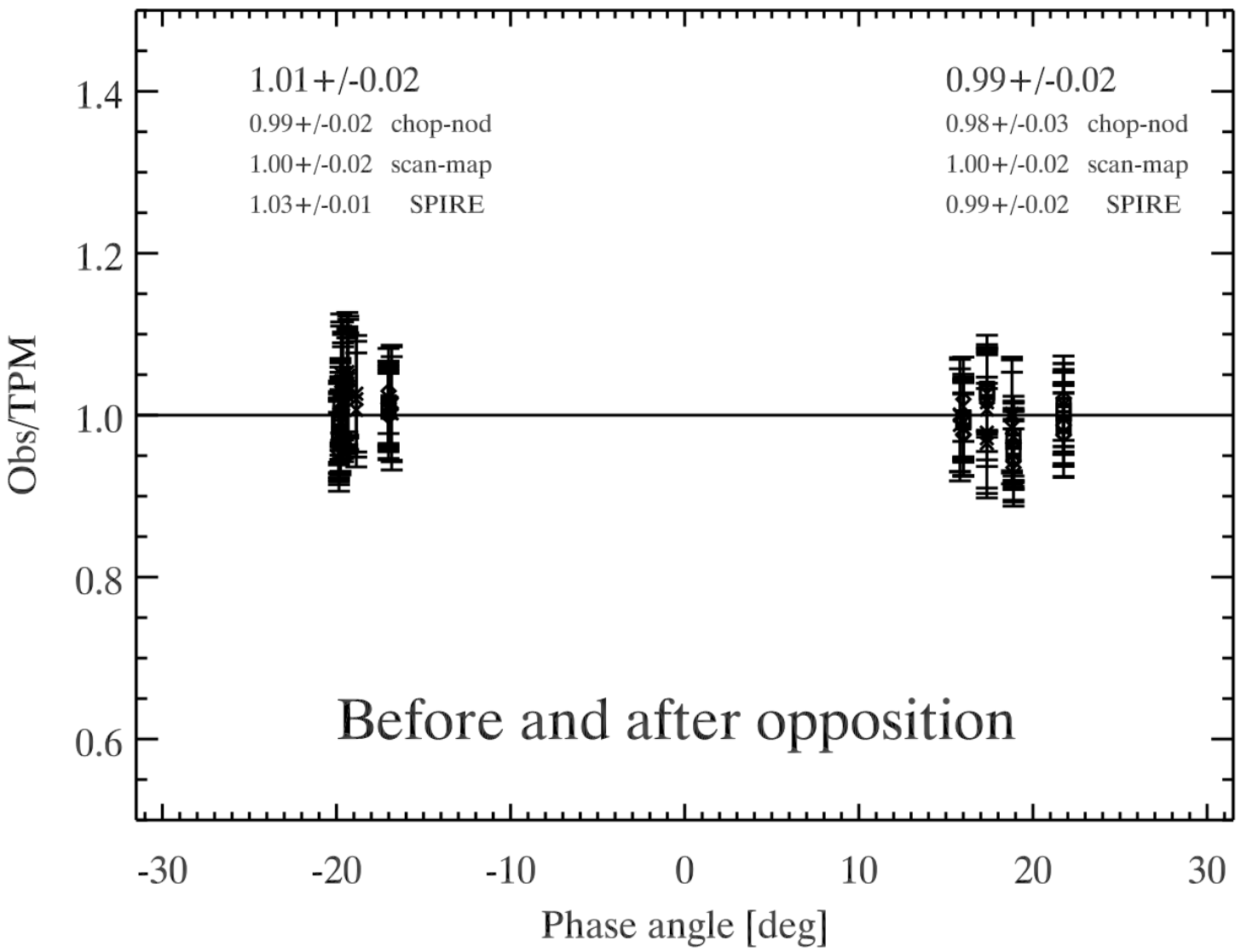
2 Pallas (HST)

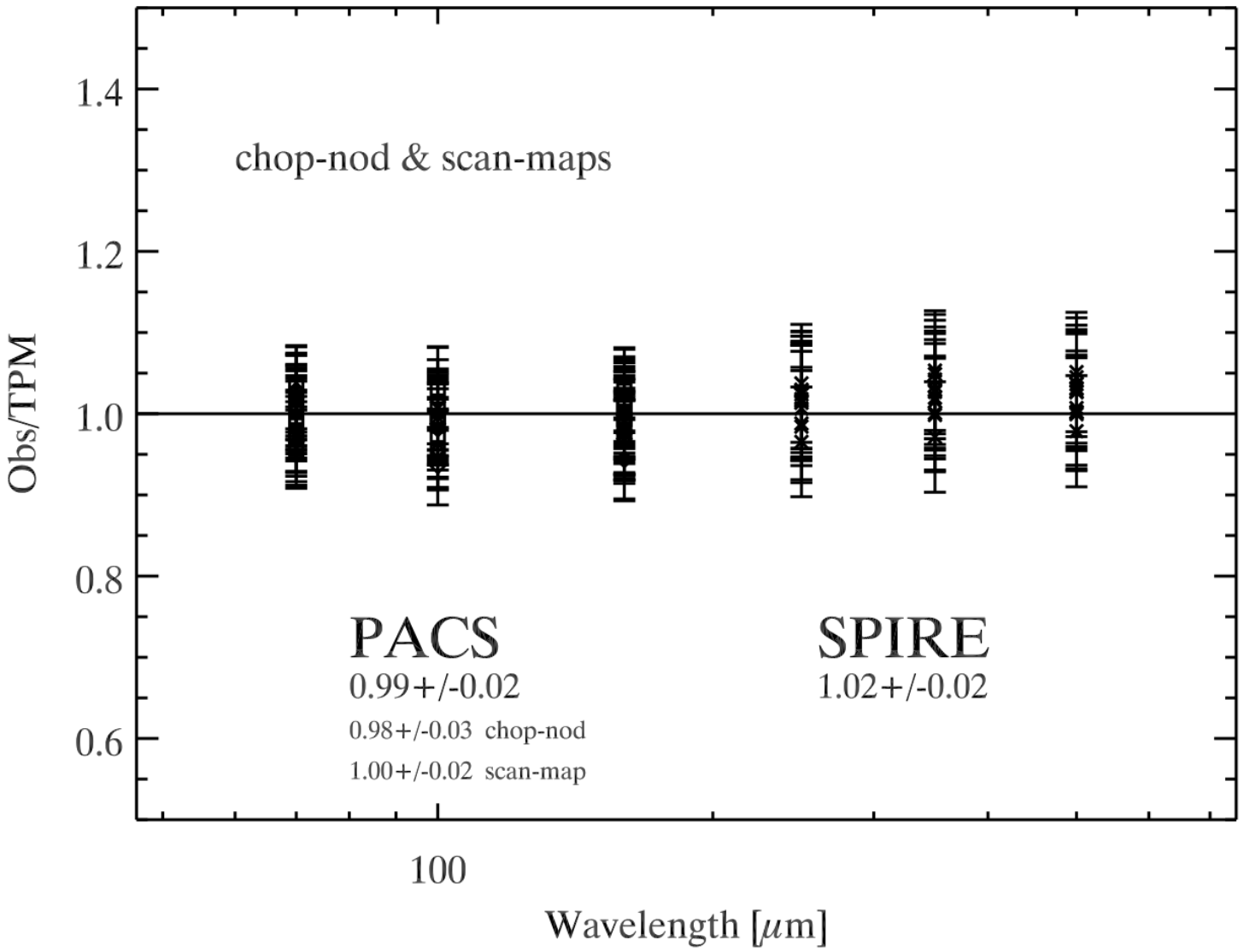
- nonconvex shape model & spin-axis properties from lightcurve inversion, adaptive optics, occultations (DAMIT; Durech et al. 2010, Carry et al. 2010)
- H-G values (Lagerkvist et al. 1992, A&A)
- most accurate size from multiple occultations (Dunham et al. 1990)
- geometric albedo calculated via size & H-mag
- default thermal properties & roughness for MBAs (Müller & Lagerros 2002, A&A)

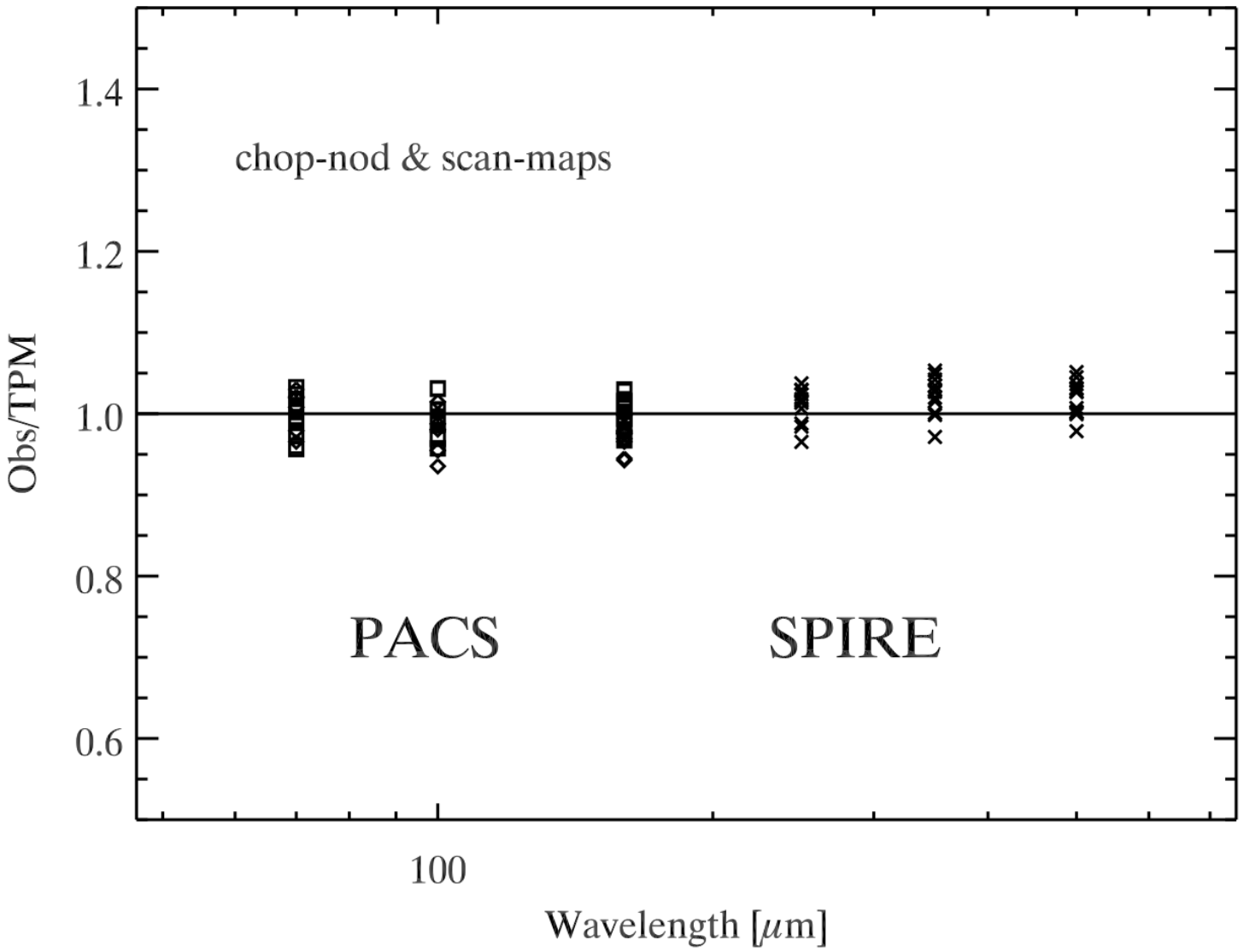


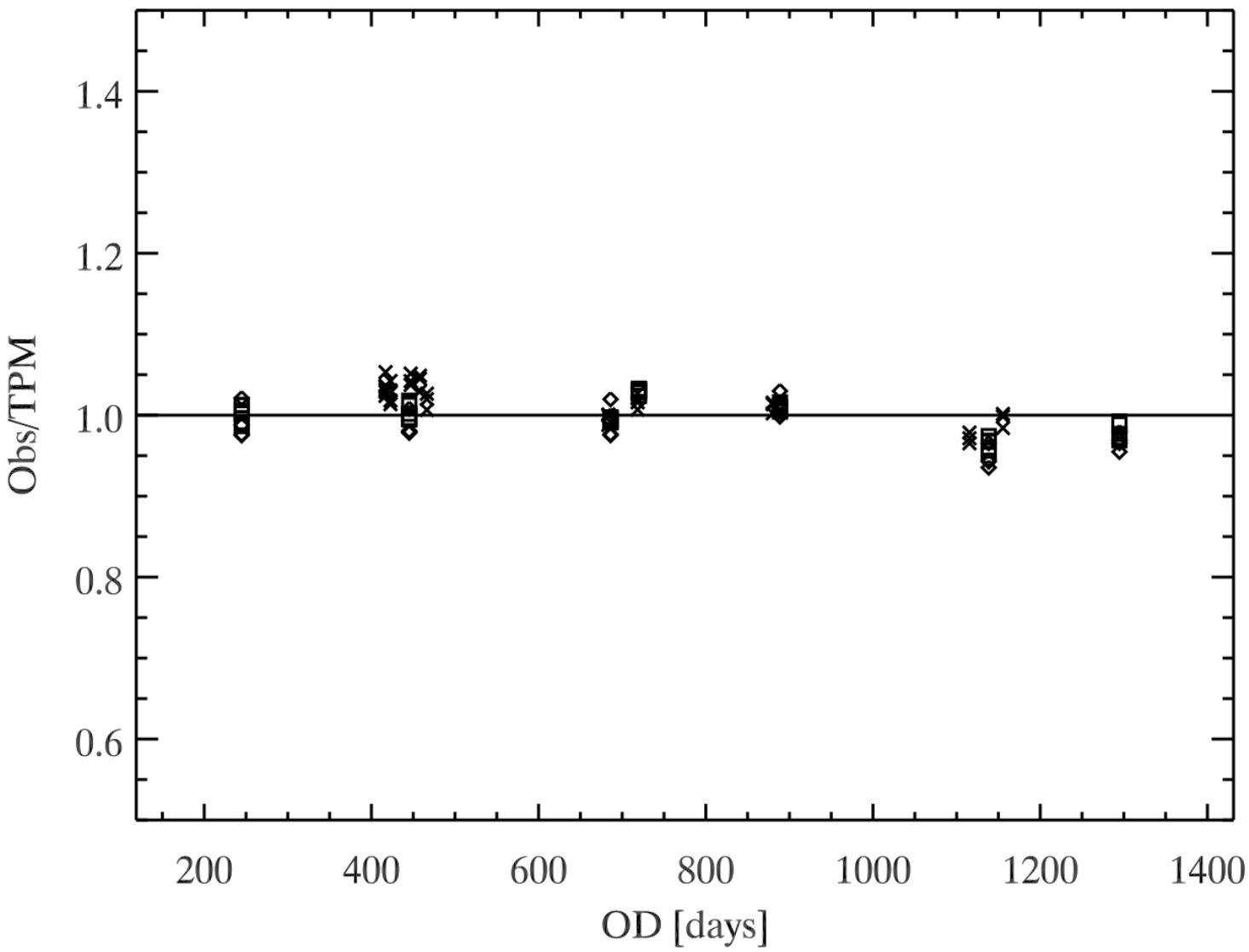

2 Pallas
without thermal inertia
with
thermal inertia
70 micron [Jy]
29-Nov-2012 (UT)
127
126
125
124
123
122
121
120
119
118
6
7
8
9
10
11
12
13
14
15


Herschel Pallas observations
PACS
SPIRE
1000
100
10
1
100
Flux [Jy]
Wavelength [μm]

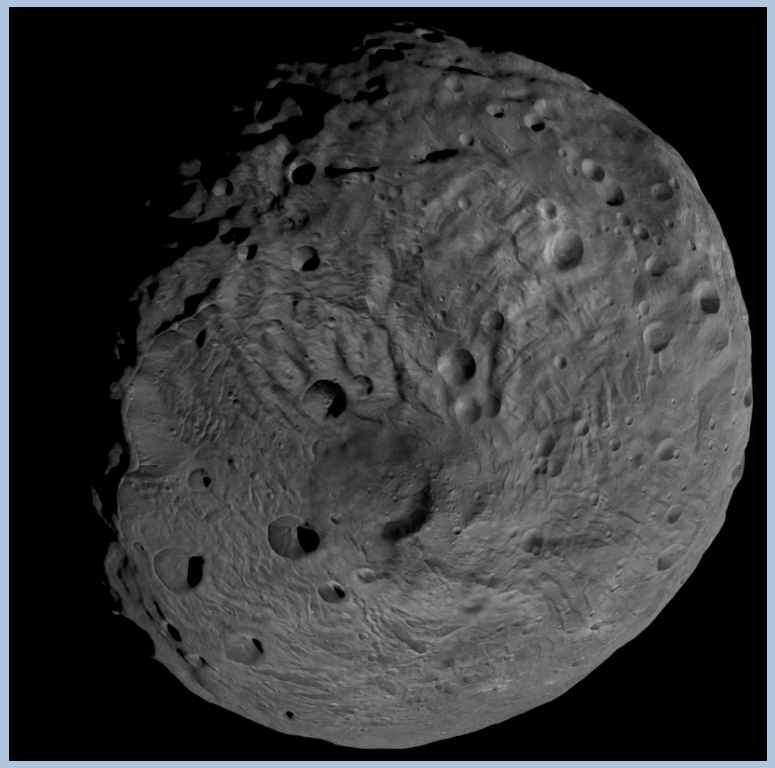

1.01+/-0.02
0.99+/-0.02 chop-nod
1.00+/-0.02 scan-map
1.03+/-0.01 SPIRE
0.99+/-0.02
0.98+/-0.03 chop-nod
1.00+/-0.02 scan-map
0.99+/-0.02 SPIRE
Before and after opposition
Obs/TPM
1.4
1.2
1.0
0.8
0.6
-30
-20
-10
0
10
20
30
Phase angle [deg]


chop-nod & scan-maps
1.4
1.2
1.0
0.8
0.6
Obs/TPM
PACS
0.99+/-0.02
0.98+/-0.03 chop-nod
1.00+/-0.02 scan-map
SPIRE
1.02+/-0.02
100
Wavelength [μm]


chop-nod & scan-maps
1.4
1.2
1.0
0.8
0.6
Obs/TPM
PACS
SPIRE
100
Wavelength [μm]

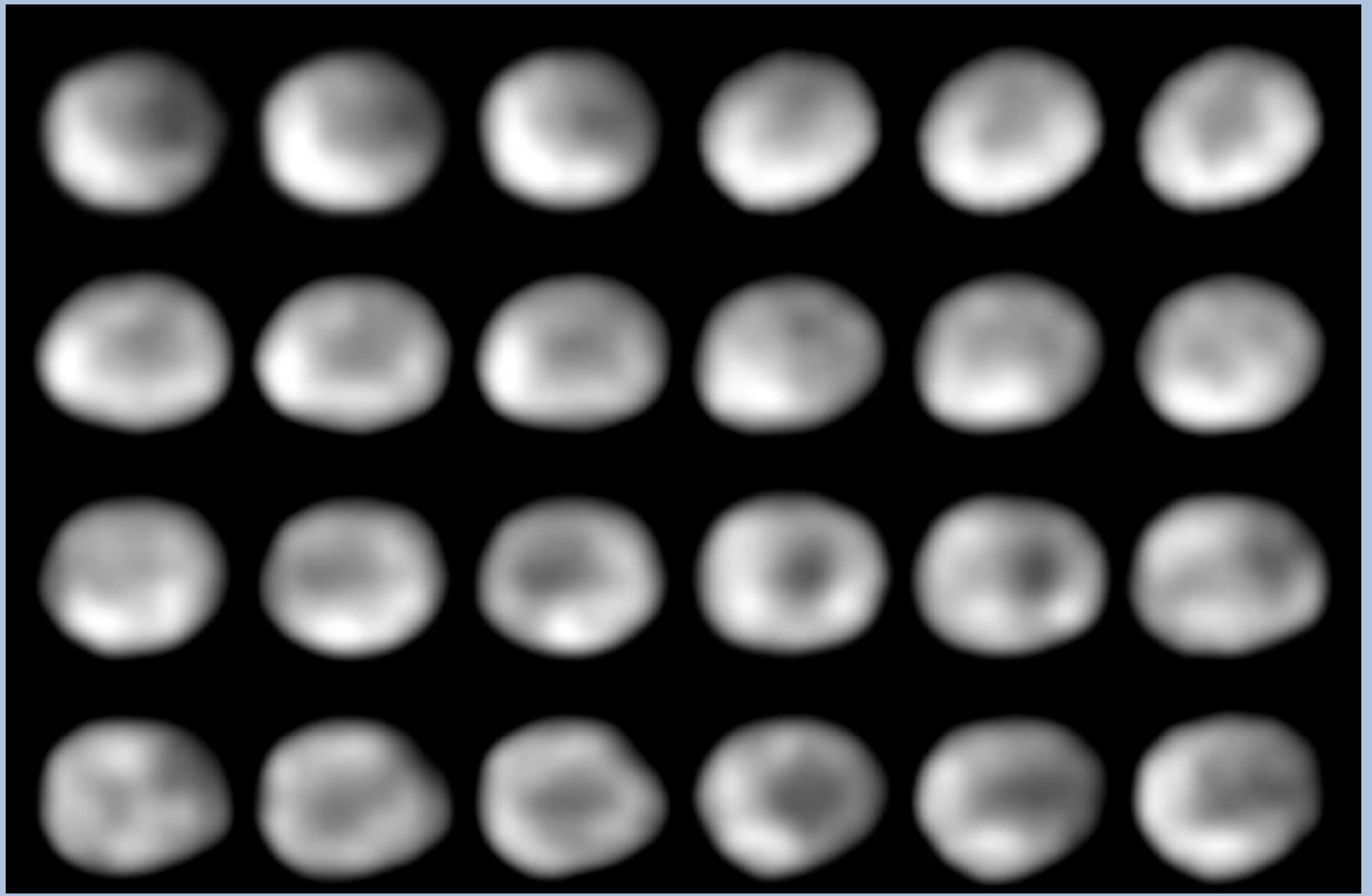

1.4
1.2
1.0
0.8
0.6
Obs/TPM
200
400
600
800
1000
1200
1400
OD [days]

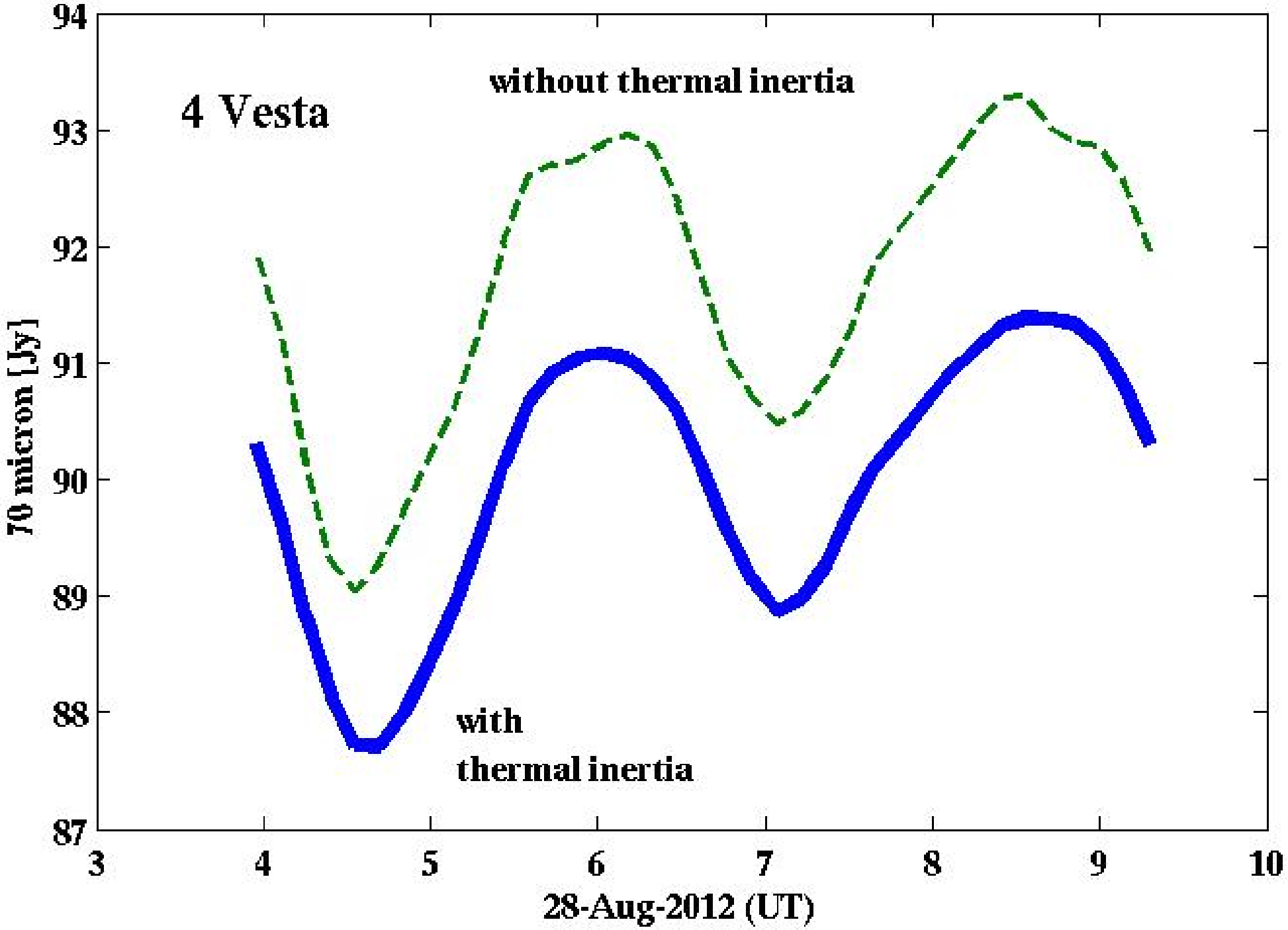
Prime calibrator (4) Vesta

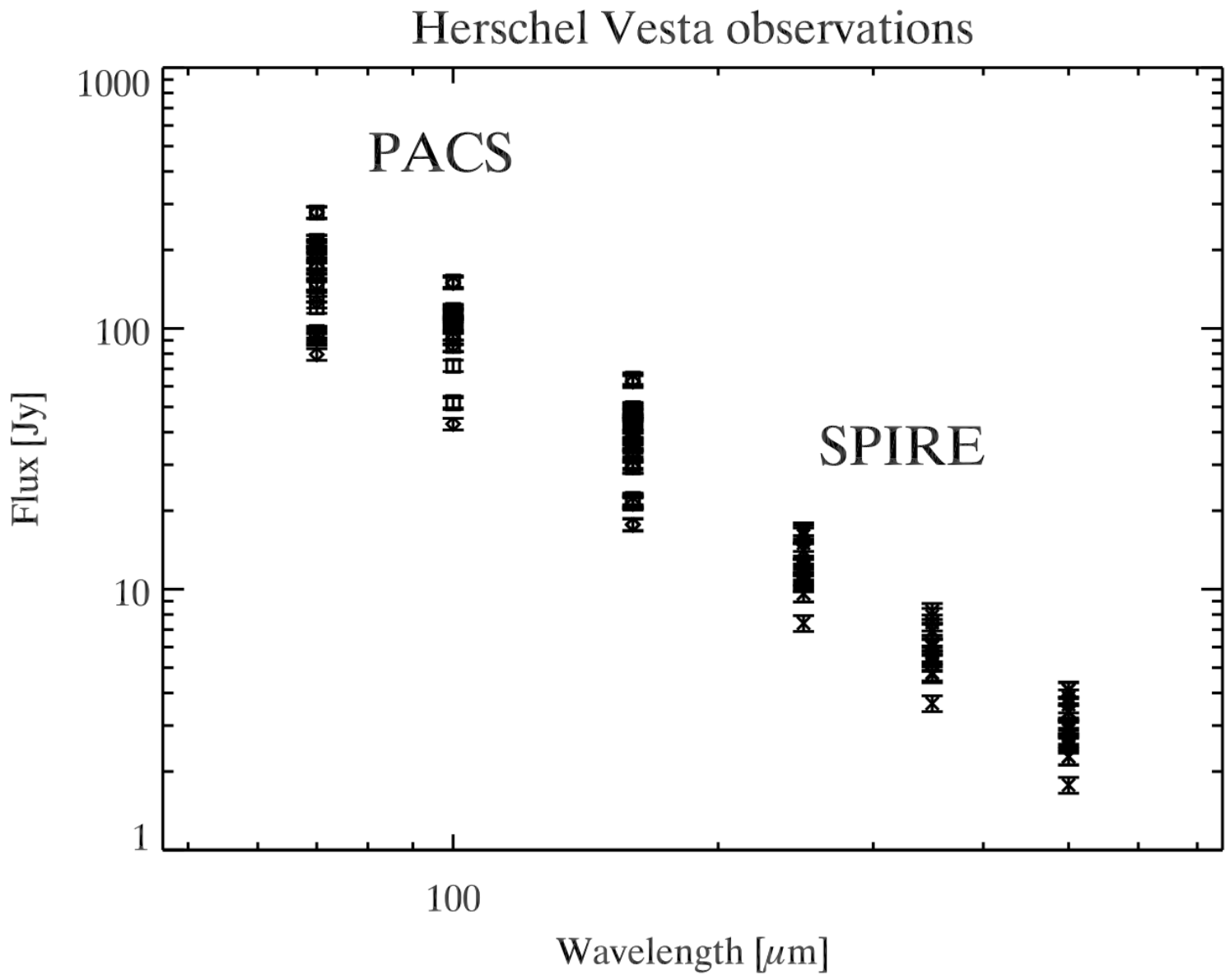


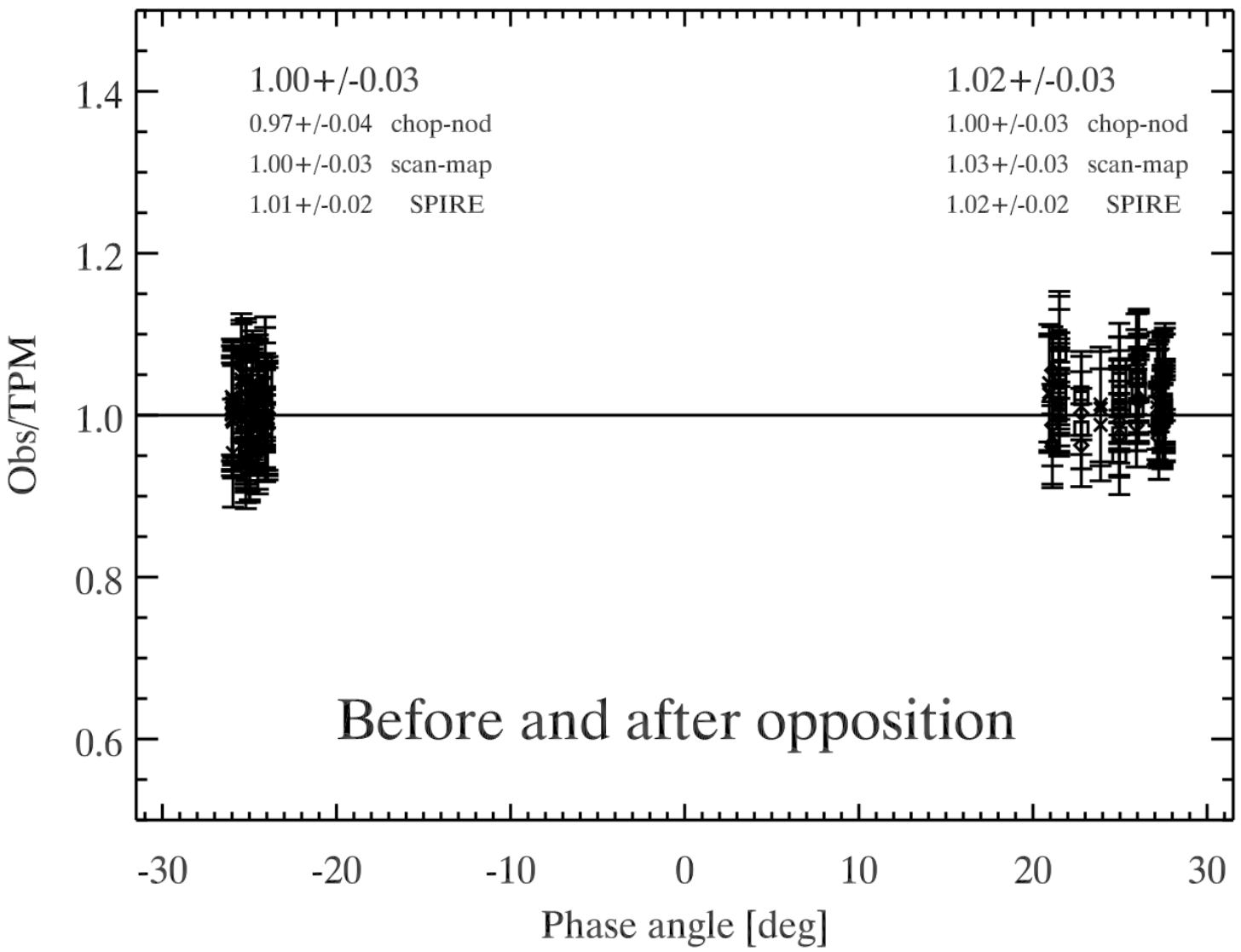
4 Vesta (DAWN)

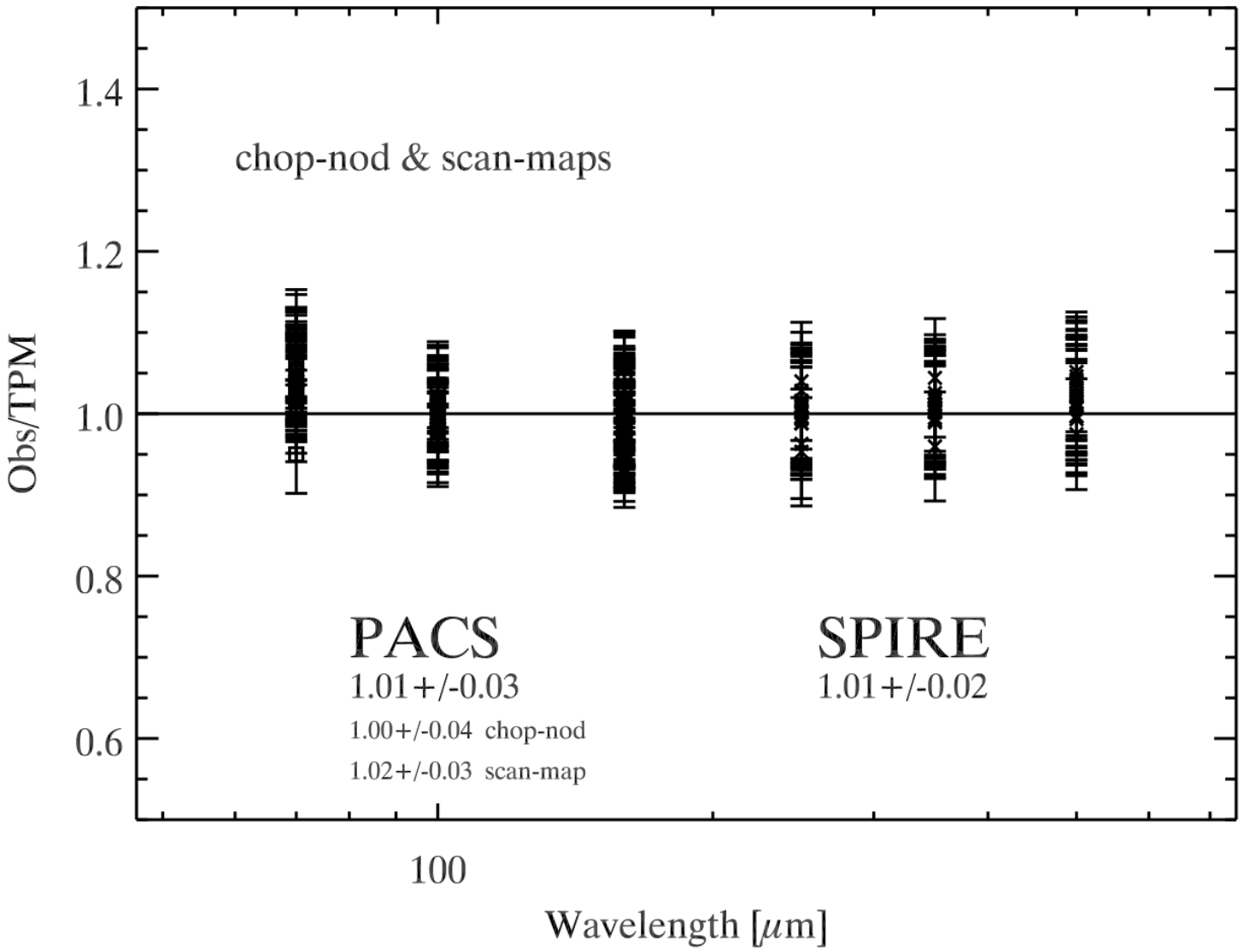
- shape model, spin-axis & rotation period derived from lightcurves and HST (Thomas et al. 1997, Nature & Note added in proof)
- H-G values: reflected light (Müller & Lagerros 1998, A&A)
- Size from the DAWN-mission (Russel et al. 2012, Science 336)
- geometric albedo calculated via size & H-mag
- special thermal properties & roughness for Vesta (Müller & Lagerros 2002, A&A)

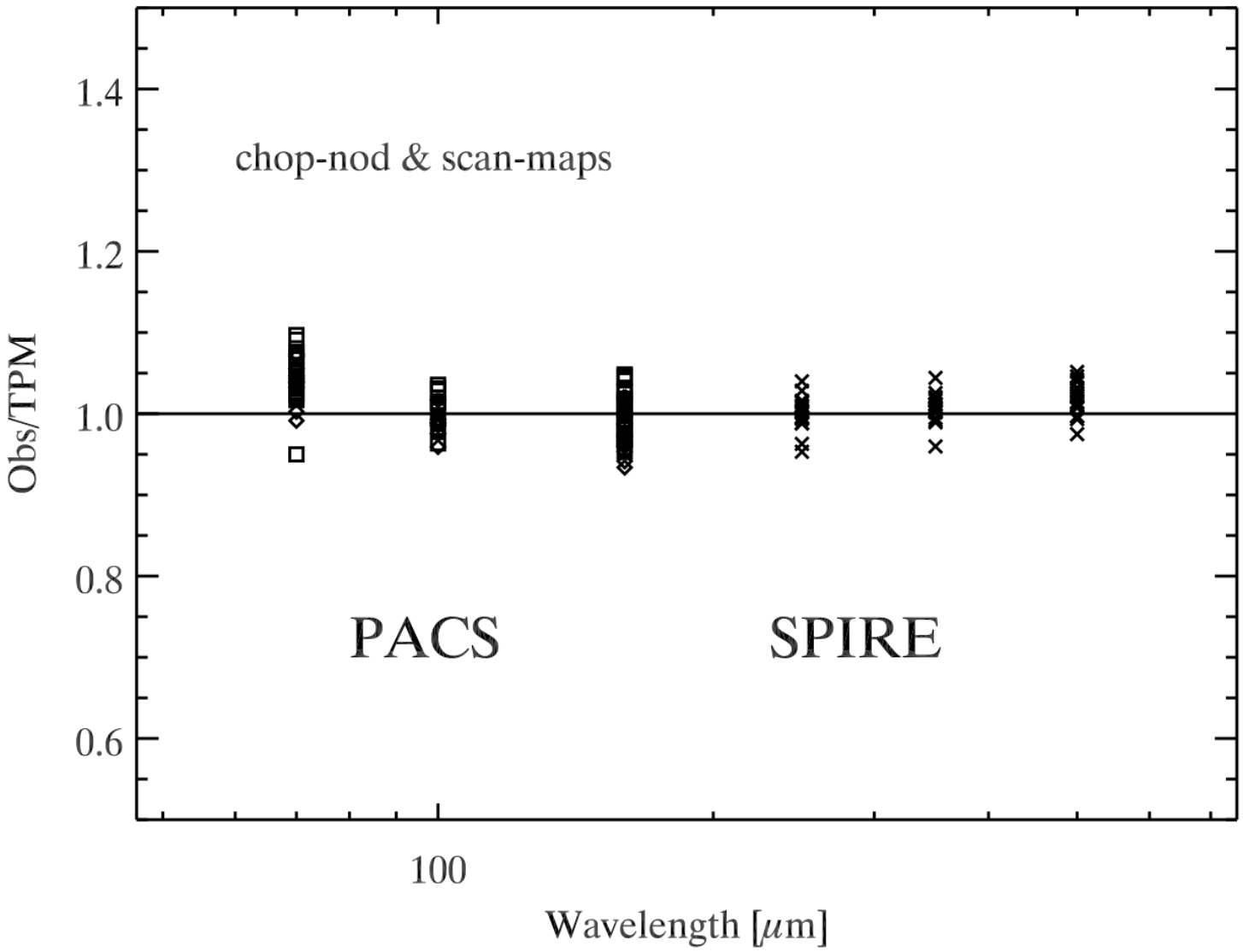


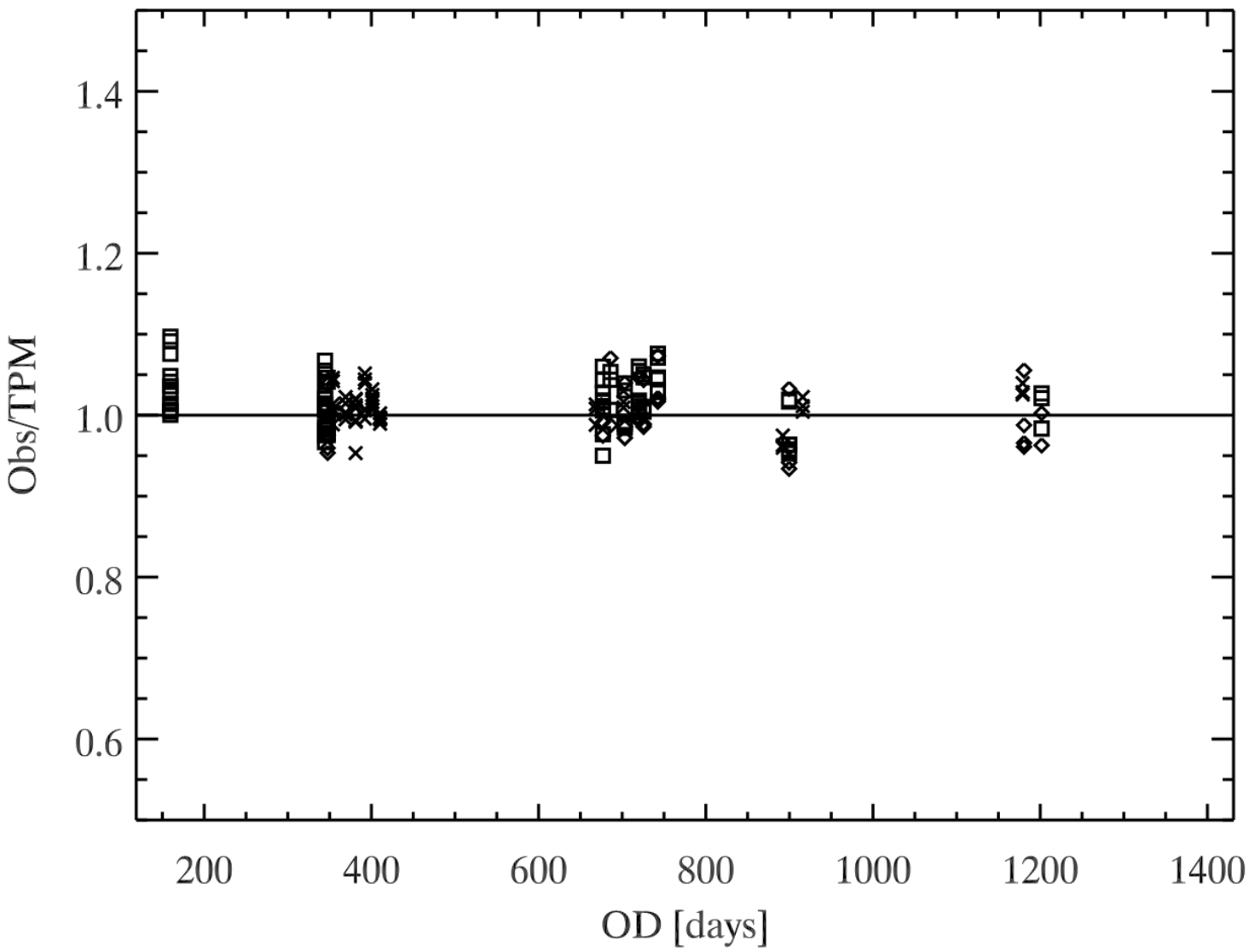

4 Vesta
without thermal inertia
with
thermal inertia
70 micron [Jy]
28-Aug-2012 (UT)
94
93
92
91
90
89
88
87
3
4
5
6
7
8
9
10


Herschel Vesta observations
PACS
SPIRE
1000
100
10
1
100
Flux [Jy]
Wavelength [μm]

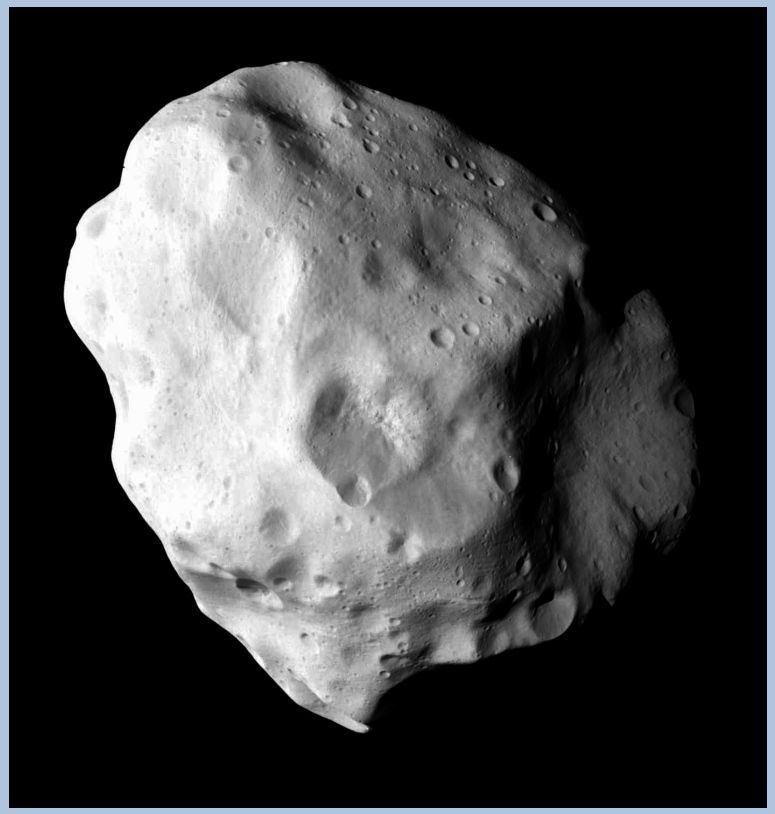

1.00+/-0.03
0.97+/-0.04 chop-nod
1.00+/-0.03 scan-map
1.01+/-0.02 SPIRE
1.02+/-0.03
1.00+/-0.03 chop-nod
1.03+/-0.03 scan-map
1.02+/-0.02 SPIRE
Before and after opposition
Obs/TPM
1.4
1.2
1.0
0.8
0.6
-30
-20
-10
0
10
20
30
Phase angle [deg]


chop-nod & scan-maps
Obs/TPM
1.4
1.2
1.0
0.8
0.6
PACS
1.01+/-0.03
1.00+/-0.04 chop-nod
1.02+/-0.03 scan-map
SPIRE
1.01+/-0.02
100
Wavelength [μm]


chop-nod & scan-maps
1.4
1.2
1.0
0.8
0.6
Obs/TPM
PACS
SPIRE
100
Wavelength [μm]

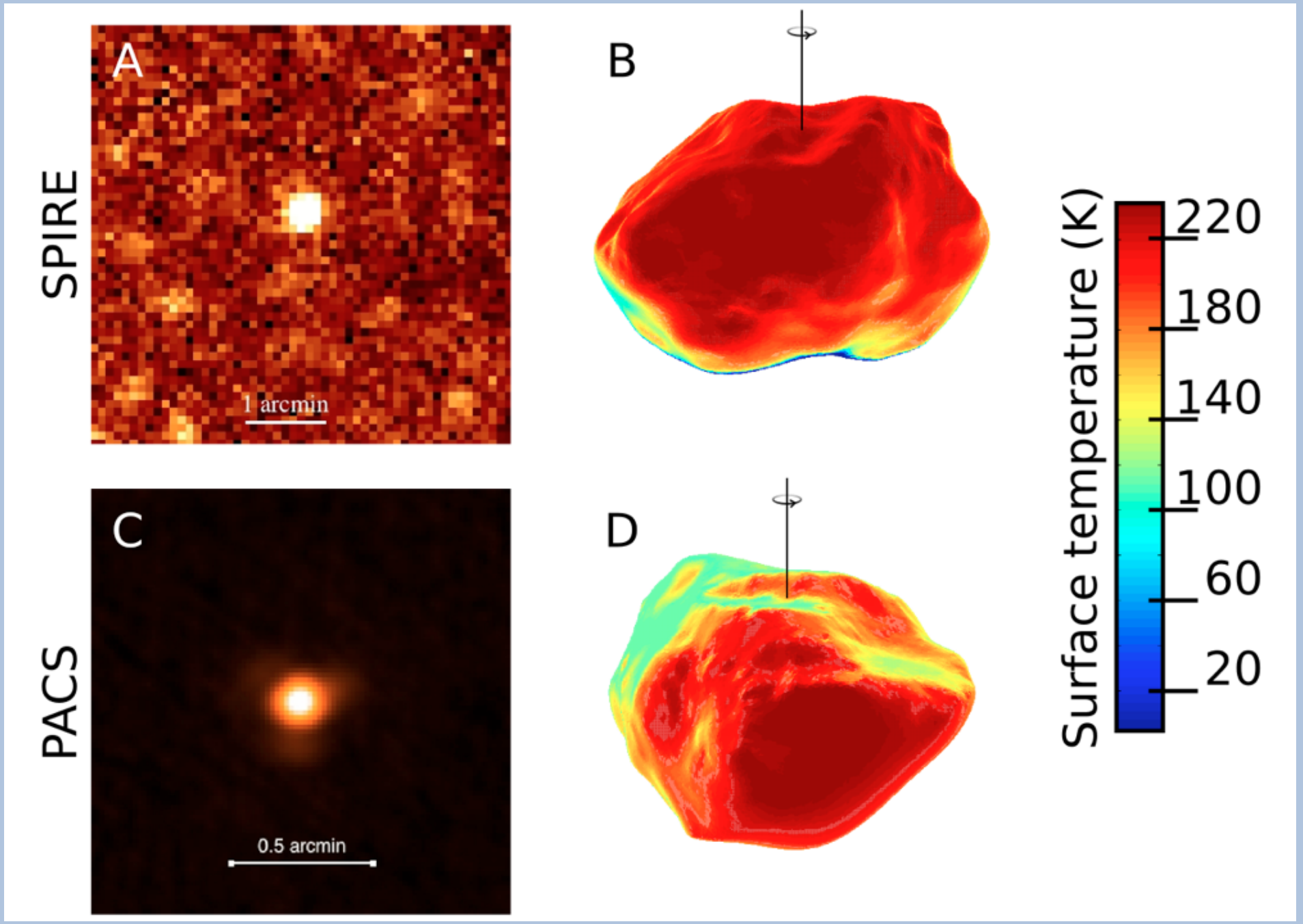

1.4
1.2
1.0
0.8
0.6
Obs/TPM
200
400
600
800
1000
1200
1400
OD [days]

Prime calibrator (21) Lutetia(?)

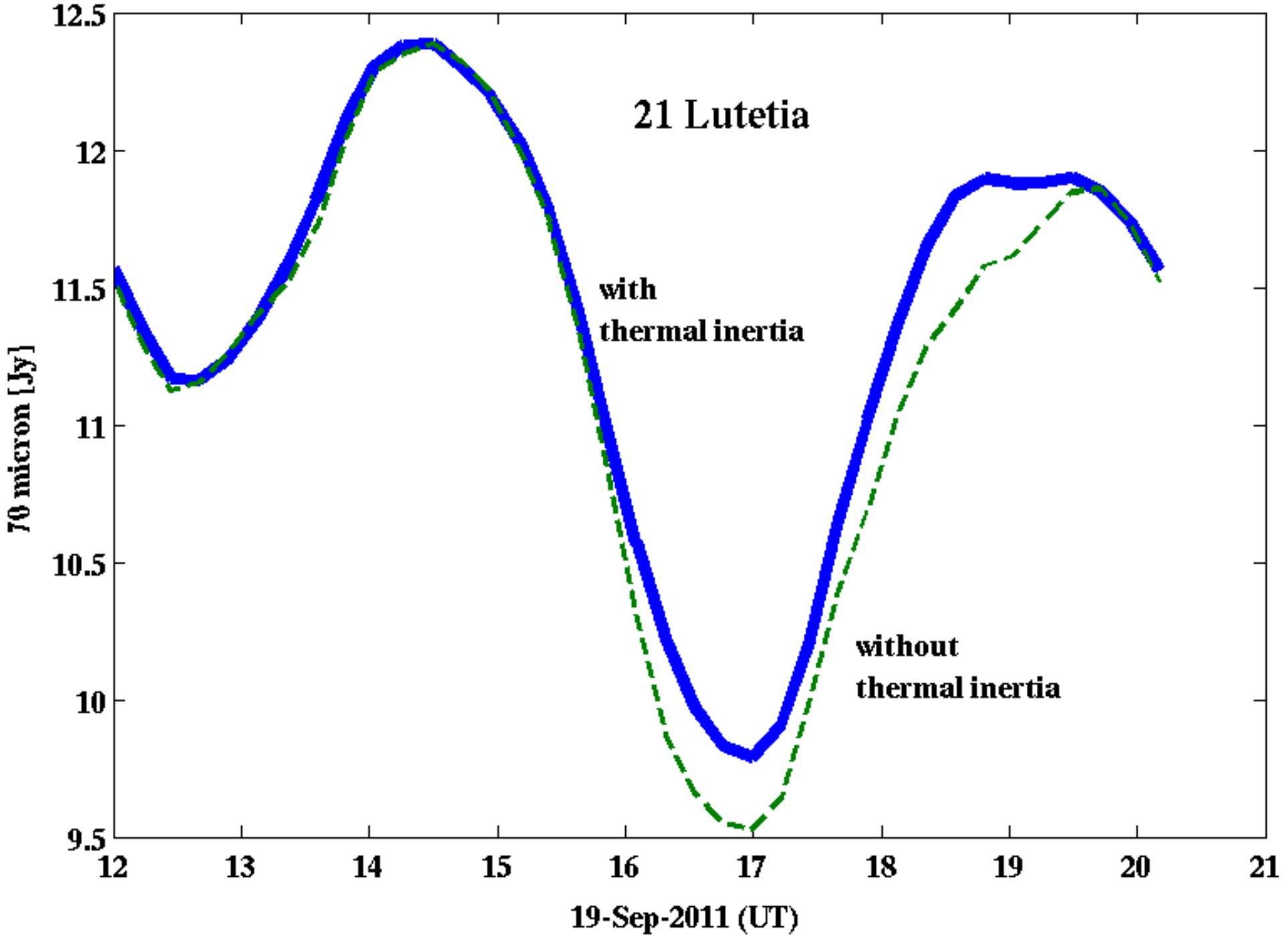


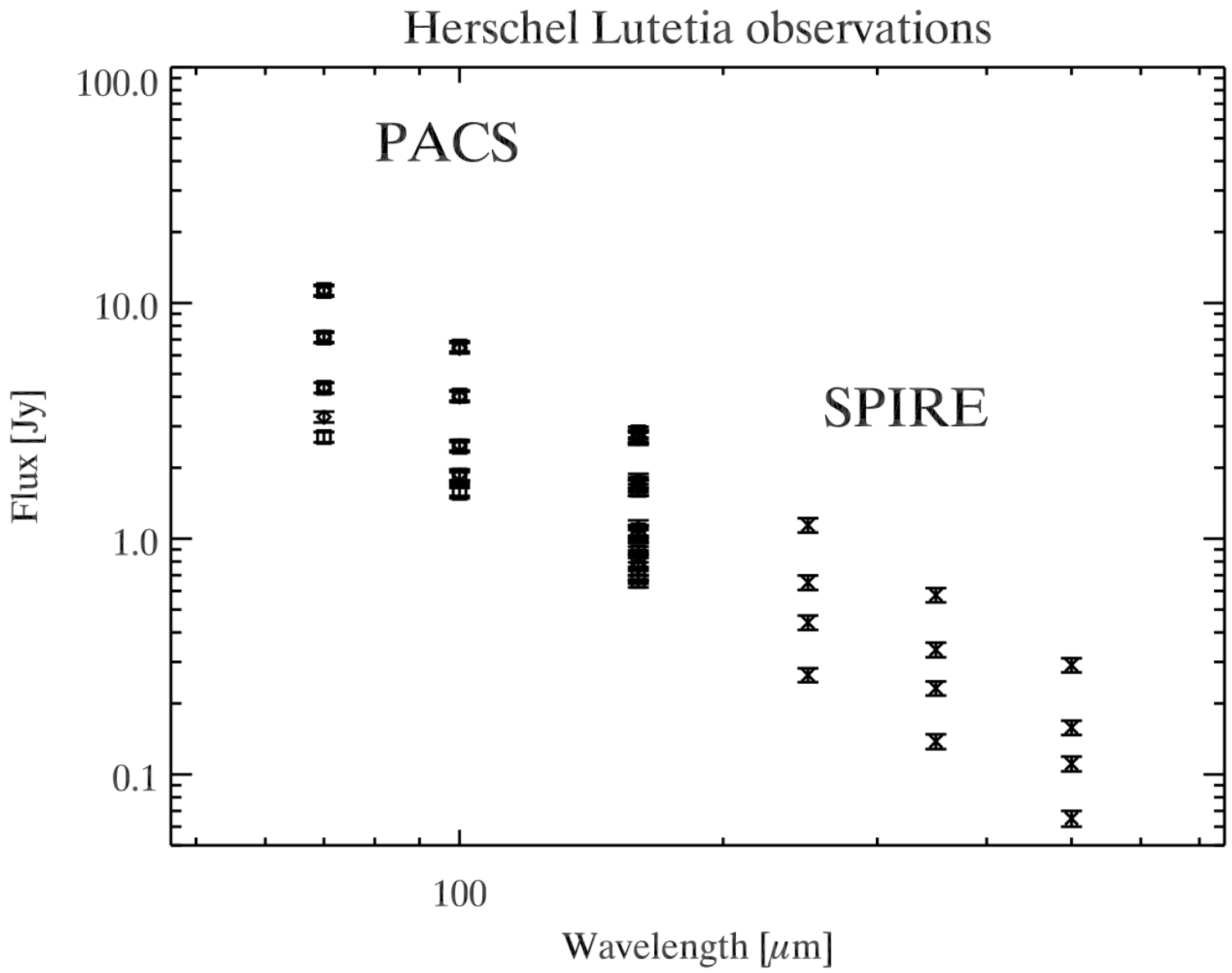
21 Lutetia (Rosetta)

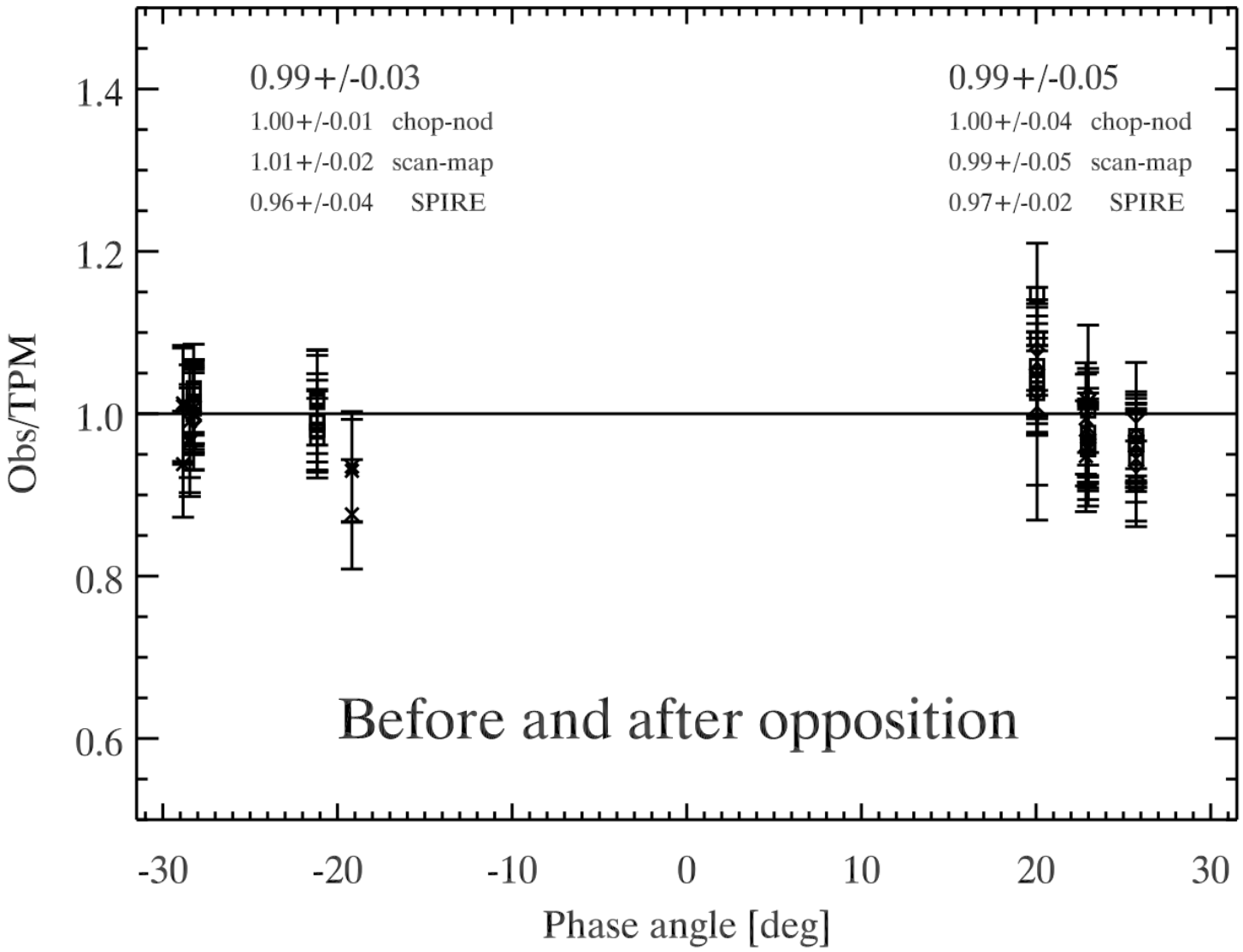
- shape model, spin-axis orientation, rotation period: derived from Rosetta flyby, adaptive optics images, lightcurve inversion (DAMIT, Carry et al. 2012)
- H-G values (Belskaya et al. 2010, A&A)
- Size from the Rosetta-mission (Schulz et al. 2012; Carry et al. 2012)
- albedo from Rosetta measurements (Sierks et al. 2011)
- thermal properties, roughness (Müller & Lagerros 2002; O'Rourke et al. 2012)

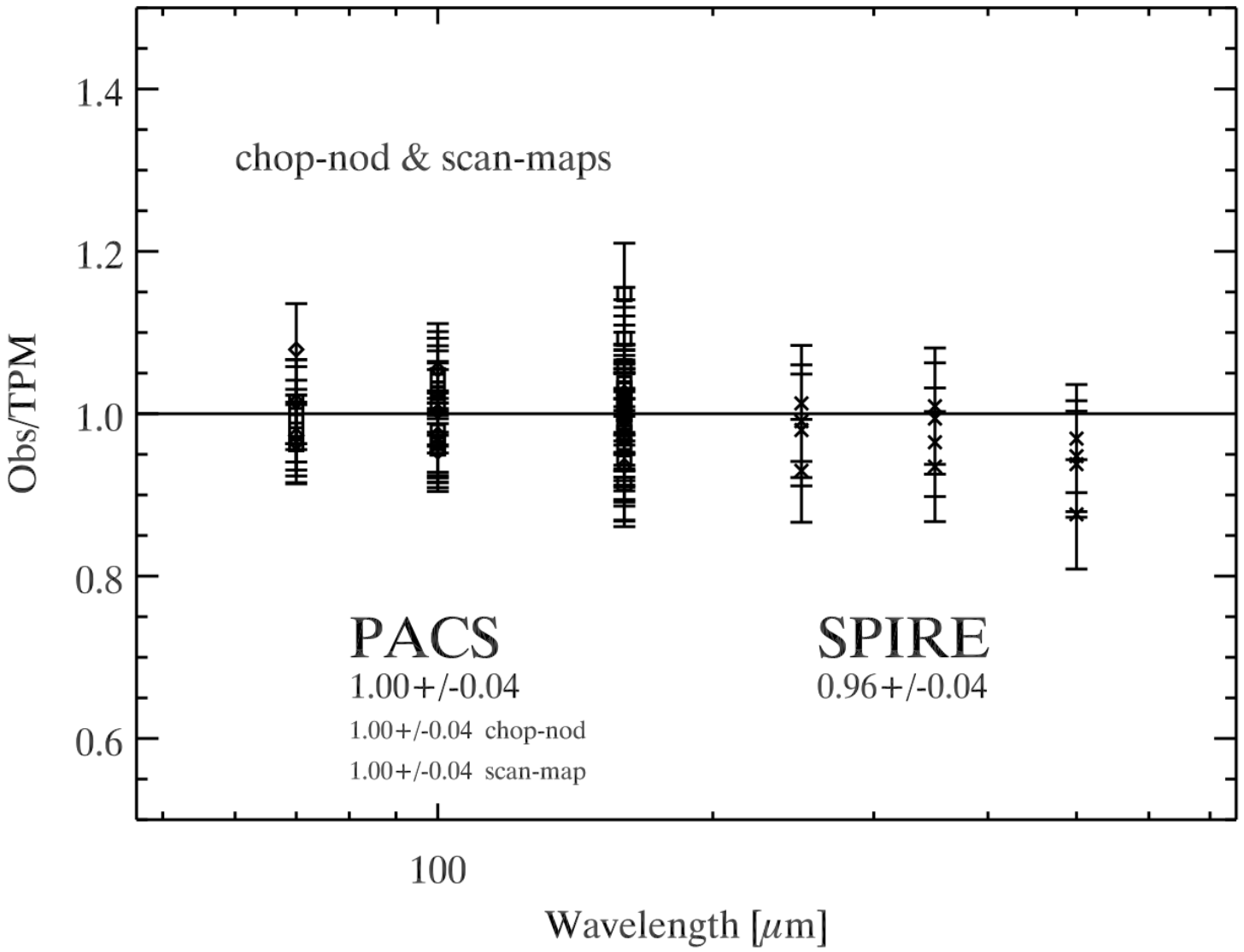


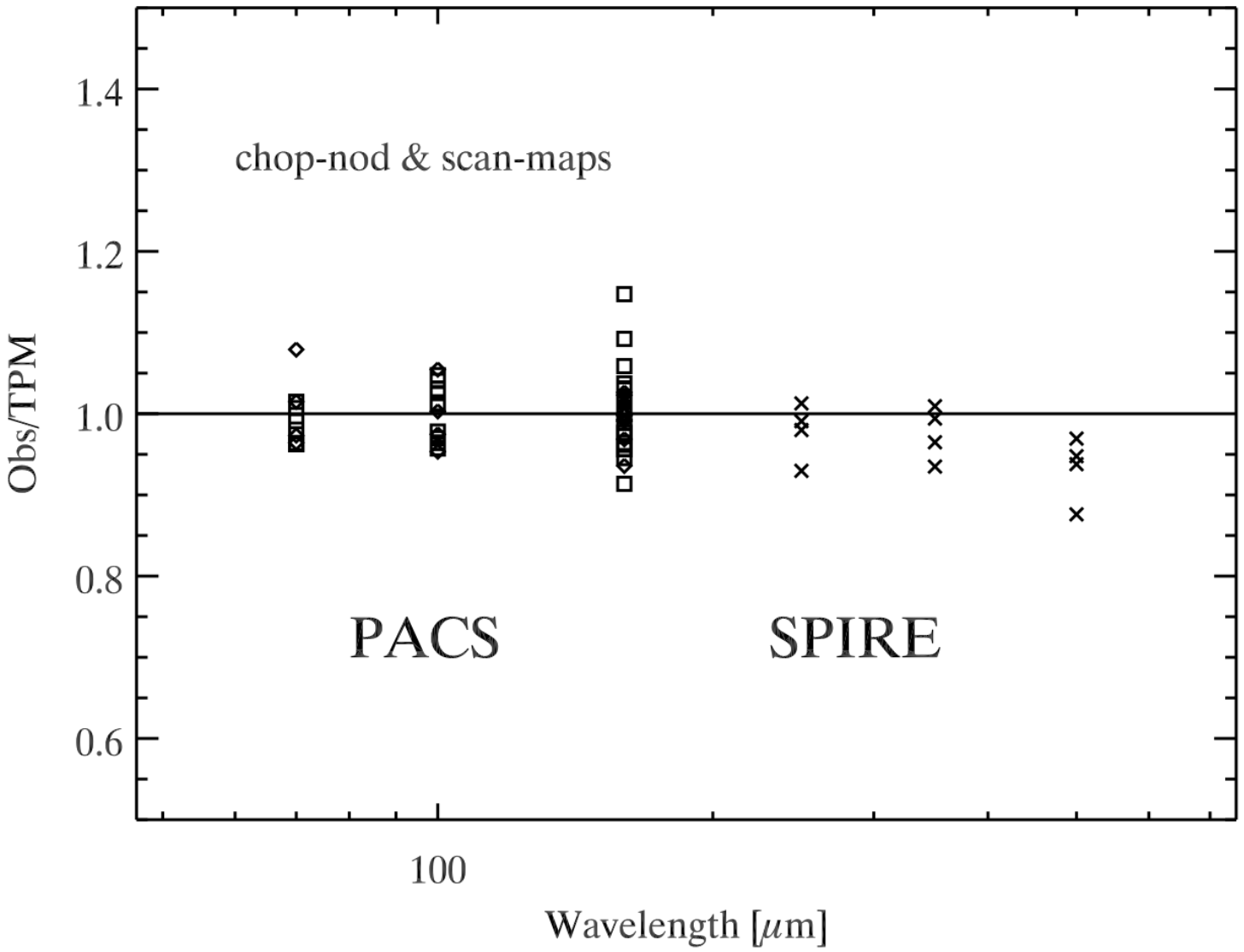
21 Lutetia O'Rourke, Müller et al. 2012

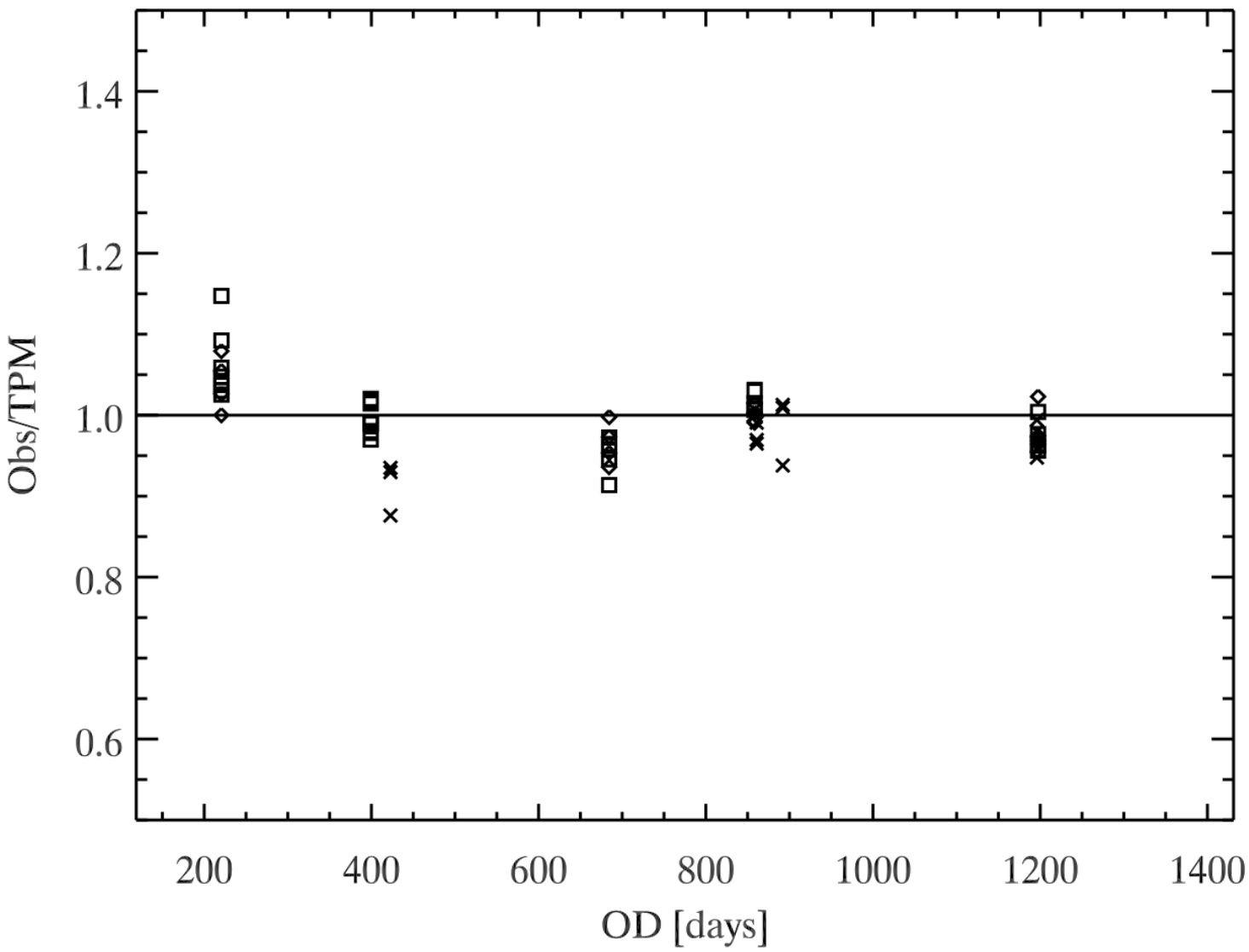

21 Lutetia
with
thermal inertia
without
thermal inertia
70 micron [Jy]
19-Sep-2011 (UT)
12.5
12
11.5
11
10.5
10
9.5
12
13
14
15
16
17
18
19
20
21


Herschel Lutetia observations
PACS
SPIRE
100.0
10.0
1.0
0.1
Flux [Jy]
100
Wavelength [μm]


0.99+/-0.03
1.00+/-0.01 chop-nod
1.01+/-0.02 scan-map
0.96+/-0.04 SPIRE
0.99+/-0.05
1.00+/-0.04 chop-nod
0.99+/-0.05 scan-map
0.97+/-0.02 SPIRE
Before and after opposition
Obs/TPM
1.4
1.2
1.0
0.8
0.6
-30
-20
-10
0
10
20
30
Phase angle [deg]


chop-nod & scan-maps
Obs/TPM
1.4
1.2
1.0
0.8
0.6
PACS
1.00+/-0.04
1.00+/-0.04 chop-nod
1.00+/-0.04 scan-map
SPIRE
0.96+/-0.04
100
Wavelength [μm]


chop-nod & scan-maps
1.4
1.2
1.0
0.8
0.6
Obs/TPM
PACS
SPIRE
100
Wavelength [μm]


1.4
1.2
1.0
0.8
0.6
Obs/TPM
200
400
600
800
1000
1200
1400
OD [days]

Results

Object	PACS chop-nod	PACS scan-map	SPIRE	HIFI
(1) Ceres	1.00 ± 0.02	1.02 ± 0.02	1.00 ± 0.04	0.94 ± 0.02
observations	40	102	60	4
(2) Pallas	0.98 ± 0.03	1.00 ± 0.02	1.02 ± 0.02	—
observations	24	56	36	0
(4) Vesta	1.00 ± 0.04	1.02 ± 0.03	1.01 ± 0.02	—
observations	34	106	54	0
(21) Lutetia	1.00 ± 0.04	1.00 ± 0.04	0.96 ± 0.04	—
observations	16	40	12	0

With Ceres, Pallas, Vesta, and Lutetia we have established a completely independent and new set of primary flux calibrators for far-IR and submm-wavelengths, connecting the NIR/MIR stellar calibration with the submm/mm U/N calibration, and connecting the high planetary flux regime with the much lower stellar flux regime.

Open Points

- final data reduction by instrument experts after end of Helium
- further updates of SPIRE flux calibration with new Uranus & Neptune models?
- further update of PACS flux calibration after stellar model modifications? PACS chop-nod data from observations before OD200 have too high fluxes (not yet corrected)
- small correction for the changing telescope flux for PACS data
- update of Vesta model after release of DAWN shape model
- test of validity of model: mid-IR range? mm-range? other phase angles? other aspect angles?
- test against thermal measurements from other missions: ISO, Akari, Spitzer and groundbased data at mir-IR and submm/mm wavelengths (ongoing)
- HIFI fluxes of Ceres are not final: H/V beam offsets and a potential revision of the aperture efficiencies could increase the fluxes by 3-4%

Re-calculation of all Ceres, Pallas, Vesta, Lutetia models for all Herschel observing epochs foreseen.