TNOs are Cool: A survey of the trans-Neptunian region. Results from the combined Herschel PACS and SPIRE observations of 9 bright targets at 70-500 μm.

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TNOs are Cool: A survey of the trans-Neptunian region

TNOs are Cool:

- 373 hours allocated ;
- PACS photometry at 70/160 and 100/160 microns of ~140 objects
- SPIRE observations at 250, 350 and 500 micron for the brightest targets (13 objects)

This talk will focus on the combined PACS+SPIRE observations of 9 bright targets:

2 Centaurs (Chiron and Chariklo)

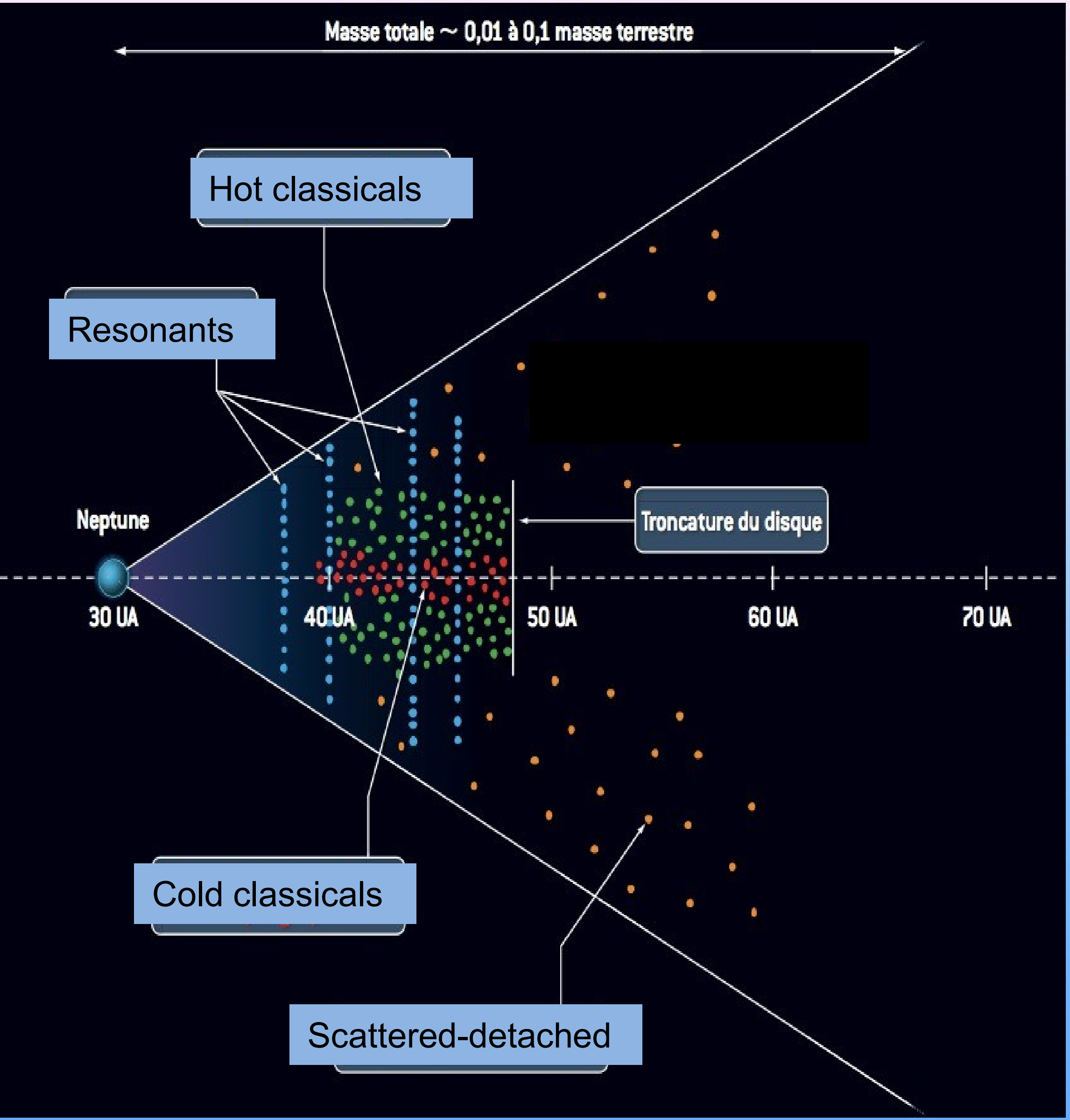
6 TNOs: 2 plutinos (Orcus, and Huya) + 3 classicals (Quaoar, Salacia, and 2002 UX25), a 2:5 resonant object (2002 TC302)

1 dwarf planet : Haumea

Themal modelling (NEATM and TPM):

the color corrected PACS and SPIRE fluxes, combined with available Spitzer observations at 24 and 70 micron, have been modeled with the NEATM

and TPM thermal models, in order to derive size, albedo and thermal properties (thermal inertia and surface emissivity, surface roughness) of the targets



Kuiper Belt:

- Sun's debris disk
- Frozen remnants of accretion epoch
- Source of JFCs (Centaurs)
- Dynamically structured
- Nknown = >1600 KBOs
- N = 5x10^4 (D>100 km)

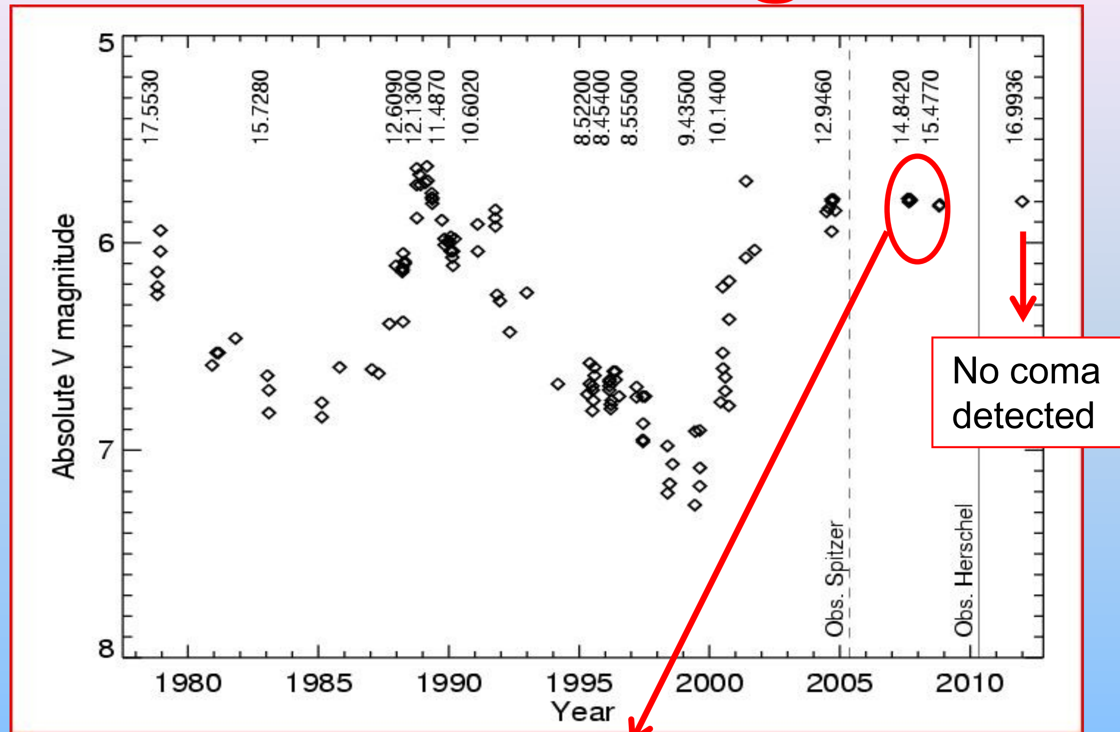
Chiron: the Hv absolute mag.

$$D = \frac{2 \times 10^{V_\odot/5} \times 10^{-H_V/5}}{\sqrt{p_V}} \times 1\ \mathrm{AU/km}$$

Hv was estimated from the analysis of previous data and on new observations at the 1.2m Calar Alto telescope on Dec. 2011

Hv=5.80 ± 0.04

No coma detected

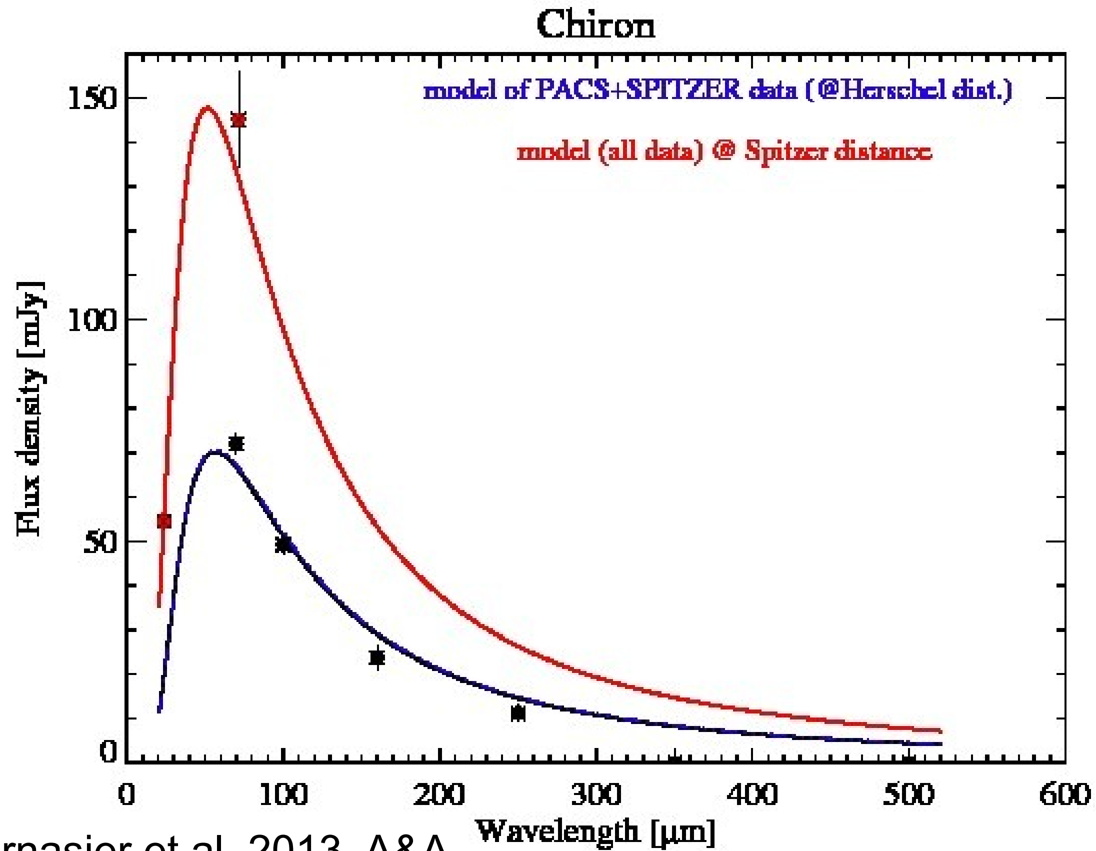


Reanalysis of 2007-2008 Chiron deep images taken at the VLT shows the presence of a faint coma with Afρ = 650±110 cm
The coma contribution is less than 10% of the Chiron flux
The adopted nuclear Chiron magnitude is H=5.92 ± 0.20

This high brightness may result from resurfacing following an activity outburst, or from an unresolved evolving coma

2060 Chiron: size and albedo

	Herschel	Spitzer
R_{sun}	16.28 AU	13.46 AU
Δ	16.67 AU	13.24 AU
Hv	5.92 ± 0.20	6.58



Fornasier et al, 2013, A&A

NEATM on COMBINED SPITZER AND HERSCHEL DATA GIVES

$p_V(\%) = 16.7^{+3.7}_{-3.0}$

D = 216 ± 10 km

$\eta = 0.95^{+0.09}_{-0.10}$

Stansberry et al. 2008

$p_V(\%) = 7.57^{+1.03}_{-0.87}$

D = 233 ± 14 km

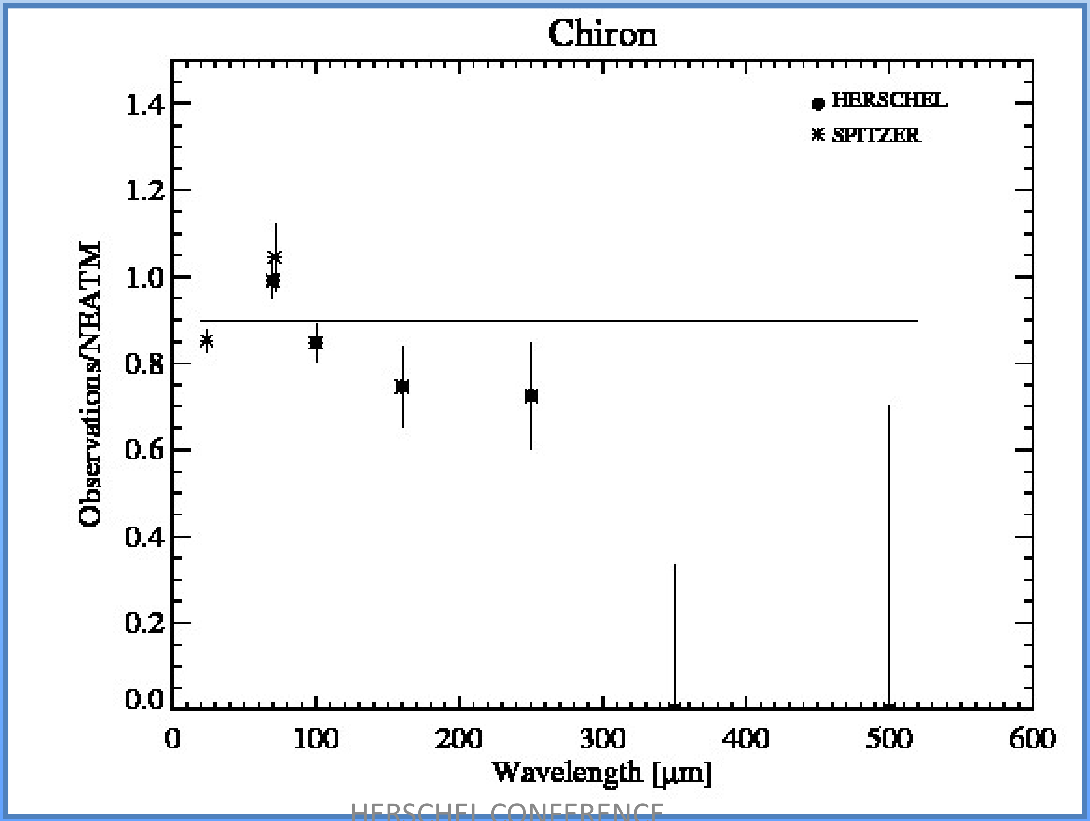
η = 1.13 ± 0.13

From occultations D> 180 km (Buie et al. 1993; Bus et al. 1996)

Chiron emissivity

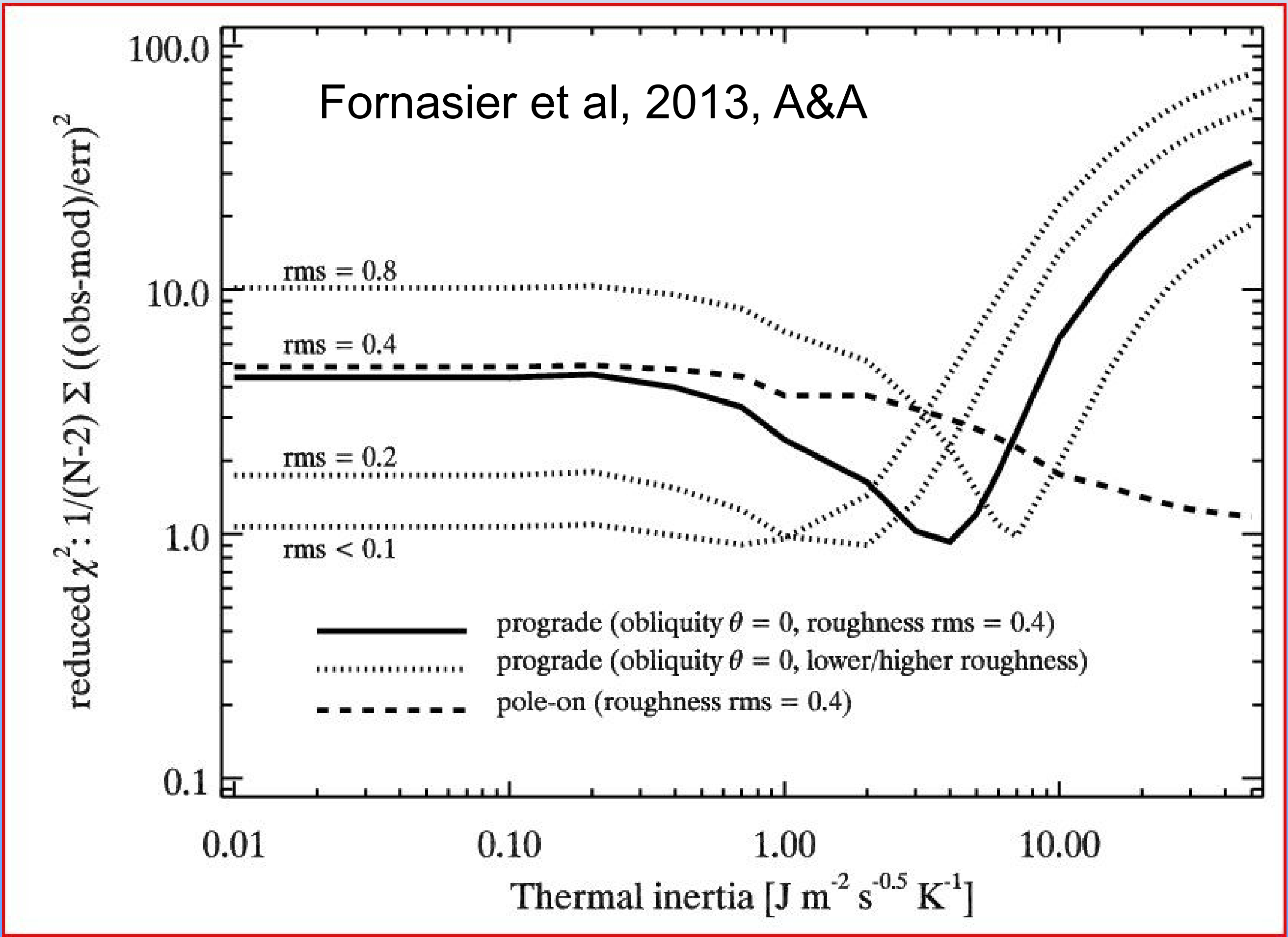
Emissivity decreases for λ > 100 micron: sub-mm thermal flux arises from sub-surface layers that are, on the dayside, colder than the surface itself.

The emissivity descrease may be due to size distribution effects of surface particles and/or to the presence of dusty and porous regolith in which backscattering within the subsurface reduces the outgoing emission (Redman 1992)



TPM analysis

- TPM with wavelength dependent emissivity derived from SED of Vesta
- Degeneracy between surface roughness and thermal inertia Γ
- Not enough data to constrain the spin vector orientation



198 < D < 238 km

13 < p_v < 19%

Γ < 3 (smooth surf.)

5< Γ <10 (rough surf.)

Upper limits in the dust production rate

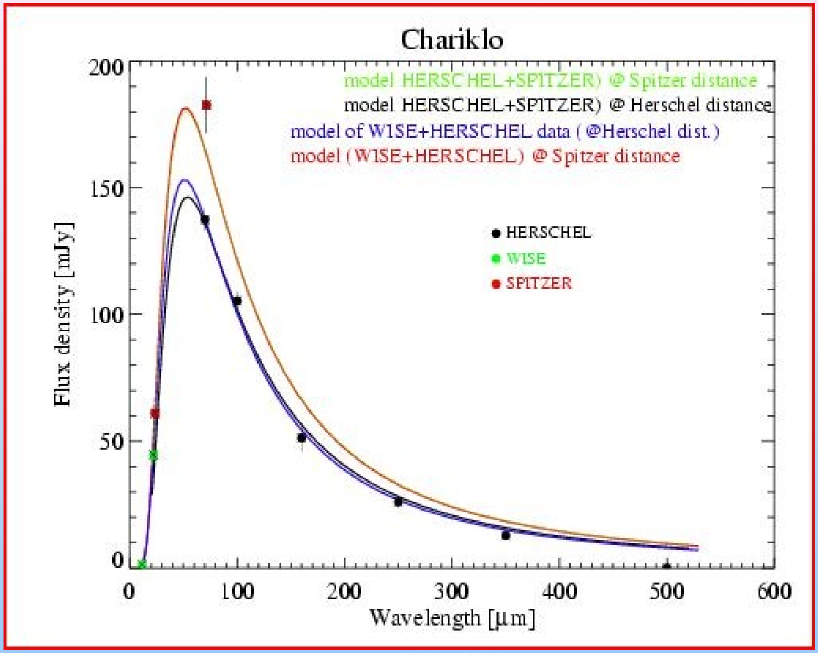
- No coma was detected in the HERSCHEL PACS images at 70 and 100 µm from the comparison of Chiron and stars FWHM

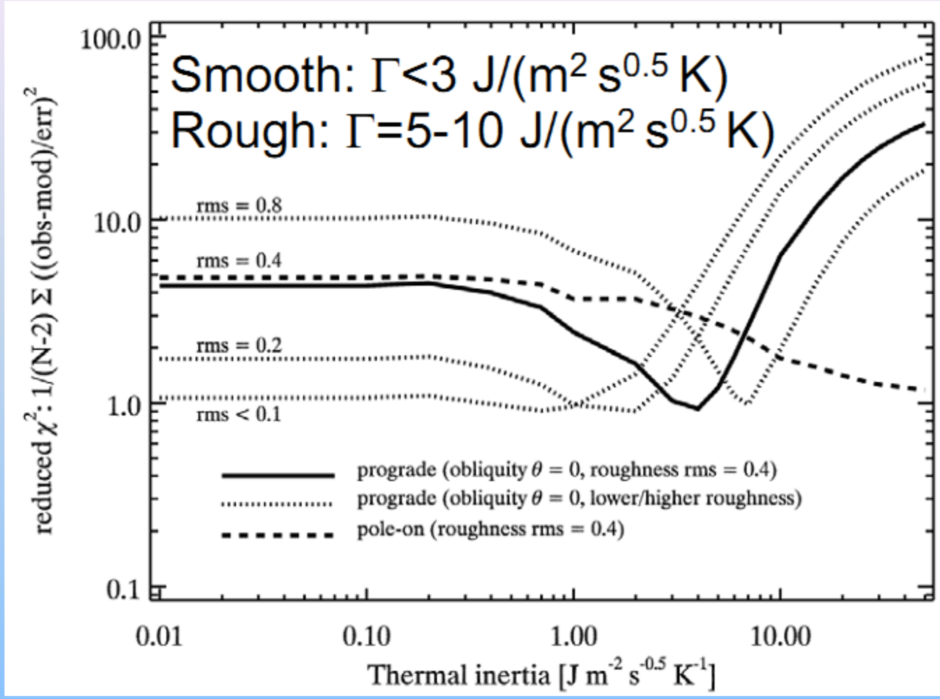
- From PACS 70 µm images the dust production rate is < 10-47 kg/s depending on the outgassing model and dust composition (carbon or olivine grains)

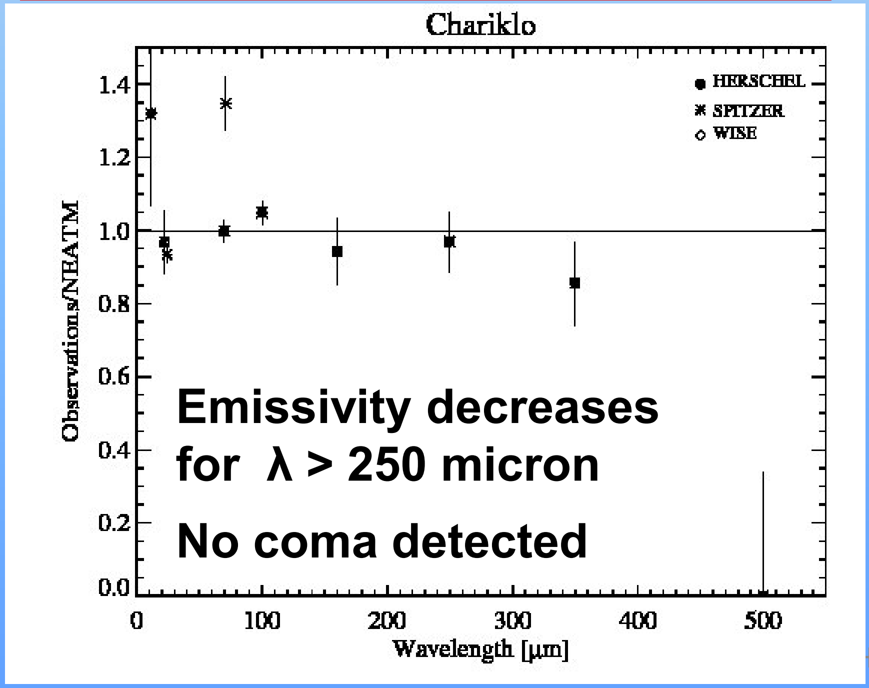
- Considering the VLT visual data from 2007-2008, a stringent dust production rate of 0.6-17 kg/s is found using the same dust size distribution and velocities used to interpret PACS data.

- The dust to gas ratio is < 0.04 , 2 order of magnitude lower than values estimated for km sized cometary nuclei

10199 Chariklo





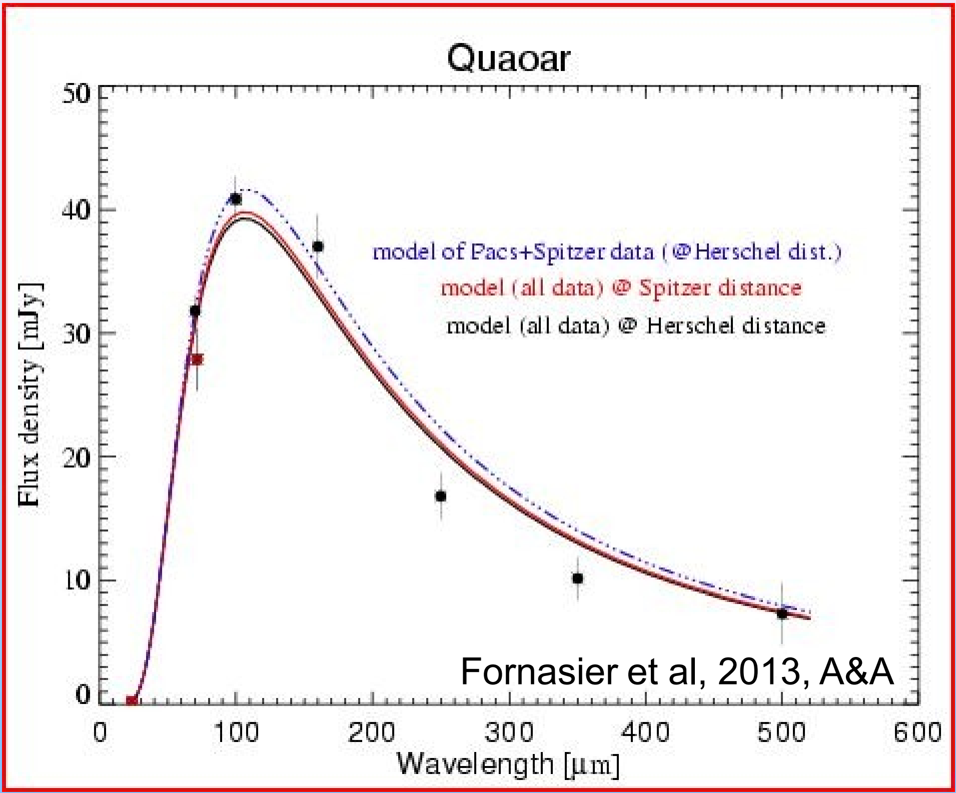


Emissivity decreases for λ > 250 micron

No coma detected

D=248+/-18 km (largest Centaur)
pV=3.5+/- 1.0 %
η=1.07-1.20
Γ=3-30 J/(m² s^0.5 K)
Orientation: equator-on

Classical TNO: 50000 Quaoar



R_{sun} = 43.14 AU (Sp.=43.31)
Δ = 43.36 AU (Sp.=43.14)
H=2.73 ± 0.06

RESULTS:

p_v (%) = 12.7 ± 1.0

D = 1074 ± 38 km

η = 1.73 ± 0.08

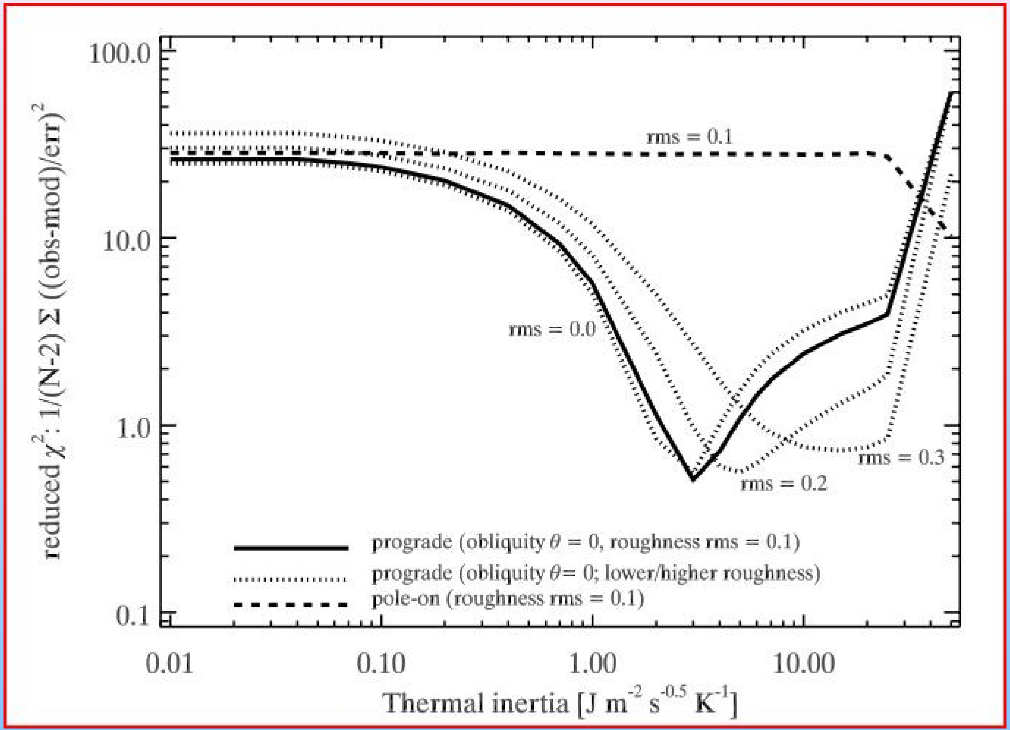
ηmean = 1.47 ± 0.43 (19 classicals, from Vilenius et al 2012)

Previous size estimates:

Hubble direct: 1260 ± 190 km (Brown & Trujillo 2004); 870±70 km (Frazer &Brown 2010)
Spitzer radiometric: 844 ± 207 km (Stansberry et al. 2008)
Spitzer radiometric: 908 ± 118 km (Brucker et al. 2009)

New occultation effective size estimate: 1111 ± 5 km (Braga-Ribas et al. 2013)

Classical TNO: 50000 Quaoar



From TPM analyses:

Th_inertia = 2-10 in SI

smooth surface

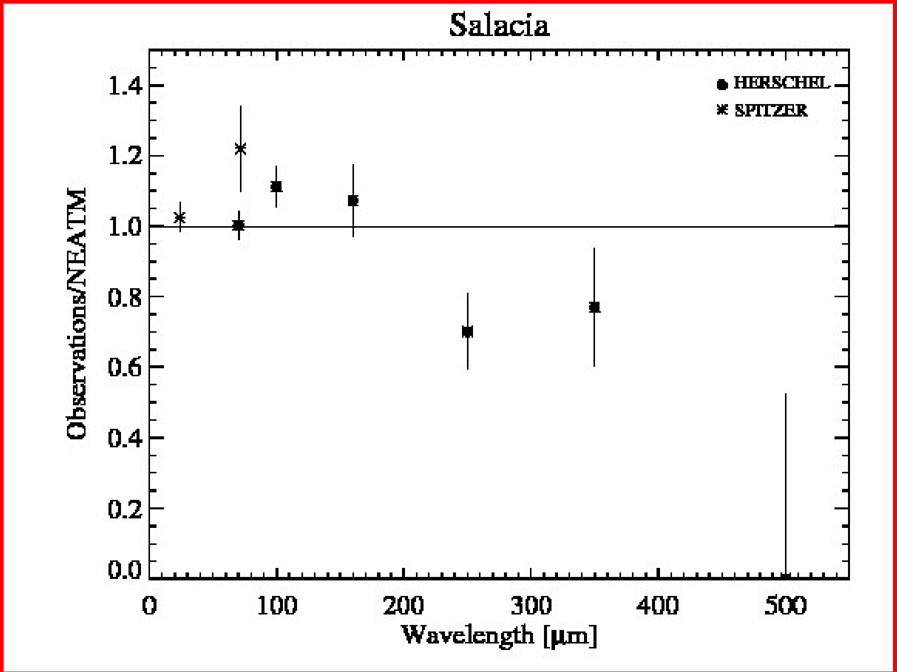
Spin orientation: not pole-on

Quaoar is a binary system of known mass (1.6 ± 0.3) x10^{21} kg with a smaller companion, Weywot.
With the size determined from Herschel data we derive a density of 2.2± 0.5 g/cm^3, similar to that of Pluto (Frazer & Brown (2010) got an unlikely density of 4.2±1.3 g/cm^3, from their HST Quaoar size estimation). Assuming the same albedo for the 2 bodies, we derive a diameter of 1070 ± 38 km for Quaoar, and 81 ± 11 km for Weywot.

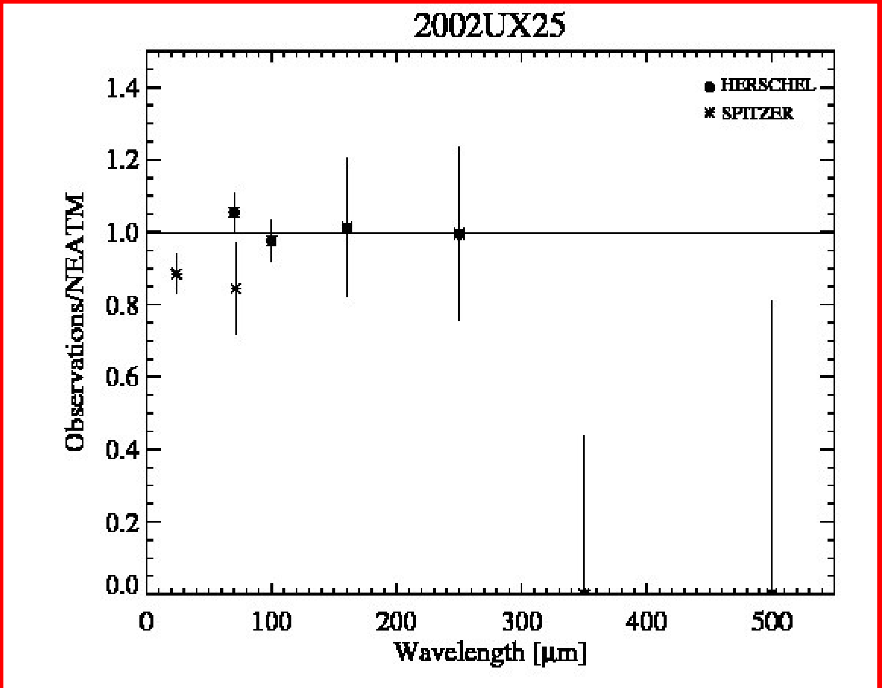
Classicals: Salacia and 2002 UX25

Object	D (km)	pV (%)	η	primary(km)	secon.(km)	density (g/cm^3)
Salacia	901±45	4.4	1.16	854±45	286±24	1.29±0.29
2002 UX25	698±24	10.7	1.07	665±29	210±30	--

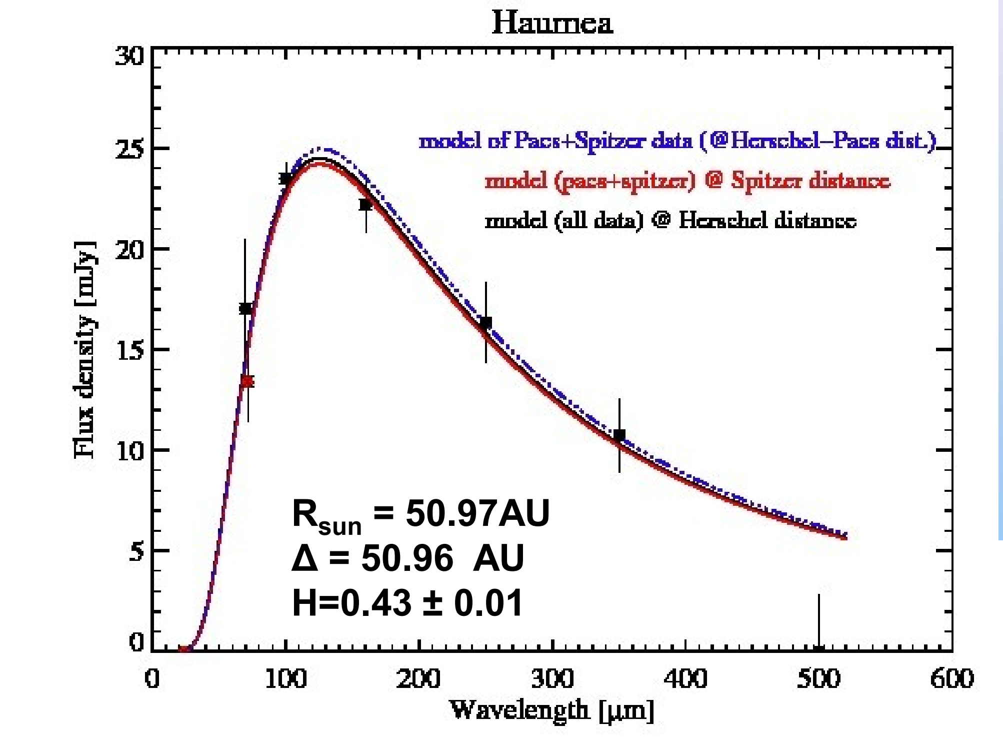
Strong emissivity decrease for λ > 200 micron



Emissivity decrease for λ > 250 micron



Dwarf planet: HAUMEA



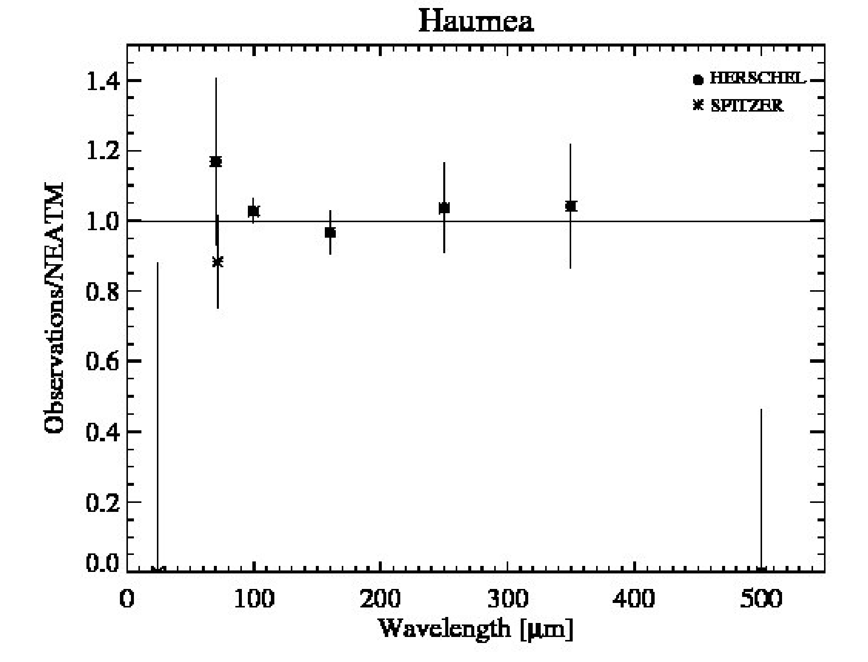
R_{sun} = 50.97AU
Δ = 50.96 AU
H=0.43 ± 0.01

RESULTS NEATM:

p_v (%) = 80 $^{+6}_{-10}$

D = 1240 $^{+69}_{-59}$ km

η = 0.95$^{+0.33}_{-0.26}$

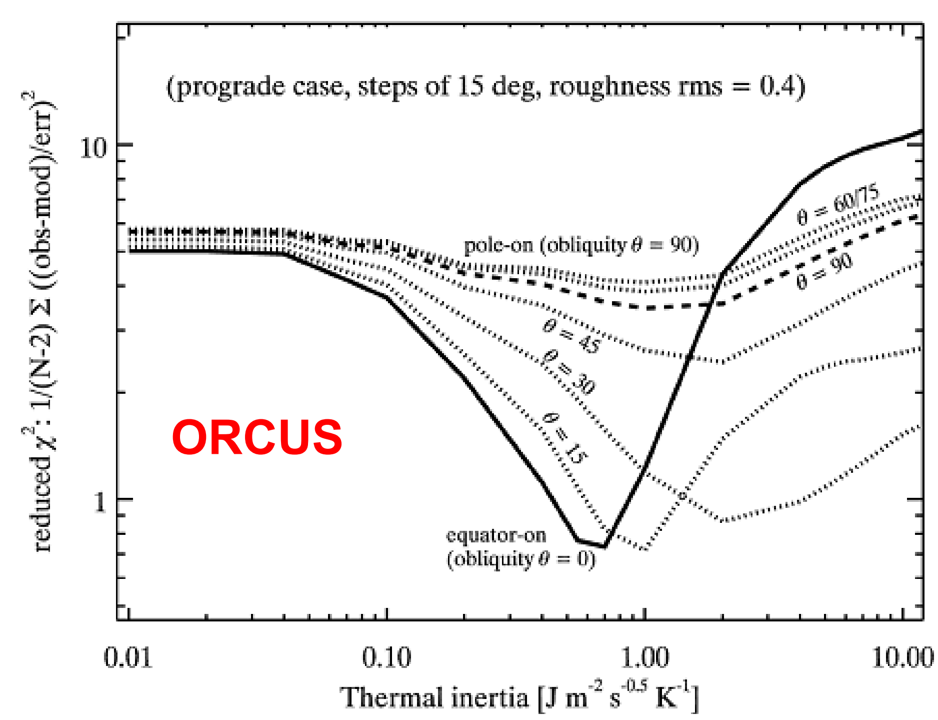


Emissivity effects begin at λ > 400 μm

Resonants: Orcus, Huya, and 2002 TC302

Object	D (km)	pV (%)	η	primary(km)	secon.(km)	Class
Huya	458±9	8.3	0.93	406±16	213±30	Plutino
2002 TC302	584±100	11.5	1.09	--	--	2:5 res.
Orcus	958±23	23.1	0.97	917± 25	276±17	Plutino

Measured albedos of Plutinos (N=18): 4-28 % (size range 150-730 km) (Mommert et al. 2012)



Orcus:

near equator on

Very low thermal inertia (0.5-2.0 J / ($m^2 s^{0.5}$K), consistent with a beaming factor close to 1

Orcus/vanth system:

Density = 1.53±0.15 g/cm^3

Conclusions: 1/2

- New precise size/albedo solutions for 9 TNOs / Centaurs observed by SPIRE + PACS onboard the Herschel Space Observatory

- Chiron has a higher albedo than previously thought: p_V=16 ±3 %

  no coma was detected on the PACS images and we derived a dust to gas ratio < 0.04, 2 order of magnitude lower than values from km-sized comets

- We confirm that Chariklo is the largest Centaur (D=248 ±18 km) with a low albedo surface (2.5%<pV<4.5%); no coma was detected and we constrain its spin axis orientation and thermal inertia (3-30 $J/(m^2 s^{0.5} K)$)

- Our radiometric size estimation of Quaoar (1074 ±38km) is the most accurate obtained so far, and in agreement with the size derived from occultation. This validates the use of NEATM model for Centaurs and TNOs

Conclusions: 2/2

- Orcus is another 1000 km sized object (D=958 km); its surface is smooth with a low thermal inertia value (0.5-2.0 J/(m2s0.5K)).

- Bulk densities of big TNOs are increasing with size: Salacia 1.29 g/cm3 (D=901 km), Orcus 1.53 g/cm3 (D=958 km), Quaoar 2.20 g/cm3 (D=1074 km).

- Emissivity effects at λ > 250 μm are clearly seen on several bodies: SPIRE probes deeper layers and sees a diurnally-averaged temperature
  The decrease of the emissivity may be related to size distribution effects of surface particles or to the presence of a dusty and porous regolith (Redman et al. 1992)

THANKS

MODELLING

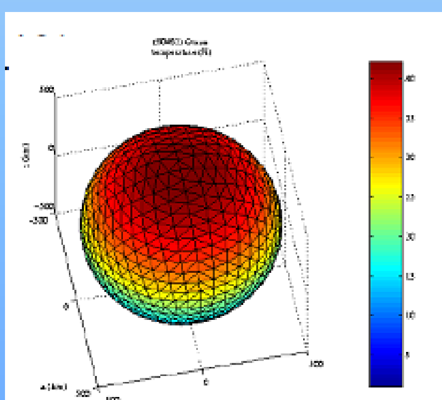
NEATM (Harris 1988)

$$T_{SS} = \sqrt[4]{\frac{(1-A)S_0}{\epsilon\eta r^2}} \qquad \mathbf{T = T_{ss}\cos^{1/4}(\theta)}$$

- D, pv, η as free parameters
- Spherical shape
- Constant emissivity ε
- $A = p_V \times q$, where $q = 0.336 p_V + 0.479$
- Absolute magnitude used to determine D and p_V

$$D = \frac{2 \times 10^{V_\odot/5} \times 10^{-H_V/5}}{\sqrt{p_V}} \times 1\ \mathrm{AU/km}$$

η ~1 : thermal inertia effects ~0
η >>1 : important thermal inertia effects
η < 1 : "beaming" (surface roughness effects)



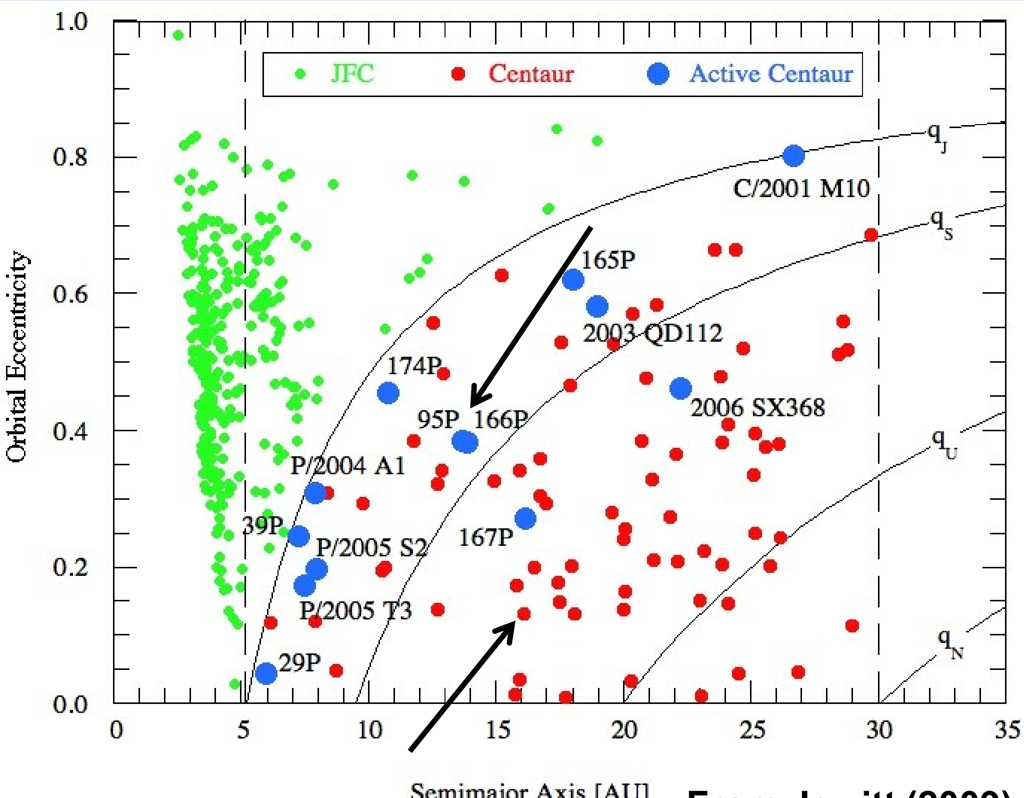
Thermophysical model (TPM, Lagerros 1988)

- Any shape model possible (often an ellipsoid)
- Wavelength-dependent emissivity possible
- Can solve or constrain spin vector orientation, thermal inertia and surface roughness

Both for NEATM and TPM models we used also the SPITZER-Mips 24 and 71 μm fluxes.

Centaurs

- Centaurs are a transitional population between TNOs and Jupiter family comets with short lifetime (their median orbital lifetime is 10 Myr)
- More than 450 Centaurs discovered, but estimations give > 40000 Centaurs bigger than 1 km in diameter



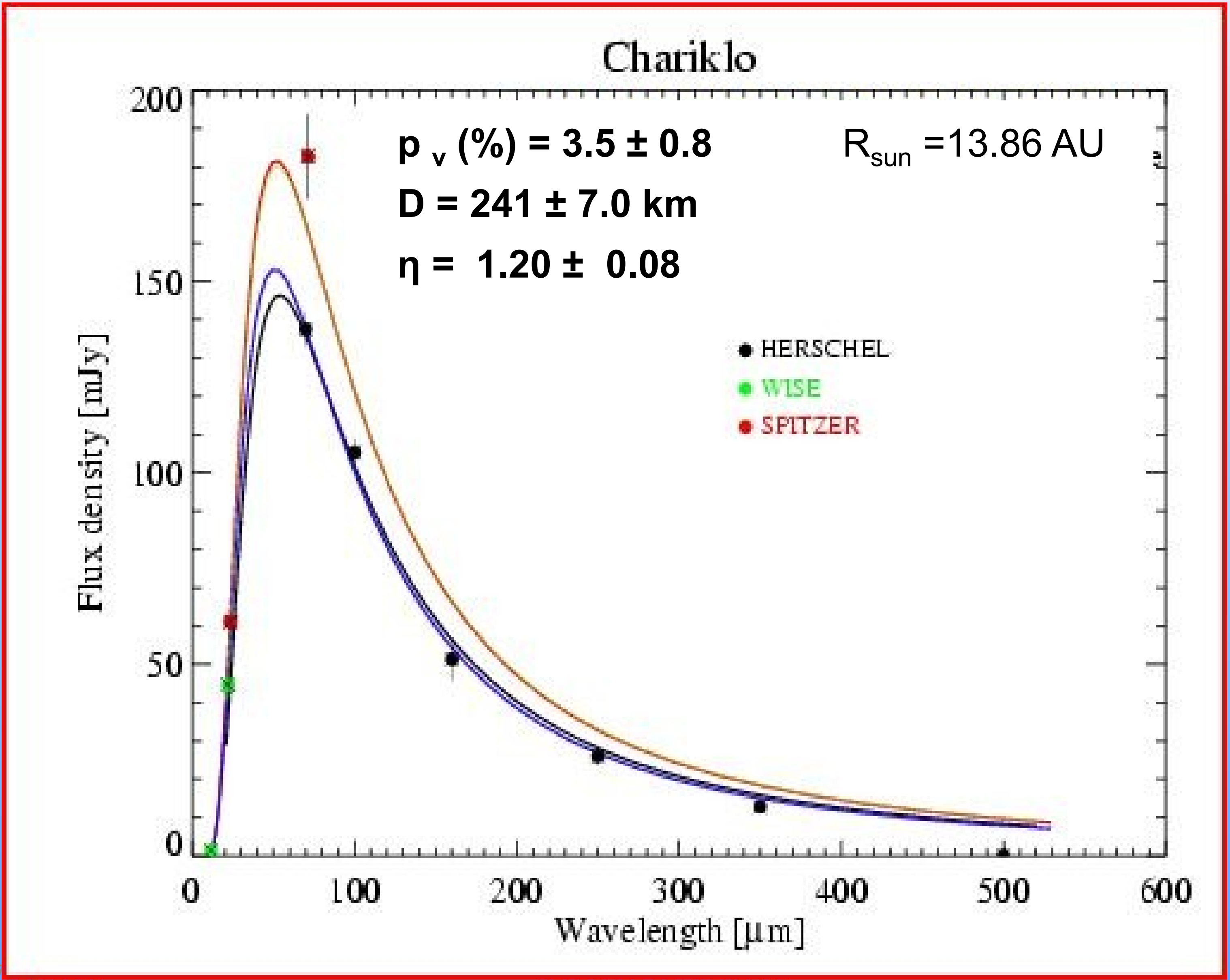
From Jewitt (2009)

Observed with PACS &SPIRE:

(2060) Chiron was the first Centaur discovered, in 1977. Also named 96P/Chiron because of its cometary activity in the past

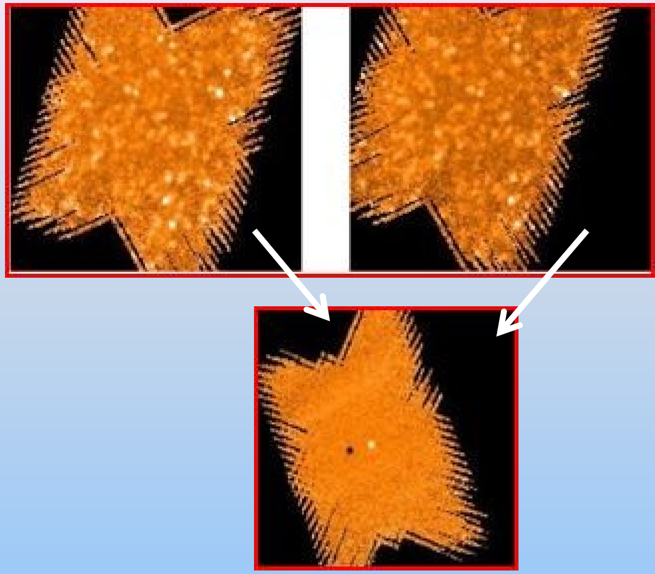
(10199) Chariklo, the larger Centaur

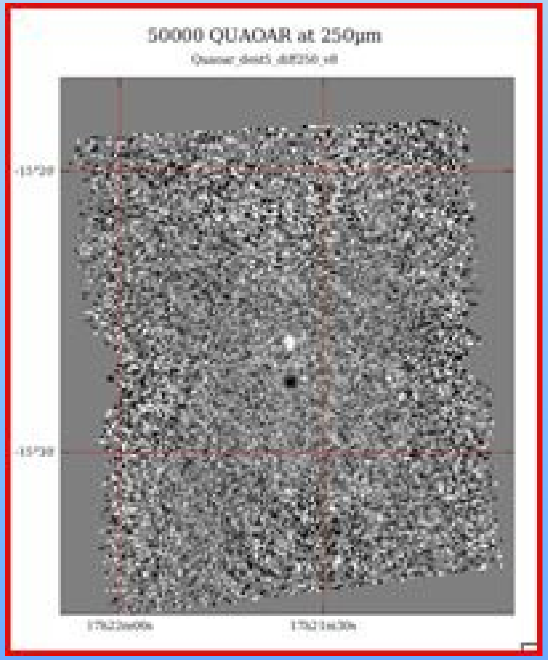
10199 Chariklo



HERSCHEL: Observing strategy

For both PACS and SPIRE observations each target is observed twice (first visit plus a follow-on):
- similar observation repeated 0.5-2 days later
-generate the map of the 2 epochs with the same sky projection and subtract one to the other



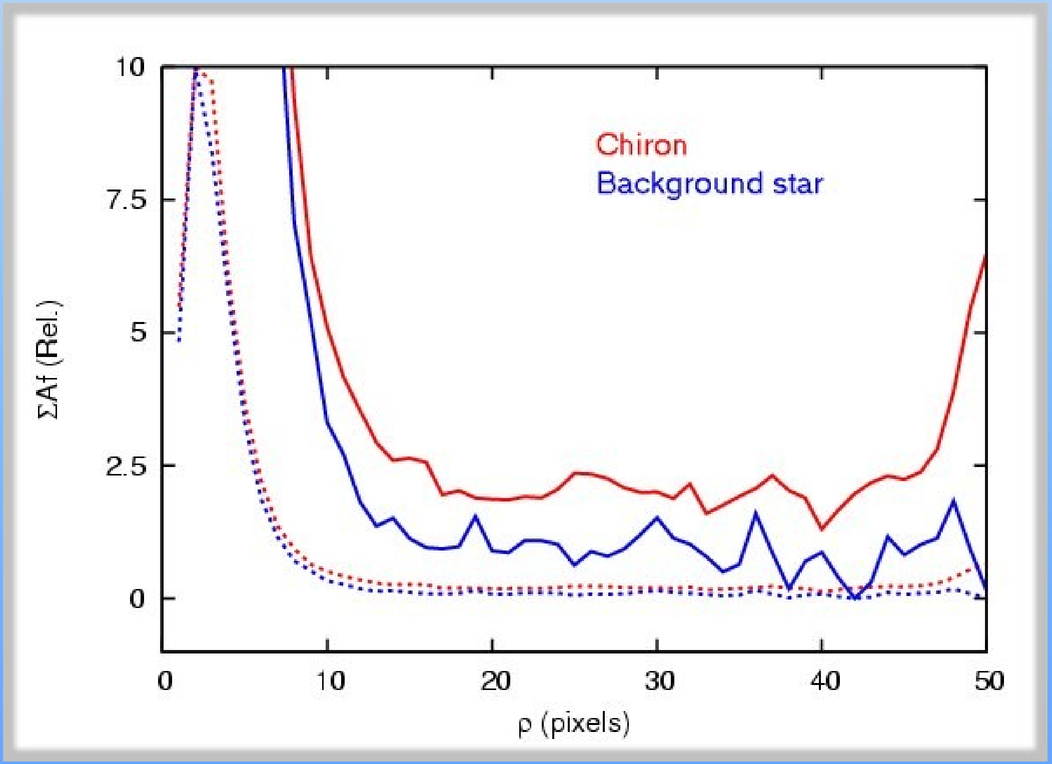


-With Pacs flux extracted by aperture photometry, with SPIRE by fitting a gaussian of fixed FWHM (17.6" @250μm, 24.9" @350μm, 35.2" @500μm)

- Flux are corrected for the pixelisation factor and color corrected

Hv: the coma contribution

- Reanalysis of 2007-2008 Chiron deep images taken at the VLT shows the presence of a faint coma
- Afρ = 650±110 cm
- The coma contribution is less than 10% of the Chiron flux
- The adopted nuclear Chiron magnitude is H=5.92 ± 0.20



Upper limits in the dust production rate

- No coma was detected in the HERSCHEL PACS images at 70 and 100 μm from the comparison of Chiron and stars FWHM
- From PACS 70 μm images the dust production rate is < 10-47 kg/s depending on the outgassing model and dust composition

Q_{gas} (s^{-1})	Outgassing	a_{max} (μm)	v_d[a] ($m\ s^{-1}$)	α	Q_{dust}[b,c] ($kg\ s^{-1}$)
(1) 1×10^{28}	isotropic	0.14	89–99	−3	<10–14
(2) 5×10^{27}	$SSL < 45°$	0.47	89–143	−3	<14–17
(3) 3×10^{28}	$SSL < 45°$	2.76	89–206	−3	<25–29
(4) 1×10^{29}	$SSL < 45°$	9.20	89–240	−3	<23–47

$n(r) \propto r^{-2} a^{\alpha} / v(r)$

Carbon grains olivine grains

- Considering the VLT visual data from 2007-2008, a stringent dust production rate of 0.6-17 kg/s is found using the same dust size distribution and velocities used to interpret PACS data.
- The dust to gas ratio is < 0.04 , 2 order of magnitude lower than values estimated for km sized cometary nuclei