TNOs are cool: a survey of the trans-neptunian region

The thermal lightcurve of 136108 Haumea

E. Lellouch
and the TNOs are cool team

The “TNOs are cool” KP-OT program

- Measurements of the thermal emission of ~140 transneptunian objects

- Goals
  - Determination of diameter & albedo of a large sample of TNOs
    - Size distribution
    - Search for correlations (with other physical – color, composition… – & orbital properties), diagnostic of physical evolution
  - Detailed studies of a subset of objects (esp. brightest)
    - 6 - λ measurements (PACS+SPIRE) → SED study, thermophysical and emissivity properties
    - Search for *thermal lightcurves*

- Volume : 372 hr (~90 % PACS, 10 % SPIRE)

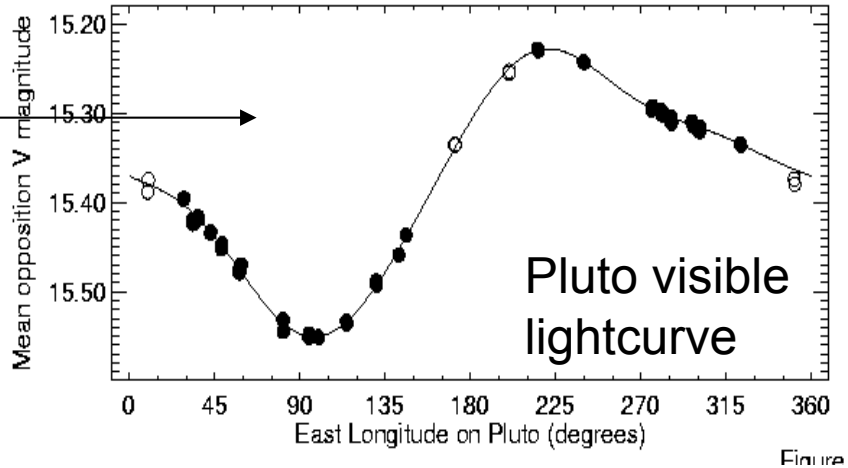
- **See talk by T. Müller on Friday morning**

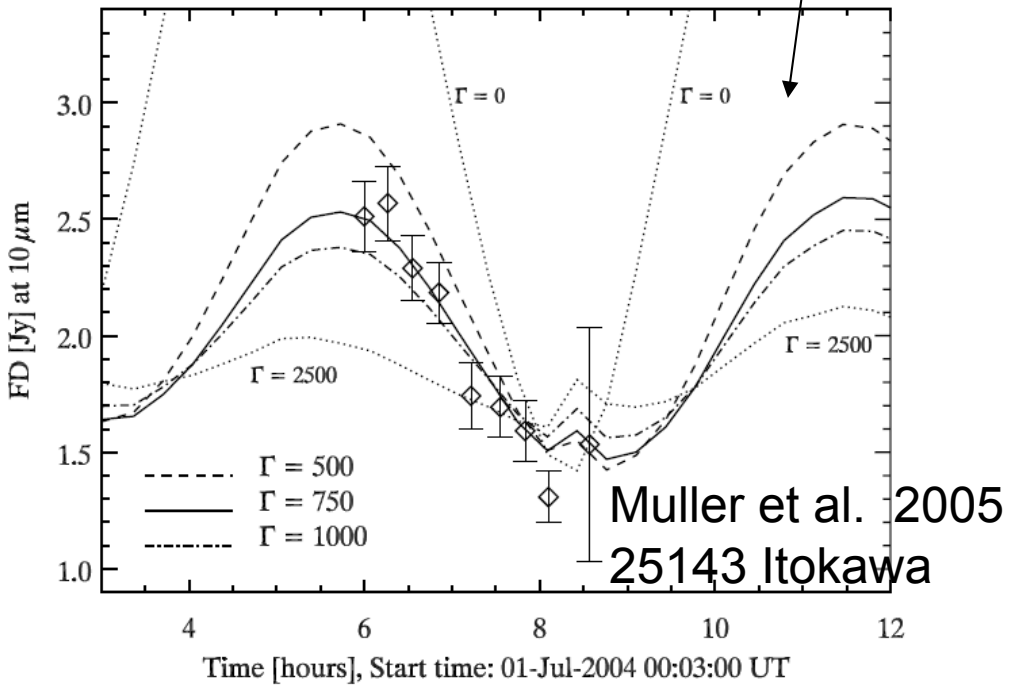
Why thermal lightcurves ?

Lightcurves (rotation) can be due to

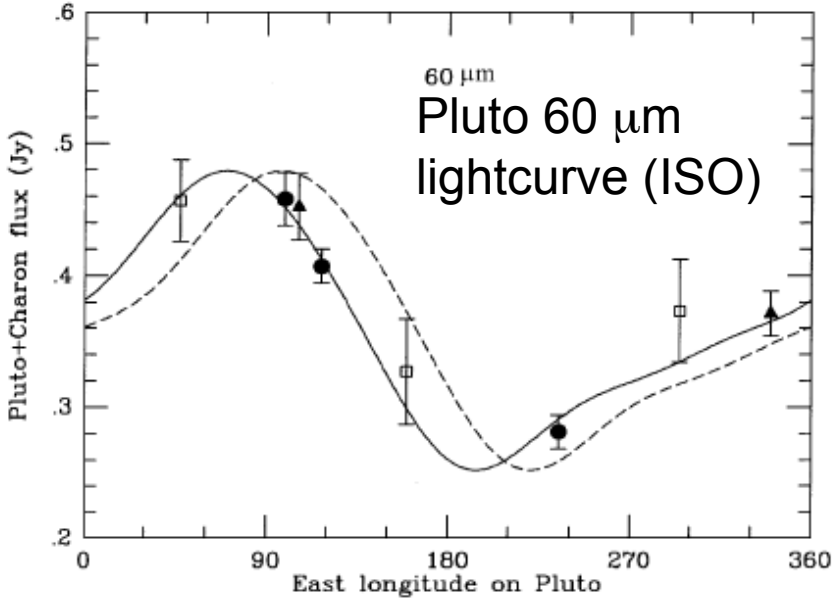
- Albedo effects (e.g. Pluto)
- Shape effects (asteroids)

in both cases, info. on thermophysical properties (thermal inertia)





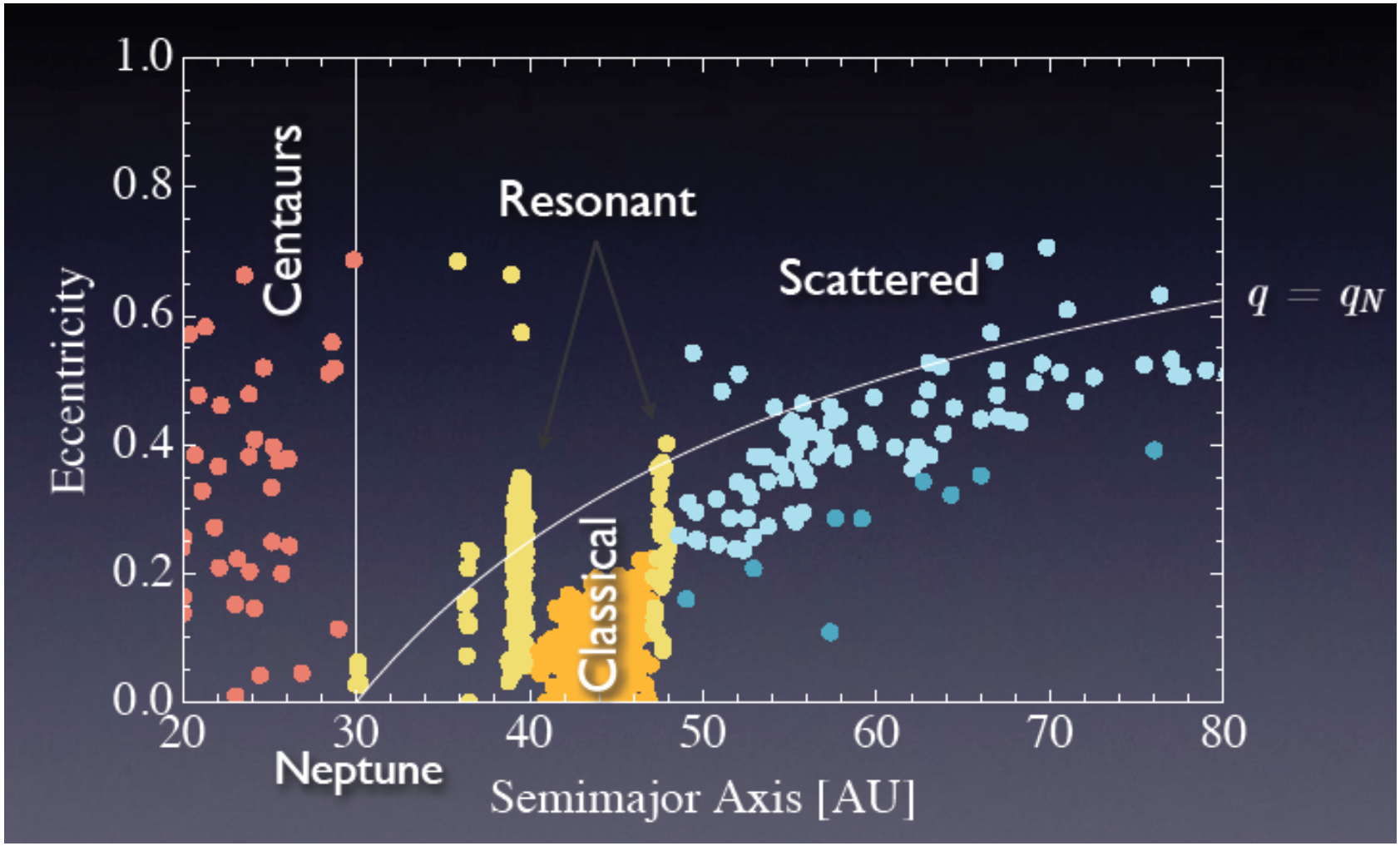
Muller et al. 2005
25143 Itokawa



Lellouch et al. 2000

136808 Haumea

- A “classical” TNO, a = 43.32 AU, e=0.19, currently at R_h = 51 AU, V~18



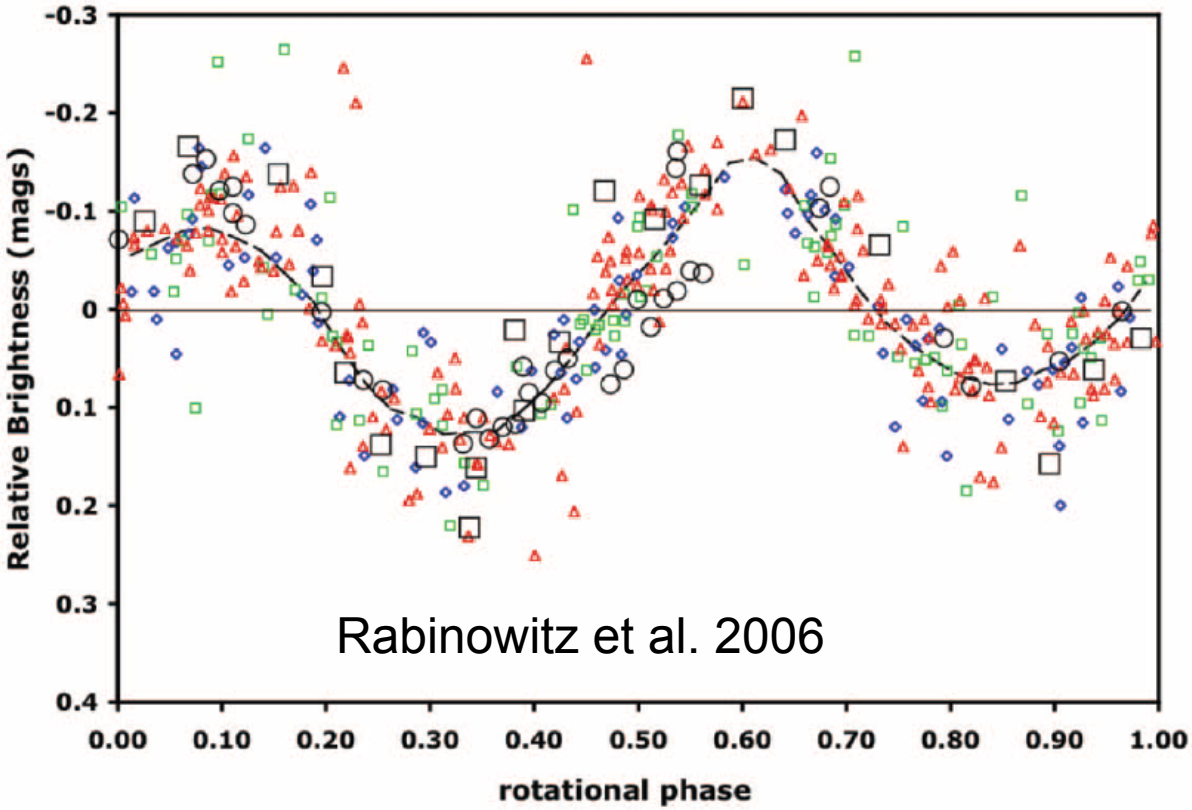
136808 Haumea, a remarkable object

- "Classical" TNO, a = 43.32 AU, e=0.19, currently at Rh = 51 AU

- *Large amplitude (Δm = 0.28 mag) lightcurve and fast rotation (P ~3.9 hr)*

→ *elongated shape (b/a ~ 0.8, c/a ~ 0.5) and large density (ρ ~2.6 g cm^{-3})*

(assuming hydrostatic equilibrium)



136808 Haumea, a remarkable object

- "Classical" TNO, a = 43.32 AU, e=0.19, currently at Rh = 51 AU
- Large amplitude (Δm = 0.28 mag) lightcurve and fast rotation (P ~3.9 hr)

→ elongated shape and large density (ρ ~2.6 g cm^{-3})

- *Two satellites*

→ *Mass known (1/3 Pluto)*

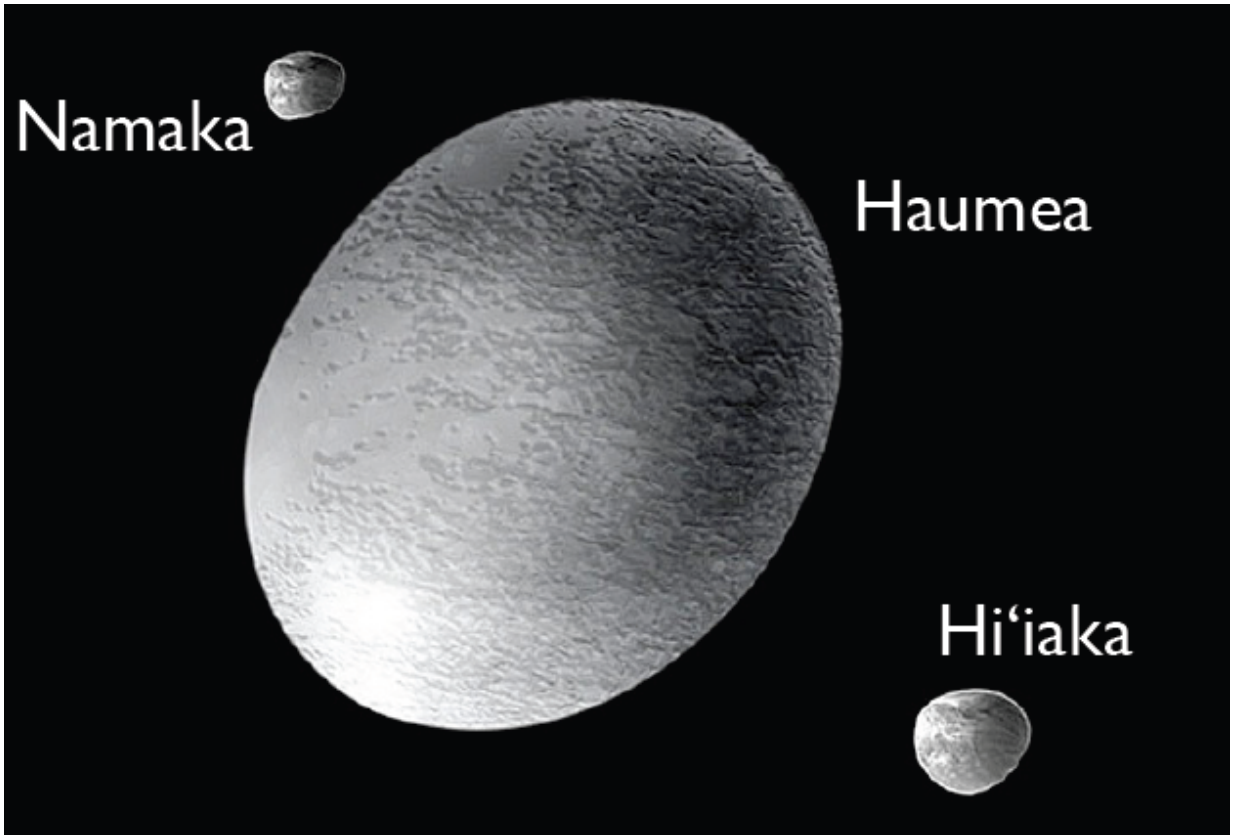
→ *Axe lengths:*

2000 x 1600 x 1000 km

Large albedo (> 60 %)

(also indicated from

Spitzer measurements)



136808 Haumea, a remarkable object

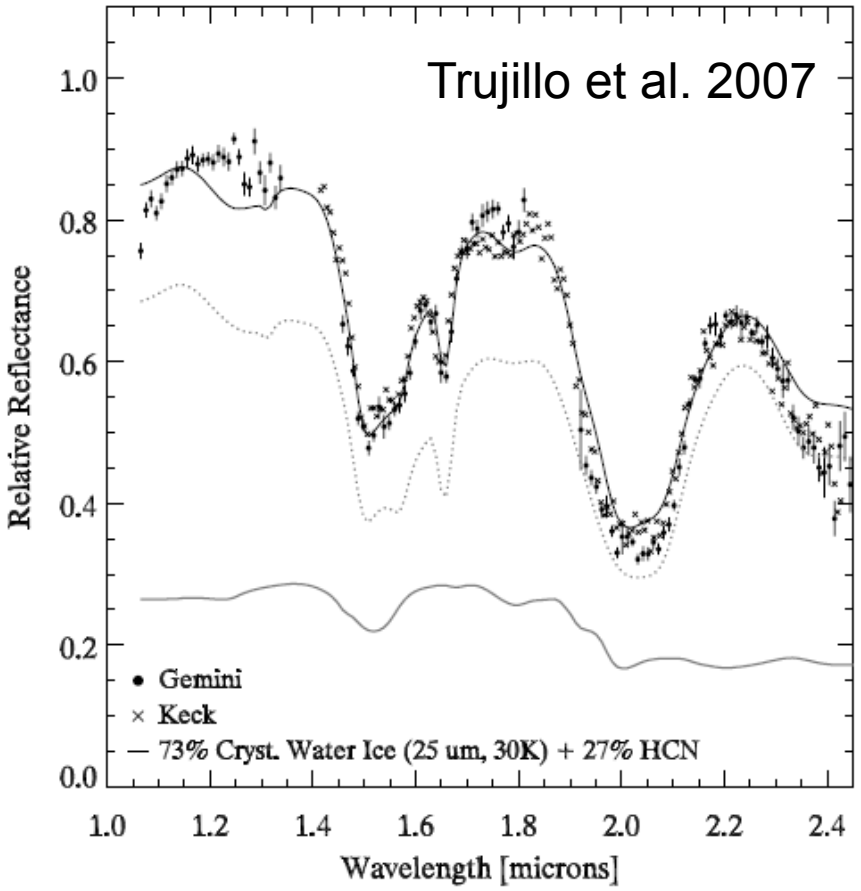
- "Classical" TNO, a = 43.32 AU, e=0.19, currently at Rh = 51 AU
- Large amplitude (Δm = 0.28 mag) lightcurve and fast rotation (P ~3.9 hr)

→ elongated shape and large density (ρ ~2.6 g cm^{-3})

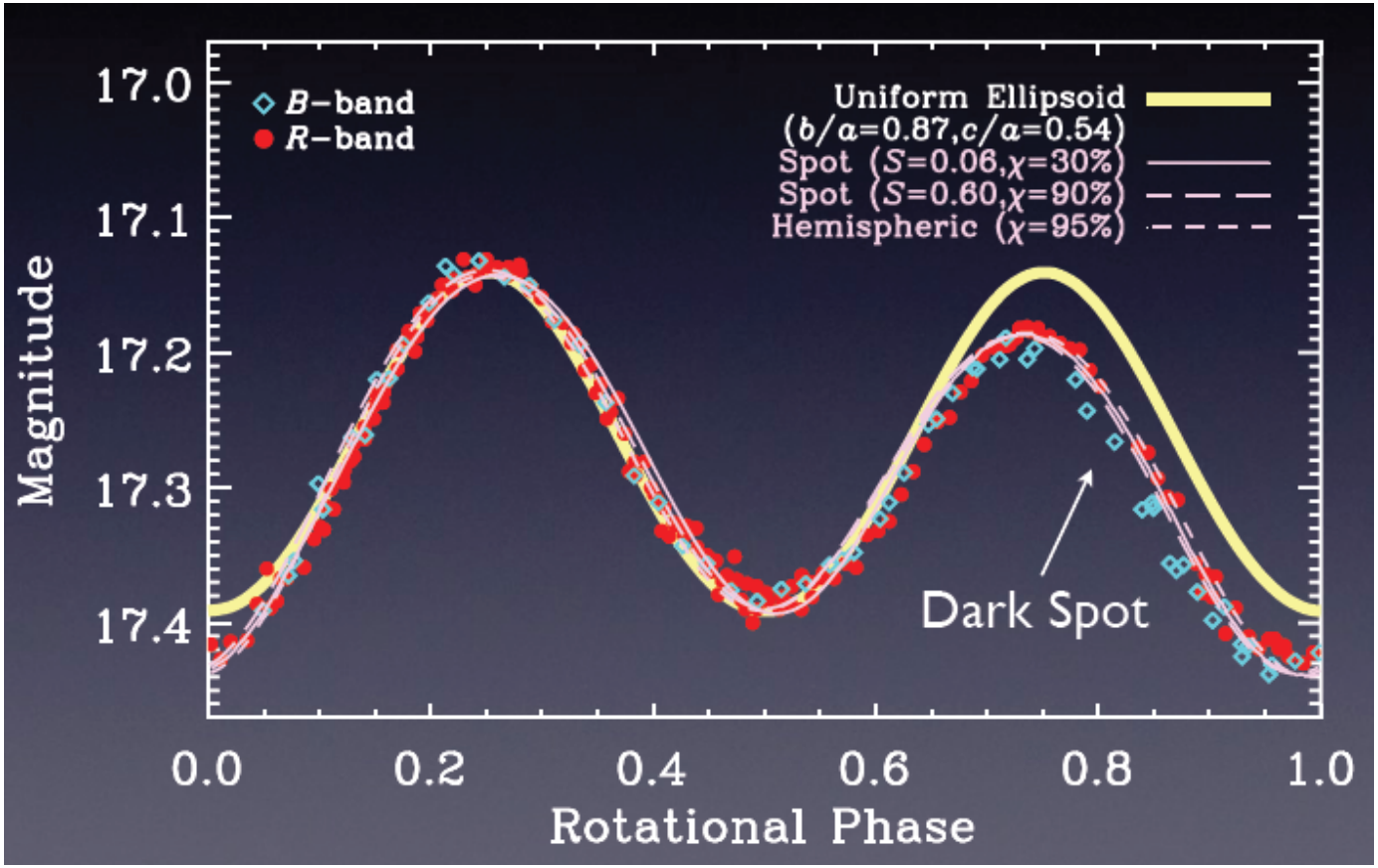
- Large mass, size, albedo

- *Crystalline-ice covered (as well as one of its satellites, and several other TNOs with similar orbital parameters)*

→ *May be the parent of a 1-Gyr old collisional family ?*



136808 Haumea, a remarkable object



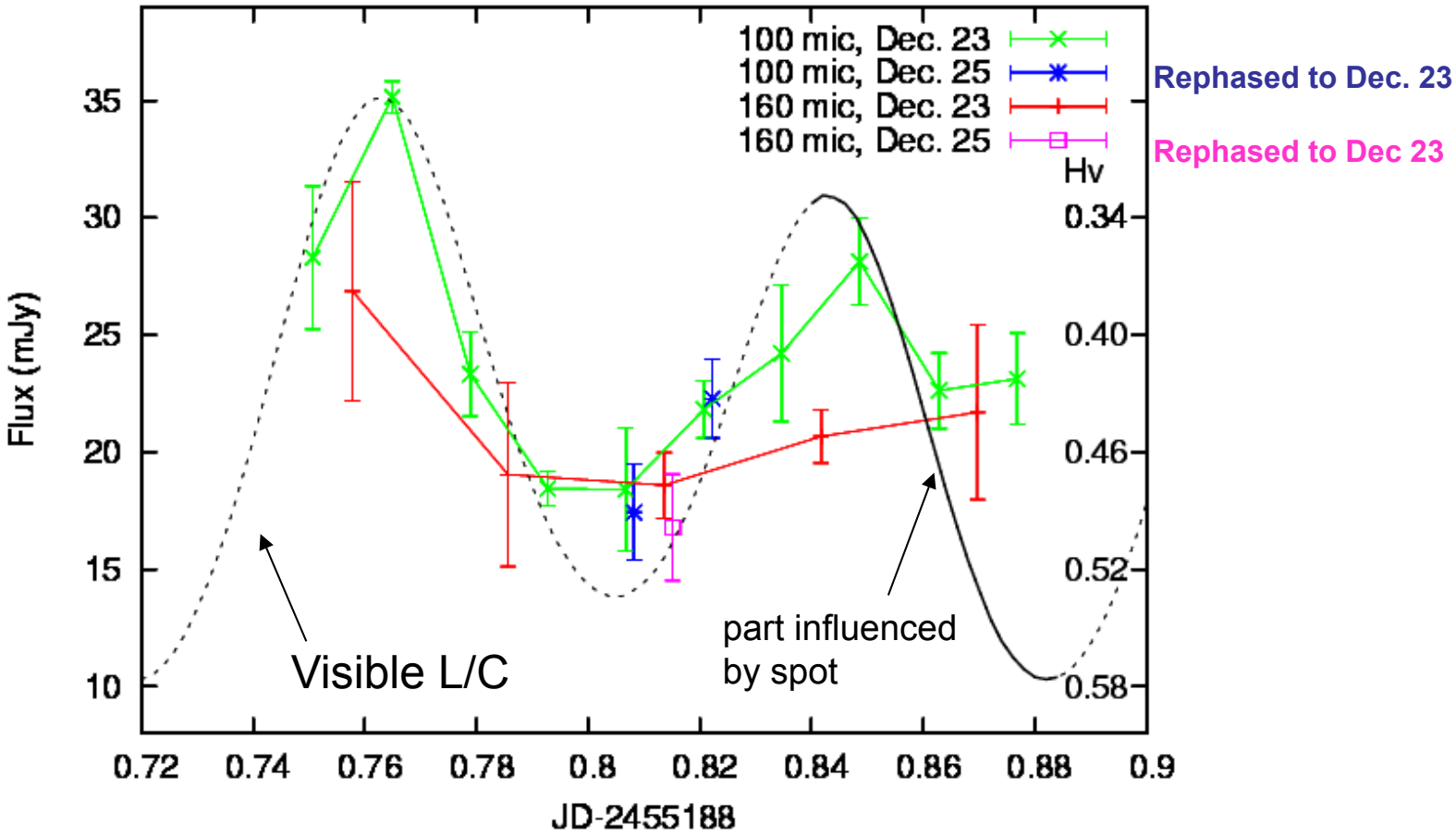
- *Double-peaked lightcurve → evidence for surface spot, darker (and redder) than rest of surface. Collisional origin ?*

Lacerda 2009

Herschel / PACS observations of Haumea

- Mini scan map mode
- 100 μm / 160 μm
- Dates:
  - 23 Dec. 2009 (3.36 hr, i.e. 86 % of lightcurve)
  - 25 Dec. 2009 (40 min; only to verify flux at one phase)
- Data rebinned by periods of 20 min (100 μm) or 40 min (160 μm)
- Phasing : visible observations acquired on Jan. 20, 2010, combined with older (2007) data → extremely accurate period P = 3.915341 hr

Haumea's thermal lightcurve



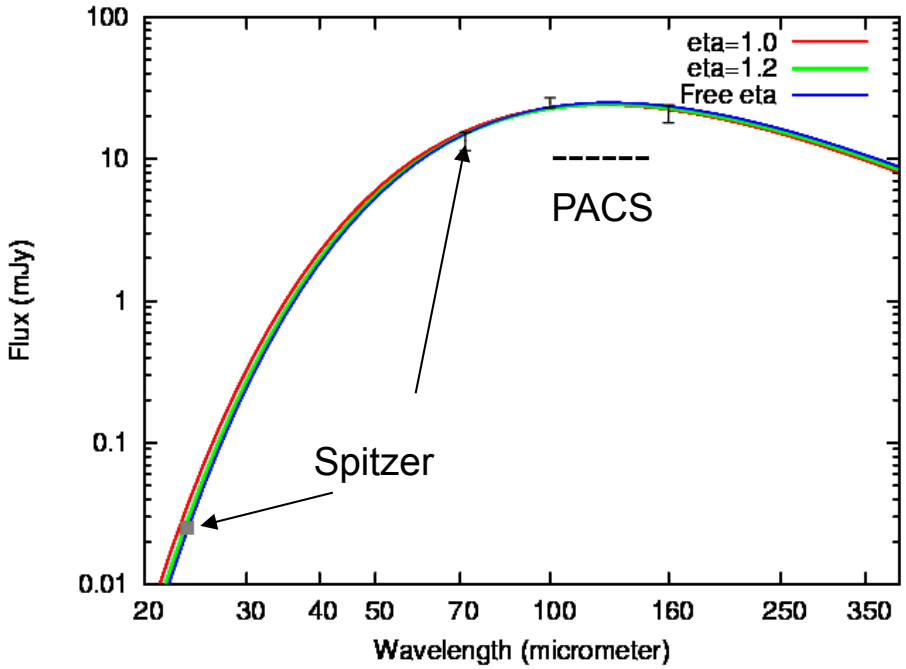
- **Clear 100 μm L/C**
  - **Correlated with visible L/C → shape confirmed**
  - **Large amplitude (almost factor of 2 !, vs only factor 1.3 for visible lightcurve)**
  - **Effect of spot unclear…**
- **Marginal 160 μm L/C**

Radiometric fits (mean fluxes)

- NEATM model (= standard thermal model, instantaneous equilibrium with solar insolation + η parameter): **T α (cos (Solar Zenith Angle) / η) ¼**
  - η ~ 1: Zero thermal inertia
  - η ~ π: Infinite thermal inertia
  - η < 1: "beaming" (e.g. self-heating from craters)
  - Spitzer results for TNO: η = 1.2+/-0.3
- Free parameters: equivalent diameter (D), geometric albedo (p_v) (+ η)

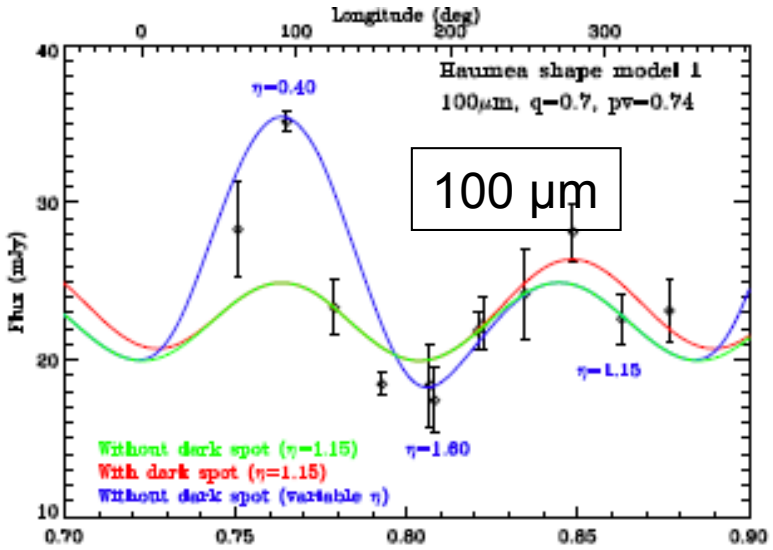
Model	η	D(km)	p_v
Fixed η	1.0	1230±18	0.810±0.024
Fixed η	1.2	1276±20	0.752±0.024
Free η	1.38±0.71	1324±167	0.698 ±0.189

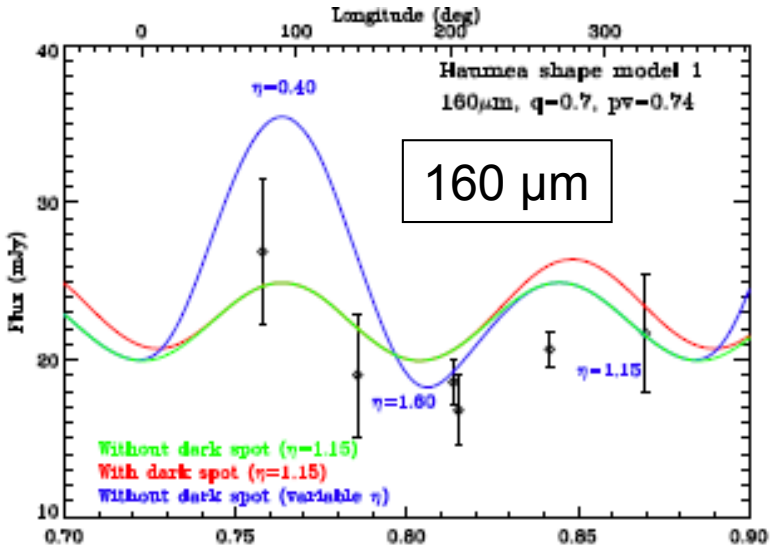
Solution:
D ~ 1300 km
P_v ~ 0.75
η ~1.4



Lightcurve fits

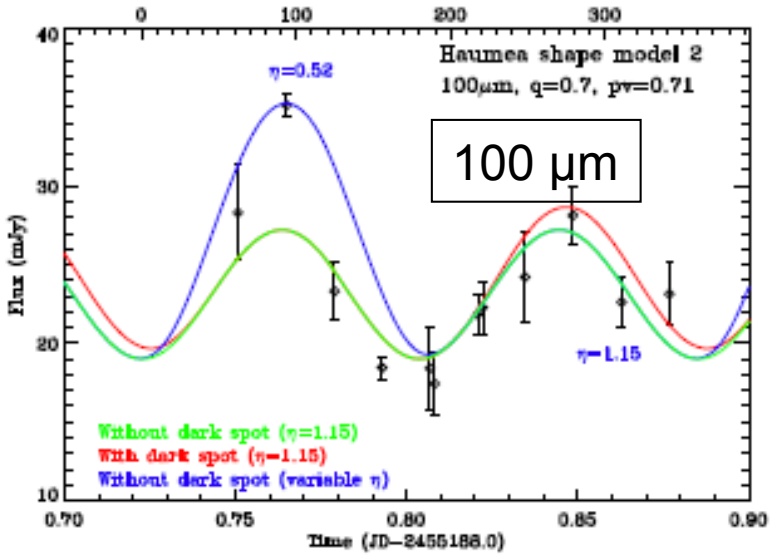
- Approach
  - Adopt physical model (a,b,c, ρ, p_v) deduced from visible lightcurve
    - Amplitude of visible L/C → b/a
    - Rotation period + *hydrostatic equilibrium* assumption (Jacobi ellipsoid) → c/a and ρ
    - Mass and ρ → a, b, c
    - Absolute magnitude H_V → p_V
    - All values are sensitive on assumed photometric behaviour of surface (e.g. Lambert reflectance, lunar-like reflectance…)
  - This gives a ~940 km, b ~790 km, c~500 km (i.e. **D_{eff} ~1310 km**), ρ ~2600 kg m^{-3}, **p_v ~0.72**: excellent agreement with radiometric fits
  - Fit thermal lightcurve with this shape and geometric albedo, only free parameter = **η**

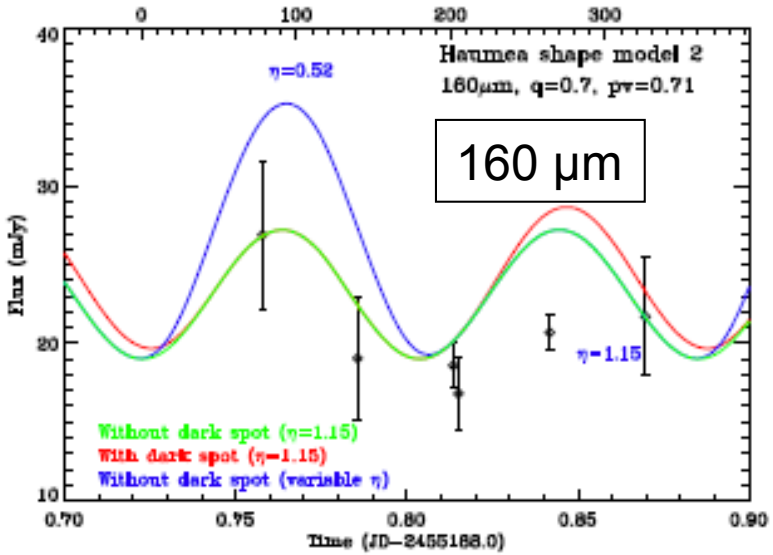




Lambert scattering

a/b = 1.15





« Lunar » scattering

a/b = 1.30

- **Large aspect ratio (projected a /b ~ 1.3)**
- **Low η (< 1.15-1.35) → low thermal inertia**
- **Regions of extremely low η (<<1) →highly craterized region ?**
- **Spot not clearly visible**

Summary & Conclusions

- The thermal lightcurve of Haumea is clearly detected at 100 μm and more marginally at 160 μm
- It is correlated with the visible lightcurve (→ shape effects) but has a much larger amplitude
- Radiometric fits indicate D_{eff} ~ 1300 km and albedo ~ 0.75
- These agree with inferences from visible lightcurve assuming hydrostatic equilibrium
- The surface has a low thermal inertia (porous regolith?), and is perhaps extremely rough at places
- The presence of a dark spot cannot be confirmed
- More observations expected late June 2010