# TNO Modelling Aspects and First Radiometric Results from the 'TNOs are Cool!' Project

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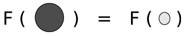
# Thermal/Thermophysical Modelling

**Why?** optical data alone are not sufficient to determine physical properties of unresolvable objects




need additional thermal IR data

**How?**

1. create model-asteroid using assumptions
2. calculate temperature distribution (analytical/numerical solution)
3. determine its thermal emission and compare it to observational data

best fit to observational data delivers best estimations of physical properties (diameter, albedo etc.)

# Thermal Modelling - some basics

**STM**(refined)

Lebofsky et al. 1986

- spherical shape
- smooth surface
- not/slow rotating
- low thermal inertia
- phase angle $= 0$

$$T_{SS} = \sqrt[4]{\frac{(1-A)S_0}{\epsilon\eta r^2}}$$

*empirical beaming parameter* $\eta = .756$

**FRM**

Veeder et al. 1989;

Lebofsky & Spencer 1989

- spherical shape
- smooth surface
- fast rotating
- high thermal inertia

$$T_{SS} = \sqrt[4]{\frac{(1-A)S_0}{\epsilon\pi r^2}}$$

**NEATM**

Harris 1998

similar to STM

*but*:

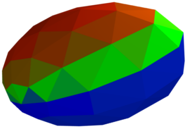
- phase angle $\neq 0$
- use $\eta$ to adjust $T_{SS}$ and therefore fit the spectral distribution to the measurements

$\rightarrow$ rather simple models but require only few data and are well tested (e.g. Stansberry et al. 2007)

# Thermophysical Modelling - more basics

Lagerros 1996, 1997, 1998; Müller & Lagerros 1998; Mueller 2007; Delbo 2003

- introduce heat conduction using *Thermal Inertia* $\Gamma = \sqrt{\kappa \varrho c}$
- surface roughness is taken into account
- allows more flexibility in shape and surface properties

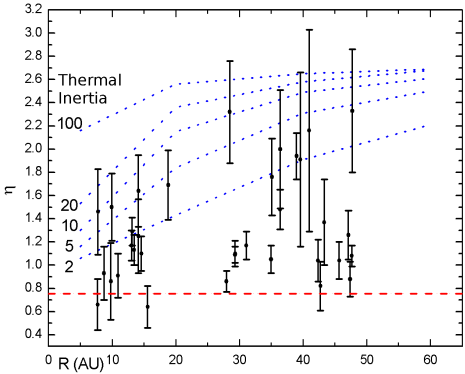


$\rightarrow$ a far more sophisticated model ('makes more use of physics'), but requires far more information on shape, pole orientation, surface characteristics

However, this information is usually not available for TNOs and therefore has to be assumed!

# TNO Modelling

- TNOs are likely to have low thermal inertias



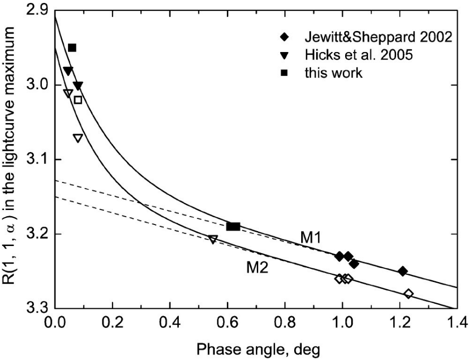
plot by A. Harris, observational data by Stansberry et al. 2008

observational data suggest that TNOs have thermal inertia not greatly exceeding

$$10 \left[\frac{\mathrm{J}}{\mathrm{m^2 s^{1/2} K}}\right]$$

# TNO Modelling

- TNOs are likely to have low thermal inertias
- Opposition effect due to low phase angles




Opposition effect of Varuna at two lightcurve maxima (Belskaya et al. 2006)


Thomas G. Müller (PI), Hermann Böhnhardt (Co-PI), Emmanuel Lellouch (CO-PI), John Stansberry (NASA-PI), Antonella Barucci, Jacques Crovisier, Audrey Delsanti, Alain Doressoundiram, Elisabetta Dotto, René Duffard, Sonia Fornasier, Olivier Groussin, Aurelie Guilbert, Pedro Gutiérrez Buenestado, Olivier Hainaut, Alan Harris, Paul Hartogh, Florence Henry, Daniel Hestroffer, Jonathan Horner, Dave Jewitt, Mark Kidger, Csaba Kiss, Pedro Lacerda, Luisa Lara López, Tanya Lim, Michael Mommert, Michael Müller, Raphael Moreno, Jose Luis Ortiz Moreno, Andras Pal, Silvia Protopapa, Miriam Rengel, Pablo Santos Sanz, Bruce Swinyard, Nicolas Thomas, Audrey Thirouin, David Trilling, Esa Vilenius

- Herschel Open Time Key Programme
- awarded some 370h of Herschel observing time
- investigating about 140 trans-Neptunian objects
- main goals: determination of size and albedo distributions, detailed study of selected objects

... more information in later talks and poster presentations

# The Herschel Space Observatory

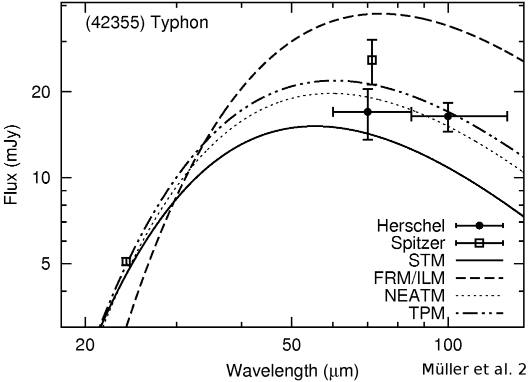
- launched May 2009, expected to operate for 3 years
- 3.5m Cassegrain telescope
- scientific payload: **PACS** (imaging photometer, integral field line spectrometer, $55 - 210\mu m$), **SPIRE** (imaging photometer, imaging Fourier transform spectrometer, $200 - 670\mu m$), **HIFI** (very high resolution heterodyne spectrometer, $157 - 625\mu m$)
- Science Demonstration Phase completed, some results will be presented here

# First Results from 'TNOs are Cool!' SDP

- STM and FRM don't fit over the entire wavelength range
- NEATM and TPM fit data points much better

an example...

| | $D$ [km] | $p_V$ |
|---|---|---|
| STM | 106 | 0.11 |
| FRM | 250 | 0.02 |
| NEATM | 138 | 0.08 |
| TPM | 144 | 0.08 |




Müller et al. 2010

# First Results from 'TNOs are Cool!' SDP - an overview

*Müller et al. 2010:*

| | | NEATM | | | | TPM | | |
|---|---|---|---|---|---|---|---|---|
| Target | $\alpha$ [°] | $D$ [km] | $p_V$ [%] | $\eta$ | $D$ [km] | $p_V$ [%] | $\Gamma$ $\left[\frac{J}{m^2 s^{1/2} K}\right]$ |
| 2003 $AZ_{84}$ | 1.11 | $896_{\pm 55}$ | $6.5_{\pm 0.8}$ | $1.31_{\pm 0.08}$ | 850 – 970 | 5 – 9 | 2 – 10 |
| 2001 $YH_{140}$ | 1.44 | $349_{\pm 81}$ | $8_{\pm 5}$ | 1.2 fix | 300 – 390 | 6 – 10 | 0 – 10 |
| 1997 $CS_{29}$ | 1.27 | $402_{\pm 69}$ | $6_{\pm 2}$ | 1.2 fix | 250 – 420 | 6 – 14 | 0 – 25 |
| 2000 $YW_{134}$ | 1.25 | only upper flux limits | | | $< 500$ | $> 8$ | 0 – 25 |
| Typhon | 2.84 | $138_{\pm 9}$ | $8_{\pm 1}$ | $0.96_{\pm 0.08}$ | 134 – 154 | 6.5 – 8.5 | 1 – 10 |
| 2006 $SX_{368}$ | 4.48 | $79_{\pm 9}$ | $5_{\pm 1}$ | 1.2 fix | 70 – 80 | 5 – 6 | 0 – 40 |
| 2005 $TB_{190}$ | 1.17 | $375_{\pm 45}$ | $19_{\pm 5}$ | 1.2 fix | 335 – 410 | 15 – 24 | 0 – 25 |

- fixed $\eta$ values were used in cases of unrealistically high fitted $\eta$ values ($\eta = 1.2$ from Stansberry et al. 2007)
- good agreement with *Spitzer* results (3 targets, Stansberry et al. 2007)
- all targets show $p_V < 10\%$, except 2005 $TB_{190}$; large diameter range
- **Conclusion**: comparison of methods show their reliability