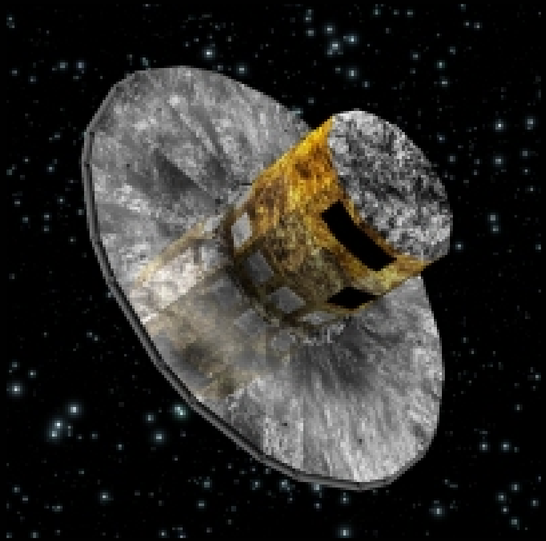
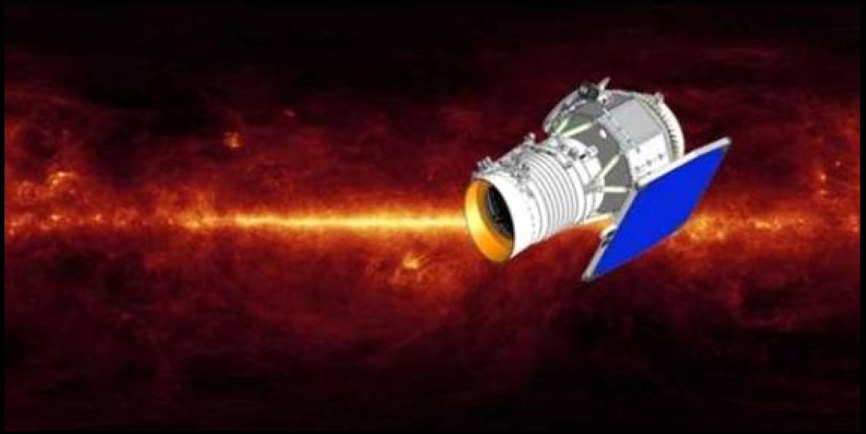
Asteroid Surface Ages
(and Diameters, and Volumes, and Albedos)
from Gaia and WISE





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Overview

Gaia: 10,000—100,000's shapes and spin axes of asteroids

- Allows better understanding of thermal data
- Better constraints on D and p_V
  - Itokawa, Lutetia, and friends
  - Mass densities to within 30—40% or so
- Thermal inertia

What is thermal inertia and why should I care?

- Yarkovsky/YORP, regolith, surface age

Data situation

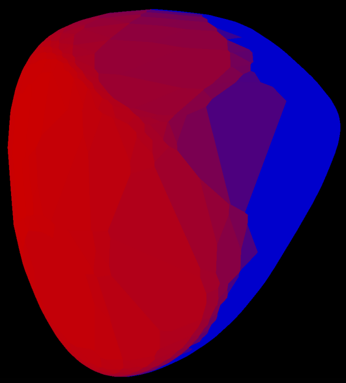
- IRAS, Spitzer, WISE, …

Modeling situation

Precursor study: IRAS + DAMIT

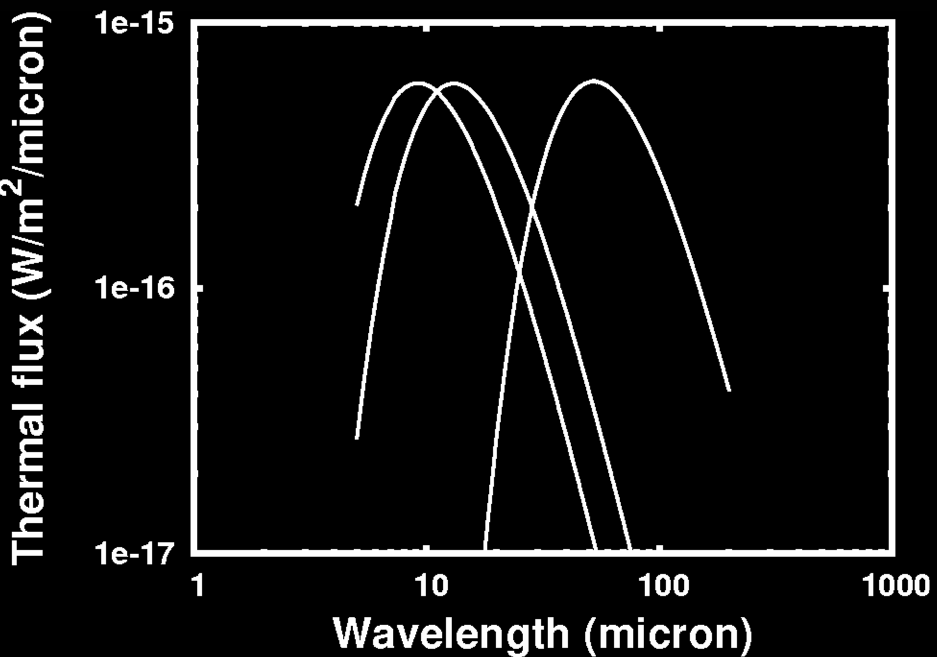
Outlook: WISE + Gaia

Thermal Emission of Asteroids



$F(\lambda) = D^2 \int \text{Planck}(\lambda, T(A))\, dA$

- Peaks between < 10 µm (NEAs) and ~100 µm (TNOs)
  - Observationally difficult but doable
- Need adequate thermal model
- Good handle on size and albedo
  - (the latter with optical photometry = measure of $D^2 * p_V$)
- … and on any thermal property

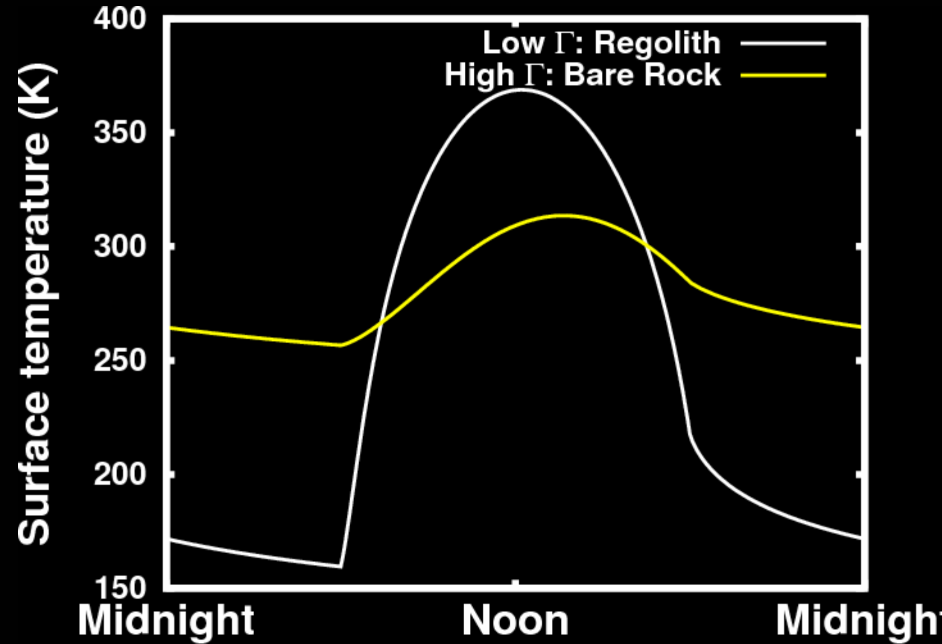


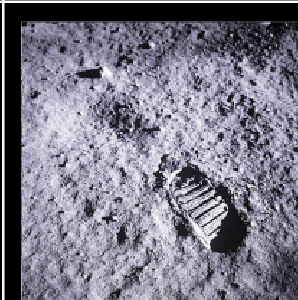
Thermal Inertia Γ

Resistance to change in surface temperature

- $\Gamma = \sqrt{(\rho c \kappa)}$
- Triggers Yarkovsky effect
- Important for mission planning

Regolith properties / surface age from Γ



Bare rock Γ ~ 2500	Itokawa Γ ~ 700	Eros Γ ~ 150	The moon Γ ~ 50
			
	Coarse regolith; pebbles	Immature regolith	Mature, fine regolith

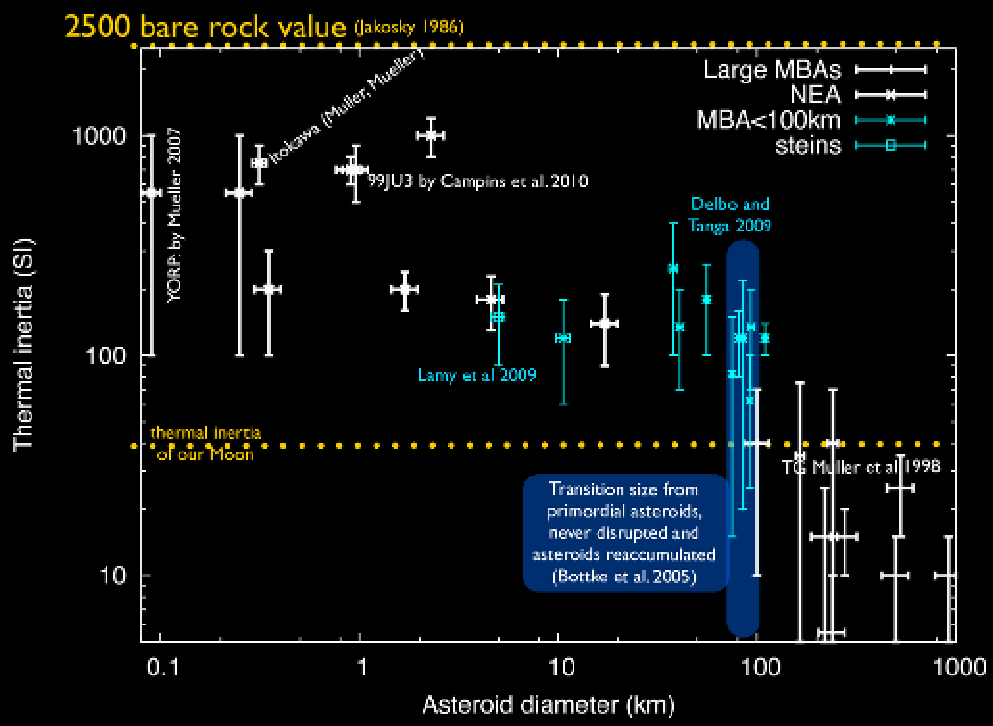
What Do We Currently Know About Γ?

Regolith even on small NEAs.

- How does it form?
  How does it stick?

Hints at correlation with D (Delbo' et al., 2007)

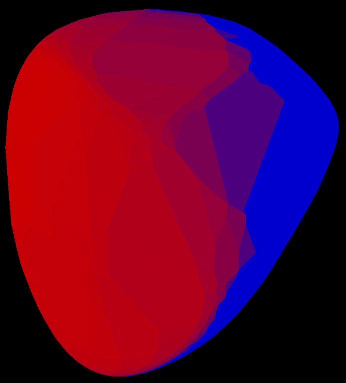
- Important for Yarkovsky and YORP
- Mission planning



Any dependence on taxonomy?
On orbit?
Family?
Anything?

We need more data!

Thermophysical Model (TPM)



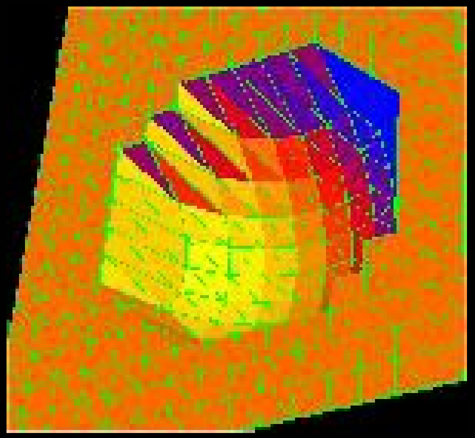
Takes direct account of

- **Shape and spin state**
- **Thermal conduction leading to thermal inertia**
- **Surface roughness**

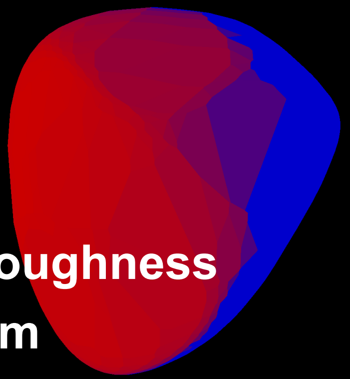
References: e.g., Spencer (1990), Lagerros (1998), Mueller (2007)

$$\frac{\partial}{\partial t'}T = \frac{\partial^2}{\partial z'^2}T$$

$$J_{\mathrm{abs}} = \epsilon\sigma T^4 - \Gamma\sqrt{\omega}\frac{\partial}{\partial z'}T$$



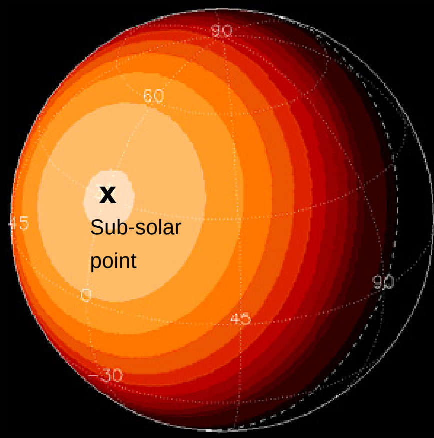
Two Modeling Approaches



Thermophysical modeling (TPM)

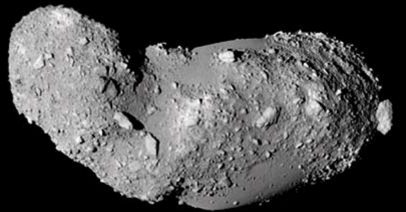
- Detailed model of shape, spin, thermal conduction, roughness
- Need: high-quality multi-wavelength thermal data from multiple nights / epochs; model of shape + spin state
- Thermal inertia
- For now: only doable for ~single objects at a time

Simple models (STM, NEATM)



- Simplistic assumptions on shape, temperature
- Less unknowns, less data required
- $\Delta D \sim 15$—20%, $\Delta p_V \sim 30$—40%
  from modest-quality single-night data
- Most prolific source of asteroid D and p_V
- Great for statistical studies / coarse studies of single objects

TPM Diameters: "Ground Truth"



(25143) Itokawa: Hayabusa rendezvous target

- D from Th. Müller et al. (2005): 0.32 ± 0.03 km
- D from Demura et al. (2006): 0.327 ± 0.006 km

(21) Lutetia: Rosetta flyby target

- D from M. Mueller et al. (2006): *98.3 ± 5.9 km*
- D from Rosetta flyby: ~ 98 km

We estimate TPM diameters to be within 10%,
that's probably conservative (more work needed).

Mass densities from AO + TPM can be good within 30—40 % – if shape + spin axis are known, if good thermal data are available, and if thermal modeling is done properly (e.g., Mueller et al., 2010).

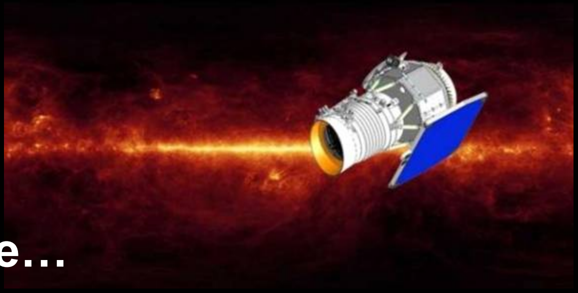
Thermal Data Situation

Ground-based observations:

- Extremely challenging due to high background
- Only practical for select targets

Current largest data set from IRAS

- All-sky survey in 1983 (!) at 12, 25, 60, 100 μm
- Coarse D and p_V of 2,288 (bright) asteroids
- Latest analysis: *Ryan & Woodward (2010)*



WISE data have just been taken (2010—2011)

- All-sky survey at 3.6, 4.5, 12, and 25 μm
- 100,000's of asteroids
- Waiting for first useful calibrated data release…
- Nominal data analysis based on assumed spherical shape
- With Gaia shapes, we can do better!

Precursor Study: IRAS + DAMIT

Can we really run the TPM in batch mode? Fully automatically, w/o crashes? Within reasonable CPU time? Do results make any sense?

Precursor study: IRAS fluxes + DAMIT shapes and spin state

- Download IR fluxes, shapes, and spin states automatically
  - 94 objects as of 28 Oct. 2010
- Retrieve ephemeris, correct for lighttime + filter breadth
- Run TPM
- Gather results, estimate error bars

Result:

- IDL batches run smoothly w/o crash nor human interference
- TPM runs done within ~30 days
- D, p_V, and Γ results of previous studies are reproduced (Mueller et al., 2006; Delbo' & Tanga, 2009 for the most part…)

What Does This Mean for Gaia + WISE Data Set?

TPM analysis can be done in ~300 days

- Using my current computer (…) but after tweaking TPM code for speed (factor 10+ speed-up possible)

Will provide best catalog of asteroid D, p_V, and Γ (10,000+ objects)

- Synergy between Gaia and WISE, and maybe ExploreNEOs

Increase # of measured Γ by 3 orders of magnitude!!!

- Allows first systematic studies of
    - Regolith vs taxonomy
    - Regolith vs orbit (nner vs outer belt, …)

Long-term goal: correlate Γ with surface age, constrain dynamical + collisional history of asteroid main belt

- Observational handle: Γ of collisional families of known age
- Auxiliary work: lab studies of thermal inertia of regolith particles; theoretical modeling of regolith formation / aging