Asteroid Themophysical Modeling Assuming Ellipsoid Shapes

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Outline

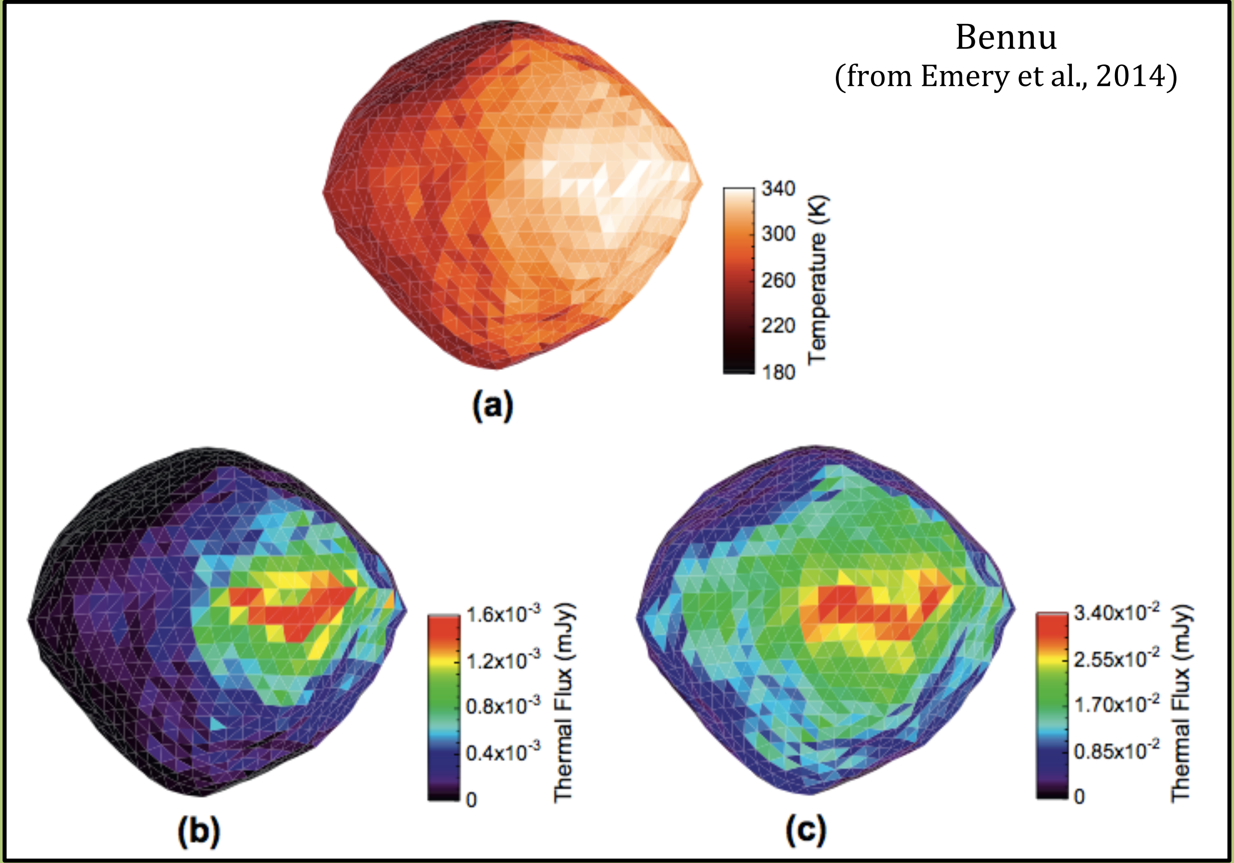
Ellipsoid Shape TPM Method

- ‘Traditional’ Approach
- Description & Application
- Validation Testing

Implementation & Analysis

- Thermal Inertia of objects observed by WISE
- Thermal Conductivity/Grain Size Modeling
- Asteroid Population Grain Size Analysis

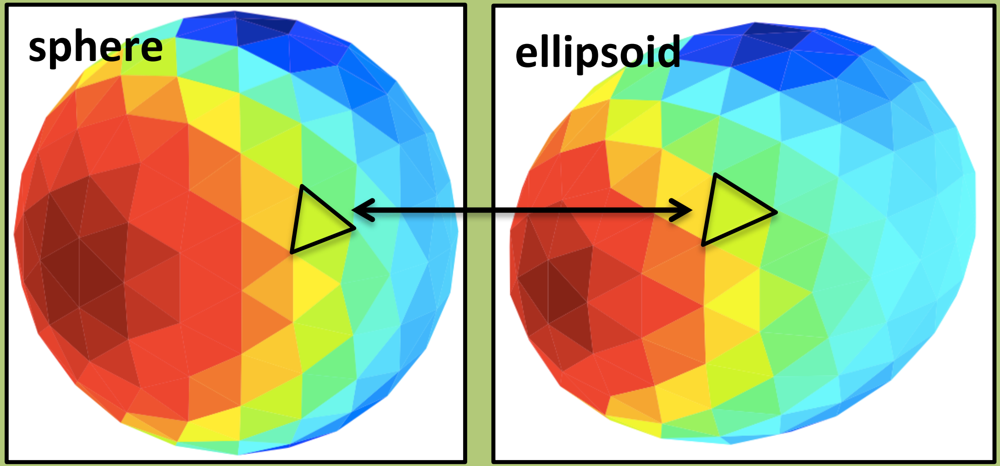
'Traditional' TPM

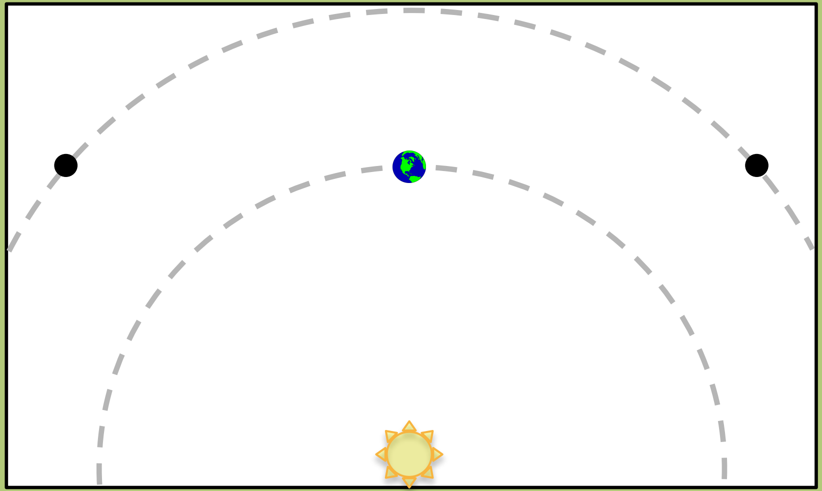


1. calculate surface energy budget across shape model
2. numerically solve the 1-D heat diffusion equation for each shape facet (top)
3. calculate the emitted flux from surface temperatures
4. integrate over entire surface to calculate emitted flux value for desired wavelength(s)
5. adjust TPM parameters to find best-fit to the data

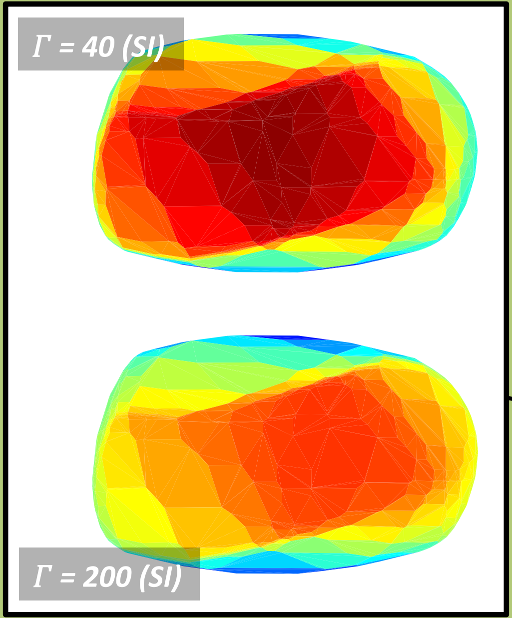
Ellipsoid TPM

1. calculate surface energy budget across sphere
2. numerically solve the 1-D heat diffusion equation for each facet
3. transform surface temperatures to prolate (b = c) ellipsoid
4. calculate the emitted flux from surface temperatures
5. integrate over entire surface to calculate emitted flux value for desired wavelength(s)
6. extract lightcurve mean and amplitude
7. adjust TPM parameters and spin axis to find best-fit to *multi-epoch* data

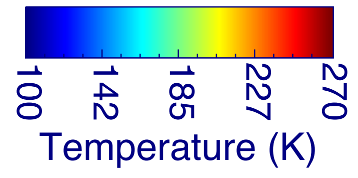




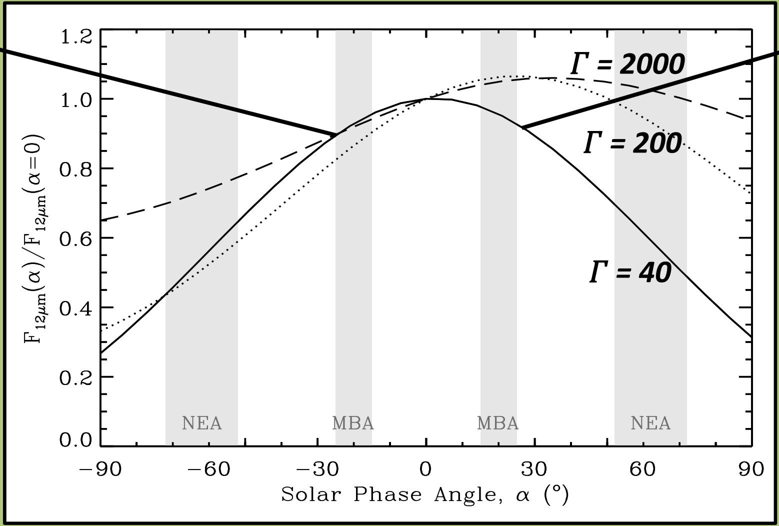
Multi-epoch Data

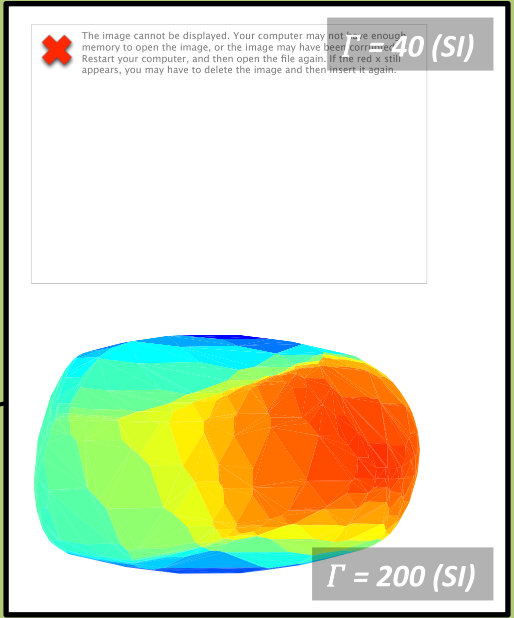


Afternoon



- pre-/post-opposition data guarantee observations of morning & afternoon
- sense of spin determines morning/afternoon temperate asymmetry
- thermal inertia affects the flux change as a function of phase angle

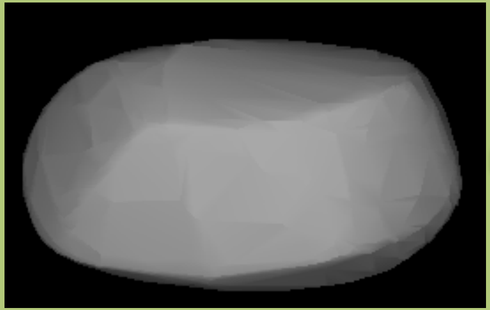




Morning

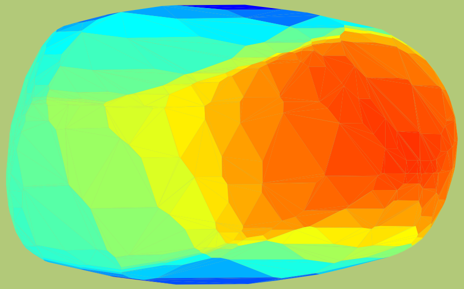
Validation using Synthetic Dataset

convex asteroid shape model from DAMIT



pre-select TPM parameters, D_{eff}, Γ, etc.

surface temperatures



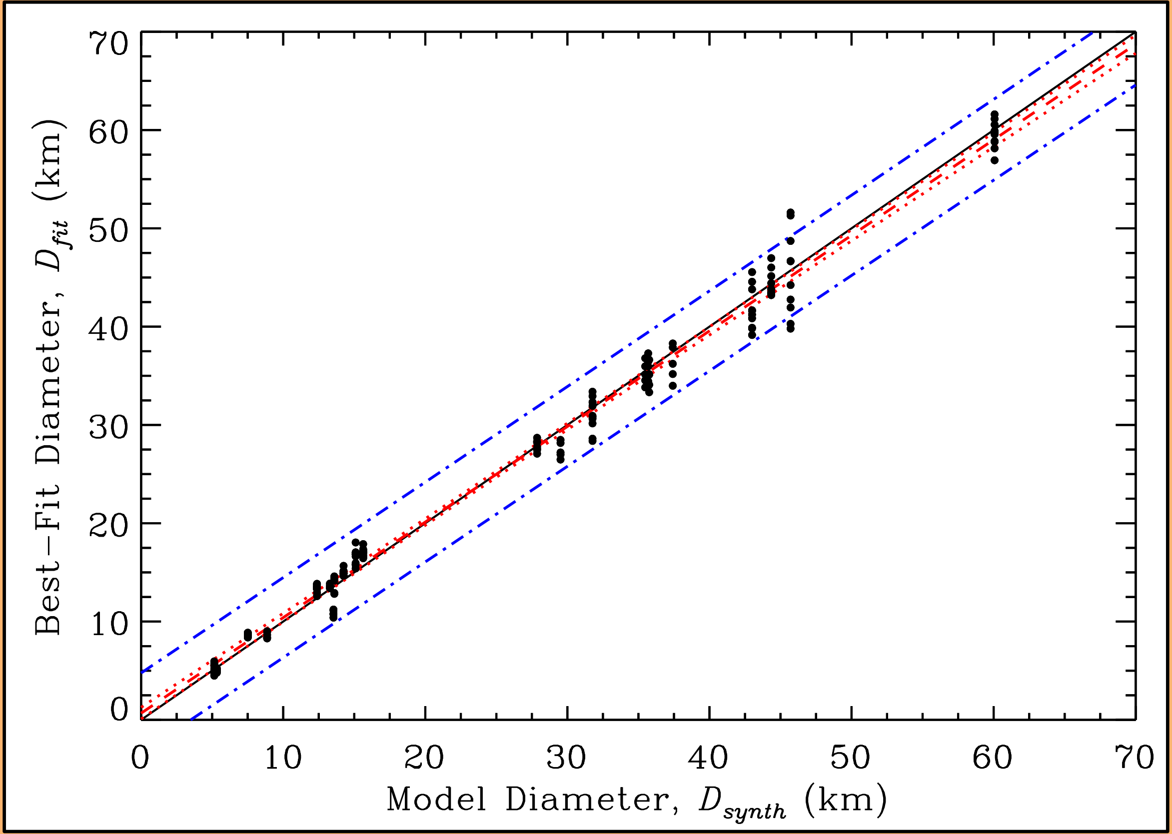
calculate multi-epoch emitted flux

fit ellipsoid models to flux dataset

search for parameter combination that minimizes chi-square

Validation Results

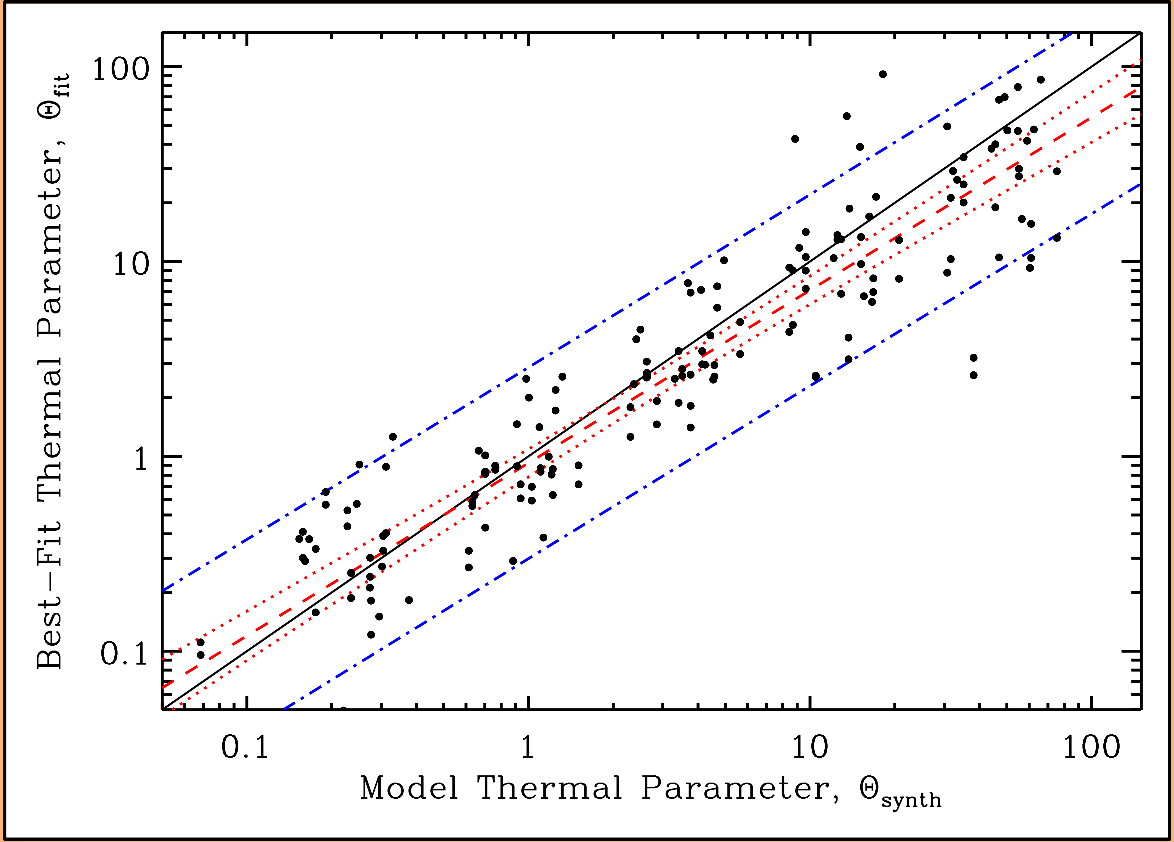
- The best-fit diameter closely follows the expected (model) diameter, within 10%



Validation Results

- The best-fit thermal parameter closely follows the synthetic (model) thermal parameter, Θ

$$\Theta = \frac{\Gamma}{\varepsilon_B \sigma_0 T_{eq}^3}\sqrt{\frac{2\pi}{P_{rot}}}$$

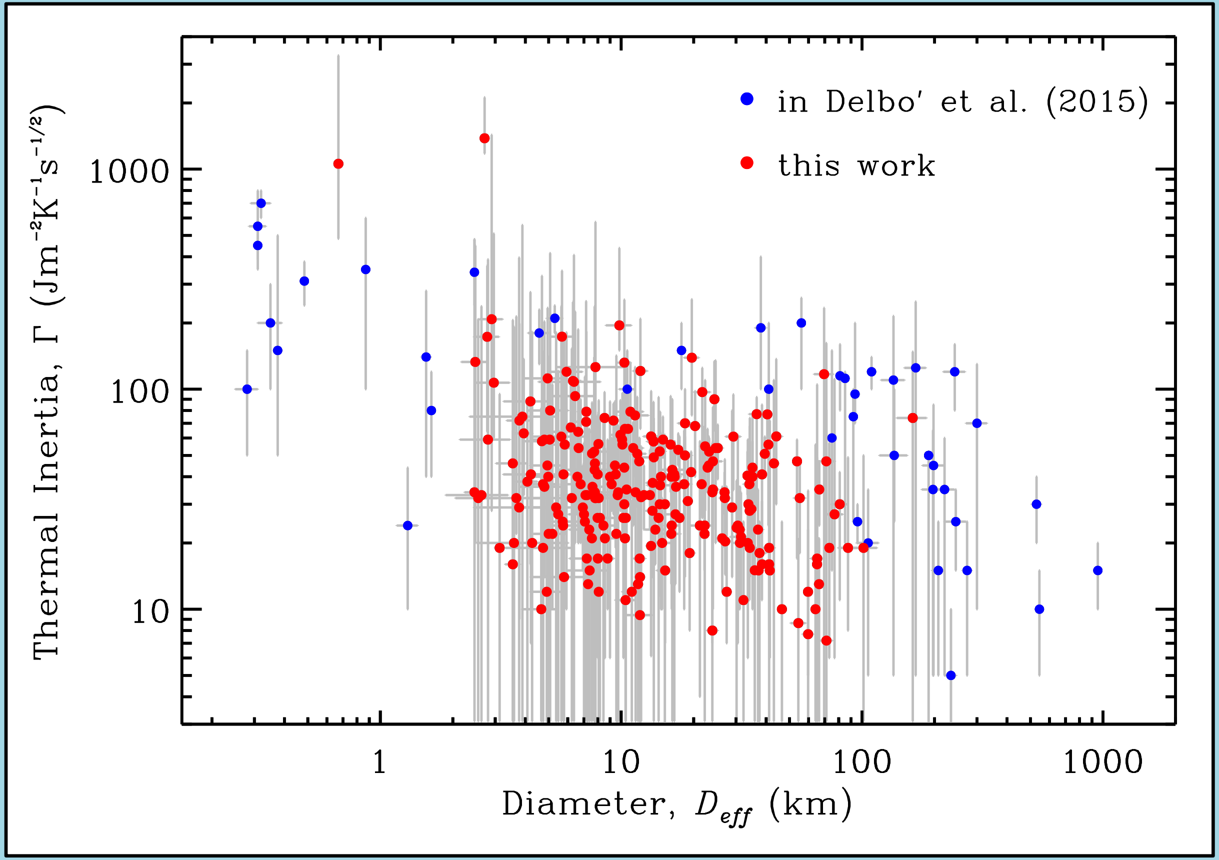


TPM Results on WISE Data

Inverse relationship between thermal inertia and asteroid size

Analysis:

1. Use thermal inertia in a thermal conductivity model to estimate the grain size
2. Run multivariate model on grain size data



Thermal Conductivity Model

Model effective thermal conductivity:

$$k_{eff} = \quad a \quad + bT^3$$

$$k_{eff} = k_{gas} + k_{solid} + k_{rad}$$

=

Observed effective thermal conductivity:

$$k_{eff} = \Gamma^2 C$$

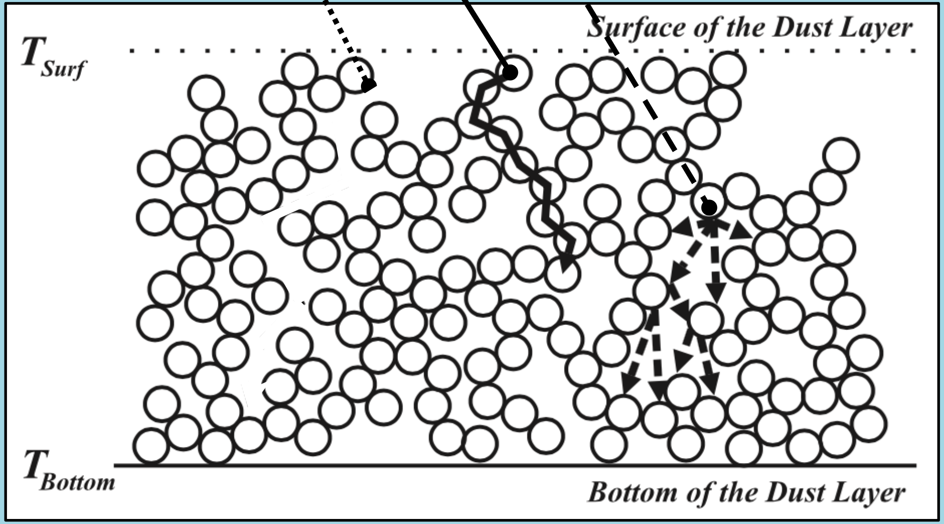
$C = \rho c \phi$, heat capacity

ρ, grain density

c, volumetric heat capacity

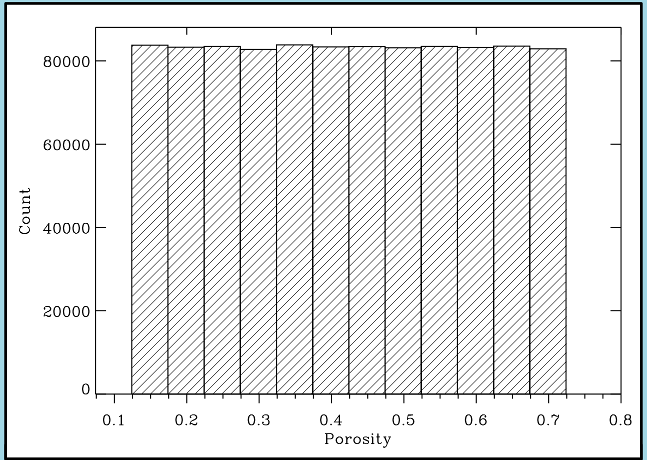
ϕ, porosity

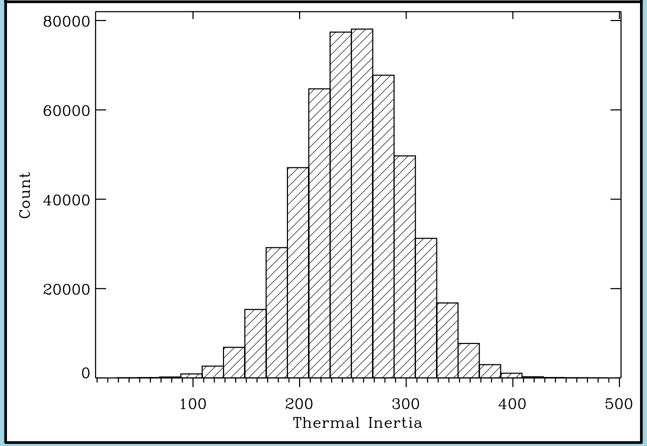
Gundlach & Blum (2013)



- a & b from G&B (2013)
- use spectral classification to infer the grain density and heat capacity
- assume several values of porosity to account for uncertainty

Grain Size Estimation

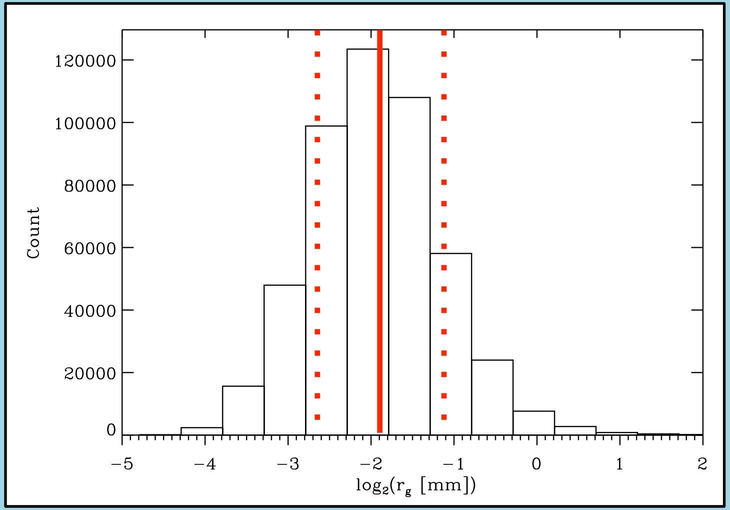




ρ, c & other material properties

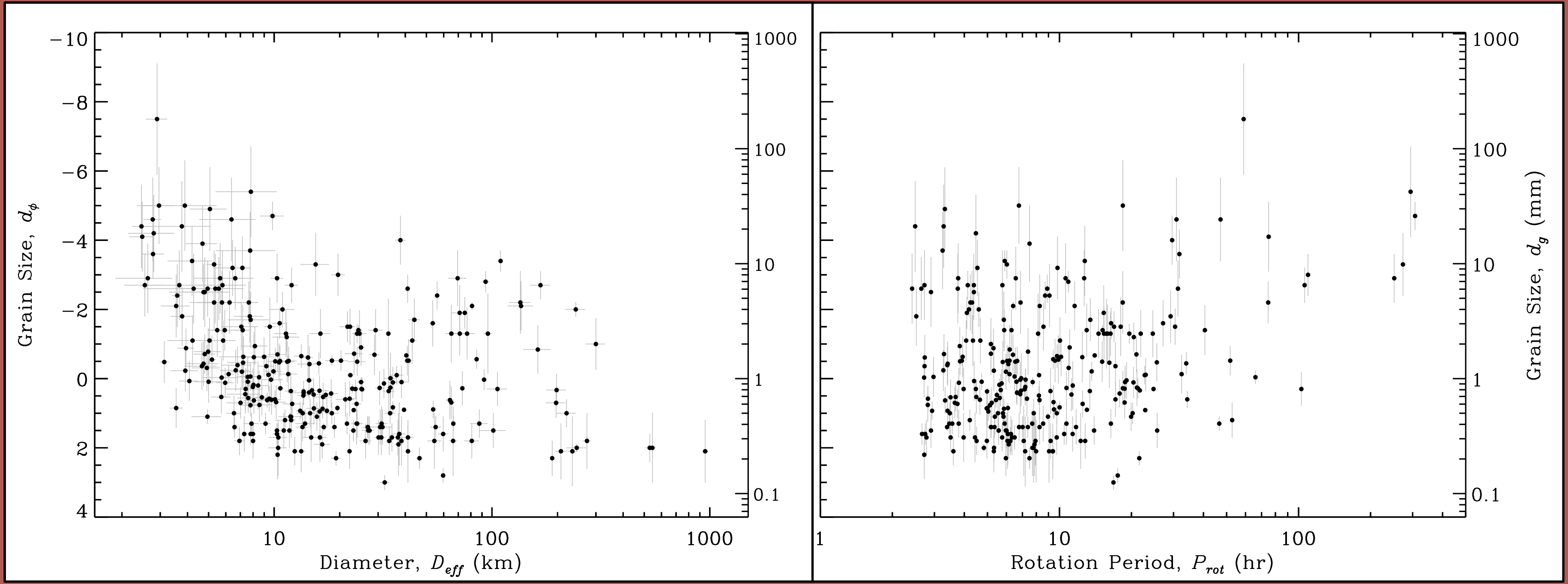
thermal conductivity model

run 1 million times



$d_\phi = \log_2(2r_g)$

Grain Size Results & Model Fit



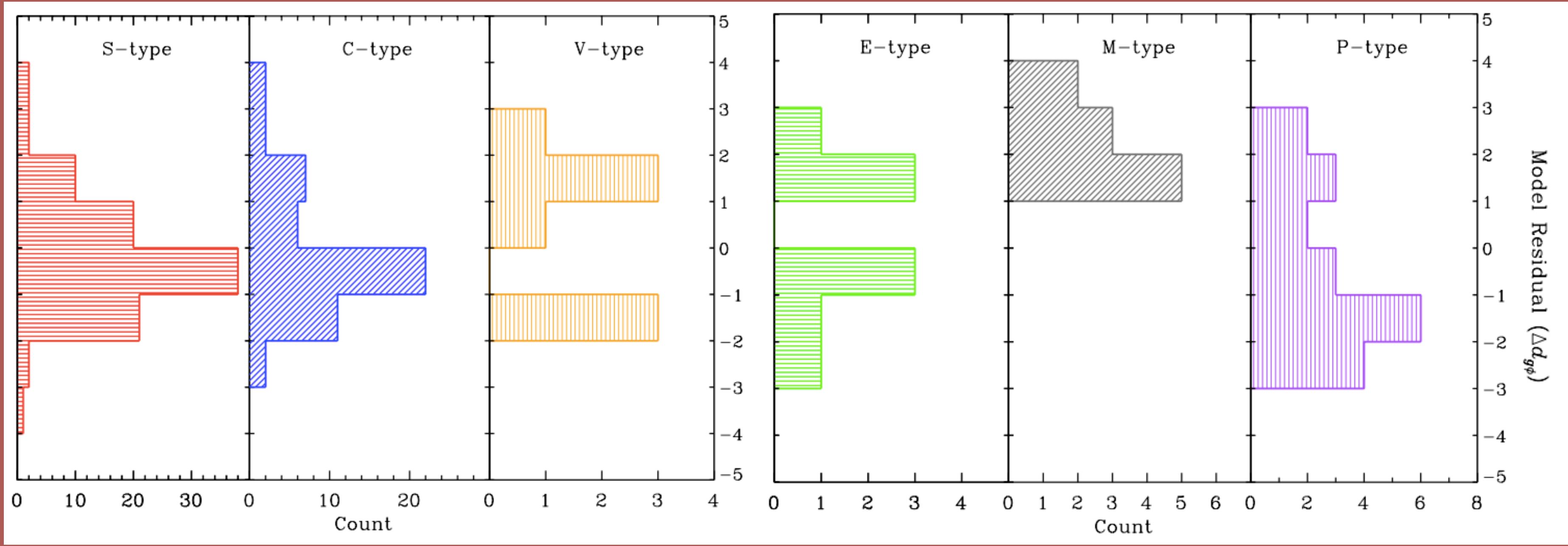
Used multivariate linear model to fit a linear function to grain size (dependent variable) and both independent variables (diameter and rotation period)

Compositional Differences

grain sizes of S-types are slightly below average

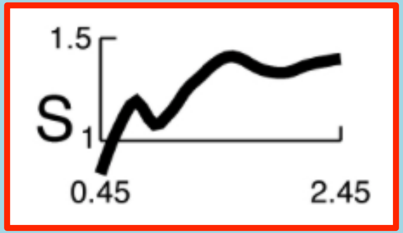
grain sizes of P-types are below average, E-types slightly above average

M-types exhibit 4 x greater regolith grain size



Thank You!

Compositional Properties



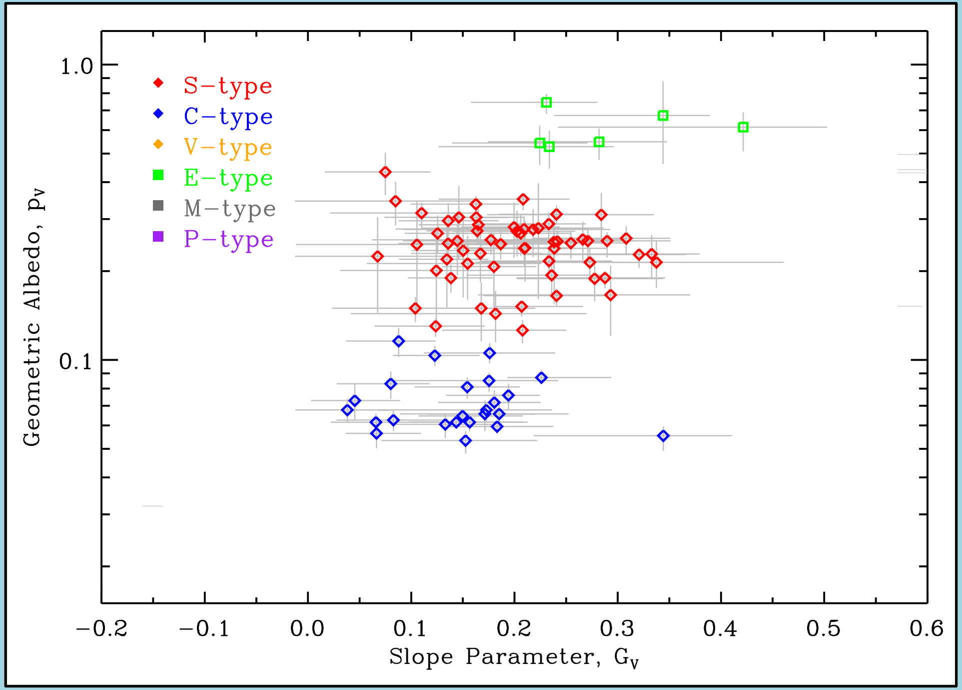
$\rho \approx 3500\ \mathrm{kg\ m^{-3}}$
$c \approx 650\ \mathrm{J\ kg^{-3} K^{-1}}$
$k_{solid} \approx 4\ \mathrm{Wm^{-1}K^{-1}}$

$\rho \approx 2700\ \mathrm{kg\ m^{-3}}$
$c \approx 650\ \mathrm{J\ kg^{-3} K^{-1}}$
$k_{solid} \approx 0.6\ \mathrm{Wm^{-1}K^{-1}}$

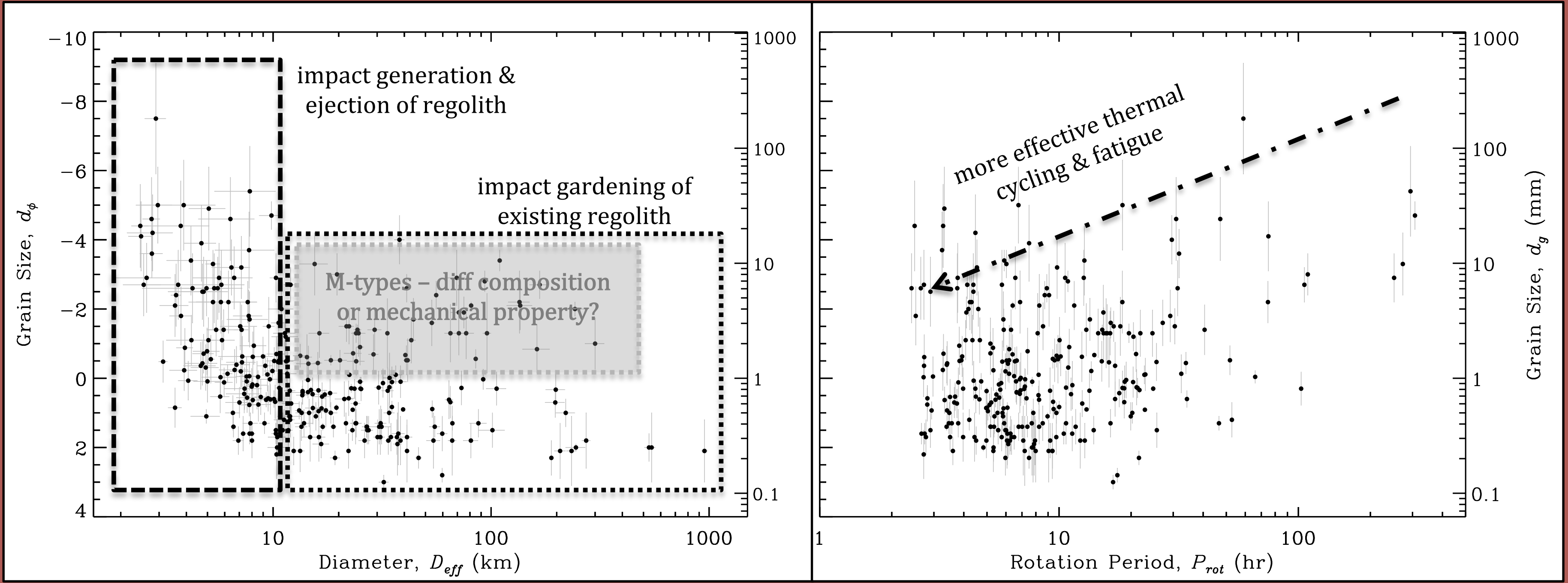
$\rho \approx 7500\ \mathrm{kg\ m^{-3}}$
$c \approx 400\ \mathrm{J\ kg^{-3} K^{-1}}$
$k_{solid} \approx 25\ \mathrm{Wm^{-1}K^{-1}}$

E	$p_V > 0.42$
M	$0.12 < p_V < 0.42$
P	$p_V < 0.12$

- Link spectral groups with meteorite analog
- Use meteorite ρ, c in conductivity model



Regolith Generation & Loss



estimated weathering timescale is 750 kyr – 1.5 My, which is longer than lifetime of a 1 km asteroid (200 kyr)

(Basilevsky et al., 2013; Holsapple et al, 2002)

above trend is consistent with modeling prediction of fast sunrises = greater thermal stress

(Molaro & Byrne, 2012)