Constraining the Size of Near Earth Asteroids

Tyler Nelson[1], Diane Wooden[2], Jeffrey Jefferson[3], Jessie Dotson[2]
1. University of Southern Maine, 2. NASA Ames, 3. University of California, Santa Cruz

Ames Research Center

SUMMARY Quick and accurate determination of the size of an asteroid is of great interest to the Asteroid Threat Assessment Project and is difficult to accomplish. With a combination of visible and thermal measurements we employ a method that leverages the size estimations of each model as physical constraints on the true diameter. This method breaks degeneracies present in the thermal and visible model from sparse data. In the visible bands we use both the established $H-G$ relationship and its successor the $H-G_1G_2$ model, which has improved capabilities in the opposition effect and large phase angles. For the thermal models we use the Near Earth Asteroid Thermal Model (NEATM), the Night Emission Simulated Thermal Model (NESTM), and the Advanced ThermoPhysical Model (ATPM).

VISIBLE MODELS

- Disk-Resolved photometry unavailable for most NEAs
- $H-G$ models the increase in V as α increases by $V(\alpha; G, H)$, G is the slope parameter, $H \coloneqq V(\alpha = 0)$
  - G = 0.15 is often assumed with sparse data
- $H-G_1G_2$ introduced to account for opposition effects, sparse data, inaccurate data, and large α
- Method: Demodulate data by binning by phase angle ranges to find an average that is fit using H-G/G_1G_2
- Results: New estimates for both H and G and respective uncertainties
- Diameter can be calculated if we assume a geometric albedo, p_v, or bond albedo, A

PHASE CURVE ANALYSIS

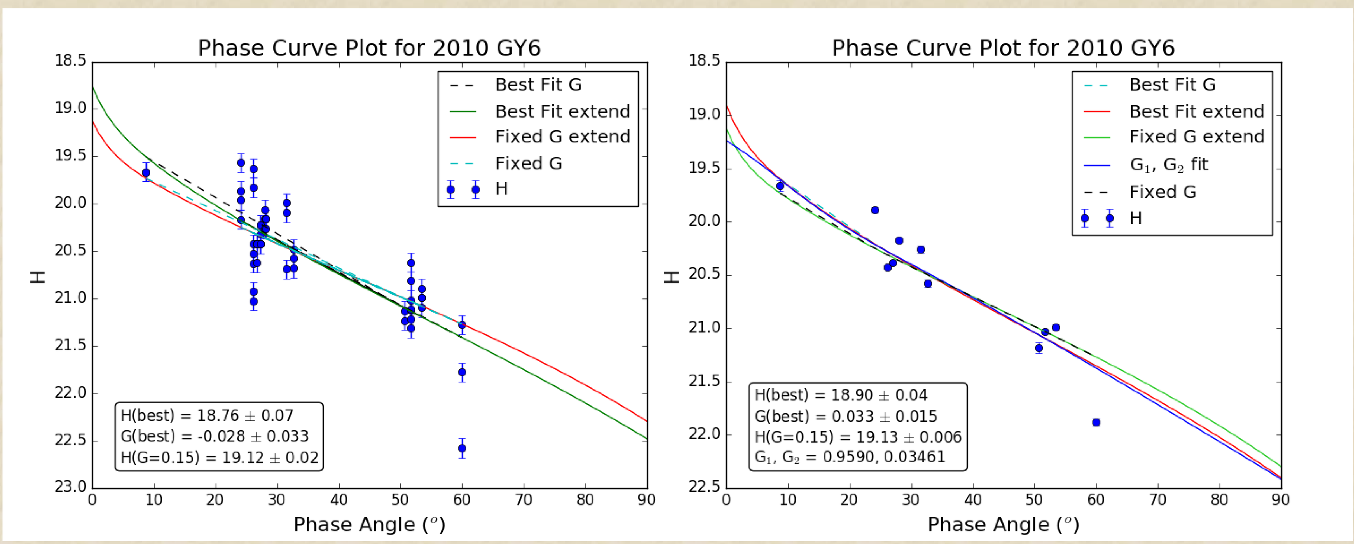

Figure 1. Raw data (left) and demodulated data (right) These phase curves limit H and p_v. For both we tested $G = 0.15$ (standard assumption) versus letting G vary freely. For the right plot we also used the $H-G_1G_2$ fit.

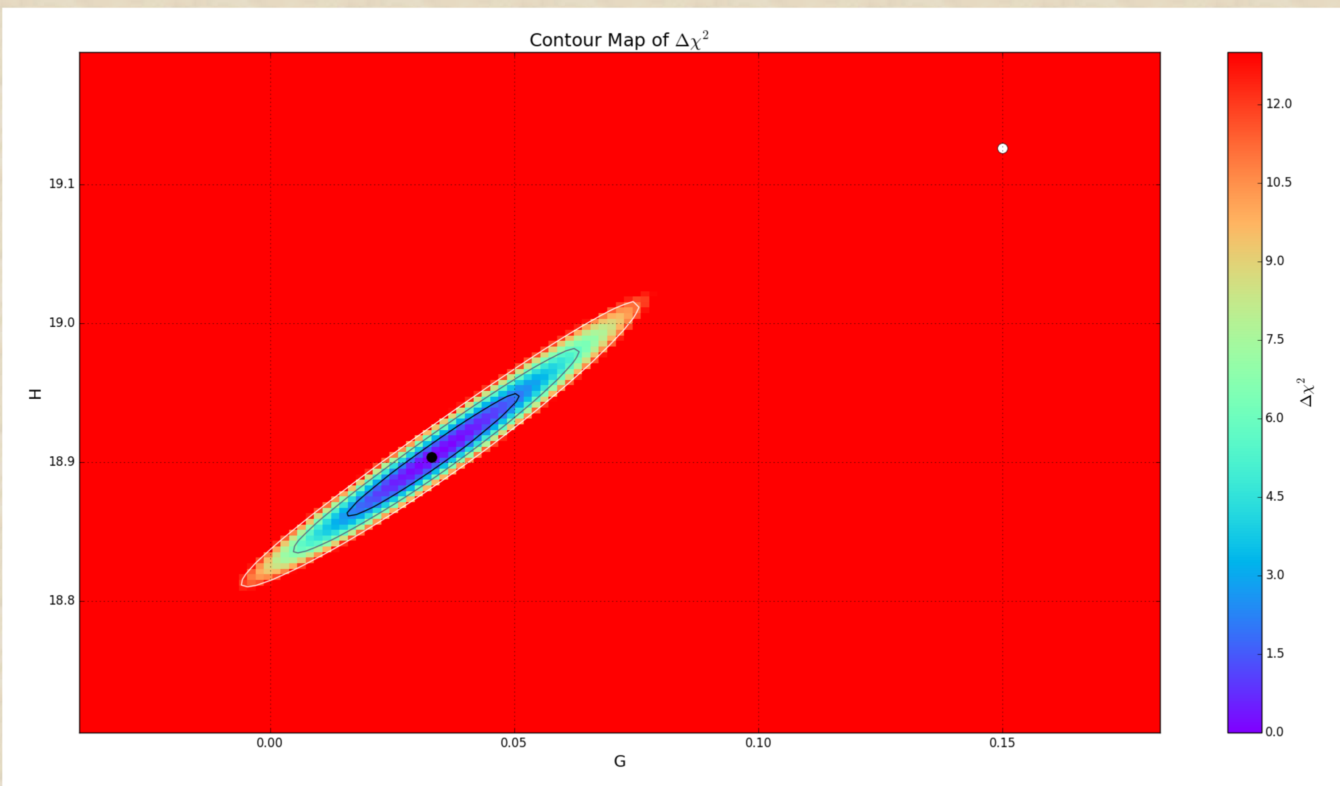

Figure 2. Uncertainty estimates using delta chi squared from the demodulated data in Figure 1. The black dot is the fit with both H and G varying, and the white dot is $G = 0.15$.

THERMAL MODELS

- Fits flux measurements from infrared bands
- Method: Solve the radiative transfer equation for these flux measurements
- Three current models: NEATM, NESTM, ATPM
- ATPM is the most general as shown in Table 1.
- NEATM and NESTM were both tested for fit but did not accurately fit the set of data
- NESTM could fit the data at $T > 400\ K$ with $\chi^2 \sim 0.7$, but we believe this is not physical

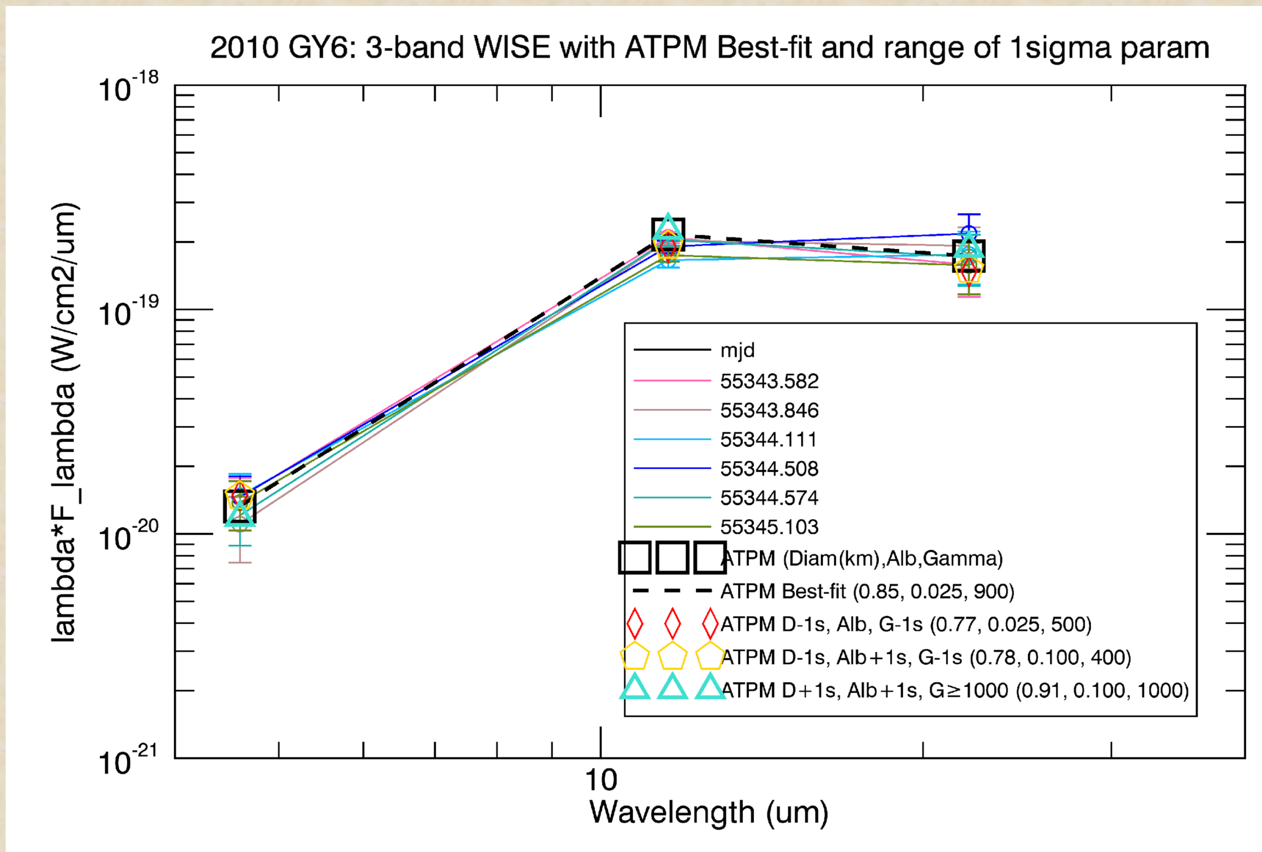

Figure 3. Best fit for ATPM. $D = 0.85$(km), $A = 0.025$, $p_v = 0.08$, $\Gamma = 900$, with a range from 500 to >1000

RESULTS

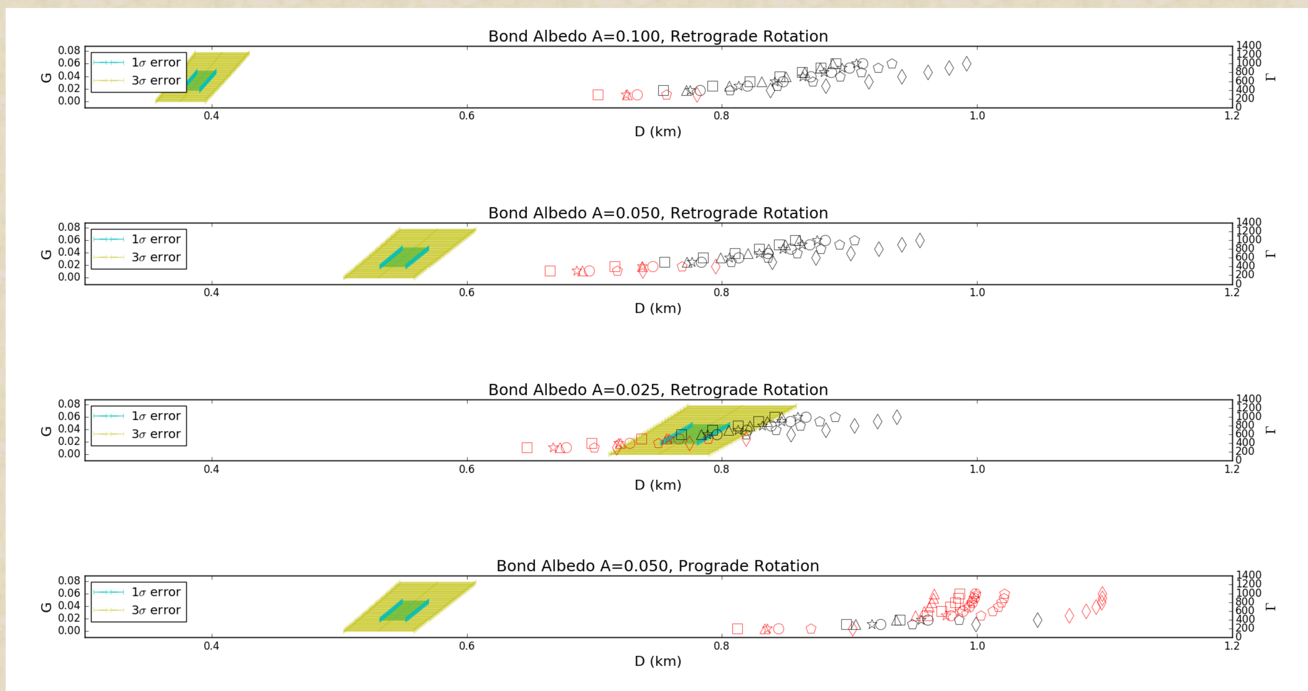

Figure 4. A double plot of the diameter predictions for the visible models using $D(H, A, q)$ and the diameters from the ATPM. The yellow-green regions are the visible model predictions. Each different shape represents a different epoch. The black shapes are in 1σ and the red are within 3σ. Each plot has a either a different bond albedo or, for the bottom, a different rotation.

THERMAL MODEL COMPARISON

Model/ Parameter	Roughness	Rotation	Γ	D	p_v	G	η	α	r_h	Δ
NEATM	X	X	X	✓	✓	✓	✓	✓	✓	✓
NESTM	X	✓	✓	✓	✓	✓	✓	✓	✓	✓
ATPM	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

Table 1. Above is a summary of the physical parameters for which each of the thermal models accounts.

CONCLUSIONS

- G = 0.15 is poorly suited for some low albedo objects leading to large differences in diameter (see Table 2).
- Using visible models in conjunction with thermal models limits the solution space to intersections of the diameters (see Figure 4).
- Using both $H-G$ and $H-G_1G_2$ provides a check on diameter predictions (see Table 2).
- Rigorous demodulation of the light curve may not be possible on NEAs so the uncertainties for V are large.

H (mag)	A	Slope Parameters	q	p_v	D (km)	Notes
19.3	0.011	0.15	0.3926	0.028	1.096	H, p_v, G from Mainzer+2011
19.4	0.025	0.15	0.3926	0.064	0.694	H, q from MPC
18.90	0.025	0.033	0.313	0.080	0.780	$H-G$ corr. fit using chi-square; Alb ATPM
19.2	0.025	0.9617, 0.01645	0.413	0.061	0.781	D-taxonomy G_1G_2 (Penttila)
19.24	0.025	0.9590, 0.01645	0.411	0.061	0.765	$H-G_1G_2$ (Penttila)

Table 2. Diameter estimates for 2010 GY6 from various sources and fits. The pink is from the literature. The grey uses the bond albedo from the ATPM and MPC values. The blue is the $H-G$ fit we did. The green are the fit results from the website $H-G_1G_2$ by Penttila et al.

FUTURE WORK

- Expand the parameter space of gamma
- Explore effects of prograde versus retrograde rotation
- Explore methods for calculating and constraining bond and/or geometric albedo
- Acquire more photometry for a Fourier Demodulation

References: $H-G_1G_2$ fit tool website: http://www.helsinki.fi/project/psr/HG1G2/
WISE data 210 GY6 – Mainzer et al. (2011)
Light Curve Data – MPC, JPL Horizons
Light Curves = Penttila et al. (2016), Lagerkvist & Magnussen (1990, 1992)
NEATM model – Wolters & Green (2009)
Advanced ThermoPhysical Model – Rozitis & Green (2012)