RELATIVE CHANGE IN CROSS-SECTIONAL AREA AND ALBEDO WITH ROTATIONAL PHASE FOR 532 HERCULINA AND 45 EUGENIA; K. L. Reed and M. J. Gaffey (Rensselaer Polytechnic Institute), L. A. Lebofsky (University of Arizona)

Simultaneous reflected and thermal infrared lightcurves were obtained in 1987 in order to solve the question of whether the lightcurve variations for 532 Herculina and 45 Eugenia are a consequence of shape or albedo spots [1,2,3]. The in-phase behavior of their lightcurves pointed to a mainly shape-derived lightcurve with only a minimal possibility of major albedo spots [3]. Using data from simultaneously-obtained near-infrared and thermal wavebands plus a simple technique of relating the incoming solar flux at an asteroid with the outgoing measured flux, an estimate of the minimal changes in relative cross-sectional area and maximum relative albedo changes was found. The comparatively large change in relative cross-sectional area and small change in relative albedo confirms the original findings that the lightcurve variations for these two asteroids are shape-dependent and not albedo-dependent.

The data used was first digitized from the graphs given in Figures 2 through 6 of [3]. The accuracy of the digitization was estimated to have a maximum error of ± 0.01 magnitude. The digitized magnitudes were then converted to fluxes relative to α Lyrae using the logarithmic magnitude-flux relation.

One filter's data set was then interpolated to the same rotational phase values as the other using a cubic spline technique in order to achieve rotational simultaneity for the data. The lightcurve data set with the most rotational coverage was interpolated to the other in order to obtain consistent and continuous data while not having to interpolate too far between points. The only exception to this is the data for 45 Eugenia taken in March of 1987. The breaks in coverage for the J flux data were too large to accurately spline the N flux data smoothly, so the J flux data were splined to the N flux data rotational phases. Relative cross-sectional area and albedo were calculated in each data set only for rotational phases for which there were actually closely-obtained near-infrared (J and K) and N flux data.

The filter fluxes relative to α Lyrae were then converted to absolute fluxes by multiplying them by conversion factors for each standard filter supplied by the <u>IRTF Photometry Manual</u> [4]. This transformed the relative fluxes through the filters into energy units.

In order to calculate the relative cross-sectional area and relative albedos, the total reflected and emitted fluxes from the body needed to be found. Conversion factors transforming flux through the J and K filters into total reflected flux were calculated by dividing the solar constant value (integrated from solar flux curve data by [5]) by the same solar flux curve which was multiplied by each filter's (J and K) bandpass. This procedure gives the ratio of total reflected flux off the body to that reflected flux measured through each respective filter. Converting the flux measured through the N filter to total emitted flux, was accomplished by assuming the body to be spherical with an emissivity of 1 and that the standard non-rotating thermal model applied to the body, then finding total emitted flux curves using this model at various solar distances and albedos. The components of this two-dimensional array of flux curves were then each integrated to get the total flux, then multiplied by the N filter bandpass and integrated to get the flux through the filter. The ratio of these two values was then taken and a two-dimensional look-up table was formed of these conversion factors.

Two simple equations were then used to iteratively find the effective cross-sectional area and the effective albedo:

I. $\text{TOTAL FLUX}_{\text{EMITTED}} = \text{AREA} * (1 - \text{ALBEDO}) * \text{SOLAR CONSTANT}$

II. $\text{TOTAL FLUX}_{\text{REFLECTED}} = \text{AREA} * \text{ALBEDO} * \text{SOLAR CONSTANT}$

Note: The albedo is here defined as the fraction of incident flux reflected into space at all wavelengths.

Knowing the solar distance of the asteroid, an albedo was assumed and the various values were substituted into equation I in order to calculate the effective cross-sectional area. This area value was then substituted into equation II in order to calculate the effective albedo. This albedo value was used to look up a new value for the emitted flux conversion and the whole process was repeated until the cross-sectional area and albedo converged to singular values within errors (taken as within 5% of the previously calculated values). It was known that using the standard thermal model would produce a large systematic error but that it should be consistent within each data set such that the relative change over any one data set could be found. According to [6], the use of the standard spherical, non-rotating thermal model would underestimate the cross-sectional areas and overestimate the albedos for an elliptical body. Therefore, the results from this technique should give us the minimum relative change in cross-sectional area and maximum relative albedo change for each object.

Since actual areas and albedos are highly model-dependent [6,7], each area and albedo value was divided by the average for each data set in order to obtain a relative value. This makes the values less susceptible to the large systematic errors of absolute measurements. This said, the absolute effective albedo values were found to be quite close to the accepted geometric albedo values (the worst case was 20% too low). This circumstance helped lend credence to the technique but will require further investigation. The absolute cross-sectional area values calculated did have large systematic errors associated with them compared to accepted values for the asteroids' diameters - in line with the model-dependent nature of absolute value calculations.

The data for 532 Herculina show a minimum change in cross-sectional area of between 23 - 25% across a full rotation with a maximum change in albedo of 14%. This result is confirmed through the use of both the K filter (for the January data) and the J filter (for the data from March and May) data giving similar results. The data for January and March show an inverse relation of albedo to cross-sectional area which may be an example of a radius-of-curvature effect on the effective albedo [6]. In the January data, the first maximum shows a broad hump which may possibly indicate a larger radius of curvature for that end than at the opposite end (it is slightly "egg-shaped"). The second maximum in area is slightly out of phase with the second minimum in albedo (by approximately 0.1 rotational phase). This may possibly indicate (1) a varying radius of curvature for this end, (2) a limb shadowing effect of some sort, or (3) a real albedo change across the surface. The other data sets show a varied relationship between the areas and albedos with the March data in inverse relation but with a mild phase off-set and with the May data in phase. This behavior would be more indicative of (1) and (2) above since (3) should be more consistent between data sets and should not have a possible relation to aspect angle.

The data for 45 Eugenia show a minimum 25% change in relative cross-sectional area, though this minimum may be larger since the lightcurve coverage was not complete for both filters. The relative albedo change was minimal, being only slightly measurable at the least significant digit (at 0.001 albedo) which suggests a maximum relative change of 10%. A mild inverse relationship of albedo and cross-sectional area was noticed in the May data set, again possibly indicating a radius-of-curvature effect.

An extension to the present analysis would use total-emitted-flux conversion factors based upon an ellipsoidal shape that corresponded to the relative changes in area presented here in order to see if the relative cross-sectional areas are altered. This would also better constrain the relative albedo and if used iteratively, using the model to find a shape and then using the shape to calculate a model, may be used to converge to a true shape.

Using this technique in concert with rotational spectral variations would lead to a powerful tool with which to study the surface mineralogy and petrology of an asteroid as a unique planetary body. This would give a better understanding of how individual asteroids formed and evolved and how they are interconnected not only among any family relationship, but among the asteroid population as a whole. A knowledge of how mineralogy and petrology changes with shape and albedo would help in the study of asteroid evolution, both of their parent bodies and their collisional evolution. Much work needs to be done with this technique in order to gain a deeper understanding of asteroids as individual worlds.

ACKNOWLEDGEMENTS: This work was supported under NASA Grant NAGW-642. L.A. Lebofsky was Visiting Astronomer at the NASA Infrared Telescope Facility which is operated by the University of Hawaii under contract to NASA.

REFERENCES: [1] Taylor *et al.* (1988) *Icarus* **73**: 314-323, [2] Taylor *et al.* (1987) *Icarus* **69**: 354-369, [3] Lebofsky, L.A. *et al.* (1988) *Icarus* **75**: 518-526, [4] Tokunaga, A.T., IRTF Photometry Manual (1986), [5] Neckel, H. and Labs, D. (1984) *Solar Phys.* **90**: 205-258, [6] Brown, R.H. (1985) *Icarus* **64**: 53-63, [7] Lebofsky, L.A. *et al.* (1978) *Icarus* **35**: 336-343