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THE SHAPE OF ASTEROID 1917 CUYO

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ABSTRACT

Lightcurves obtained for 1917 Cuyo at solar phase angles near 54° have an amplitude $\Delta m = 0.44$ mag. However, convex-profile inversion of the lightcurves yields an estimate of the asteroid's mean cross section ($\underline{C}$, a 2-D average of the 3-D shape) that is only slightly noncircular, with an elongation ~ 1.15. The estimate of $\underline{C}$ undoubtedly contains systematic errors, the most severe of which could arise from non-equatorial viewing/illumination geometry. However, Cuyo's radar echo shows very little variation in bandwidth vs. rotation phase, supporting the hypothesis that this asteroid's elongation is rather modest.

INTRODUCTION

The Amor asteroid 1917 Cuyo (1968 AA) passed within 0.15 AU from Earth in October 1989, during the most favorable apparition for groundbased astronomy until 2030 (Harvey, 1989). The object was observed by one of us (WZW) with a CCD camera on the 2.3-meter Steward Observatory telescope on Kitt Peak and with radar by Ostro et al. (1991) from Arecibo and Goldstone during a two-week period near closest approach (Table 1). Figure 1 shows the lightcurves and results of inverting those data, and Fig. 2 shows radar echo spectra. All analyses discussed here use the apparent rotation period, $P = 2.693$ h, determined from the lightcurves.

Table 1. Observations of Cuyo

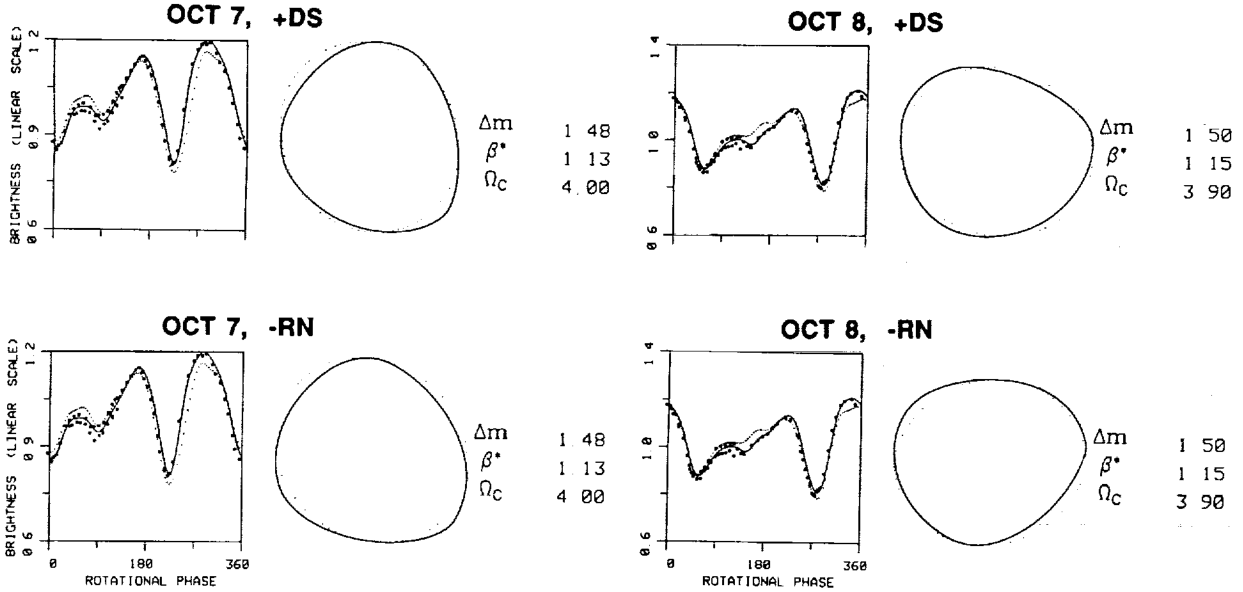
Observation	UTC dates spanned	RA (h)	Dec.	Distance (AU) Earth	Distance (AU) Sun
radar (Arecibo)	1989 Sep 26 to 30	20.3	9°	0.17	
CCD photometry	1989 Oct 7	21.0	-13°	0.14	1.08
	to 8	21.1	-16°	0.14	1.08
radar (Goldstone)	1989 Oct 9 to 11	21.3	-22°	0.14	

SHAPE CONSTRAINTS FROM LIGHTCURVES

Under certain ideal conditions, one can use "convex-profile inversion" of a lightcurve to estimate a profile that is a 2-D average of the asteroid's shape (Ostro et al. 1988). That profile is called the mean cross section, $\underline{C}$, and is defined as the average of the envelopes on all the surface contours parallel to the equator. The ideal conditions for estimating $\underline{C}$ include Condition GEO, that the scattering is uniform and geometric; Condition EVIG, that the viewing-illumination geometry is equatorial; and Condition PHASE, that the solar phase angle ϕ is known and nonzero. The logic behind these conditions is that they collapse the 3-D lightcurve inversion problem, which cannot be solved uniquely, into a 2-D problem that can.

Condition EVIG, that the sub-Earth and sub-Sun points lie on the equator, and Condition PHASE imply that ϕ equals its equatorial component ϕ_{eq}; this component creates the mapping between odd harmonics in $\underline{C}$ and those in the lightcurve. If $\phi_{eq} = 0$, then an equatorial lightcurve of a uniform, geometrically scattering asteroid will contain no odd harmonics. For this reason, inversion of an opposition lightcurve furnishes an even-harmonic-only version of $\underline{C}$ called the symmetrized mean cross section, $\underline{C}_s$.

Convex-profile inversion of the Cuyo lightcurves yields the estimates of $\underline{C}$ and $\underline{C}_s$ shown in Fig. 1. These averages of Cuyo's shape rotate clockwise. The Earth is at the top of the page and the Sun is ϕ degrees clockwise from that direction. For each date, the rotation phase origin is defined by the first data point *on that date*. A subtlety of Condition PHASE is that the sign of ϕ used in "convex-profile inversion" corresponds to the asteroid's rotation sense. The sign is positive if the asteroid rotates through ϕ from the Earth direction to the Sun direction, a configuration that pertains to Cuyo in October 1989 if the asteroid's rotation is direct. The inversions in Fig. 1 that use a positive sign for ϕ are labeled "+DS" because here our view of the mean cross section is from the south, i.e., parallel to the spin vector. The sign of ϕ is negative if the asteroid rotates through ϕ from the Sun direction to the Earth direction, a configuration that pertains to Cuyo in October 1989 if the asteroid's rotation is retrograde. The inversions in Fig. 1 that use a negative sign for ϕ are labeled "-RN" because here our view of the mean cross section is from the north, i.e., antiparallel to the spin vector. For our data, the two signs are equally acceptable and give nearly identical results.



OCT 7, +DS

OCT 8, +DS

OCT 7, -RN

OCT 8, -RN

Figure 1. Cuyo lightcurves obtained on Oct. 7 and 8, and convex-profile inversion results obtained for each date using +/- signs for the solar phase angle (top/bottom plots). Estimates of $\underline{C}$ and $\underline{C}_s$ are shown as solid profiles and dotted profiles. Lightcurves are plotted on linear scales, with unit average brightness; the large symbols are the data, the solid curve was derived from a Fourier series fit to the data, and the dotted curve was derived from a constrained Fourier series corresponding to the estimate of $\underline{C}$. On the right, Δm is the ratio of the lightcurve's maximum to its minimum; β^* is $\underline{C}$'s breadth ratio; and Ω_c is $\underline{C}$'s non-circularity, defined as the "distance" of the mean cross section from a circle (Ostro et al. 1988).

Cuyo's elongation

The mean cross section $\underline{C}$ can be represented by a radius-of-curvature function or by that function's Fourier series $\mathbf{x}$. Under the ideal conditions, there is a one-to-one mapping from the coefficients in $\mathbf{x}$ to the coefficients in the Fourier series for the lightcurve. At phase angles as large as those during the Cuyo photometry, $\underline{C}$'s third harmonic (and to a lesser extent each of its higher odd harmonics) propagates very efficiently into the lightcurve's corresponding harmonic; see Fig. 3 of Ostro et al. 1988. That is why convex-profile inversion of Cuyo's lightcurves, which contain a very strong third harmonic, yields a "quasi-triangular" estimate of mean cross section.

The breadth ratio, β^*, of Cuyo's mean cross section is estimated to be about 1.14. That is, the elongation of the asteroid's mean latitudinal contour is apparently very small. Here we have a good example of how the amplitude of a large-ϕ lightcurve severely overestimates elongation. This bias, which is commonly referred to as the phase-amplitude relation, is a consequence of basic aspects of lightcurve-acquisition geometry that are codified in convex-profile inversion theory (Ostro et al. 1988).

The estimates of $\underline{C}$ and hence β^* can contain systematic error if Conditions GEO or EVIG are violated, as they must be to some extent). Ostro et al. (1988) studied such error under simplified circumstances. At large ϕ, nongeometric scattering can distort estimates of $\underline{C}$, but the distortions are not very severe. On the other hand, if the viewing/illumination geometry is far from equatorial, then an elongated asteroid's β^* can be severely underestimated unless the Earth and Sun are opposite sides of the objects's equatorial plane; see section IV.A of the referenced paper.

INFORMATION FROM RADAR

The Cuyo datasets from Arecibo and Goldstone (Ostro et al. 1991) consist of echo spectra that provide fine rotation-phase coverage but are not quite strong enough to yield a reliable estimate of the object's pole-on silhouette, as has been done for a few other objects. However, visual inspection of the spectra leads to two useful conclusions, as follows.

First, the echo bandwidth varies imperceptibly with rotation, supporting the inference from the lightcurve inversion that this asteroid is not very elongated. Second, the Goldstone and Arecibo weighted-sum spectra have bandwidths (~160 Hz, ~40 Hz) only slightly larger than the ratio of the telescopes' transmitter frequencies (8495 MHz, 2380 MHz), implying that cos δ, the cosine of the asteroid-centered declination of the radar, did not change very much during Sep 26 - Oct 11 despite a 34° change in geocentric direction. This result suggests that the view during the photometry was closer to equatorial than to pole-on, and that the view may have been slightly closer to equatorial during the October observations than in September. Hence, we find no evidence in the radar spectra for severe violation of Condition EVIG.

CONCLUSION

Our photoelectric and radar observations support the hypothesis that 1917 Cuyo is a relatively unelongated asteroid.

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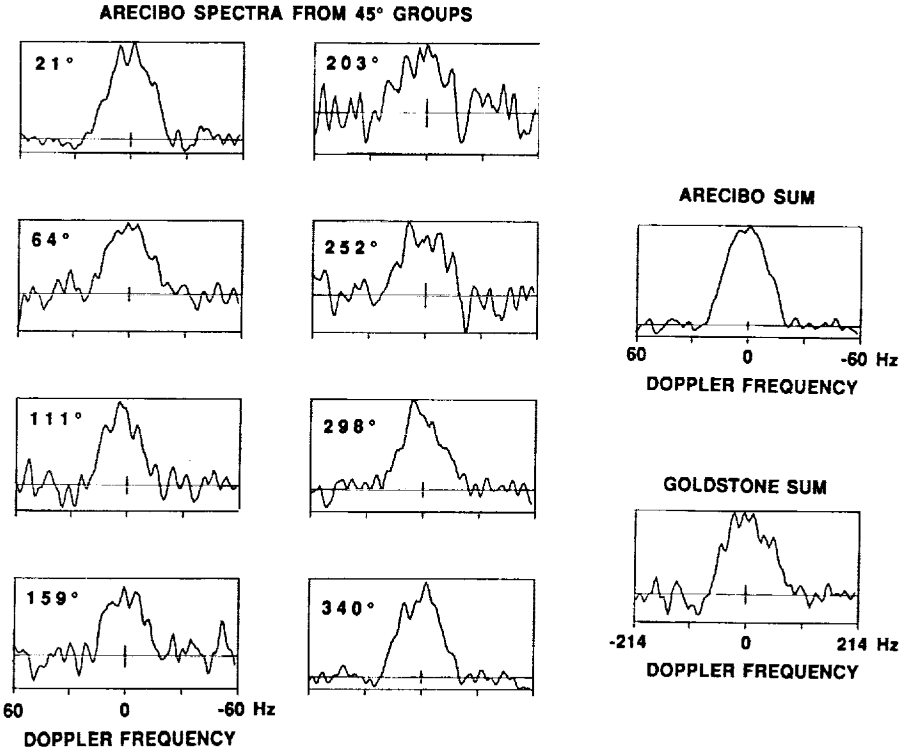

Figure 2. Radar echo spectra for 1917 Cuyo from observations reported by Ostro et al. (1991). In each plot, echo power in the OC polarization is plotted on an arbitrary linear scale vs. frequency, relative to the central frequency estimated by those authors. A horizontal line is drawn at the zero power level and a vertical bar at the origin indicates ± 1 standard deviation. At the left are weighted sums of Arecibo spectra from eight, 45° intervals of rotation phase; the weighted-mean phase is given. On the right are Arecibo and Goldstone weighted-sum spectra, smoothed to frequency resolutions (4.0, 14.3 Hz) and vignetted to windows (120, 428 Hz) in the same ratio as the instruments' transmitter frequencies (2380, 8495 MHz). These spectra can be thought of as one-dimensional images, or brightness scans across Cuyo's disc through a slit parallel to the projected spin vector. The length equivalent, in units of km/cos δ, of frequency is the same for all the spectra in this figure. δ, the asteroid-centered declination of the radar, may have changed during the dates spanned by the radar observations; see text. The ~40-Hz bandwidth of the Arecibo sum, when combined with the rotation period from the lightcurve, implies that the maximum breadth of Cuyo's pole-on silhouette is ~3.9 km/cos δ_A, with δ_A the value of δ during the Arecibo runs.

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