LIGHTCURVE AND PHASE FUNCTION PHOTOMETRY OF THE OSIRIS-REx TARGET (101955) 1999 RQ_{36}.

C. W. Hergenrother[1], D. J. Scheeres[2], M. Nolan[3], C. d'Aubigny[1], M. A. Barucci[4], B. E. Clark[5], E. Dotto[6], J. P. Emery[7], D. S. Lauretta[1], J. Licandro[8], and B. Rizk[1], [1]Lunar and Planetary Laboratory, University of Arizona, 1629 E. University Blvd, Tucson, AZ 85721 (chergen@lpl.arizona.edu), [2]Univ. Colorado-Boulder, [3]Arecibo Obs., [4]Obs. de Paris, [5]Ithaca College, [6]INAF-Oss. Astro. di Roma, [7]Univ. Tennessee, [8]Inst. Astro. de Canarias.

Introduction: The OSIRIS-REx mission is the third New Frontiers-class mission selected for flight by NASA. Scheduled for launch in 2016, the spacecraft will rendezvous with and collect samples from the near-Earth asteroid (101955) 1999 RQ_{36}. These samples will then be returned to Earth in 2023 [1].

1999 RQ_{36} is a carbonaceous B-type Apollo near-Earth asteroid on a low delta-V orbit with respect to Earth. Near-, mid-, and thermal-infrared photometric and spectroscopic data suggest a very low albedo of 0.03-0.04 [2][3]. Analysis of visible to near-infrared reflectance spectra identifies the most similar meteorite analogs to be CI and/or CM meteorites [2]. It is also a potential Earth impactor with a probability of impact of 10^{-3} in the late 22nd century [4].

We present characterization of the photometric properties of 1999 RQ_{36} at visible wavelengths including determination of its rotation period and phase function. We also discuss implications for the detection of YORP induced rotation rate changes.

Lightcurve Photometry: Time-series photometry was obtained with the University of Arizona Kuiper 1.5-m over four consecutive nights in September 2005. Observations were made using multiple Eight-Color Asteroid Survey (ECAS) filters though the *w* (0.70 μm) filter was primarily used. A 10th order Fourier series fit finds a rotation period of 4.2968 ± 0.0017 hr with amplitude of 0.17 magnitudes (Figure 1). The low amplitude and trimodal (three maxima and three minima) lightcurve is consistent with the rotation of a nearly spherical body observed at high phase angles [5].

This result is twice the value found in 1999 [6]. The discrepancy is due to not observing a total rotation period during any of the 1999 nights. As a result, they incorrectly arrived at a sub-multiple of the real period.

Phase Function Photometry: Determining the relationship between the brightness of an asteroid and the observed phase angle (α) allows an estimate of the absolute magnitude (H) or brightness of the asteroid at zero degrees phase angle (where the phase angle is defined as the Sun-asteroid-Earth angle). The relationship between brightness and phase angle is determined by normalizing the observed apparent magnitude of 1999 RQ_{36} to a heliocentric and geocentric distance of 1 AU. The phase function can be modeled by a simple linear least squares fit and the IAU H-G photometric system for airless bodies [7].

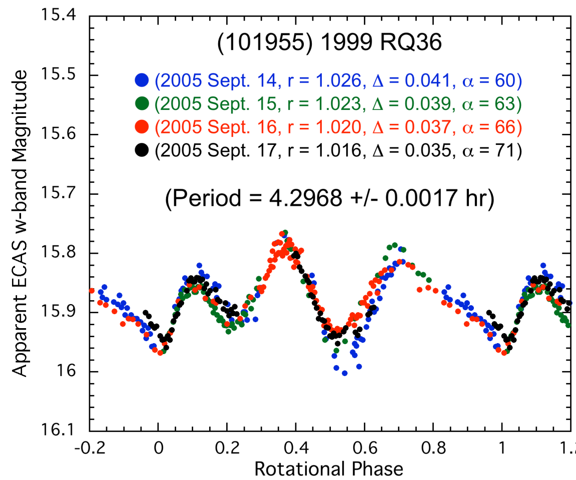

Fig 1. – Phased lightcurve obtained over the course of 4 nights in September 1999.

The dataset for 1999 RQ_{36} consists of *V*, *R*, and ECAS *w*-band magnitude measurements made between 2005 Sept. 14 UT and 2012 Nov. 27 UT that cover phase angles from 15° to 100°. All non-*V* photometry was transformed to *V* based on color indices derived from visible spectroscopy [2]. Observations were acquired with the Kuiper 1.5-m and VATT 1.8-m. Additional observations from the Magdalena Ridge Obs. 2.2-m by W. Ryan and E. Ryan were extracted from the Minor Planet Center database.

Results and Discussion: *Rotation State and YORP*. Based on the current 1999 RQ_{36} shape model we have computed the expected YORP torque on this asteroid using the approach outlined in [11]. Assuming an obliquity near 180° the 1999 RQ_{36} shape model has a normalized YORP coefficient value of -0.004, which falls within the range of values reported in the literature. Assuming a density of 1.0 g/cm^3 and a Lambertian scattering coefficient of 2/3 yields an average YORP torque of -6.7 x 10^{-8} degrees/second/year. In terms of asteroid rotation angle, this corresponds to a 1 degree/$year^2$ shift, producing a 100° shift in lightcurve phasing in about 10 years.

At the current rotation period precision of 0.0017 hr it would take approximately 143 years for the spin rate to change by a measurable amount. Instead, assuming a similar precision of measurement to what NEAR achieved at Eros (1.5 x 10^{-4} degrees/day) [12], it would

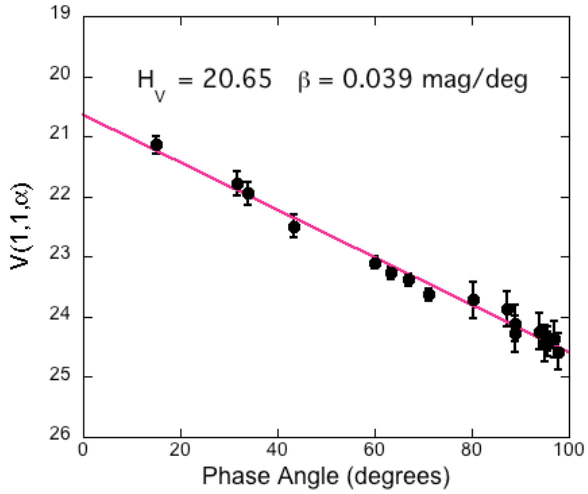

Fig 2. – Linear phase function fit to V-band photometry obtained over phase angles ranging from 15° to 100°.

take only 10 days for the spin rate to shift by a detectable amount, implying that this level of YORP acceleration should be measurable once rendezvous is achieved by OSIRIS-REx.

It must be noted that YORP accelerations are extremely sensitive to the model resolution, mass distribution and surface morphology [13][14][15]. Thus, these predictions should be viewed as highly uncertain, with final resolution of the actual predicted YORP torque delayed until the arrival of OSIRIS-REx.

Phase Function Analysis. A linear least squares fit through the phase function data yields H_V = 20.65 ± 0.20 and phase slope (β) of 0.039 ± 0.005 magnitude per degree of phase angle (Figure 2). The linear fit does not include any opposition effect, which usually occurs at phase angles of much less than 15°. Low albedo carbonaceous asteroids show shallow opposition effects of ~0.15 ± 0.15 [8][9]. Assuming such an opposition effect for 1999 RQ_{36} results in an H_V of 20.50 ± 0.30. Solving within the IAU H-G system produces values of H_V = 19.90 ± 0.10 and G = −0.14 ± 0.02. The H-G system is known to have difficulty with low albedo objects like 1999 RQ_{36} [10]. The H_V value from this system is derived from an extrapolated opposition effect that is much larger than those observed for dark objects. As a result the H-G fit is suspect and should not be used without knowledge of the low phase angle behavior of the phase function.

A correlation exists between the slope of the linear phase function and the albedo of asteroids [16][17]. Generally the phase function slope increases as the albedo decreases. A comparison of phase function slopes with albedo for well-measured near-Earth asteroids is shown in Figure 3. A phase function slope of 0.039 mag/deg is consistent with the infrared-derived albedo of 0.03-0.04. Such large phase slopes are commonly found among carbonaceous asteroids and comets [18].

The 2011-2012 apparition marks the last opportunity to characterize 1999 RQ_{36} before launch in 2016. Additional lightcurve observations and phase function photometry down to a phase angle of 12° are planned. Due to the lack of low phase angle observations a program to measure the opposition effect of carbonaceous, and especially B-type, asteroids in the inner Main Belt is being conducted. This region is the most likely source of 1999 RQ_{36} [19].

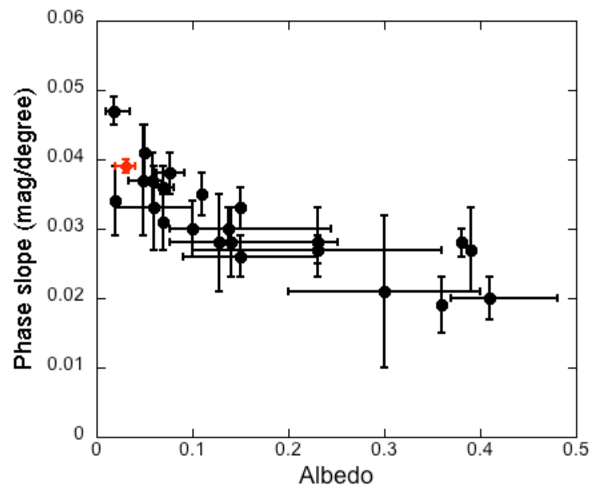

Fig 3. – Correlation between the phase slope and albedo of near-Earth asteroids. The dataset is limited to near Earth asteroids with accurate phase slopes and albedo measurements. 1999 RQ_{36} is denoted in red.

References: [1] Lauretta D. S. et al. (2012) *LPS XLIII*. [2] Clark B. E. et al. (2011) *Icarus*, 216, 462. [3] Emery J. P. (2010) *LPS XLI*, Abstract #2282. [4] Milani A. et al. (2009) *Icarus*, 203, 460. [5] Nolan M. C. et al. (2008) *Bull. Amer. Astron. Soc.*, 39, 433. [6] Krugly Yu. N. et al. (2002) *Icarus*, 158, 294. [7] Bowell E. et al. (1989) In *Asteroids II*, 524. [8] Shevchenko V. G. et al. (2008) *Icarus*, 196, 601. [9] Muinonen K. et al. (2010) *Icarus,* 209, 542. [10] Shevchenko V. G. et al. (2012) *Icarus*, 217, 202. [11] Scheeres D. J. (2007) *Icarus*, 188, 430. [12] Miller J. K. et al. (2002) *Icarus*, 155, 3. [13] Scheeres D. J. et al. (2007) *Icarus*, 188, 425. [14] Scheeres D. J. and Gaskell R. W. (2008) *Icarus*, 198, 125. [15] Statler T. S. (2009) *Icarus*, 202, 502. [16] Belskaya I. N. and Shevchenko V. G. (2000) *Icarus*, 147, 94. [17] Oszkiewicz D. A. et al. (2011) *J. Quant. Spect. Rad. Transfer*, 112, 1919. [18] Li J-. Y. et al. (2009) *Icarus*, 204, 209. [19] Campins H. et al. (2010) *Astrophys. J. L.*, 721, L53.