THE FAST SPIN OF NEAR-EARTH ASTEROID (455213) 2001 OE84, REVISITED AFTER 14 YEARS – ARGUMENTS FOR A HIGHLY COHESIVE INTERNAL STRUCTURE. D. Polishook1, N. Moskovitz2, A. Thirouin2, A. Bosh1, S. Levine3, C. Zuluaga3, S. Tegler4 and O. Aharonson1. 1Weizmann Institute of Science (234 Herzl St. Rehovot 7610001, Israel, david.polishook@weizmann.ac.il), 2Lowell Observatory (1400 West Mars Hill Road, Flagstaff, AZ 86001, USA), 3Massachusetts Institute of Technology (77 Massachusetts Avenue, Cambridge, MA 02139, USA), 4Northern Arizona University (527 S Beaver Street, Flagstaff, AZ 86011, USA).

Introduction: With a mean diameter of about 650 meters, the near-Earth asteroid (455213) 2001 OE84 (OE84 for short) has a rapid rotation period of ~29 minutes which is highly uncommon for asteroids larger than ~200 m (Fig. 1). We estimate that at least one out of a thousand asteroids, with an OE84-like diameter, has a similar internal structure. This object's unique nature allows us to distinguish between leading models of asteroid structure: namely a collection of constituent fragments (i.e. a “rubble pile”) with [1] or without [2] cohesion between the components, versus a body with a monolithic interior. A rubble pile OE84, bound only by self-gravity, will shed mass and as a result will reduce its spin rate to conserve rotational angular momentum. On the other hand, a model with cohesion remains bound and the asteroid maintains its fast spin.

Fig. 1: Asteroid diameters vs. spin rates. OE84 is marked with a red circle. The “rubble pile spin barrier” at ~10 cycles per day for asteroids larger than ~200 m is easily noticed. Data is from the lightcurve database [3].

Observations and Shape Modeling: We revisited OE84 14 years after it was first, and last, observed by [4] in order to re-measure its spin rate and to search for changes. Observations were conducted over 4 separate nights on Lowell Observatory’s 4.3 m Discovery Channel Telescope (DCT) between January 19 to March 12, 2016, while the asteroid’s visible magnitude ranged from 20.5 to 21.2. Image reduction and spin analysis followed standard techniques [5,6]. We have confirmed the rapid rotation deriving a synodic period of 0.486545 ± 0.000004 hours (Fig. 2). This period is ~0.1 seconds longer than the synodic period derived by [4], due to differences in the aspect angle OE84 was observed at 2001 and 2016. By fitting the photometric data from 2001 and 2016 together using the lightcurve inversion technique [7], we determined:

- A retrograde sense of rotation, with the spin axis very close to the ecliptic south pole;
- An oblate shape model of $a/b=1.32±0.04$ and $b/c=1.8±0.2$ ($a$, $b$, $c$ represent the physical axes of an oblate shape, where $a>b>c$ and the asteroid rotates around the $c$ axis);
- No change in the sidereal spin rate between 2001 and 2016.

Fig. 2: Folded lightcurve of OE84 from our 2016 campaign. The best-fit synodic period is 0.486545 ± 0.000004 hours.

Analysis: The persistence of the exceptionally fast spin rate of OE84 supports the argument that OE84 is not a strengthless rubble pile but is a cohesively bound body. We estimate a limit to the internal cohesion using the Drucker-Prager yield criterion that calculates the shear stress in a rotating ellipsoidal body at breakup [1]. We found that current estimates of cohesion in asteroids (up to ~80 Pa, [8,9]) are insufficient to maintain a rubble pile intact at the measured spin rate of OE84. Alternatively, we tested a model with a stronger, more cohesive core surrounded by a loose, weakly cohesive rubble pile shell [10]. Even though this model produces lower cohesion values, the minimal cohesion of the core to keep the body bound is
about 400 Pa, at least ~5 to ~16 times higher than the cohesion estimated for other objects [8,9]. This suggests that a two-layer model with a more cohesive core is also less likely.

A monolithic structure for OE84 would resist disruption since the cohesion of solid rocks is on the order of 10^6 Pa [11]. Based on spacecraft imagery and ground-based radar observations, hundred-meter-sized asteroids without surface boulders do not seem to exist [12,13], thus we demonstrate how a monolithic asteroid with a shallow granular shell of weakly cohesive boulders can rotate quickly without shedding mass and without slowing spin rate. We argue that this model is the most likely for OE84. Therefore, while OE84 has a unique combination of size and spin rate, that may represent less than a percent of all asteroids of OE84’s size, mitigation plans against asteroid impacts would benefit by considering the possibility of solid monolithic bodies within the near-Earth asteroids population.

If indeed OE84 has a monolithic-like nature, it most probably avoided collisions that would have cracked it. This would suggest a young age for OE84. Using the intrinsic collision probabilities between near-Earth asteroids and between main belt asteroids [14], we calculate that an OE84-sized asteroid will suffer a collision every few tens of millions of years. This timescale is lower than the time required for the thermal YORP effect [15] to spin-up OE84 into its current spin rate, suggesting its current fast spin originated from a collision and not from the YORP effect.

The existence of a shell of boulders, the possibility of a bald monolithic body, or an unusually high cohesion for OE84, may be constrained in the future using thermal observations to determine the thermal inertia of the surface. In addition, near-IR spectroscopy could provide information about compositional links to specific collisional families in the main asteroid belt, which might help to constrain the collision age of OE84 and thus determine whether it is possible for a monolithic body to survive undisturbed since removal from its parent body. OE84 will be in favorite conditions for such observations in August 2025 and October 2032.

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