Radar-derived asteroid shapes point to a 'zone of stability' for topography slopes and surface erosion rates

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Previous studies of the combined effects of asteroid shape, spin, and self-gravity have focused primarily upon the failure limits for bodies with a variety of standard shapes, friction, and cohesion values [1,2,3]. In this study, we look in the opposite direction and utilize 22 asteroid shape-models derived from radar inversion [4] and 7 small body shape-models derived from spacecraft observations [5] to investigate the region in shape/spin space [1,2] wherein self-gravity and rotation combine to produce a stable minimum state with respect to surface potential differences, dynamic topography, slope magnitudes, and erosion rates. This erosional minimum state is self-correcting, such that changes in the body's rotation rate, either up or down, will increase slope magnitudes across the body, thereby driving up erosion rates non-linearly until the body has once again reached a stable, minimized surface state [5]. We investigated this phenomenon in a systematic fashion using a series of synthesized, increasingly prolate spheroid shape models. Adjusting the rotation rate of each synthetic shape to minimize surface potential differences, dynamic topography, and slope magnitudes results in the magenta curve of the figure (right side), defining the zone of maximum surface stability (MSS). This MSS zone is invariant both with respect to body size (gravitational potential and rotational potential scale together with radius), and density when the scaled-spin of [2] is used. Within our sample of observationally derived small-body shape models, slow rotators (Group A: blue points), that are not in the maximum surface stability (MSS) zone and where gravity dominates the slopes, will generally experience moderate erosion rates (left plot) and will tend to move up and to the right in shape/spin space as the body evolves (right plot). Fast rotators (Group C: red points), that are not in the MSS zone and where spin dominates the slopes, will generally experience high erosion rates (left plot) and will tend to move down and to the left in shape/spin space as the body evolves (right plot), barring other influences such as YORP spin-up [6]. Moderate rotators (Group B: green points) have slopes that are influenced equally by gravity and spin, lie in or near the self-correcting MSS zone (right plot), and will generally experience the lowest erosion rates (left plot). These objects comprise 12 (43%) of the 28 bodies studied, perhaps indicating some prevalence for the MSS zone. On the other hand, a sample of 1300 asteroid shape and spin parameters (small grey points), derived from asteroid lightcurve data [7], do not show this same degree of correlation, perhaps indicating the relative weakness of erosion-driven shape modification as compared to other influences. We will continue to investigate this phenomenon as the number of detailed shape models from ground-based radar and other observations continues to increase.

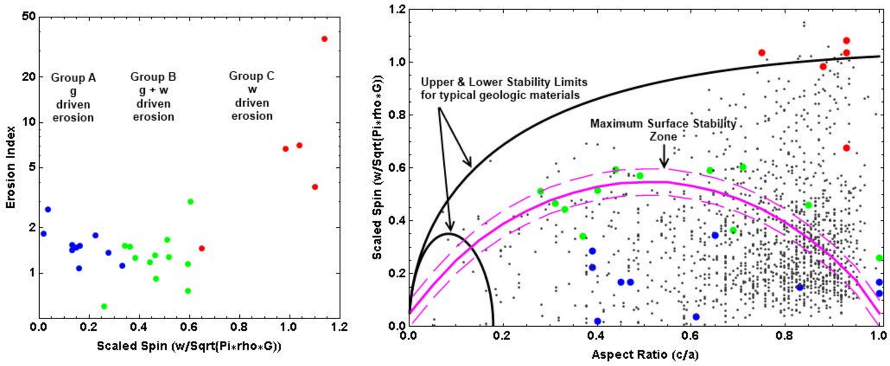

Figure: (left) A plot of the normalized, mean erosion rate for each body studied, divided into 3 groups based upon the dominant factor driving slope degradation. (right) A plot of the maximum surface stability zone (magenta lines) as a function of body aspect ratio and scaled spin state, compared to actual small-body shape models (large points) and asteroid lightcurve data (small points). Also shown are the upper and lower stability limits for strengthless, oblate spheroids possessing typical geologic material friction [2].

References: [1] K. Holsapple, Icarus, 154, 432–448 (2001). [2] K. Holsapple, Icarus, 172, 272–303 (2004). [3] K. Holsapple, Icarus, 187, 500–509 (2007). [4] J. Magri et al., Icarus, 186, 152–187 (2007). [5] J. Richardson and T. Bowling, Icarus, 234, 53–65 (2014). [6] Rubincam, D., Icarus, 148, 2–11 (2000). [7] Minor Planets Center (MPC) lightcurve parameters (A. Harris and B Warner).