A STOCHASTIC MODEL OF ASTEROID ROTATION,

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The rotational state of an asteroid is influenced, perhaps dominated, by collisions with other asteroids. An analytic theory by Harris (1) predicts mean rotation rates which are in reasonable agreement with observations (2). However, it does not predict the dispersion about the mean due to the stochastic nature of collisions. Also, Harris' model is valid only for power-law mass distributions, $N(m)dm \propto m^{-q}dm$, with $q<2.0$. This condition is satisfied in the present belt ($q \simeq 11/6$), but plausible primordial populations could have had larger q (3). Moreover, the analytic theory does not distinguish between cratering erosion and shattering of the asteroid, which may produce different distributions of ejecta mass and angular momentum. I have addressed these problems using the following numerical model.

Conceptual Framework. An initial target mass M and rotation frequency ω are specified. A projectile mass distribution is defined with an expectation which follows a power law with arbitrary index between specified bounds. The projectile mass, impact parameter, and direction with respect to the target's spin vector are chosen randomly. If the energy density in the target is less than its impact strength S(4), surface cratering is assumed. The ejecta mass is computed by energy scaling, with a cumulative velocity distribution $\propto v^{-9/4}$ (4). The mass which exceeds the escape velocity is removed, and is assumed to carry off the specific angular momentum of the impact site (radial symmetry of ejecta in the crater's frame). New values of M and ω are computed, assuming spherical symmetry, and the process repeated.

If the energy density exceeds S the target is shattered, but may remain gravitationally bound. The mass/velocity distribution is somewhat arbitrary, due to lack of experimental data. I assume the entire mass M is "ejecta," with the $^{-9/4}$ power velocity distribution, with velocity coefficient adjusted so that a specified fraction f of the impact energy appears as kinetic energy of the fragments. In order for the escaping mass to increase monotonically from cratering to shattering, f (shattering) must be $\gtrsim 5/3$ f(cratering).

Results. Fig. 1 shows a computation of ω vs. radius R, in which parameters were chosen to match those of Harris (compare with Fig. 1 of (1)). This required impact energies $\leq 1.2GM^2/R+MS/\rho$, although the ejecta velocity law adopted here allows larger impacts without disruption. Asteroids with low initial ω appear to spin up to a quasi-equilibrium value, but with fairly large dispersion. Spin rates are somewhat larger than Harris' values, since the numerical model does not yet incorporate forward scattering of ejecta in oblique impacts, which should result in lower ω. These are not true evolutionary tracks for individual bodies, since destruction would normally occur before large changes in R. However, any section of

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a track represents a possible history before disruption. The increase in ω at R<10 km reflects the change in binding from self-gravitation to material strength.

The results for different runs are sensitive to the ejecta mass and velocity distributions used; this points out the need for more experimental data on hypervelocity impacts into finite targets. Better models for the transfer of momentum in oblique collisions, and the combined mass/velocity distribution of ejecta in shattering events are required to refine these results.

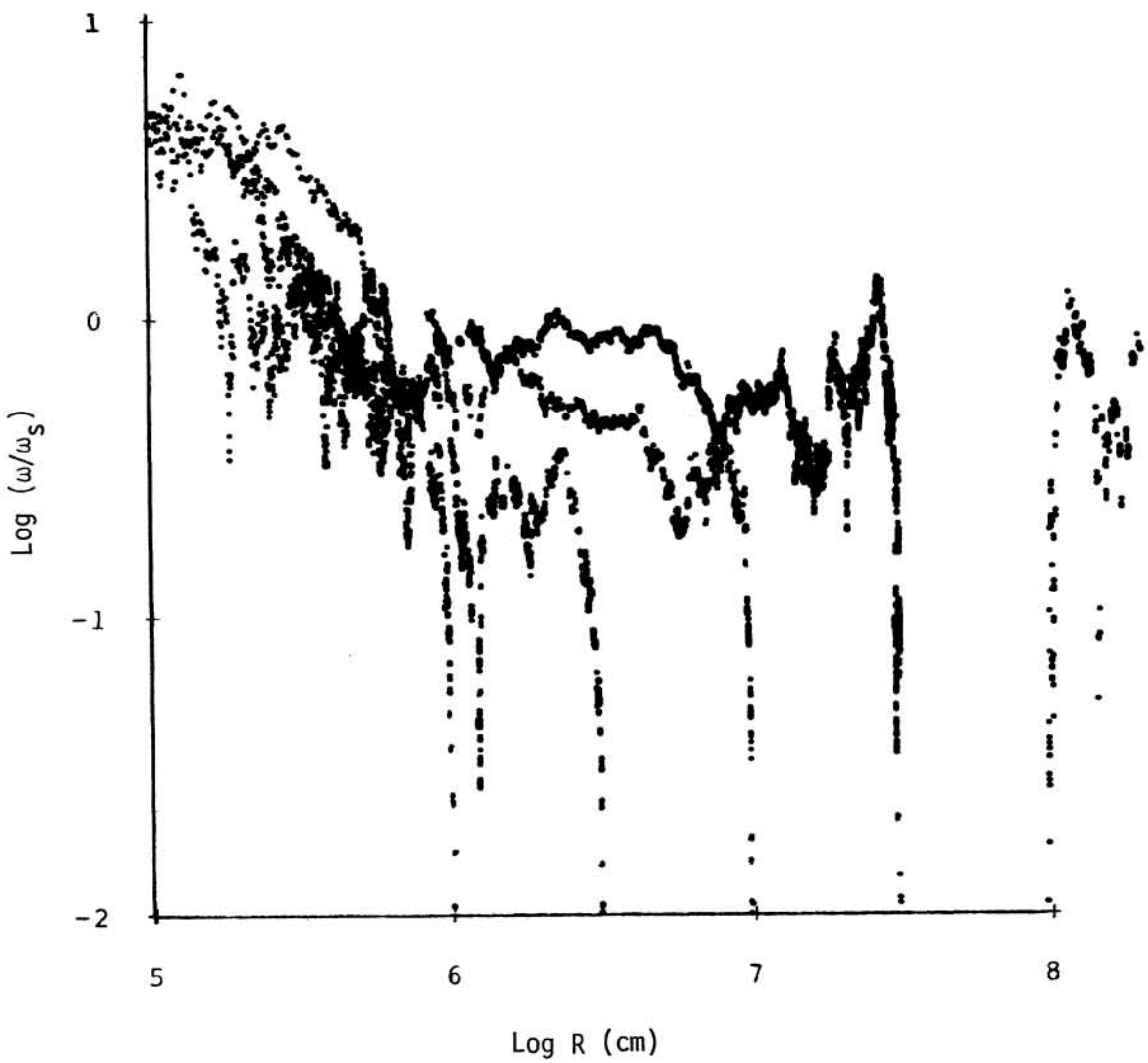

Figure 1. Angular velocity (in units of the surface orbit frequency $\omega_s = [4\pi G\rho/3]^{\frac{1}{2}}$) vs. R. Parameters used: $S = 3\times10^7$ erg/cm^3, $\rho = 3$ g/cm^3, $q = 11/6$, impact velocity = 5 km/s, f(cratering) = 0.1, f(shattering) = 0.2; $\omega = \omega_s$ corresponds to rotation period 1.9 hr. Starting conditions: $\omega = .01\omega_s$, R = 10, 32, 100, 320, and 1000 km.

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Any attempt at this time to use observations of asteroid rotation rates to infer collisional strengths, densities, etc., would be premature. Such inferences may be possible in the near future after acquisition of a suitable data base.

References

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