288 GLAUKE AND 1220 CROCUS: PRECESSING BINARY ASTEROIDS?

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For the asteroids 288 Glauke and 1220 Crocus we have observed lightcurves of large amplitudes (>0.5 mag) and extremely long periods (~50 and ~31 days, respectively). In the case of 1220 Crocus, a small amplitude (~0.15 mag) modulation with a period of ~7.9 hours was also observed near minimum light of the longer period variation and the amplitude of this modulation decreased towards maximum light of the long period variation (1). 288 Glauke showed no sign of more rapid variation near maximum light. Unfortunately, we did not observe it with sufficient frequency to detect such variations near minimum light. Additional observations in 1984 confirm the long period variation of 288 Glauke, but observations to detect shorter period variations were inconclusive due to poor weather and the faintness of the asteroid near minimum light.

We interpret the longer periods of variation as precession periods of the asteroids' spin axes, since such long periods of rotation are implausible as primordial rotation rates, and tidal evolution (e.g. Pluto-Charon) cannot lead to periods longer than ~6-10 days for plausible dissipation rates over 4.5 by. The short period variation of 1220 Crocus is, we claim, the actual rotational variation, which is most apparent near minimum light when the asteroid is seen at a near equatorial aspect. Near maximum light of the longer period variation, the asteroid is viewed more nearly pole-on, and the rotational variation is expected to be less apparent.

The only possible modes of precessional motion are a free wobble, such as might be induced by a large, recent impact event, or a forced precession (analogous to the precession of the equinoxes of the earth). The former motion would have a period longer than the rotation period by a factor of the inverse moment of inertia differences, $C/\{C-(A+B)/2\}$. Since the lightcurve amplitudes are large in both cases, indicating very oblate figures, these factors must be near unity for both asteroids. Wobble periods of 30-60 days imply rotation periods nearly as long, and thus do not offer an acceptable explanation for the observations.

The period of the free precession of an asteroid's spin axis due to the torque exerted by the sun would be >1000 years. However, the presence of a massive satellite of the asteroid could lead to a much more rapid precession, perhaps as short as 1-2 months, and thus account for our observations. Several constraints can be placed on such a binary model for these asteroids, as follow:

I. Most of the angular momentum must be in the satellite orbital motion, rather than in the spin of the primary, otherwise the orbit would precess and the spin axis would remain nearly stationary. Thus:

$$m\Omega a^2 \gtrsim \frac{2}{5} M R^2 \omega_r$$

where M and m are the masses of the primary and secondary, respectively, R is the equatorial radius of the primary, a is the orbital radius, Ω is the orbit freqency, and ω_r is the rotation frequency of the primary. Note that the moment of inertia of an oblate spheroid about its short axis is $2/5\ MR^2$, the same as a sphere, except that R refers to the equatorial radius.

II. The precession frequency is known from observations, and must satisfy the condition:

$$\omega_p = \frac{C - \frac{1}{2}(A+B)}{C} \frac{m}{M} \frac{\Omega^2}{\omega_r}$$

where ω_p is the precession frequency. For a totally flat figure, the moment of inertia figure is 1/2 ; for a less flattened body it is less. Since the asteroids in question must be very oblate, we take it to be 1/2 .

III. The timescale of tidal evolution must be at least as long as the age of the solar system to assure that the system could have existed that long. This requirement could be relaxed somewhat if one believes that such systems may be formed under present conditions in the asteroid belt and thus may not be primordial. We doubt this, but call attention to the possibility. Constraint I implies that the evolution of the spin of the primary is more rapid than that of the orbit. The timescale of evolution of the primary's spin is (2):

$$t \sim \frac{2}{3} \frac{Q}{k_2} \left[\frac{M}{m}\right]^2 \frac{C}{MR^2} \left[\frac{a}{R}\right]^6 \frac{\omega_r}{\Omega_o^2} \gtrsim 4.5 \text{ by}$$

where $\Omega_o^2 = 4/3\ \pi G \rho$ is the rotation frequency squared at the surface of a sphere of mean density ρ ; Q and k_2 are the tidal effective Q and potential Love number of the primary, respectively. Q is expected to be of the order 100 and k_2 is scaled proportional to R from a value of ~0.03 for the moon (2).

The above constraints imply for 288 Glauke a satellite of mass ratio $m/M \sim 0.1$ with an orbit radius $a/R \sim 12-15$. The orbit period of the satellite is of the order 100 hr, and the (unobserved) spin period of the primary must be only a factor of a few times shorter. For 1220 Crocus, the observed rotation period of only ~8 hours constrains the model to require a more massive satellite to produce the larger necessary precessional torque. This in turn suggests a somewhat shorter timescale of tidal evolution, $\sim 10^8$ years. As we have noted, shorter timescales cannot be completely ruled out if such systems are forming under present conditions. We prefer, however, the possibility that our assumed values of Q and/or k_2 are incorrect, thus yielding an underestimate of the tidal timescale. Another possibility is that the detection of the 7.9 hour rotation period is incorrect.

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