Chaotic rotation of Hyperion?

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Saturn's satellite Hyperion has been predicted to be in a chaotic rotation state as a result of its irregular shape and tidal interactions[1]. However, an analysis of Voyager 2 images by Thomas *et al.*[2] contradicted this prediction. These authors analysed 14 images obtained over 61 days and interpreted them to be consistent with a coherent (non-chaotic) rotation period of 13.1 days. The interpretation of the Voyager data has, however, been criticized by Peale and Wisdom[3], who argued that the low sampling frequency does not allow chaotic or non-chaotic rotation to be distinguished. We report here new observations which were obtained with a higher sampling frequency. These data conclusively show that the 13.1-day period found by Thomas *et al.* was not due to coherent rotation.

Charge-coupled device (CCD) images of Hyperion were obtained on eight nights between 16 and 30 April, 1985 UT using the McDonald Observatory 0.76-m telescope and a CCD camera with an RCA 320 × 512 detector. Hyperion was easily identified using offsets from the 1985 *Astronomical Almanac*. Two to six images were obtained each night through a *V* filter and exposure times ranged from 20 to 60 s. For each image, Hyperion was placed near the edge (20–30 pixels) of the chip so that almost all of the glare from Saturn was excluded. A nearby comparison star, SAO159426, spectral type K2, was imaged separately in the same area of the chip. *V* magnitude calibrations were performed by imaging solar-type standard stars[4].

Photometric measurements were performed by integrating each Hyperion image within a circular aperture. Aperture sizes were chosen by measuring the width of Hyperion's image profile out to the 99% level. Sky subtraction was performed using an annulus of equal area around the Hyperion aperture. All images were flat-fielded and bias-corrected. Hyperion's light curve is presented in Fig. 1. The comparison star, SAO159426, was reduced in an identical fashion and remained at a constant *V* magnitude of 9.44 ± 0.02.

Our light curve of Hyperion (Fig. 1) shows an amplitude of nearly 1 magnitude. The data cover a span of 14 days and rule out a 13.1-day period because the 16 and 17 April data are near maximum light and the 29 and 30 April data are near minimum light. These new observations imply that the 13.1-day period derived from the Voyager data[2] was not due to coherent rotation. Thus, the contention[3] that the Voyager period could have resulted from the infrequent sampling of a chaotic rotation is supported.

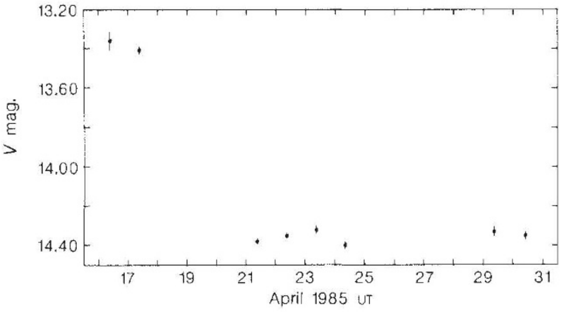

Fig. 1 Light curve of Hyperion obtained in April 1985. The dates (UT) of the observations are given on the abscissa. The *V* magnitudes from each night have been reduced to a common viewing geometry: $r = 9.5$ AU, $\Delta = 8.5$ AU, phase angle = 2.5°, where r = Sun–Saturn distance, Δ = Earth–Saturn distance. This latter value represents the mean of the range of observed phase angles (1.8–3.2°) and the phase correction used a coefficient of 0.026 mag. $\deg^{-1}$. The error bars indicate the photometric accuracy for the mean of the images on each night, which was typically 0.04 mag. or better.

This new result alone does not resolve the question as to whether Hyperion is in a chaotic or non-chaotic rotation state. If Hyperion's rotation is non-chaotic, the light-curve periods determined at various times should always be in close agreement. The Voyager light curve obtained over a 61-day interval in 1981 displayed several maxima and minima, indicating that if Hyperion is in a non-chaotic state, its rotation period is a small fraction of 61 days. Thomas *et al.* performed a period search over the range of residuals which tightly constrains their solution to a value near 13.1 days.

If Hyperion is in a chaotic rotation state, the light-curve period would be changing randomly with time. Light-curve periods determined at various times would not be expected to be in close agreement. Therefore, the incompatibility of our new data with the period found by Thomas *et al.* is fully consistent with Hyperion being in a chaotic rotation state. Although this incompatibility does not conclusively prove that Hyperion's rotation state is chaotic, it is strong evidence in favour of this hypothesis.

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Experimental observation of ultra-low-frequency waves generated in the ionosphere

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Nonlinear properties of the ionosphere can be used to produce electromagnetic waves of ultra-low frequencies (ULF, 0–300 Hz). This can be achieved either by modulating one strong high-frequency (HF, 3–30 MHz) wave or by beating two strong radiowaves with a frequency difference Δf which lies in the ULF band. I report here observations of such ULF signals in two experiments. In the first, four HF transmitters were split into two pairs and operated with a frequency separation Δf between each of the pairs. In the second experiment, all of the transmitters were operated at the same high frequency and were pulsed. The ULF signals at 3, 5 and 6.25 Hz and with intensities of ~150–350 × 10^{-11} G $\text{Hz}^{-1/2}$ were received on the island of Mona, which is ~150 km west of the transmitting site.

Periodic plasma heating has been used for ULF wave generation in the ionosphere[1–3]. These results have typically been explained in terms of changes in conductivity and subsequent modulation of the ambient current system in the lower ionosphere. A different experiment is presented here, in which two HF transmitters were used with a frequency separation of Δf. The beat frequency with proper w and k matching conditions was produced in the night-time F-region of the ionosphere. The mechanism does not require any existing current system in the ionosphere. The k matching conditions are different from those obtained by periodic plasma heating. The nonlinearity in this case arises through ponderomotive forces[5–7]. In the three-wave

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