FREQUENCY ANALYSIS OF THE RAPIDLY OSCILLATING Ap STAR HD 60435

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ABSTRACT. The cool Ap star HD 60435 was monitored in a programme of rapid B photometry during 18 nights in January/February 1984, from two stations widely spaced in longitude (the University of Toronto 0.6-m telescope at the Carnegie Southern Observatory (CARSO) on Las Campanas, Chile, and the 0.5-m telescope of the South African Astronomical Observatory (SAAO)). On six of those nights, contiguous light curves from both sites were obtained.

Fourier analysis of these data confirms the rapid variability first reported by Kurtz (1984) and reveals several additional transient oscillations. HD 60435 exhibits persistent - but modulated - oscillations at a frequency near 1.4 mHz (period = 11.9 minutes), and short-lived oscillations at frequencies near 1.1 and 4.2 mHz (periods of 15.2 and 4.0 minutes, respectively). These latter two periods represent the longest and shortest yet observed in the class of rapidly oscillating Ap stars.

We have applied the oblique pulsator model (Kurtz 1982) to the fine-scale splittings detected in the frequency spectra of the 1.4 and 1.1 mHz oscillations. Also, the series of frequencies close to 1.4 mHz which fall into a pattern of roughly equal spacing is compared to such spacings predicted for overtones in pulsating main-sequence A stars (Shibahashi and Saio 1984). Both approaches suggest that HD 60435 is undergoing non-radial pulsations of odd *and* even degree (probably with $\ell \lesssim 3$).

The oblique pulsator interpretation of the splittings in the frequency spectrum and the amplitude modulation of the 1.4 mHz oscillations also predict a rotation period of approximately eight days for this star. Mean photometry of HD 60435, collected by the authors, supports a similar value of 7.7 days for the period.

Analysis of the oscillations is hampered by ambiguities due to daily aliases present in the data, and by the complicated structure and time-dependence of the frequency spectrum. Further observations of HD 60435 are essential if we are to fully understand its rapid variations.

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C. R. Cowley et al (eds.), Upper Main Sequence Stars with Anomalous Abundances, 239–242.

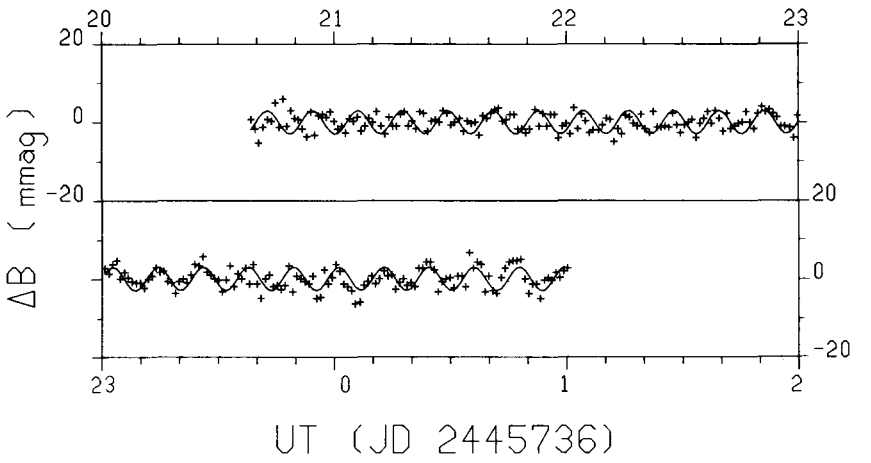

FIGURE 1. Light curve of rapid B photometry of HD 60435 from the night of JD 2445735. The crosses represent three-point averages of 20-second integrations. No comparison star was used. A sinusoid with a period of 11.8 minutes has been superimposed on the data.

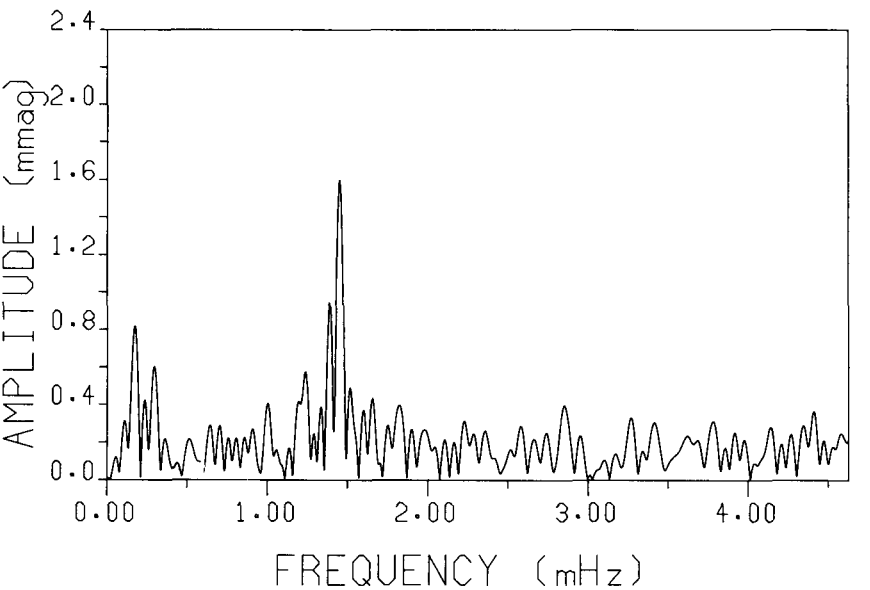

FIGURE 2. Amplitude spectrum of the light curve shown in Figure 1. The largest peak occurs at a frequency near 1.4 mHz. A second smaller peak is resolved just shortward in frequency. This hints at the more complicated frequency structure revealed by later detailed analysis.

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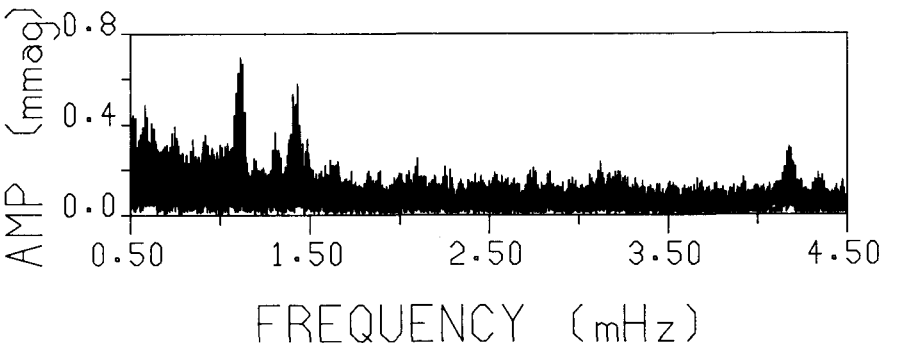

FIGURE 3. Amplitude spectrum of the entire data set, spanning JD 2445719-37, and including six nights of contiguous data from both observing sites. Additional oscillations are revealed at frequencies near 1.1 and 4.2 mHz (15.2- and 4.0-minute periods). An oscillation with a frequency near 2.8 mHz (period = 6 min) - not visible here - was observed on a few nights by DWK. We propose that this and the 4.2 mHz frequency may be resonances with the 1.2 mHz variation.

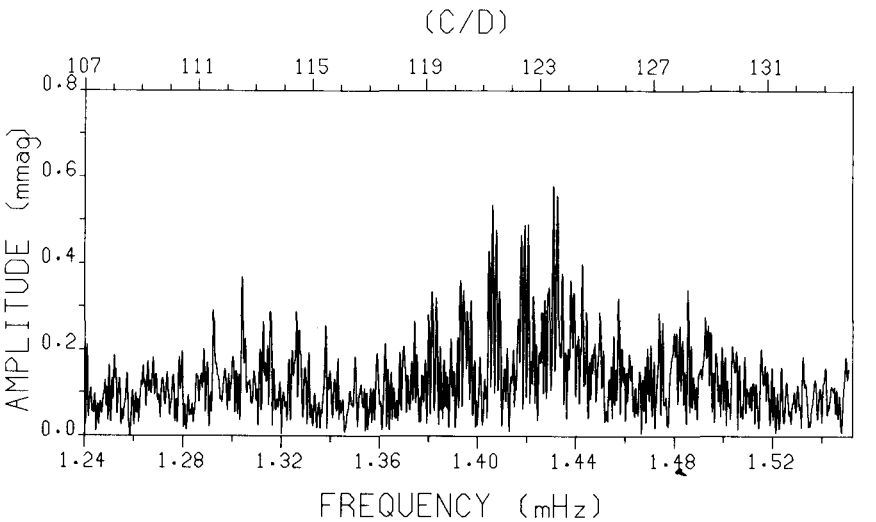

FIGURE 4. Amplitude spectrum in the frequency region around 1.4 mHz. Several peaks and their associated one-day aliases are apparent. The fine-splitting seen in the peaks between 1.40 and 1.44 mHz corresponds to a frequency spacing of about 1.4 ± 0.2 μHz (period = 8.3 ± 1.5 days). The oblique pulsator model predicts that an $\ell = 1$ ($\ell = 2$) oscillation will show up in the Fourier spectrum as a frequency triplet (quintuplet) with a spacing corresponding to the star's rotation frequency. This spectrum is therefore consistent with a rotation period for the star of approximately eight days.

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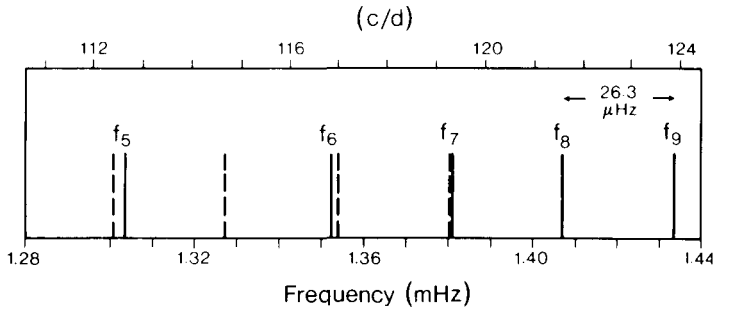

FIGURE 5. Schematic representation of the frequencies observed between 1.30 and 1.44 mHz in HD 60435. Frequencies f_7-f_9 were resolved in a single night of combined CARSO and SAAO data (in which one-day aliases are absent) from JD 2445728. These peaks appear in Figure 4, but the situation is confused by aliasing. Frequency f_5 occurs in Figure 4, and f_6 was detected by one of the authors (DWK) in a 1983 observing run. The dashed lines represent the expected position of frequencies if the spacing were a uniform 26.2 μHz.

By comparing this spacing with the predictions of Shibahashi and Saio (1984) for pulsating main-sequence A stars, we suggest that HD 60435 is undergoing non-radial pulsations of odd and even degree (probably ℓ = 1 and/or 3, and ℓ = 2.

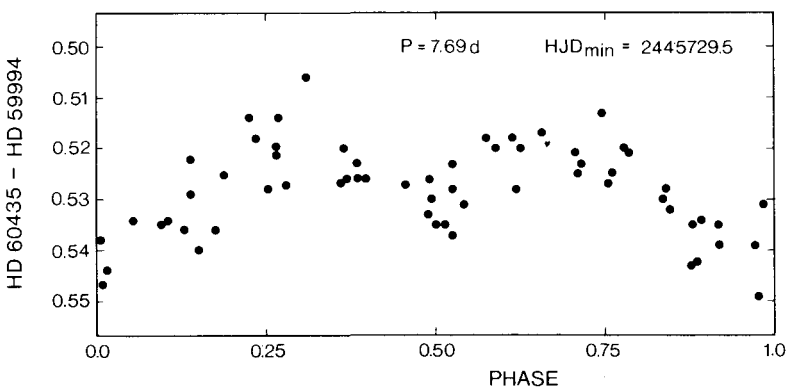

FIGURE 6. Phase diagram of mean photometry of HD 60435, using HD 59994AB as a comparison, collected during January/February 1985, plus 13 additional nights obtained by DWK in 1983. The data is plotted assuming a period of 7.69 days. If this is interpreted as the rotation period of HD 60435, it agrees with the values estimated from the splittings observed in the Fourier spectrum (see Fig.4) and the modulation of the rapid oscillation amplitude. (Note: The light curve possesses a secondary minimum, suggesting that the inclination and obliquity of HD 60435 are such that both magnetic poles are visible as it rotates).

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