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PG 0122+200: A NEW MEMBER OF THE GW VIRGINIS (PG 1159−035) CLASS OF EXTREMELY HOT PULSATING WHITE DWARFS

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ABSTRACT

High-speed photometry reveals that the hot (~100,000 K), hydrogen-deficient white dwarf PG 0122+200 is a low-amplitude pulsating variable. The dominant periodicities are in the range 402–489 s, and appear to be due to nonradial *g*-modes. PG 0122+200 thus becomes the fifth known member of the PG 1159−035 (GW Vir) class, which includes three other PG white dwarfs and the central star of the planetary nebula K1-16. PG 0122+200 may present favorable circumstances for direct measurement of its evolutionary contraction rate through monitoring of its pulsation periods.

Subject headings: stars: individual (PG 0122+200) — stars: pulsation — stars: white dwarfs

I. THE GW VIRGINIS (PG 1159−035)-TYPE PULSATORS

Wesemael, Green, and Liebert (1985) have identified a class of DO-type white dwarfs with effective temperatures near 100,000 K, whose prototype is PG 1159−035. The class is defined spectroscopically by the presence of He II and C IV absorption lines (sometimes with emission cores) and the absence of Balmer lines. Wesmael *et al.* included seven objects in the "PG 1159" spectroscopic class.

PG 1159−035 itself (= GW Vir) was found to be a low-amplitude multiperiodic pulsator by McGraw *et al.* (1979). More recently, Bond *et al.* (1984) discovered that the spectroscopically similar objects PG 1707+427 and PG 2131+066 are also pulsating variables; all three stars display complex nonradial *g*-modes with periodicities of order 6–10 minutes. Moreover, Grauer and Bond (1984) discovered that the central star of the planetary nebula Kohoutek 1-16 exhibits similar spectroscopic and pulsational properties, but with somewhat longer periodicities near 25–28 minutes.

PG 1159−035, PG 1707+427, PG 2131+066, and K1-16 appear to define a new class of pulsating stars located at the extreme left-hand edge of the H-R diagram. Starrfield *et al.* (1984, 1985) have attributed the pulsational instability to cyclical ionization of carbon and/or oxygen in a hydrogen-deficient envelope. Observational support for this attribution comes from the discovery of strong O VI features in the optical spectra of K1-16 and several PG 1159 objects (Sion, Liebert, and Starrfield 1985).

On the other hand, evolutionary models of, among others, Iben (1984) and Wood and Faulkner (1986) have shown that hydrogen-deficient planetary-nebula nuclei (PNNs) and their immediate descendants contain helium-burning shells. Kawaler *et al.* (1986) have shown theoretically that these shells, if present, are pulsationally unstable (the ε-mechanism).

Of the seven members of the PG 1159 spectroscopic class identified by Wesemael *et al.*, three are known to be pulsating variables as described above. Three further members of the class were recently observed photometrically by Grauer *et al.* (1987) and showed no periodic variations with amplitudes greater than a few millimagnitudes (i.e., with amplitudes well below those of the known GW Vir variables). Moreover, Grauer *et al.* (1987) found that 11 hot, hydrogen-deficient PNNs and DO white dwarfs, lying near the GW Vir instability region in the H-R diagram, are also nonvariables. These results would appear to cast doubt on the ε-mechanism proposed by Kawaler *et al.*, since for this mechanism all objects in this region of the H-R diagram and below 2000 $L_\odot$ (Kawaler *et al.* 1987) would be expected to be pulsationally unstable.

The remaining unobserved member of the PG 1159 spectroscopic class is the 16th mag star PG 0122+200. Like the other PG objects, this star was discovered in the high-latitude survey for ultraviolet-excess objects carried out by Green, Schmidt, and Liebert (1986); its 1950 coordinates are $1^h22^m40^s$, $+20°02'15''$, and a finding chart is given by Green *et al.* Observations in Hα by Reynolds (1987) have shown that PG 0122+200 is not surrounded by a planetary nebula to a surface brightness limit some 60 times fainter than that of the Palomar Sky Survey.

In this *Letter*, we report our discovery that PG 0122+200 is a pulsating variable, completing our photometric survey of the known PG 1159 objects, and bringing the number of known pulsators of the GW Vir class to five.

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TABLE 1

OBSERVING LOG FOR PG 0122+200

Date (1986)	Telescope	Starting UT	Run Duration (hr)	Integration Time (s)
Sep 29	KPNO 1.3 m	08:44:50	2.5	7
Sep 30	KPNO 1.3 m	10:12:45	1.7	7
Oct 1	KPNO 1.3 m	07:27:25	4.4	7
Oct 9	UAO 1.6 m	08:44:30	2.5	7

II. HIGH-SPEED PHOTOMETRY OF PG 0122+200

We obtained high-speed photometric observations of PG 0122+200 on four nights in 1986 September–October, using the University of Arkansas at Little Rock two-star photometer. On the first three nights, the photometer was attached to the 1.3 m telescope at Kitt Peak National Observatory (KPNO), while on the final night it was used on the 1.6 m University of Arizona Observatories (UAO) reflector at Mount Bigelow. An observing log is given in Table 1.

The two-star photometer and our data-reduction techniques have been described by Grauer and Bond (1981). PG 0122+200 and a comparison star located 207″ east and 281″ south were observed simultaneously with the two separate photomultipliers, and the sky-subtracted comparison star counts were divided into the corresponding variable star counts in order to remove effects of atmospheric extinction and transparency variations. (The first three nights were of photometric quality; on the last night, transparency variations of a few percent were noted, but were divided out readily.) In order to maximize the count rates, we used no filters in the light paths, giving a broad-band blue response with our bialkali photomultipliers.

III. LIGHT CURVES AND POWER SPECTRA

The character of the variations of PG 0122+200 was found to change from night to night. Representative portions of three of our light curves are shown in Figures 1*a*–1*c*. On 1986 September 30 (Fig. 1*a*) and October 9 (Fig. 1*c*), PG 0122+200 showed a series of well-defined maxima and minima, separated by a mean interval of about 425 s. Some destructive interference between different modes was evident on October 9, as shown by the low amplitudes at the beginning and end of the plotted interval. A more extreme case of such interference was exhibited on 1986 October 1 (Fig. 1*b*), for which the variations were of very low amplitude throughout the run.

The complexity of the light curves of PG 0122+200 points to the simultaneous presence of a number of nonradial *g*-modes with different frequencies, as is typically seen in the other GW Vir variables, as well as in the cooler pulsating DB (V777 Her) and DA (ZZ Ceti) white dwarfs. The modes can be explored further with the aid of power spectra.

Figures 2*a*–2*c* show power spectra for three of our nights of photometric monitoring, which were computed with an FFT program kindly provided by Richard L. White. The power is plotted only over the frequency range 1–6 mHz. At very low frequencies (~ 0.5 mHz and below), we often find enhanced power in our photometry, even for nonvariable stars (see Grauer *et al.* 1987); we believe this to be due to instrumental and/or atmospheric effects (such as flexure between the two photometer channels, or variable seeing). At the high-frequency end, we examined the power spectra of PG 0122+200 up to the Nyquist frequency (71 mHz), and found no significant peaks outside the range plotted in Figures 2*a*–2*c*.

As Figures 2*a*–2*c* show, two strong peaks were present on two of the nights, at frequencies of about 2.25 and 2.48 mHz (periods of 444 and 402 s); they were also present on September 29, which is not plotted. These two frequencies, when they are in phase, give rise to the peaks at intervals of about 425 s that were noted in Figures 1*a* and 1*c*. The beat period between these two frequencies, about 70 minutes = 0.049 day, may account for the diminished amplitudes at the start and end of the interval plotted in Figure 1*c*.

Figures 2*a*–2*c* show, however, that the amplitudes of both the 402 s and 444 s modes are variable from night to night; in fact, the power at *all* frequencies was low on one of the nights, October 1, as shown both by the light curve (Fig. 1*b*) and the power spectrum (Fig. 2*b*).

The variable amplitudes suggest that both of the peaks in our nightly power spectra are actually composed of two or more frequencies that are unresolved in a single night's data, but whose beating causes longer-term amplitude variations. To increase the frequency resolution, we calculated the power spectrum for all four nights of data combined, as shown in Figure 3*a*. Only the region around the two prominent peaks in the nightly power spectra is plotted. Because of the long gaps between the nights, severe aliasing is introduced; this is illustrated by Figure 3*b*, which shows the window function for the four nights (i.e., the power spectrum for a pure sinusoid sampled at the same times as the actual data).

The power spectrum in Figure 3*a* is dominated by a peak at 2.4857 mHz; the corresponding period (as indicated in the figure) is 402.3 s, and the fractional semiamplitude is about 0.01. For our data covering a 10 day span, the period is determined to an accuracy of about ±0.1 s, on the assumption that we have not selected a 1 day alias of the true period. The next strongest peak in the power spectrum lies at 2.2539 mHz (P = 443.7 s) and has a fractional amplitude of about 0.006.

The complex structure surrounding the two labelled peaks in Figure 3*a*, as compared with the window function in Figure 3*b*, demonstrates that neither peak corresponds to a single frequency. As anticipated above, additional closely spaced frequencies are present and give rise to the variable amplitudes seen in the nightly power spectra.

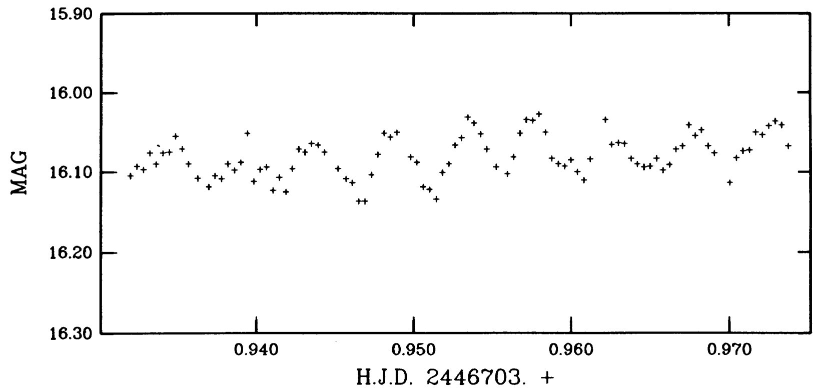

FIG. 1*a*

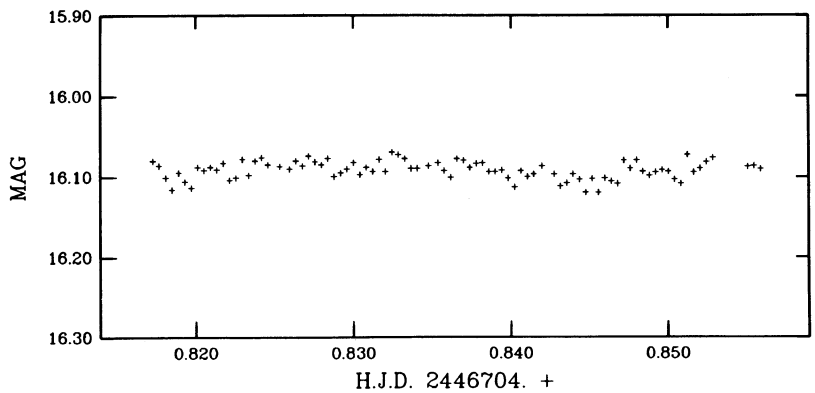

FIG. 1*b*

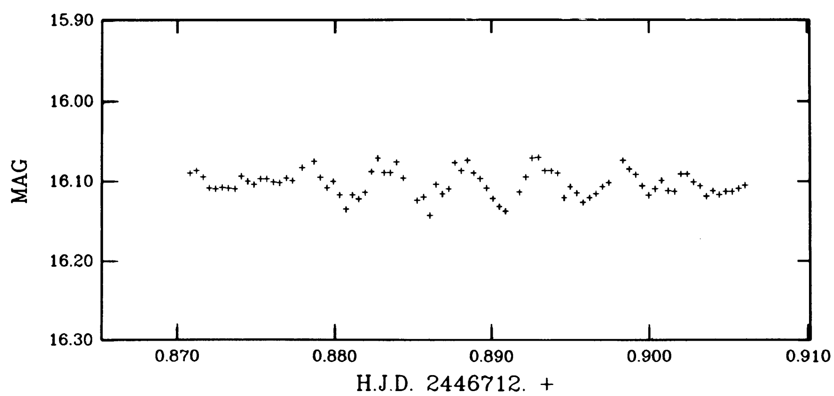

FIG. 1*c*

FIG. 1.—(*a*) Portion of the light curve of PG 0122+200 on 1986 September 30. The original 7 s integrations have been summed into 35 s bins and converted to blue magnitudes (for which the zero-point is only approximate). The interval between ticks on the horizontal axis is 0.01 day = 14.4 minutes. In this figure, PG 0122+200 shows peak-to-peak variations of about 0.1 mag, with maxima spaced at intervals of about 425 s. (*b*) Portion of the light curve of PG 0122+200 on 1986 October 1. The star's brightness was nearly constant during this interval. Interruptions in the light curves are for guiding and/or sky-background measurements. (*c*) Portion of the light curve of PG 0122+200 on 1986 October 9. The 425 s variation is present again, but at lower amplitude. Beating is present at the beginning and end of this interval.

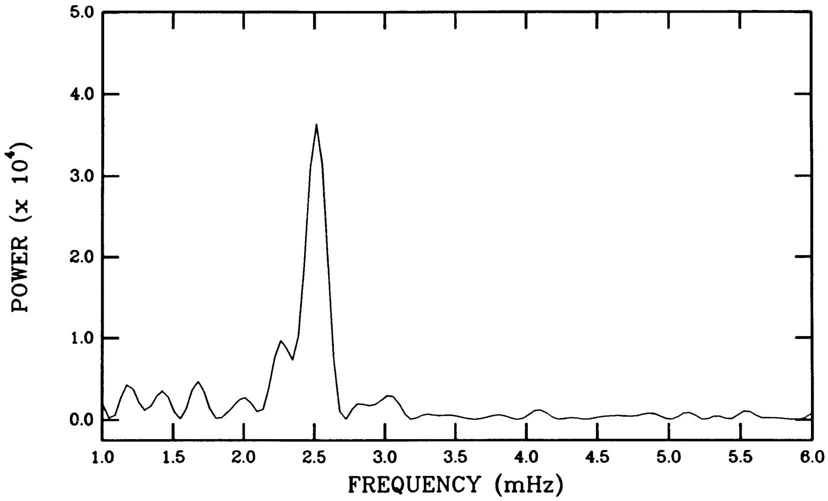

FIG. 2*a*

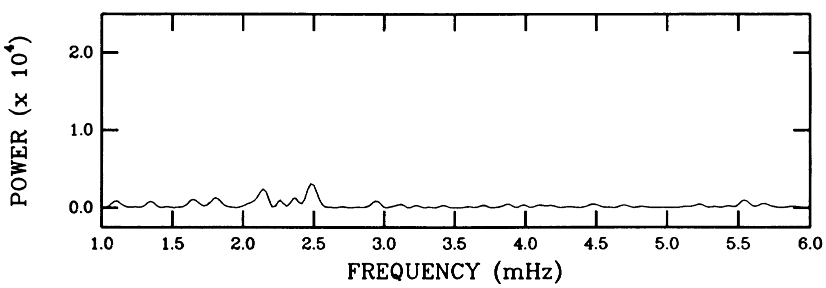

FIG. 2*b*

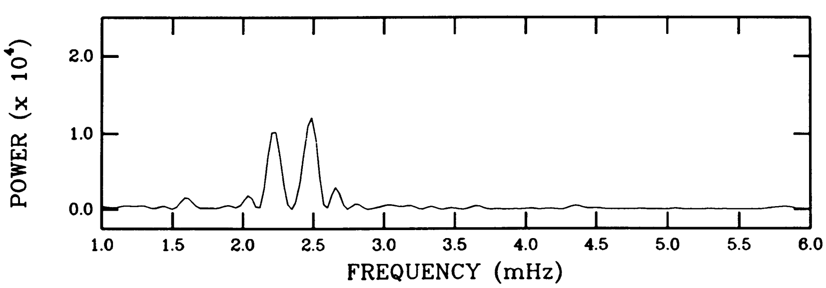

FIG. 2*c*

FIG. 2.—(*a*) Power spectrum for the 1.7 hr run on 1986 September 30. The power (square of the fractional semiamplitude) is plotted against frequency in mHz. The power spectrum is dominated by just two peaks, at frequencies of about 2.25 and 2.48 mHz (corresponding to periods of 444 and 402 s); the 402 s mode had a large amplitude of 0.02 mag during this run. Figs. 2*a*–2*c* are all plotted to the same vertical and horizontal scales. (*b*) Power spectrum for the 4.4 hr run on 1986 October 1. On this night, the power was very low at all frequencies, indicating nearly complete destructive interference between the pulsation modes. (*c*) Power spectrum for the 2.5 hr run on 1986 October 9. The 402 s and 444 s modes are present in about equal strength. The power spectrum for September 29 was nearly identical.

We attempted to identify the stronger of these additional frequencies by successive steps of "prewhitening" the data (i.e., by finding the frequency at which the peak power is present in the power spectrum, subtracting the corresponding sinusoid from the data, calculating a new power spectrum, and repeating the process). The strongest neighbors of the peaks at 402.3 and 443.7 s appear to lie at 402.9 and 447.6 s, respectively; however, the danger of selecting an incorrect alias is even larger for these lower amplitude modes. The only other mode that we find to have a fractional amplitude as large as 0.003 lies at 489.6 s, but at least half a dozen additional lower amplitude modes appear to be present at

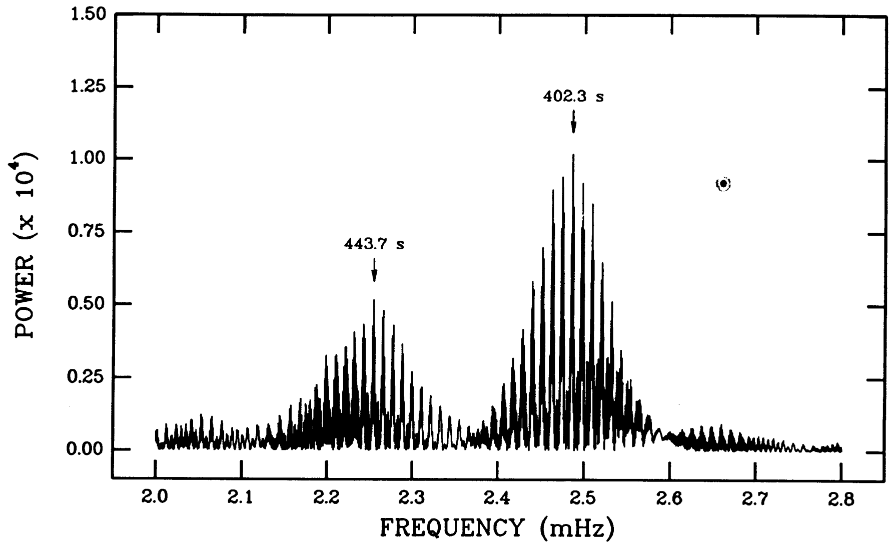

FIG. 3*a*

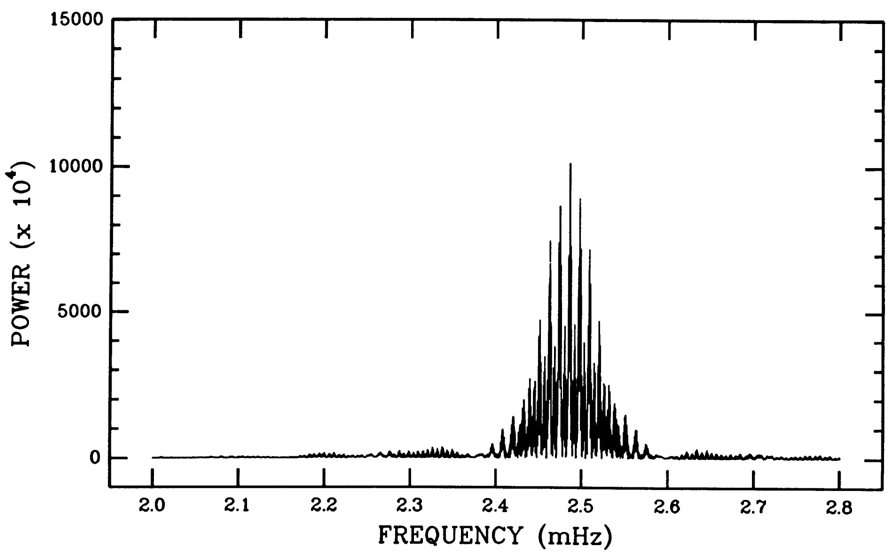

FIG. 3*b*

FIG. 3.—(*a*) Power spectrum for the combined four nights' data on PG 0122+200. Severe aliasing is introduced by the internight gaps in the data. The two peaks seen in the nightly power spectra appear to consist of strong components at 402.3 s and 443.7 s, along with additional lower-amplitude modes. (*b*) Window function for the power spectrum plotted in Fig. 3*a*. This shows the alias structure that results from a single pure sinusoid sampled at the same times as the actual data.

other periods. It is clear that much additional data will be required for confident identification of all the modes that are present in this very complicated light curve.

It is possibly significant that our two strongest periods, 402.3 and 443.7 s, are separated by 2 × 20.7 s. Modes separated by 21.1 s have been noted in GW Vir by Kawaler (1986) and discussed in terms of the *l* values of the individual modes and the resulting constraints on the stellar mass.

IV. SUMMARY AND FUTURE WORK

Our high-speed photometric observations have shown PG 0122+200 to be a new member of the GW Vir class of pulsating hot white dwarfs. Its complex variability, which is typical of all of the GW Vir variables, is due to the presence of a large number of individual nonradial pulsation periods.

It would be important to obtain further intensive photometric observations of PG 0122+200. A fully resolved power spectrum would allow direct comparison with the prediction of Kawaler (1986) of modes that are equally spaced in period, and could lead to an extremely accurate stellar mass determination. A primary aim of such observations, however, would be to measure the rate of period change, dP/dt, for one or more of the pulsation modes. Since the evolutionary time scales of GW Vir-type objects are expected to be of order 10^6 yr (Winget *et al.* 1985), it should be possible to

measure dP/dt over just a few observing seasons. On the basis of our admittedly limited data, it appears that PG 0122+200 exhibits two prominent modes (near 402.3 and 443.7 s) that may be suitable for such measurements. Considerably more data will be required to confirm that these modes are not themselves resolvable into subcomponents, but at present it appears that PG 0122+200 present favorable circumstances for such a "real-time" detection of an effect of stellar evolution.

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