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Discovery of a Long-Period Photometric Variation in the V361 Hya Star HS 0702+6043

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Abstract. We report the discovery of a long-period g-mode oscillation in the previously known short-period p-mode sdB pulsator HS 0702+6043. This makes this star an extraordinary object, unique as a member of the family of sdB pulsators, and one of the very few known pulsating stars overall exhibiting excited modes along both the acoustic and gravity branches of the nonradial pulsation spectrum. Because p-modes and g-modes probe different regions of a pulsating star, HS 0702+6043 holds a tremendous potential for future detailed asteroseismological investigations.

1. SdB Asteroseismology: V361 Hya and lpsdBV Stars

Subluminous B (sdB) stars dominate the population of faint blue stars of our own galaxy down to $m_V \approx 16$ and are found in the disk (field sdBs) as well as in globular clusters. SdB stars can be identified with models of the Extended Horizontal Branch (EHB) burning He in their core (Heber 1986). Photometric variations due to radial and non-radial pulsations in some of the sdB stars (V361 Hya stars, formerly referred to as EC 14026 or sdBV stars, 33 are known today) were detected by Kilkenny et al. (1997). The periods of these stars are found to be in the range 80 – 600 s with low amplitudes (few mmag). Log g and $T_{\rm eff}$ for the pulsators range from 5.3 – 6.1 dex and 29 000 – 36 000 K. The pulsations are driven by an opacity bump due to mainly Fe in subphotospheric layers (Charpinet et al. 1997). First successes in asteroseismological analyses of sdBVs were reported by Brassard et al. (2001) and Charpinet et al. (these proceedings). A new class of multi-mode sdB pulsators has been discovered by Green et al. (2003, 25 so-called lpsdBV known today, for which PG 1716+426 is the prototype). Their pulsation periods are about 10 times longer ($\approx$ 1 h) than those of the V361 Hya stars. Hence the sdB variables come in two flavours, the V361 Hya and the lpsdBV stars. The longer periods (lp) in the lpsdBV imply the presence of excited high radial order gravity modes (g-modes), in contrast to the pressure modes (p-modes) present in the V361 Hya stars. The driving

Table 1. Data log of photometric observations obtained for HS 0702+6043.

Observatory	Telescope	Filter	UT date [y/m/d]	start [h:m]	stop [h:m]	cycle time [s]
Calar Alto	1.2 m	*none*	1999/12/07	01:19	06:16	18
Calar Alto	1.2 m	*none*	1999/12/08	04:28	06:23	16
Calar Alto	1.2 m	*none*	1999/12/09	04:46	06:09	21
Tübingen	0.8 m	G(green)	2004/02/04	19:55	03:12*	38
Steward	2.3 m	F555W	2004/02/09	02:36	08:25	86
Steward	2.3 m	F555W	2004/02/10	02:40	08:55	86

*implies date change between start and stop

mechanism for these new pulsators is under discussion. Fontaine et al. (2003) favour the iron opacity bump meachnism, but also consider excitation by tidal forces in close binaries a viable alternative. Constructing pulsation models based on such physical insights is a necessary prerequisite to interpret asteroseismological observations. The internal structure obtained from such modeling allows to extract clues on the evolutionary history of sdBs which is still much under debate, and constrains the future evolution: sdB stars evolve directly into white dwarfs and hence represent one of the feeder channel to white dwarfs.

2. Frequency Analysis of HS 0702+6043

In follow-up observations of hot subdwarfs from the Hamburg Quasar survey, the $m_B = 15$ object HS 0702+6043 was discovered as a new V361 Hya star by Dreizler et al. (2002). The main pulsation period was 363 s at a relatively large amplitude of 29 mmag. A second period of 382 s was present at a much smaller amplitude of 3.8 mmag. The atmospheric parameters derived by quantitative model atmosphere analysis, $T_{\rm eff} = 28\,400$ K and $\log g = 5.35$, make it one of the coolest V361 Hya stars known. With refined time series analysis tools, we recently discovered in the original data set that HS 0702+6043 shows long period variations of about 1 h (at a much lower amplitude) along with the short period oscillations. The initial discovery was confirmed by observations with the 2.3 m Steward telescope atop Kitt Peak in February 2004. Table 1 lists the photometric observations available for HS 0702+6043 so far. Figure 1 shows the corresponding light curves. An analysis of the short periods in the 1999 Calar Alto data set has been published in Dreizler et al. (2002). In a re-analysis of these data, a third period of about 1 h started to emerge (Fig. 2), which prompted us to initiate follow-up observations. The data obtained in Tübingen allow to recover the strongest mode at 363 s only. As the telescope is located inside the city limits of Tübingen, we regard this detection as a success. Of course, the nearly noise-free Steward data are much better suited for our aim. The two consecutive nights not only allow to extract the two short periods previously published but also one mean long period (Table 2). In addition they indicate a more complicated structure of the low-frequency variation (Fig. 3). Thus, the existence of the long period is clearly confirmed; it is still present four years after the first observation.

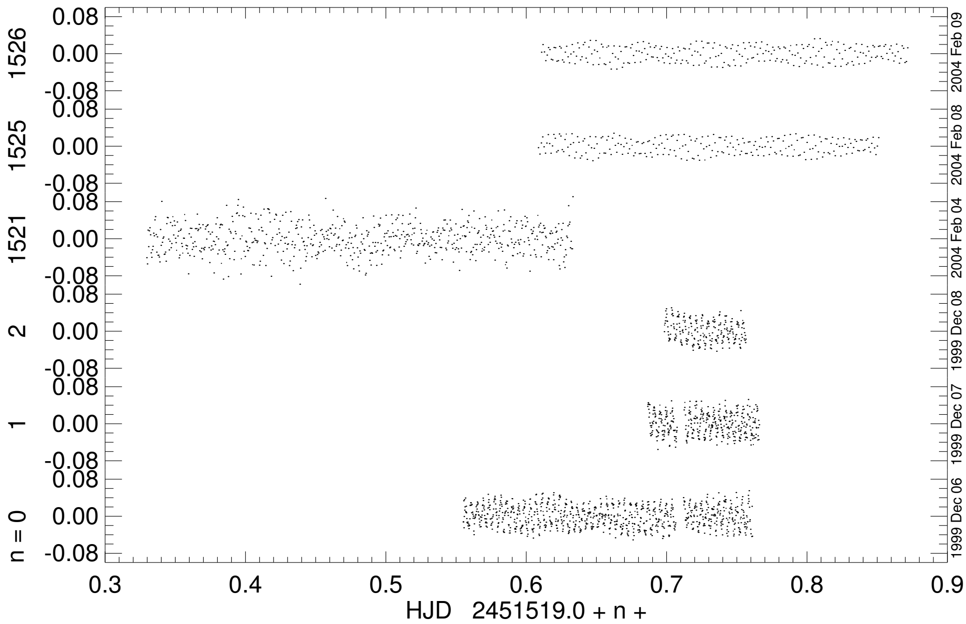

Figure 1. Photometric observations obtained for HS 0702+6043; y-axis in mi (modulation intensity, $\Delta I/\bar{I}$)

It can be detected in both nights of the new data set already in the frequency spectrum of the full light curve without prewhitening. We show the spectrum of the first night in Fig. 2. After prewhitening of the three periods listed in Table 2, there are still significant residual amplitudes, implying the presence of more than one period in the low-frequency range (again, this is true for both nights). This finding strongly argues for a pulsational character of the new low-amplitude variation. It also supports the view that the new frequency is not simply a higher-order combination frequency as might be inferred from Table 2 due to the consistency of the difference within the errors, but rather corresponds to an independent mode. The complete absence of all further combination frequencies that could be expected at a detectable level also dismisses this suggestion.

Table 2. Frequencies found from Feb. 2004 Steward 2.3 m telescope data

	frequency [μHz]	period [s]	amplitude [mmi]	Δf [μHz]
f_1	2754 (9)	363	21.7(5)	
f_2	2617 (9)	382	4.6(5)	
f_3	283 (9)	3538	3.7(5)	$2(f_1 - f_2) = 274$

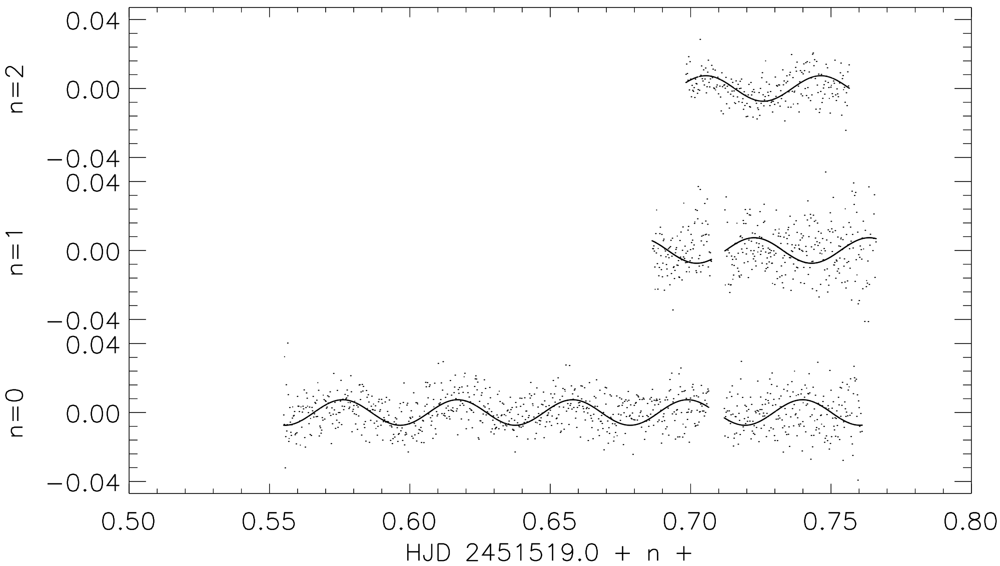

Figure 2. Calar Alto 1.2 m light curves (individual data points) from December 1999 with two short-period oszillations (f_1 and f_2) subtracted; the y-axis unit is in mi. Overlaid (full line) is a sine curve corresponding to f_3.

3. Interpretation of the New 1 h Period as a g-Mode Pulsation

Both the relative shortness of an hypothetical orbital or rotational period as well as the multi-mode character of the photometric variation make a successful explanation through binary or rotational motion highly unlikely. On the other hand, it is known that g-mode pulsators with similar periods and amplitudes exist among sdBs with parameters close to those found for HS 0702+6043: its effective temperature places it at the cool end of the p-mode, and hence at the same time close to the hot end of the g-mode, empirically determined instability regions. This strongly suggests that p-mode and high-order g-mode pulsations coexist in this star, indicating that the instability strip for lpsdBV stars might overlap with that for V361 Hya stars. Whether or not the instability strips for lpsdBV and V361 Hya stars overlap is an important question. In Fig. 4 we plot the published atmospheric parameters of 27 V361 Hya stars and 6 lpsdBVs (Maxted et al. 2001) indicating that the two instability regions do indeed touch. However, a homogenous set of accurate atmospheric parameters is still needed. In a first attempt, which in particular includes more lpsdBV stars, spectroscopic work by two of us (E.M.G. and G.F., see Fig. 4) has homogenized the parameter determination to obtain comparable temperatures and gravities. This analysis yields spectroscopic parameters of $T_{\rm eff} = 29\,500$ K and $\log g = 5.44$ for HS 0702+6043 that differ from the earlier results. Despite systematic shifts introduced by neglecting metal-line blanketing effects, the relative position of HS 0702+6043 confirmes the conclusion that the two instability regions touch. This position makes HS 0702+6043 a key object in (not only sdB) asteroseismol-

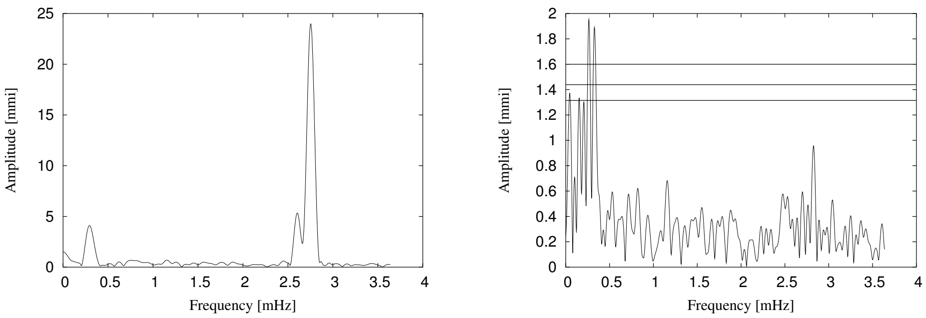

Figure 3. Left panel: Fourier spectrum of one 6 h-observation of HS 0702+6043 with the 2.3 m Steward telescope at Kitt Peak: the three main modes from the full light curve are clearly visible. Right panel: Fourier spectrum of the same light curve after substraction of the three modes as listed in Table 2: There are remaining amplitudes well above the significance levels expected of spectra from time series conforming to the hypothesis of independent identically distributed noise (from bottom to top, the horizontal lines mark false alarm probabilities of 0.05, 0.01 and 0.001).

ogy since simultaneous p- and g-mode pulsations sample different parts of a star. Fontaine et al. (2003) suggested that the sdBV/lpsdBV have a main sequence analogy in the β Cep/[SPB] variables. In this context, it is interesting to note that, according to Handler et al. (2004), the β Cep star ν Eri might also show an [SPB]-like frequency. Similarly, Handler et al. (2002) have reported a possibly δ Sct-like frequency in the γ Dor object HD 209295. With HS 0702+6043 belonging to both sdBV classes, it challenges theory's description of stability and driving mechanisms in current pulsational models. We have constructed a preliminary stellar structure pulsational model for HS 0702+6042 where both short-period, low-order p-modes and long-period, high-order g-modes can be excited. This is in good qualitative agreement with what we observe in HS 0702+6043, but the effective temperature of that model is somewhat lower than desirable. Alternatively, we propose that those g-modes whose frequencies happen to fall close to nonlinear peaks from p-modes (combination frequencies) could be excited through resonance coupling. When the star is "hit" at a frequency $f_2 - f_1$ at relatively large amplitudes, g-modes which happen to have very similar frequencies (if they exist), and which are normally stable, would then be driven to observable amplitude because they resonate with the "engine" that hits them. This would also imply that the low-frequency peaks are real g-modes excited through resonance at those frequencies and not merely nonlinear features.

4. Summary and Outlook

We report the recent discovery of a new period in the sdB star HS 0702+6043 already known as a V361 Hya variable. The additional detection is a low-amplitude, long-period light variation that is most probably due to independent pulsations. The interpretation as a member of the recently discovered class of g-mode pulsators among sdB stars makes this variable the first recognized to show both of the known types of pulsational variations for sdBs. The current light

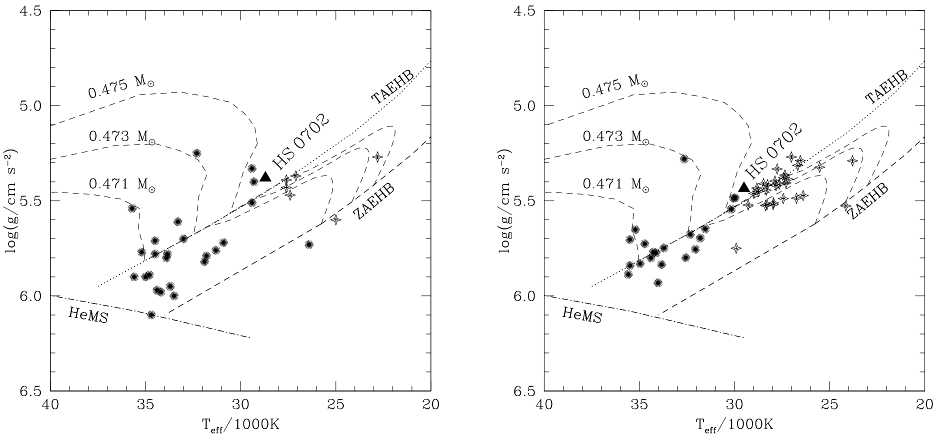

Figure 4. Known sdBV and lpsdBV pulsators (all published parameters: left, all observed by E.M.G.: right) in the $\log g - \mathrm{T_{eff}}$ diagram: sdBV locations are identified through asterisks, lpsdBV locations by square stars. The helium main sequence, zero and terminal age extended horizontal branches and HS0702+6043 are marked; also shown are evolutionary tracks off the extended horizontal branch by Dorman et al. (1995).

curves prove that beyond the one g-mode type period confirmed so far, there is residual power in the low-frequency regime, suggesting a more complicated structure. We plan to obtain a good frequency spectrum from a longer light curve to further investigate the g-modes, and adequately resolve the low-frequency spectral structure. There are clues that HS 0702+6043 might in fact represent the prototype of a whole new class of similar objects: rumours at this conference suggest that the interesting behaviour observed in HS 0702+6043 may also have been uncovered in other V361 Hya stars, but this remains to be confirmed.

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