A&A 426, L45–L48 (2004)
DOI: 10.1051/0004-6361:200400079

Astronomy & Astrophysics

Letter to the Editor

Detection of non-radial g-mode pulsations in the newly discovered PG 1159 star HE 1429–1209

T. Nagel and K. Werner

Institut für Astronomie und Astrophysik, Abteilung Astronomie, Universität Tübingen, Sand 1, 72076 Tübingen, Germany
e-mail: nagel@astro.uni-tuebingen.de

Received 23 August 2004 / Accepted 10 September 2004

Abstract. We performed time-series photometry of the PG 1159-type star HE 1429–1209, which was recently discovered in the ESO SPY survey. We show that the star is a low-amplitude (≈0.05 mag) non-radial g-mode pulsator with a period of 919 s. HE 1429–1209 is among the hottest known post-AGB stars ($T_{\rm eff}$ = 160 000 K) and, together with the known pulsator RX J2117.1+3412, it defines empirically the blue edge of the GW Vir instability strip in the HRD at high luminosities.

Key words. stars: white dwarfs – stars: individual: HE 1429–1209 – stars: variables: GW Vir – stars: AGB and post-AGB

1. Introduction

PG 1159 stars are hot hydrogen-deficient (pre-) white dwarfs ($T_{\rm eff}$ = 75 000–200 000 K, $\log g$ = 5.5–8 [cm/s^2]; Werner 2001). They are probably the outcome of a late helium-shell flash, a phenomenon that drives the currently observed fast evolutionary rates of three well-known objects (FG Sge, Sakurai's object, V605 Aql). Flash-induced envelope mixing produces a H-deficient stellar surface. The photospheric composition then essentially reflects that of the region between the H- and He-burning shells in the precursor AGB star. The He-shell flash forces the star back to the AGB. The subsequent, second post-AGB evolution explains the existence of Wolf-Rayet central stars of planetary nebulae and their successors, the PG 1159 stars.

Ten out of the 32 currently known PG 1159 stars (including the object studied here) are non-radial g-mode pulsators (Table 1). They are of considerable interest for asteroseismology studies, because one can reveal the interior stellar structure and thus obtain important hints as to the evolutionary history of these peculiar stars. The pulsators form the group of GW Vir variables, named after the prototype GW Vir (=PG 1159–035). Sometimes this group is divided into two subgroups, termed PNNV (Planetary Nebula Nuclei Variables) and DOV (DO Variables; DOs are hot white dwarfs with He-rich atmospheres). The six PNNV are low-gravity, hence high-luminosity stars, whereas the four DOV are of high gravity (Fig. 1). This subdivision is somewhat artificial, because the physical pulsation driving mechanism is identical for all GW Vir variables. In addition, two of the objects located within the PNNV region of the $\log g$ – $\log T_{\rm eff}$ diagram have no known associated planetary nebula (HS2324+3944 and HE 1429–1209). We also mention that in Fig. 1 we have plotted

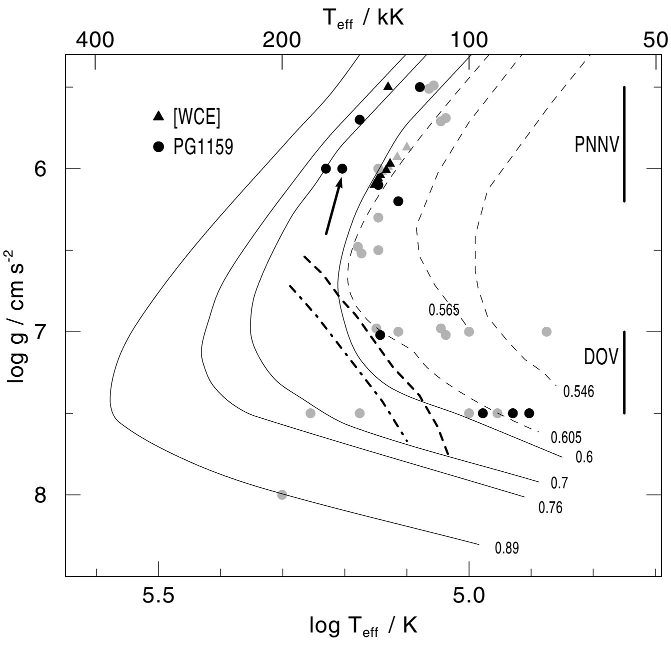

Fig. 1. Location of the new pulsator (arrow) in the $\log g$ – $\log T_{\rm eff}$ diagram among PG 1159 stars (for parameters see Table 1) and [WCE] central stars. All of the known GW Vir pulsators are plotted with black symbols. According to their low and high surface gravity (corresponding to high and low luminosity, respectively), they can be grouped into two distinct classes of variable stars: planetary nebulae nuclei (PNNV) and DO variables (DOV), as indicated by the vertical bars. Although the new pulsator is within the PNNV region of the instability strip, no associated planetary nebula is known. The thick dashed and dashed-dotted lines represent the theoretical blue edge of the instability strip for l = 1 and l = 2 modes, respectively (Gautschy 2004). Post-AGB evolutionary tracks are taken from Schönberner (1983), Blöcker (1995) (dashed lines), and Wood & Faulkner (1986) (solid lines) (labels: mass in $M_\odot$).

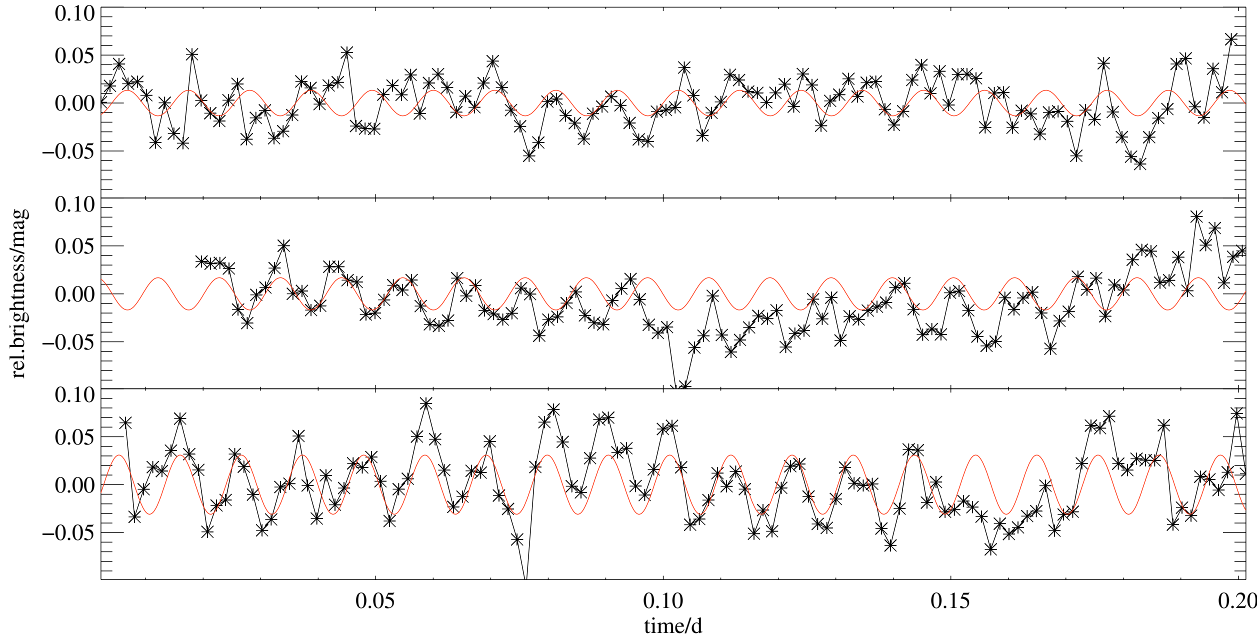

Fig. 2. Lightcurves (rebinned by factor of 2) of HE 1429−1209 during three consecutive nights (*from top to bottom*) and a sine fit with the detected period of 919 s. The time is measured in fractions of a day, beginning with the start of observations.

the location of [WCE] (early-type C-rich Wolf-Rayet) central stars, which are thought to be the progenitors of PG 1159 stars. Among them, we marked six pulsators (NGC 6905, Sand 3, NGC 2867, NGC 5189, NGC 1501, NGC 2371), which in addition to the six PG 1159 stars mentioned above are also termed PNN variables (Ciardullo & Bond 1996; atmospheric parameters were taken from Hamann 1997 and Herald & Bianchi 2004). It seems obvious that these Wolf-Rayet central stars also belong to the GW Vir variables in a sense that their pulsation driving mechanism is identical.

The GW Vir variables define a new instability strip in the HRD. The driving mechanism has been discussed in the past with considerable controversy. The basic ingredient, the κ-mechanism associated with the partial ionization zone of K-shell electrons of C and O in stellar model envelope just beneath the photosphere, has been identified in the pioneering work by Starrfield et al. (1983). However, these models required a very He-deficient composition, in contrast to the observed surface chemistry. Therefore a composition gradient had to be assumed, which is difficult to understand considering on-going mass-loss from these objects, what prevents gravitational settling of heavy elements. In contrast, later work by Saio (1996), Gautschy (1997), and Quirion et al. (2004) showed that pulsations can easily be driven in chemically homogeneous envelopes with abundances according to spectroscopic analyses. In particular, Quirion et al. (2004) can successfully explain pulsation properties of individual PG 1159 stars. But still, these results are at odds with conclusions from Bradley & Dziembowski (1996) and Cox (2003), which both require different envelope and atmospheric compositions.

In view of this controversy and the relatively small number of GW Vir variables spread out over a wide range in the $\log g - \log T_{\rm eff}$ diagram, the discovery of a new member of this class is interesting for the question of pulsation driving of these variables and asteroseismology investigation of the PG 1159 group as a whole.

Recently, the discovery of a new PG 1159 star, HE 1429−1209, within the SPY (Supernova Ia Progenitor Survey, Napiwotzki et al. 2003) has been announced (Werner et al. 2004a). It is among the hottest objects within this group and has a low surface gravity ($T_{\rm eff}$ = 160 000 K, $\log g$ = 6), hence it is located within the GW Vir instability strip, right among the PNN variables. This fact along with a high carbon abundance (C = 54%, He = 38%, O = 6%, Ne = 2%, by mass), which is a prerequisite for pulsation driving within the instability strip (Quirion et al. 2004), strongly suggested that HE 1429−1209 might be a new GW Vir pulsator.

2. Photometry of HE 1429−1209

Photometric observations of HE 1429−1209 ($m_{\rm V}$ = 16.1) were performed during three consecutive nights (Table 2) using our institute's 0.8 m f/8 telescope with an SBIG ST-7E CCD camera. To achieve good time resolution we chose clear filter exposures with a binning of 2 × 2 pixels to reduce readout time. The exposure time was $T_{\rm exp}$ = 60 s and the readout time 8 s, resulting in a cycle time of $T_{\rm cycl}$ = 68 s. Data were obtained over almost five hours per night. The observing conditions have been good during all three nights, considering that the telescope is located in the city of Tübingen.

Data reduction was done with our IDL software TRIPP (Time Resolved Imaging Photometry Package, Schuh et al. 2003), performing aperture photometry. All images are background and flatfield corrected. The relative flux of the object is calculated with respect to one or more comparison stars. To minimize flux errors, different aperture radii were tested in respect of the comparison star flux variances. This procedure allows the detection of very small brightness variations. The resulting lightcurve is displayed in Fig. 2.

Table 1. Parameters of all known pulsating PG 1159 stars (corresponding to filled dots in Fig. 1), including the new pulsator HE 1429−1209. See text for references.

Name	$T_{\rm eff}$ (1000 K)	$\log g$ (cm/s^2)	M ($M_\odot$)	Unstable periods (s)	Observed periods (s)
PG 0122+200	80	7.5	0.50	202–822	336–612
PG 1159-035	140	7.0	0.53	483–704	430–840
PG 1707+427	85	7.5	0.52	200–778	336–942
RX J2117.1+3412	170	6.0	0.70	1289–2332	694–1530
PG 2131+066	95	7.5	0.55	191–643	339–598
HS 2324+3944	130	6.2	0.55	1355–3013	2005–2569
K1-16	140	6.4	0.50	857–2192	1500–1700
NGC 246	150	5.7	0.70	1160–1466	1460–1840
Longmore 4	120	5.5	0.65		831–2325
HE 1429−1209	160	6.0	0.68		919

Table 2. Observation log.

Date	UT	$T_{\rm exp}$/s	$T_{\rm cycl}$/s	Duration/s
22.05.2004	20:17	60	68	17 799
23.05.2004	20:20	60	68	17 485
24.05.2004	20:18	60	68	17 312

To analyse the combined lightcurve of the three nights, we used CAFE (Common Astronomical Fit Environment, Göhler, priv. comm.), a sample of routines written in IDL.

We calculated a Lomb-Scargle periodogram (Scargle 1982) and simulated a lightcurve with the same time sampling and noise characteristics as the observations and with the suspected period in order to get the spectral window. In Fig. 3 the Lomb-Scargle periodogram of the combined lightcurve of the three nights is presented. A peak which exceeds a 99% false-alarm probability (which was estimated according a prescription of Scargle et al. 1982) of 11.8 by a factor of three indicates a pulsation period of 919 s for HE 1429−1209. To check the period for artefacts, we simulated a lightcurve with the same statistical behaviour like the observed lightcurve. Its spectral window is shown in Fig. 4 as well as the periodogram of the lightcurves. In Fig. 2 the binned lightcurves of HE 1429−1209 and a sine fit with the detected period of 919 s are compared. The observed variability has a mean amplitude of about 0.05 mag, with significant variation from night to night, indicating the possible presence of additional beat periods.

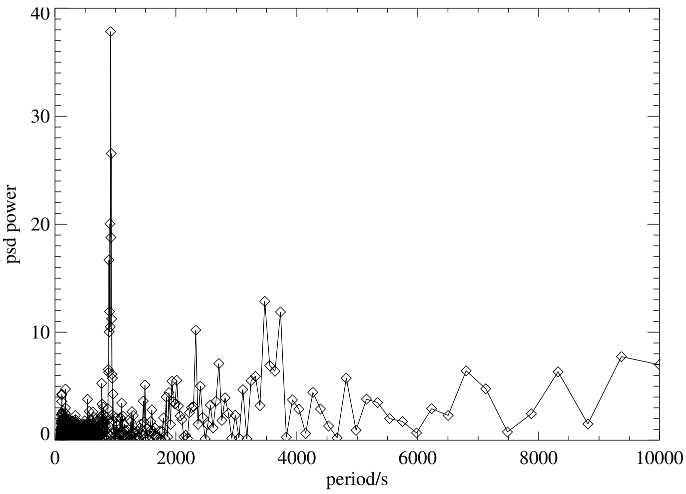

Fig. 3. Lomb-Scargle periodogram of the combined lightcurve of HE 1429−1209. The power spectral density (psd) is a measure for the probability of a period being present in the lightcurve. The confidence limit of 99 % is at psd = 11.8.

3. Discussion

We have discovered a 919 s period in the lightcurve of the recently identified PG 1159 star HE 1429−1209 ($T_{\rm eff}$ = 160 000 K, $\log g$ = 6). Its location among other pulsators in the GW Vir instability strip suggests that the star is a non-radial g-mode pulsator. Together with RX J2117.1+3412 ($T_{\rm eff}$ = 170 000 K, $\log g$ = 6) this new pulsator defines empirically the blue edge of the GW Vir instability strip at low gravities, i.e., at high luminosities in the HRD. This is in complete agreement with recent pulsation modeling (Quirion et al. 2004; Gautschy 2004). In Fig. 1 we have plotted the location of the blue edge, recently derived by Gautschy (2004). The high amount of carbon found in HE 1429−1209 (Werner et al. 2004a) confirms the conclusion of Quirion et al. (2004) that the co-existence of non-pulsating stars in the instability strip is due to a low carbon abundance relative to helium in the non-pulsators, i.e., helium-poisoning of pulsations.

The atmospheric parameters of HE 1429−1209 are, within error limits, identical to those of RX J2117.1+3412 and thus, we can compare the detected 919 s period with the pulsation periods found in that star and with the respective model calculations presented by Quirion et al. (2004). In Table 1 we list stellar parameters as well as observed and predicted pulsation periods for all ten known pulsating PG 1159 stars. The table was essentially taken from Quirion et al. (2004, see references therein) and it is augmented by the central star Longmore 4 and the new pulsator. Parameters and observed pulsation

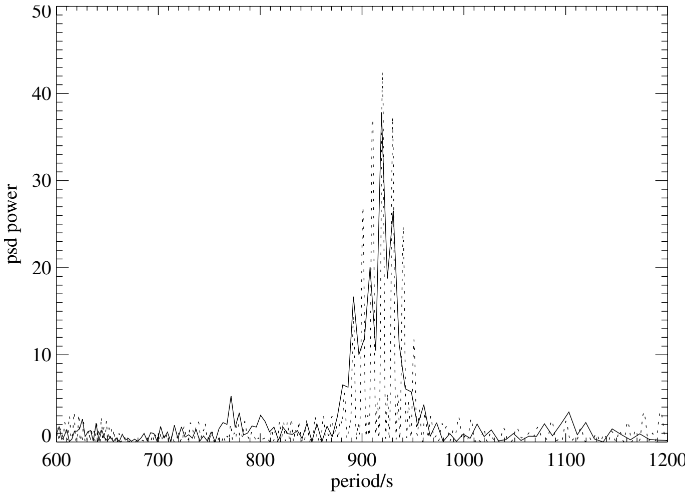

Fig. 4. Period spectrum (solid line) and spectral window (dotted line) of the combined lightcurve of HE 1429−1209.

periods of Longmore 4 are taken from Werner et al. (2004b) and Bond & Meakes (1990), respectively. But note that we speculated in the referenced work that T_{eff} is probably underestimated. Obviously, the detected 919 s period in HE 1429−1209 is within the intervals of observed and predicted periods of RX J2117.1+3412, supporting our discovery of g-mode pulsations.

Future observations of HE 1429−1209 during longer, uninterrupted time intervals will almost certainly reveal other, weaker pulsation periods which will allow a detailed study of the interior structure of this star with asteroseismology tools.

Acknowledgements. We thank Sonja Schuh (Göttingen) and Eckart Göhler (Tübingen) for helpful discussions, and Alfred Gautschy (Basel) for allowing us to present his calculated blue edges of the GW Vir strip in advance of publication.

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