Confining the Edges of the GW Vir Instability Strip

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We report on our NLTE model atmosphere analyses of PG 1159 stars. The results enable us to confine the location of the GW Vir instability region in the Hertzsprung-Russell diagram. The analysis of a spectrum of the non-pulsator PG 1520+525 taken with the *EUVE* satellite in comparison with HST data of the pulsating protoype PG 1159-035 (=GW Vir) locates the blue edge of the instability strip near $T_{\rm eff}$=140 000 K for stars in the respective luminosity range.

1. The GW Vir Instability Strip

PG 1159 stars are hydrogen-deficient and extremely hot pre-White Dwarfs. According to our current understanding they have lost their hydrogen envelope either by extraordinarily strong mass loss events or by ingestion and burning of hydrogen. This might be a consequence of a late thermal pulse during previous post-AGB evolution. Spectroscopically the PG 1159 stars are characterized by strong C IV and occasionally O VI lines, together with He II, but H Balmer lines are absent. Within the last years the number of known PG 1159 stars was brought up to 26. Eight stars of this group were identified as multimode nonradial g-mode pulsators (and four of the eight pulsators are Planetary Nebula central stars). They allow probing their interior structure by means of asteroseismology and thus play a key role in our understanding of post-AGB stellar evolution.

The GW Vir instability strip is defined by the pulsating PG 1159 stars. The pulsations are driven by cyclic ionization of C and O (Starrfield et al. 1984). The stellar pulsational model calculations can be subject to a stringent test if we compare the predicted instability region in the HRD with the observationally determined position of the PG 1159 stars.

2. Spectroscopic Analyses

Non-LTE model atmosphere analyses are in progress in order to find the photospheric parameters of all known PG 1159 stars. Figure 1 shows the positions of most of these objects in the $T_{\rm eff}$–surface gravity plane. The models include H, He, C, O and are computed with a NLTE code developed in Kiel and Bamberg. Most recent models include line blanketing by millions of lines from iron group elements. As an example Figure 2 shows the EUV flux of such an iron line blanketed model for a H-rich central star. More details on work done so far can be found in a recent review given by Dreizler, Werner & Heber (1995).

Among the first PG 1159 stars analysed were the spectroscopic twins PG 1159-035 and PG 1520+525. This pulsator/non-pulsator pair holds the key for the determination of the blue edge of the instability strip. Our optical analysis gave an equal $T_{\rm eff}$ (140 kK) for both of them, however, within a large error range (± 15 kK). The determination of more precise atmospheric parameters is hampered by the fact that temperature indicators in

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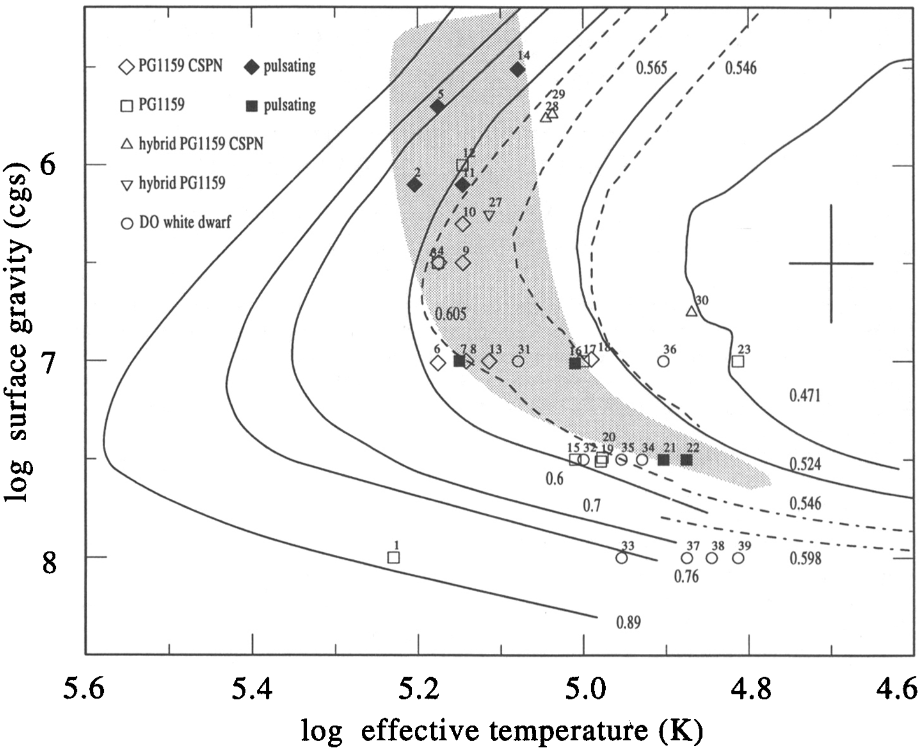

FIGURE 1. Location of the GW Vir instability strip (shaded region), comprising the pulsating PG 1159 stars (filled symbols). Evolutionary tracks are labeled with the respective stellar mass. A typical error bar is shown. For object identification see Table 1 (PG 1159 stars, labels 1–26) and Dreizler et al. (1995) for other objects

the optical spectral region are relatively insensitive. In the UV region, however, we can exploit the O v/O vi ionisation equilibrium by line profile fitting. Alternatively, the EUV region can be used for line and continuum fitting. The latter is particularly useful because the PG 1159 stars have their flux maximum in the EUV range and the continuum flux and shape are very temperature sensitive. The oxygen ionization balance method has been used to derive a rather precise value for $T_{\rm eff}$ of PG 1159-035 from a HST-FOS spectrum (Werner & Heber 1993). The result was again 140kK but now with a much smaller uncertainty ($\pm$ 5 kK). No usable UV spectrum of the other twin was recorded up to now, so we decided to observe both twins with *EUVE*.

3. *EUVE* Observation of PG 1520+525

Model atmospheres predict a very strong EUV flux, however, interstellar column densities are high. Therefore weak but still detectable fluxes at earth were expected in the region around 100Å. Unfortunately the extinction towards PG 1159-035 turned out to be higher than expected: A 38ks exposure taken during Apr 06–07 (1993) is underexposed. On the other hand a 155ks exposure of PG 1520+525 taken on Feb 09–15 (1994) shows a noisy but still usable spectrum (Fig. 3). Compared to a 140kK model spectrum we

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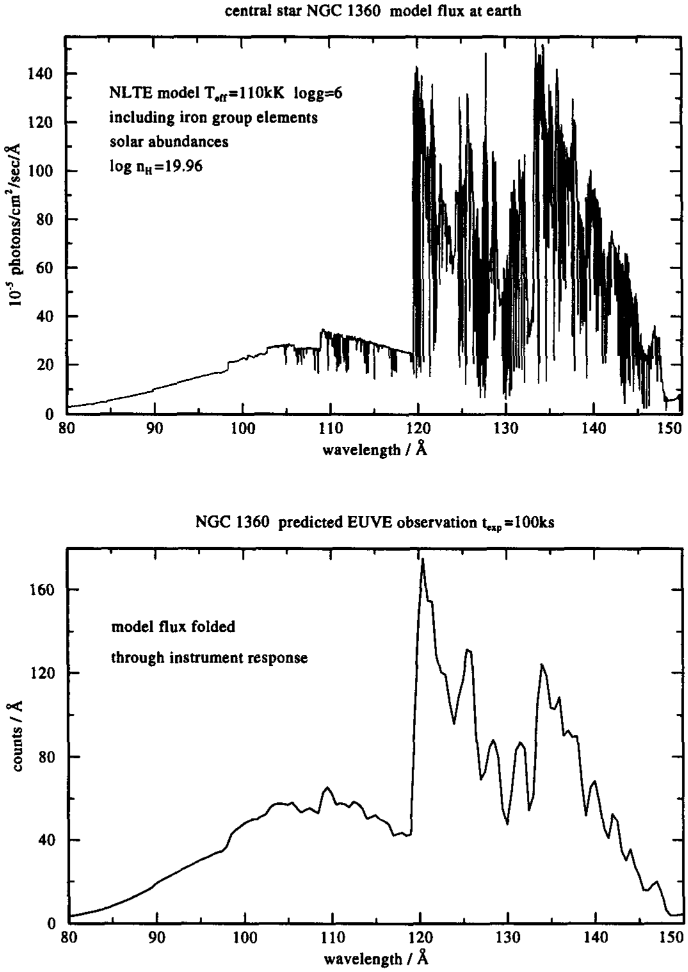

FIGURE 2. Top: Non-LTE model flux for a hot planetary nebula central star. Line blanketing by iron group elements is included. Bottom: Model folded through the *EUVE* SW instrument response. Such models are currently under construction in order to analyze an *EUVE* spectrum of NGC 1360

would expect to see a strong O V absorption edge at 120Å, but it is not detectable. We must have a higher T_{eff} in order to depopulate O V and to weaken this edge: It can be seen that the 150kK model has a much weaker O V edge. We conclude that T_{eff} of PG 1520+525 (150kK) is slightly higher than that of the pulsating prototype (140kK). Hence the blue edge of the GW Vir instability strip runs right between the loci of these two stars in the T_{eff}–$\log g$ plane.

Another pulsator/non-pulsator pair comprises PG 1707+427 and PG 1424+535. These define the red edge of the instability strip, which is found near T_{eff}=100kK. Analogously, this is what we learned from optical spectra. Their temperatures are much too low to produce enough EUV photons that could penetrate the ISM, so they cannot be detected

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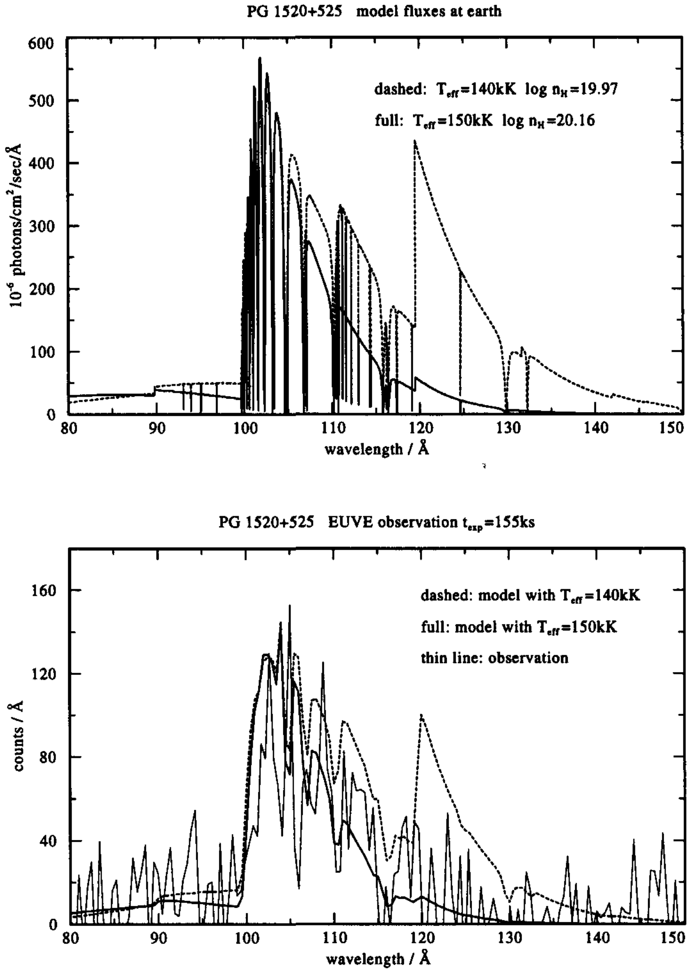

FIGURE 3. Top: Non-LTE model fluxes (for two different effective temperatures) attenuated by the ISM. Note the strong O V absorption edge at 120Å in the cooler model. It almost disappears when T_{eff} is increased by only 10kK. Another strong edge (at 100Å) is due to O VI (2p). The absorption line spectrum is dominated by the respective O VI series as well as C IV lines. Other model parameters, taken from Werner et al. (1991): $\log g = 7$, He/C/O=0.33/0.50/0.17 (mass fractions).
Bottom: Both models folded through the *EUVE* SW instrument response and compared to the observation. The non-detection of the 120Å edge suggests that T_{eff} exceeds 140 000 K

by *EUVE*. Instead, HST-GHRS observations are approved for Cycle 5 to find subtle differences in their atmospheric parameters.

After all, the picture as we have described it up to now is not as simple. The location of the instability region is not only dependent on surface gravity (and hence luminosity), but also on C and O abundances in the pulsation driving regions of the stars. Although these are very close below the photosphere, their composition may differ from the photospheric abundances. This fact might explain the presence of non-pulsators in the instability

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TABLE 1. The complete list of known PG 1159 stars (ordered by decreasing effective temperature), their spectroscopic subtype and atmospheric parameters (: =uncertain). Columns 3 and 4 denote if the star is variable or has a planetary nebula. Abundances are given in % mass fraction, $T_{\rm eff}$ in kK. The consecutive numbers in the last column refer to the labels in Fig. 1. For more details see Dreizler et al. (1995)

Star	Type	Var.	PN	$T_{\rm eff}$	log g	H	He	C	N	O	Nr.
H 1504+65	Ep	no	no	170	8.0			50		50	1
RX J 2117+3412	lgE	yes	yes	160	6.1		38	56		6	2
PG 1144+005	Ep	no	no	150	6.5		39	58	1.5	1.6	3
Jn 1	E	no	yes	150:	6.5		30	46		24	4
NGC 246	lgE	yes	yes	150:	5.7		38	56		6	5
PG 1520+525	E	no	yes	150	7.0	<8	30	46	<0.3	16	6
PG 1159-035	E	yes	no	140	7.0	<8	30	46	<0.3	16	7
NGC 650	E		yes	140:	7.0						8
Abell 21=Ym29	E		yes	140:	6.5		35	51		14	9
Longmore 3	lgE	no	yes	140:	6.3		38	56		6	10
K 1-16	lgE	yes	yes	140:	6.1		38	56		6	11
PG 1151-029	lgE	no	no	140:	6.0		35	51		14	12
VV 47	E	no	yes	130:	7.0		35	51		14	13
Longmore 4	lgEp	yes	yes	120	5.5		46	43		11	14
HS 0444+0453	A		no	100:	7.5						15
PG 1707+427	A	yes	no	100	7.0	<8	30	46	<0.3	16	16
PG 1424+535	A	no	no	100	7.0	<8	30	46	<0.3	16	17
IW 1	A	no	yes	100:	7.0						18
MCT 0130-1937	A	no	no	95	7.5		50:	30		20	19
HS 1517+7403	A		no	95	7.5		61	37		2	20
PG 2131+066	A	yes	no	80	7.5		50:	30		20	21
PG 0122+200	A	yes	no	75	7.5		50	30		20	22
HS 0704+6153	A		no	65	7.0	<10	44	26		20	23
NGC 6852	lgE:		yes								24
NGC 6765	lgE:		yes								25
Sh 2-78	A		yes								26

region. One example is HS 2324+3944, a so-called hybrid-PG 1159 star (nr. 27 in Fig. 1). It does have hydrogen in the photosphere. If present in deeper layers, too, hydrogen would "poison" the pulsations.

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