Abstract. The archival spectrum of SDSS J212531.92-010745.9 shows not only the typical signature of a PG 1159 star, but also indicates the presence of a companion. With time-series photometry of SDSS J212531.92-010745.9 during 10 nights, spread over one month, with the Tübingen 80 cm and the Göttingen 50 cm telescopes, the binary nature of this object has recently been proven. An orbital period of 6.9 h could be determined, and the observed light curve fitted with the \texttt{nightfall} program. A comparison of the spectrum of SDSS J212531.92-010745.9 with NLTE models further constrained the light curve solution. We emphasize that this is the first system of this kind which will allow a dynamical mass determination for a PG 1159 star.

1. Masses of PG 1159 stars

PG 1159 stars are hot hydrogen-deficient pre-WDs which are believed to be the outcome of a late (or very late) helium-shell flash. Their non-standard evolutionary history, including a second passing through post-AGB stages, is reflected in their unusual surface composition (see also Reiff et al. 2007; Jahn et al. 2007) which is characterized by strong hydrogen-depletion. Spectroscopic masses have in the past usually been derived from hydrogen-rich models, using the sets by Schönberner (1983) and Blöcker (1995) and Wood & Faulkner (1986).

1.1. Spectroscopic masses

The derivation of spectroscopic masses requires to obtain accurate photospheric parameters ($T_{\text{eff}}$, $\log g$) and combine them with evolutionary model calculations. The most comprehensive compilation, using NLTE stellar atmosphere on the one hand and actual late helium-shell flash modelling on the other hand, has recently been presented by Werner & Herwig (2006), collecting together a total of 40 objects in their analysis. A further set of state-of-the-art evolutionary tracks has simultaneously been presented by Miller Bertolami et al. (2006). Both finally make available late thermal pulse post-AGB evolutionary models, but differ in details on which mass track actually corresponds to a given position in $T_{\text{eff}}$, $\log g$ diagrams.
Table 1. Results from asteroseismology of PG 1159 stars and the [WC4] central star of NGC 1501. This compilation (adopted from Table 3 of Werner & Herwig 2006) compares the stellar mass derived by spectroscopic means $M_{\text{spec}}$ with the pulsational mass $M_{\text{puls}}$. Other columns list envelope mass $M_{\text{env}}$ (all masses in solar units) and rotation period $P_{\text{rot}}$ in days.

| Star            | $M_{\text{spec}}$ | $M_{\text{puls}}$ | $M_{\text{env}}$ | $P_{\text{rot}}$ | Reference           |
|-----------------|-------------------|-------------------|------------------|------------------|---------------------|
| PG 2131+066     | 0.58              | 0.61              | 0.006            | 0.21             | Kawaler et al. (1995) |
| PG 0122+200     | 0.58              | 0.59              | 1.66             | Fu et al. (submitted) |
| RX J2117.1+3    | 0.70              | 0.56              | 0.045            | 1.16             | Vauclair et al. (2002) |
| PG 1159−035     | 0.60              | 0.59              | 0.045            | 1.38             | Kawaler & Bradley (1994) |
| PG 1707+427     | 0.59              | 0.57              | 1.17             | Kawaler et al. (2004) |
| NGC 1501        | 0.55              | 1.17              | Bond et al. (1996) |

1.2. Asteroseismic masses

A complementary approach uses the fact that ten of the currently known PG 1159 stars lie in the GW Vir instability strip (for the current status of work trying to theoretically and empirically constrain the red and blue edges of the GW Vir instability strip, see the contributions by Quirion 2007; Vauclair 2007; Werner et al. 2007). From an analysis of the GW Vir stars’ pulsational eigenmodes, fundamental parameters including the mass can be derived through comparison to structural models (usually requiring some additional spectroscopic information to narrow down the number of possible solutions). Such solutions have been found for five objects so far (Table I).

1.3. Dynamical masses

Both of the above methods require a substantial amount of modelling, incorporating assumptions on the evolutionary state of these objects that one would ideally want to constraint with independently derived measurements of the mass in the first place. About the only way to do this with as little a priori information as possible is to dynamically weigh the components in a binary system.

NGC 246 has long been known to be one component in a wide pair, but at a separation of $3''8$ from its companion, an observation of the dynamical aspect of their orbit is out of reach. It is still very useful, though, as the distance to the system and surrounding planetary nebula could be derived from photometry of the companion (Bond & Ciardullo 1999). Furthermore, it has recently been claimed to be pulsating (González Pérez, Solheim, & Kambe 2006).

Yet another pulsator, PG 2131+066, was found to show an 3.9 h periodicity, in addition to the shorter pulsational photometric variations, by Paunzen, König, & Dreizler (1998), who attributed this to orbital motion in a close binary. The close binary hypothesis was supported by the observation of a red excess (Wesemael, Green, & Liebert 1985) and Hα and Hβ emission superimposed on the PG 1159 spectrum, but was disputed by Reed, Kawaler, & O’Brien (2000), who measure a physical companion $0''3$ away from the primary in HST WFPC1 images and argue that
the emission is caused by that farther-away companion alone. The claim that PG 2131+066 resides in a close binary therefore remains unconfirmed.

The only other PG 1159 star known to be part of a binary system is the recently discovered SDSS J212531.92−010745.9, and it is finally without doubt also a close one, i.e. suitable for dynamical mass determination.

2. SDSS J212531.92−010745.9

Schreiber & Gänsidee (2007) systematically searched SDSS archival data for WD+MS companion candidates and discovered Hα emission and a red colour excess in SDSS J212531.92−010745.9. The candidate was further analysed by Nagel et al. (2006); we briefly recapitulate their main results below.

2.1. SDSS spectrum

To fit a composite spectrum to the SDSS data, the model grid and fitting method described by Hülsemeyer et al. (2007) has been employed, but a more complex iterative procedure was required to account for the contribution of the secondary. As the latter was realized as a simple black-body contribution, the best-fit composite ($T_{\text{eff}} = 90000$ K, $\log g = 7.6$ for the PG 1159 component) obviously fails to reproduce the emission line features. In the PG 1159 spectrum, $\text{Civ}$ is furthermore too weak in the model. This only reinforces, however, the identification as a genuine PG 1159 star, and prompted Nagel et al. (2006) to secure time-series photometry of the object in the 2005 observing season.

2.2. Light curve

Photometric observations of SDSS J212531.92−010745.9 were obtained on ten nights during September and October 2005 with the Tübingen 80 cm and the Göttingen 50 cm telescopes (Fig. 1).

The light curve of SDSS J212531.92−010745.9 shows photometric variability with a period of 6.9 h and a peak-to-peak amplitude of 0.7 mmag. The 6.9 h periodicity is interpreted as the orbital period of the system. A profile is obtained by folding the observations with this period. It shows no eclipses (this constrains the inclination in the light curve solution), a flat part, and periodic brightening that is attributed to the light contribution by the irradiated side of the cool companion.

Collecting together spectroscopic parameters, reasonable assumptions, photometric observations, and performing a fit to the folded profile with the nightfall program, Nagel et al. (2006) arrived at one possible system solution as presented in Table 2. A key parameter of interest, the mass of the primary, will however have to await radial velocity measurements for an independent determination.

The light curve does not suggest the presence of pulsations in the PG 1159 star, but the constraints to exclude pulsations are weak: The existing data exclude pulsations with amplitudes above 50 mmag at periods longer than about 8 min.
Figure 1. The photometric data from observing season 2005 (small crosses) can in the first instance be fit by a simple sine function (continuous line) with a 6.95616(33) h period (adopted from Fig. 3 in Nagel et al. 2006).

Table 2. Resulting stellar and system parameters of SDSS J212531.92−010745.9, derived from comparison with NLTE model spectra (boldface), or assumed (normal font), and derived from photometric analysis (⋆) and a nightfall simulation (italic).

| parameter       | PG 1159 star | companion | system               |
|-----------------|--------------|-----------|----------------------|
| $T_{\text{eff}}$ [K] | 90 000±20 000 | 3 500±150 | 8 200                |
| $T_{\text{eff, irr}}$ [K] |             |           |                      |
| $\log (g$ [cm s$^{-2}$]) | 7.6±0.5      |           |                      |
| $m$ [M$_\odot$] | 0.6          | 0.4±0.1   | 1.0±0.1              |
| $r$ [R$_\odot$] | 0.1          | 0.4±0.1   |                      |
| $P_{\text{orb}}$ [h] |             |           | 6.95616±0.00033      |
| $\Delta m$ [mag] |             | 0.354±0.003 |                     |
| $a$ [R$_\odot$] |             |           | 1.85                 |
| $i$ [$^\circ$] |             |           | 70±5                 |
2.3. Outlook

Since the results cited above must be considered as preliminary, the next step should be a full two-component analysis of orbital phase resolved spectroscopy. These observations are in the queue, and will be assisted by ongoing monitoring in the current 2006 observing season which will allow us to much refine the ephemeris. Ultimately, a precise mass for a PG 1159 star derived with the help of radial velocity measurements will allow to check born-again scenarios of post-AGB evolutionary models.

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