A PG 1159 close binary system

New light curves and spectra of SDSS J212531.92−010745.9

Sonja Schuh[1], **Thorsten Nagel**[2], **Iris Traulsen**[1], **Benjamin Beeck**[1]

[1]Institut für Astrophysik, Georg-August-Universität Göttingen, Friedrich-Hund-Platz 1, D–37077 Göttingen, Germany
[2]Institut für Astronomie und Astrophysik, Eberhard-Karls-Universität Tübingen, Sand 1, D–72076 Tübingen, Germany

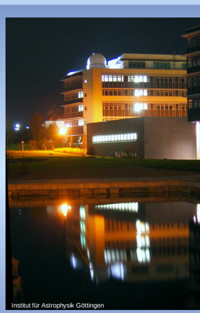
Summary

Methods to measure masses of PG 1159 stars in order to test evolutionary scenarios are currently based on spectroscopic masses or asteroseismological mass determinations. SDSS J212531.92−010745.9, a recently discovered PG 1159 star in a close binary system, may finally allow the first dynamical mass determination, and has so far been analysed on the basis of one SDSS spectrum and photometric monitoring.

In order to be able to phase radial velocity measurements of the system SDSS J212531.92−010745.9, we have followed up the photometric monitoring of this system. New white-light time series of the brightness variation of SDSS J212531.92−010745.9 with the Tübingen 80 cm and Göttingen 50 cm telescopes extend the monitoring into a second season (2006), and provide the observational basis for an improved orbital ephemeris determination.

A series of phase-resolved medium-resolution spectra have been obtained with the TWIN spectrograph at the 3.5 m telescope at Calar Alto, which will allow us to derive the radial velocity curves for the system, and to perform spectral analyses of the irradiating and irradiated components at different phases.

We give the improved ephemeris for the orbital motion of the system, based on a sine fit which now results in a period of 6.95573(5) h, and discuss the associated new amplitude determination in the context of the phased light curve variation profile. Furthermore, we present a first look at the newly obtained spectra. The light curve and radial velocities combined will allow us to carry out a mass determination.



The system SDSS J212531.92−010745.9

Discovery SDSS J212531.92−010745.9 was discovered to show Hα emission during a systematic search of SDSS archival data for white dwarf + main sequence companion candidates. Its SDSS magnitudes are u=17.15, g=17.54, r=17.75, i=17.79, z=17.83.

Classification It was subsequently classified as a PG 1159 star from a spectral analysis of the SDSS spectrum, which shows significant features that are typical for PG 1159 stars, e.g. the strong C IV absorption lines at $4650-4700$ Å and He II at 4686 Å (Figure 1). Furthermore, the spectrum shows features which indicate the presence of a companion. The Balmer series of hydrogen is seen in emission, H_α-H_δ can clearly be identified.

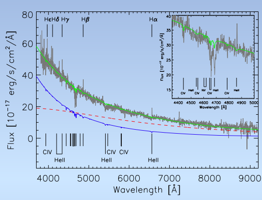


Figure 1: SDSS Spectrum of SDSS J212531.92−010745.9 (gray line, t_{exp}=3703 s), overlayed with a PG 1159 NLTE model spectrum with T_{eff} = 90 000 K, $\log g$ = 7.60, C / He = 0.05, and N / He = 0.01 (blue), a blackbody model spectrum with T = 8 200 K (red), representing the contribution from the irradiated companion, and the sum of the two model spectra (green). The Balmer series in emission (top), and some of the PG 1159 star's helium and carbon lines are marked (bottom). The parameters of both stellar components are estimates obtained from a qualitative comparison (Nagel, Schuh, Kusterer, Stahn, Hügelmeyer, Dreizler, Gänsicke, & Schreiber 2006, A&A 448, 25L). Detailed parameters need to be derived from a full two-component analysis of orbital phase resolved spectroscopy.

Variability And indeed, the system has been found to undergo brightness variations in follow-up time-resolved photometry. The light curve shows a periodicity of 6.95616(33) h, attributable to orbital motion, with a flat bottom part, and no eclipses. The periodic brightening with a peak-to-peak amplitude of 0.7 mag can be interpreted as the light contribution by the irradiated side of the cool companion.

Open questions

- UHEI features in spectrum: The overall shape of the observed spectrum is well fitted with the combination of a PG 1159 star and a cool, irradiated companion, but especially the C IV spectral lines of the PG 1159 model atmosphere are not strong enough. There is another PG 1159 star showing this phenomenon (Hügelmeyer, Dreizler, Homeier, Krzesinski, Werner, Nitta, & Kleinman 2006, A&A 454, 617), and also none of the deep absorption lines which some DO white dwarfs show can be fitted (e.g. Werner, Dreizler, Heber, Rauch, Wisotzki, & Hagen 1995, A&A 293, 75).
- Improved orbital and stellar parameters including mass determination: Since there are no eclipses in SDSS J212531.92−010745.9, a full solution must combine the individual projected radial velocity amplitudes of the two components with an inclination obtained from the light curve solution.
- Physics of reflection effect: A major uncertainty in the light curve solution will come from the poorly known physics for irradtiation of a companion by a very hot central object (see e.g. Aungwerojwit, Gänsicke, Rodríguez-Gil, Hagen, Giannakis, Papadimitriou, Allende Prieto, & Engels 2007, A&A 469, 297, or Edelmann et al. on HW Vir, in prep.). It will therefore be necessary to test if the reflection effect is adequately modelled by different light curve simulation programs.

Light curve and ephemeris

Table 1: Observation log. All observations were performed with clear filter.

Date	$t_{exp} [s]$	$t_{cycle} [s]$	Duration $[s]$	Telescope	Camera
2005/09/21	90	98	18900	80 cm	ST-7E
2005/09/22	90	98	18899	80 cm	ST-7E
2005/09/23	90	98	21758	80 cm	ST-7E
2005/09/23	180	194	4051	50 cm	STL-6303E
2005/09/23	240	254	9656	50 cm	STL-6303E
2005/10/06	240	248	10202	50 cm	STL-6303E
2005/10/07	240	246	14897	50 cm	STL-6303E
2005/10/08	240	248	9298	50 cm	STL-6303E
2005/10/10	90	98	19852	80 cm	ST-7E
2005/10/11	240	248	17872	50 cm	STL-6303E
2005/10/18	90	98	16532	80 cm	ST-7E
2005/10/26	90	98	20095	80 cm	ST-7E
2006/09/12	60	63	15919	80 cm	STL-1001E
2006/09/13	60	63	21312	80 cm	STL-1001E
2006/09/20	60	63	23056	80 cm	STL-1001E
2006/09/20	240	247	17321	50 cm	STL-6303E
2006/09/21	60	63	22489	80 cm	STL-1001E
2006/09/21	180	187	21441	50 cm	STL-6303E
2006/09/22	60	63	22299	80 cm	STL-1001E
2006/09/22	180	187	1922	50 cm	STL-6303E
2006/09/22	420	427	13388	50 cm	STL-6303E
2006/09/23	90	93	22008	80 cm	STL-1001E
2006/09/23	180	187	20595	50 cm	STL-6303E
2006/09/24	60	63	9805	80 cm	STL-1001E
2006/09/24	240	247	24678	50 cm	STL-6303E
2006/09/27	90	93	9470	80 cm	STL-1001E
2006/09/27	240	247	3205	50 cm	STL-6303E
2006/10/08	240	247	11601	50 cm	STL-6303E
2006/10/09	240	247	19808	50 cm	STL-6303E
2006/10/10	240	247	19241	50 cm	STL-6303E
2006/10/11	240	247	19721	50 cm	STL-6303E
2006/10/12	60	63	18105	80 cm	STL-1001E
2006/10/16	60	63	17602	80 cm	STL-1001E
2006/10/16	240	247	16763	50 cm	STL-6303E
2006/10/17	60	63	13798	80 cm	STL-1001E
2006/10/17	120	123	4052	80 cm	STL-1001E
2006/10/17	240	247	18798	50 cm	STL-6303E
2006/10/26	60	63	16031	80 cm	STL-1001E
2006/10/27	60	63	19739	80 cm	STL-1001E
2006/10/30	40	43	11609	80 cm	STL-1001E
2006/11/15	240	247	18264	50 cm	STL-6303E

We have obtained new observations with the Tübingen 80 cm and the Göttingen 50 cm telescopes during 19 nights between September and November 2006. The full data set now available is listed in Table 1 with details of the set-up.

In Figure 2, we show the periodogram of the combined light curve from 2005 and 2006. The correct position of the dominant frequency can unambiguously be identified from the strong alias pattern. The gain in accuracy over the 2005 data alone is illustrated by the central peak (grey line in the lower panel). The combined light curve was fitted with a nonlinear least-squares sine fit. It resulted in an improved period determination of 6.95573(5) h and a sinusoidal amplitude of 0.299(33) relative intensity change (0.284(28) mag).

Referring to the most recent observation to define the zero point, we determine the ephemeris of predicted *maxima* times to be

$$\mathrm{HJD} = 2454055^{\mathrm{d}}_{.}2134(4)\ +\ 0^{\mathrm{d}}_{.}289822(2)\cdot E.$$

In Figure 3, we compare the folded profile to the sinusoidal amplitude of 0.299(33) relative intensity change. Clearly, the observed peak-to-peak variation is not fully reproduced by the fit: this light curve shape emphasizes the superiority of a more realistic model over a plain sine fit, and validates the interpretation of the observed brightening as a reflection effect.

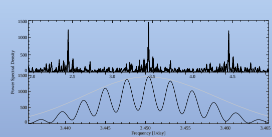


Figure 2: Periodogram of the combined light curve: frequency range illustrating the one-day (upper panel) and the yearly alias patterns (lower panel), compared to the central peak of the periodogram obtained from the 2005 data alone (grey line).

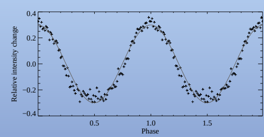


Figure 3: Profile of the combined light curve obtained by folding it onto the orbital period and rebinning into 100 phase bins (crosses), and overplotted sine fit (grey line).

Evolutionary context

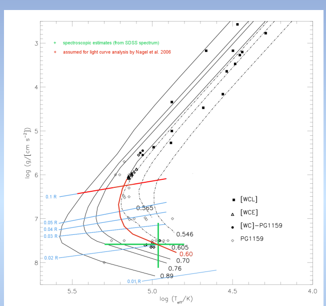


Figure 4: Positions of SDSS J212531.92−010745.9 (spectroscopically photometrically) and other PG 1159 stars compared to evolutionary tracks from Blöcker 1995, A&A 299, 755 and Schönberner 1983, ApJ 272, 708 (dash-dotted lines), and Wood & Faulkner 1986, ApJ 307, 659 (solid lines). PG 1159 stars are represented by black (SDSS) and grey (previously known PG 1159 stars) diamonds. The plot also includes early and late Wolf-Rayet type CSPNe ([WCE], [WCL], and [WC]-PG 1159) as proposed progenitor objects. Tracks are labelled with their mass in $M_\odot$. An updated version of this plot will incorporate the new evolutionary tracks presented by Miller Bertolami & Althaus 2006, A&A 454, 845.

Table 2: Results from asteroseismology of PG 1159 stars. This compilation compares the stellar mass derived by spectroscopic means M_{spec} with the pulsational mass M_{puls} (all masses in solar units; adopted from Table 3 of Werner & Herwig 2006, PASP 118, 183, updated with spectroscopic masses from Table 2 in Miller Bertolami & Althaus 2006, A&A 454, 845 and new references).

Star	M_{spec}	M_{puls}	Reference
PG 2131+066	0.55	0.61	Kawaler, O'Brien, Clemens, et al. 1995, ApJ 450, 350
"		0.60	Corsico & Althaus 2006, A&A 454, 863
PG 0122+200	0.53	0.59	Fu, Vauclair, Solheim, et al. 2007, A&A 467, 237
"		0.56	Corsico & Althaus 2007b, astro-ph/0709.0280
RX J2117.1+3	0.72	0.56	Vauclair, Moskalik, Pfeiffer, et al. 2002, A&A 381, 122
"		0.56	Corsico, Althaus, Miller Bertolami, et al. 2007a, A&A 461, 1095
PG 1159−035	0.54	0.59	Kawaler & Bradley 1994, ApJ 427, 415
"		0.56	Corsico & Althaus 2006, A&A 454, 863
"		0.57	Corsico, Althaus, Kepler, et al.,this conference
"		0.59	Costa, Kepler, Winget, et al. 2007, A&A in press
PG 1707+427	0.53	0.57	Kawaler, Potter, Vučković, et al. 2004, A&A 428, 969
"		0.55	Corsico & Althaus 2006, A&A 454, 863

PG 1159 stars are hot hydrogen-deficient pre-WDs, believed to be the outcome of a late or very late helium-shell flash during their post-AGB evolution. About 40 such objects are known at present (Werner & Herwig 2006, PASP 118, 183; see also Figure 4), and a subset of currently 11 objects forms the class of the pulsating GW Vir variables. From their evolutionary history, typical masses should be around 0.6 $M_\odot$. Spectroscopic and asteroseismological mass determinations rely on stellar structure and evolution modelling (Table 2). Given the uncertainties (up to $\approx$0.1 $M_\odot$) both in evolutionary tracks and asteroseismological masses, an independent test would be desirable.

Phase-resolved spectroscopic observations

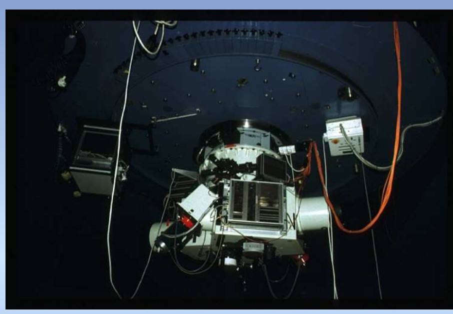


Figure 5: Spectra were obtained with the TWIN instrument at the 3.5 m telescope of Calar Alto observatory (2007/08/20).

We obtained spectra of SDSS J212531.92−010745.9 in late August, 2007 (see Table 3). Figure 5 shows a first look at the extracted spectra, some lines are marked. One clearly sees that the emission spectrum of the companion, irradiated by the PG 1159, varies with phase (values as predicted by the ephemeris) and almost vanishes at phase 0.5, leaving the PG 1159 spectrum with its typical absorption features. The variation in the continuum also shows that at phase ~ 1.0 the irradiated part of the companion contributes significantly to the system's overall flux. The emission lines of the companion show variable Doppler shifts due to its changing radial velocity while orbiting the PG 1159.

Table 3: Observation log for spectra.

Date	$t_{exp} [s]$	$t_{cycle} [s]$	Duration $[s]$	Telescope	Camera
2007/08/20	1800	1920	21120	3.5 m	TWIN
2007/08/21	1800	1830	7320	3.5 m	TWIN

Acknowledgements We would like to thank Elke Reiff, Derek Homeier, Heike Schwager, Daniel-Jens Kusterer, Ronny Lutz, Sylvia Brandert, Sebastian Wende, Jens Adamczak, Agnes Hoffmann, Ralf Kotulla, Simon Hügelmeyer, Markus Hundertmark, and Johannes Fleig for supporting the 2006 observations; and Klaus Reinsch for encouragement and technical support. We gratefully acknowledge the initialization of this project by Boris Gänsicke and Matthias Schreiber who first directed our attention to this special object. B. Beeck thanks the organizers for generous support. I. Traulsen acknowledges a travel grant by the DLR.