15th *European Workshop on White Dwarfs*
ASP Conference Series, Vol. 372, 2007
R. Napiwotzki and M. R. Burleigh

HS 2231+2441: A New Eclipsing sdB Binary of the HW Vir Type

R. Østensen

Instituut voor Sterenkunde, K.U.Leuven, Celestijnenlaan 200D B-3001 Heverlee, Belgium

R. Oreiro

Instituto de Astrofísica de Canarias, 38200 La Laguna, Spain

H. Drechsel and U. Heber

Dr. Remeis-Sternwarte, Sternwartstr. 7, 96049 Bamberg, Germany

A. Baran

Mt. Suhora Observatory, Pedagogical University, Podchorążych 2, 30-084 Cracow, Poland

A. Pigulski

Instytut Astronomiczny Uniwersytetu Wrocławskiego, Kopernika 11, 51-622 Wrocław, Poland

Abstract. The discovery of a new eclipsing sdB+dM system is announced. We present photometric and spectroscopic data which allow us to calculate the physical parameters of the components and solve the orbit of the system. The cool companion must be at the low mass limit for an M dwarf star, with an orbital radial velocity semi-amplitude of $K_1 = 49.1$ km/s. In other respects the system is strikingly similar to the other three known systems of the HW Vir type.

1. Introduction

Evidence has accumulated that a significant fraction of the subdwarf B (sdB) stars in the field are found in short period binary systems, and their formation can be explained by common envelope evolution (Maxted et al. 2001). Three eclipsing systems have been known up to now that all show deep eclipses and a spectacular reflection effect, all with orbital periods between 130 and 170 minutes: HW Vir, NY Vir = PG 1336−018 and HS 0705+6700 (Drechsel et al. 2001). Here we present the discovery of a fourth such system: HS 2231+2441. This new system is similar in properties to the other three with the exception that the M dwarf companion has a somewhat lower mass.

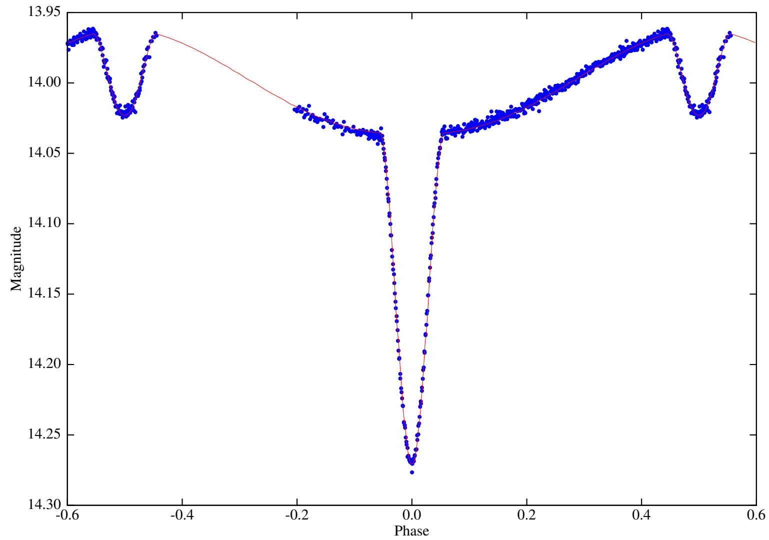

Figure 1. The discovery light curve of HS 2231+2441. Data from two runs on consecutive nights that both cover less than a full cycle have been folded on the orbital period and plotted together with a synthetic orbit solution.

2. Observations

HS 2231+2441 (α = 22:34:21.43, δ = +24:56:58.45) was observed as part of a search to detect new short-period pulsating sdB stars with the 2.5 m Nordic Optical Telescope on La Palma. Photometric data of this $B = 14.1$ magnitude star was obtained before morning twilight on June 1$^{\rm st}$, 2005, with a follow-up run the next night. Both runs cover less than a full orbital period and due to their overlap, they do not combine to cover a full period either (see Fig. 1). However, the excellent quality of the data ensures that a good orbital solution can be found. Follow-up BVI photometry was obtained with the Bialkow 60 cm telescope in Poland 150 days later, and the extended baseline provided by these observations ensures that we have a reliable ephemeris. Spectroscopic follow-up observations consisting of 27 five minute integrations covering a complete orbital cycle were obtained with the 4.2 m William Herschel Telescope on La Palma on September 9$^{\rm th}$, 2005. We were using the ISIS spectrograph with the R600B grating giving a dispersion of about 0.45 Å/pixel. The spectra were extracted using standard IRAF tasks.

3. Ephemeris and Spectroscopic Analysis

From the discovery light curve and the supplementary data from Bialkow Observatory we have obtained an ephemeris solution with an HJD time for the minimum and a period of:

$$T_0 = 2453522.66873 \pm 0.00004\,\mathrm{d}$$
$$P = 0.1105880 \pm 0.0000005\,\mathrm{d}$$

Analysing the individual spectra by fitting model spectra to the Balmer and helium lines gives quite reasonable solutions for the effective temperature, gravity,

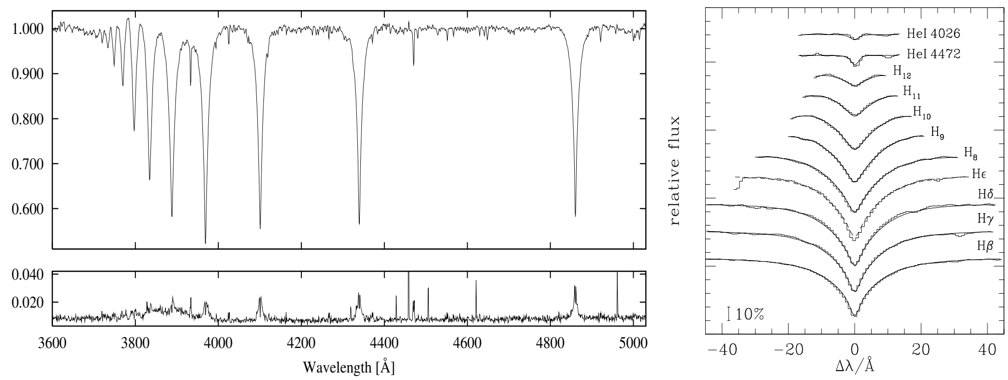

Figure 2. *Left panel:* The mean of 27 spectra of HS2231+2441 (top) and the rms variance spectrum (bottom). *Right panel:* Spectroscopic model fit to the orbit corrected mean spectrum. The radial velocity was kept fixed for the individual lines in this fit.

Table 1. Computed system solutions

	q	i	M_1	M_2	r_1	r_2
MORO	0.159	79.6	0.470	0.075	0.250	0.127
PHOEBE	0.145	79.1	0.499	0.072	0.250	0.129

and helium abundance, as well as a good estimate of the radial velocity shift of each spectrum. The left panel of Fig. 3 shows the radial velocity (average of the six best lines) for each of the 27 individual spectra, plotted as a function of orbital phase. A sinusoidal fit to the RV curve gives an RV amplitude of:

$$K_1 = 49.1 \pm 3.2\,\mathrm{km/s}$$

After shifting and adding the 27 spectra to correct for the orbital motion we obtain the mean spectrum shown in the left panel of Fig. 2. Using this mean spectrum we obtain a better model fit with parameters:

$$\begin{aligned} T_{\rm eff} &= 28370 \pm 80\,\mathrm{K} \\ \log g &= 5.39 \pm 0.01\,\mathrm{dex} \\ \log n(\mathrm{He})/n(\mathrm{H}) &= -2.91 \pm 0.04\,\mathrm{dex} \end{aligned}$$

The right panel of Fig. 2 shows the lines used in the fitting. The H_ϵ line was kept out of the fit due to contamination by CaII.

4. Orbit Solution

Solutions to the orbit have been computed using the MORO (Drechsel et al. 1995) and PHOEBE (Prša & Zwitter 2005) programs (see Table 1). The spectroscopic radial velocity solution provides a mass function that effectively eliminates the mass ratio degeneracy of the light curve solution. Using $K_1 = 49.1\,\mathrm{km/s}$ we get a mass function of $f(m) = 0.00135$, which directly gives $M_2 = 0.075\,M_\odot$ for

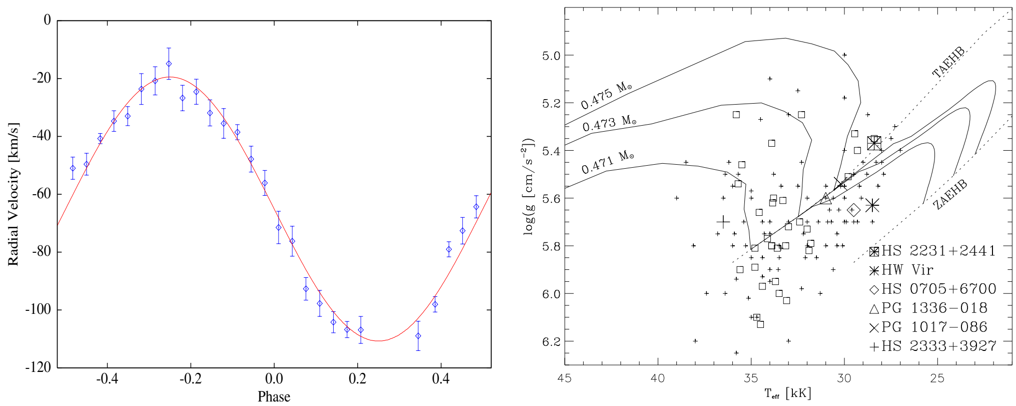

Figure 3. *Left panel:* The radial velocity measurements as derived from fitting spectroscopic models to the observed spectra. The best fit orbital solution is drawn as a curve. *Right panel:* The location of HS 2231+2441 in the $T_{\rm eff}/\log g$ plane The squares show known pulsators and + symbols non-pulsators.

a canonical $M_1 = 0.470 M_\odot$ subdwarf. Thus, the mass ratio must be close to $q = 0.159$. Also, by including the spectroscopic gravity of the primary we can directly constrain its radius. This approach has been used when obtaining the MORO solution. With PHOEBE the radial velocity curve is supplied as input, and the differential minimisation searches for a solution that is compatible with all the observational data. However, while the determined effective temperature was used as a constrain for PHOEBE, the gravity was not. Indeed, PHOEBE converges to a solution that indicates a gravity of $\log g = 5.53$, which is somewhat higher than our spectroscopic value. For this reason we prefer the MORO solution, although the two fits are quite similar.

5. Discussion

The sdB star HS 2231+2441 was discovered to be an eclipsing system of the HW Vir type, with a companion at the low mass limit for an M dwarf stellar object. Our spectroscopic determination of the primary's effective temperature and gravity is very close to those of the other three known systems of this type and practically on top of some of the cooler pulsating sdB stars (see right panel of Fig. 3). The pulsator just on top of the location of HS 2231+2441 is HS 0702+6043. The two additional objects named in this plot, PG 1017-086 and HS 2333+3927, are the two known non-eclipsing reflection binaries with similar components as the other four systems.

References

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