Spectroscopy of the Proposed White Dwarf Pulsar ASASSN-V J205543.90+240033.5

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ABSTRACT

We obtained spectra of ASASSN-V J205543.90+240033.5 (J2055), a system that shows photometric variations similar to the white dwarf (WD) pulsar AR Scorpii. Our spectra display a continuum rising steeply toward the blue as well as an array of emission lines. Resolved Balmer and Paschen lines are seen with Hα and Hβ having central absorption features. The strongest lines are unresolved C II, C III, and N III as well as doubly ionized helium. The spectra are similar to that of YY Hyα, and suggest that J2055 is a post-common envelope binary consisting of a hot compact star irradiating the face of a secondary of unknown spectral type. Velocity variations detected from the emission lines confirm the binary nature of J2055. The origin of the 10-minute photometric variation remains uncertain.

Keywords: variable stars, close binary stars, common envelope evolution, white dwarf stars, AR Sco

INTRODUCTION

Optical photometry of ASASSN-V J205543.90+240033.5 (J2055 hereafter) reveals periodic variations on 12-hour and 10-minute timescales (Kato 2021; Kato et al. 2021) that are similar to variability seen in the white dwarf (WD) pulsar AR Sco (Marsh et al. 2016; Stiller et al. 2018). AR Sco is a binary consisting of a red dwarf detached from a magnetic WD that rotates with a period of 1.95 minutes. For J2055, the 12-hour variation is thought to be related to the binary orbit while the origin of the 9.77-minute periodicity is uncertain.

DATA

We obtained spectra of J2055 using the Large Binocular Telescope (LBT1) and twin Multi-Object Dual Spectrographs (MODS; Pogge et al. 2012) on 2021, September 16 (UT). A sequence of eleven, 150s exposures were taken with MODS1 through the SX telescope providing coverage over 36 minutes including readout and overheads. The same exposure sequence was obtained with MODS2 through the DX telescope. The image quality averaged 0.7 to 0.8 arcseconds during the observation. A 0.8 arcsec wide slit was employed with the gratings to give a spectral resolution in the red of 1350, or 215 km s\(^{-1}\) (FWHM) at Hα. In the blue, the resolution is 1890, or 160 km s\(^{-1}\) (FWHM) at Hβ. Each spectrograph has a red and blue arm split at 5650 Å by a dichroic mirror allowing wavelength coverage from 3200 Å to 1.01 µm.

The spectra were taken near photometric phase 0.04 based on the ephemeris from Kato et al. (2021). This is very close to the peak brightness of the 12-hour photometric periodicity.
ANALYSIS

The resulting average spectrum is displayed in the top panel of Figure 1. It shows a continuum rising toward the blue with a large number of narrow emission lines from the ultraviolet to the near infrared. The Balmer and Paschen hydrogen emission sequences are evident. However, the strongest lines are permitted carbon and nitrogen emission features with a range of ionization states. For example, the blend of C III lines at 4649 Å is 50% brighter than Hβ. Also, the C II 6578+6583 Å is half the flux of Hα. He II emission is also significant at 4686, 5411, and 8237 Å.

Hα and Hβ show a central absorption that vanishes toward the higher Balmer lines. The Hα and Hβ line widths are 600 km s$^{-1}$ (FWHM). The base of the Hβ line extends to ±900 km s$^{-1}$. The Balmer widths decrease toward the higher level transitions with He having a width of 440 km s$^{-1}$ (FWHM). The Balmer decrement is inverted, with the Hα/Hβ=0.5. The He II and carbon lines are unresolved at this resolution.

Cross-correlation between the average spectrum and each of the 11 exposures shows a systematic decrease in velocity totalling 44 km s$^{-1}$ over the 36 minutes of data. This appears to confirm the binary nature of the system, although the spectra cover only 5% of the photometric period. Narrow absorption features are detected from Na I and Ca II. The absorption lines do not show any significant variation in velocity suggesting they originate in circumstellar or interstellar gas.

CONCLUSIONS

The spectrum of J2055 near maximum is similar to the post-common envelope binaries (aka pre-cataclysmic binaries) TW CrV (Shimansky et al. 2016) and YY Hya (Kimeswenger et al. 2021). These systems consist of a hot compact
star, probably a WD, irradiating the face of a late-type (K or M type) star. No evidence of the cool secondary is seen in our spectra, possibly because they were obtained near maximum light when the irradiated face dominates the flux.

The optical spectrum of J2055 is clearly quite distinct from that of AR Sco (Marsh et al. 2016; Garnavich et al. 2019). The WD in AR Sco has a relatively cool surface temperature (Garnavich et al. 2021), leading to a spectrum dominated by Balmer, neutral helium, and Ca II emission lines. The heating of its secondary may be enhanced by non-thermal radiation. The temperature of the WD in J2055 appears much higher than for AR Sco, and post-common envelope systems often show enhancement of CNO elements (Shimansky et al. 2011). The differences in spectral properties between J2055 and AR Sco are likely due to the combination of enhanced CNO abundances and higher temperatures in J2055.

The origin of the 9.77-minute periodicity (Kato 2021) remains uncertain. It may come from surface temperature variations on a rotating WD, or, as in AR Sco, the beat period arising from the interaction of the WD magnetic field interacting with the secondary star.

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