FUSE Spectroscopic Analysis of the Slowest Symbiotic Nova AG Peg During Quiescence

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Received 2018 July 18; revised 2019 February 19; accepted 2019 February 24; published 2019 April 5

Abstract

We present a far-UV (FUV) spectroscopic analysis of the slowest known symbiotic nova AG Peg that underwent a nova explosion in 1850 followed by a very slow decline that did not end until ~1996, marking the beginning of quiescence. In 2015 June, when AG Peg exhibited a Z And-type outburst with an optical amplitude of ~1.5 mag. We used accretion disk and WD photosphere synthetic spectral modeling of a FUSE spectrum obtained on 2003 June 5.618. The spectrum is heavily affected by ISM absorption as well as strong emission lines. We dereddened the FUSE fluxes assuming $E(B-V) = 0.10$, which is the maximum galactic reddening in the direction of AG Peg. We discuss our adoption of the pre-Gaia distance over the Gaia parallax. For a range of white dwarf surface gravities and surface temperatures, we find that the best-fitting photosphere is a hot WD with a temperature $T_{\text{wd}} = 150,000$ K, and a low gravity $\log g \sim 6.0-6.5$. For a distance of 800 pc, the scaled WD radius is $R_{\text{wd}} \sim 0.06 \times R_{\odot}$, giving $g = 6.67$ for a 0.65 $M_{\odot}$ WD mass. The Luminosity we obtain from this model is $L = 1729 L_{\odot}$. The hot photosphere models provide better fits than the accretion disk models, which have FUV flux deficits toward the shorter wavelengths of FUSE, down to the Lyman limit. Given the uncertainty of the nature of a true symbiotic accretion disk, and, while a very hot low gravity degenerate star dominates the FUV flux, the presence of a steady-state (standard) accretion disk cannot be summarily ruled out.

Key words: novae, cataclysmic variables

1. Introduction

AG Peg is the slowest known symbiotic nova (M3/II-III giant + hot white dwarf; $P_{\text{orb}} \approx 818.4$ days) which underwent a nova explosion in 1850 followed by $\sim 165$ yr of decline and quiescence. A number of studies (Kenyon et al. 2001; Yoo 2006, 2008; Kim & Hyung 2008; Sanad & Bobrowsky 2017) document the very slow decline, since the 1850 nova explosion, and the transition into quiescence (up to ~1995). From roughly 1997 to 2015 June, the brightness of AG Peg appears to be fairly constant: its visual magnitude appears to be fairly constant: its visual magnitude

In order to shed light on the nature of the hot component (the "central engine"), we present here an analysis of a Far-Ultraviolet Spectroscopic Explorer (FUSE) spectrum of AG Peg obtained in quiescence. In this far-ultraviolet wavelength range down to the Lyman limit, the contribution of the nebular continuum produced by the photoionization of the red giant wind (which flattens the slope) is totally negligible. In this region, we are probing the flux of the innermost disk and white dwarf photosphere.

The published orbital and physical parameters of AG Peg are listed in Table 1 with their references. Its Gaia (DR2, Prusti et al. 2016; Brown et al. 2018) parallax is $\varpi \sim 0.380298 \pm 0.01982$ mas, giving a distance is $d = 2629 \pm 463$ pc. However, the standard uncertainty in $D = 0.2$ for a 9 mag star (e.g., Schaefer 2018) with such a parallax ($\varpi \sim 0.4$ mas), or four times smaller. The uncertainty in distance ($d = 1/\varpi$) will have a substantially non-Gaussian shape when $d$ grows to a substantial fraction of the parallax $\varpi$. The problem becomes nontrivial for cases where $\sigma_d/\varpi \sim 0.2$ or larger (Bailer-Jones 2015). The parallax of AG Peg has a significant value of 4.6$\sigma$, and from its quality flags (e.g., goodness of fit, number of visibility periods) it appears that the Gaia parallax for AG Peg is actually unreliable (see, e.g., Eyer et al. 2018; Luri et al. 2018; see also https://gea.esac.esa.int/archive/documentation/GDR2/Data_processing/). One of the explanations for the unreliability of AG Peg parallax is the fact that a long-period binary orbit will cause the center of light to wobble with a shift comparable to the parallax. As the binary separation is about 2 au with a period of almost 2 yr, over a 6 month period, the components move a distance of the order $\sim 1$ au (depending on the exact mass ratio and inclination). Therefore, we mainly present results based on the widely accepted pre-Gaia distance to AG Peg of $\sim 800$ pc.
scratches. Our grid has nonstandard accretion disk models in the form of (inner and outer) disk truncation, and covers parameter space outside of the Wade and Hubeny grid. In Section 3, we present the results of our synthetic spectral analysis of the FUSE data using accretion disk models and white dwarf models. Finally, in Section 4 we summarize our conclusions.

2. Observations and Method of Analysis

2.1. The FUSE Spectrum

AG Peg was observed with FUSE on 2003 June 5.618 (exposure start time MJD 52795.61791667) and data from the AAVSO indicate that it had a magnitude \( m_v = 8.5 \). The orbital phase at the time of the FUSE observation was \( \phi = 0.31 \), which we derived using the orbital ephemeris of Fekel et al. (2000) \( 2,447,165.3(\pm 48) + 818.2(\pm 1.6) \times E \) (itself based upon the inferior conjunction of the M3/4 giant). We retrieved the FUSE data (ID Q1110103) from the MAST archive. The instrument was set in time-tag and the data were obtained through the MDRS aperture with an exposure time of 2116 s (one single FUSE orbit). The data were calibrated through the pipeline with the final version of CalFUSE (Dixon et al. 2007) and further processed using our suite of FORTRAN programs, unix scripts, and IRAF procedures especially written for this purpose (Godon et al. 2012). The FUSE data come in the form of eight spectral segments (SiC1a, SiC1b, SiC2a, SiC2b, LiF1a, LiF1b, LiF2a, and LiF2b), which have to be combined together to give the final FUSE spectrum. These spectral segments do overlap and provide a way to renormalize the spectra in the SiC1, SiC2, and LiF2 channels to the flux in the LiF1 channel (which is the most reliable segment). In the present case, the two SiC channels experienced intermittent (and unexplained) drops in the count rates (which was more severe for the SiC2 channel than for the SiC1 channel). When combining the eight spectral segments together, we took care to renormalize the SiC spectral segments to the LiF spectral segments.

The FUSE spectrum with line identifications is displayed in Figure 1. Many ISM molecular hydrogen absorption lines are indicated with vertical tick marks. Numerous helium lines dominate the shortest wavelengths. Also seen are neon emission lines. FPN is a fixed pattern noise from the FUSE detector.

The FUSE spectrum was previously analyzed by Eriksson et al. (2006) who studied the locations, origins, and excitation mechanisms of the emission lines, and by Skopal et al. (2017) who used the FUSE spectrum to analyze the OVI 1032 Å line as part of a multiwavelength analysis.

In preparation for the spectral analysis, we dereddened the FUSE spectrum assuming \( E(B-V) = 0.10 \) (see Table 1) and using our dereddening script based on the extinction curve from Fitzpatrick & Massa (2007) with \( R = 3.1 \).

2.2. Spectral Modeling and Analysis

The spectral analysis is carried out by fitting the observed FUSE spectrum of AG Peg with theoretical (synthetic) model spectra of WDs and accretion disks.

We use Hubeny’s suite of codes TLUSTY and SYNSPEC (Hubeny 1988; Hubeny & Lanz 1995) to generate synthetic spectra for high-gravity stellar atmosphere WD models. A one-dimensional vertical stellar atmosphere structure is first generated with TLUSTY for a given surface gravity (\( \log(g) \)), effective surface temperature (\( T_{\text{eff}} \)), and surface composition (here we assume solar composition). The code SYNSPEC is then used to solve for the radiation field and generate a synthetic stellar spectrum over a given wavelength range between 900 Å and 7500 Å. Finally, the code ROTIN is used to reproduce rotational and instrumental broadening as well as limb darkening. In this manner we generate a grid of stellar photospheric models covering a wide range of effective temperatures and surface gravities.

The accretion disk spectra are generated by dividing the disk into rings, each with a given radius, temperature, effective surface (vertical) gravity, and density obtained from the standard disk model (Pringle 1981). For each ring the code TLUSTY is then run to generate a one-dimensional vertical structure. This is then followed by a run of SYNSPEC to create a spectrum for each individual ring. The ring spectra are then combined using DISKSYN, which includes the effects of Keplerian rotational broadening, inclination, and limb darkening. All our disk models used here, as well as Wade & Hubeny’s (1998) disk models, have solar abundances.

A complete description of our recently updated accretion disk modeling is given in Darnley et al. (2017) and Godon et al. (2017, 2018). The main implementation in our disk models is that the inner and outer radii of the disk are chosen to fit the parameters of the system that is being modeled. In the present case, the outer radius of the disk was extended to several hundred times the radius of the accreting white dwarf, where the disk temperature drops to ~3500 K. In the disks of Wade & Hubeny (1998), the outer disk extends only to where the temperature reaches 10,000 K. Nevertheless, because of the large mass accretion rate (and ensuing higher disk temperature) and the short wavelength coverage of FUSE, the inclusion of a more extended (and colder) outer disk does not contribute additional flux to the far-UV (FUV; our new disk spectra models also extend into the optical where the larger outer disk significantly increases the flux).

In the present work we also use model accretion disks from the optically thick, steady-state disk model grid of Wade & Hubeny (1998) as explained in the next section.

Since the FUSE spectrum of AG Peg is heavily affected by ISM molecular hydrogen absorption lines, we decided to model the ISM lines to obtain a better fit. Since our main purpose is not to assess the hydrogen atomic and molecular column densities, but only to improve our spectral fit, we use some of the ISM models we generated in Godon et al. (2009) and refer the reader to that work for further details.

| Parameter                        | Value       | References                      |
|----------------------------------|-------------|---------------------------------|
| Period                            | 818.4 days  | Fekel et al. (2000)             |
| Inclination                       | 50°         | Kenyon et al. (1993)            |
| Distance                          | 800 pc      | Kenyon et al. (1993)            |
| Separation                        | 2.5 ± 0.1 au| Kenyon et al. (1993)            |
| \( E(B - V) \)                    | 0.10 ± 0.05 | Kenyon et al. (1993)            |
| RG Spectral Type                  | M3/III     | Kenyon et al. (1993)            |
| WD Mass                           | 0.65 ± 0.1 \( M_{\odot} \) | Kenyon et al. (1993) |
| WD Radius (quiescence)            | ~0.05-0.06 \( R_{\odot} \) | Skopal et al. (2017) |
| WD Temperature                    | 95k K, ~160k K | Mürset et al. (1991),         |
| (quiescence)                      |             | Skopal et al. (2017)            |
| RG Mass                           | 2.6 ± 0.4 \( M_{\odot} \) | Kenyon et al. (1993) |
| RG Temperature                    | 3787 ± 387 K | Akras et al. (2019)             |
3. Results

In the following, we adopt a distance of 800 pc, an inclination of 50°, a WD mass of about 0.65 $M_\odot$ and we expect the WD temperature to be at least of the order of 100,000 K (see Table 1). We carry out all the disk and photosphere model fits for these values.

3.1. NLTE WD Photosphere Analysis

The input gravity of the models was varied from log $(g) = 6.0$ to log $(g) = 8.0$ in steps of 0.5, and the WD temperature was varied from $\sim$40,000 to $\sim$200,000 K (in steps of 5000 and 10,000 K). We find that the best-fit WD photosphere models are obtained for the lowest gravity (log $(g) = 6.0, 6.5$) in our grid of models and for a temperature $T_{\text{wd}} = 100,000$ to 180,000 K. The radius of the WD is then obtained by scaling the theoretical spectrum obtained for a distance of 800 pc to the observed spectrum. The exact mass of the WD is unknown but it is likely around $\sim 0.65 M_\odot$ (see Table 1), and an output value of the gravity, log $(g)$, can then be obtained and compared to the input value of log $(g)$ for self-consistency.

Explicitly, for $T_{\text{wd}} = 100,000$ K, the WD radius scaled to a distance of 800 pc is $R_{\text{wd}} = 55.5 \times 10^9$ cm ($\sim 0.08 R_\odot$), giving log $(g) = 6.44$ for an assumed WD mass of $M_{\text{wd}} = 0.65 M_\odot$ (see Table 2). Values of log $(g)$ are also listed for a 0.4 $M_\odot$ and 1 $M_\odot$ WD masses and are consistent with the best fits obtained for log $(g) = 6.0$ and log $(g) = 6.5$.

For the hottest model $T_{\text{wd}} = 180,000$ K, the WD radius scaled to a distance of 800 pc is $R_{\text{wd}} = 39.6 \times 10^9$ cm (0.057 $R_\odot$), giving log $(g) = 6.74$ for a 0.65 $M_\odot$ WD mass (Table 2). The 100,000 K model is slightly deficient in flux around 930–950 Å, while the 180,000 K model provides slightly too much flux in that region. At longer wavelengths, the models provide the same fit. Among these models, the best-fitting photosphere (namely in the 930–950 Å region) has $T_{\text{wd}} = 150,000$ K, and the WD radius scaled to a distance of 800 pc is $R_{\text{wd}} = 42.9 \times 10^9$ cm (0.0615 $R_\odot$), giving log $(g) = 6.67$ for a 0.65 $M_\odot$ WD mass.
The WD photosphere model fit to the FUSE spectrum is displayed in Figure 2, and includes the addition of ISM absorption lines. We note that our derived value of $T_{\text{wd}}$ agrees with the multiwavelength analysis of Skopal et al. (2017) who took $T_{\text{wd}} = 160,000$ K but did not model the FUSE spectrum explicitly. The low mass (and/or low gravity) of the white dwarf is consistent with the very small mass function derived from the full orbit solution of Fekel et al. (2000).

To further check the self-consistency of these models, we compute the luminosity (see Table 2, last column). Our best-fit model has a luminosity of $1729 \, L_\odot$, which agrees with Skopal et al.’s (2017) estimate, which is not surprising because the temperature is of the same order as Skopal et al.’s (2017). However, our hottest model has a luminosity about twice as large, which must be ruled out.

**Table 2**

| $T_b$ (1000 K) | $R_b$ (1000 km) | $R_h$ (R$_\odot$) | $M_h$ (M$_\odot$) | Log($g$) | $L$ ($L_\odot$) | $L$ (erg s$^{-1}$) |
|---------------|----------------|-----------------|-----------------|-----------|----------------|------------------|
| 100           | 55.5           | 0.0798          | 0.4             | 6.23      | 572            | $2.19 \times 10^{36}$ |
| 100           | 55.5           | 0.0798          | 0.65            | 6.44      | 572            | $2.19 \times 10^{36}$ |
| 100           | 55.5           | 0.0798          | 1.0             | 6.63      | 572            | $2.19 \times 10^{36}$ |
| 150           | 42.9           | 0.0615          | 0.4             | 6.46      | 1729           | $6.64 \times 10^{36}$ |
| 150           | 42.9           | 0.0615          | 0.65            | 6.67      | 1729           | $6.64 \times 10^{36}$ |
| 150           | 42.9           | 0.0615          | 1.0             | 6.86      | 1729           | $6.64 \times 10^{36}$ |
| 180           | 39.6           | 0.0570          | 0.4             | 6.53      | 3056           | $1.17 \times 10^{37}$ |
| 180           | 39.6           | 0.0570          | 0.65            | 6.74      | 3056           | $1.17 \times 10^{37}$ |
| 180           | 39.6           | 0.0570          | 1.0             | 6.93      | 3056           | $1.17 \times 10^{37}$ |

**Note.** The radius of the hot component $R_h$ is derived by scaling the model flux to the observed flux assuming a distance of 800 pc. The output gravity is then obtained assuming a given mass for the hot component.
3.2. NLTE Accretion Disk Analysis

We extended our analysis of the FUSE spectrum to optically thick, steady-state accretion disk models. We first used the grid of UV disk models by Wade & Hubeny (1998), and found that AG Peg must have a high-mass transfer rate if one ascribes all of the FUV flux to accretion luminosity. We tried the highest mass accretion rate models of Wade & Hubeny (1998) with \( M = 10^{-7} M_\odot \) yr\(^{-1}\), \( M_{\text{wd}} = 0.55 M_\odot \), and \( M_{\text{wd}} = 0.80 M_\odot \), all with an inclination \( i = 41^\circ \). However, all these disk models yielded derived distances much shorter, and did not provide enough flux in the short wavelength range of FUSE (\( \lambda < 960 \) Å). When linearly scaling these disk models to 800 pc, we found that the mass accretion rate should be of the order of \( M \approx 10^{-7} \) to \( 10^{-6} M_\odot \) yr\(^{-1}\). Consequently, we generated accretion disk models for larger mass accretion rates using TLUSTY and SYNSPEC (Hubeny 1988; Hubeny & Lanz 1995) as described in the previous section.

We chose a WD mass \( M_{\text{wd}} = 0.7 M_\odot \), with a radius \( R_{\text{wd}} = 8500 \) km, and an inclination \( i = 50^\circ \). The disk extends to where its temperature \( T_{\text{disk}} \) drops to \( \approx 3500 \) K. For a given mass accretion rate the disk model scales to a given distance.

To match a distance of 800 pc we obtained that the mass accretion rate has to be \( M = 1.8 \times 10^{-7} M_\odot \) yr\(^{-1}\). This disk model has an inner radius of 850 km and an outer radius of \( \sim 1 \) million km, with solar abundances. The inclination of the system has been set to \( i = 50^\circ \). The FUSE spectrum is in red (with masked portions in blue), and the disk model (including ISM absorption) is drawn with the solid black line (the model without the ISM absorption is drawn with the dashed black line).

Figure 3. Accretion disk model fit to the FUSE spectrum of AG Peg. The accreting WD mass has been set to \( M_{\text{wd}} = 0.7 M_\odot \), with a radius \( R_{\text{wd}} = 8500 \) km. The disk model has a mass accretion rate \( M = 1.8 \times 10^{-7} M_\odot \) yr\(^{-1}\), an inner radius of 850 km, and an outer radius of \( \sim 1 \) million km, with solar abundances. The inclination of the system has been set to \( i = 50^\circ \). The FUSE spectrum is in red (with masked portions in blue), and the disk model (including ISM absorption) is drawn with the solid black line (the model without the ISM absorption is drawn with the dashed black line).

We note that even if we increase the mass accretion to \( M = 1 \times 10^{-6} M_\odot \) yr\(^{-1}\), the fit in the short wavelength range of FUSE is not as good as for the single hot WD model fit (Figure 2), as the model is deficient in flux.

We also tried combined WD + accretion disk models where the WD contributes a significant fraction of the flux, and the result was intermediate between the single WD models and the single disk models. Namely, the WD+disk models were improved over the single disk models, but did not provide a fit as good as the single WD models.
4. Discussion and Conclusions

On the basis of fitting very hot NLTE white dwarf photosphere models to the FUSE spectrum of AG Peg in quiescence and comparing with the best-fitting high $M$ ($10^{-7}$–$10^{-6}$ $M_{\odot}$ yr$^{-1}$) disk models, we report evidence that a very hot white dwarf with a temperature $T_{wd} = 150,000$ K dominates the entire FUSE wavelength range while an accretion disk with high $M$ gives a poorer fit in the short wavelengths ($\lambda < 960$ Å). This hot WD model has a gravity log($g$) $\sim$ 6.5, and the distance of 800 pc gives a scaled radius $R_{wd} \sim 43 \times 10^9$ cm ($\sim$0.06 $R_{\odot}$). The addition of an accretion disk only degrades the hot WD fit and implies that the WD is possibly overshadowing the disk.

It is interesting to compare our results on the hot component of AG Peg using FUSE spectra with a recent multiwavelength analysis by Skopal et al. (2017). They computed the peak luminosity of the June 2015 Z-And-like outburst of AG Peg to be $(2–11) \times 10^{37}$ erg s$^{-1}$ (for a distance of 0.8 kpc). They estimated that the white dwarf had to be accreting at $\sim 3 \times 10^{-7} M_{\odot}$ yr$^{-1}$, which they claimed exceeds the stable burning limit by which one assumes is the steady-state limit in which the accreted material is burned at the same rate that it accretes.

Our best-fitting NLTE high-gravity photosphere models were fit best with $T_{wd} = 150,000$ K, which is in agreement with the modeling of the UV/Optical continuum in quiescence from 1993 to 1996 (Skopal et al. 2017), and considerably lower than the hot component of AG Peg in outburst. The luminosity of our best-fit model also agrees with the quiescent luminosity estimate of Skopal et al. (2017). During the outburst, the effective radius of the hot component, $R_{\text{he}}$, varies between $\sim 0.09 R_{\odot}$ and $\sim 0.15 R_{\odot}$. The accretion rate they found, on average, was a factor of 2–3 larger during the outburst than during quiescence.

Note that Mürset et al. (1991) obtained temperatures and luminosities of the hot component in symbiotic novae using the modified Zanstra method. For AG Peg they obtained a hot component temperature between 95,000 and 100,000 K during the decline phase. However, we note that Mürset et al. (1991)
adopted a shorter distance (650 pc versus 800 pc) as well as a smaller $E(B-V) = 0.05$ (versus 0.10), which leads to a lower effective temperature for the hot component (because the UV continuum is less steep and has a much lower luminosity than that derived by Kenyon et al. 1993, 2001). Other attempts assumed black bodies to fit the SED of AG Peg encompassing the optical all the way to the IUE SWP range. These efforts obtained temperatures significantly cooler than the temperature of 150,000 K that we obtained from the best-fitting NLTE model atmosphere to the $FUSE$ spectrum.

It is interesting to note that our method of deriving the temperature of the hot component gives a temperature ($\log(T_{\text{eff}}) = 5.17$) similar to the temperature obtained from an analysis of the optical H I and He II lines (see Figure 5 in Kenyon et al. 2001), but much higher than the temperature derived from an analysis of the UV lines or the UV continuum.

The luminosity we derive here is significantly larger than that derived by these three methods (Kenyon et al. 2001). In the present work we dereddened the $FUSE$ spectrum using the extinction law given by Fitzpatrick & Massa (2007), while Kenyon et al. (2001) adopted Mathis’ (1990) extinction curve (which itself is the Cardelli et al. 1989 extinction law). In the FUV region the difference between Cardelli et al. (1989) and Fitzpatrick & Massa (2007) extinction laws increases with decreasing wavelength and can gives different results (see, e.g., Selvelli & Gilmozzi 2013). It is possible that the difference in the extinction laws in the shortest wavelengths of $FUSE$ increased the flux (in the dereddened spectrum) to better match a 150,000 K model, because the difference between the 100,000 K model and the 150,000 K model is very small. A temperature closer to 100,000 K gives a luminosity in better agreement with the quiescent luminosity.

It is also possible that the observed difference in temperature is due to a real change in the WD surface temperature. The short wavelength range of the $FUSE$ spacecraft down to the Lyman limit probes the radiation from the innermost disk/ boundary layer/white dwarf, which likely accounts for the higher temperature that we obtain. No previous attempts to derive a temperature for the hot component in AG Peg covered a wavelength range down to the Lyman Limit.

Overall, our result suggests the possibility that the system is dominated by a very hot, low gravity white dwarf. This is similar to our analysis of the $FUSE$ spectrum of the S-Type symbiotic star RW Hydrae (Sion et al. 2017), which indicates that it also contains a very hot, bare white dwarf with no evidence of an accretion disk. An important question now is whether the Z-And-type outbursts are due to bursts of accretion from the M3/4III companion or if they are also thermonuclear powered like the 1850 nova outburst.

On the other hand, the actual structure of an accretion disk surrounding a hot stellar component in symbiotic binary is poorly understood compared to cataclysmic variables. First, the scale of a symbiotic binary relative to a cataclysmic variable is vastly larger and second, the mass transfer occurs via a red giant donor that may or may not fill its Roche lobe. This points to the possibility that the disk models might be different than the standard disk model. 3D hydrodynamic model simulations of symbiotic binaries (de Val-Borro et al. 2009, 2017) reveal that a disk-like structure resembling a steady-state disk does appear to form, but the thin disk approximation may break down in symbiotics. Given the uncertainty in what a true symbiotic accretion disk would look like, and that a very hot low gravity degenerate star dominates the FUV flux, the presence of a steady-state (standard) accretion disk cannot be summarily ruled out or denied.

However, we note that for the hot WD to contribute a significant fraction of the total flux to the $FUSE$ spectrum, in addition to that of an accretion disk, its emitting photosphere radius has to be inflated (Section 3.1). With a radius of the order of $R_{\text{WD}} \sim 0.05 R_\odot$, rather than $R_{\text{WD}} \sim 0.01 R_\odot$, the accretion disk temperature drops significantly (Godon et al. 2017). For example, at a mass accretion rate of $M = 10^{-7} M_\odot \text{yr}^{-1}$ the peak temperature in the disk reaches 103,000 K if $R_{\text{WD}} = 8500$ km (which is the radius of a $\sim 30,000$ K WD of mass $0.7 M_\odot$). However, for a WD radius of $R_{\text{WD}} = 35,000$ km $\sim 0.05 R_\odot$, the peak temperature of such a disk drops to 36,500 K. At a mass accretion rate of $M = 10^{-6} M_\odot \text{yr}^{-1}$, the disk peak temperature drops from $\sim 171,000$ to $\sim 65,000$ K. In both cases ($M = 10^{-7} M_\odot \text{yr}^{-1}$ and $M = 10^{-6} M_\odot \text{yr}^{-1}$) the disk will contribute little flux to the $FUSE$ spectrum if $R_{\text{WD}} = 0.05 R_\odot$. As the accretion luminosity decreases like $\propto 1/R_{\text{WD}}$, so does the disk luminosity, and as long as the WD radius remains inflated it will dominate the FUV spectrum.

This work is supported by funding from the National Aeronautics and Space Administration (NASA) under grant number NNX17AF36G issued through the Office of Astrophysics and Data Analysis Program (ADAP) to Villanova University. This study has also been supported in part by the National Science Centre, Poland, grant OPUS 2017/27/B/ ST9/01940. P.G. is pleased to thank William (Bill) P. Blair at the Henry Augustus Rowland Department of Physics and Astronomy at the Johns Hopkins University, Baltimore, Maryland, USA, for his kind hospitality. We made use of online data from the AAVSO and we are thankful to the AAVSO and its members worldwide for their constant monitoring of CVs and for making their data public.

Facility: $FUSE$.

Software: IRAF (v2.16.1, Tody (1993)), Thusty (v203) Synspec (v48) Rotin(v4) Disksyn (v7) (Hubeny & Lanz 2017a, 2017b, 2017c), PGPLOT (v5.2), Cygwin-X (Cygwin v1.7.16), xmgrace (Grace v2), XV (v3.10).

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References
Akras, S., Guzman-Ramirez, L., Leal-Ferreira, M. L., & Ramos-Larios, G. 2019, ApJS, 240, 21
Bailer-Jones, C. A. 2015, PASP, 127, 994
Brown, A. G. A., Vallenari, A., Prusti, T., et al. 2018, A&A, 616, 1
Cardelli, J. A., Clayton, G. C., & Mathis, J. S. 1989, ApJ, 345, 245
Darnley, M. J., Hounsell, R., Godon, P., et al. 2017, ApJ, 849, 96
de Val-Borro, M., Karovska, M., & Sasselov, D. 2009, ApJ, 700, 1148
de Val-Borro, M., Karovska, M., Sasselov, D. D., & Stone, J. M. 2017, MNRAS, 468, 3408
Dixon, W. V., Sahnow, D. J., Barrett, P. E., et al. 2007, PASP, 119, 527
Eriksson, M., Johansson, S., & Wahlgren, B. M. 2006, A&A, 451, 157
Eyer, L., Gu, P., Distefano, E., et al. 2018, A&A, in press (arXiv:180409382)
Fekel, F., Francis, C., Joyce, R. E., et al. 2000, AJ, 119, 1375
Fitzpatrick, E. L., & Massa, D. 2007, ApJ, 663, 320
Godon, P., Sion, E. M., Balman, S., & Blair, W. P. 2017, ApJ, 846, 52
Godon, P., Sion, E. M., Barrett, P. E., & Linnell, A. P. 2009, ApJ, 699, 1229
