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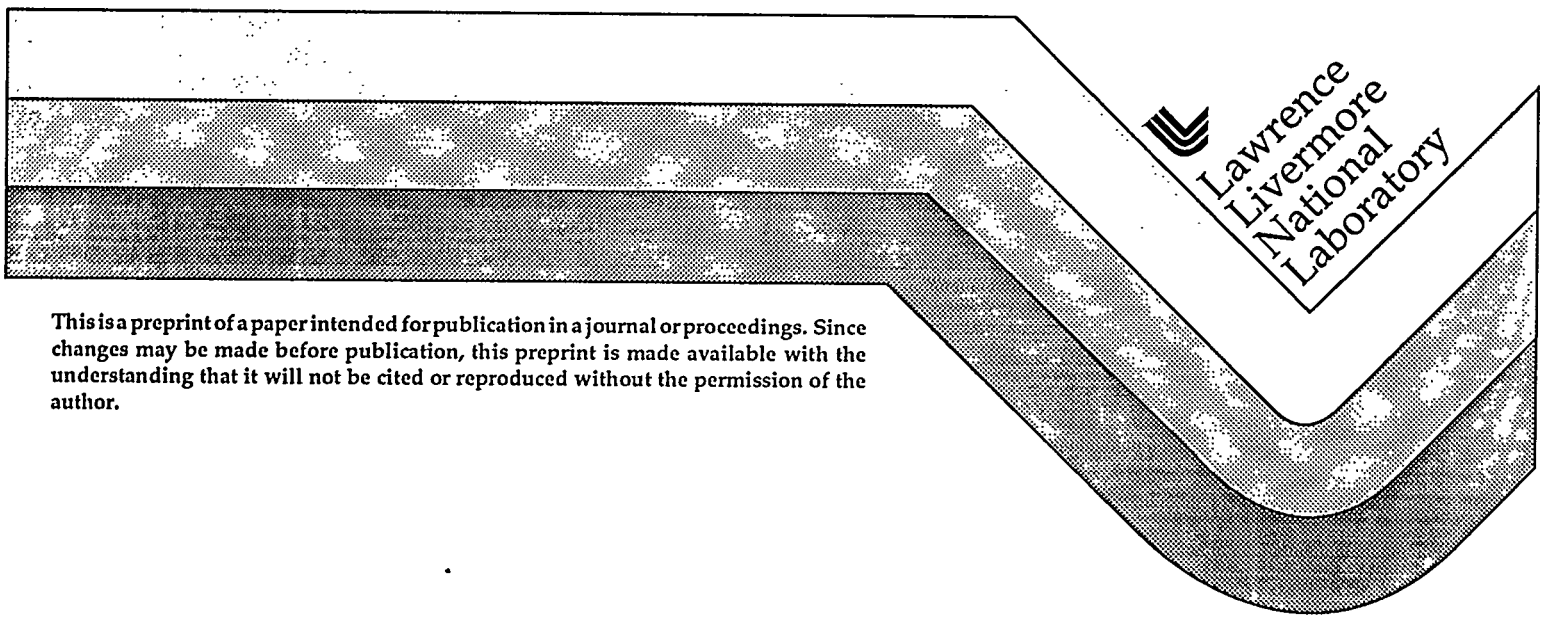

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ORFEUS and EUVE Observations of AM Herculis

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Abstract. We describe the results of spectroscopic observations of AM Her in a high optical state obtained in 1993 September with the *ORFEUS*[1] and *EUVE* satellites.

1. ORFEUS Far-UV Spectra

Far-UV spectra of AM Her in a high optical state were obtained in 1993 September with the University of California, Berkeley (UCB) spectrometer aboard the *ORFEUS* telescope. The UCB spectrometer has a spectral resolution $\lambda/\Delta\lambda \approx$ 3000 and covers the 390–1170 Å bandpass, but interstellar absorption leaves no detectable flux below the Lyman limit. Details about the UCB spectrometer are contained in Hurwitz & Bowyer (1991); the *ORFEUS* telescope and mission are described in Grewing et al. (1991).

Spectra of AM Her were acquired during the intervals 04:19:40–04:36:26 UT on September 16 and 08:34:03–09:09:06 UT on September 17 of 1993. The corresponding magnetic phases are 0.75–0.84 and 0.88–1.07 according to the linear polarization ephemeris of S. Tapia (quoted in Heise & Verbunt 1988). Figure 1 shows the first spectrum binned to a resolution of 0.28 Å. The main spectral features are the O VI doublet, C III λ977, and He II λ1085 (Balmer γ). The bright C III λ1176 multiplet, which is detected by *IUE*, is at the very end of the spectrum. At the full spectral resolution of the instrument, the O VI doublet shows broad and narrow components similar to that of the optical emission lines. The intensity ratio of the narrow component of the O VI doublet is $\sim$ 1.3:1, much closer to the optically thick limit of 1:1 than the optically thin ratio of 2:1.

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[1]Orbiting and Retrievable Far and Extreme Ultraviolet Spectrometers; a collaboration of the Astronomical Institute of the University of Tübingen, the Space Astrophysics Group, University of California, Berkeley, and the Landessternwarte Heidelberg.

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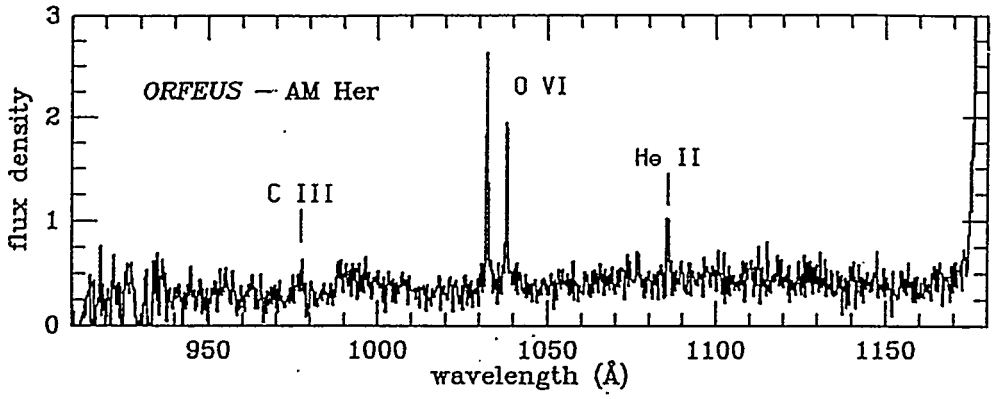

Figure 1. *ORFEUS* spectrum at magnetic phase 0.75–0.84. Units of flux density are 10^{-12} erg cm^{-2} s^{-1} Å^{-1}.

The simultaneous measurement of the He II λ1085 and O VI line strengths allows important constraints to be placed on the physical conditions of the narrow and broad line-emitting regions in AM Her. We first determine the total luminosity of the ionizing flux from the strength of the He II λ1085 narrow component (for details, see Raymond et al. 1995). Assuming case B recombination, the number of He II λ1085 recombinations $s^{-1} = 4\pi d^2 (F_{\lambda 1085}/E_{\lambda 1085})(\alpha_B/\alpha^{\rm eff}_{\lambda 1085})$, where $F_{\lambda 1085}$ is the observed flux in the He II λ1085 line. The number of He II ionizations $s^{-1} = \int_{54\,{\rm eV}}^{280\,{\rm eV}} [F(E)/E]dE = L/\langle E_{\rm ion}\rangle$, where $F(E)$ is the spectral energy distribution of the ionizing radiation and the lower and upper bounds on the integral correspond to the ionization energy of He II and the K edge of carbon, respectively. For a blackbody spectral energy distribution at a temperature of ~ 30 eV, $\langle E_{\rm ion}\rangle \sim 130$ eV. Accounting for the solid angle subtended by the secondary and the geometric foreshortening of the accretion spot, the luminosity is $L = 4\pi d^2 F_{\lambda 1085}(2\pi/\Omega \sin\beta\cos\psi)(\alpha_B/\alpha^{\rm eff}_{\lambda 1085})(\langle E_{\rm ion}\rangle/E_{\lambda 1085}) \sim 6\times 10^{33}$ erg s^{-1}.

With this information, we are able to determine the physical conditions in the narrow and broad emission-line regions. Given the observed peak flux density of the narrow component of O VI λ1032 and the assumption that this transition is fully optically thick, the effective temperature of the narrow emission-line region is $T \approx 16{,}000$ K. Since O VI is not fully optically thick, and since the lines are broadened by the rotation of the companion, the temperature must be somewhat higher. In gas illuminated by a mixture of hard and soft X-rays, O VI exists over a range of ionization parameters $\xi \approx 30$–60, peaking at $\xi \approx 35$ (Kallman & McCray 1982). The temperatures corresponding to these ionization parameters are $T \approx 20{,}000$–$100{,}000$ K and $T \approx 20{,}000$ K, respectively. Based on its small velocity width and on the phase of its radial velocity curve, the narrow-line region is associated with the heated face of the secondary; by a similar argument, the broad-line region is associated with the gas stream. The density of the narrow-line region is $n_{\rm nlr} = L\sin\beta\cos\psi/\xi r^2_{\rm nlr} \sim 4\times 10^{10}$ cm^{-3}, where $r_{\rm nlr} = 5.3\times 10^{10}$ cm is the distance from the white dwarf to the face of the secondary. The density of the broad-line region must be higher because it is much closer to the white dwarf: $n_{\rm blr} = L/\xi r^2_{\rm blr} \sim 2\times 10^{12}\ (r_{\rm blr}/10^{10}\ {\rm cm})^{-2}$ cm^{-3} $\sim 100\times n_{\rm nlr}$.

2. EUVE Extreme-UV Spectra

Extreme-UV observations of AM Her in a high optical state were obtained with the *EUVE* satellite approximately one week after the *ORFEUS* observations. The source was detected in the Deep Survey (DS) instrument, a photometer sensitive between $\sim$ 70–200 Å, and in the Short Wavelength (SW) spectrometer, which has a spectral resolution $\lambda/\Delta\lambda \approx 200$ and covers the 70–200 Å bandpass, but interstellar absorption leaves no detectable flux longward of $\sim$ 130 Å. Details about the *EUVE* satellite are contained in Bowyer & Malina (1991) and Bowyer et al. (1994).

Photometric and spectroscopic observations of AM Her were acquired between 18:05:41 UT on September 23 and 12:16:39 UT on September 28 of 1993. In total, 36.9 3.09 hr orbits of AM Her were covered, though the satellite takes data for only $\sim 1/3$ of each 1.58 hr orbit, and the near 2:1 commensurability of the binary and satellite orbits results in only a slow (2.3%) progression of the binary phase interval covered during each satellite orbit. The mean count rate in the Deep Survey instrument was ~ 3.3 counts s^{-1}, hence allowing the EUV light curve of individual orbits of AM Her to be examined, but we have to date examined only the binary phase-folded EUV light curve and spectra.

The EUV light curve measured by the DS instrument shows the (partial) eclipse of the accreting pole by the body of the white dwarf during linear polarization phases $\Phi \approx 0.12 \pm 0.10$, a bright phase (mean count rate ~ 5.8 s^{-1}) between $\Phi \approx 0.3$–0.7, and a relatively dim phase (mean count rate ~ 2.9 s^{-1}) between $\Phi \approx 0.7$–1.0. We accumulated SW spectra in each of these three light curve phases, plus the phase of egress from eclipse between $\Phi \approx 0.2$–0.3. Dividing the spectra from the dim, egress, and eclipse phases by the spectrum from the bright phase, it is clear that (modest) spectral variations accompany the count rate variations recorded by the DS instrument. To quantify this result, we fit blackbody spectra modified by interstellar absorption to the SW spectra from each of the four above-mentioned EUV light curve phases. Due to space limitations, we present the results for only the bright phase of the EUV light curve (for further details, see Paerels et al. 1995).

The SW spectrum from the bright phase of the EUV light curve is shown in Figure 2 with the best blackbody fit superposed (*dotted curve*). The parameters of the fit are: $kT = 17.6$ eV and $N_{\rm H} = 8.8 \times 10^{19}$ cm^{-2}. The low temperature and high column density of this fit relative to previous *Einstein* OGS (Heise et al. 1984) and *EXOSAT* TGS (Paerels et al. 1994) fits to the X-ray spectrum of AM Her is due to the flattening of the SW spectrum below $\sim$ 85 Å. Motivated by the residuals of this fit to the observed spectrum and by the comparatively low temperature and high column density of the fit parameters, we modified the blackbody spectrum via the bound-free opacity ($\propto \exp\{-\tau_0[\lambda/\lambda_0]^3\}$ below λ_0) of two absorption edges at 85.2 and 78.5 Å; the wavelengths of the ground state ($2s^2 2p$) and first excited state ($2s2p^2$) of Ne VI. The resulting best-fit spectrum is shown superposed on the SW spectrum in Figure 2 (*full curve*). The parameters of the fit are: $kT = 24.5$ eV and $N_{\rm H} = 7.1 \times 10^{19}$ cm^{-2} (comparable to the *EXOSAT* TGS results), $\tau_{\lambda 85.2} = 0.16$, and $\tau_{\lambda 78.5} = 0.22$. The fractional emitting area and bolometric luminosity of this fit are $f = 0.002$ and $L_{\rm soft} = 3.2 \times 10^{33}$ erg s^{-1} ($d = 75$ pc), respectively. The phase-averaged 1–10 keV

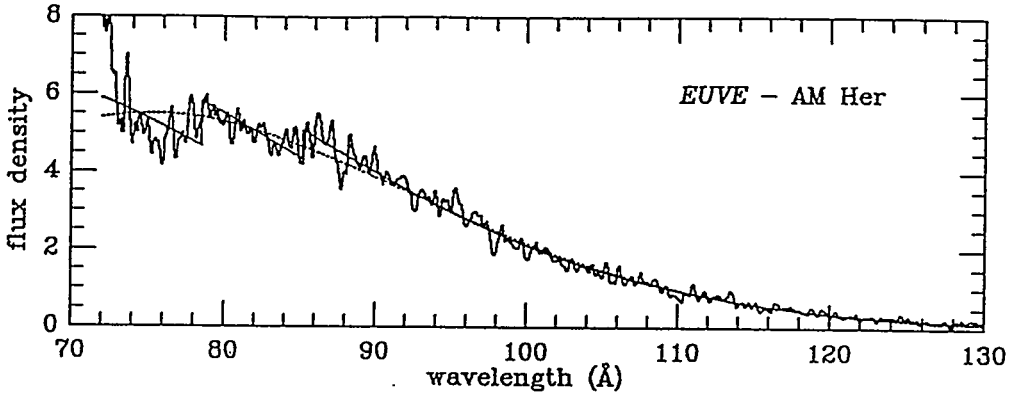

Figure 2. *EUVE* spectrum of the bright phase.. The best-fit blackbody (*dotted curve*) and blackbody with edges (*full curve*) are superposed. Units of flux density are 10^{-12} erg cm^{-2} s^{-1} Å^{-1}.

luminosity measured nearly simultaneously by *ASCA* is $L_{\rm hard} = 3 \times 10^{31}$ erg s^{-1} (Osborne 1995, personal communication). Accounting for the duration and relative brightness of the bright phase of the EUV light curve, the ratio of the soft to hard X-ray luminosities of AM Her is therefore $\sim$ 60. This is the famous "soft X-ray problem" (see, e.g., Beuermann & Schwope 1994), present with a vengeance in AM Her despite its relatively low magnetic field strength.

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