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Letter to the Editor

An active K0 IV–V star and a hot white dwarf (EUVE J0702+129) in a wide binary

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Abstract. We present far ultraviolet and optical spectroscopy of the *Extreme Ultraviolet Explorer* (*EUVE*) survey source EUVE J0702+129 revealing a composite K0 star plus DA white dwarf spectrum. The *International Ultraviolet Explorer* spectra show continuum emission from a hot white dwarf ($T_{\rm eff}$ = $30-40,000$ K) and a rising contribution from the K0 star at $\lambda \geq 2500$ Å. High resolution optical spectroscopy uncovers a high level of activity with strong Hα and Ca H&K emission; application of the Wilson-Bappu relation indicates that the secondary star is slightly above the main sequence (K0 IV–V). Both objects are found at a distance of ~ 130 pc and they likely constitute a physical pair. The EUV emission is dominated by the white dwarf, but the late-type star certainly contributes at higher energy. An interesting parallel is drawn with other DA+K0 pairs with moderately active secondaries such as HD 18131 and HR 1608. The present discovery as well as other recent ones demonstrate the existence of a large population of white dwarfs hidden by evolved companions (III–IV).

Key words: binaries: general — Stars: chromospheres — Stars: evolution — white dwarfs — Stars: individual: EUVE J0702+129

1. Binaries in the EUV-selected white dwarf population

Recent extreme ultraviolet (EUV) all-sky surveys (*EUVE*, Bowyer et al. 1996; *ROSAT* WFC, Pye et al. 1995) revealed several new white dwarfs paired with a luminous secondary star. Landsman, Simon, & Bergeron (1993) and Vennes et al. (1995) report on two hydrogen-rich (DA) white dwarfs (EUVE J0459–102 and EUVE J0254–053) associated with the bright K0 IV stars HR 1608 and HD 18131. Both systems, comprising an evolved secondary, may help constrain initial-to-final-mass relations for white dwarf stars. Very little is known of the secondary stars themselves, and further studies should be aimed at identifying intrinsic properties such as the level of activity, rotation period, and abundance; we need to search for evidence of past interaction with the post-AGB primary. Kellet et al. (1995) found possible evidence of such interactions in the fast rotating secondary star of the K0V+DA binary BD + 08°102. Jeffries, Burleigh, & Robb (1996) uncovered similar behavior in the K2V star 2RE J0357+283; Jeffries & Stevens (1996) theorize that accretion from the red giant wind may possibly increase the rotational velocity of the secondary star up to $\sim 100\,{\rm km\,s^{-1}}$.

We initiated a systematic survey of EUV-selected G and K stars at ultraviolet wavelengths using the *International Ultraviolet Explorer* (*IUE*). We present in § 2 our far ultraviolet (FUV) spectra and discovery of a new DA white dwarf, and we present high- and low-dispersion optical spectroscopy of the secondary star. We discuss the properties of the white dwarf in § 3, and some characteristics of the binary and its secondary star in § 4.

2. Ultraviolet and optical observations

A K0 star (GSC 00757-01608) was tentatively associated with a new EUV source (EUVE J0702+129, Bowyer et al. 1996; 2RE J0702+125, Pye et al. 1995). GSC 00757-01608 is, in fact, a double star composed of a bright K0 star and a K4 V star a few arcseconds to the NNE and $3\overset{\rm m}{.}5$ fainter. The source of EUV emission was presumed to lie with the K0 star, and Bowyer et

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al. estimated count rates of C_{100} = 124 ± 15 counts ks^{-1}, and C_{200} = 28 ± 13 counts ks^{-1}. Pye et al. estimated count rates of C_{S1} = 74 ± 7 counts ks^{-1}, and C_{S2} = 112 ± 11 counts ks^{-1}. *IUE* spectra of the bright star (m_V = 10.0 ± 0.3, from GSC) were obtained by M. Garcia-Vargas (Vilspa service observations) on 1995 November 11 (Table 1). The large aperture and low dispersion gratings were used; the short wavelength spectrum (swp56186llg) is unfortunately saturated between 1234 and 1412 Å. A second exposure could not be scheduled. Two long wavelength spectra (lwp31688llg, lwp31689llg) were acquired; the first exposure shows a spurious feature near 3120 Å and was discarded. The spectra were processed with the standard "NEWSIPS" reduction (Nichols & Linsky 1996).

Table 1. Far ultraviolet and optical observation log.

Date (UT)	JD (2450000+)	Instrument
1995 Nov 11	32.9904	*IUE* (swp56186llg)
1995 Nov 11	33.0676	*IUE* (lwp31688llg)
1995 Nov 11	33.1252	*IUE* (lwp31689llg)
1995 Nov 28	49.9189	Lick Hamilton
1995 Nov 28	49.9622	Lick Hamilton
1995 Nov 29	50.9302	Lick Hamilton
1995 Nov 29	51.0437	Lick Hamilton
1995 Nov 30	51.8513	Lick Hamilton
1995 Nov 30	51.9470	Lick Hamilton
1995 Nov 30	51.9904	Lick Hamilton
1995 Dec 24	75.8567	Lick Hamilton
1996 Jan 06	88.9097	MDM MarkIII
1996 Oct 22	379.0084	Lick Hamilton
1996 Nov 12	399.8832	Lick Hamilton
	399.9270	Lick Hamilton
1996 Dec 17	434.9105	Lick Hamilton
	434.9956	Lick Hamilton
1996 Dec 18	435.9090	Lick Hamilton
	435.9973	Lick Hamilton

Following the discovery of a white dwarf companion to the K0 star in EUVE J0702+129, we monitered the system at Lick Observatory using the coudé auxiliary telescope (CAT) and the Hamilton echelle spectrograph (Vogt 1987) in 1995 November and December, and 1996 October, November, and December (Table 1). We used a 2048 × 2048 CCD binned 2 × 2 with a dispersion of 0.033 Å pixel^{-1} at Ca H&K and 0.054 Å pixel^{-1} at Hα; the spectral resolution is 7.5 km s^{-1}. We then observed the K0 star with the Michigan-Dartmouth-MIT 2.4m telescope on 1996 January 6. We used the Mark III spectrograph and a Tek 1024 × 1024 CCD with a wavelength coverage of 3600–6000 Å at 5 − 6 Å resolution. The combined optical and ultraviolet spectrum is a composite of a K0 star and a hot DA white dwarf star (Fig. 1).

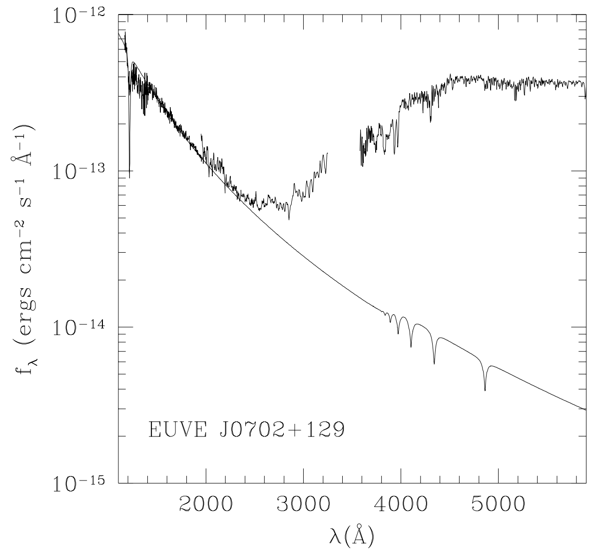

Fig. 1. The K0+DA binary EUVE J0702+129 between λ = 1150 and 5850 Å, and a representative DA white dwarf synthetic spectrum.

3. The DA white dwarf

We determine the properties of the white dwarf using the Lyα line profile and the FUV continuum. A grid of FUV synthetic spectra, based on hydrogen line-blanketed model atmospheres, was computed using Schoning & Butler's (1995) stark-broadened H I line profiles. We then normalized the synthetic spectra to the observed spectrum between 1500 and 1800 Å. The fit is restricted to wavelengths between 1150 and 1310 Å and excludes bad pixels. Despite the low quality of the spectrum, a correlation holds between $T_{\rm eff}$ and $\log g$. Figure 2 (*top*) shows the formal solution, but a wide range of acceptable solutions is also defined by the 1 σ countour (66%, Fig. 2 *bottom*). Table 2 summarizes the properties of the white dwarf; the mass (M) and absolute magnitude (M_V) are extracted from the measured temperature and surface gravity using Wood's (1995) mass-radius relation. An estimate of the distance (d) is also given using the inferred apparent magnitude V (m_V).

Additional properties of the white dwarf are obtained from an analysis of the EUV count rates. Figure 3 shows solutions to the EUV measurements in the ($T_{\rm eff}$, n_H^{ISM}) plane assuming a pure hydrogen composition. Upper limits (99%) to the temperature and neutral hydrogen column density in the local interstellar medium (ISM) are set at 41,000 K and $n_H^{ISM} \leq 3.0 \times 10^{19}$ cm^{-2}, respectively. A joint FUV/EUV solution (1 σ), assuming a pure hydrogen atmosphere, gives $T_{\rm eff}$= $27 - 36,000$ K and $\log g <$ 8.8. Higher temperatures imply atmospheric impurities, such as helium. Therefore, assuming a pure hydrogen atmosphere, the white dwarf is located at a distance of d > 70 pc and the neutral hydrogen column density in the ISM is $n_H^{ISM} \leq 1.7 \times 10^{19}$ cm^{-2}. The low interstellar column density excludes appreciable interstellar reddening.

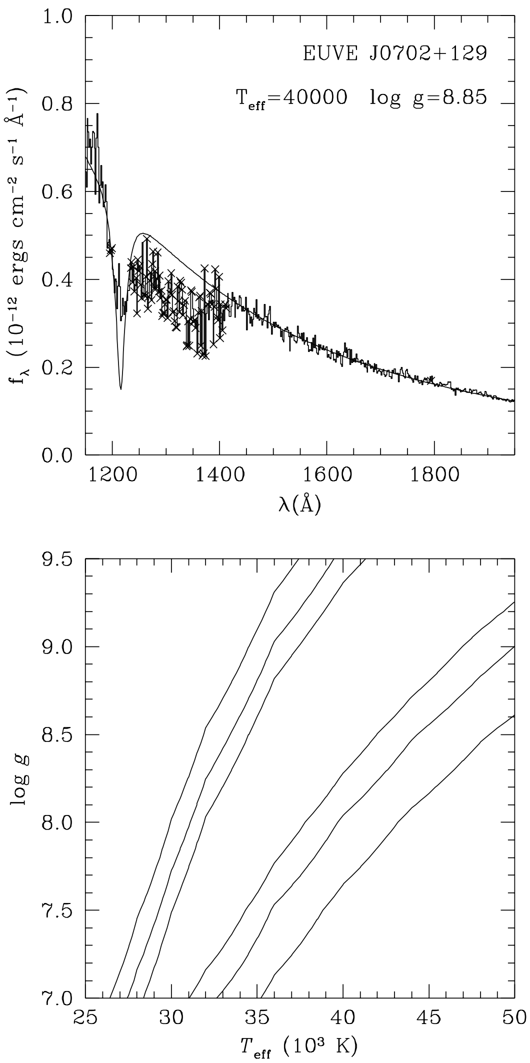

Fig. 2. (*top*) Far ultraviolet spectroscopy of the hot white dwarf in the binary EUVE J0702+129. The red wing of Lyα was unfortunately saturated, but the continuum at longer wavelengths and the blue wing of Lyα are well exposed. (*bottom*) χ^2 confidence contours at 66%, 90%, and 99% in the ($T_{\rm eff}$, $\log g$) plane. A narrow correlation holds between $T_{\rm eff}$ and $\log g$. Bad pixels are marked with crosses.

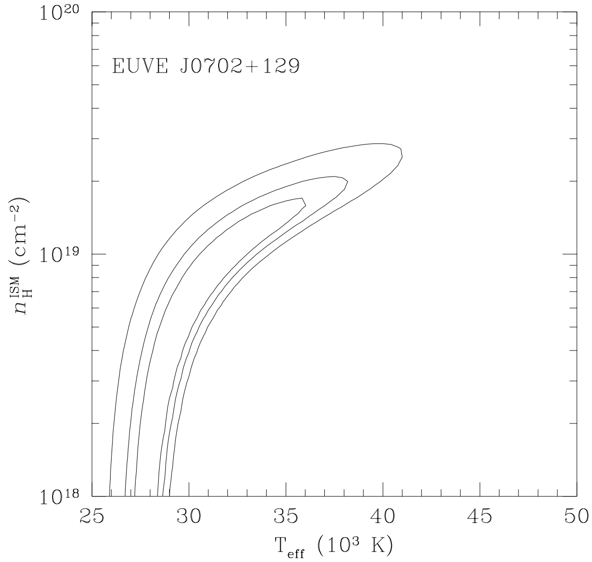

Fig. 3. Analysis of *EUVE* and *ROSAT* WFC count rates using pure hydrogen model atmospheres. Confidence contours are given at 68%, 90% and 99%. A joint FUV/EUV solution (see Fig. 2) suggests a temperature of $32-36,000$ K, a surface gravity $\log g$= $7.7-8.6$, and a pure hydrogen atmosphere.

Table 2. Range of properties of the white dwarf.

$\log g$	$T_{\rm eff}$ (K)	M ($M_\odot$)	$M_{\rm V}$	$m_{\rm V}$	d (pc)
7.0	30000	0.22	8.68	14.83	170
7.5	32000	0.40	9.13	14.92	144
8.0	34500	0.62	9.77	15.00	111
8.5	37500	0.93	10.45	15.07	84
9.0	41000	1.21	11.30	15.14	59

4. The binary EUVE J0702+129

High-resolution optical spectroscopy offers two important insights into binary properties. Figure 4 shows the Hα line in emission, indicating that the K0 star is chromospherically active. Narrow photospheric lines place an upper limit of 5 km s^{-1} on the rotational velocity. Monitoring over time periods of hours, days, and months (Table 1) also shows no evidence of radial velocity (heliocentric) variations: $< v_{\rm r} >= -10.5\pm1.1$ km s^{-1}. A study of the Ca H&K lines and a comparison with other K0+DA binaries (HR 1608 and HD 18131) further constrain the properties of the K0 star (Figure 5). The K0 star in EUVE J0702+129 appears more active than its counterparts in the two other systems. Moreover, the Ca K full width at half maximum (FWHM) is 34 ± 3 km s^{-1} compared to 52 km s^{-1} for both HR 1608 and HD 18131; application of the Wilson-Bappu relation for active stars (see Montes et al. 1994) implies an absolute magnitude $M_{\rm V}$ = 4.7 ± 0.4 for EUVE J0702+129 and ~ 2.0 for the two other systems. All three K0 stars are evolved; according to this relation, EUVE J0702+129 belongs to the luminosity class IV–V, and HR 1608 and HD 18131 to the class III–IV.

Voges et al. (1996) find a strong X-ray source near the position of EUVE J0702+129 ($C_{\rm PSPC}$ = 0.77 ± 0.05 counts s^{-1}) with a hardness ratio *HR1*= -0.73. The hardness ratio implies a count rate of 0.10 counts s^{-1} in the $0.52-2.01$ keV band. White dwarfs do not emit at high energy, their range extending to only about 0.25 keV; the hard PSPC band count rate is dominated by the late-type companion. Assuming a hydrogen column density of 1.2×10^{19} cm^{-2} and a distance of 130 pc, we generate an emission measure and a model spectrum using Monsignori-Fossi & Landini (1994) line emissivities. The model spectrum was then folded with the PSPC soft band (0.11–0.41 keV) effective areas,

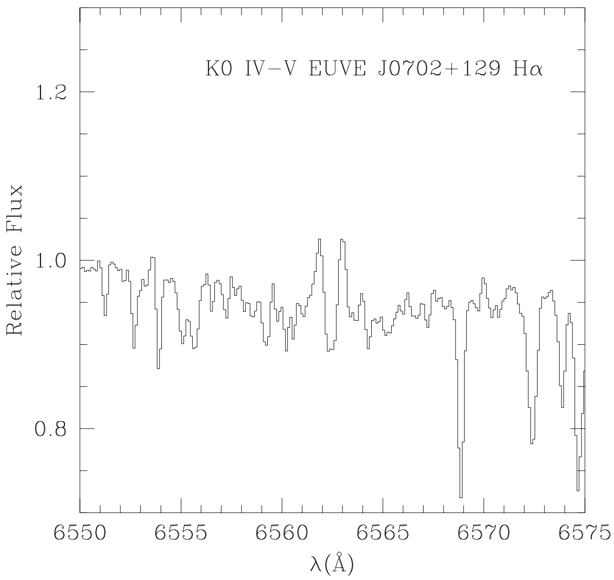

Fig. 4. Lick Hamilton echelle spectrum of the Hα emission line in the K0 star. Bad columns are excluded from the plot.

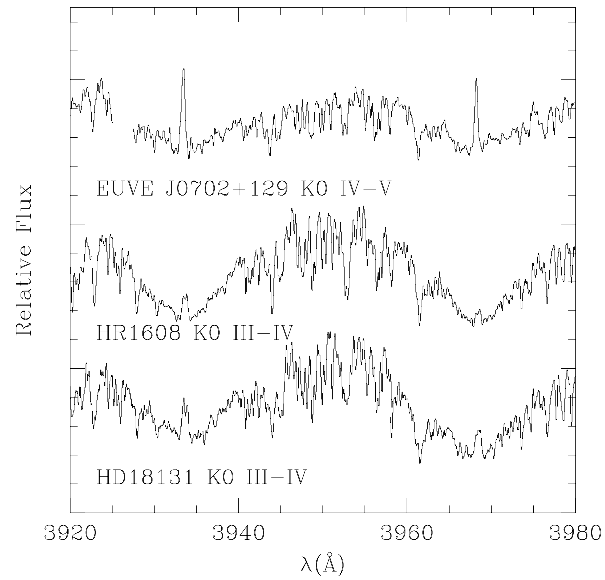

Fig. 5. Lick Hamiton echelle spectra of Ca H&K lines of the K0 star in EUVE J0702+129 compared to two K0 stars paired with hot DA white dwarfs (HR 1608 or EUVE J0459–102, and HD 18131 or EUVE J0254–053). Application of the Wilson-Bappu relation shows that all three stars are above the main sequence: EUVE J0702+129 in the IV–V luminosity class and the two others in the III–IV range.

which predicts a count rate of approximately 0.1 counts s^{-1}. The soft PSPC band is therefore dominated by the white dwarf.

In summary, we find the K0 IV–V star in EUVE J0702+129 at a distance of $91 - 145$ pc. The white dwarf and the K0 IV–V may form a physical pair, with the corollary that the white dwarf has a normal surface gravity ($\log g = 7.5 - 8.4$). Both objects are mingled in the LWP spatially resolved image implying a separation of less than $3''$. The white dwarf possibly has a pure hydrogen atmosphere, in agreement with an identified abundance pattern in hot DA white dwarfs. The K0 IV–V star is active and displays Ca H&K and Hα emission; *ROSAT* PSPC observations show a hard emission component, interpreted as coronal emission from the K0 star. If indeed the stars are associated, the absence of radial velocity variations on a timescale of one year would still imply a wide separation.

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