The *EUVE* Optical Identification Campaign II: Late-Type and White Dwarf Stars

N. CRAIG,[1] A. FRUSCIONE,[1] J. DUPUIS,[1] M. MATHIOUDAKIS,[1] J. J. DRAKE,[1] M. ABBOTT,[1] C. CHRISTIAN,[1] R. GREEN,[2] T. BOROSON,[2] AND S. B. HOWELL[3]

[1]Center for EUV Astrophysics, 2150 Kittredge Street, University of California, Berkeley, CA 94720-5030, USA

[2]NOAO, P.O. Box 26732, 950 N. Cherry, Tucson AZ 85726-6732, USA

[3]Planetary Science Institute, 620 N. Sixth Ave., Tucson, AZ 85705-8331, USA

We present optical identifications of nine previously unidentified extreme ultraviolet (EUV) sources discovered during the *Extreme Ultraviolet Explorer* (*EUVE*) satellite surveys. The all-sky survey detected four of the sources and the more sensitive deep survey detected the other five sources. Three of the four all-sky survey sources, EUVE_J1918+59.9, EUVE_J2249+58.5, and EUVE_J2329+41.4, are listed in present catalogs as having possible associations with optical counterparts but without spectral class. The first two of these sources are hot DA white dwarfs showing an optical spectrum with broad Balmer lines. The source EUVE_J2329+41.4 is listed as having a possible association with an unclassified M star. We show that a pair of dMe stars are actually optical counterparts located within the error circle of the *EUVE* source position. The EUVE_J2114+503 remains unidentified even though all the possible candidates have been studied. Based on the count rates we predict a fainter white dwarf or a cataclysmic variable counterpart for this candidate. All five sources discovered with the *EUVE* deep survey, EUVE_J0318+184, EUVE_J0419+217, EUVE_J2053-175, EUVE_J2056-171 and EUVE_J2233-096, have been identified as late-type stars. The spectral classes, distances, visual magnitudes, and estimated hydrogen column densities for these *EUVE* sources are presented.

1. Introduction

Opening new windows to the electromagnetic spectrum for astronomical study has traditionally resulted in exciting discoveries of new classes of astrophysical objects. The new types of objects are often relatively inconspicuous at optical and other wavelengths. Examples include the X-ray binaries and the radio galaxies. Consequently, the promise of such rewarding discoveries has formed a large part of the scientific motivation for building instruments to observe in hitherto unobserved bandpasses. The last major remaining window to the electromagnetic spectrum opened for astronomers was the extreme ultraviolet (EUV), a region roughly identified with the wavelength range 50-900 Å.

The *Extreme Ultraviolet Explorer* satellite (*EUVE*) has recently completed an all-sky survey between 60 and 740 Å and a deep survey (DS) between 67 and 364 Å in a 2° × 180° swath along the ecliptic (Bowyer & Malina 1991). The spectral region longward of 200 Å was surveyed for the first time by *EUVE*. To date, the surveys and subsequent observations have resulted in three published catalogs of approximately 500 EUV sources: the Bright Source List (BSL) of Malina et al. (1994); the First *EUVE* Source Catalog (FESC) of Bowyer et al. (1994); and the McDonald et al. (1994) catalog of serendipitous EUV sources detected in the first year of the Right Angle Program (RAP). It was found that the counterparts to about 80% of the sources in these catalogs could be readily identified from existing astronomical catalogs by searching for objects

S. Bowyer and R. F. Malina (eds.), Astrophysics in the Extreme Ultraviolet, 491–496.

thought to be EUV-bright and that coincided with the observed source positions (e.g., see Bowyer et al. 1994).

The EUV range provides coverage of a critically important and very wide temperature range, and contains plasmas with temperatures ranging from several 10^4 K to $\sim 20 \times 10^6$ K that produce photons in the EUV from many different elements in a wide variety of ionization stages. Consequently, about 50% of the EUV sources detected by *EUVE* were found to be active late-type stars (G, K, and M dwarfs and tidally interacting binaries) whose coronae have typical temperatures of $\sim 1 - 10 \times 10^6$ K (e.g., Pallavicini 1989). The other ~50% comprise primarily hot white dwarfs, with a smaller number of early-type stars, active galactic nuclei (AGN), planetary nebulae, cataclysmic variables (CVs), X-ray binaries, and even one or two novae and thermally emitting neutron stars.

In this paper, second in the *EUVE* Optical Identification Campaign series (c.f., Craig et al. 1995 and Mathioudakis et al. 1995b), we present optical identifications for nine of the *EUVE* sources that currently do not have identified optical counterparts.

1.1. *EUVE_J0318+184*

Six possible optical counterparts were observed in the field of this NOID type EUVE_J0318+184. The source which is 35″ from the *EUVE* position displays the spectrum the chromospheric activity indicators of Hα emission in (6563 Å) as well as Ca II H & K emission (3963 and 3934 Å, respectively). The spectral type of the counterpart is estimated as late K (dK5e–dK7e).

1.2. *EUVE_J0419+217*

EUVE_J0419+217 is detected in the DS Lexan filter (60−200 Å) and is listed as a possible counterpart in the BSL with spectral type A0sp and visual magnitude $m_v = 5.38$ with identification 56 Tau. The identification quality is Q = 2 indicating that this A0 type star is within the error circle. As the general criterion, if a detected object has a spectral class earlier than A0 and is brighter than $m_v = 5$, the emission could be a UV leak (Bowyer et al. 1994). Further investigation of this DS Lexan/B detection (Fig. 2*b* of McDonald et al. 1994) with 13 counts ks^{-1} is consistent with what one expect s from a UV leak for the given visual magnitude, $m_v = 5.38$.

Another possibility is that the A0 star 56 Tau has a visually unresolved hot white dwarf companion as the EUV source. This star is similar in brightness to several A stars found by *ROSAT* (Fleming et al. 1991), e.g., A3V star β Crt, and *EUVE*, and which were later identified as hot whit e dwarfs through *IUE* followup observations.

We have observed all the sources within the error circle as well as the brighter candidates outside the 1′ error circle in this field. Two candidates display signatures of high chromospheric activity. From the measurements of TiO (4670 Å) and MgH (4780 Å) bands we derived dM2e, dM3e, type spectra, respectively.

In order to examine whether the DS Lexan/B count rate can be attributed to the dMe stars we used the Monsignori Fossi & Landini (1994) line emissivities for a coronal temperature of log $T = 6.8$ and determined the EUV flux. This flux is consistent with the EUV fluxes of the most active dMe stars presented by Mathioudakis et al. (1995a).

Because the active late-type stars lie within the error circle, it appears that the two counterparts, are the likely contributors to the EUV emission and that "Possible ID" 56 Tau (Malina et al. 1994) is not the *EUVE* source but a UV leak also contributing to the total counts.

1.3. *EUVE_J1918+599 and EUVE_J2249+585*

EUVE_J1918+599 and EUVE_J2249+585 are detected by both the *EUVE* survey (Bowyer et al. 1994) and by the *ROSAT* WFC (Pounds et al. 1993). The optical counterparts are published as a "blue star," LB342, (Dixon & Sonnenborg 1980) and "UV-emission source," LAN 23, respectively (Lanning 1973). No spectral type is given in the literature for these sources. Within the EUV error circle, the candidates were observed and the candidates for EUVE_J1918+599 and EUVE_J2249+585 clearly reveal white dwarf spectra that exhibit broad H lines as illustrated in Figure 1.

The quasi-equivalent widths were measured in Å, based upon truncating the line profiles at 50 Å relative to the line center. The residual intensity at these points defines the baseline of the integration. This definition of width has the advantage of avoiding uncertainties caused by the continuum placement, which can be quite large because of the broad wings. The equivalent widths of Hβ and Hγ of both of the white dwarfs were fitted against the line blanketed model atmospheres of Wesemael (1980) for log $g = 8$. The accuracy of the equivalent widths are within few percent in each case and will contribute about 10% error to the temperature determination. The errors caused by the uncertainty of the choice of log g is also in about the 10% range for EUVE_J1918−599 but closer to 20% for EUVE_J2249+585. We obtain a range of $T_{\rm eff} = 30000$–35000 for EUVE_J1918+599 and of 55000–60000 for EUVE_J2249+585. From the $T_{\rm eff}$ values we obtained the M_v values given by Liebert (1988). We estimate M_v in the range of $9.7 - 10.1$ for EUVE_J1918+599 while for EUVE_J2249+585 a range of $8.9 - 9.2$. These values reflect the uncertainties in the equivalent widths and the model log g value. From the absolute visual magnitude, M_v, and estimated visual magnitude, m_v, from our KPNO spectra (which are also in good agreement with the SIMBAD m_v values), we derive distances to these white dwarfs. Distances of 95 and 110 pc are derived for EUVE_J1918−599 and EUVE_J2249+585. The errors in distances are on the order of 10% to 20%. Based on preliminary follow-up results conducted by Vennes, Thejll, & Dupuis (1995), EUVE_J2249+585 and EUVE_J1918+599 are DA1.0 and DA1.5 temperature class white dwarfs, which agree with the results of this work.

1.4. *EUVE_J2053−175*

The spectrum of the brightest object within the error circle, has been obtained with the Perkins Telescope of the Lowell Observatory. Two other brighter candidates, 7 and 13, outside the error circle, were obtained at KPNO. Bright candidate reveals a spectral type late K. However, it does not show the clear evidence for chromospheric activity such as Balmer emission. It is premature to comment on the Ca emission since the spectral region does not extend to the 3900 Å range. The EUV light curve was constructed from the DS data to examine the source variability in the EUV, and no variability was detected. No conclusive spectral type nor definitive optical identification can be attributed to this field. However the source fits the description of "late-type star with no documented activity." Thus, this candidate is a possible counterpart or, in Bowyer et al.'s scheme, has identification quality Q = 2.

1.5. *EUVE_J2056−171*

EUVE_J2056−171 is one of the brightest DS *EUVE* sources. This object has recently been identified as a very active late-type dwarf. The spectrum exhibits the Hα and Ca II H and K emission lines and is given securely as type dK7e–dM0e. A large flare with an energy in excess of 10^{35} ergs was observed during the *EUVE* observations in the Lexan/B band. The optical spectrum of the source shows strong Hα and Ca II H and K emission. The Li I 6707.8 Å absorption line is al so present in the spectrum. The Li I

https://doi.org/10.1017/S0252921100036447 Published online by Cambridge University Press

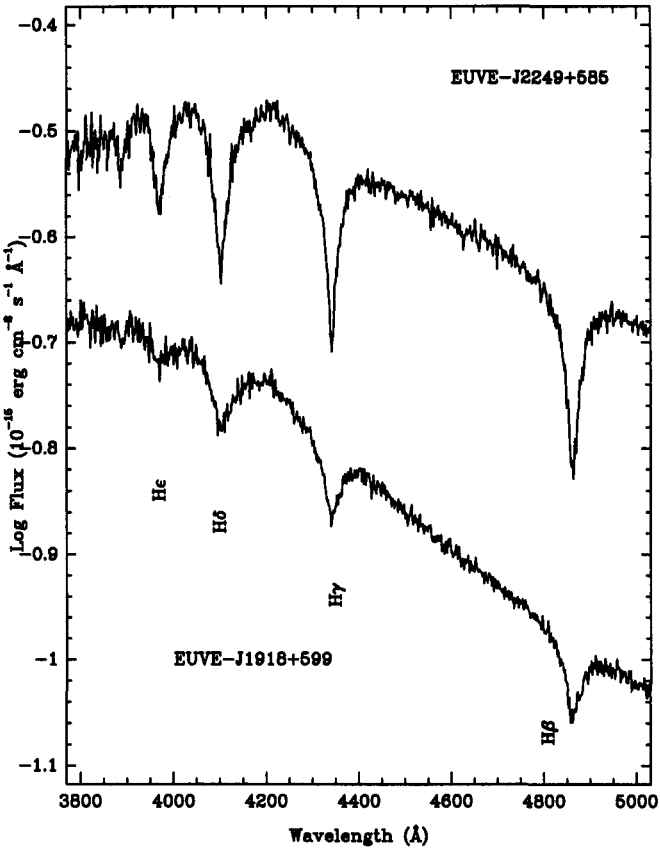

FIGURE 1. Spectra of the optical counterparts of EUVE_J1918+59 and EUVE_J2249+585

equivalent width implies a Li abundance of log $N(\mathrm{Li}) = 2.5 \pm 0.4$. A detailed analysis of EUVE_J2056−171 has been presented by Mathioudakis et al. (1995b)

1.6. *EUVE_J2114+503*

The field of EUVE_J2114+503 is a very reddened field in the Galactic plane. Six candidates were observed at Kitt Peak in 1993, but none of the spectra indicated obvious EUV emission signatures. In 1994 additional bright candidates outside the 1′ radius were observed at Lowell Observatory. Again we do not detect any likely EUV candidates. All the remaining possible candidates in this field have magnitudes less than $m_v = 14$. This fact suggests that it is a very bright object in the EUV and relatively faint in optical wavelengths. Moreover, because this source lies in the Galactic plane, it must be relatively nearby—within 100 pc or so. If we plot this source on the count rate vs. visual magnitude diagram in Figure 5 of the BSL (Malina et al. 1994), with Lexan/B counts 60 counts ks^{-1} and $m_v = 14$ and fainter, it falls into either the class of white dwarf stars or cataclysmic variables. Both possibilities fit the observational evidence.

https://doi.org/10.1017/S0252921100036447 Published online by Cambridge University Press

1.7. *EUVE_J2233−096*

EUVE_J2233−096 is detected in the DS Lexan/B filter and cataloged in the FESC with count rate 11 counts ks^{-1}. Previous work by Stephenson (1986) and Gliese & Jahreiss (1991), reported an M3 star within the error circle at this position. However, no references to any activity was given. Spectra of the two brightest stars within the error circle were obtained. A candidate which is 18″ from the *EUVE* source position, shows a spectrum characteristic of type dMe with Hβ and Hγ prominent in emission. From the TiO band measurements, we estimate a spectral type of dM3.5e.

1.8. *EUVE_J2329+414*

Currently EUVE_J2329+414 is identified as a "possible" ID, as an M star (G 19 0–28) in the FESC and as G 190–27 in the BSL. They are a pair of dMe stars, both located within the 1′ error circle of the *EUVE* position. Spectra show Balmer emission lines in both counterparts 6A and 6B. Both stars are likely to contribute to the observed EUV emission. The Hα, Hβ, Hγ, and Hδ flux measurements and comparison with the libraries of stellar spectra of Jacoby et al. (1984), Pettersen & Hawley (1989), and Mathioudakis & Doyle (1991) suggest the spectral types are dM4.5e and dM3.5e, respectively. Visual magnitudes of 11.87 and 12.44 are derived for these candidates. From the TiO band we derive the absolute magnitudes $M_v = 12$ and 11.97, respectively, and a distance of 14.2 pc for the pair. Note that the Gliese Catalog lists these objects as M2 and M3 stars and gives a distance of 14.8 pc, which is in a good agreement with our findings.

This work has been supported by NASA contract NAS5–29298.

REFERENCES

BOWYER, S., & MALINA, R. F. 1991, in Extreme Ultraviolet Astronomy, ed. R. F. Malina & S. Bowyer, New York: Pergamon, 397

BOWYER, S., LIEU, R., LAMPTON, M., LEWIS, J., & WU, X. 1994, ApJ, 93, 569

CRAIG, N., ET AL. 1995, AJ, in press

DIXON, R. S., & SONNEBORN, G. 1980, A Master List of Nonstellar Optical Astronomical Objects, Columbus: Ohio State U. Press

FLEMING, T. A., SCHMITT, J. H. M. M., BARSTOW, M. A., MITTAZ, J., P., D. 1991, A&A, 246L, 47

GLIESE, W. 1991, Catalog of Nearby Stars IDL Database Library

JACOBY, G. H., HUNTER, D., & CHRISTIAN, C. A. 1984, ApJS, 56, 257

LANNING, H. H. 1973, PASP, 85, 70

LIEBERT, J., DAHN, C. C., & MONET, D. G. 1988, ApJ, 332, 891

MALINA, R. F., ET AL. 1994, AJ, 107, 751

MATHIOUDAKIS, M., FRUSCIONE, A., DRAKE, J. J., MCDONALD, K., BOWYER, S., & MALINA, R. F. 1995a, A&A, in press

MATHIOUDAKIS, M., ET AL. 1995b, A&A, in press

MATHIOUDAKIS, M. & DOYLE, J. G. 1991, A&A, 244, 409

MCDONALD, K., CRAIG, N., SIRK, M. M., DRAKE, J. J., FRUSCIONE, A., VALLERGA, J. V., & MALINA, R. F. 1994, AJ, 108, 1843

MONSIGNORI-FOSSI, B. & LANDINI, M. 1994, Solar Physics, 152, 81

PALLAVICINI, R. 1989, A&AR, 1, 177

PETTERSEN, B. R., & HAWLEY, S. L. 1989, A&A, 217, 187

STEPHENSON, C. B. 1986, AJ, 91, 144

VENNES, S., THEJLL, X., & DUPUIS, J. 1995, in prereparation

WESEMAEL, F., AUER, L. H., VAN, HORN, H. M., & SAVEDOFF, M. P. 1980, ApJS, 43, 59

https://doi.org/10.1017/S0252921100036447 Published online by Cambridge University Press