SPECTROSCOPIC SEGREGATION IN BINARY SYSTEMS*

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Abstract. Binary systems displaying spectroscopic segregation, whereby line spectra of the two components overlap little or not at all in wavelength, account for a small subset of LUV objects (late-type ultraviolet). Optical and ultraviolet (IUE) spectra for one such system, HD 15351 + UV0225 + 13 (F4–5 V + sdO), are presented and a few related systems described. The role of LUV objects in establishing an absolute luminosity calibration for hot subdwarfs is emphasized, along with their significance for stellar evolution. A search strategy for additional spectroscopically segregated LUV objects is outlined.

Spectroscopic and spectrophotometric observations in the near and far ultraviolet have revealed a small but intriguing new class of binary stars. Ultraviolet surveys such as those conducted by Celescope on OAO-2 (Davis *et al.*, 1973), the S2/68 experiment on TD-1A (Thompson *et al.*, 1978) and the UV experiment on ANS (Wesselius *et al.*, 1982) turn up occasional contradictory objects, apparently single, whose UV colours are unacceptably blue for their nominal spectral type as determined from observations in the visual region. For convenience these can be called LUV objects (standing for late-type ultraviolet – properly speaking a contradiction in terms). For the most part the denomination of LUV objects is factitious since many stars in this category will disappear on closer scrutiny.

Sky surveys can generate spurious stellar LUV objects in the following ways: (1) erroneous fluxes – rarely a problem except for faint sources covered by few satellite passes or else observations contaminated by high, variable background radiation such as in the South Atlantic Anomaly; (2) misidentification through the presence of a rich star field or conceivably through an error in the attitude solution; (3) blending with an extended source or by two sources of comparable magnitude with a strong UV component – less of a problem on ANS (aperture $2\farcm5 \times 2\farcm5$) than on S2/68 (aperture $11' \times 17'$); and (4) misclassification of the assumed late-type component. In practice the vast majority of spurious LUV objects arise through errors of the last type (see, for example, Barbier *et al.*, 1978; Berger and Fringant, 1980; Jaschek and Jaschek, 1980) although the difficulties are increasingly attenuated by publication of revised spectral catalogues such as those by Houk and Cowley (1975) and Houk (1978) among others. It should be emphasized that on first inspection the sources we are considering appear to be single field objects, known binary systems being *de facto* excluded. Naturally enough, systems of eclipsing binaries of β Lyrae type (such as BF Aur) and late-type

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primaries with recognized hot secondaries (such as α Sco, comprised of M1 Ib + B4 V) in part mimic the characteristics of LUV objects.

What then do we make of a star of confirmed spectral type late A or cooler which nevertheless displays a steep UV slope, say m (1550 Å) − m (2750 Å) < −1.3, on the basis of uncontaminated UV data? Following Doyle's dictum (Doyle, 1890) that after the elimination of the impossible whatever remains must be the truth, we infer that non-spurious LUV objects must be examples of binary systems displaying an extreme case of spectroscopic segregation. That is to say, they consist of late-type primaries with subluminous hot secondaries where the former is completely dominated by the latter in the ultraviolet, and the latter by the former in the optical region.

An outstanding instance of spectroscopic segregation is furnished by HD 17576, considered by Darius and Whitelock (1978). Spectra obtained at a dispersion of 30 Å mm^{-1} clearly vindicated its classification as G0V; yet S2/68 observations of UV0246–37 (precisely identified with HD 17576 in position) indicated a temperature estimated to be in excess of 35000 K. The identification of UV0246–37 as a hot subdwarf secondary to the late primary HD 17576 has since been corroborated by studies with the International Ultraviolet Explorer (IUE). The UV spectrum (SWP 4104) displays Lα λ1215, Si II λ1260, O I λ1302, and the Si IV doublet $\lambda\lambda$1392/1402 prominently, along with weaker evidence for C IV λ1550 and N IV λ1718.

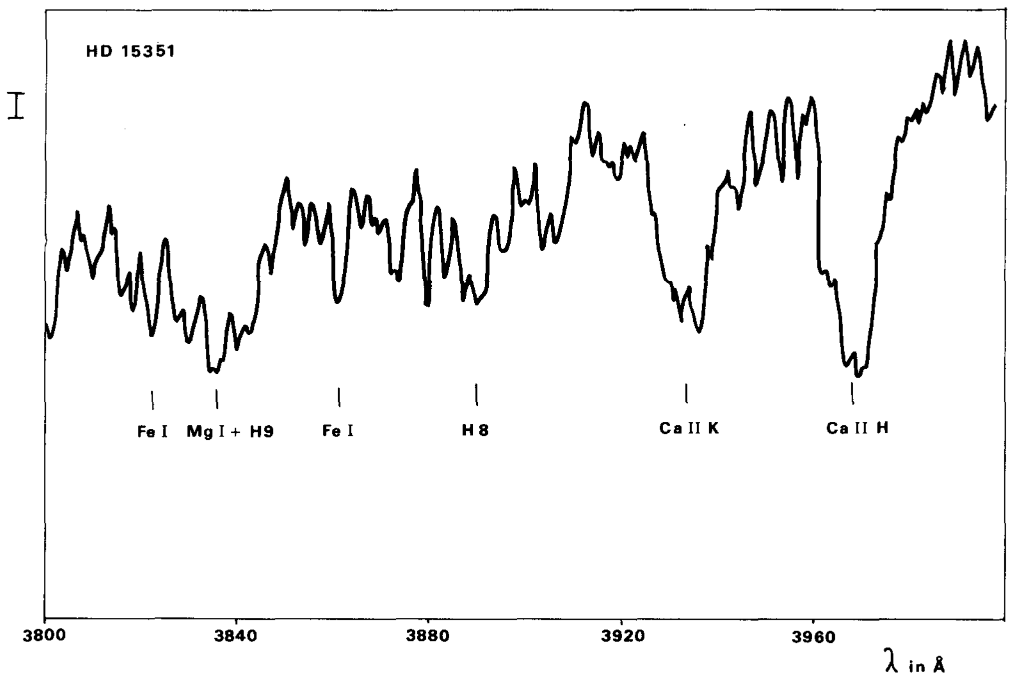

Fig. 1. Portion of optical spectrum of HD 15351, taken with f/1.4 EMI image-tube spectrograph at 30 Å mm^{-1} (second-order blue) on 1.9 m telescope at South African Astronomical Observatory. Salient features are identified.

The presence of the hot companion, almost indistinguishable spectroscopically in the optical region, can nevertheless be inferred from Strömgren photometry.

I should like to describe another remarkable system in this paper, the LUV object UV0225 + 13 identified with HD 15351. It was classified as F5 in the HD catalogue, yet registered as a strong UV source according to S2/68 observations, its colours best approximated by B1. Barbier *et al.* (1978) estimated F2 from an objective-prism spectrum. A high-quality spectrum at 30 Å mm^{-1} was obtained with the Image-Tube Spectrograph on the 1.9 m telescope at SAAO by Whitelock (1977), and it was found that the mid-F classification is vindicated. From the relative strengths of the hydrogen lines and metallic-line luminosity-class discriminants, coupled with a photometric measurement at Hβ (Whitelock, 1977), we can confidently claim HD 15351 to be F4–5 V. The only slight indication of a binary component is a marginal lowering in the Ca II K : H ratio (see Figure 1) through infilling of the K line.

When HD 15351 was re-observed in the ultraviolet, this time with IUE, the results were unequivocal (Figure 2). Those familiar with the appearance of late-type stars in the short-wavelength SWP camera (1150 to 1950 Å) know how abruptly the short-wavelength tail peters out at one end of the channel. Again, spectroscopic segregation explains the seeming contradiction between the visible late-type object and the ultraviolet early-type. Although it may not be immediately clear from Figure 3, comparison of the large- and small-aperture spectra of SWP 4083 confirms the presence of several features

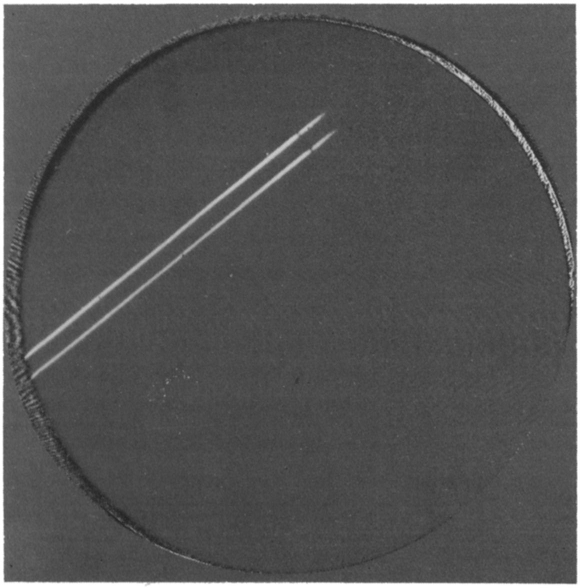

Fig. 2. GPHOT image (geometrically and photometrically corrected) showing short-wavelength, low-resolution IUE spectra of UV0225 + 13 (HD 15351) in large and small apertures, to left and right respectively. Wavelength decreases upward, the strong feature toward upper right being Lα.

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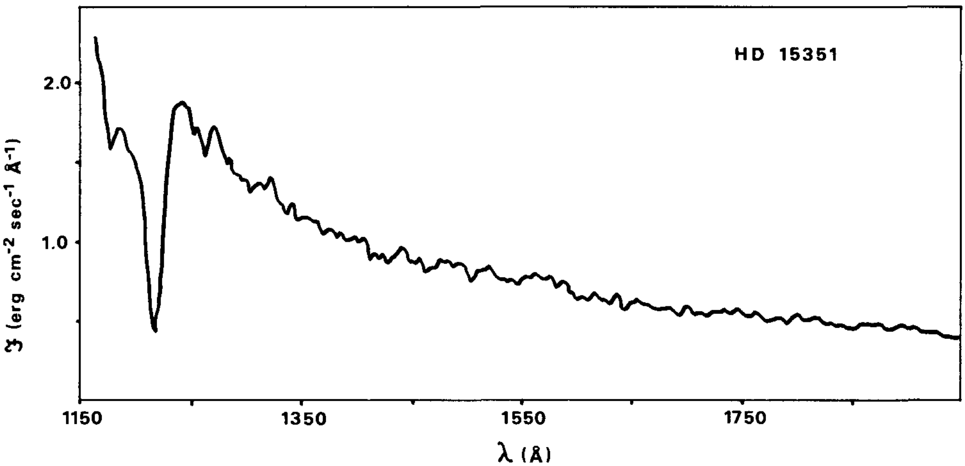

Fig. 3. Low-resolution, large-aperture IUE spectrum SWP 4083 of UV0225 + 13 (HD 15351). Réseau marks have been deleted and the adjacent continuum smoothed.

besides Lα in the SWP channel: C III λ1175, Si II blended at λ1260, possibly C II λ1334, Fe II + Si I at λ1427 and He II λ1640. Fe II λ1690 and N IV λ1718 are marginally possible.

TABLE I

Low-resolution IUE observations discussed in text

Target	Camera	Image number	Aperture	Exposure time (min)
UV0225 + 13 (HD 15351)	LWR	7044	Large	2.1
			Small	3.4
	SWP	4083	Large	1.6
			Small	2.5
UV0246 − 37 (HD 17576)	LWR	3635	Large	1.3
			Small	2.0
	SWP	4104	Large	1.2
			Small	1.6
UV2158 − 02 (BD-3°5357)	LWR	1855	Large	10.0
			Small	14.6
	SWP	2055	Large	6.0

In the long-wavelength channel (Table I) it might at first appear that there are strong features (Figure 4), but again comparison of large- and small-aperture data is invaluable – albeit in the opposite sense. Aside from some weak Fe II features, the LWR spectrum appears nearly line-free at low resolution. Note too the absence of any λ2200 interstellar absorption feature.

To infer the absolute magnitude of the hot secondary, we use the distance modulus

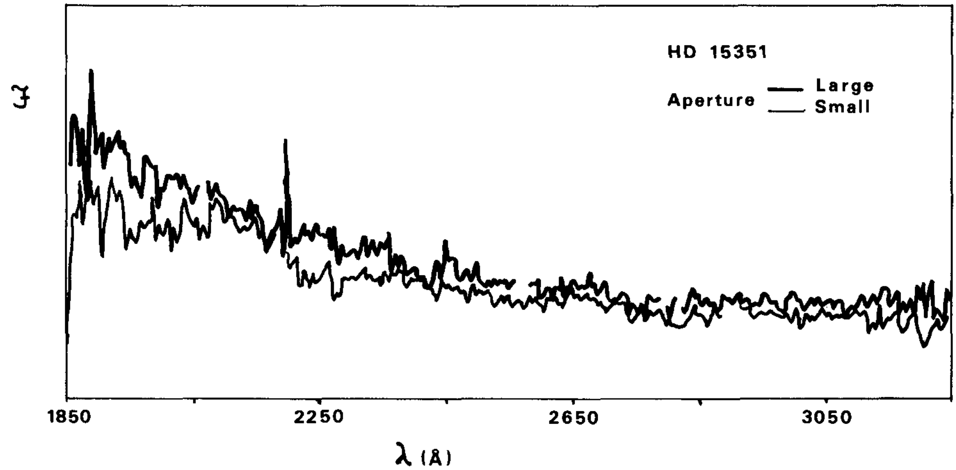

Fig. 4. Low-resolution IUE spectra LWR 7044, both apertures, of UV0225 + 13 (HD 15351). Gaps mark réseaux. Flux units are arbitrary.

provided by the cool primary, coupled with an extrapolation from the UV slope past the A1 datum at $\lambda 2740$ provided by S2/68 (m_{A1} = 8.2) to yield an apparent magnitude of 10.2. Through Allen (1973) we find the absolute magnitude to be 5.1 – though it could be as low as 4.7 on a different luminosity calibration (Mikami, 1978) – and a new hot subdwarf has declared itself. The unreddened Strömgren indices $[m_1] = 0.153$ and $[c_1] = 0.209$ found from photometry by Whitelock (1977) are, if anything, more anomalous than those of HD 17576.

Another, better-known instance of a LUV object is UV2158–02, or BD $-3°5357$. A spectrum at 42 Å mm^{-1} taken at Mount Wilson points to a G8 III or G5 III–IV classification, whilst the broad-band UV colours imply B2. In this case, however, unexpected evidence of the system's peculiarity was found in its variability and in the presence of Hα (as well as Ca II H and K components) in emission. In the event, *UBV* photometry reveals an eclipsing binary system with a 13^h eclipse every $9^d.2$ ($\Delta U = 1^m.2$). The radius of the hot component is ~2% that of the cool subgiant. Dworetsky *et al.* (1977) suggest that the secondary has $M_v = 4.7$ and $\log g = 6.1$ – an evident hot subdwarf which at 300 pc has $m_v = 12.2$, 3 mag. fainter than the subgiant. IUE long-wavelength spectra at low resolution (Table I) manifest no certian features, but SWP spectra show well-defined C III $\lambda 1175$, Lα $\lambda 1215$, Si IV doublet $\sim\lambda 1400$, C IV doublet $\sim\lambda 1550$. The temperature is perhaps 5000 K hotter than that of HD 17576.

To allow us to infer absolute magnitudes for these hot subdwarfs is perhaps the greatest service that spectroscopically segregated LUV objects can render us. Subdwarf luminosities are very poorly known (see Greenstein and Sargent, 1974) save for such examples as the two in the galactic plane reported by Walker (1981) with $M_v \geq 3.2$ for one and $M_v \geq 5.6$ for the other. There is also the famous example of probable hot subdwarfs found by Kilkenny *et al.* (1978), LB 3459, whose primary they considered to be a $0.5\,\mathfrak{M}_\odot$ star with $M_v = 7.0 \pm 0.8$ (Kilkenny *et al.*, 1981). But undoubtedly the best magnitude determinations originate in systems of cool primaries of well calibrated luminosity paired with subluminous hot companions. (In addition to the LUV objects above, note those analyzed by Goy, 1977; Stickland and Harmer, 1978; Goy, 1980; Gilra *et al.*, 1980.)

Only a handful of confirmed LUV objects of the type described are known at present. Bear in mind that other evolved primaries with hot secondaries have long been recognized from their composite spectra; to belong to this category is a necessary but not a sufficient condition to guarantee spectroscopic segregation (e.g., Parsons *et al.*, 1976). For the long-wavelength tail of the flux from the hot secondary to overlap with the short-wavelength tail of the cooler primary without making its presence evident in the line spectrum, the prescription is evidently F, G, or K + sdO. The question arises whether there are many more such sdO's lurking in unrecognized binary systems. While it is true that this possibility is unlikely for Main-Sequence stars down to $\sim 10^m$, the low intrinsic luminosity of hot subdwarfs would tend to conceal them if the primary were either much fainter or much farther. If the primary were a supergiant, the sheer magnitude difference would militate against detection of the subdwarf companion except in an interacting system.

As shown by Darius and Whitelock (1978) for HD 17576 and again for HD 15351 above, *ubvy* and Hβ photometry proves quite effective at distinguishing candidate LUV objects from mid-F to late K. So does the seven-colour photometric system of Geneva, as shown by Goy (1977, 1980) for HD 128220 and HD 113001. Primaries of earlier type impede discrimination by standard photometric means, but R. Barbier and the author are working on an alternative approach. Walraven *VBLUW* photometry affords better UV passbands ($V - B$, $U - W$) for testing stars of earlier type for possible duplicity, and we are now reducing ESO observations of likely candidates taken on the Dutch 90 cm telescope at La Silla. There are strong reasons for resorting to Walraven photometry: among the LUV objects scanned by S2/68 there was a very large population of A0 (and some A1) stars rather too blue for their spectral type. It is the fate of most LUV objects to evaporate on closer scrutiny, but this approach stands a good chance of turning up a few more genuine binaries with spectroscopic segregation.

Double-star specialists whose main concern lies in mass transfer during evolution may consider these non-interacting systems uninteresting. However, the fact that no evidence of mass exchange is found in most systems of the type described here does not imply that it has not taken place. The canonical position, one infers, must be that evolution of the original primary is very nearly complete and that the next phase must see the Main-Sequence companion begin to expand, fill its Roche lobe and transfer mass and angular momentum to the compact 'primary' provided that their separation not be too great. HD 15351 and its ilk may be seen as precursors of V471 Tauri-type systems containing a white dwarf plus Main-Sequence star (except that their separation is known to be small). It will be argued that the reason so few LUV objects are known is the rapidity of evolution through the subdwarf phase according to some models, but equally the observational selection effects mentioned earlier hinder their recognition. Let us hope that deeper surveys in the satellite ultraviolet and the successful application of

Walraven photometry will increase the number of these systems and allow us (1) to obtain the first secure absolute luminosity calibration for hot subdwarfs, and (2) to account for their evolutionary position.

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References

Allen, C. W.: 1973, *Astrophysical Quantities*, 3rd ed., Athlone Press, London.

Barbier, R., Dossin, F., Jaschek, C., Jaschek, M., Klutz, M., Swings, J. P., and Vreux, J. M.: 1978, *Astron. Astrophys.* **66**, L9.

Berger, J. and Fringant, A.-M.: 1980, *Astron. Astrophys.* **85**, 367.

Darius, J. and Whitelock, P. A.: 1978, *Nature* **275**, 428.

Davis, R. J., Deutschman, W. A., and Haramundanis, K.: 1973, *Celescope Catalog of Ultraviolet Stellar Observations*, Smithsonian Institution Press, Washington, D.C.

Doyle, A. C.: 1890, *The Sign of Four*, Spencer Blackett, London.

Dworetsky, M. M., Lanning, H. H., Etzel, P. B., and Patenaude, D. J.: 1977, *Monthly Notices Roy. Astron. Soc.* **181**, 13P.

Gilra, D. P., Wesselius, P. R., and Rao, N. K.: 1980, *Proceedings of Second European IUE Conference*, ESA SP-157, p. 227.

Goy, G.: 1977, *Astron. Astrophys.* **57**, 449.

Goy, G.: 1980, *Astron. Astrophys.* **88**, 370.

Greenstein, J. L. and Sargent, A. I.: 1974, *Astrophys. J. Suppl.* **28**, 157.

Houk, N.: 1978, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars*, Vol. 2, Department of Astronomy, University of Michigan, Ann Arbor.

Houk, N. and Cowley, A. P.: 1975, *University of Michigan Catalogue of Two-Dimensional Spectral Types for the HD Stars*, Vol. 1, Department of Astronomy, University of Michigan, Ann Arbor.

Jaschek, M. and Jaschek, C.: 1980, *Astron. Astrophys. Suppl.* **42**, 115.

Kilkenny, D., Hilditch, R. W., and Penfold, J. E.: 1978, *Monthly Notices Roy. Astron. Soc.* **183**, 523.

Kilkenny, D., Hill, P. W., and Penfold, J. E.: 1981, *Monthly Notices Roy. Astron. Soc.* **194**, 429.

Mikami, T.: 1978, *Publ. Astron. Soc. Japan* **30**, 207.

Parsons, S. B., Wray, J. D., Kondo, Y., Henize, K. G., and Benedict, G. F.: 1976, *Astrophys. J.* **203**, 435.

Stickland, D. J. and Harmer, D. L.: 1978, *Astron. Astrophys.* **70**, L53.

Thompson, G. I., Nandy, K., Jamar, C., Monfils, A., Houziaux, L., Carnochan, D. J., and Wilson, R.: 1978, *Catalogue of Stellar Ultraviolet Fluxes*, Science Research Council, U.K.

Walker, A. R.: 1981, *Monthly Notices Roy. Astron. Soc.* **197**, 241.

Wesselius, P. R., van Duinen, R. J., de Jonge, A. R. W., Aalders, J. W. G., Luinge, W., and Wildeman, K. J.: 1982, *Astron. Astrophys. Suppl.* **49**, 427.

Whitelock, P. A.: 1977, unpublished data.