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A Search for Ultraviolet Objects

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A search for ultraviolet objects

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The observations of the sky-survey telescope in the TD-1A satellite are being searched for ultraviolet objects. The first results, covering about 10 % of the sky, are presented and rough limits on space density and luminosity are derived. It is concluded that the frequency population of hot objects lying a few magnitudes below the main sequence is probably much greater than had been thought hitherto. Some examples of the observed ultraviolet spectra are presented.

Introduction

The sky-survey telescope S2-68 (Boksenberg *et al.* 1973) in the E.S.R.O. satellite TD-1A carries out a controlled scan of the sky and obtains ultraviolet spectra of point sources, reaching about 9–10th visual magnitude for unreddened early type stars. The data are recorded in four channels using pulse counting photomultipliers. One (A_1) is a photometric channel whose response is centred at 2740 Å with a bandwidth of about 300 Å; the other three (A_2, A_3 A_4) give low resolution ($\delta\lambda \sim 35$ Å) spectra over a total wavelength range of 1350–2550 Å.

Many of the investigations being carried out with the S2-68 data have an approach similar to that of an observing astronomer in that 'observing lists' are compiled, the tapes are searched for those objects and the data extracted. However, the data format is equally amenable to search programs in which objects with defined characteristics can be extracted and then identified. One such program is a search for ultraviolet objects on the criterion

$$m(A_2) - m(A_1) < -1.1 \text{ mag}.$$

where $m(A_2)$ is the magnitude of the average flux in the A_2 channel corresponding to a 400 Å bandwidth centred on 1550 Å and $m(A_1)$ is the magnitude in the A_1 channel (bandwidth 300 Å centred at 2740 Å). The criterion corresponds to the selection of unreddened O and B stars (Humphries, Nandy & Thompson 1973) and all detectable objects which satisfy it are being extracted. The purpose of this paper is to describe the present state of this study.

The data

So far about 10 % of the sky has been searched and, because of the nature of the scan mode, this is in the form of a segment passing through the ecliptic poles. It therefore cuts the galactic plane at two points ($l^{\text{II}} = 60°$ and 230°) as can be seen in figure 1 which plots the location of the ultraviolet objects extracted in galactic coordinates. A further subdivision in colour has been made in that the very ultraviolet objects with $m(A_2) - m(A_1) \leqslant -1.6$ mag are identified separately with a cross. In all, 133 objects met the criterion of which 67 are in the galactic plane ($\pm 10°$) and 66 at higher latitudes. There is a suggestion that the more ultraviolet objects (×) are more openly distributed than the others (•) without the same strong tendency to

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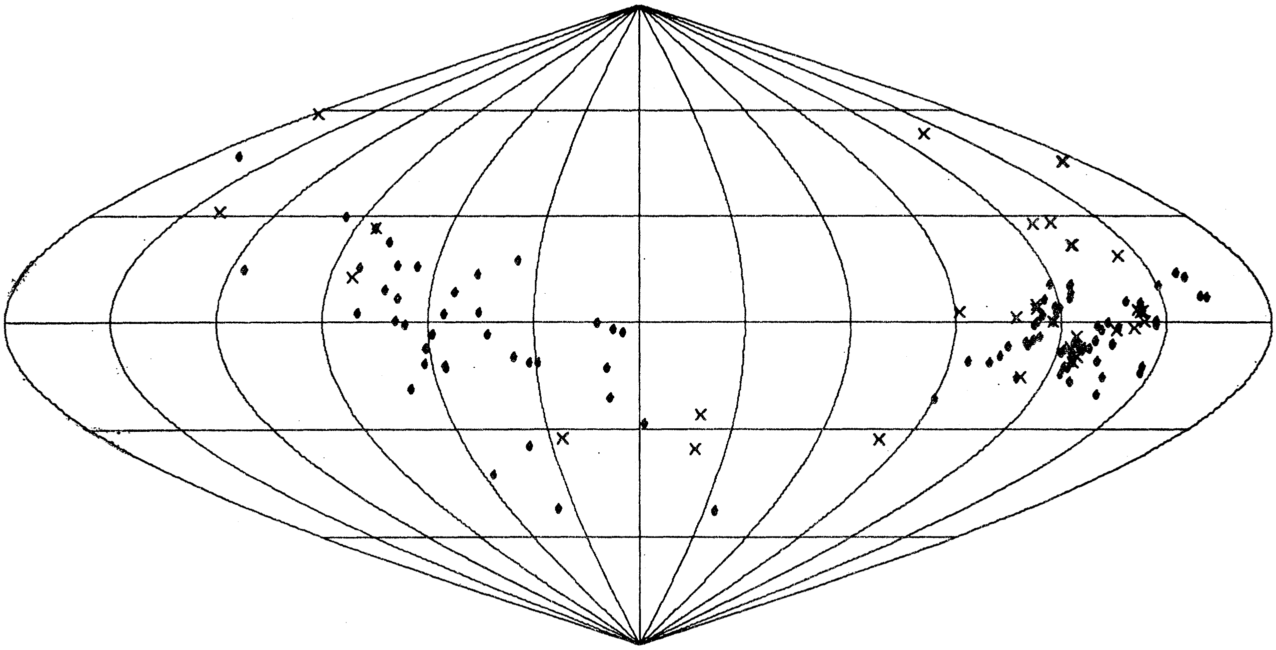

FIGURE 1. Galactic distribution of ultraviolet objects so far extracted from a 10% sky coverage. They are divided into two groups according to colour, the crosses being the very ultraviolet group.

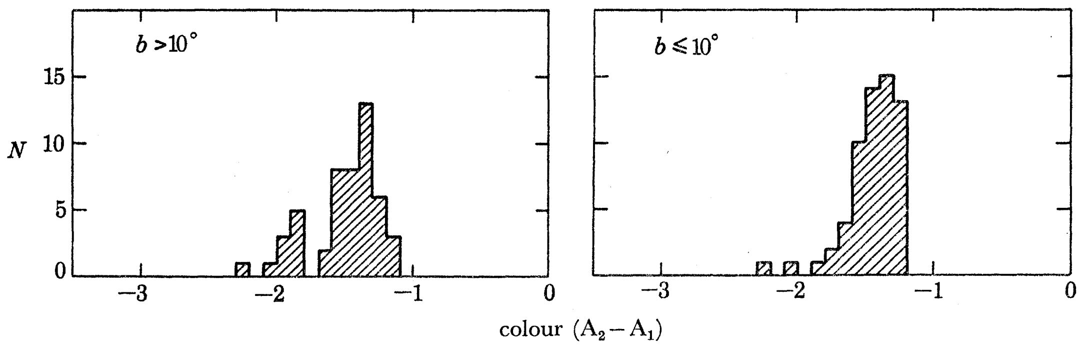

FIGURE 2. Frequency distribution of ultraviolet objects with colour for in-plane ($b \leqslant 10°$) and out-of-plane ($b > 10°$) objects.

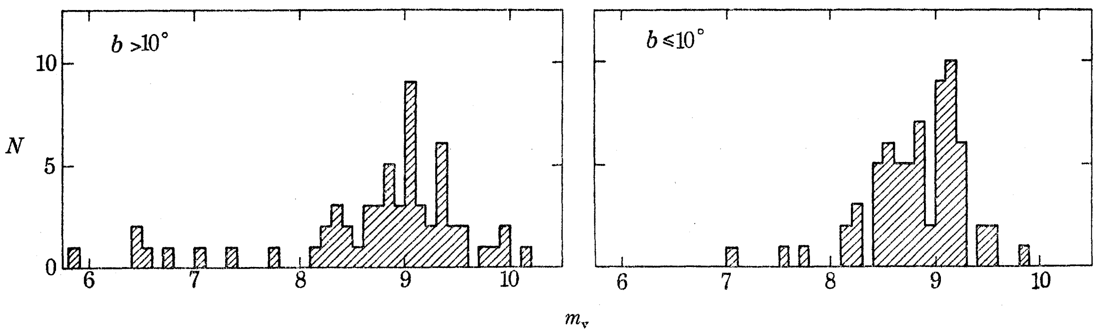

FIGURE 3. Frequency distribution of ultraviolet objects with apparent visual magnitude for in-plane and out-of-plane objects.

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concentration in the galactic plane. However, the numbers are such that no significant conclusion can be reached and such questions of distribution will need to await the reduction of the data for the whole sky.

The frequency distribution with colour for objects outside the galactic plane are shown in figure 2 which plots the number of objects in 0.1 magnitude colour intervals against the $m(A_2)-m(A_1)$ colour. The distributions in and out of the plane are similar and both show a marked fall in population with increasing ultraviolet colour above the selection criterion (-1.1). The most ultraviolet of the objects with $m(A_2)-m(A_1) \lesssim -2$ are probably very hot and equivalent to O type spectra. A reasonable practical limit to the colour is given by an infinitely hot black-body for which $m(A_2)-m(A_1) = -2.47$.

The frequency distribution with apparent visual magnitude is displayed in figure 3 and, as in the case of ultraviolet colour, objects outside the galactic plane show the same general form as those within it. There is a marked increase in number density beginning at $m_V \approx 8$ with a maximum at $m_V \approx 9$. The fall off at fainter magnitudes is observational in character and is imposed by the sensitivity limit of the system which lies at about $m_V = 9$–10. In general, the objects brighter than 8th magnitude are early-type main sequence and giant stars which are sufficiently free from interstellar reddening that their ultraviolet colours have not been reduced below the selection criterion. The greater number of such objects off the galactic plane is probably significant and represents the reduced level of interstellar obscuration. The objects fainter than $m_V = 8$, which represent the majority of the present sample, cannot be so readily understood and the remainder of this paper is confined to a discussion of these.

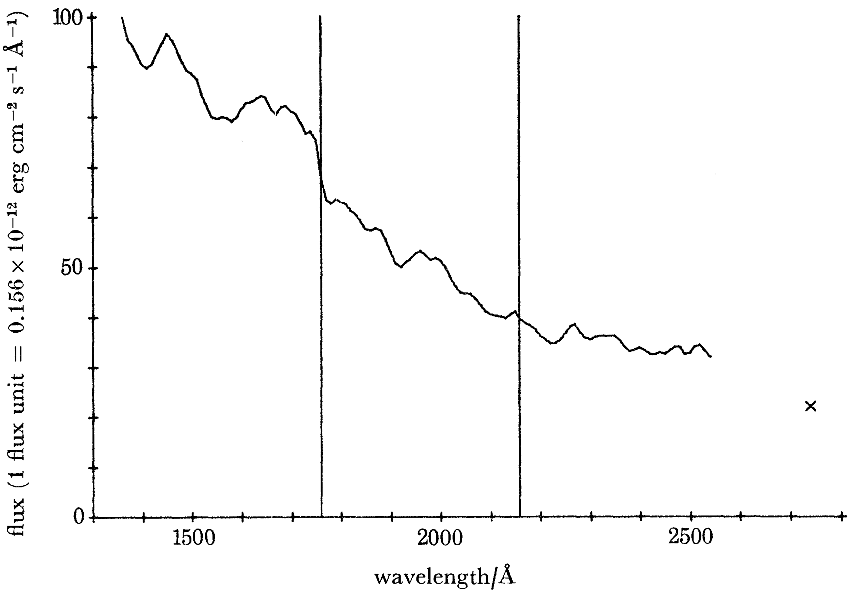

FIGURE 4. Mean spectrum of ultraviolet objects located within the galactic plane ($b = \pm 10°$).

SPACE DENSITY

There is no direct way that the distances of the objects can be inferred from the present observations. The only means (at present) of obtaining some estimate of distance, and hence of luminosity and space density, lies in a consideration of interstellar extinction and this can only be applied to the objects lying within the galactic plane. Since the individual spectra of these are too noisy to derive extinction effects, they have been combined to form the mean spectrum reproduced in figure 4. The combination of the spectra of these 67 in-plane ultraviolet objects implies the assumption that they are a homogeneous group and has no justification other than the simplicity of the approach.

It is clear that there is little interstellar extinction in the mean spectrum since the strong absorption feature centred near 2200 Å (Bless & Savage 1972; Nandy *et al.* 1974) is not evident. A careful examination of the mean spectrum and a comparison with the spectra of unreddened early-type stars (e.g. ζ Pup) leads to the conclusion that the interstellar extinction at 2200 Å, $E\,(2200\,\text{Å}) \leqslant 0.04$ mag. This can be related to the visual colour excess via the extinction curve to give $E_{\text{B-V}} \leqslant 0.02$ mag and, with the normal ratio of 3 for total to selective extinction, this gives the limit on the total visual extinction to be $A_{\text{v}} \leqslant 0.06$ mag.

The average extinction in the galactic plane is given by Allen (1973) as $A_{\text{v}} = 1.9$ mag kpc^{-1} of which 1.6 mag is due to clouds and 0.3 mag due to the intercloud medium. The galactic map compiled by FitzGerald (1968) shows that the two particular directions of the present observations ($l^{\text{II}} = 60°$ and 230°) are low obscuration areas in the local vicinity and hence are more representative of an intercloud medium. The value of 0.3 mag kpc^{-1} has therefore been adopted; its selection is also consistent with the limiting nature of this calculation. This results in a limiting distance for the in-plane ultraviolet objects of $D \leqslant 200$ pc. This is a somewhat crude estimate but some confirmation is given by FitzGerald's galactic map. This shows that in the two observed directions, heavy obscuration sets in at a distance of 200 pc, thereby suggesting the same upper limit in distance.

If we now take the solid angle within which the 67 in-plane ultraviolet objects are viewed together with the upper limit in distance, an upper limit in volume can be obtained and, hence, a lower limit in space density $N_{\text{u.v.}}$. This gives

$$N_{\text{u.v.}} \geqslant 8 \times 10^{-5}\ \text{pc}^{-3}.$$

Assuming a uniform spatial distribution, simple geometry gives the upper limit of the average distance to be 150 pc and hence a distance modulus $\geqslant 6$ mag. This places an upper limit on the intrinsic luminosities of the ultraviolet objects which, in terms of absolute visual magnitude, is

$$M_{\text{v}} \geqslant +3.$$

The frequency distribution with apparent visual magnitude shown in figure 2 is consistent with a uniform spatial distribution of objects of the same absolute magnitude. In other words, it is not possible from the observations to say whether a dispersion in luminosity exists.

The most probable candidates for the ultraviolet objects being viewed are hot subdwarfs, old novae and planetary nebulae. However, the derived lower limit on space density is high since it is equal to the total space density of all hot stars other than the white dwarfs (Allen 1973). We conclude that the population density of hot stars lying a few magnitudes below the main sequence is much higher than was thought hitherto.

Identifications

Nearly all the ultraviolet objects so far extracted have been identified with entries in the SAO or BD catalogues. About a quarter have no listed spectral type and only 16 % have one in the expected range (0–B5); more than half have a late B or A-type entry with a few of even later spectral type. A literature search is under way to determine any further information about the objects but clearly additional ground based observations are required.

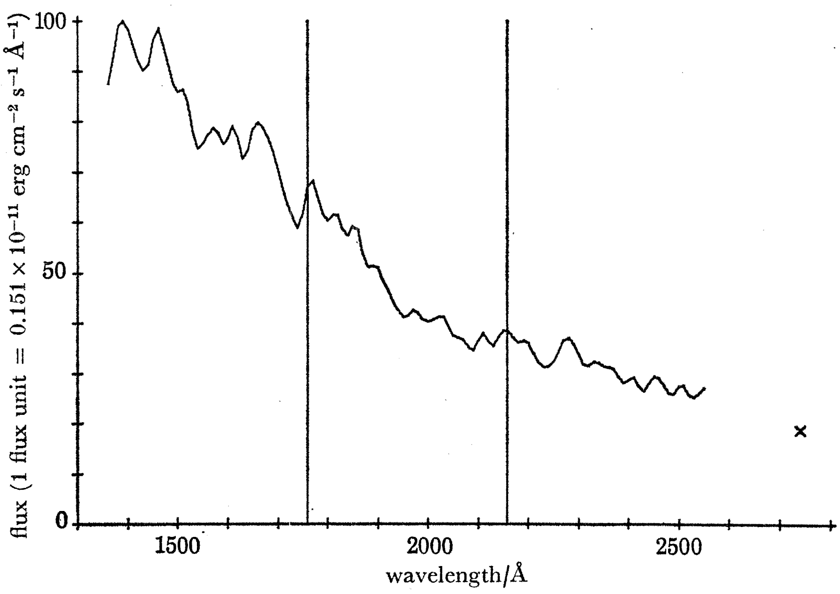

Figure 5. The observed ultraviolet spectrum of HD 180183 (m_v = 7), a high velocity B star.

Selected examples

Three individual ultraviolet objects have been selected as examples for illustration and discussion. The first is from the brighter and better known objects, HD180183 whose spectrum is reproduced in figure 5. This is a 7th magnitude, off-plane, southern hemisphere star with a high radial velocity of +162 km s^{-1} (Buscombe & Kennedy 1965). Its ultraviolet colour $m(A_2)-m(A_1) = -1.6$ and its spectrum, which shows the Si IV and C IV resonance lines near 1400 and 1550 Å respectively, is broadly consistent with the spectral type of B3IV listed by Buscombe & Kennedy.

The second example is BD+75325 (m_v = 9.6), one of the best known hot subdwarfs. It has been studied by Gould, Herbig & Morgan (1957), who concluded that it was a very hot, O-type subdwarf from the appearance of its spectrum which was dominated by the strong, broad lines of the Pickering series of He II. The present data show it to be very ultraviolet with $m(A_2)-m(A_1) = -1.9$ and give a mean spectrum, compiled from eight passes, which is reproduced in figure 6. The most dominant line in this spectrum is the He II line at 1640 Å.

As the final example, one of the most ultraviolet of the objects so far observed was selected. This is BD+37° 1977 which is listed with a visual magnitude 9.2 but no spectral type. Its ultraviolet colour $m(A_2)-m(A_1) = -2.1$ and its mean spectrum obtained from three passes is reproduced in figure 7. The nature of this spectrum is not fully understood. There is some possibility of contamination from a nearby object but it seems very probable that the spectrum is dominated by strong emission lines. However, no unambiguous identification of these seems immediately possible.

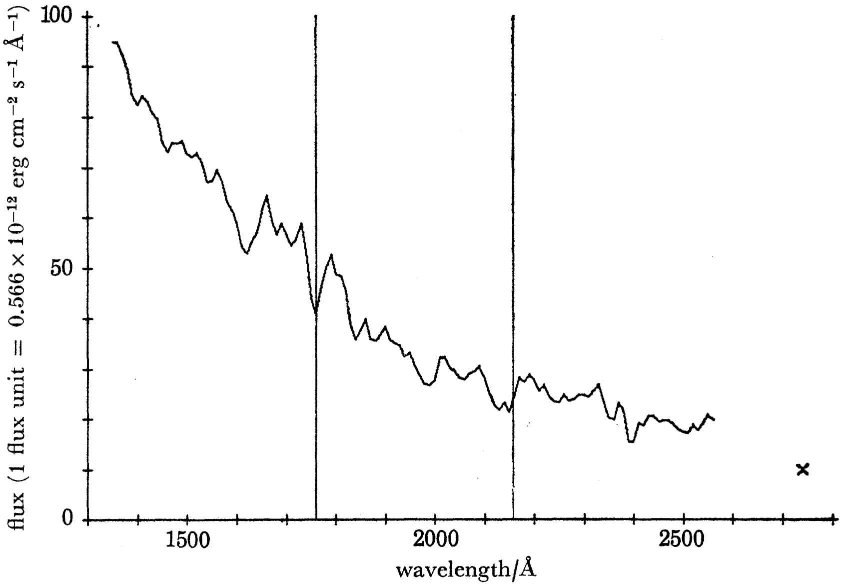

FIGURE 6. The observed ultraviolet spectrum of BD+75 325 (m_v = 9.6) a very hot subdwarf.

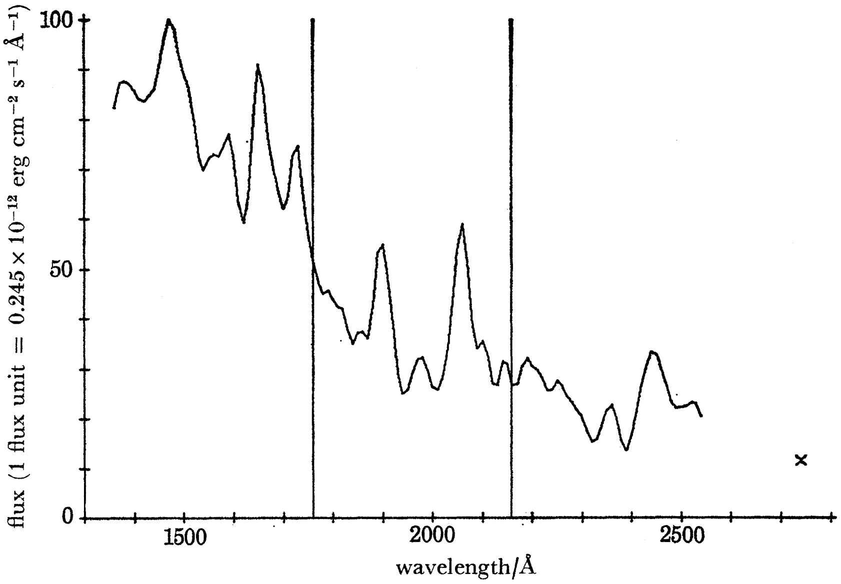

FIGURE 7. The observed ultraviolet spectrum of BD+37 1977 (m_v = 9.2) one of the most ultraviolet objects yet detected.

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