Model Atmosphere and Kinematical Analyses of Early-Type Stars from the Edinburgh-Cape Survey

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Abstract: We present high-resolution spectroscopic observations of 21 B-type stars, selected from the Edinburgh-Cape faint blue object survey. Model atmosphere analyses confirm 14 of these stars to be young, main-sequence B-type stars with Population I chemical compositions. The remaining 7 are found to be evolved objects, such as subdwarfs, Horizontal Branch or post-AGB objects. A kinematical analysis shows that all 14 young main-sequence objects could have formed in the disk and been subsequently ejected into the halo. These results are combined with the analysis of a previous sample of stars taken from the survey, giving a complete magnitude limited sample of 46 objects within ~ 800 square degrees of the halo. Of the complete sample of 46 objects, 31 have been found to be young, main-sequence objects, with formation in the disk, and subsequent ejection into the halo, being a possible formation scenario.

1 Introduction

The presence of faint blue stars at high galactic latitudes has been known since the early work of Humason & Zwicky (1947). Most of these were found to be subluminous evolved Population II objects, but some objects that are spectroscopically similar to main-sequence Population I objects, have also been identified (Conlon et al. 1992). A careful abundance analysis of these objects have shown some of them to be subluminous objects (Carrasco, Aguilar & Recillas-Cruz 1982).

However, there have also been a number of stars which, after abundance analysis, have been confirmed as main-sequence B-type stars (Rolleston et al. 1997, 1999). For the majority of these stars, their presence at high galactic latitudes can be explained in terms of formation in the Galactic disk and subsequent ejection into the halo. Two main mechanisms which may be responsible are the supernova ejection method (Blauuw 1961) and the cluster ejection method (Poveda et al. 1967).
However, not all these young stars can be explained by ejection mechanisms. There are some whose only explanation is star formation in the halo itself (Conlon et al. 1992), which is unlikely in view of the halo's low gas density. However, Dyson & Hartquist (1983) have suggested that supersonic collisions between cloudlets within high velocity clouds (HVCs), which are known to exist in the halo, could result in shock induced star formation.

In order to estimate the density and distribution of young B-type stars at high galactic latitudes and constrain possible theories of their formation, a number of magnitude limited samples have been obtained from surveys of the halo (Little et al. 1995, Rolleston et al. 1999). Possibly normal B-type stars, in the magnitude range $8 < B < 14$, have been identified from the Edinburgh-Cape (EC) survey of Stobie et al. (1997), using the low resolution spectroscopy detailed in Kilkenny, O'Donoghue & Stobie (1991) and Kilkenny et al. (1995). The EC survey aims to detect all blue objects, $(U - B) < 0.04$, brighter than $B \sim 16.5$ at galactic latitudes $|b| > 30^\circ$ and with declinations south of $\delta \sim -13^\circ$. Rolleston et al. (1997) performed model atmosphere and kinematical analyses of 25 of these objects. In this paper we continue this spectroscopic follow-up with analysis of a further 21 stars giving a complete sample of 46 stars in the magnitude range $8 < V < 14$, for a total of $\sim 800$ deg$^2$.

2 Atmospheric Parameters and Abundance Analyses

Effective temperatures were obtained primarily from Strömgren photometry by applying the calibration of Napiwotzki, Schönberner & Wenske (1993) to the reddening-free Strömgren indices. Where no photometry was available, temperatures were obtained by balancing the silicon abundances from lines due to Si II, Si III and Si IV ions, taking account of non-LTE corrections for the Si II lines. For 5 stars there was neither photometry, nor sufficient silicon lines and the line strength of the helium lines was used as a temperature indicator, assuming a normal helium abundance. Estimates of the surface gravities were obtained by comparing profiles of H$\gamma$, H$\delta$, generated with a range of gravities, with the observed profiles, a typical fit is shown in Fig. 1.

LTE abundances were determined from the equivalent widths and atmospheric parameters using model atmosphere codes based on the grid of line-blanketed model atmospheres of Kurucz (1991). Errors in the logarithmic gravities have been estimated as $\pm 0.2$ dex, whilst for the effective temperatures, errors are of the order of $\pm 2000$ K, resulting in an overall uncertainty in the absolute abundances of less than $\pm 0.4$ dex. A line-by-line differential abundance analysis was also performed for each of the programme stars relative to a normal B-type star with similar atmospheric parameters. From the abundance analyses 7 stars have been identified as evolved objects and have not been considered further, the remaining 14 would appear to have chemical compositions similar to young main-sequence B-type stars.

3 Evolutionary Parameters and Kinematical Analyses

Stellar masses and evolutionary ages ($T_{\text{evol}}$) were obtained from the evolutionary tracks of Claret & Giménez (1992) and bolometric corrections were taken from Kurucz (1979). Stellar luminosities and absolute visual magnitudes were then determined, allowing an estimate of the stellar distances and current $z$ height above the Galactic plane to be made.

Proper motions were available for 9 of the stars identified as young B-type main-sequence stars. The proper motion vectors ($\mu, \theta$) in the equatorial system were converted to the Galactic
coordinate system using numerical routines within SLALIB (Wallace 1992). These were used to determine velocity components perpendicular and parallel to the Galactic plane and hence estimate the time of flight, \( T_f \), and ejection velocity, \( v_{ej} \) required for the stars to reach their current position in the halo, assuming the gravitational potential function of House & Kilkenny (1990).

There were no proper motions for 5 stars and in their case the radial velocities were used to put limits on the ejection velocities and flight times by initially assuming a zero velocity component parallel to the Galactic disk. The component perpendicular to the plane \( v_z \) was then given by \( v_z = v_r / \sin b \) and this was used to obtain, values for the flight times and ejection velocities (perpendicular to the disk). A comparison of these flight times with the stellar evolutionary ages was used to determine if formation in the disk, followed by ejection into the halo, was a viable option.

4 Results

From the kinematical analysis, it is clear that all but 4 of the young main-sequence stars could have formed in the disk and been subsequently ejected into the halo, and reached their current \( z \) positions within their estimated evolutionary ages. A closer analysis of the remaining 4 stars has shown that including possible errors in both their effective temperatures and logarithmic gravities, which can both increase the evolutionary ages and decrease the stellar distance and \( z \) height, or the large errors in the proper motions, they too could have formed in the disk. We conclude therefore that disk formation, with subsequent ejection into the halo, is possible for all of the 14 stars.

We can combine the results found here with those from Rolleston et al. (1997) who found, from a total of 25 stars, 17 were young normal B-type stars, all of which could have formed in
the disk. For this combined sample of 46 stars, we find 31 young normal B-type stars for all of which disk formation and subsequent ejection into the halo is possible. Our 29 fields cover \( \sim 800 \, \text{deg}^2 \), however only fields containing B-type stars within our magnitude range have been selected. It is evident from the EC Survey that less than 1 in 2 fields contain B-type stars, with the number of B-stars decreasing rapidly at higher galactic latitudes. Initial calculations of the surface density of normal B-type stars give 0.019 per square degree for our magnitude range. A more detailed analysis can be found in Magee et al. (in preparation).

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