Explaining the Praesepe blue straggler HD 73666
(Research Note)

L. Fossati$^{1,2}$, S. Mochnacki$^3$, J. Landstreet$^4$, and W. Weiss$^1$

1 Institut für Astronomie, Universität Wien, Türkenschanzstraße 17, 1180 Wien, Austria
e-mail: weiss@astro.univie.ac.at
2 Department of Physics and Astronomy, The Open University, Milton Keynes, MK7 6AA, UK
e-mail: l.fossati@open.ac.uk
3 Department of Astronomy & Astrophysics, University of Toronto, 50 St. George St, Rm.101, Toronto, ON, Canada M5S 3H4
e-mail: stefan@astro.utoronto.ca
4 Department of Physics & Astronomy, University of Western Ontario, London, ON, Canada N6A 3K7
e-mail: jlandstr@astro.uwo.ca

ABSTRACT

Aims. The blue straggler phenomenon is not yet well explained by current theory; however, evolutionary models of star clusters call for a good knowledge of it. Here we try to understand the possible formation scenario of HD 73666, a blue straggler member of the Praesepe cluster.

Methods. We compile the known physical properties of HD 73666 found in the literature, focusing in particular on possible binarity and the abundance pattern.

Results. HD 73666 appears to be slowly rotating, has no detectable magnetic field, and has normal abundances, thereby excluding close binary evolution and mass transfer processes. There is no evidence of a hot radiation source.

Conclusions. With the use of theoretical results on blue straggler formation present in literature, we are able to conclude that HD 73666 was probably formed by physical collision involving at least one binary system, between 5 and 350 Myr (50 Myr if the star is an intrinsic slow rotator) ago.

1. Introduction

Blue stragglers are stars that lay on the extension of the main sequence and are bluer and brighter compared to the main sequence turn-off stars. These objects are found in star clusters, dwarf galaxies and in the field. The existence of blue stragglers probably can be explained only by an interaction between two or more stars, and so to understand this phenomenon we study the interaction of stars in stellar systems (see Leonard 1989; Bailyn & Pinsonneault 1995; Sandquist et al. 1997; Sills et al. 1997; Chen & Han 2004; Ahumada & Lapasset 2007).

Recently, Ahumada & Lapasset (2007) listed the most frequently cited theories to explain the formation of blue stragglers. They could be (1) horizontal-branch stars that appear above the main sequence turn-off point, (2) stars of second or third generation, (3) stars that have extended their main-sequence life due to some internal mixing (this would generate a chemically peculiar blue straggler), (4) stars formed by collision of two single stars, (5) the result of mass transfer in a close binary system, (6) produced by merger of the components of a binary system or (7) the result of collision between two or more binary systems. Of those seven theories they considered the last four as major channels of formation.

Recently, comprehensive catalogues of blue stragglers in open and globular clusters have been published. Ahumada & Lapasset (1995) created the first consistent catalogue of blue stragglers in open clusters, which was then expanded by de Marchi et al. (2006) and finally superseded by Ahumada & Lapasset (2007). These catalogues make it possible to analyse blue stragglers on a solid statistical base, leading, for example, to the conclusion that the number of blue stragglers increases with cluster age (see Fig. 5 by Ahumada & Lapasset 2007). In the light of this result, evolutionary models of open clusters need to consider this not well understood phenomenon. For this reason it is important to find clues which allow us to distinguish between different blue straggler formation channels.

The A1V star HD 73666 (40 Cnc, $V = 6.61$) is an extreme blue straggler (Ahumada & Lapasset 2007) in the nearby, well-studied cluster Praesepe (NGC 2632). This paper will show that it is a particularly important example, and provides an excellent test for theories of blue straggler formation. This paper can also be seen as the continuation of Conti et al. (1974) in the light of more than thirty years of new astronomical knowledge and instrumental development.

In Sect. 2 we discuss the membership of HD 73666 in the Praesepe cluster. Fundamental parameters and other physical properties are given in Sect. 3 where we show that the star is a blue straggler. In Sect. 4 we describe the possible formation scenario. Conclusions are gathered in Sect. 6.

2. Cluster membership

Determination of cluster membership is the first step to demonstrate that a star is a blue straggler. For this purpose the Praesepe cluster is a perfect object since it has proper motions and mean radial velocity that are distinct from the field stars in its vicinity. This peculiarity can be seen on the atlas of the Praesepe cluster published by Kharchenko et al. (2005) where they show the proper motions of the cluster members, concentrated around the
mean (−35.90, −12.88) mas/yr, compared with the motions of the field stars lying in the same region of (−8.68, −1.37) mas/yr with a dispersion, of the cluster stars, of \( \sigma_{\mu_\alpha} = 13.58 \pm 3.71 \) mas/yr (Kharchenko et al. 2004).

In recent years major studies of cluster membership have been published by Wang et al. (1995), Robichon et al. (1999), Baumgardt et al. (2000), Kharchenko et al. (2004) and Dias et al. (2006). HD 73666 is considered by Robichon et al. (1999) and Baumgardt et al. (2000) to be a cluster member, and used to derive the mean cluster astrometric parameters and mean radial velocity. Kharchenko et al. (2004) as well consider HD 73666 as a cluster member having a kinematic membership probability of 0.3175, a photometric membership probability of 1.0000 and a positional probability of 1 (Kharchenko considers every star with a kinematic and photometric membership probability higher than 0.14 as a probable member of the cluster).

Table 1 shows a comparison between the cluster mean values of parallax, proper motion and radial velocity for Praesepe, and the individual values for HD 73666. \( \mu_\alpha \cos(\delta) \) and the radial velocity are in agreement within one \( \sigma \), but \( \mu_\delta \) for the cluster and the star differ by 2.7\( \sigma \). If one takes the cluster members listed by Robichon et al. (1999), and selects from the recent re-reduction of the Hipparcos data by van Leeuwen (2007) the 12 proper motions with measurement uncertainties comparable to those of HD 73666, it is found that the dispersion of \( \mu_\delta \) is approximately 1.1 mas/yr, a value very similar to the difference between the Praesepe \( \mu_\delta \) cluster mean and the value for HD 73666. Thus the apparent discrepancy between cluster and star values of \( \mu_\delta \) is typical of all the most precise \( \mu_\delta \) values for the cluster. The origin of this effect is not clear to us, but our conclusion is that the agreement between cluster and stellar mean values is as satisfactory for HD 73666 as it is for most of the most precisely measured stars in the cluster, and is not a cause for concern for this specific star.

### 3. Fundamental parameters and Color-Magnitude diagram

Fossati et al. (2007) derived, from high resolution spectroscopy, \( T_{\text{eff}} \) and \( \log g \) of HD 73666. They obtained \( T_{\text{eff}} = 9380 \pm 200 \) K and \( \log g = 3.78 \pm 0.2 \). These parameters are confirmed also by spectrophotometry taken from Clampitt & Burstein (1997), we calculated theoretical stellar fluxes with the model atmosphere code ATLAS9 (Kurucz 1979) with these values of \( T_{\text{eff}} \) and \( \log g \) and then normalised the fluxes at 5560 Å. The comparison between the spectrophotometry and the normalised fluxes is shown in Fig. 2.

![Fig. 2. Comparison between spectrophotometry from Clampitt & Burstein (1997) and theoretical fluxes normalised at 5560 Å with the fundamental parameters of HD 73666.](image)

Figure 3 shows the color-magnitude (CM) diagram of the cluster, built using the photometry taken from Johnson (1952). In the plot we display also two isochrones from Girardi et al. (2002), with metallicity \( Z = 0.024 \pm 0.002 \) dex taken from Chen et al. (2003), but with different ages. The full line represents the isochrone corresponding to the cluster age of \( \log t = 8.85 \pm 0.15 \) dex (González-Garcí et al. 2006), while the dashed line represents the isochrone that best fits the position of HD 73666 on the HR diagram, corresponding to an age of \( \log t = 8.55 \). In Fig. 3 we adopted a distance modulus of 6.30 mag (van Leeuwen 2007) and a reddening of 0.009 mag (Mermilliod & Paunzen 2003; van den Bergh 2006).

The CM diagram shows clearly the blue straggler property of HD 73666. According to Fossati et al. (2008), HD 73666 appears to be about 1200 K hotter than the hottest main sequence star member of the cluster. The mass of HD 73666 that Fossati et al. (2008) derived, from the Hertzsprung-Russell (HR) diagram, is \( 2.46 \pm 0.12 \) M\(_\odot\). This value is about 0.4 M\(_\odot\) higher than the mass of the other most massive (mass higher or equal to 2 M\(_\odot\)) main sequence cluster stars. Infact following the results of Fossati et al. (2008), the four most massive main sequence stars (excluding HD 73666) are: HD 73618 (2.16 \pm 0.22 M\(_\odot\)), HD 72846 (2.09 \pm 0.15 M\(_\odot\)), HD 73711 (2.08 \pm 0.10 M\(_\odot\)), and HD 73709 (2.00 \pm 0.14 M\(_\odot\)). From \( T_{\text{eff}} \) and \( \log L/L_\odot \) we derive a radius of \( R/R_\odot = 2.72 \pm 0.12 \).

One of the possible explanations of the existence of blue stragglers is that the star is a horizontal branch star with the same temperature and luminosity of main sequence stars. This

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**Fig. 1.** Location of HD 73666 relative to stars with a membership probability higher than 40% as tabulated in Adams et al. (2002). The center of the cluster is also shown.

**Fig. 1.** Location of HD 73666 relative to other cluster members, which is very near to the center of the cluster. In conclusion, there is very little reason to doubt that HD 73666 is a member of Praesepe.
Table 1. Proper motion and radial velocity of the Praesepe cluster and HD 73666.

|       | RA      | DEC     | π      | σ_π     | μ_α cos(δ) | σ_μ_α cos(δ) | μ_δ       | σ_μ_δ | v_r | σ_v_r | T_eff | log L/L⊙ |
|-------|---------|---------|--------|---------|------------|-------------|-----------|-------|-----|-------|-------|----------|
| Praesepe | 08 40.4 | +19 41  | 5.49   | 0.19    | −35.68     | 0.30        | −12.72    | 0.25  | 34.5 | 0.0   | (…)   | (…)     |
| HD 73666 | 08 40.2 | +19 58  | 5.53   | 0.50    | −35.52     | 0.62        | −13.97    | 0.39  | 34.1 | 0.4   | 9380   | 1.71     |

v_r, σ_v_r, and T_eff of HD 73666 are taken from Fossati et al. (2007). log L/L⊙ of HD 73666 is taken from Fossati et al. (2008). All the other data are taken from van Leeuwen (2007).

Fig. 3. Color-magnitude diagram of the Praesepe cluster. The full square indicates the position of HD 73666. The photometry was taken from Johnson (1952). The full line shows an isochrone from Girardi et al. (2002) for the age and metallicity given in the literature by González-García et al. (2006) and Chen et al. (2003) respectively (log t = 8.85 dex; Z = 0.024). The dashed line represents an isochrone with the same metallicity, but an age of log t = 8.55, that best fits the position of HD 73666 in the HR diagram.

Fig. 4. Comparison between the observed and synthetic Hα line profile assuming a fixed T_eff = 9380 K and two different log g: 3.78 (assumed – dashed line) and 3.5 (maximum for an horizontal branch star – dotted line).

exploration does not seem very probable: the horizontal branch is bluer in a low-metallicity environment (see e.g. Sandage & Wallerstein 1960) and the metallicity of the Praesepe cluster is Z = 0.024±0.002 dex (Chen et al. 2003) showing that Praesepe is not a low-metallicity open cluster. However, a few such stars might exist unrecognised, and so we examine this possibility.

What distinguishes horizontal branch from main sequence stars is their mass-radius relation leading to log g values different from the ones typical of main sequence stars. For horizontal branch stars at T_eff ~ 9000 K log g ranges between 3.1 and 3.5 (Mohler 2004). For a star of the same values of T_eff and log L/L⊙ (and hence K/R⊙) that we observe, but a mass of 0.6M⊙, log g would be 3.35 ± 0.05. Figure 4 shows the observed Hα line profile of HD 73666 in comparison with two synthetic profiles, calculated with Synth3 (Kochukhov 2007), assuming T_eff = 9380 K, log g = 3.78 (dashed line) and log g = 3.5 (dotted line). We calculated the probability that the observed Hα line profile is fitted by the synthetic profile calculated with log g = 3.78 or log g = 3.5. With the higher log g we obtained a probability of 99.95%, while with the lower log g the probability is of 0.05%. The lower log g value is too low, indicating that HD 73666 is very probably not a horizontal branch star appearing above the turn-off point. This statement disagrees with the conclusion of Conti et al. (1974).

4. Abundances

The abundance pattern of HD 73666 was recently derived by Andrievsky (1998), Burkhart & Coupry (1998) and Fossati et al. (2007). The three abundance patterns are all comparable; the most complete determination is given by Fossati et al. (2007) and is reproduced in Fig. 5 together with the mean abundance pattern of the A- and F-type stars member of the cluster.

The main characteristics of the abundance pattern of HD 73666 are: a solar He abundance, overabundance of about 0.4 dex for C, N and O, solar abundance for Ca and Sc (that excludes an Am classification) and a mean overabundance of about 0.4 dex for the other analysed elements (Na, Mg, Al, Si, Ar, K, Ti, V, Cr, Mn, Fe, Ni, Y and Ba). The Li abundance shown in Fig. 5 (+2.8 dex, relative to the Sun) is an upper limit since at the T_eff of HD 73666 the strongest Li line visible in the optical region (at λ ~ 6707 Å) appears in a synthetic spectrum with

1 The abundances are in log(N/X tot) − log(N/X tot) solar.
Fig. 5. Comparison between the abundances of the analysed elements obtained for HD 73666 (open circles) and the mean abundances obtained for the A-type (open squares) and F-type (open triangles) stars member of the cluster. The error bar given to the abundances of HD 73666 is fixed to 0.2 dex for all elements. The uncertainty given to the mean abundances are the standard deviations from the mean abundance. The arrow indicates that the Li abundances are relative to the Sun (Asplund et al. 2005) and were taken from Fossati et al. (2007) and Fossati et al. (2008).

5. Other formation scenarios

5.1. HD 73666 as a second generation star

One possible formation scenario for a blue straggler is that the object is a second or even third generation star. Multiple episodes of star formation manifest themselves in a split of different evolutionary sequences when observed in a cluster color-magnitude diagram. Multiple stellar populations were already discovered in galactic and Magellanic Cloud clusters (Piotto 2008).

The color-magnitude diagram of the Praesepe cluster, displayed in Fig. 3, shows clearly the presence of one evolutionary sequence. If a second evolutionary sequence is present, the further episode of star formation happened at a time within the uncertainty given for the cluster age. The possibility that HD 73666 is a second or third generation star would imply the existence of a star formation mechanism that is able to form a single star of about $2.5 \, M_{\odot}$ close to the center of the cluster. We find this possibility extremely unlikely.

5.2. Mass transfer

5.2.1. Distant companion

Hartkopf & McAlister (1984) observed HD 73666 using speckle interferometry to determine binarity, because of the over luminosity of the star, but did not find a companion. McAlister et al. (1987) made speckle interferometry observations of HD 73666 in 1983. They discovered the presence of a companion star at a separation $\rho=0.425 \pm 0.009$ and a position angle $\theta=127.6 \pm 0.5$ degrees on 1983.0477. Mason et al. (1993) observed the star another 11 times, detecting the companion only twice, on 1986.8922 ($\rho=0.434 \pm 0.009$, $\theta=133.7 \pm 0.5$ degrees) and 1987.2664 ($\rho=0.425 \pm 0.009$, $\theta=134.1 \pm 0.5$ degrees), concluding that the star “shows little orbital motion”. These measurements suggest that the companion star probably has common proper motion with HD 73666.

The secondary is $2.5 \pm 0.5$ magnitudes fainter (Mason, private communication) than the primary star. This would make the secondary an F star of about $1.5 \, M_{\odot}$. At a distance of 180 pc, the angular separation would mean a minimum separation at this time about 80 AU, which suggests a period of order 450 yr or more. The derived separation of 80 AU excludes any interaction between the two stars, unless the mutual orbit is extremely eccentric, a characteristic which would hardly survive a period of heavy mass exchange.

Binarity has several consequences. Firstly, it favors the present location of the system at the cluster center, since Praesepe clearly shows mass segregation effects (Kraus & Hillenbrand 2007). Secondly, collisions involving binary systems are an effective way of forming blue stragglers (Leonard & Linnell 1992).

5.2.2. Close companion

The detection of a white dwarf or subdwarf companion close to HD 73666 would be very important, as it would clearly show that the blue straggler has been formed by mass transfer. Such a companion could be detectable through variable radial velocity or visible in the spectrum of HD 73666.

The presence of a small close companion (white dwarf or subdwarf) can be tested by searching for radial velocity variability. Fossati et al. (2008), in their Fig. 13 and Fig. 14, show that the star had no radial velocity variations between January 2006 and March 2007. The two measured radial velocities are also in agreement (see also Table 1) with the cluster mean. Fossati et al. (2008) also collected the radial velocity measurements obtained in the past by Abt (1970), Conti et al. (1974), Abt & Willmarch (1999) and Madsen et al. (2002), concluding that all these measurements are consistent with one another and with the cluster mean. In particular Conti et al. (1974) measured the radial velocity 33 times over 14 years. They tried to fit a periodic function to their data and concluded that no periodic variation can be fit to the data. From these data they derived the probability that a close companion could go undetected, assuming a random orientation of the orbital plane (see their Fig. 1). They assumed a 5:1 mass ratio (compatible with the possibility of a subdwarf or white dwarf companion) and a conservative velocity amplitude $K_1 \leq 1 \, \text{km s}^{-1}$. Note that a companion as distant as 15 AU, about the limit possible for orbital stability (Bailyn 1987) and well beyond the limit for significant mass transfer, would have an orbital velocity of order $12 \, \text{km s}^{-1}$. Conti et al. (1974) concluded that “for systems likely to be involved in mass exchange, the chance of their being undiscovered is remote indeed”.

| element | HD 73666 | mean A-type stars | mean F-type stars |
|---------|---------|-----------------|-----------------|
| He      |         |                 |                 |
| Li      |         |                 |                 |
| C       |         |                 |                 |
| N       |         |                 |                 |
| O       |         |                 |                 |
| Na      |         |                 |                 |
| Mg      |         |                 |                 |
| Al      |         |                 |                 |
| Si      |         |                 |                 |
| S       |         |                 |                 |
| Ar      |         |                 |                 |
| K       |         |                 |                 |
| Ca      |         |                 |                 |
| Sc      |         |                 |                 |
| Ti      |         |                 |                 |
| V       |         |                 |                 |
| Cr      |         |                 |                 |
| Mn      |         |                 |                 |
| Fe      |         |                 |                 |
| Ni      |         |                 |                 |
| Y       |         |                 |                 |
| Ba      |         |                 |                 |

abundance relative to the Sun

| element | 0 | 0.4 | 0.8 | 1.2 | 1.6 | 2 | 2.4 | 2.8 |
|---------|---|----|----|----|----|---|----|----|
| HD 73666 | O |     |    |    |    |   |     |     |
| mean A-type stars | O |     |    |    |    |   |     |     |
| mean F-type stars | O |     |    |    |    |   |     |     |
We extended the analysis of Conti et al. (1974) by carrying out a frequency analysis on the basis of all the radial velocity data found in literature (65 data points), which now span a time base of about 52 years. We have excluded a priori all the frequency peaks corresponding to periods of less than 1 year, since they should have already been previously detected. Three peaks at periods between 20 and 70 years are found, but all of them have a probability density (which ranges between 0 and 1) of less than 0.00002, making the presence of a close companion very unlikely. Note that Fossati et al. (2007) listed HD 73666 as a single-line spectroscopic binary (SB1), an incorrect classification which should be ignored.

The presence of a hot close companion can be checked through UV spectra as well. Figure 5 shows a comparison of IUE spectrophotometry of HD 73666, calculated fluxes for this star assuming that it is a single object, theoretical fluxes for a typical white dwarf \( T_{\text{eff}} = 15000 \text{ K} \ – \) upper panel; \( T_{\text{eff}} = 20000 \text{ K} \ – \) lower panel), and the sum of the two theoretical fluxes. For the white dwarf we assumed \( \log g = 8.0, R/R_{\odot} = 0.013 \) and the abundances obtained by Kawka et al. (2008) for BPM 65B2, which has fundamental parameters similar to those assumed here. The fluxes were calculated with the use of the LTE code LLMODELS, which uses direct sampling of the line opacities (Shulyak et al. 2004) and makes it possible to compute model atmospheres with an individualised abundance pattern. Taking into account the radii of the two objects we have derived the total flux that would be visible if HD 73666 were to have this particular white dwarf companion. The plot shows that UV fluxes would not clearly reveal the presence of a white dwarf companion of \( T_{\text{eff}} = 15000 \text{ K} \), but would allow us to recognise the presence of a hotter white dwarf.

According to the cooling sequences published by Prada-Moroni & Straniero (2002), a white dwarf formed more than half the cluster age ago, would have a luminosity of \( \log L/L_{\odot} \leq -2 \), with a temperature \( T_{\text{eff}} \leq 15000 \text{ K} \). Thus the observed fluxes of HD 73666 do not exclude the presence of a white dwarf companion if mass transfer had occurred during the first half of the cluster age, within the first 350 Myr. Figure 6 however excludes mass transfer onto HD 73666 during roughly the past 200 Myr.

On the basis of the analysis of the collected radial velocity measurements and of the UV analysis we conclude that the primary component of HD 73666 is therefore itself very likely a single star, with only the visual companion to make it a binary system. If this is not the case and mass transfer produced the blue straggler, it must have occurred at least of order 200 Myr ago.

5.3. Merging and collisional formation scenario

As mentioned in Sect. 1, Ahumada & Lapasset (2007) reviewed the different theories of blue straggler formation. From these theories we already concluded that both the horizontal branch confusion, multiple episodes of star formation and mass transfer from a close companion are quite improbable. Among the seven scenario, the remaining possible channels of blue straggler formation for HD 73666 are: collisional mergers of two stars, merger of the two components of a close binary system, and collisional mergers between binary systems.

To consider stellar mergers and collisions as an effective way to form blue stragglers, it is important to estimate the merger and collision probability. Portegies Zwart et al. (2004) modelled the evolution of Praesepe-like open clusters, using simulations that include stellar dynamics and effects of stellar evolution. Portegies Zwart et al. (2004) considers that all mergers are due to binaries: either binary coalescence due to unstable mass transfer, or due to perturbation by a third body. They concluded that for Praesepe-like open clusters the collision rate is about one per 100 Myr and the merger rate of two components of a close binary system is about one per 50 Myr. Taking into account an age for the Praesepe cluster of about 700 Myr, the fact that Praesepe shows mass segregation (Kraus & Hillenbrand 2007) and that HD 73666 is placed close to the cluster center, it is highly probable that within the given cluster age stellar collisions and mergers happened.

Fig. 6. Comparison between IUE spectrophotometry (thin full line) and theoretical LLMODELS fluxes for HD 73666 (thick full line), for a typical white dwarf \( T_{\text{eff}} = 15000 \text{ K} \ – \) upper panel / \( T_{\text{eff}} = 20000 \text{ K} \ – \) lower panel, \( \log g = 8.0, R/R_{\odot} = 0.013 \) dotted line and for the two components together (dashed line). All the theoretical fluxes take into account the estimated stellar radii. The theoretical fluxes have a different resolution (~900) than the IUE spectra (~900) for visualisation reasons.

Shetrone & Sandquist (2000) derived abundances of blue stragglers and turn-off stars in M 67, to obtain chemical signatures to distinguish between stragglers formed by collision or by binary mass transfer. They mention that a severe lack of lithium could be an important signature of a stellar collision (Lombardi et al. 2002), although a lack of lithium is expected as well in blue stragglers formed for mass transfer, so that the lithium depletion alone is not enough to indicate a collisional origin. In HD 73666 Li is also not observed and it is not possible to detect if this is a temperature effect or a real lack of lithium. Shetrone & Sandquist (2000) also concluded that C, N and O may be more
useful. In particular, a blue straggler formed by collision will not change the original CNO abundances, which should be similar to those of the turn-off stars. In case of formation by binary mass transfer, CNO should be modified and the secondary would become a helium or CO white dwarf. Following the model published by Chen & Han (2004) it is possible to deduce how much the CNO abundances of the primary star would change due to mass transfer. According to their models, the oxygen abundance should not vary, while the carbon abundance should decrease by about 50% and the nitrogen abundance increase by about 150%. Both the nitrogen and carbon abundances of HD 73666 are comparable with the ones of the other A-type stars of the cluster (see Fig. 5). This result is consistent with our conclusion given in Sect. 5.2 that most likely HD 73666 does not have a close companion and therefore did not undergo mass transfer. Since we have eliminated the alternatives, we conclude that HD 73666 was very probably formed by merging or collision.

6. Discussion and conclusion

We next consider whether the surface CNO abundances could provide information about a stellar collision. We consider the predictions of Sills et al. (2005) on the surface helium and CNO abundance of stragglers formed after the collision of two low mass stars (0.6 $M_\odot$). They found that the He and CNO abundance change from the original abundance of the two colliding stars but not fast enough to be visible within 350 Myr, that is the estimated maximum age of HD 73666 since becoming a blue straggler (see Sect. 6.1).

If instead we consider a collision between a 2 $M_\odot$ star (operating via CNO cycle) and a 0.5 $M_\odot$ star, we would expect that the CNO present in the core would stay in the core of the remnant star, as He does in low mass stars. Note however that the collision of a high mass and a low mass star, as forming mechanism for HD 73666, is somewhat less probable than the collision of two stars of masses near 1 $M_\odot$, considering that in the center of the cluster the mean stellar mass is about 0.8 $M_\odot$ (Adams et al. 2002). It is also important to mention that the models proposed by Lombardi et al. (1996) and Lombardi et al. (2002) show a small mass-loss, during the collision (between 1 and 10% of the total mass of the colliding stars).

We conclude that the abundances of CNO in HD 73666, which are similar to those of the turn-off stars, are consistent with collisional formation.

Since we did not find any evidence to contradict the merging and collisional formation scenario, it seems probable that HD 73666 was formed through a collisional mergers of two stars or a merger of the two components of a close binary system or a collisional mergers between binary systems.

It is important to stress that we are not able to establish which of these two formation mechanisms is the most probable for HD 73666.

6.1. Minimum and Maximum Times Since Formation

A minimum age can be deduced if the blue straggler was formed by a physical stellar collision. Sills et al. (1997, 2001, 2002) showed that the remnants of physical stellar collisions, in particular of off-axis collisions, should be very fast rotating objects with typical rotational velocities similar or greater than the break-up velocity. This brought to the conclusion that if blue stragglers are formed also by stellar collisions a mechanism to reduce the angular momentum must exist. Sills et al. (2005) showed that such spin-down mechanism can be effective through mass loss and that the star loses about 80% of its angular momentum within 5 Myr, while a blue straggler like HD 73666 need about 1.4 Myr to reach the main sequence after the collision. HD 73666 shows an unusual slow rotation for an A1V star, so that if the star is actually slowly rotating the minimum age of the star as a blue straggler could be set close to 5 Myr.

Fossati et al. (2007) derived a non-zero microturbulence velocity: $v_{mic} = 1.9 \pm 0.2$ km s$^{-1}$, but this is a fairly normal value for a star of this mass, and appears to indicate the disappearing of large scale convection zones, near the surface of the star. This is in agreement with several recent modelling of collisionally formed blue stragglers (e.g. Sills et al. 1997, Glebbeek & Pols 2008).

The maximum age of HD 73666 since becoming a blue straggler is given by the age of the isochrone on which it lies in Fig. 3. This is about 350 Myr. If HD 73666 is an intrinsically slow rotator ($v \sin i \leq 90$ km s$^{-1}$, Charbonneau & Michaud 1991), a further maximum age limit is provided by the time it takes for a slowly-rotating A1V star to develop chemical abundance anomalies, such as Am characteristics, by diffusion since the end of convection in its outer envelope. Laloe et al. (2006) computed evolutionary models with diffusion for stars of 1.7 to 2.5 $M_\odot$. Their most relevant model, labeled 2.5P2, for a star of mass 2.5 $M_\odot$ and rotation speed 15 km s$^{-1}$, shows clear abundance anomalies before 50 Myr, which we can conservatively set as the maximum age of HD 73666. This is, of course, valid if HD 73666 is now an intrinsically slow rotator. The fact that HD 73666 appears so far off the ZAMS does not contradict the given maximum age of 50 Myr since collisionally formed blue stragglers appear on the main sequence not on the ZAMS, but at an already evolved stage.

6.2. Conclusion

We conclude that the Praesepe blue straggler, HD 73666, was likely formed by physical stellar collision and merger of two low-mass stars, between 5 and 350 Myr ago (50 Myr if the star is an intrinsic slow rotator) if current models are correct.

On the basis of our knowledge of HD 73666 it is not possible to distinguish between a direct stellar collision and binary coalescence as the formation mechanism for HD73666. HD 73666 could be a perfect object to test current models of collisionally formed blue stragglers. The wide and detailed knowledge available about this star and the environment in which this star is present would allow to test the reliability of current models and to give important constraints for their future development.

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