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Is WD0433+270 an iron–core white dwarf?

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We study a common proper motion pair formed by a white dwarf (WD0433+270) and a main-sequence star (BD+26 730) that apparently has been classified as a member of the Hyades open cluster. Previous studies of the white dwarf component yielded a cooling time of ~ 4 Gyr. Although it has not been discussed before explicitly, this result is 6 times larger than the age of the Hyades cluster, giving rise to an apparent conflict between the cooling ages of white dwarfs and those of main sequence stars. We investigate whether this system really belongs to the Hyades cluster and, accordingly, provide a possible explanation of the nature of the white dwarf member considering different core compositions.

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1. Introduction

In this contribution we discuss a case that presents an interesting puzzle in which the age estimate stemming from the white dwarf cooling sequence is in apparent conflict with the age estimate obtained from cluster membership. The object is G39−27/289, a common proper motion pair formed by a DA white dwarf (WD0433+270) and a K type star (BD+26 730), which is a well studied variable star (V833 Tau) and also a single–lined spectroscopic binary with a very low–mass companion. The members of a common proper motion pair were likely born simultaneously and with the same chemical composition. Since the components are well separated ($\sim 2\,200$ AU), no mass exchange has taken place and they have evolved as isolated stars. Thus, it is logical to assume that both components of G39−27/289 have the same age and the same original metallicity. The K–star component, and, by extension, its common proper motion companion, were classified as Hyades members in Ref. [1] and therefore would have an age ranging from about 0.6 to 0.7 Gyr. However, this stands in obvious conflict with the cooling time of WD0433+270, which has been estimated to be about 4 Gyr [2].

2. Observations and analysis

We have observed both components of the common proper motion pair with the objective of characterizing their properties. In the case of BD +26730, we performed observations with the FOCES echelle spectrograph on the 2.2 m telescope at CAHA (Almería, Spain), obtaining $R \sim 47\,000$. The data were reduced following the standard procedures using the echelle tasks of the IRAF package. Following the method described in Ref. [3], we derived its effective temperature and metallicity. The resulting value of $T_{\rm eff} = 4595 \pm 30$ K is in good agreement with previous determinations. The chemical composition analysis yielded a nearly solar metallicity of [Fe/H]= 0.03 ± 0.09. The total luminosity is $L = -0.527 \pm 0.021$. The age of BD+26730 can not be determined reliably from the fit to model isochrones because of the relative proximity of the star to the zero–age main sequence. Note, however, that a determination of the Li abundance of this star, $\log N_{\rm Li} = 0.23$, has been derived previously [4]. The comparison of the Li abundance and the effective temperature with Li depletion isochrones yields an age of 800 Myr. Both, the Li abundance and this latter result, suggest a Hyades age for BD+26 730.

In the case of WD0433+270 we performed observations with the LCS spectrograph of the Harlan J. Smith (2.7 m) telescope at McDonald Observatory (Texas, USA) covering some of the main Balmer lines (from 3 885 to 5 267 Å) and obtaining a resolving power of ~ 5 Å FWHM. We used the standard procedures within the single–slit tasks of the IRAF package. The spectrum shows weak absorption lines but we were able to unambiguously identify H_β and classify this white dwarf as a DA white dwarf, in good agreement with previous analyses [2, 5]. The luminosity of the white dwarf can be derived from its effective temperature, $T_{\rm eff} = 5\,620 \pm 110$ K, and distance, $d = 16.95 \pm 0.86$ pc, and considering its apparent magnitude and the suitable bolometric corrections. We obtained $\log(L/L_\odot) = -3.92 \pm 0.04$, and, from this, a radius of $R = 0.0115 \pm 0.0010\ R_\odot$. Both results are in good agreement with those reported in Ref. [2].

	μ_α (mas/yr)	μ_δ (mas/yr)	v_r (km/s)	$U \pm \sigma_U$ (km/s)	$V \pm \sigma_V$ (km/s)	$W \pm \sigma_W$ (km/s)
WD0433+270[a]	228	−155	+36.3	−39.2	−15.5	−1.8
WD0433+270[b]	228	−155	+41.7	−44.4	−15.7	−3.9
BD+26 730[c]	232.36	−147.11	$+36.18 \pm 0.08$	−39.4	−17.2	−1.6
Hyades OC	...	...	...	-42.8 ± 3.6	-17.9 ± 3.2	-2.2 ± 5.2
Hyades SCl(1)	...	...	...	-31.6 ± 2.8	-15.8 ± 2.8	0.8 ± 2.7
Hyades SCl(2)	...	...	...	-33.0 ± 4.2	-14.1 ± 4.0	-5.1 ± 3.1
Hyades SCl(3)	...	...	...	-32.8 ± 2.8	-11.8 ± 2.8	-8.9 ± 2.9
Hyades Stream	...	...	...	-30.3 ± 1.5	-20.3 ± 0.6	-8.8 ± 4.0

Table 1: Spatial velocities for the studied stars and the Hyades cluster and streams.

[a] Proper motions from [15] and velocities from [5].
[b] Proper motions from [15] and velocities recalculated considering a Fe-core composition (see §4).
[c] Spatial velocities calculated from the radial velocity and proper motions reported by [1].

3. Membership to the Hyades

The color index of WD0433+270 is too red to be a member of the Hyades cluster [6], although the radial velocity of its companion is identical to the value predicted from membership. Consequently, it has been concluded that G39−27/289 is projected on the cluster but only at about a third of the cluster's distance. Additionally, 5 490 stars of the Hipparcos Catalog corresponding to the field of the Hyades have been analyzed and it has been found that the distance of BD+26 730 to the center of the cluster is 29 pc [1]. Therefore, WD0433+270 has been classified as a former member of the Hyades cluster, currently lying beyond the tidal radius (∼10 pc). The density–velocity inhomogeneities of an absolute magnitude limited sample of A–F type dwarfs in the Hyades supercluster have been recently mapped [7]. Three different clumps within the Hyades stream have been distinguished, each one of them with characteristic space velocities. Probably, the Hyades stream contains three groups of 0.5–0.6 Gyr, 1 Gyr and 1.6–2 Gyr, which are in an advanced stage of dispersion in the same velocity volume. In Table 3 we provide the radial and space velocities of BD+26 730 and WD0433+270. We also give the kinematic properties of the Hyades open cluster (OCl) and of each clump (SCl) within the stream [7]. The recently derived spatial velocities of the Hyades stream [8] are also listed. As can be seen, both members of the common proper motion pair have velocities compatible with those of the Hyades open cluster and are somewhat different from the velocities characteristic of the Hyades stream or the clumps within the stream.

The metallicity derived here, $[\mathrm{Fe/H}] = 0.03 \pm 0.09$, is in reasonably good agreement with the Hyades metallicity, $[\mathrm{Fe/H}] = 0.14 \pm 0.05$. Another important point is the Li abundance of BD+26 730, which clearly favors a relatively young age for this object. Hence, the metallicity, the kinematic properties and the Li abundance of BD+26 730 seem to favor the hypothesis that this system is indeed linked with the Hyades cluster, although it has a location beyond the tidal radius of the cluster. If this is correct, the members of the pair should have the age of the Hyades cluster (625 ± 50 Myr).

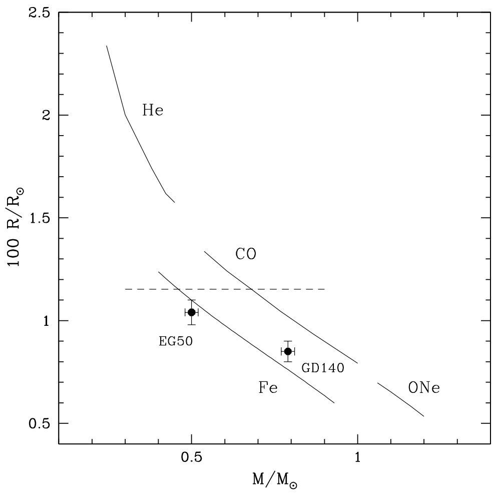

Figure 1: Mass–radius relations for different core compositions. The dashed line corresponds to the radius of WD0433+270. The filled circles correspond to observational data of other white dwarfs [13].

	$M_{\rm WD}\,(M_\odot)$	$t_{\rm cool}$ (Gyr)
C/O core	0.67 ± 0.03	4.1 ± 1.2
Fe core	0.46 ± 0.07	1.0 ± 0.1

Table 2: Masses and cooling times for WD0433+270 assuming a C/O core and a Fe core.

4. The composition of WD0433+270

In order to unveil the nature of WD0433+270 we consider all the feasible compositions that have been proposed to date. In Fig. 1 we show mass-radius relations considering different core compositions: He [9], C/O [10], O/Ne [11] and Fe [12]. All these relations correspond to $T_{\rm eff} = 5\,500$ K. As can be seen, the radius of WD0433+270 only has a corresponding mass in the case of C/O and Fe cores. The radii of several field white dwarfs have been derived using parallaxes and effective temperatures. From these radii and the surface gravities, which were previously determined independently from spectroscopic fits to white dwarf models, the masses can be derived. In two cases (GD140 and EG50) the masses derived in this way were too small to fit the C/O mass–radius relation. The best explanation for these stars that they have a Fe core [13].

The gravitational redshift and the radial velocity of a white dwarf are two interdependent parameters. The radial velocity of WD0433+270 assuming a C/O composition is known [5]. We have recomputed this value considering the mass–radius relation of Fe white dwarfs. In both cases — see Table 3 — the velocities are compatible with those of the Hyades cluster. We can also assume that WD0433+270 has the same radial velocity as BD+26 730 and estimate its mass independently of the composition of the core by using the observed velocity. The result obtained, $\sim 0.55\,M_\odot$, does not conclusively favor any of the two compositions (C/O or Fe). Once the masses

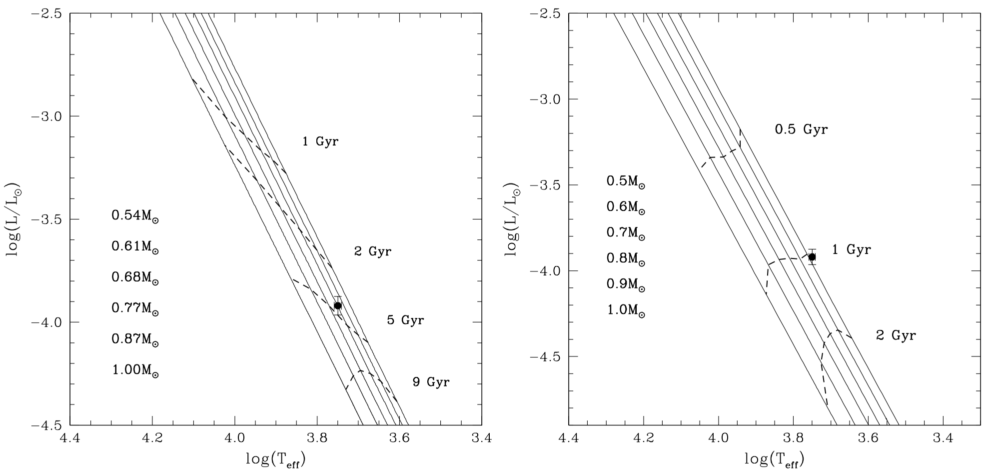

Figure 2: Luminosity versus $T_{\rm eff}$ for different cooling tracks: C/O core (left) and Fe core (right).

that correspond to each core composition are known (see Table 4) we can calculate the cooling times using the proper cooling sequences. As expected from mass–radius relations we have not obtained a correspondence with the O/Ne- and He-core model sequences since the physics of white dwarfs with these compositions predicts masses that are too large or too small, respectively. In Fig. 2 we show the cooling sequences for C/O white dwarfs (left panel) and for Fe white dwarfs (right panel). The dashed lines correspond to cooling isochrones. The filled circle corresponds to WD0433+270. The cooling time derived when considering the cooling sequences of C/O white dwarfs is $\sim$4 Gyr, which is in excellent agreement with previous results [2]. This cooling time is 6 times larger than the age of the Hyades open cluster and 2 times larger than that of the older Hyades stream group — about $\sim$2 Gyr [7]. On the other hand, the cooling time obtained when considering an Fe core is $\sim$1 Gyr, which is 4 times smaller than that of C/O white dwarfs. This is because Fe nuclei are much heavier than C or O nuclei and, hence, the specific heat per gram is much smaller. This latter result is in better agreement with the age of the Hyades open cluster. The total age of a white dwarf includes also the progenitor lifetime, but for the case in which a Fe white dwarf is considered it can be neglected, since the progenitor is massive.

5. Conclusions

We have characterized better the members of the common proper motion pair G39−27/289. The kinematic properties of the members of the pair and the Li detection in BD+26 730 favors the scenario in which this pair is indeed a former member of the Hyades cluster, and thus its members have a coeval age of $\sim$0.6–0.7 Gyr. Having evaluated different compositions for WD0433+270, the young age inferred from cluster membership is only compatible with this white dwarf having an Fe core, with a cooling time of $\sim$1 Gyr. The existence of white dwarfs with an Fe core has important consequences for the models of thermonuclear explosion of stellar degenerate cores. According to the theory of stellar evolution, all stars that develop an Fe core experience a collapse to a neutron star or a black hole, regardless of the mass–loss rate assumed. However, there is still an alternative possibility of avoiding this final fate, which relies on the failure of the thermonuclear explosion of a degenerate white dwarf near the Chandrasekhar limit [14].

Another possibility is that the common proper motion pair might not be related in any way to the Hyades cluster. In this case, the age of both members could be $\sim$4 Gyr, which is compatible with a C/O composition. This would have some interesting consequences for our current view of moving groups in the Galaxy. The Hyades stream contains at least three distinct age groups with ages up to 2 Gyr [7]. This upper limit was probably a consequence of using A–F stars as kinematic tracers, which would have a cutoff age at about 2–3 Gyr. With an age of 4 Gyr, this pair would indicate the existence of an even older population in the Hyades stream, thus completely ruling out any coevality within the members. This would lend strong support to the model of a resonant origin for the Hyades stream. Another implication of such an old age is the conflict with Li detection, which would imply much lower destruction rates than expected. Definitive proof supporting one of these scenarios will have to await an unambiguous determination of the mass of the white dwarf or a more conclusive study of the evolutionary link with the Hyades cluster.

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