The evolutionary state of the chemically peculiar members of the open cluster NGC 2516

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ABSTRACT
We aim at establishing safe membership and evolutionary status of 11 chemically peculiar (CP) stars that are residing in the domain of the open cluster NGC 2516 and are frequently referred to as cluster members. We queried the Gaia EDR3 catalogue in an area with a radius of 1 deg and selected 37508 stars brighter than G = 19 mag. The cluster membership was determined in parallax-proper motion-space and 719 probable and 764 possible members were found. The obtained average astrometric and photometric parameters of the cluster are in good agreement with the most recent literature data. The evolutionary status of the target stars was determined with respect to Padova isochrones. After minor adjustments including the metallicity, the reddening, and the transformation scale variation, a perfect fit of the model to the observations over the whole observed magnitude range was achieved. Only 5 of the 11 considered CP stars could be classified as highly probable cluster members. Among the Ap/Bp stars with previously detected magnetic fields HD 65987 and HD 65712 have a high membership probability and the magnetic star CPD−60 944B is a possible cluster member. Further we discuss the blue straggler nature of HD 66194 and the magnetic star HD 65987. To our knowledge, HD 65987 is currently the only known blue straggler, with a field of the order of a few hundred Gauss. The most striking result of our study is that the strongly magnetic A0p star HD 66318 with previously reported very low fractional age does not belong to the NGC 2516 cluster at a high level of confidence.

Key words: methods: data analysis — stars: chemically peculiar — open clusters and associations: individual: NGC 2516 — blue stragglers — stars: magnetic field — stars: evolution

1 INTRODUCTION
Knowledge about the evolutionary state of the intermediate-mass main-sequence chemically peculiar (CP) A- and B-type stars is essential to understand both the physical processes taking place in these stars and the origin of their magnetic fields. Moss (2003) suggested that magnetic Ap/Bp stars acquire their magnetic field at the time of their formation or early in their evolution and what is currently observed is then a fossil field. The competing dynamo theory proposes that the magnetic field is generated by a turbulent dynamo operating in the star’s convective core (Spruit 2002). As long as it was accepted that strong magnetic fields are observed at all evolutionary states from the zero-age main sequence (ZAMS) to the terminal-age main sequence (TAMS), one of the difficulties for the dynamo theory was to explain how the field reaches the stellar surface in the rather short time available before the arrival of the star on the main sequence. Alternatively, magnetic fields may be generated by strong binary interaction, i.e., in stellar mergers. Scenarios for the origin of the magnetic fields of Ap/Bp stars, in which these stars result from the merging of two lower mass stars or protostars were suggested by Tutukov & Fedorova (2010) and Ferrario et al. (2009), respectively. The mergers would produce a brief period of strong differential rotation and give rise to large-scale fields in the radiative envelopes. It is therefore possible that the binaries with Ap/Bp components that we observe now were triple systems earlier in their history (e.g. Mathys 2017).

Obviously, understanding the origin and evolution of the magnetic fields of Ap/Bp stars requires knowledge of their evolutionary status. Whether they become magnetic at a certain evolutionary state before reaching the ZAMS, or during core hydrogen burning, or at the end of their main-sequence life requires either systematic studies of field stars with accurate Gaia parallaxes, established cluster or association members with known ages, or binary systems.

In previous studies of the evolutionary state of magnetic Ap and Bp stars with accurate Hipparcos parallaxes (Perryman et al. 1997) and photometric data in the
Strömgren or the Geneva system (Hauck & North 1993; Hauck & Kunzli 1996), Hubrig et al. (2000, 2005) showed that the distribution of magnetic stars with masses below \(3 M_\odot\) differs from that of normal stars in the same temperature range at a high level of significance. Normal A stars occupy the whole width of the main sequence, without a gap, whereas magnetic stars are concentrated towards the centre of the main-sequence band. On the other hand, Landstreet et al. (2007, and references therein) studied about 80 Ap/Bp stars that are potential members of open clusters with masses in the range between 2 and 10 \(M_\odot\). In contrast to the results of Hubrig et al. (2000, 2005), the authors reported that magnetic fields are present at essentially all evolutionary stages between ZAMS and TAMS for stellar masses between about 2 and 5 \(M_\odot\).

More recent studies based on very different datasets imply that a certain amount of time is necessary for the magnetic field to build up to become measurable using spectropolarimetry. These studies, such as the volume-limited survey of 52 Ap and Bp stars within 100 pc by Sikora et al. (2019), the survey of 294 Ap/Bp stars by Bernhard et al. (2020) using a colour-magnitude diagram based on the homogeneous Gaia DR2 photometry from Arenou et al. (2018), and the LAMOST DR4 survey by Hümmerich et al. (2018), confirm the concentration of Ap/Bp stars with \(M < 3 M_\odot\) towards the centre of the main-sequence band.

A substantial number of potential CP stars were previously identified in several open clusters using photometric and spectroscopic surveys. Compared to other open clusters, the open cluster NGC 2516 is well-known to harbor a comparatiely large number of chemically peculiar stars (e.g. https://webda.physics.muni.cz), including classical Ap/Bp stars with measured magnetic fields and stars with a HgMn peculiarity, possessing only rather weak magnetic fields (e.g. Mathys & Hubrig 1995; Hubrig & Mathys 1995; Hubrig et al. 2012, 2020). Furthermore, the cluster NGC 2516 is especially interesting in view of the frequent detection of X-ray sources among chemically peculiar stars. As reported by Jeffries et al. (1997), chemically peculiar late-B and A stars are more likely to be detected as X-ray emitters than normal A-type stars at a confidence level of 90–95%, although it is not clear whether this emission is intrinsic and magnetospheric in origin, or if the observed X-ray emission is generated in unresolved late-type companions. As only very few magnetic CP stars are known to be members of close binaries, it is quite possible that the observed emission is intrinsic. Assuming an intrinsic model for the generation of the X-ray emission, magnetically confined wind-shocks were considered by Babel & Montmerle (1997). Among the identified chemically peculiar late-B and A stars in NGC 2516, X-ray emission was detected in HD 66318, CPD−60 978, CPD−60 981, HD 66295, the binary CPD−60 944, and HD 65949. Only the magnetic stars HD 65712 and HD 65987 remained undetected in the survey of Jeffries et al. (1997).

Measurable magnetic fields have been reported for five Ap and Bp stars assumed to be cluster members: HD 66318, HD 65987, CPD−60 944B, HD 66295, and HD 65712 (Bagnulo et al. 2006). Among them, HD 66318 (A0p SrCrEu), the coolest of these five stars, possesses a strong mean longitudinal magnetic field with a strength of about 4.5 kG, and has been studied in detail by Bagnulo et al. (2003). Using the isochrone for a cluster of age of \(1.6 \times 10^9\) yr and the Geneva stellar evolution tracks for \(Z = 0.02\) from Schaller et al. (1992), the authors concluded that HD 66318 has completed only about 16 ± 5% of its main sequence life. This conclusion contradicted the results by Hubrig et al. (2000) that magnetic fields appear in Ap stars after about 30% of their main sequence lifetime has elapsed.

Advantageously, the recent availability of homogeneous Gaia EDR3 data allows us now to reconsider diverse characteristics of the open cluster NGC 2516 and to put much more reliable constraints on membership and age of the chemically peculiar stars. The first successes of space astrometry presented by the Hipparcos project invoked a series of proper motion and photometric membership all-sky studies of open clusters and led to the identification of a uniform population of the Galactic disk (Kharchenko et al. 2005, 2013). The recent highly accurate and homogeneous Gaia EDR3 release (Gaia Collaboration et al. 2021) caused a further rise of publications on studies of galactic open clusters and on stars populating these clusters. Castro-Ginard et al. (2022) reported the identification of 664 new clusters used as main tracers of the Milky Way spiral structure. Gaia EDR3 data were used by Tarricq et al. (2022) to study the external regions (coroanae and tidal tails) of 467 local open clusters. The authors found extended coronae in 389 objects and identified footprints of tidal tails in 71 of them. Similarly, Heyl et al. (2021) studied in the Gaia EDR3 data the wide neighbourhood of the nearest young clusters (Pleiades, \(\alpha\) Per, NGC 2451A, IC 2391, IC 2502) reporting 1700 confident members in the inner parts of the clusters and 1200 candidate members outside. Li et al. (2021) and Pang et al. (2021) used Gaia EDR3 to study the 3D morphology of open clusters and found evidence of tidal tails in nearby clusters. Jackson et al. (2022) joined Gaia EDR3 astrometric and Gaia-ESO spectroscopic data for the calculation of the 3D kinematic membership probability for 63 open and 7 globular clusters. There are also recent publications devoted exclusively to the NGC 2516 cluster. A study of the wide neighbourhood of this cluster using Gaia DR2/EDR3, TESS, Gaia-ESO and GALAH data aiming at the confirmation of the existence of a 500 pc wide halo was carried out by Bouma et al. (2021). Healy et al. (2021) used spectrophotometric observations combined with data from the TESS, Gaia-ESO, and GALAH surveys to study stellar rotation in NGC 2516.

In this paper, we concentrate on the determination of Gaia EDR3-based cluster membership and respective evolutionary status of the known CP stars observed in the area of NGC 2516. In the following sections, we show our analysis of the astrometric and astrophysical parameters of NGC 2516 and discuss the membership probability of the currently known CP stars as well as of a few presumably normal targets. Finally, we discuss the impact of our results on the current understanding of the magnetic field origin in such stars.

2 CHARACTERISING NGC 2516 WITH GAIA EDR3

The primary goal of this study is to examine on the basis of Gaia EDR3 data (Gaia Collaboration et al. 2021) the cluster membership of known CP stars in NGC 2516. Since the CP stars in our sample are bright and occupy the cluster central area, there is no need to consider the data completeness all
Figure 1. Geometry of the sky area with the stars queried from Gaia EDR3. Grey dots mark all queried objects and blue dots correspond to the selected cluster members as described in Sect. 2.2. The green symbols indicate the adopted cluster centre (the plus corresponding to the Milky Way Star Clusters (Kharchenko et al. 2013) and the cross corresponding to the current average). Red five-point stars represent the CP targets selected for this study (see Sect. 2.1).

over the cluster area, nor the full representativity of the cluster member sample. On the other hand, in order to derive membership correctly, based on average parameters of the cluster members, a wider coverage of the cluster population is necessary. Therefore, the general approach of this study is to obtain secure cluster membership on the basis of the most accurate average parameters of the cluster by taking into account the astrometric accuracy limits, the photometric limits due to faint stars and the spatial distribution avoiding the cluster outskirts.

2.1 Input sample

The data were queried with the topcat facility from the Gaia EDR3 catalogue\footnote{tables gaiaedr3.gaia\_source and gaiaedr3.gaia\_source\_corrections} at the ARI site\footnote{https://gaia.ari.uni-heidelberg.de/tap}. The query area is centered at the cluster position ($RA = 119.490$, $Dec = -60.750$) deg as defined in the Milky Way Star Clusters (MWSC) project (Kharchenko et al. 2013), with a radius equal to 1 deg, which according to the MWSC exceeds the apparent radius of the cluster by a factor of two. We applied corrections for the parallax, the $G$ magnitude, and the flux excess (Riello et al. 2021; Lindegren et al. 2021) using the algorithms from https://www.cosmos.esa.int/web/gaia/edr3-code and the data provided by ARI’s Gaia services. The corrections for saturation for the few brightest sources ($G < 8$ mag)
are applied according to Riello et al. (2021). In total 88815 objects were selected, 8635 of them were rejected due to lack of data in at least one of the 26 queried columns. Considering the astrometric and photometric limitations mentioned above, the final working sample consisted of 37508 objects with a brightness level \( G < 19 \) mag. The search area and the queried stars are shown in Fig. 1.

The sample of CP stars previously reported as cluster members includes five Ap/Bp stars with measurable magnetic fields, HD 66318, HD 65987, CPD –60 944B, HD 66295, and HD 65712, the two HgMn stars HD 65949 and HD 65950, and the blue straggler candidate fast rotating B3Vn star HD 66194 (e.g. González & Lapasset 2000). Three more targets were included in our sample: CPD –60 944A, CPD –60 978, and CPD –60 981. The visual companion in the system CPD –60 944, CPD –60 944A, exhibits in the spectra strong lines of Hg\(\text{II}\), Mn\(\text{II}\), P\(\text{II}\), Ga\(\text{II}\), and Xe\(\text{II}\) and was identified as a HgMn star by González et al. (1972). The target CPD –60 981 is a short-period eclipsing binary with \( P_{\text{orb}} = 3.2 \) d (Debernardi & North 2001) and was classified as an Ap star with SrCrEu peculiarity type by Hartoog (1976). All three targets were reported as X-ray emitters, although no definite detection of a magnetic field was reported for them by Bagnulo et al. (2006).

### 2.2 Cluster membership

Since the primary goal of this work is to study the evolutionary status of the Ap cluster member stars, which is directly related to the cluster color-magnitude-diagram (CMD), we decided, to avoid unnecessary biases, not to use photometric member selection, which normally is a part of the MWSC membership pipeline (Kharchenko et al. 2012). In addition, as EDR3 has not yet released measurements of radial velocities (RVs), in order to keep the kinematic membership approach uniform over all studied objects, we do not use in our study the RV data for membership evaluation. This is one of the basic differences between our work and the works of Landstreet et al. (2007) and González & Lapasset (2000), who also considered radial velocities. Given the proximity of the cluster, it is sufficient to select cluster members based exclusively on proper motion and parallax, which allows us to identify among the selected members a number of co-moving field stars.

Following Kharchenko et al. (2012), our study makes use of a probabilistic selection of cluster members. Each star in the dataset is assigned the value \( P_c \), representing a combined probability of sharing space and kinematics with other members:

\[
P_c = \min\{P_{\text{kin}}, P_\odot\},
\]

where the probabilities based on kinematics (essentially proper motions) and parallax data, \( P_{\text{kin}} \) and \( P_\odot \), are calculated as described below. Since the search area covers a relatively restricted area of the sky, the kinematic probability \( P_{\text{kin}}^i \) for the \( i \)-th star to belong to the cluster is defined in its simplified form

\[
P_{\text{kin}}^i = \exp\left\{-\left(\frac{\mu_\alpha^i - \overline{\mu}_\alpha}{2\sigma_{\mu_\alpha}}\right)^2 + \left(\frac{\mu_\delta^i - \overline{\mu}_\delta}{2\sigma_{\mu_\delta}}\right)^2\right\},
\]

where \( \mu_\alpha^i \) and \( \mu_\delta^i \) are values of proper motions of the star in right ascension and declination, and \( \overline{\mu}_\alpha \) and \( \overline{\mu}_\delta \) are average proper motions, corresponding to the centre of the member distribution in the vector point diagram, the VPD (see Fig. 2 for illustration). The parameters \( \sigma_{\mu_\alpha} \) and \( \sigma_{\mu_\delta} \) are the

\[\text{Figure 2.} \] The distribution of stars in the NGC 2516 area in the vector point (top panel) and parallax-magnitude (bottom panel) diagrams. Green dots show field stars, blue dots indicate stars used for the calculation of the cluster member distribution parameters, where the cyan plus corresponds to the average proper motion. The orange horizontal line indicates the average parallax. The large cyan oval (almost a circle) indicates the ellipse of the proper motion standard deviations \( \sigma_{\mu_\alpha} \) and \( \sigma_{\mu_\delta} \). The cyan bars in the bottom panel show individual parallax errors for cluster members. The vertical orange line is the adopted magnitude limit.
observed standard deviations, arising both from internal motions of the cluster stars and from the measurement errors. In the case of NGC 2516, the former effect is of the order of 0.1–0.5 mas/yr, which is much higher than the observation errors $\varepsilon_{\mu}$, which in the magnitudes range of interest ($G < 17$ mag) are much lower ($\varepsilon_{\mu} < 0.05$ mas/yr), and are comparable to it at fainter magnitudes only. The distribution parameters were calculated in an iterative process in a close neighbourhood of the distribution center, rapidly converging to the final values. The initial guess parameters were selected by eye.

A visual inspection of the diagram ($\pi, G$) (see e.g. Fig. 2) indicates a perfect separation of cluster member candidates and field stars. Therefore we decided to apply also for the calculation of $P_{\pi}$ a simple approach:

$$P_{\pi} = \exp \left\{ -\left( \frac{\pi^i - \bar{\pi}}{2\sigma_{\pi}} \right)^2 \right\},$$

assuming that the distribution parameters are the same as in Eq. (2). Here $\pi^i$ is the measured parallax of $i$th star, $\bar{\pi}$ is the member average parallax, and $\sigma_{\pi}$ is the standard deviation of the distribution. In contrast to the proper motions, the dispersion of the parallaxes is dominated by the inaccuracy of the observations rather than by the actual dispersion of the distances within the cluster.

Following MWSC (Kharchenko et al. 2012), the above probability distribution parameters are used for cluster membership classification. We adopt the criterion that stars shifted from the distribution centre by less than one standard deviation ($P \gtrsim 0.61$) are highly probable proper motion or parallax members of the cluster, also referred to as $1\sigma$-members. We consider the $1\sigma$-stars as bona fide cluster members. Those stars with deviations between one and two standard deviations ($0.14 \lesssim P \lesssim 0.61$) are called possible (or $2\sigma$) members, and compose together with $1\sigma$-stars the bulk of the potential member population. The next category of outliers ($3\sigma$-stars, $0.01 \lesssim P \lesssim 0.14$) includes a very low fraction of cluster stars, which are classified as possible field stars.

In Fig. 3 we compare the CMDs for two member classes, the $1\sigma$ and $2\sigma$ members. One can see that, in general, both populations produce very similar patterns, especially for brighter stars ($G \lesssim 15$ mag). At fainter magnitudes, both sequences demonstrate an increase of the contamination by field stars. As expected, the contamination degree for the $2\sigma$-population is higher. As a result, we can conclude that for the bright magnitude domain the contamination in both diagrams is similar and not too strong. At $G > 16$ mag both sequences become broader due to the increase of photometric errors.

2.3 Cluster parameters

As we discuss in Sect. 2.2 (see also Fig. 3), it is possible to construct an extremely accurate CMD for the cluster members, from bright stars down to faint stars, allowing us to investigate the detailed structure of the cluster CMD.

 Isochrones for the Gaia EDR3 passbands are interpolated with help of CMD3.5, the publicly available Padova webserver. An important reference line corresponding to the Zero Age Main Sequence (ZAMS) was computed as the blue edge of a set of isochrones of various ages and other common parameters (metallicity, BC-scale, etc.) extending from brightest to faintest absolute magnitude of interest. Since we are interested in the detailed structure of the CMD, we tried to select the best fitting the isochrone by modest variations of isochrone parameters provided by the server around the expected values.

Taking into account the spectroscopic evidence of a slightly enhanced metal abundance of the NGC 2516 stars with respect to the Sun (Heiter et al. 2014), we varied the isochrone metallicity between $[\text{M/H}] = -0.05$ and $+0.05$. For the bolometric correction and effective temperature scales, we con-
considered all three options available in CMD3.5. For the determination of reddening, we followed the CMD3.5 recommendations to use the extinction coefficients $A_{\lambda}/A_0$ for the Gaia photometric bands (Gaia Collaboration et al. 2018) computed at every isochrone point (except for the OBC case, where one uses constant coefficients). For the calculation of the scaling extinction $A_0$, we used a relation between the average colour excess $E(B - V)$ and the extinction $A_G$ following the relations by Cardelli et al. (1989) and O’Donnell (1994), which led to $A_G/E(B - V) \approx 2.05$. As a reference, we employed the main sequence inflection point at $(G, B - V) \approx (11.4, 0.65)$. The transformation of intrinsic isochrone photometry to reddened values is performed along with the following relations:

$$ (B - V) = (B - V)_0 + E(B - V), \quad (4) $$

and

$$ G = M_G + 10 - 5 \log \left( \frac{\lambda}{\mu} \right) + A_G, \quad (5) $$

where $(B - V)_0$ and $M_G$ are the intrinsic colour and the absolute magnitude of the isochrone, and respective reddening or extinction are depending on the adopted reddening scheme.

As expected, the metal abundance variations within the considered limits only symbolically affect the cluster CMD. Therefore, we accept for the isochrone the spectroscopic determination of $[\text{M/H}] = +0.05$ without anticipating any noticeable change of the resulting cluster parameters. The effect of the bolometric scales is more prominent. Generally, the comparison of the Gaia observations and the Padova isochrones shows a reasonable agreement of the sequences. At the same time, at a lower significance level one observes in some temperature/luminosity segments a disagreement between the isochrone and the observations, whereas in other segments of the same isochrone the agreement is perfect. For example, the isochrones, denoted in the CMD3.5 interface as OBC, use scales traditional for the Padova server (Girardi et al. 2002; Marigo et al. 2017), and perfectly fit the cluster sequence at brighter magnitudes ($G \lesssim 15$ mag). In contrast, the YBC and YBC/Vega scales are perfect in the bright and the faint segments ($G < 12$ mag or $G > 16$ mag), but disagree with observations at intermediate magnitudes. Since in this study we are interested in the brighter stars, we select the YBC scale for further comparisons, keeping in mind this peculiarity.

In Fig. 4, we show the observed CMD together with the fitted isochrone and respective ZAMS, adopting a metallicity $+0.05$ and using the BC-scale YBC. The isochrone is shifted in the CMD according to Eqs. 4 and 5 with the extinction coefficients depending on the effective temperature and the scaling factor equal to the average extinction that is adopted to be a free parameter. The best fit is provided by the average colour excess value $E(B - V) = 0.18$ mag and the age log $t = 8.10$. One can see that the isochrone perfectly fits the observations in the bright star domain $G < 12$ mag and for faint stars with $G > 16$ mag. For intermediate magnitudes, the isochrone is redder by about 0.1 mag at maximum. We relate this peculiarity to the effect of the BC-scale discussed above: the OBC scale provides in the intermediate region of magnitudes a perfect fit. It is worth to note that the selected isochrone accurately fits the data both for very bright ($G < 7$ mag) and very faint magnitudes ($G > 17$ mag) where one can easily distinguish the Pre-Main-Sequence branch of the cluster, which forks of the ZAMS at $G \approx 17$ mag. The Main Sequence (MS) between $G \approx 9$ mag and $G \approx 17$ mag is very sharp and well populated, therefore conclusions on the isochrone shape along a wide range of magnitudes seem to be very firm. Even for the brightest stars in the MS turn off region and in the red supergiant region the agreement is impressive, in spite of the very poor member statistics. We also note that apart from the classical population building up the MS, there is quite a fraction of stars populating the MS strip with a width of about 0.75 mag all over the magnitude range. Evidently, this fraction of stars is related to unresolved binary/multiple systems, either physical or apparent. The most impressive example of such stars is the brightest cluster member blue straggler candidate HD 66194, evidently deviating from the isochrone, but spatially and kinematically appearing as a 98% cluster member.

In Table 1 we present the cluster parameters determined from the cluster member sample constructed in Sects. 2.2 and 2.3.

| $\ell$ (mas/yr) | $N_{\text{mb}}$ | $\sigma_{\mu_\alpha}$ (mas/yr) | $\sigma_{\mu_\delta}$ (mas/yr) | $\sigma_{\mu_\alpha}$ (mas/yr) | $\sigma_{\mu_\delta}$ (mas/yr) | $\sigma$ (mas) | $d$ (pc) |
|----------------|----------------|-------------------------------|-------------------------------|-------------------------------|-------------------------------|----------------|---------|
| 4.648          | 1483           | 11.208                        | 0.308                         | 0.806                         | 0.260                         | 2.454          | 8.10    |
| 0.066          | 407.5          | 208                            | 397                           | 408                           | 0.81                          | 648            | 1180    |

Table 1. Derived cluster parameters of NGC 2516.
The most recent open cluster and \({\text{Kharchenko et al. 2012}}\) and \({\text{Kharchenko et al. 2013}}\) Bagnulo et al. catalogue. For example, the Tycho-based proper motions and photometric membership established by \(\text{https://cdsarc.cds.unistra.fr/viz-bin/cat/I/239}\) \(\text{https://cdsarc.cds.unistra.fr/viz-bin/cat/I/259}\) \(\text{https://cdsarc.cds.unistra.fr/viz-bin/cat/I/246}\) proper motions and parallaxes with their errors (columns 3,5,7), standard deviations (columns 4,6,8), the colour excess, the apparent distance modulus, the distance, log age, and the photometric system.

For example, the Tycho-based proper motions and photometric membership established by \(\text{Kharchenko et al. 2005}\) provided average proper motion, photometric distance and reddening for about 650 local open clusters within about 2 kpc from the Sun (the survey is referred hereafter as COCD). \(\text{van Leeuwen 2009}\) has reduced the original Hipparcos observations\(^5\) and was able to present more accurate data (including trigonometric parallaxes) for the 20 nearest open clusters. The open cluster survey MWSC (\(\text{Kharchenko et al. 2013}\)) was based on ground-based observations (the catalogues PPMXL\(^6\), and 2MASS\(^7\)) and only indirectly was related to the Hipparcos project being astrometrically tied to the Hipparcos/Tycho system. The photometry data of MWSC involved 2MASS near-IR photometry (\(\text{Roester et al. 2010}\)). The most recent open cluster survey of \(\text{Cantat-Gaudin et al. 2018}\) was based on the Gaia DR2 catalogue and demonstrated a revolutionary raise of the data quality, compared to previous observations.

All surveys mentioned above included NGC 2516, one of the clusters nearest to the Sun, allowing us to compare their results, presented in Table 2. The comparison indicates a considerable improvement of the cluster parameter data in the study based on the Gaia results. At the same time, studies based on different Gaia releases reproduce approximately similar results on the cluster position and kinematics. A few recent papers discussed the cluster parameters of NGC 2516 in the studies of different issues of the nearby open clusters. For example, \(\text{Meingast et al. 2021}\) used Gaia EDR3 considering a wide area five-parameter based cluster membership (\(N = 1860\)) and reported that the distance to the maximum of the member density distribution is equal to \(d_c = 410.5 \pm 3.1\) pc. Using Gaia EDR3 astrometry and Gaia-ESO spectroscopy, \(\text{Jackson et al. 2022}\) were able to determine the 3D kinematics in 70 open and globular clusters and to assign a kinematic membership probability for the studied stars. Using highly probable members, they established parallax-based distance moduli and reddening, which for NGC 2516 are equal to \(m_0 - M = 8.07\) and \(E(B-V) = 0.11\). Employing high quality Gaia astrometry and GALAH/APOGEE spectroscopy, \(\text{Spina et al. 2021}\) determined the metallicity for 134 clusters with secure membership. For NGC 2516, from the study of two secure cluster members, the authors reported a cluster metallicity equal to \([\text{Fe/H}] = -0.079 \pm 0.025\). In a somewhat earlier work, \(\text{Cummings \& Kalirai 2018}\) used UVB data, a few sets of isochrones for \([\text{Fe/H}] = 0\), Gaia DR2 proper motions and parallax membership to determine the age \(\log t = 8.22 - 8.29\) and a photometric distance of NGC 2516 \(V_0 - M_V = 8.04 - 8.11\).

### 2.4 Comparison with previous results

As a number of studies of NGC 2516 were published in the post-Hipparcos era, we can compare our cluster parameters with those presented in the literature. There was a series of all-sky cluster star surveys based on Hipparcos observations and collecting astrometric and general-purpose information based on homogeneous data from the Hipparcos\(^5\) and Tycho\(^6\) catalogues. For example, the Tycho-based proper motions and photometric membership established by \(\text{Kharchenko et al. 2005}\) provided average proper motion, photometric distance and reddening for about 650 local open clusters within about 2 kpc from the Sun (the survey is referred hereafter as COCD). \(\text{van Leeuwen 2009}\) has reduced the original Hipparcos observations\(^5\) and was able to present more accurate data (including trigonometric parallaxes) for the 20 nearest open clusters. The open cluster survey MWSC (\(\text{Kharchenko et al. 2013}\)) was based on ground-based observations (the catalogues PPMXL\(^6\), and 2MASS\(^7\)) and only indirectly was related to the Hipparcos project being astrometrically tied to the Hipparcos/Tycho system. The photometry data of MWSC involved 2MASS near-IR photometry (\(\text{Roester et al. 2010}\)). The most recent open cluster survey of \(\text{Cantat-Gaudin et al. 2018}\) was based on the Gaia DR2 catalogue and demonstrated a revolutionary raise of the data quality, compared to previous observations.

### 3 NGC 2516 MEMBERSHIP AND EVOLUTIONARY STATE OF THE CP STARS

In Table 3 we present our sample stars studied for membership in NGC 2516 and their position in the enlarged version of the CMD is shown in Fig. 5. The information gathered in this table can be used to identify the stars in Fig. 4 and includes their EDR3 identifiers and other relevant data (photometry, proper motions, and parallaxes) with their errors. In Table 4 we present the membership probabilities, stellar masses \(\log M/M_\odot\), ages as \(\log t\), and fractional MS-ages \(\tau(\text{MS})\). The parameters were interpolated over the set of Padova isochrones specified in Sect. 2.3 and covering respective ranges of magnitudes and colours. We used for the interpolation our well developed method applied earlier to cluster stars in the projects COCD (\(\text{Kharchenko et al. 2005}\)) and MWSC (\(\text{Kharchenko et al. 2012}\)). Following \(\text{Bagnulo et al. 2003}\), we define the fractional age of each star with mass \(M/M_\odot\) as a fraction of its main sequence lifetime, measured from the ZAMS to the TAMS \(\tau(\text{MS}) = (t(\text{MS}) - t(\text{ZAMS})) / (t(\text{TAMS}) - t(\text{ZAMS}))\). The errors of the evolutionary parameters were propagated from the uncertainties of the stellar positions in the CMD \(\varepsilon_G, \varepsilon_M\), and \(\varepsilon(E_{BP}-R_V)\) via Monte Carlo simulations.

The spread of the individual ages with respect to the cluster isochrone can have different origins. Specifically in our case, where the random CMD-placement errors are negligible, reddward shifts (\(\log t > 8.10\)) may reflect the unresolved nature of the source, whereas a blueward displacement may

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| Survey  | N   | \(\mu_\alpha\) (mas/yr) | \(\sigma_{\mu_\alpha}\) (mas/yr) | \(\mu_\delta\) (mas/yr) | \(\sigma_{\mu_\delta}\) (mas/yr) | \(\sigma_\pi\) (mas) | \(\sigma_\varpi\) (mas) | CE (mag) | \(m - M\) (mag) | d (pc) | \(\log t\) (yr) | Photom. |
|--------|-----|------------------------|-------------------------------|------------------------|-------------------------------|------------------|------------------|----------|----------------|------|----------------|---------|
| COCD\(^a\) | 53  | -4.13 ± 0.41           |                               | 10.15 ± 0.22          |                               | -                | -                | 0.07     | 7.91           | 346  | 8.08 ± 0.12    | BV      |
| HRR\(^b\) | 11  | -4.17 ± 0.11           |                               | 11.91 ± 0.11          |                               | 2.92 ± 0.10      | -                | 7.68 ± 0.07 | -              | -    | 373            | JHKs    |
| MWSC\(^c\) | 698 | -3.50 ± 0.29           |                               | 10.20 ± 0.29          |                               | -                | 0.034           | 7.88     | 408.9          | -    | 8.48 ± 0.12    | Gaia    |
| GDR2\(^d\) | 798 | -4.748 ± 0.017         | 0.441                         | 11.221 ± 0.014        | 0.345                         | 2.417 ± 0.002    | 0.045           | -        | -              | -    | -              | -       |

\(^a\text{Kharchenko et al. (2005); bvan Leeuwen (2009); cKharchenko et al. (2013); dCantat-Gaudin et al. (2018)}\)
Table 3. List of investigated membership for membership together with the Gaia EDR3 parameters and their errors. In the first column we show the sample running number, then the EDR3 identification and coordinates, followed by value/error pairs for the G-magnitude, colour (BP − RP), proper motions μα, μβ, and parallax ϖ.

| # | Gaia EDR3 | l (deg) | b (deg) | G (mag) | εG | BP − RP | ε(BP−RP) | μα (mas/yr) | εμα | μβ (mas/yr) | εμβ | ϖ (mas) | εϖ |
|---|-----------|--------|--------|--------|-----|--------|---------|-----------|------|-----------|------|--------|------|
| 1 | 529082062661822848 | 273.687004 | −15.793607 | 7.5863 | 0.0008 | −0.0220 | 0.0011 | −5.023 | 0.037 | 11.201 | 0.031 | 2.414 | 0.031 |
| 2 | 5290767390708069888 | 273.937409 | −15.725538 | 9.6011 | 0.0004 | 0.1233 | 0.0004 | −7.236 | 0.090 | 11.891 | 0.077 | 2.170 | 0.068 |
| 3 | 5290767150189898496 | 273.949001 | −15.745614 | 9.0624 | 0.0007 | 0.0739 | 0.0008 | −3.940 | 0.048 | 10.628 | 0.041 | 2.372 | 0.036 |
| 4 | 5290676829193665320 | 273.928518 | −15.896285 | 9.4731 | 0.0008 | 0.2890 | 0.0005 | −4.526 | 0.024 | 9.926 | 0.025 | 2.506 | 0.020 |
| 5 | 5290832364727758008 | 273.667326 | −15.818870 | 8.3476 | 0.0005 | −0.0008 | 0.0004 | −3.981 | 0.032 | 10.661 | 0.028 | 2.492 | 0.025 |
| 6 | 529067173195996416 | 273.397022 | −15.969642 | 6.8391 | 0.0006 | 0.0483 | 0.0005 | −4.460 | 0.033 | 11.200 | 0.034 | 2.463 | 0.027 |
| 7 | 5290727101839876864 | 273.689213 | −15.886130 | 8.8994 | 0.0011 | 0.1359 | 0.0016 | −4.160 | 0.025 | 13.210 | 0.021 | 2.430 | 0.019 |
| 8 | 5290722792920592640 | 273.759792 | −16.026672 | 8.3232 | 0.0005 | 0.0545 | 0.0004 | −4.719 | 0.025 | 11.331 | 0.023 | 2.495 | 0.019 |
| 9 | 5290722792920592896 | 273.797944 | −16.025092 | 8.7743 | 0.0020 | 0.1195 | 0.0021 | −4.408 | 0.070 | 11.550 | 0.061 | 2.648 | 0.049 |
| 10 | 5290665336465950976 | 273.208409 | −16.281212 | 9.3395 | 0.0017 | 0.1185 | 0.0020 | −4.594 | 0.020 | 11.256 | 0.021 | 2.464 | 0.017 |
| 11 | 52907067631226220032 | 273.926845 | −15.804975 | 5.8160 | 0.0022 | −0.1006 | 0.0028 | −4.661 | 0.077 | 11.226 | 0.063 | 2.471 | 0.053 |

be considered as a sign of fast rotation. In the case of the brightest MS stars located at the top of the Main Sequence (HD 66194 and HD 65987), their younger “apparent” age is interpreted as evidence of the blue straggler nature of the star. In contrast, the fractional age reflects the evolutionary advance of the star towards the TAMS.

The most striking result of our study of cluster membership is that from the consideration of the parallax-proper motion membership, the strongly magnetic A0p star HD 66318 with a mean longitudinal magnetic field (Bz) of about 4.5 kG and a mean magnetic field modulus (B) of about 14.5 kG (Bagnulo et al. 2003) does not belong to the NGC 2516 cluster at a high level of confidence. Using the isochrone for a cluster with an age of 1.6 × 10⁸ yr and the Geneva stellar evolution tracks for Z = 0.02 from Schaller et al. (1992), Bagnulo et al. (2003) concluded that HD 66318 is at a very young age and has completed only about 16 ± 5% of its main sequence life. The young age of this star was frequently mentioned in the literature as an argument in favour of the fossil origin of magnetic fields in chemically peculiar Ap and Bp stars. However, it is evident that this star does not belong to NGC 2516. Thus, its real evolutionary state is undefined.

Four more chemically peculiar Ap and Bp stars in NGC 2516 were reported to possess detectable mean longitudinal magnetic fields. To investigate the link between the presence of a magnetic field and the evolutionary state in chemically peculiar Ap and Bp stars, Bagnulo et al. (2006) carried out magnetic field measurements in a number of A and B-type stars mentioned in the literature as members of NGC 2516. The authors reported the presence of a magnetic field in the B9p stars HD 65987, CPD−60 944B, and HD 66295, and in the A0p star HD 65712. Interestingly, out of these five known magnetic stars, three are reported to be X-ray sources (Jeffries et al. 1997). The detected X-ray emission could indicate the presence of close unresolved lower mass magnetically active companions (e.g. Hubrig et al. 2001). According to the work of Jiménez-Esteban et al. (2019), who used the Gaia DR2 catalogue to identify bright comoving systems in a five-dimensional space (sky position, parallax, and proper motion), all four stars belong either to a comoving binary or multiple stellar candidate systems. In contrast, only HD 65987 was reported to have been accompanied by Kerrela et al. (2019) due to the presence of a proper motion anomaly detected using the Hipparcos and Gaia DR2 catalogues. González & Lapasset (2000) studied the cluster membership of the stars HD 65987, HD 66295, and CPD−60 944B using astrometric and radial velocity data and concluded that HD 65987 and HD 66295 are cluster members.

In our study, out of the five bona-fide magnetic chemically peculiar stars, only two stars, HD 65987 and HD 65712, have a high membership probability. Further, the chemically peculiar star CPD−60 944A, the HgMn star HD 65959, and the blue straggler candidate HD 66194 are confirmed as cluster members. CPD−60 944B can be considered as a proper motion cluster member. Additional information on the targets in our sample is presented in the Appendix.

In contrast to the work of Landstreet et al. (2007), who considered the magnetic chemically peculiar stars HD 66295, CPD−60 978, and HD 66318 as cluster members, our study shows that all three stars do not fulfill the membership criteria. While Landstreet et al. (2007) report that the magnetic chemically peculiar stars HD 66318 and HD 65712 have fractional ages below 0.30 – 0.15 and 0.20, respectively – and therefore definitely contradict the work of Hubrig et al. (2000, 2005), our results do not confirm cluster membership for HD 66318 and indicate a fractional age of 0.320 for HD 65712.

The position of the studied chemically peculiar stars in the CMD of NGC 2516 is presented in the upper panel of Fig.5. The obtained main-sequence fractional ages for the bona fide (1σ) cluster members range from 0.320 for the fainter chemically peculiar magnetic star HD 65712 to 0.944 as determined for the second brightest HgMn star in the sample, HD 65950. The brightest star, HD 66194, with a fractional age of 0.886, demonstrates an individual age significantly younger than the common cluster age of log t = 8.10. HD 65987 with a fractional age of 0.606 also appears to be younger than the cluster itself. The apparent younger ages of HD 66194 and HD 65987 suggest that they are associated with stellar merging, where a merge or mass transfer took place.

Among the chemically peculiar stars with confirmed cluster membership, the strongest mean longitudinal magnetic field was measured for HD 65712 (⟨Bz⟩ = 1.1 ± 0.05 kG) showing the lowest fractional age of 0.320. The second strongest mean longitudinal magnetic field (⟨Bz⟩ = 0.6 ± 0.1 kG) was measured for HD 65987 with τ(MS) = 0.606, and the third...
Table 4. Membership probabilities of the peculiar stars and their evolutionary parameters computed from the star positions in the CMD. In the first three columns we show the running number, the star name, and the spectral classification given in SIMBAD, followed by the membership probabilities $P_m$ and $P_{\text{kin}}$. In the last six columns, we present stellar mass $M$, age $t$, and the fractional MS age $\tau(MS)$, with their respective errors.

| #   | Name       | Spectral Type | $P_m$   | $P_{\text{kin}}$ | $\log M$ | $\log t$ | $\log \tau(MS)$ | $\tau(MS)$ |
|-----|------------|---------------|---------|-----------------|----------|----------|------------------|-----------|
| 1   | HD 65987   | B9.5IVpSi     | 0.910   | 0.807           | 0.638    | 0.002    | 7.960           | 0.007     |
| 2   | HD 66318   | A0pEuCrSr     | 0.099   | 0.000           | 0.377    | 0.003    | 8.072           | 0.125     |
| 3   | HD 66295   | B8/9pSi       | 0.674   | 0.287           | 0.445    | 0.002    | 8.132           | 0.031     |
| 4   | CPD–60 981 | A2VpSrCrEu   | 0.855   | 0.077           | 0.322    | 0.001    | 8.840           | 0.001     |
| 5   | HD 65949   | B8/9HgMn      | 0.921   | 0.330           | 0.566    | 0.002    | 7.816           | 0.020     |
| 6   | HD 65950   | B8IIIHgMn     | 0.995   | 0.950           | 0.927    | 0.002    | 8.163           | 0.004     |
| 7   | CPD–60 978 | A0pEuCrSr     | 0.966   | 0.001           | 0.410    | 0.001    | 8.559           | 0.005     |
| 8   | CPD–60 944 | B8SpSi       | 0.908   | 0.962           | 0.507    | 0.001    | 8.283           | 0.003     |
| 9   | CPD–60 944B | B8III       | 0.111   | 0.750           | 0.428    | 0.003    | 8.516           | 0.008     |
| 10  | HD 65712   | ApSi         | 0.994   | 0.989           | 0.396    | 0.002    | 8.320           | 0.018     |
| 11  | HD 66194   | B3Vn         | 0.984   | 0.998           | 0.851    | 0.005    | 7.614           | 0.010     |

The strongest field ($\langle B_z \rangle = 0.35 \pm 0.06\,\text{Kg}$) was determined for CPD–60 944B with a fractional age of 0.629. The fact that the strongest magnetic field was detected in a star with the lowest fractional age is, however, difficult to interpret in terms of stellar evolution effects, as our sample is much too small to allow the deduction of any statistical evidence.

4 DISCUSSION

In this study, we have aimed at using the most accurate and complete Gaia EDR3 data on stellar astrometry and photometry in the area of the nearby rich open cluster NGC 2516 to establish the membership probability of known peculiar stars and to deduce the evolutionary state of these stars. Since the stars reside in the central area of the cluster, we have confined ourselves with the consideration of the inner part of the cluster with a radius of 1 deg and selected 37508 stars brighter than $G = 19$ mag. To determine their membership probabilities, we used our tried-and-true approach already applied for the COCD and MWSC surveys. The only difference between the presented and previous studies is that we do not use the photometric data for membership evaluation.

As a byproduct, we have determined the average astrometric parameters of the cluster (the proper motion and parallax), allowing the accurate placement of the cluster stars in the CMD. In order to use effectively the cluster CMD, we applied the Padova isochrones for the determination of the evolutionary parameters. The high precision of the EDR3 data allowed us to employ the full range of the available magnitudes from the very top of the cluster CMD down to the faintest stars. The modest variations of the isochrone metallicity and the used transformation scale around the expected values enabled us to find the best combination of the model parameters providing the best fit of the isochrone and the observations in the $G, B_p − R_p$ plane. We find that the isochrone perfectly fits the observed cluster locus, both in the brightest red giant domain at $G \approx 5$ mag, and at the faintest magnitudes $G \approx 18$ (with a marginally visible pre-MS branch).

In spite of the perfect overall agreement, we have to note some disaccord of $\Delta (B_p − R_p) \lesssim 0.1$ between the model and the observational colours for intermediate magnitudes $(G \simeq 12 − 16)$. Note that both the upper CMD of the selected members and its lower part agree well with an isochrone of $t = 8.10$. The derived cluster parameters allowed us to safely discriminate in parallax-proper motion space between foreground and background field stars and probable cluster members. In total, we found in the queried sample 719 probable ($P_t > 0.61$) and 764 possible ($P_t = 0.14 − 0.61$) members of the cluster.

The parallax-proper motion membership pipeline indicates that only 5 of the 11 considered CP stars (HD 65987, HD 65950, CPD–60 944 A, HD 65712, and HD 66194) should be classified as highly probable members, and three more (HD 66295 and HD 65949, and CPD–60 944B) as possible members. The remaining CP stars are definite field stars, being incompatible with the cluster kinematics (HD 66318, CPD–60 981, and CPD–60 978).

In general, the Ap stars of our sample are bright enough ($7 \lesssim G \lesssim 10$ mag) and appear to be excellent targets from the formal point Gaia EDR3 observations (Gaia Collaboration et al. 2021; Riello et al. 2021; Fabricius et al. 2021) to provide a robust estimation of their membership probability. One should, however, keep in mind that their physical nature and their environment may affect the derived parameters and change the reached conclusions. Indeed, these stars are immersed as a rule in a dense stellar field and several targets in our sample are binary or multiple systems. As an example of such a complication, we can mention CPD–60 944, which according to the CCDM catalogue (Dommniger & Nys 2002) is a quadruple system with bright ($V \sim 9 − 11$ mag) components located at a distance of 9 to 46 arcsec from the primary. Only for the A and B components the Gaia EDR3 is able to provide data. However, the Gaia data obtained for the A and B components of about the same apparent magnitude $G$ show rather different proper motions and parallaxes (only marginally compatible to each other) and are accompanied with twice as large errors. The high parallax membership probability for the primary, and the low probability for the secondary leads to only a small chance for the secondary to belong to the cluster. As a result, the combined membership probability $P_t$ of the secondary falls below the possible cluster member threshold adopted in this study. This indicates that a statistical approach does not work for
Figure 5. Enlarged version of the CMD shown in Fig. 4 in the Turn Off-region (top panel). Most designations are the same as in Fig. 4. Additionally, we show the stars from Table 3 with blue five-point star symbols. The thin dark red line in the top panel shows the TAMS. The green insert is enlarged in the bottom panel.

this star, due to either an error in the parallax determination or to a wrong classification as a physical companion of the primary. Currently, we are inclined to regard this star to be a proper motion cluster member with complicated parallax data. Therefore, for this, as well as some other difficult cases (e.g., for HD 65949, which is a triple system) one should treat the derived probabilities with caution and consider additional arguments such as photometry, spatial position, radial velocities (expected soon with the Gaia DR3 release), to establish their membership more reliably.

The possible blue straggler nature of HD 65987 was already mentioned by Ahumada & Lapasset (1995) and is discussed here again based on the high precise Gaia EDR3 data (Gaia Collaboration et al. 2021). Ahumada & Lapasset (1995) found blue stragglers in all clusters of all ages and the percentage of clusters with blue stragglers grows with age and richness of the cluster. In NGC 2516, HD 66194 and HD 65987 are clearly located to the left of the cluster main sequence isochrone and can be considered as blue stragglers. As already mentioned in Sect. 3, HD 65987 is reported to have a companion by Kervella et al. (2019) due to the presence of a proper motion anomaly detected using the Hipparcos and Gaia DR2 catalogues. Also González & Lapasset (2000) reported on variations in the line profiles, suggesting the probable presence of a companion. To our knowledge, HD 65987 is the first chemically peculiar blue straggler with a detected magnetic field of the order of a few hundred Gauss. No significant magnetic field was detected in the previous rare attempts to measure a magnetic field in blue stragglers belonging to other clusters and associations (e.g., Hubrig et al. 2008). According to Hubrig et al. (2008), the star θ Car, a blue straggler in the open cluster IC 2602, was rejuvenated due to a previous mass-transfer episode. The results of the search for a magnetic field using FORS 1 at the VLT consisting of 26 measurements over a time span of 1.2 h have been rather inconclusive with only a few measurements having a significance level of 3σ.

As mentioned in Sect. 1, the mechanism of the generation and the maintenance of magnetic fields in chemically peculiar stars is not well understood yet, although the currently most popular scenario is that magnetic fields may be generated by strong binary interaction. Therefore, with respect to the various scenarios for the magnetic field origin in upper main sequence stars, the confirmation of the blue straggler status of the chemically peculiar magnetic star HD 65987 is of great importance. Obviously, future magnetic studies should involve a search for magnetic fields in astrometrically confirmed blue stragglers to support the suggested scenario.

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DATA AVAILABILITY

The data used in this study was queried with the topcat facility from the Gaia EDR3 catalogue (tables gaiaedr3.gaia_source and gaiaedr3.gaia_source_corrections) at Astronomisches Rechen-Institut, Heidelberg, Germany (site https://gaia.ari.uni-heidelberg.de/tap) using the
following ADQL query

SELECT TOP 100000
FROM gaiaedr3.gaia_source AS edr
JOIN gaiaedr3.gaia_source_corrections USING (source_id)
WHERE
1=CONTAINS(POINT('ICRS', edr.ra, edr.dec),
CIRCLE('ICRS', 119.490, -60.750, 1.000 ))

APPENDIX A: ADDITIONAL INFORMATION ON INDIVIDUAL TARGETS

CPD−60 944B: This star was reported to be a member of a visual pair with the visual companion CPD−60 944A, with an undetected magnetic field (Bagnulo et al. 2006). It exhibits in its spectrum strong lines of Hg II, Mn II, P II, Ga II, and Xe II and was identified as an HgMn star (González et al. 2014). Radial velocity measurements of CPD−60 944A carried out by González & Lapasset (2000) suggested the presence of an additional companion, making CPD−60 944A a triple system. However, according to the CCM catalogue CPD−60 944A and CPD−60 944B belong to a quadruple system. Based solely on its low parallax membership probability, the magnetic B9p star CPD−60 944B seems not to be a member of the cluster NGC 2516. However, CPD−60 944B shows sufficient kinematical probability to be a safe cluster member, which is in agreement with the study by González & Lapasset (2000). Currently, we consider this star to be a proper motion cluster member. Due to the complex nature of this system it is necessary to use additional criteria for the membership like photometry, spatial position, and radial velocities.

CPD−60 978: The chemical peculiarities in the atmosphere of CPD−60 978, typical for magnetic Ap stars, were mentioned for the first time by Dachs (1972). This star was also reported as an X-ray emission source. No definite detection of a magnetic field was reported by Bagnulo et al. (2006). In contrast to the results of the study by González & Lapasset (2000), who identify this star as a cluster member, our work shows a very low $P_{\text{kin}}$.

CPD−60 981: Our study shows that CPD−60 981, with a membership probability $P_{\text{kin}}$ of only 7.7% is a possible field star according to our classification criteria. This star is a short-period eclipsing binary with an orbital period $P_{\text{orb}} = 3.2$ d (Debernardi & North 2001) and was classified as an Ap star with SrCrEu peculiarity type by Hartoog (1976). Maitzen & Hensberge (1981) reported on the measurement of a small value of the photometric $\delta a$ index, indicating that this system might host a magnetic Ap star. However, Debernardi & North (2001) were not able to detect any strong peculiarity of Ap type and concluded that any peculiarity, if present, can only be very mild. No detection of a magnetic field was achieved by Bagnulo et al. (2006).

HD 66194: The blue straggler nature of the fast rotating B3Vn star HD 66194 was discussed at length by González & Lapasset (2000). It is a photometric variable of $\gamma$ Cas-type and the spectrum of this star presents Balmer emission lines. This star was mentioned to have a companion by Kervella et al. (2019) due to the presence of a proper motion anomaly detected using the Hipparcos and Gaia DR2 catalogues. The high rotation rate of this star may indicate the presence of mass transfer in a close binary system. No magnetic field was detected in this star by Bagnulo et al. (2006) using low-resolution spectropolarimetry. This target was reported as the strongest X-ray source in the X-ray cluster survey carried out by Jeffries et al. (1997). Our results confirm membership of this star in NGC 2516.

HD 65950 and HD 65949: The presence of a weak magnetic field was detected in the two HgMn stars HD 65950 and HD 65949 by Hubrig et al. (2006) using low-resolution FORS1 spectropolarimetry. A weak mean longitudinal magnetic field was detected in HD 65949 also using high-resolution HARPS spectropolarimetry (Hubrig et al. 2020). In our study only HD 65950 is confirmed to be a bona fide member of NGC 2516, in accordance with the work of González & Lapasset (2000). HD 65949 was suggested to be a triple system due to a small variation in the centre-of-mass velocity, interpreted as due to the presence of a third body (Cowley et al. 2010). Also HD 65950 is not a single star, as it was reported to have a companion due to the presence of a proper motion anomaly, detected using the Hipparcos and Gaia DR2 catalogues (Kervella et al. 2019). In contrast to the chemically peculiar Ap and late Bp stars, which are rarely members of close binaries, but rather frequently members of wide systems (Mathys 1997), HgMn stars predominantly appear in binary and multiple systems (Hubrig & Mathys 1995; Schöller et al. 2010; Chojnowski et al. 2020), in particular in close binaries with orbital periods between 3 and 20 d (Hubrig & Mathys 1995; Hubrig et al. 2020).

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