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What can we expect from a census of Ap stars in open star clusters in the Galaxy and beyond?

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Abstract. We discuss the presence of magnetic peculiar stars in open clusters on the basis of photometric identification, in a sample that covers not only the solar neighbourhood but also wider galactic regions. Our study includes the possible influence of metallicity and/or other environmental properties. The compactness of a cluster is investigated as a parameter in Ap-star formation. For that purpose we use the classical *p*-*m*-*r* "richness" groups defined by Trumpler (1930), together with approximate cluster volumes derived from a recent study of cluster diameters by van den Bergh (2006). Basing our study on a sample of 80 galactic clusters with published Δa photometry, we notice (a) that the Trumpler richness groups correspond to distinctly separated mean cluster diameters (2.0/3.4/4.9 pc) and (b) that the resulting densities (Ap stars per pc^3) point overwhelmingly to the *p* group as the principal domain of Ap stars. A special feature is the prevailing appearance of *p*-group Ap stars alone in the inner galactic quadrants, unaccompanied by parallel behaviour of the *m* and *r* groups. Whether or not this is a metallicity effect has to be substantiated by the including additional clusters to improve the statistics. It does seem to be the case in the Large Magellanic Cloud, according to a study of a photometric sample of Ap stars, though the frequency is clearly lower on account of the lower metallicity of this satellite galaxy.

Key words: Galaxy: open clusters – stars: chemically peculiar

1. Introduction

Chemically-peculiar stars of the upper main sequence are attractive objects, especially for observers, because of their very rich phenomenology. 110 years after their detection we are still busy finding the reasons for their origin, especially that of their strong magnetic fields. An empirical approach has to consider the questions: why do only roughly 5 % of the upper main-sequence stars exhibit spectral and related peculiarities, and – since their appearance seems to be related to the presence of a strong global magnetic field – when, where and how were such fields created? While great efforts have been expended in investigating the enormous diversity of spectral features and abundances among Ap stars in the solar neighbourhood, no convincing answer to the creation of such magnetic fields has so far emerged, and at present we have only vague explanations about frozen-in surviving primordial field relics, or a dynamo that is somehow brought into action.

In order to find a comprehensive model which favours the formation of Ap stars, one must therefore resort to another type of approach other than studying individual peculiarities. An important step was made by Abt (1979), who investigated the "Occurrence of Abnormal Stars in Open Clusters" based on spectra taken at classification dispersion (and also at higher dispersion) for 661 stars in 11 open clusters and 3 associations. Abt studied statistically not only classical, i.e. magnetic, Ap stars but also other peculiar stars (metallic-lined, HgMn, Be and shell stars) in order to investigate evolutionary evidence for them. He introduced a concept of emerging and increasing peculiarity due to the action of a magnetic field. Around the same time it was becoming clear that statistical studies of Ap stars must be more specific, by aiming primarily at the magnetic objects, and also that the number of stars in a study needs to be increased dramatically.

Increased sampling was made possible by detecting the broadband flux depression around 520 nm, which is measurable for virtually all magnetic Ap stars (CP2 and CP4) by the photometric Δa index introduced by Maitzen (1976). The middle band 3 filter system used in this index was shown to supersede previous spectroscopic Ap-star searches very efficiently, thus opening access to remote galactic regions even with rather moderate-sized telescopes. A much larger number of galactic clusters could now be included in Ap-star searches, and other questions could be raised, such as time series of Ap-star features (spectral and photometric variations). Besides the detection of Ap stars via Δa photometry we can also determine cluster parameters like age, reddening and distance using isochrones for the system (Claret *et al.*, 2003). Even the calibration of the effective temperature for early-B to mid-F stars is now possible (Paunzen *et al.*, 2006 a). North (1993) reviewed open clusters to investigate the evolutionary status of peculiar stars using published spectroscopic and photometric detections, including Geneva photometric indices. Furthermore, through extending the radius of sampled galactic clusters out to 5 kpc from the Sun, and by the (successful) search for Ap stars in the Large Magellanic Cloud based on Δa photometry (for references, see Paunzen *et al.*, 2006 b), aspects of environmental influences upon the formation of magnetic peculiar stars entered our research and discussions, and we could ask (e.g.): Is the production of magnetic Ap stars influenced by the metallicity, and/or other factors like the local galactic magnetic field, and/or other specific conditions, in the star-forming molecular cloud?

To explain the origin of magnetic stars, Bidelman (2002) suggested a model of merging close, interacting binaries. In the HR-diagram of open clusters the Ap stars should, as a consequence, populate the region of Blue Stragglers, but Observational data do not generally support that. Moreover, Bidelman's model is unlikely to explain the complex geometry of magnetic versus rotational axes in Ap stars, since the merging would occur after the elapse of a significant period after binary formation. We would like to propose a modification to that model, in which interaction between stars takes place in the early phases of open cluster formation, thereby permitting a wide range of geometrical configurations. Such interactions would increase with the compactness of the cluster. Measurements of the Ap-star content in clusters of different richness classes might therefore indicate whether the production of Ap stars per unit volume is the same for p(poor), m(medium) and r(rich) clusters – the classical classification groups according to Trumpler (1930) - or if not, in which sense is it different?

2. Status of the Δa project in clusters

Our project of Δa photometry now comprises 80 published open clusters in the Galaxy, 38 observed by photoelectric photometry (PP, for references see Maitzen, 1993), 42 by the CCD technique (for references, see Netopil *et al.*, 2007), with a few clusters in common in order to check consistency. The overlap between both techniques is narrow, PP reaches out to 1000 pc, while CCD objects are mostly at larger distances.

The richness classifications were taken from the catalogue of Lynga (1987). In order to determine volumes for the clusters we have resorted to the list of open-cluster diameters in van den Bergh (2006). When calculating the typical linear diameter for each of the 3 richness groups we chose median instead of mean values in order to minimize the influence of outliers. We want to stress that the determination of linear cluster diameters is hampered not only by the uncertainty of the cluster distances but also by their angular sizes.

Our r group includes 24 clusters: 13 observed by PP and 11 by CCD. It is remarkable that the yield of Ap stars distinctly differs between them: while the PP measurements showed up 30 Ap stars through their substantially positive Δa values, our CCD clusters appear to contain only 8 such objects. The difference is mainly due to three Ap-rich clusters (NGC 2516, 3114 and 6475), which together contribute 17 peculiar stars (=45 %) to the r group. From a median value of 4.85 pc for the linear cluster diameter we calculated the sum volume of all clusters (1433.6 pc^3) of the group and compared it with it the total number (38) of Ap stars. The resulting number density is then 0.0265 Ap stars per pc^3. The uncertainty of that value should be around 20 %. However, were we to eliminate the three Ap rich clusters from our calculation we would derive a number density of only 0.0167 per pc^3.

The m group shows a nearly equal balance of PP and CCD identifications: 28 Ap stars identified in 19 clusters by PP compared to 26 such objects in 18 clusters from CCD. Since the total number of clusters in this group (37) represents nearly half the whole sample of open clusters in our investigation, we deem this balance as a satisfactory indicator of the completeness of both observing techniques in detecting peculiar stars via the Δa index. From the median value of 3.4 pc we derived a total volume of 761.4 pc^3 in which 54 Ap stars are located, corresponding to a number density of 0.0709 of such stars per pc^3; that is substantially higher than in the r group, taking into consideration an uncertainty of about 15 %.

The p group is similar to the r group in having unequal numbers of PP and CCD, but in a reverse sense: 6 versus 13 clusters, yielding 4 and 34 peculiar stars, respectively. That proportion might be influenced by the substantially larger distances of the CCD clusters, and the fact that they are embedded in copious galactic fields. However, the linear diameters of the CCD clusters are not significantly different from the (admittedly few) nearer PP clusters of this group. We therefore obtained a median value of 2.0 pc for all p clusters. The latter fill a volume of 79.6 pc^3, and the 38 objects found represent a number density of 0.4774 peculiar stars pc^3, roughly six times larger than the number density in the m group clusters, and 18 times that in the r group.

The average volumes per cluster which we found, from the p via the m to the r groups in our sample, correspond to the relationship 1 : 4.9 : 14.3. That result demonstrates quite clearly that the Trumpler richness classes correlate with the average volumes of the clusters. However, since the inverse average densities of Ap stars behave as 1 : 6.7 : 18.0 and the average numbers of Ap stars *per cluster* are 2 .0 (p), 1.46 (m) and 1.58 (r), that means that the average formation of those stars is it not proportional to the volumes and the overall number of member stars in the home clusters. This can be nicely demonstrated by assuming a constant number density of Ap stars for all richness groups: if we take the derived value for the p group (0.4774 per pc^3, yielding an average of 2.0 Ap stars per cluster) we should expect to find 9.8 Ap stars in an average m cluster instead of 1.46, and 28.6 Ap stars in typical r clusters. Even the Ap "burst" clusters NGC 2516, 3114 und 6475 of the r group should then contain together not merely 17 Ap stars but 286, when calculating the sum of their volumes from their individual diameters, and at least 86 Ap stars using the average cluster diameter of the r group for each of these 3 clusters!

Another interesting aspect concerns the galactic location of the clusters. If we consider radial symmetry alone, we can follow the distribution of Ap stars per cluster from 5.9 to 10.8 kpc from the galactic centre – 96 % are closer than 9.5 kpc (assuming 8 kpc for the distance of the Sun from the centre). Our sample reveals no significant variation for the m and r class over this interval of galactocentric distances, but exhibits a definite decline of Ap stars in p-type clusters from the inner to the outer galactic quadrants. That might be interpreted as following the galactic abundance gradient, but should be substantiated by extending the search to clusters in the anti-center direction in order to get a longer baseline for metallicity differences. On the other hand, clusters younger than 10 Myr tend to have fewer Ap stars. We therefore have to stress the need to increase the available statistical material when addressing the question of factors which contribute to the creation and appearance of Ap stars in open clusters in our Galaxy. It is clear that the complexity of the phenomenon cannot be tackled with just a dozen clusters, as was thought a couple of decades ago.

In conclusion, we can state that there is surprising evidence, from our previously published census of Ap stars in open clusters of the Galaxy, that the smaller, less populated clusters have produced Ap stars more efficiently than the bigger and richer ones. A more quantitative statement about this efficiency must depend upon reliable knowledge of the cluster masses (average values for the richness groups are needed) in order to know how the volumes of the richness groups scale with their masses.

At this stage it is therefore still a matter of speculation whether the formation of compact clusters could favour the creation of Ap stars through close encounters or mergers of extremely young stars (those near the ZAMS). It has to be stressed that our sample of p-group clusters is not older than the m and r groups but only about half as old (40 Myrs) on average, so any possible loss of members must have occurred at an early stage of their lives and may be attributable to the generally stronger gravitational interaction between members in a compact young cluster enhancing stellar motions that tend to cause disintegration.

2.1. Peculiar stars in the Large Magellanic Cloud

While metallicity varies only slowly over the galactic disk and our sample feels its impact only weakly, the LMC nevertheless shows a clear difference in the impact which that metallicity has. Paunzen *et al.* (2006 b) have summarized the Δa search for peculiar stars in the giant ("globular") young clusters NGC 1866, NGC 1711 and the double cluster NGC 2136/7, including field measurements. Despite the technical problems due to the large distance it seems clear that the numbers of Ap stars in those clusters are reduced by a factor of 2 in comparison with normal stars of the same spectral domain in the Milky Way. One can conclude, therefore, that metallicity does seem to play a role in Ap-star formation. However, one should take account of the fact that the global magnetic field situation is different compared to the Milky Way, and might thereby additionally influence the scenario. Again, the enlargement of the data base for clusters and Δa photometry in the LMC is obviously desirable.

2.2. Comparison with Geneva photometry

When we applied the Ap detection indices Δ(V1-G) and δZ (North, Cramer 1981) to Geneva photometry in open clusters, we found 21 clusters in common to the present study, and divided into r-m-p groups as follows: 10/10/1 clusters, 18/6/1 = 25 Ap stars in the Geneva system, 28/15/1 = 44 Ap stars in the Δa system. 1.190 Ap stars were therefore identified per cluster by Geneva photometry, compared to 2.195 by Δa photometry. The Geneva result is to be regarded with caution since the programme had found only 17 clusters with positive detections of peculiar stars while the remaining 19 clusters did not appear to contain any Ap stars.

By working from the catalogue of Renson (1992), in which spectroscopic and photometric identifications of Ap and Am stars in open clusters are collected, North (1993) discussed the statistics of the magnetic Ap stars. He extracted 86 reliable CP2 (and hence magnetic Ap) stars from a sample of 72 open clusters (16 of which gave zero detections), yielding an average of 1.194 such objects per cluster. This is clearly lower than our collective result of 130 Ap stars in 80 clusters (26 with no Ap), or 1.625 per cluster as mean value, and 36.1% more than found by North. The two studies have an overlap of 12 r, 17 m and only four p clusters. The r group is biased by the presence of the three Ap rich clusters mentioned above, and the p group is marginal. No reliable statistics can therefore be obtained for the relationship of the p class to m and r from that material. If we included all the clusters measured by North (1993) we would find 25 r, 34 m and 13 p clusters, but we cannot use that result since North did not explicitly list the number of Ap (CP2) stars belonging to each cluster.

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