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Magnetic field of chemically peculiar stars in the Orion OB1 Association

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The article presents the results of studies of the magnetic field of chemically peculiar stars in the association of young stars Orion OB1. Our results indicate a sharp drop in the proportion of magnetic stars and a simultaneous decrease in their magnetic field with age. The observations were made with the 6-m BTA telescope of SAO RAS. On the whole, the obtained data testify in favor of the theory of the relict origin of the magnetic field of chemically peculiar stars. However, the formation process itself may have a number of features that have observational manifestations.

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1. Introduction

The OB1 association in the Orion constellation is rich in bright B stars. Its center is located at a distance of about 400 pc. Our previous studies have shown that this association contains the largest of all known groups of early massive chemically peculiar stars, many of which potentially have a magnetic field [1]. This, as well as the important fact that the age of the stars in the association, in contrast to the field stars, is determined quite reliably, were the main motives for choosing the object of study.

We presented a detailed substantiation of the need for such studies in [1], where the problem statement was presented, individual stars were identified, and their main parameters were found. The observation program was carried out with the 6-m BTA telescope. Over 10 years of its implementation, more than 600 Zeeman spectra were obtained for 60 chemically peculiar stars. To date, the observational part of the program has been completed.

The results of measurements and magnetic field studies of each program star are described in detail in [2–5]. In this article, we briefly present the main results of our research.

There are many schemes for dividing an association into subgroups in Orion. By the time our project began, the scheme proposed by Blaauw [6] was generally accepted. Within the association, he identified four subgroups, each of which differs in age and stellar composition. New studies indicate a more complex distribution of stars in the association; nevertheless, for homogeneity, we adhere to the Blaauw scheme as proposed in [1].

According to [6], the oldest part of the association 1a is located north of the "Orion belt" and is about 10 million years old. Subgroup 1b is the "Orion belt" with an age of about 2 million years. An extensive subgroup 1c occupies the lower part of the constellation south of the "Orion belt". The small subgroup 1d is very small and is in fact located inside the subgroup 1c — these are stars in the region of the large Orion nebula.

2. Selection of chemically peculiar stars

The principles of selection and the lists of identified chemically peculiar stars of the Orion OB1 association are given by us in [1]. The method for identifying CP stars in all subgroups was the same. The same applies to the observation technique, magnetic field measurements, and data analysis.

The stellar population of the Orion association includes 814 objects, according to the most comprehensive work by Brown et al. [7]. We decided to select chemically peculiar (CP) stars among them. The Renson and Manfroid catalog [8] was used as a source of information about CP stars.

Using it, we identified 85 CP stars of different types of peculiarity. Thus, the proportion of CP stars among the objects of the association is 10.4%, which corresponds to the average value for all samples of CP stars.

A more careful analysis performed in [1] showed that 23 of them are nonmagnetic stars with enhanced metal lines (Am stars). Moreover, the distance analysis based on the Gaia satellite data [9] showed that Am stars do not belong to the association; they are foreground objects and are simply projected onto it.

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Table 1: Occurrence and mean rms magnetic field of CP and magnetic CP stars in different subgroups of the association.

Subgroup	$\log t$	N_{tot}	$N_{\rm CP}$	$N_{\rm mCP}$	ϕ_1, %	ϕ_2, %	$\langle B_{\rm rms}\rangle$, G	$\sigma_{\rm rms}$, G
1a	7.0	311	15	7	46.6	2.2	1286	229
1b	6.2	139	15	11	73.3	7.9	3014	212
1c	6.6	350	24	13	54.2	3.7	1074	145
1d	<6.0	14	3	0	0	0	—	—

Thus, we identified 62 potentially magnetic chemically peculiar stars in the association. Previously [10], 17 magnetic stars with strong fields were found in it. We decided to perform spectropolarimetric observations of all 62 objects in order to search for new magnetic stars and to plot longitudinal field variability curves for the previously known ones.

3. Observations and analysis of the obtained data

Most of the observations of CP stars in the Orion OB1 association were carried out in the period from 2013 to 2020 with the Main Stellar Spectrograph (MSS) of the 6-m BTA telescope. Instruments, methods of observation and data analysis have been repeatedly described earlier [e.g., 2–5]. For most stars, we obtained at least four spectra on different dates. The exposure time was chosen so that the signal-to-noise ratio (S/N) in the spectra was at least 150–200. The bulk of the spectra covers the wavelength range of 4450–4950 Å with an average resolution of $R \approx 15\,000$.

The results of measurements of individual stars, as we have already mentioned above, are presented in [2–5]. Here we describe the main conclusions.

We found that the association contains at least 31 magnetic stars with fields above 500 G. It is possible that among the CP stars there are additional magnetic stars, but with weaker fields, but our technique did not allow us to detect them. Let us take into account that the accuracy of magnetic field measurements and, consequently, the lower limit of its detection depends on the number of lines in the spectrum and their width. The magnetic field of hot fast rotators, which include most of the CP stars in the Orion OB1 association, is much more difficult to measure than for slowly rotating cold stars with a large number of lines in their spectra. However, we want to emphasize that in all subgroups of the association, the measurement accuracy was the same and the analysis was carried out in the same way, so the differences identified are objective.

Table 1 shows the fraction and the rms magnetic field of CP stars in different subgroups of the Orion OB1 association. In the columns of the table: $\log t$ is the age of stars in the subgroup according to [1], $N_{\rm tot}$ is the total number of stars according to [1], $N_{\rm CP}$ is the total number of CP stars [1], $N_{\rm mCP}$ is the total number of magnetic stars [4], $\phi_1 = N_{\rm mCP}/N_{\rm CP}$ is the proportion of peculiar stars relative to all A and B stars, $\phi_2 = N_{\rm mCP}/N_{\rm tot}$ is the proportion of magnetic relative to all A and B stars.

Thus, we see that in the association the proportion of chemically peculiar stars relative to all A and B stars sharply decreases with age. A separate question about the subgroup 1d. The fact is that according to our spectra it is difficult to distinguish HAEBE-type stars with an H_α emission line from a hot B[e] star simply located in a nebula, and emission in H_α is not a sign of a star: the nebula glows in its spectrum. It is possible that all three objects of subgroup 1d are objects of Herbig Ae/Be type.

Now let's compare the magnitudes of the magnetic field of the stars in the association subgroups (table 1).

We see that the field strengths in subgroups 1a and 1c are on average the same, but the degree of reliability of identifying magnetic stars in subgroup 1c is much higher. And in the youngest subgroup 1b, the field is three times higher. The reliability of the obtained differences is high.

Note that, contrary to our expectations, the strongest field for stars in the Orion OB1 association was found not in star-forming regions, but on its periphery. The most typical examples are HD 34736 and HD 37776 — the stars with a record strong field (more than 5 kG). In the center of the star-forming region of the Large Orion Nebula, only one star has a field whose longitudinal component is 2 kG.

While working on the survey of the association, we noticed that there are very few magnetic stars among the peculiar stars included in the Parenago catalog [11]. An analysis of our data shows that at distances closer than the Orion Nebula, the interstellar absorption and polarizations are small. They originate in the nebula itself.

Of the 24 stars of subgroup 1c, 12 are included in the Orion Nebula, of which 3 are magnetic and 9 are non-magnetic. All three CP stars of subgroup 1d are included in the Orion Nebula, and none of them has a strong field. Outside the Nebula, but in its vicinity, in subgroup 1c we have 9 magnetic and 2 non-magnetic stars.

As a result, we obtain an expressive effect: the proportion of magnetic stars in the Nebula is 20%, and 83% outside it in the subgroup 1c. The magnetic field for stars outside the Nebula is twice as high as for the stars in the Nebula.

Of course, we are dealing with small samples, but it is necessary to pay attention to this trend. It is possible that instrumental selection is taking place, which makes it difficult to classify magnetic (or chemically peculiar) stars in the Orion Nebula. It is possible that two types of stars with emissions are observed in the Orion Nebula. Firstly, they really can be objects like Ae/Be Herbig, and, secondly, they can be just hot stars whose glow comes from the surrounding nebula.

One way or another, we are getting information about a significant difference in the magnetic properties of stars inside and outside the Orion Nebula. The proportion of magnetic stars in the Nebula is four times, and the average magnitude of the magnetic field is two times smaller than that of objects outside it.

4. Conclusions

As a result of observations with the 6-m BTA telescope and data processing, we found that the total number of magnetic stars is about half of all chemically peculiar stars in the Orion OB1 association, which is twice as high as the proportion of magnetic stars in the entire sample of CP stars.

We found a sharp drop in the proportion of chemically peculiar stars in the association in the age range from 2 million years to 10 million years. We also see a sharp decrease in the proportion

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of magnetic stars in the Orion Nebula. It is obvious that the formation of the magnetic field of stars occurs in a complex way. Our data support the hypothesis of the relict origin of the magnetic fields of chemically peculiar stars.

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