Magnetism and Other Properties of CP Stars in Orion OB1

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We present the state-of-the-art results of an ongoing survey of the chemically peculiar star population in the association Ori OB1. Aiming to achieve uniform measurement of the magnetic field and other stellar parameters of the sample, from early 2011 we have collected over 500 spectra for more than 60 stars which had been classified in the literature as the bearers of peculiar spectra. With new measurements, we extended our knowledge about the magnetic field and multiplicity of the stellar population in Ori OB1.

1 Introduction

Gould's Belt, a ring-shaped structure in the solar vicinity, delineates in the sky the area of young stellar associations under the age of 30 million years (Lindblad et al., 1997). The interest to chemically peculiar stars in stellar associations arose in the second part of the 20th century and was caused by the progress in studies of stellar evolution. Chemically peculiar or CP stars form a $10 - 15\,\%$ fraction of the stars of a given spectral type (Renson & Manfroid, 2009). In the case of open clusters, the total number of peculiar stars is insufficient for statistics, so naturally, scientists turned their sights to stellar associations. Such structures are more sparse than clusters but their population is more numerous and their age can be established with acceptable accuracy.

One of the closest stellar associations extends over two constellations and is located approximately $150 - 200$ pc from the Sun. The association Sco-Cen OB1 is rich in high-mass and intermediate-mass stars, which ages ranging from 5 to 17 Myr depending on the region. Despite the proximity of the association, its southern location does not allow the efficient study of the CP stars there with large observational facilities hosted in the northern hemisphere.

Another matter is Ori OB1. Stars from this association form the constellation and represent a substantial part of the galactic structure. The mean distance to the association Ori OB1 is about 360 pc which is larger than that of Sco-Cen OB1, but still enough to be observable with all available modern telescopes. For example, in this association, the faintest B-type stars of about $10 - 11$ mag are achievable for the largest telescopes equipped with polarimeters. The equatorial position of the constellation also inspires its study.

The Ori OB1 association consists of several parts of different ages. In his review from 1964, Blaauw divided the association into four groups, *a* to *d*, of different age and location (see Fig. 1). In 1994, Brown et al. published the results of a thoughtful study of the stellar population in Orion. This paper reviews basic parameters for

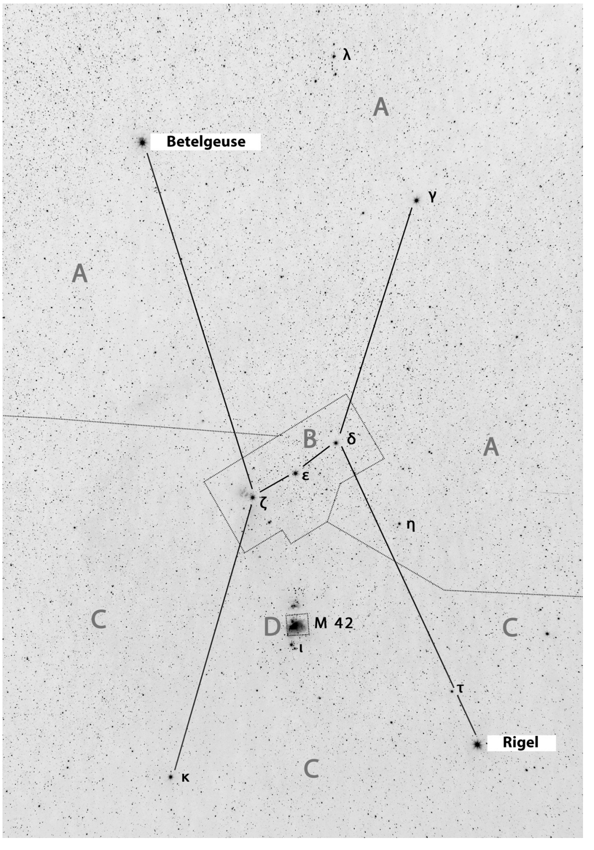

Fig. 1: Scheme of the association Ori OB1 following Blaauw (1964).

almost all stars in Orion and remains relevant even now. New studies based on the results of the *Gaia* mission revealed a more complex structure of the association. The recent series of papers by Zari et al. (2017, 2018, 2019) summarizes these studies.

2 Chemically peculiar stars in Ori OB1

Like the other stellar groups, the associations also have a fraction of stars with abnormal spectra. Because of the young age of Ori OB1, this association mostly hosts CP stars with helium-type anomalies, but there is also a fraction of cooler stars with an enhanced abundance of silicon. Individual CP stars in Orion became the targets of searches for magnetic field soon after the pioneering works of Babcock, who had designed a differential circular polarisation analyser and discovered the longitudinal magnetic field in CP stars (Babcock, 1947). His analyser was well-suited for measuring stars with sharp metallic lines but was ineffective in the case of the rapidly rotating hot stars in Orion. Systematic measurement of the magnetic field in Orion stars started with an application of a hydrogen-line magnetometer to the stars (Landstreet & Borra, 1977, 1978; Borra & Landstreet, 1979). The new technique was able to reveal the presence of the magnetic field in many stars, including very exotic ones like HD 37776. Altogether these works initiated practical searches for the answer to the question of how the magnetic field impacts the evolution of chemical peculiarities (Strittmatter & Norris, 1971). Initiated in the 1970s by John Landstreet, this study of the evolution of the magnetic CP stars in clusters and associations was further developed by his followers and, decades after, it keeps going with the new instrumentation and new techniques (Brown et al., 1981; Thompson et al., 1987; Bagnulo et al., 2006; Landstreet et al., 2007, 2008; Bailey & Landstreet, 2013).

Even with the progress achieved by the beginning of the 2010s, our knowledge about the magnetism of CP stars in Orion remained incomplete. To fill this gap, at the Special Astrophysical Observatory, we launched a project aimed at a complete survey of all Orion stars showing chemical anomalies. In this project, we proposed new searches for the magnetic field in little-studied CP stars and constraining their physical parameters. After careful inspection of data published by Brown et al. (1994) and Renson & Manfroid. (2009) we identified 85 stars with anomalies in their spectra. All details of data selection are described by Romanyuk et al. (2013). In our research, we were following the division into subgroups proposed by Blaauw (1964). We have found that the fraction of CP stars in Ori OB1 is in anticorrelation with age, and increases from 8 % (group *a*, mean age ≈10 Myr) to 21 % (group *d*, age ≈1 Myr). The spatial distribution of CP stars with known *Gaia* parallaxes in galactic rectangular coordinates is shown in Fig. 2.

As a further step, we planned to observe all the CP stars, excepting those that had already been studied in detail, with the use of spectropolarimetric equipment of the Russian 6-m telescope BTA. The observational programme started in 2011.

3 Observations and measurements

Spectropolarimetry of CP stars at the 6-m telescope of the SAO RAS has been performing with the Main Stellar Spectrograph for many decades (Panchuk et al., 2014). This device is installed at the Nasmyth focus and equipped with a circular polarisation analyser which is combined with a double image slicer[1]. Observational technique and procedures of data reduction and measurement, were described many times in papers related to the project (Romanyuk et al., 2016, 2017, 2019).

By the end of the 2018/2019 winter season, the first run of the programme was completed. At this stage, the Zeeman spectra were collected for all targets in our list, excluding metallic-line stars. Overall, for more than 60 stars in eight years we obtained over 500 spectra. Each star was observed at least twice at different moments. This allows us not only to search for variable magnetic fields but also to detect previously unknown binaries. The signal-to-noise ratio of spectra is at least 200 at 4600 Å. In the wavelength range $4400 - 5000$ Å the mean resolving power R of the spectra is 14500.

To measure the longitudinal magnetic field of the stars we utilized three different techniques. All details regarding their use are presented in cited papers. One method should be discussed separately. This method is a software implementation of John Landstreet's hydrogen-line magnetometer approach. A small programme written in Python allows measuring a signal of circular polarisation in the wings of any hydrogen line (although not limited to H) selected by the user. The width of two

[1] `http://www.sao.ru/hq/lizm/mss/en/`

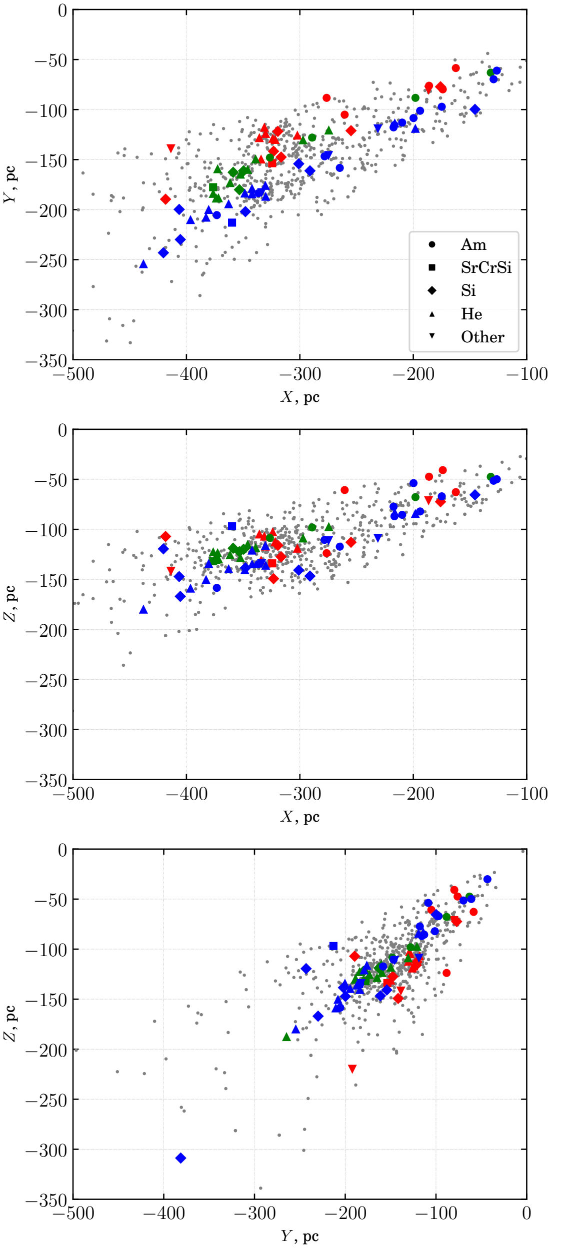

Fig. 2: Spatial distribution of CP stars by their type of anomalies in rectangular galactic coordinates. The population of groups *a*, *b*, and *c* are in red, green, and blue colours, respectively. The youngest group *d* is not displayed due to the low number of stars there. Gray dots are the normal members of the association according to Brown et al. 1994 with known *Gaia* parallaxes.

rectangular 'filters', and the space between them, can be adjusted interactively, but their position is always symmetrical with respect to the centre of the selected line. Our experience of application of such a 'software magnetometer' to the MSS data shows that CP stars usually show a lower value of the longitudinal field B_z measured from H lines than that measured from metals. However, exceptions also exist. The real value of this method can be demonstrated by the example of HD 36313, a binary star with a fast rotating magnetic component in Ori OB1b. The longitudinal field of this star was detected for the first time in hydrogen lines by Borra (1981). None of our eight observations made during eight years showed a significant signal of the field in metallic lines, though the spectrum of HD 36313 is very rich in narrow lines. The source of discrepancies between Borra's results and our measurements is stellar multiplicity: the magnetic star HD 36313A is a fast rotating star with $v \sin i \gg 80\,\mathrm{km\,s^{-1}}$ with very broad lines. Thus in this unique case, strong hydrogen lines are the only proxies suitable for the detection of the longitudinal field.

4 Results overview

The most complete survey was done for the oldest group *a* of the association. Apparently, this group consists of several clusters of different ages, but none of them hosts even two CP stars. Among 311 stars mentioned by Brown et al. (1994) only 24 stars were recognised as peculiar. This number includes non-magnetic Am and HgMn species. At least seven CP stars have He-weak type of anomalies. An analysis of our own results and published information about magnetic properties of stars in Ori OB1a let us conclude that 7 out of 15 potentially magnetic CP stars are the bearers of magnetic field. Five stars have the field definitely while the remaining two are suspected to be magnetic, but independent confirmation is required (Romanyuk et al., 2019). Thus, the fraction of magnetic stars among all CP stars in Ori OB1a is 45 %. Additionally, we have found a variable radial velocity in seven stars of our sample. This fact allows us to state that 45 % of CP stars in Ori OB1a are binary or multiple stars (Semenko et al., 2019). The last conclusion must be treated with care as the MSS, which was used for this work, does not fit properly for accurate measuring of the absolute radial velocity. Also, during this survey, we faced the problem of misclassification of published chemical anomalies. In the case of rapidly rotating stars, the lines used for the classification could be wrongly associated with other elements. This problem is very important as most of the stars were classified using low-resolution spectra. To overcome this limitation, we plan to get additional spectra of CP stars in Orion with a wider range of wavelengths.

Table 1 summarises the information about CP stars in group *a*.

Despite the fact that the minimal number of spectra need for the survey of the other three groups has been reached, the analysis of acquired data is still incomplete, and the observations are ongoing. In group *b*, whose age is around $4 - 11$ Myr, the population of helium stars is the highest. Large scatter in age determination is due to the highly heterogeneous structure of this part of the constellation. At the moment, we can state that 10 instances in our list are confirmed magnetic CP stars and another 4 are suspected. The total number of CP stars in group *b* is 16. Hence, at least 62 % of CP stars were recognised as magnetic.

The group *c* of the Ori OB1 association forms the southern part of the constellation. The age of the population here varies from 7 to 11 Myr because of different

Tab. 1: Information about observations, magnetic properties, and multiplicity of CP stars in Orion OB1a.

HD number	Sp type	Number of spectra	Magnetic	Binary	$v \sin i$
33917	A0 Si	4	No	Yes	60+170
34859	B8 Si	4	Yes	No	86
35008	B9 Si	3	?	No	205
35039	B2 He-r	3	No	Yes	30
35177	B9 Si	5	Yes	?	220
35298	B6 He-wk	12	Yes	No	59
35456	B7 He-wk	5	Yes	Yes	25
35502	B5-He-wk	Sikora et al. (2016)			
35575	B3 He-wk	4	No	No	88
35730	B4 He-wk	5	No	No	50
35881	B8 He-wk	6	?	No	335
36429	B6 He-wk	3	No	No	93
36549	B7 He-wk	8	No	Yes	52
38912	B8 Si	3	No	Yes	80
294046	B8 Si	4	Yes	?	130

times of birth in various regions. Our preliminary results give evidence that at least half of CP stars (12 out of 24) possess a detectable magnetic field. Four stars in our observations showed the signature of the longitudinal field, but this result needs to be confirmed.

The youngest and less populated group *d* contains only several CP stars, but the measurement of their spectra is not complete.

The list of future works within our survey includes a thoughtful look at individual stars. We plan to analyse the chemical composition and classify the type of anomalies in those cases, where the discrepancies between available classification and detected anomalies are very strong. For example, HD 35575 is known as a B2 He-wk star while its spectra clearly show enhanced lines of helium. Also, for some objects, their current He-wk or Si type of anomalies may be found to be HgMn and vice versa. The special interest is in the use of new data obtained with the *Gaia* and *TESS* missions. With these supplemental works we expect to finish the survey in $2-3$ years.

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