Main Results of Magnetic Field Studies of CP Stars with the 6-m Telescope over the Past 15 Years

I. I. Romanyuk[1], D. O. Kudryavtsev[1], E. A. Semenko[1,2], I. A. Yakunin[1,3], A. V. Moiseeva[1]

[1] Special Astrophysical Observatory, Russian Academy of Sciences, Nizhny Arkhyz, Russia,
roman@sao.ru,
[2] National Astronomical Research Institute of Thailand, Chiang Mai, Thailand
[3] Saint Petersburg State University, Saint Petersburg, Russia

Abstract. Spectropolarimetric observations of more than 200 chemically peculiar stars have been carried out during 2005-2019 at the 6m telescope with the aim of searching for the presence of stellar magnetic fields. Magnetic fields have been detected in 80 of them. Different correlation between magnetic fields and anomalies in the energy distribution in the continua of the stars have been considered. We have studied magnetic fields and other physical parameters of chemically peculiar stars in Orion OB1 association. We have obtained at least 500 zeeman spectra for 55 very young stars, we have found 10 new magnetic stars in association. We have studied very slow rotation of magnetic stars with period of rotation more than 1 year. We have found very long period of rotation for three stars: 3.7 years for HD 18078, 29 years for HD 50169 and 17 years for HD 965. The results of unique star observations are discussed. We can conclude that SAO system of magnetic measurements is stable during last 40 years and corresponds to international one.

Keywords: stars: chemically peculiar; stars: magnetic fields

DOI:10.26119/978-5-6045062-0-2_2020_56

1 General Review

Magnetic field measurements with the 6m telescope BTA were carried out for wide range of different type stars. Time Allocation Committee offered 550 nights from 2005 to 2019 for all type of magnetic stars for observations with the BTA, which corresponds to approximately 13% of the distributed time.

Most of observations were executed using Main Stellar Spectrograph (MSS[4]) (Panchuk et al. 2014) (R=15000, CCD 4600x2000 px, $\Delta\lambda$ = 500 Å). Zeeman analyzers designed and constructed by Chountonov (2004). Raw MSS frames were reduced in a common spectroscopic way using the sets of routines from ESO-MIDAS (Kudryavtsev 2000) and IRAF system.

2 Main Results of Magnetic Field Measurements, Obtained by SAO Group

Main directions of SAO RAS group activity concerning on magnetic chemically peculiar stars study:

1. Search for new magnetic stars.
2. Magnetic field of massive stars.
3. Very slowly rotating stars.
4. Study of various unique stars.

2.1 Search for New Magnetic Stars

The Zeeman effect is very weak and its influence on the spectrum in general is insufficient. Only 25% of chemically peculiar stars have measurable magnetic fields. Search for effective candidates is very important because of high pressure for observation time at large telescopes.

The best way for selections of magnetic candidates is study of CP stars with large flux depression at λ 5200 Å. The results are know from Δ a (Maitzen 1976) photometry from the Vienna observatory and Z-parameter from Geneva photometric system (North & Hauck 1979). Cramer & Maeder (1980) found correlation between intensity of flux depression and magnetic field value on the surface of CP stars.

We observed all possible CP stars with large Δa or Z-parameters. Practically all of the stars have large magnetic field. We founded 72 new magnetic CP stars among 96 candidates (Kudryavtsev et al. 2006) and more than 80 new magnetic CP stars after 2006 and now the total number of magnetic CP stars is about 500: 200 of them were found with the 6m telescope (Romanyuk et al. 2014), (Romanyuk et al. 2015b, 2016, 2017, 2018, 2020).

A few conclusions concerning on the all sample of magnetic CP stars.

1. No large-scale magnetic field stronger than 50 kG is found in CP stars. This is the limit: a stronger field cannot be formed in CP stars.

[4] Main Stellar Spectrograph – https://www.sao.ru/hq/lizm/mss/en/index.html

2. The distribution function of a magnetic field of CP stars: the number of stars strongly decreases for field larger than 1 kG. For the stars with field weaker then 1 kG very strong influence of different instrumental effects.
3. Magnetic CP stars are observed in the age interval from 1 million to hundreds of million years in clusters of different ages and in the field.
4. No differences in spatial distribution between peculiar and normal A and B-stars.

Unfortunately, no new measurements of Vienna Δa and Geneva Z-parameters. New possibilities have appeared recently. Accurate photometric observations with satellites Kepler and TESS are available now. Light curves of magnetic CP stars are of typical shape. Hundreds of light curves have been obtained for CP stars already. These new opportunity to search for them is available (detail in the paper by Yakunin et el, this meeting).

We calculated fundamental parameters of 160 new magnetic CP stars (detail in the report by Moiseeva et al, this meeting (Moiseeva et al. 2019b)). New data are in the good coincidence with the previous one.

2.2 Magnetic Field of Massive Stars

Introduction. It is need to know the age of different type of CP stars for study the evolution of their magnetic fields. For this study we selected massive magnetic Bp-stars. Most of them (75%) are cluster members with well determined ages. We selected for observation 17 open clusters and associations of different age with 3 CP stars at least. Most of them are Bp-stars.

The list of these clusters are presented in Table 1.

Orion OB1 association matched best, we selected 85 CP stars in it using the Renson & Manfroid (2009) catalogue. Among them: 23 Am-stars, 7 He-rich, 27 He-weak, 19 Si,Si+ and 9 peculiar stars of other type.

CP Stars in Orion OB1 Association. Stellar content of Orion OB1 association numbers of 814 objects (Brown et al. 1994). Total fraction of CP stars is 10.4% which is usual for field stars. Orion OB1 association can be divided in 4 subgroups (A, B, C, D) of different age (details in Romanyuk et al. (2013)).

Age of subgroups and number of all A and B-stars and CP stars are presented in Table 2.

The fraction of CP stars decrease with age from 21.4% (subgroup D) to 7.7% (subgroup A). GAIA parallaxes indicate distances from 100 and 300 pc for 23 Am stars, they appeared not to be members of the Orion OB1 association 59 Bp stars, account 13.4% of the total number of B-stars in association.

Table 1. CP stars in open clusters and association.

Cluster	Age (log t)	Number of stars
Orion OB1	6-7	85
Sco-Cen	6-7	34
Pleiades	8.13	5
Alpha Per	7.85	8
Coma	8.65	8
NGC 2242	7.85	7
NGC 2287	8.38	12
IC 4756	8.70	6
IC 4665	7.63	3
Hyades	8.90	3
Berkley 11	7.72	3
NGC 884	7.03	3
NGC 1039	8.25	4
NGC 6350	6.87	3
NGC 6871	6.96	3
NGC 7092	8.45	4
Trumpler 57	7.05	7

We determined magnetic fields, radial velocities V_R, rotational velocities $v_e \sin i$, effective temperatures T_{eff}, log g and other fundamental parameters (log g, $L/L_\odot$, $M/M_\odot$, $R/R_\odot$) for most stars in association (see Moiseeva et al. (2019a)). We found 10 new magnetic CP stars in Orion, HD 34736 among them is extremely anomalous (Semenko et al. 2014) and more than 15 new double and multiple stars.

Preliminary results on magnetic field measurements of CP stars in different subgroups of association are in Table 3.

There are no data for 3 CP stars: we need to get new observations for subgroup D.

Conclusion. The proportion of CP stars among normal and the proportion of magnetic stars (for subgroups A, B, C) decrease with age in the Orion OB1 association. Average magnetic field $\langle B_e \rangle_{rms}$ in youngest subgroup B is essentially higher than in subgroups A and C. Because of the effective temperatures in subgroups A, B and C are approximately equal (see at Moiseeva et al. (2019a)), we have age dependence but not temperature dependence.

Table 2. Age of subgroups and number of all A and B-stars and CP stars.

Subgroup stars	Age (log t)	All stars	Cp stars	Fraction
A	7.05	311	24	7.7%
B	6.23	139	21	15.1%
C	6.66	350	37	10.6%
D	< 6.0	14	3	21.4%

Table 3. Results on magnetic field measurements of CP stars in subgroups. Average $\langle B_e \rangle_{rms}$ calculated, using regression method (Bagnulo et al. 2002).

Subgroup	Number of mCP	Fraction, %	Average $\langle B_e \rangle_{rms}$, G
A	7 of 15	46.7	1286 ± 229
B	11 of 15	73.3	3014 ± 211
C	13 of 24	54.2	920 ± 1399

2.3 Very Slowly Rotation Magnetic Stars

We studied very slowly rotating stars (with period of rotation more than 1 year). Exiting of such stars are very powerfully evidence against dynamo theory of large scale magnetic field of CP stars forming.

We will demonstrate below results of our magnetic monitoring for 3 CP stars: HD 18078, HD 50169 and HD 965. Studying fundamental parameters of this stars are described at paper Moiseeva et. al, this meeting.

HD 18078 Period of rotation $P = 1358 \pm 12$ days. Mean longitudinal magnetic field (top) and mean magnetic field modulus (bottom) of HD 18078 against rotation phase (see at Mathys et al. (2016, Fig. 2, p.4)).

HD 50169 Period of rotation $P = 29.04 \pm 0.82$ years. Mean longitudinal magnetic field of HD 50169 against rotation phase see at Mathys et al. (2019a, Fig. 1, Fig. 2, p.6). Detail study of this star is presented in paper by Mathys et al. (2019a).

HD 965 Magnetic field of this star were found during the observation with the 6m telescope. Details in paper by Romanyuk et al. (2015a). Period of rotation $P = 16.5 \pm 0.5$ years. Mean longitudinal magnetic field of HD 965 against rotation phase see at Mathys et al. (2019b, Fig. 2, Fig. 3, p.5). Long time measurements of longitudinal magnetic fields demonstrates that our results are stable during decades.

2.4 Unique Stars

We have detailed study of most interesting stars with rotational phase. As for example, we demonstrated below the results of our investigation of chemically peculiar star HD 34736, member of Orion OB1 association (see at Fig. 1).

The star is a SB2 binary. The primary, secondary components have temperatures of T_{eff} = 13700 K and T_{eff} = 11500 K. The lines of the primary component are broad with $v_e \sin i$ = 75 km s^{-1}, the secondary component lines are even broader with $v_e \sin i > 100$ km s^{-1}. The orbital period is not determined exactly and is in within the limits from 80 to 85 d, eccentricity exceeds $e = 0.8$.

Magnetic field of the star was discovered from observation from 6m telescope. We have obtained more than 130 zeeman spectra.

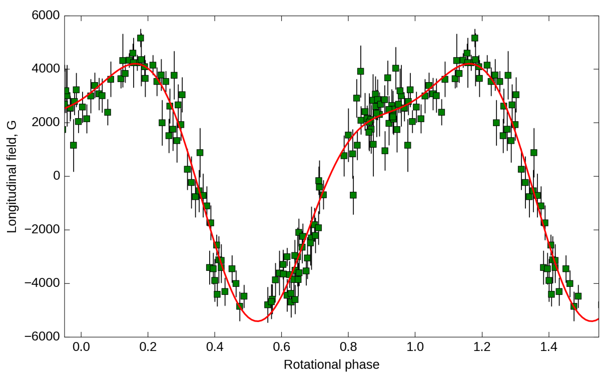

Fig. 1. Longitudinal field variations of HD 34736 against phase of rotation period $P = 1.29$ day. Magnetic field in the surface of the star exceed 10 kG.

3 Conclusion

The system of SAO magnetic measurements is stable during last 40 years and corresponds to international one.

The BTA remains one of the main world telescope, where magnetic fields are measured. As for CP stars, 200 out of 500 magnetic stars have been discovered with our telescope.

We have found evolutionary effects. In Orion OB1 association the frequency of magnetic stars and magnetic field strength decrease with age in the time interval from 1 to 10 million years and the speed of this decrease is larger than predicted theoretically. We have found new important observational test.

Acknowledgements. AVM, IIR thank Russian Foundation for Basic Research (RFBR) No. 18-29-21030, No. 20-02-00233; IAY – No. 19-32-60007. Observations with the SAO RAS telescopes are supported by the Ministry of Science and Higher Education of the Russian Federation (including agreement No. 05.619.21.0016, project ID RFMEFI61919X0016).

Bibliography

Bagnulo, S., Landi Degl'Innocenti, M., Landolfi, M., & Mathys, G. 2002, A&A, 394, 1023

Brown, A. G. A., de Geus, E. J., & de Zeeuw, P. T. 1994, A&A, 289, 101

Chountonov, G. A. 2004, in Magnetic Stars, 286–291

Cramer, N. & Maeder, A. 1980, A&A, 88, 135

Kudryavtsev, D. O. 2000, in Magnetic Fields of Chemically Peculiar and Related Stars, ed. Y. V. Glagolevskij & I. I. Romanyuk, 84–88

Kudryavtsev, D. O., Romanyuk, I. I., Elkin, V. G., & Paunzen, E. 2006, MNRAS, 372, 1804

Maitzen, H. M. 1976, A&A, 51, 223

Mathys, G., Romanyuk, I. I., Hubrig, S., et al. 2019a, A&A, 624, A32

Mathys, G., Romanyuk, I. I., Hubrig, S., et al. 2019b, A&A, 629, A39

Mathys, G., Romanyuk, I. I., Kudryavtsev, D. O., et al. 2016, A&A, 586, A85

Moiseeva, A. V., Romanyuk, I. I., & Semenko, E. A. 2019a, in Astronomical Society of the Pacific Conference Series, Vol. 518, Physics of Magnetic Stars, ed. D. O. Kudryavtsev, I. I. Romanyuk, & I. A. Yakunin, 52

Moiseeva, A. V., Romanyuk, I. I., Semenko, E. A., Kudryavtsev, D. O., & Yakunin, I. A. 2019b, Astrophysical Bulletin, 74, 62

North, P. & Hauck, B. 1979, Dudley Observatory Reports, 14, 183

Panchuk, V. E., Chuntonov, G. A., & Naidenov, I. D. 2014, Astrophysical Bulletin, 69, 339

Renson, P. & Manfroid, J. 2009, A&A, 498, 961

Romanyuk, I. I., Kudryavtsev, D. O., Semenko, E. A., & Yakunin, I. A. 2015a, Astrophysical Bulletin, 70, 456

Romanyuk, I. I., Moiseeva, A. V., Semenko, E. A., Kudryavtsev, D. O., & Yakunin, I. A. 2020, Astrophysical Bulletin, 75, 294
Romanyuk, I. I., Semenko, E. A., & Kudryavtsev, D. O. 2014, Astrophysical Bulletin, 69, 427
Romanyuk, I. I., Semenko, E. A., & Kudryavtsev, D. O. 2015b, Astrophysical Bulletin, 70, 444
Romanyuk, I. I., Semenko, E. A., Kudryavtsev, D. O., Moiseeva, A. V., & Yakunin, I. A. 2017, Astrophysical Bulletin, 72, 391
Romanyuk, I. I., Semenko, E. A., Kudryavtsev, D. O., & Moiseevaa, A. V. 2016, Astrophysical Bulletin, 71, 302
Romanyuk, I. I., Semenko, E. A., Moiseeva, A. V., Kudryavtsev, D. O., & Yakunin, I. A. 2018, Astrophysical Bulletin, 73, 178
Romanyuk, I. I., Semenko, E. A., Yakunin, I. A., & Kudryavtsev, D. O. 2013, Astrophysical Bulletin, 68, 300
Semenko, E. A., Romanyuk, I. I., Kudryavtsev, D. O., & Yakunin, I. A. 2014, Astrophysical Bulletin, 69, 191