Russian Academy of Sciences
Special Astrophysical Observatory

Main results of magnetic field studies with 6-m telescope BTA in last decade (2005-2019)

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7-11 октября 2019 г.

Всероссийская конференция: "Современная звездная астрономия – 2019"

General review

Time Allocation Commitee offered 550 nights from 2005 to 2018 for all magnetic stars for observations with the BTA, which corresponds to approximately 13% of the distributed time.

Author	Affiliation	Program	Nights
Kudryavtsev D. O.	SAO RAS	New magnetic CP stars	101
Romanyuk I. I.	SAO RAS	Magnetic field of massive stars	85
Wade G.	Canada	Geometry of magnetic field of CP stars	71
Piskunov N. E.	Uppsala Sweden	Magnetic mapping of CP star	48
Lamzin S. A.	SAI MSU	Magnetic field of T Tau stars	45
Polosukhina N. S.	CrAO, Crimea	Litium in magnetic stars	32
Kholtygin A. F.	SBBU	Microvariability of OB stars	25
Valyavin G. G.	SAO RAS	Magnetic field of white dwarfs	25

In addition, the telescope time was allocated for programs by Yu. Glagolevskij, E. Semenko, I.Savanov, M. Sachkov. A. Kolbin et al.

Total: **12000** zeeman and echelle spectra

Main results of magnetic field measurements obtained by SAO group

1. Search for new magnetic stars

2. Magnetic field of massive stars

3. Very slowly rotating stars

4. Study of various unique stars

Search for new magnetic stars

The Zeeman effect is very weak and its influence on the spectrum in general is unsufficient.

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.

For comparison: we measured radial velocities for tens of thousands of stars, while magnetic fields for less than 1000 stars only.

Search for new magnetic stars

The best way for selection of magnetic star candidates is study of CP stars with large flux depression at 5200 Å.

The results are know from Δa (Maitzen, 1976) photometry from the Vienna observatory and Z-parameter from Geneva photmetric system (Rufener, 1988).

Cramer and Maeder (1980) found correlation between intensity of flux depression and magnetic field value on the surface of CP stars.

A detailed analysis from one of such CP stars you can find at a poster by Moiseeva A. V. et al.: "FUNDAMENTAL PARAMETERS OF MCP STAR HD 17330 WITH WIDE DEPRESSIONS IN THE CONTINUUM."

Search for new magnetic stars

Mon. Not. R. Astron. Soc. **372,** 1804–1828 (2006) doi:10.1111/j.1365-2966.2006.10994.x

New magnetic chemically peculiar stars★

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Search for new magnetic stars

Mon. Not. R. Astron. Soc. **372,** 1804–1828 (2006)

New magnetic chemically peculiar stars★

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Accepted 2006 August 22. Received 2006 July 5; in original form 2005 October 4

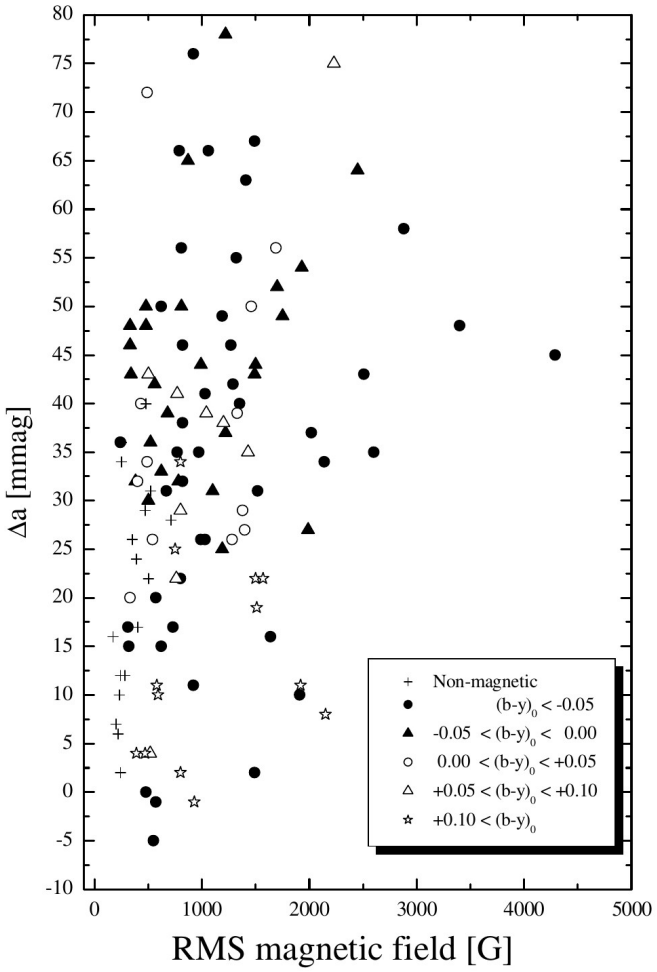


Figure 14. Relationship between the rms magnetic field $\langle B_e^2 \rangle^{1/2}$ and photometric index Δa for five groups of magnetic CP stars with different values of the magnitude $(b - y)_0$.

But we found that the correlation coffiecient is small (~ 0.5).

Search for new magnetic stars. Results

We observed all possible CP stars with large of Δa or Z-parameters. Practically all of the stars have large magnetic fields.

We founded:

1) **72** new mCP stars among **96** candidates (Kudryavtsev et al, 2006, MNRAS, v.372, 1804);

2) more than **70** new mCP stars after 2006 and now the total number of magnetic CP stars is about **500.** 200 of them were found with 6-m the telescope;

Search for new magnetic stars. Results

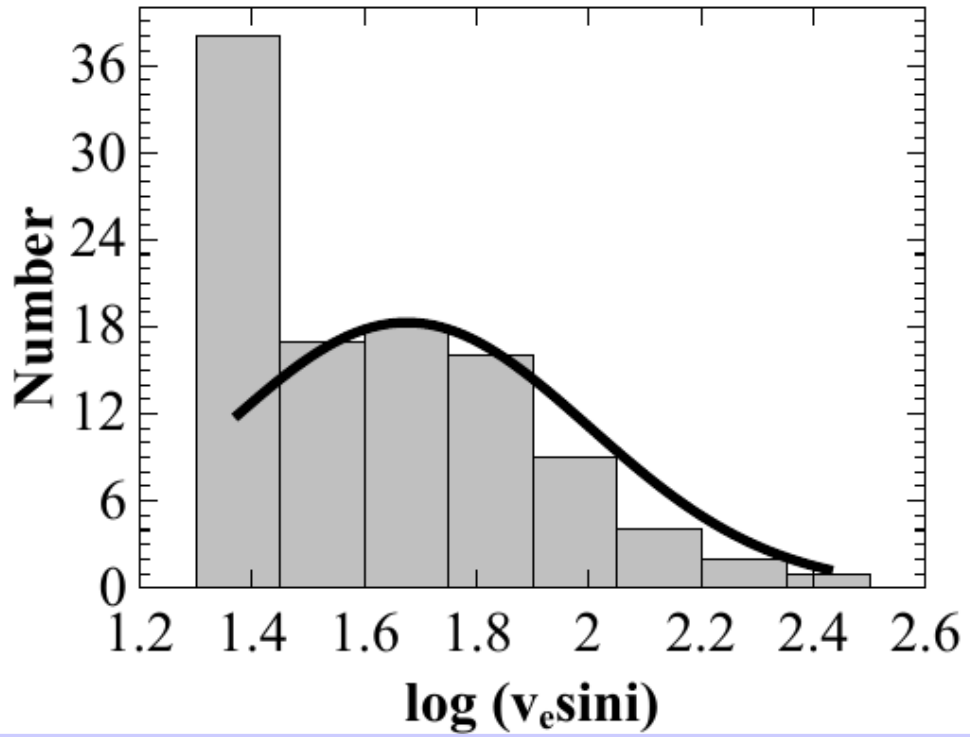
3) no large-scale magnetic field stronger than 50 kG is found in CP stars. This is the limit: a stronger field cannot be formed in CP stars;

4) the distribution function of a magnetic field of CP stars: the number of stars strongly decreases for field large 1 kG (for example, Kholtygin et al.). For the stars with field weaker then 1 kG very strong influence of different instrumental effects;

5) mCP stars are observed in the age interval from 1 million to hundreds of millions of years in clusters of different ages and in the field;

6) no differences in spatial distribution between peculiar and normal A and B-stars.

Fundamental parameters of CP stars

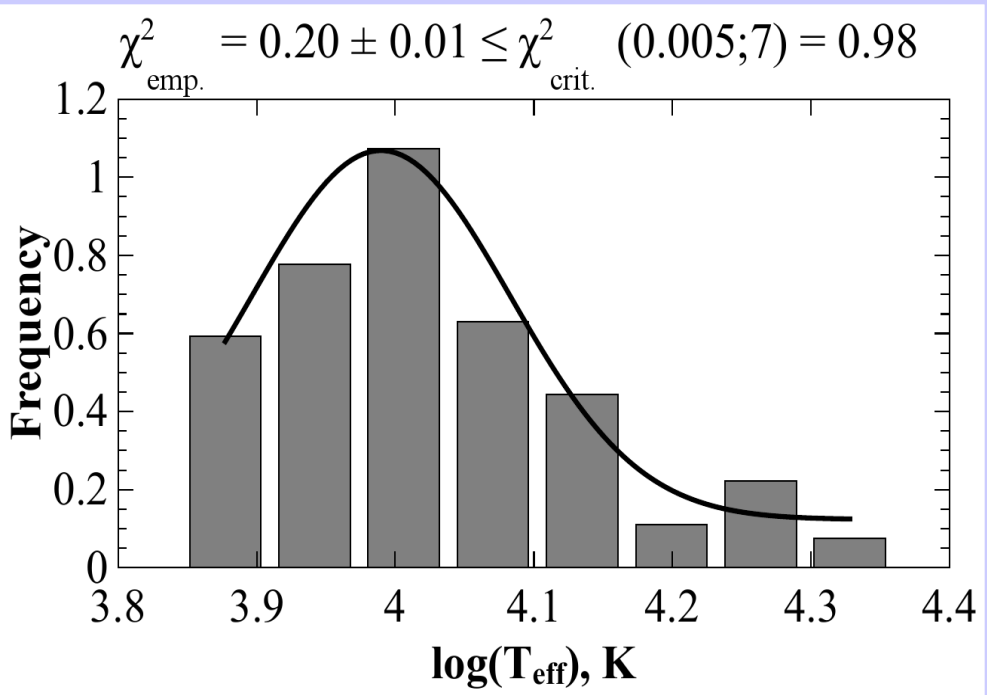


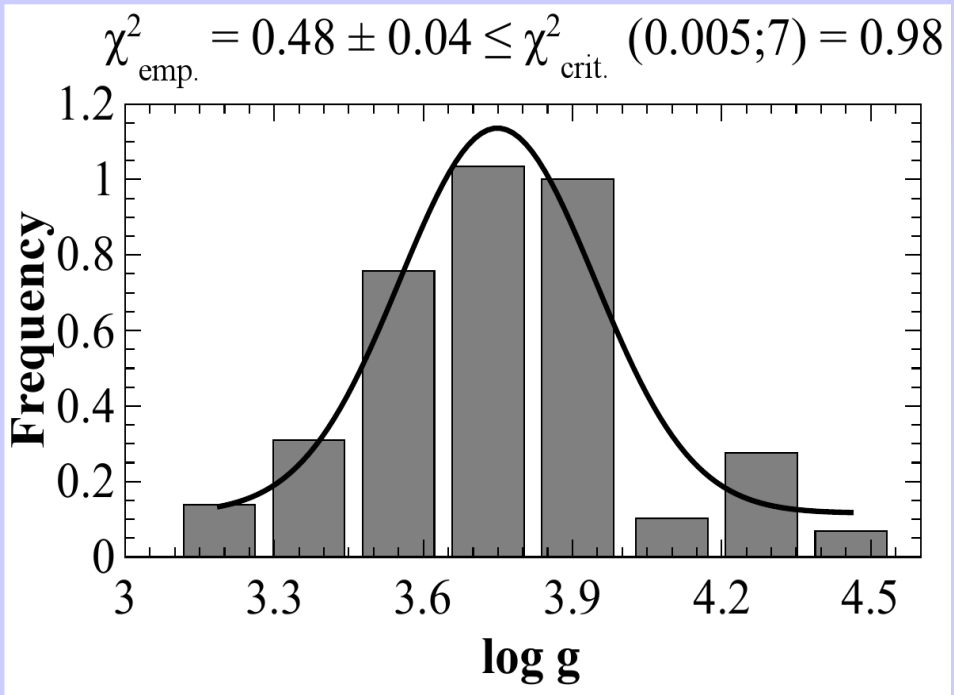
87% from 62 CP stars:

$\log (v_e \sin i) \sim 1.49\text{-}1.78$ (30.9-60.3 km s^{-1})

$\langle \log(v_e \sin i) \rangle = 1.71 \pm 0.18$ (51.3 ± 1.5 km s^{-1})

Fundamental parameters of CP stars





63% from 106 CP stars:
$\log(T_{eff}) \sim 3.94\text{-}4.07$ (8700-11750 K)
$\langle\log(T_{eff})\rangle = 3.99 \pm 0.19$ (9770 ± 2 K)

76% from 106 CP stars:
$\log g \sim 3.55\text{-}3.91$
$\langle\log g\rangle = 3.75 \pm 0.14$

Magnetic field of massive stars. Introduction

Study of magnetic stars of different ages

• most of Ap stars (70%) are field stars and their ages are poorly known

• most of Bp stars (75%) are cluster members with well determined ages

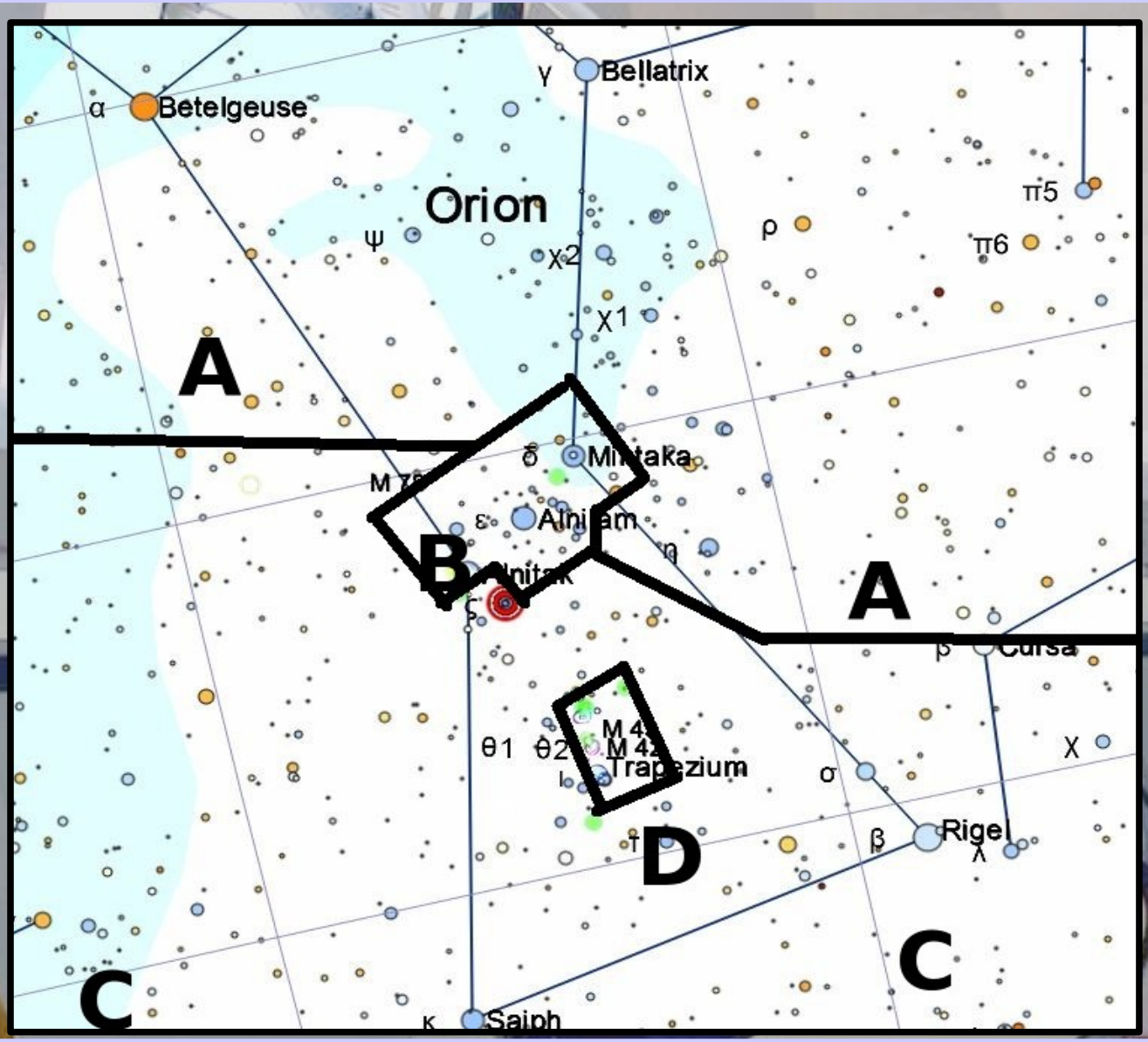
• we selected 17 open clusters and association with 3 CP stars at least

• Orion OB1 association matched best , we selected 85 stars in it

Ap/Bp stars in open clusters and associations

Cluster	Age (log *t*)	CP stars	Cluster	Age (log *t*)	CP stars
OrionOB1	6-7	85	Sco-Cen	6-7	34
Pleiades	8.13	5	Alpha Per	7.85	8
Coma	8.65	8	NGC 2287	8.38	12
NGC 2422	7.85	7	IC 4665	7.63	3
IC 4756	8.70	6	Berkley 11	7.72	3
Hyades	8.90	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	198 stars total		

Four subgroups in Orion OB1 association



Age of subgoups and number of normal and CP stars

Subgroup Orion OB1	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 %

CP stars in different subgroups of Orion OB1 association

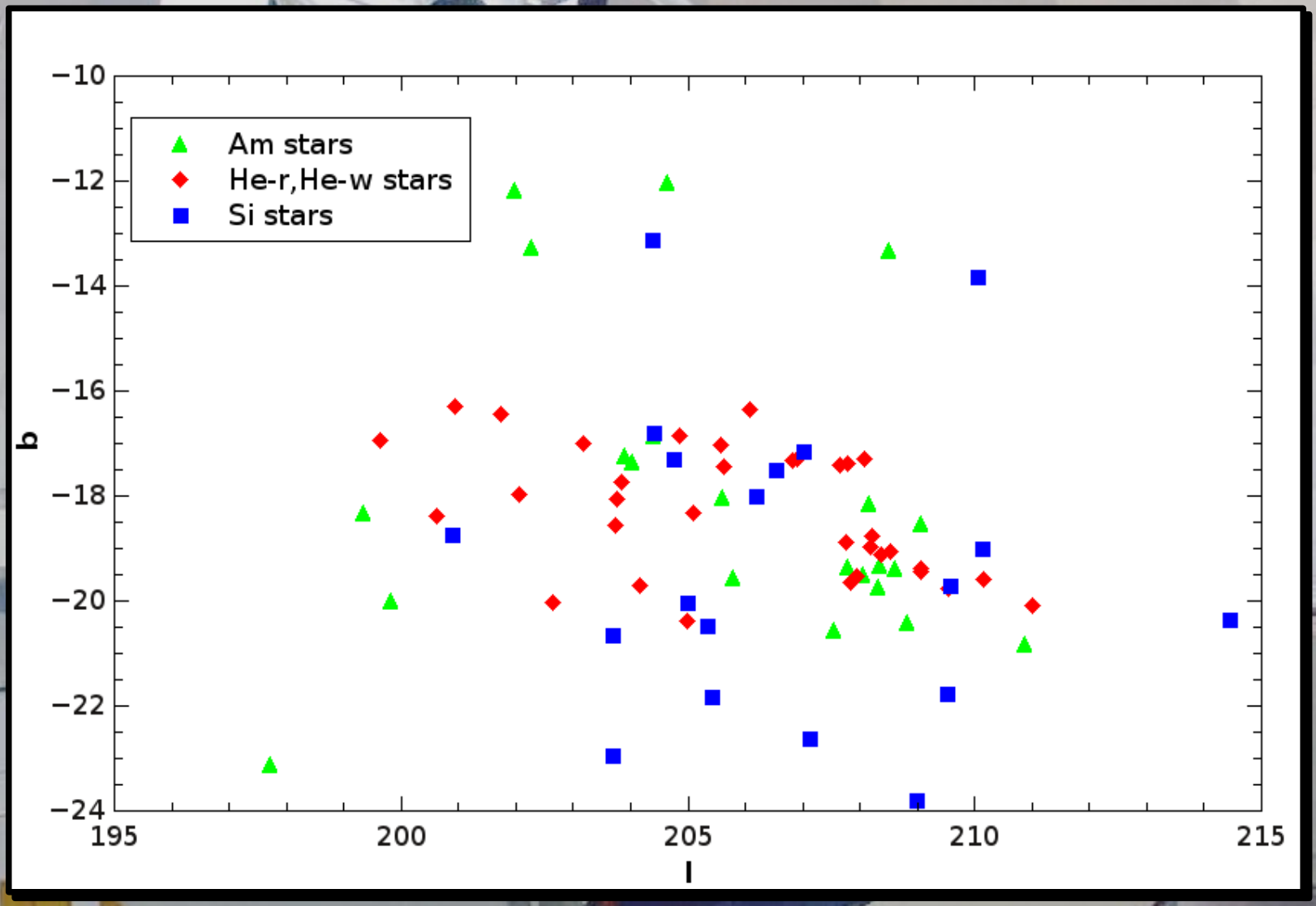
The fraction of CP stars decrease with age from 21.4% (subgroup D) to 7.7% (subgroup A)

23 Am stars: Gaia parallaxes indicate distances between 100 and 300 pc, they appear not to be members of the Orion OB1 association

59 Bp stars, account 13.4% of the total number of B-stars in association

spatial distribution of Am stars: they are found in subgroups a, b. c

Spatial distribution of CP stars



Magnetic fields of CP stars in the Orion OB1 association

We determined:

magnetic fields, radial velocities V_R, $v_e \sin i$, effective temperatures T_{eff} and other fundamental parameters for most stars in Orion OB1

We found:

1) 10 new magnetic stars in Orion, HD 34736 among them is extremely anomalous

2) more than 15 new double and multiple stars

Magnetic fields of CP stars in the Orion OB1 association

HD 34736	B8 Si	-5000/+5000	HD 36697	A0p	+1600
HD 34889	B9 Si	-900	HD 36916	B8 He-wk, Si	-1100/0
HD 35298	B6 He-wk	-3000/+3000	HD 36955	A2 CrEu	-1300/-410
HD 35456	B7 He-wk	-400/+1080	HD 37017	B2 He-r	-2300/-300
HD 35502	B6 SrCrSi	-2250/-180	HD 37058	B2 He-wk, Sr	-1200/+1200
HD 35730	B7 He-wk	-450/+250	HD 37140	B8 SiSr	-1050/+400
HD 36313	B8 He-wk	-1500/-1100	HD 37479	B2 He-r	-1600/+3500
HD 36429	B6 He-wk	-840/+160	HD 37642	B9 He-wk, Si	-3000/+3000
HD 36485	B2 He-r	-3700/+3000	HD 37687	B7 He-wk	-600/+500
HD 36526	B8 He-wk,Si	-3500/+3400	HD 37776	B2 He-r	-2000/+2000
HD 36540	B7 He-wk	-900/+1030	HD 37808	B9 Si	1900
HD 36629	B3 He-wk	-1300/+1100	HD 40759	B9 SrCrEu	+1500/+2000
HD 36668	B7 He-wk,Si	-2200/+2000	HD 290665	B9 SrCrEu	-1600/+5000

Magnetic stars in subgroups A, B, C (preliminary results)

subgroup A:	**7** stars out **15** are magnetic (**46.7%**). Average $\langle B_e \rangle$ = **915 ± 298 G** (for 7 stars), using regression method (Bagnulo et al., 2002)
subgroup B:	**10** magnetic and **4** probably magnetic stars out of **16** Ap/Bp stars
subgroup C:	**12** magnetic and **4** probably magnetic stars out of **24** Ap/Bp stars
subgroup D:	no data for **3** CP stars

We need to get new observations for subroups B,C and D

Magnetic stars in subgroups A, B, C. Conclusion

The proportion of CP stars among normal and the proportion of magnetic stars among CP stars (for subroups A,B,C) decrease with age in the Orion OB1 association

Because of the effective temperatures in subgroups A, B and C are approximately equal, we have age dependence but not temperature dependence

Very slowly rotating magnetic stars. HD 18078

Basic data :

HD 18078 -- Variable Star of alpha2 CVn type

Other object types:	* (HD,AG,...), **a2*** (Ref), **V*** (NSV), **IR** (2MASS)
ICRS coord. *(ep=J2000) :*	**02 56 32.0100802361 +56 10 41.427097237 (Optical) [0.0337 0.0343 90]**
FK4 coord. *(ep=B1950 eq=1950) :*	02 52 49.6821682005 +55 58 36.414260072 [0.0337 0.0343 90]
Gal coord. *(ep=J2000) :*	139.7444686531121 -02.5550165759024 [0.0337 0.0343 90]
Proper motions *mas/yr* :	**-2.209 5.463 [0.096 0.094 90] A 2018yCat.1345....0G**
Radial velocity / Redshift / cz :	**V(km/s) -21.40 [1.4] /** z(~) -0.000071 [0.000005] **/ cz -21.40 [1.40] B 2006AstL...32..759G**
Parallaxes *(mas)*:	**2.5193 [0.0520] A 2018yCat.1345....0G**
Fluxes (6) :	**B 8.50 [0.02] D 2000A&A...355L..27H** **V 8.27 [0.01] D 2000A&A...355L..27H** **G 8.1939 [0.0006] C 2018yCat.1345....0G** **J 7.711 [0.019] C 2003yCat.2246....0C** **H 7.733 [0.020] C 2003yCat.2246....0C** **K 7.675 [0.020] C 2003yCat.2246....0C**

Very slowly rotating magnetic stars. HD 18078

A&A 586, A85 (2016)
DOI: 10.1051/0004-6361/201527476

Astronomy & Astrophysics

HD 18078: A very slowly rotating Ap star with an unusual magnetic field structure⋆,⋆⋆

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Very slowly rotating magnetic stars. HD 18078

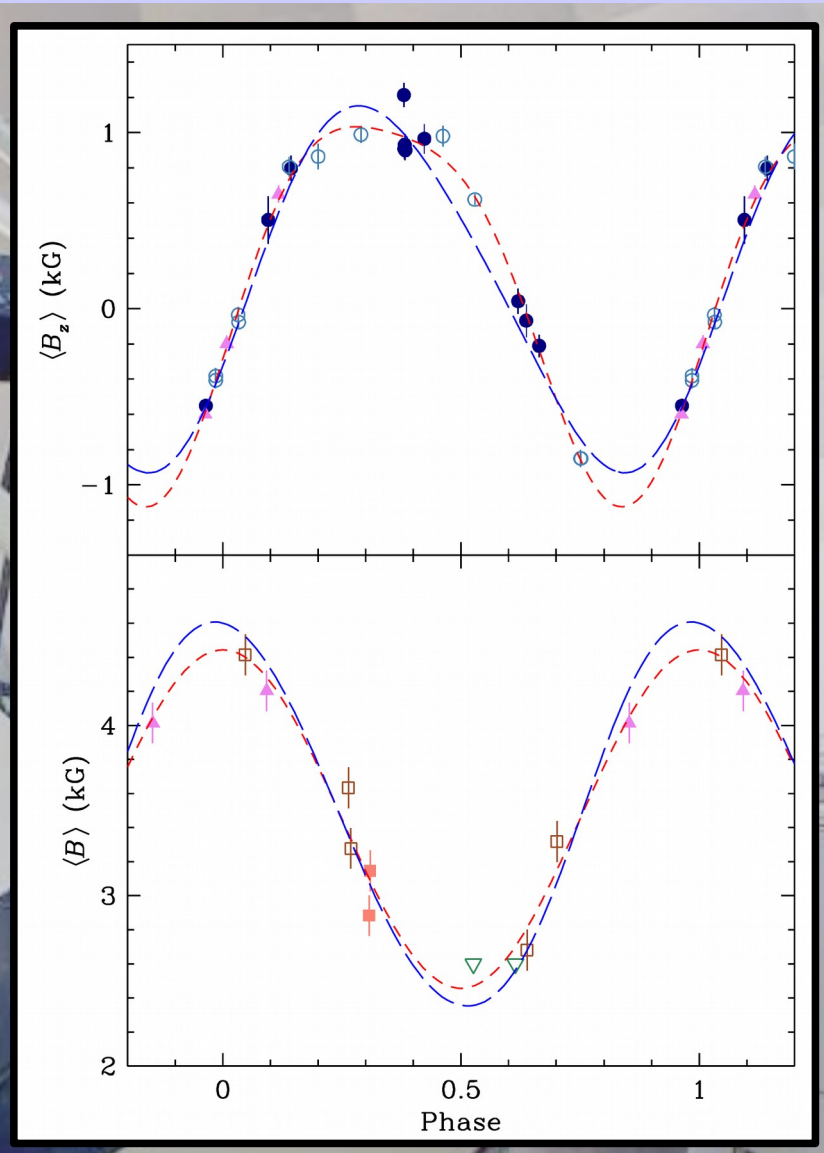

Fig. 2. Mean longitudinal magnetic field (*top*) and mean magnetic field modulus (*bottom*) of HD 18078 against rotation phase. In the *top panel* the different symbols distinguish observations obtained in three different consecutive cycles (in order, filled dots, open circles, and filled triangles). In the *bottom panel*, open squares correspond to observations obtained with AURELIE, filled squares to KPNO coudé spectra, and filled triangles to GECKO data. The two open triangles pointing downwards identify upper limit estimates from AURELIE spectra in which the Fe II λ 6149.2 line is not magnetically resolved (see text). The short-dashed lines are the best fits of the observations by a cosine wave (for $\langle B \rangle$) and by a cosine wave and its first harmonic (for $\langle B_z \rangle$). The long-dashed lines show the variations of the two considered field moments that are predicted by the simple model discussed in Sect. 4.

Period of rotation:

$P = 1358^{d} \pm 12^{d}$

Very slowly rotating magnetic stars. HD 50169

Basic data :

HD 50169 -- Emission-line Star

Other object types:	* (HD,AG,...), **Em*** (EM*), **IR** (2MASS)
ICRS coord. *(ep=J2000) :*	**06 51 59.2282603066 -01 38 40.393959773 (Optical) [0.0545 0.0485 90]**
FK4 coord. *(ep=B1950 eq=1950) :*	06 49 27.3460129726 -01 35 00.396746731 [0.0545 0.0485 90]
Gal coord. *(ep=J2000) :*	214.4582072109056 -00.6276506347879 [0.0545 0.0485 90]
Proper motions *mas/yr* :	**-5.612 -0.299 [0.101 0.087 90] A 2018yCat.1345....0G**
Radial velocity / Redshift / cz :	**V(km/s) 13.20 [0.7]** / z(~) 0.000044 [0.000002] / cz 13.20 [0.70] **A 2006AstL...32..759G**
Parallaxes *(mas)*:	**1.7384 [0.0612] A 2018yCat.1345....0G**
Spectral type:	**ApEuSrCr D 1999MSS...C05....0H**
Fluxes (6) :	**B 9.01 [0.02] D 2000A&A...355L..27H**
	V 8.98 [0.02] D 2000A&A...355L..27H
	G 8.9637 [0.0005] C 2018yCat.1345....0G
	J 8.901 [0.027] C 2003yCat.2246....0C
	H 8.945 [0.022] C 2003yCat.2246....0C
	K 8.920 [0.021] C 2003yCat.2246....0C

Very slowly rotating magnetic stars. HD 50169

A&A 624, A32 (2019)
https://doi.org/10.1051/0004-6361/201834706

Astronomy & Astrophysics

Variation of the magnetic field of the Ap star HD 50169 over its 29-year rotation period★

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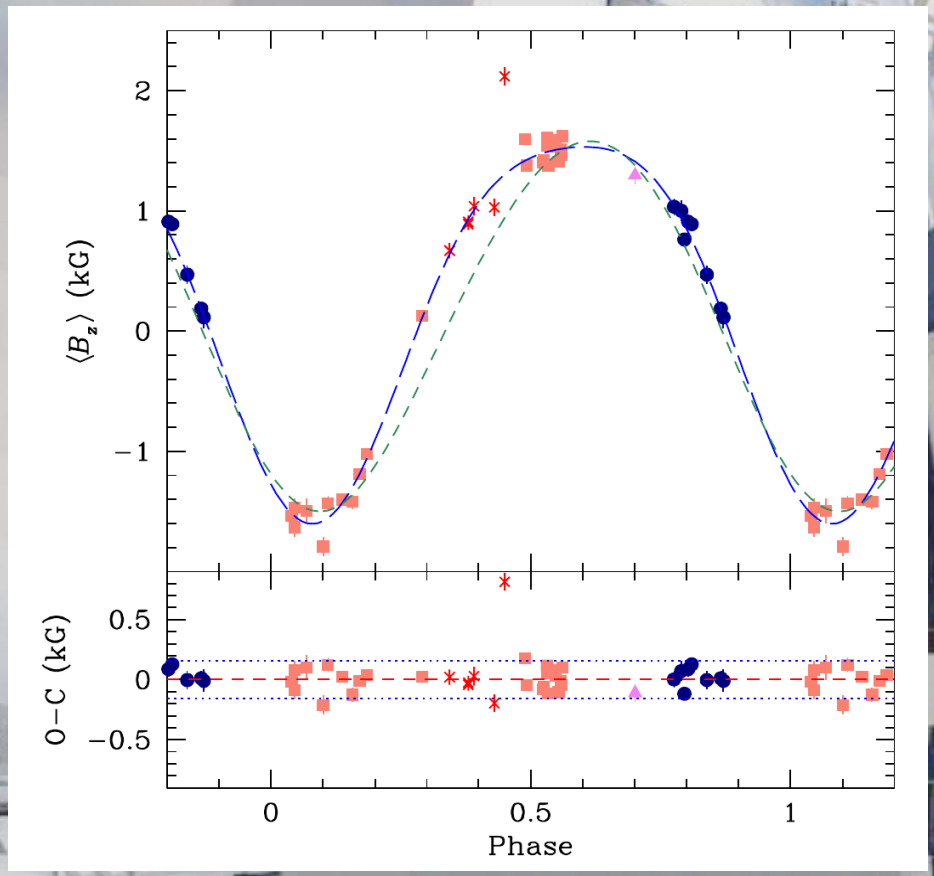
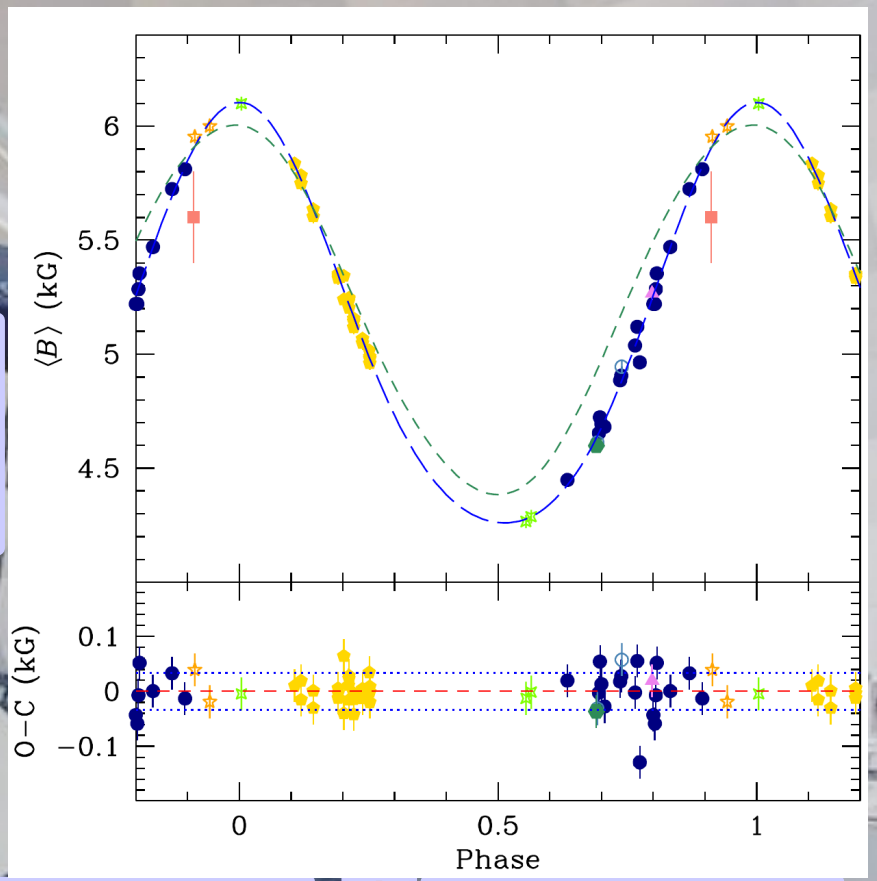
Very slowly rotating magnetic stars. HD 50169



Period of rotation:
P = 29.04^y ± 0.82^y



Babcock (1958)	3.6-m + CES LC
Mathys & Hubrig (1997)	CFHT + Gecko
Mathys (2017)	CAT+CES LC
Romanyuk et al. (2014)	CAT+CES LC

3.6-m + CES VLC	
UT2 + UVES	
3.6 m + HARPS	
Preston (1971)	

Very slowly rotating magnetic stars. HD 965

Basic data :

HD 965 -- Star

Other object types:	* (HD,AG,...), **IR** (2MASS), **UV** (TD1)
ICRS coord. *(ep=J2000) :*	**00 14 04.0647520206 -00 02 00.101552192 (Optical) [0.0682 0.0488 90]**
FK4 coord. *(ep=B1950 eq=1950) :*	00 11 30.2277420154 -00 18 40.266613271 [0.0682 0.0488 90]
Gal coord. *(ep=J2000) :*	103.0714031237006 -61.4557277915350 [0.0682 0.0488 90]
Proper motions *mas/yr* :	**25.322 -11.344 [0.170 0.102 90] A 2018yCat.1345....0G**
Radial velocity / Redshift / cz :	**V(km/s) -5.10 [4.2]** / z(~) -0.000017 [0.000014] / cz -5.10 [4.20] C 2006AstL...32..759G
Parallaxes *(mas)*:	**4.5238 [0.0831] A 2018yCat.1345....0G**
Spectral type:	**ApSrEuCr D 1999MSS...C05....0H**
Fluxes (6) :	**B 8.94 [~] E ~**
	V 8.57 [~] E ~
	G 8.5720 [0.0004] C 2018yCat.1345....0G
	J 8.144 [0.020] C 2003yCat.2246....0C
	H 8.116 [0.024] C 2003yCat.2246....0C
	K 8.094 [0.021] C 2003yCat.2246....0C

Very slowly rotating magnetic stars. HD 965

Astronomy & Astrophysics manuscript no. hd965per
July 26, 2019

HD 965: An extremely peculiar A star with an extremely long rotation period⋆

G. Mathys[1], I. I. Romanyuk[2,3], S. Hubrig[4], D. O. Kudryavtsev[2], M. Schöller[5], E. A. Semenko[2,6], and I. A. Yakunin[2]

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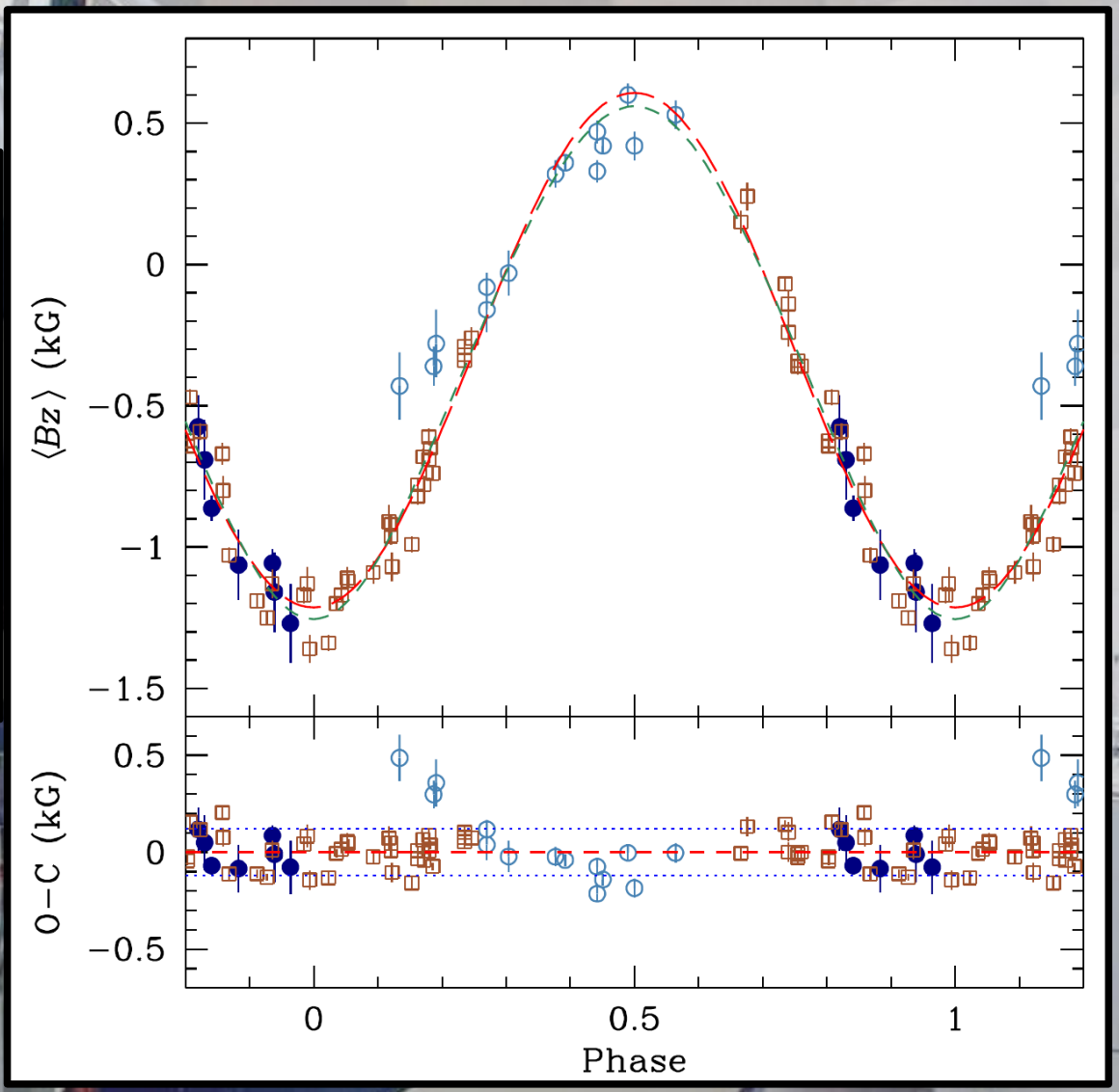
Received . . . / Accepted . . .

Very slowly rotating magnetic stars. HD 965

Fig. 1. *Upper panel:* Mean longitudinal magnetic field of HD 965 against rotation phase. To distinguish measurements obtained at similar phases in different cycles, circles (blue) were used to identify observations acquired until 2008; squares (brown) correspond to spectra taken since 2009. Filled symbols are used for the measurements of Mathys (2017), and open symbols for all determinations based on SAO spectra. The long-dashed line (red) is the best fit of the observations by a cosine wave – see Eq. (4). The short-dashed line (green) corresponds to the superposition of low-order multipoles discussed in Sect. 4. *Lower panel:* Differences O − C between the individual $\langle B_z \rangle$ measurements and the best fit curve, against rotation phase. The dotted lines (blue) correspond to ±1 rms deviation of the observational data about the fit (red dashed line). The symbols are the same as in the upper panel.



Period of rotation:

$P = 16.5^{y} \pm 0.5^{y}$

Unique stars. HD 37776

Basic data :

V* V901 Ori -- Rotationally variable Star

Other object types:	* (AG,ALS,...), **UV** (CEL,TD1,...), **V*** (V*,CSV), ***iN** (VDB), **Ro*** (Ref), **IR** (2MASS)
ICRS coord. *(ep=J2000) :*	**05 40 56.3704270929 -01 30 25.856714776 (Optical) [0.0478 0.0478 90] A 2018yCat.1345....0G**
FK4 coord. *(ep=B1950 eq=1950) :*	05 38 24.3880209894 -01 31 54.747338091 [0.0478 0.0478 90]
Gal coord. *(ep=J2000) :*	206.0726539656253 -16.3419895284439 [0.0478 0.0478 90]
Proper motions *mas/yr* :	**2.767 1.660 [0.092 0.081 90] A 2018yCat.1345....0G**
Radial velocity / Redshift / cz :	**V(km/s) 27.70 [3.5]** / z(~) 0.000092 [0.000012] / cz 27.70 [3.50] **C 2006AstL...32..759G**
Parallaxes *(mas)*:	**2.2859 [0.0562] A 2018yCat.1345....0G**
Spectral type:	**B2V C 1999MSS...C05....0H**
Fluxes (7) :	**U 5.96 [~] C 2002yCat.2237....0D** **B 6.82 [~] C 2002yCat.2237....0D** **V 6.96 [~] C 2002yCat.2237....0D** **G 6.9532 [0.0008] C 2018yCat.1345....0G** **J 7.287 [0.027] C 2003yCat.2246....0C** **H 7.424 [0.040] C 2003yCat.2246....0C** **K 7.415 [0.024] C 2003yCat.2246....0C**

Unique stars. HD 37776

The Astrophysical Journal, 726:24 (8pp), 2011 January 1 doi:10.1088/0004-637X/726/1/24

THE EXTRAORDINARY COMPLEX MAGNETIC FIELD OF THE HELIUM-STRONG STAR HD 37776

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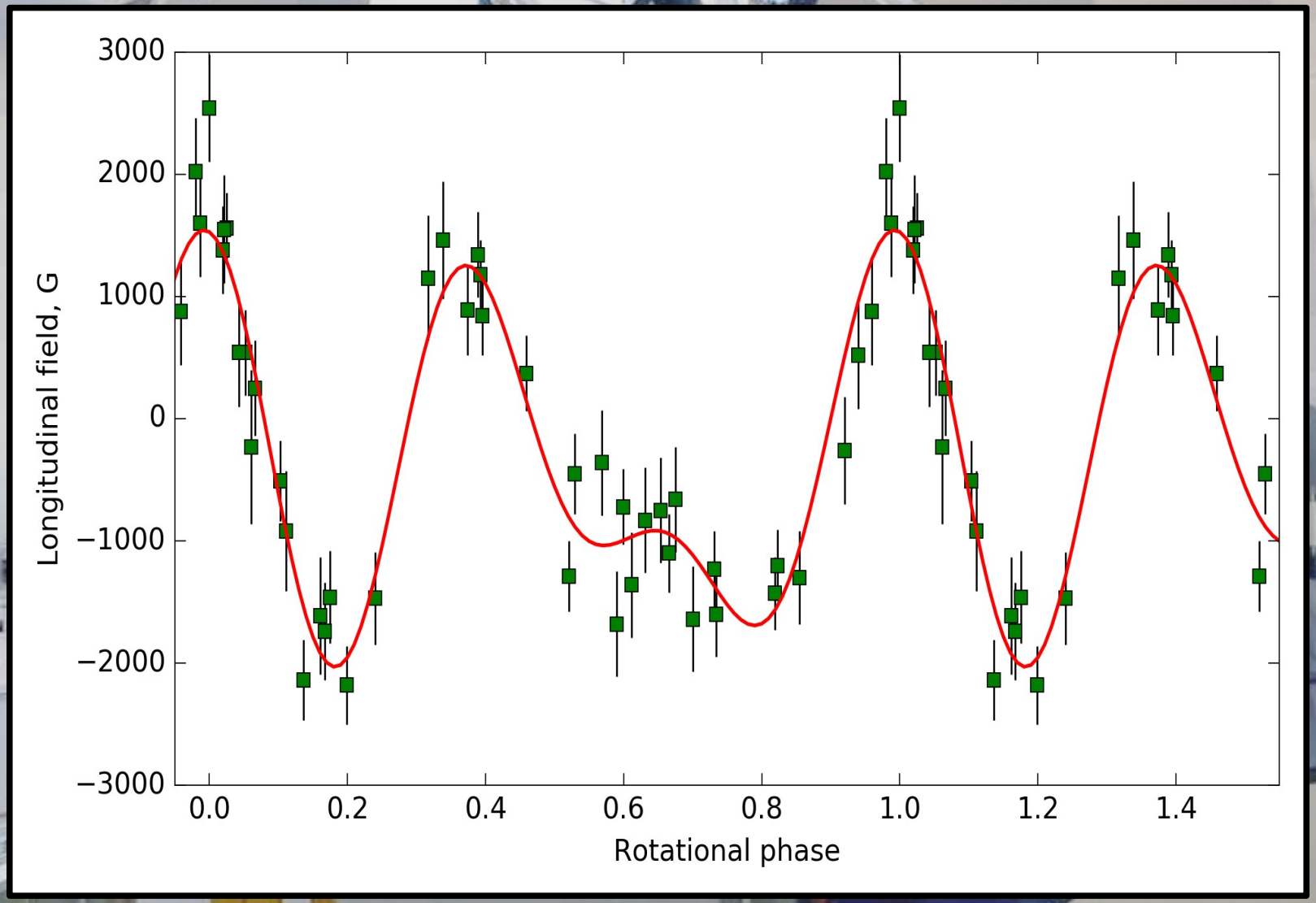
ABSTRACT

The early-type chemically peculiar stars often show strong magnetic fields on their surfaces. These magnetic topologies are organized on large scales and are believed to be close to an oblique dipole for most of the stars. In a striking exception to this general trend, the helium-strong star HD 37776 shows an extraordinary double-wave rotational modulation of the longitudinal magnetic field measurements, indicating a topologically complex and, possibly, record-strong magnetic field. Here we present a new investigation of the magnetic field structure of HD 37776, using both simple geometrical interpretation of the longitudinal field curve and detailed modeling of the time-resolved circular polarization line profiles with the help of a magnetic Doppler imaging technique. We derive a model of the magnetic field structure of HD 37776, which reconciles for the first time all magnetic observations available for this star. We find that the local surface field strength does not exceed ≈30 kG, while the overall field topology of HD 37776 is dominated by a non-axisymmetric component and represents by far the most complex magnetic field configuration found among early-type stars.

Key words: magnetic fields – polarization – stars: atmospheres – stars: chemically peculiar – stars: individual (HD 37776)

Online-only material: color figures

Unique stars. HD 37776



Mesurements from MSS BTA

Period of rotation:
$P = 1.^{d}5387.$

Unique stars. HD 37776

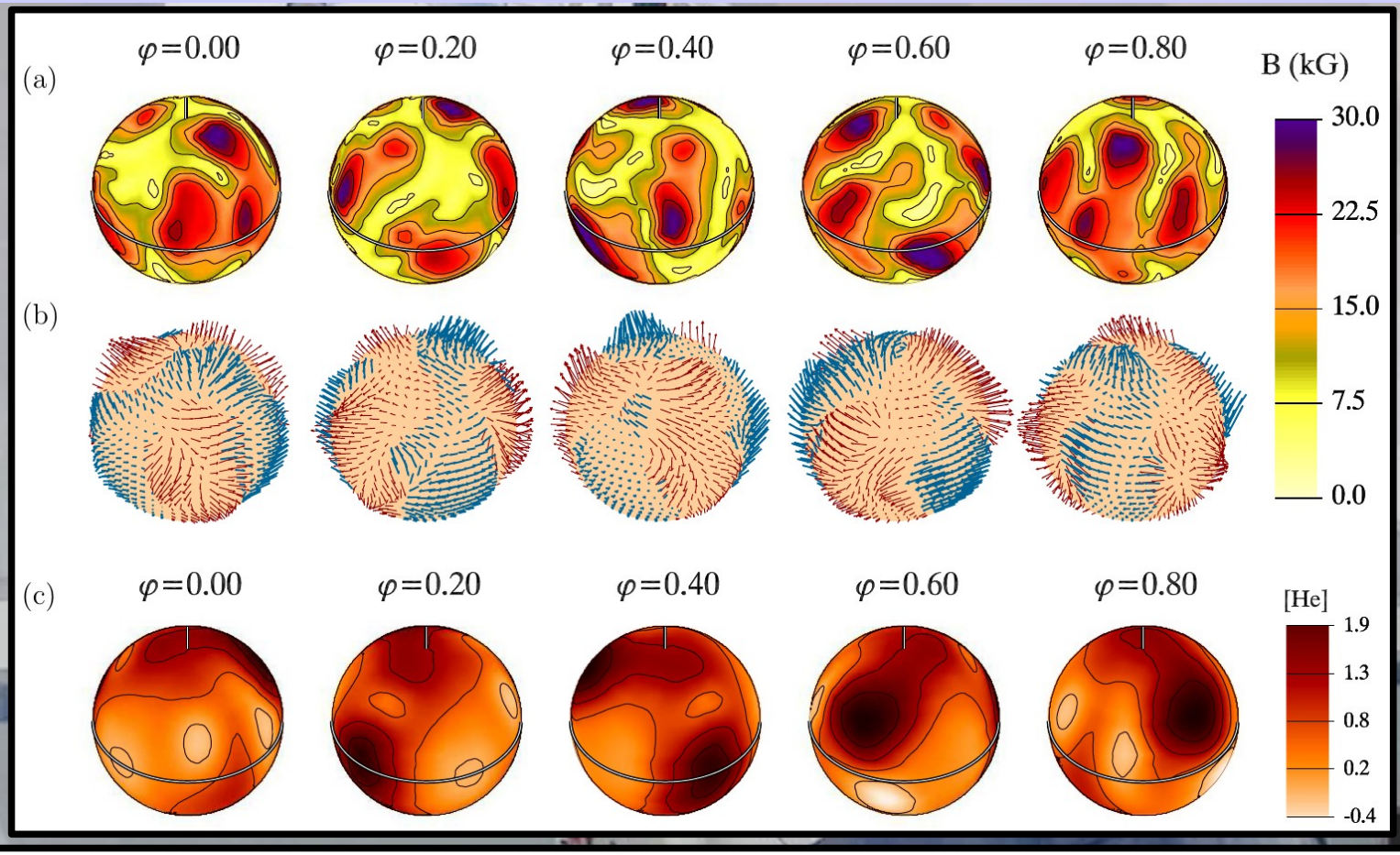


Figure 4. Surface magnetic field structure and He distribution of HD 37776 derived with magnetic DI. The star is shown at five equidistant rotational phases as indicated above the first and third row of spherical plots. The aspect corresponds to the inclination angle $i = 50^\circ$ and vertically oriented rotational axis. (a) The distribution of the field strength, with contours of equal magnetic field strength plotted every 5 kG. The thick line shows the stellar rotational equator. The rotational axis is indicated by the short vertical bar. (b) The orientation of the magnetic field vectors. In these vector maps, the light arrows show field vectors pointing outward from the stellar surface and the dark arrows correspond to the vectors pointing inward. The arrow length is proportional to the field strength. (c) The surface distribution of the He abundance, measured relative to the Sun, obtained simultaneously with the magnetic field geometry. The contour lines in the spherical abundance maps are plotted with a step of 0.5 dex.

Unique stars. HD 37776

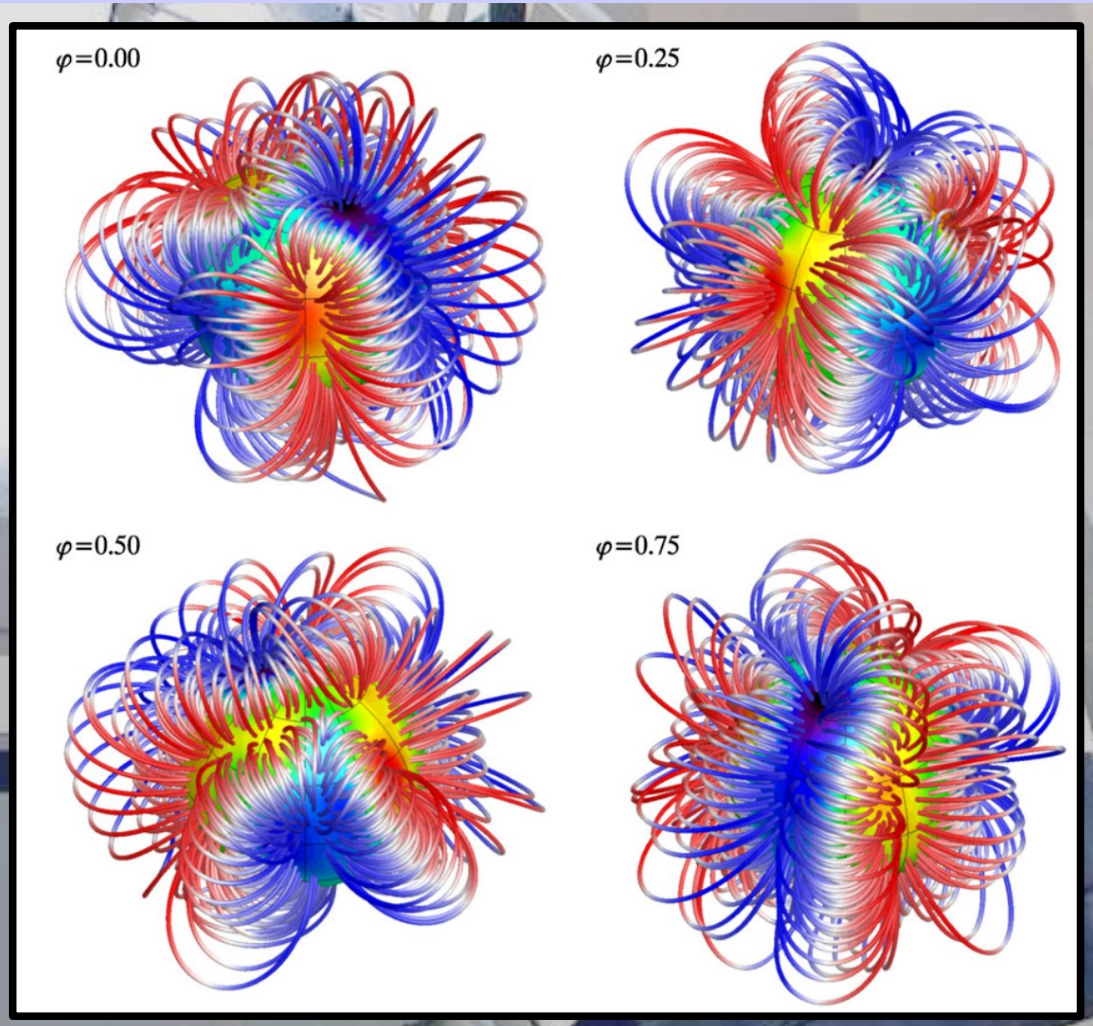


Figure 7. Magnetospheric structure of HD 37776 inferred with the potential field extrapolation of the surface field determined with magnetic DI. The star is shown at four rotation phases and the inclination angle $i = 50°$. Only the field lines closed within a sphere of $R = 2R_\star$ are shown here. The color along each field line and across the stellar surface changes according to the value of the radial magnetic field component.

Unique stars. HD 34736

Basic data :

HD 34736 -- Variable Star

Other object types:	* (HD,BD,...), **UV** (CEL,TD1,...), **V*** (NSV,AAVSO), **IR** (2MASS)
ICRS coord. *(ep=J2000) :*	**05 19 21.2292109318 -07 20 50.042389180 (Optical) [0.0575 0.0529 90]**
FK4 coord. *(ep=B1950 eq=1950) :*	05 16 55.9927889338 -07 23 52.104897213 [0.0575 0.0529 90]
Gal coord. *(ep=J2000) :*	208.9810368280716 -23.7972388858348 [0.0575 0.0529 90]
Proper motions *mas/yr* :	**-0.325 -0.231 [0.150 0.119 90] A 2018yCat.1345....0G**
Radial velocity / Redshift / cz :	**V(km/s) 22.60 [3.1] /** z(~) 0.000075 [0.000010] / cz 22.60 [3.10] **C 2006AstL...32..759G**
Parallaxes *(mas)*:	**2.7470 [0.0783] A 2018yCat.1345....0G**
Spectral type:	**ApSi D 1999MSS...C05....0H**
Fluxes (6) :	**B 7.74 [~] E ~**
	V 7.82 [~] E ~
	G 7.7918 [0.0007] C 2018yCat.1345....0G
	J 7.918 [0.024] C 2003yCat.2246....0C
	H 7.961 [0.034] C 2003yCat.2246....0C
	K 7.963 [0.023] C 2003yCat.2246....0C

Unique stars. HD 34736

Stars: from Collapse to Collapse
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Yu. Yu. Balega, D. O. Kudryavtsev, I. I. Romanyuk, and I. A. Yakunin, eds.

A Study of Magnetic CP Stars in Open Clusters and Associations with the 6-m Telescope

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Abstract. The study of magnetic CP stars in groups of different ages allows us to obtain data on the origin and evolution of large-scale magnetic fields. We selected 17 groups for observation with the 6-m telescope. Here we draw first conclusions from the study of the Orion OB1 association. Six new magnetic stars in it are added to those seventeen that had been known earlier, ten more CP stars were suspected to have fields. A complex structure of the magnetic field in the star HD 34736 has been found, which is indicative of its fossil origin.

Unique stars. HD 34736

The star is a SB2 binary.

The primary, secondary components have temperatures of 13700 K and 11500 K.

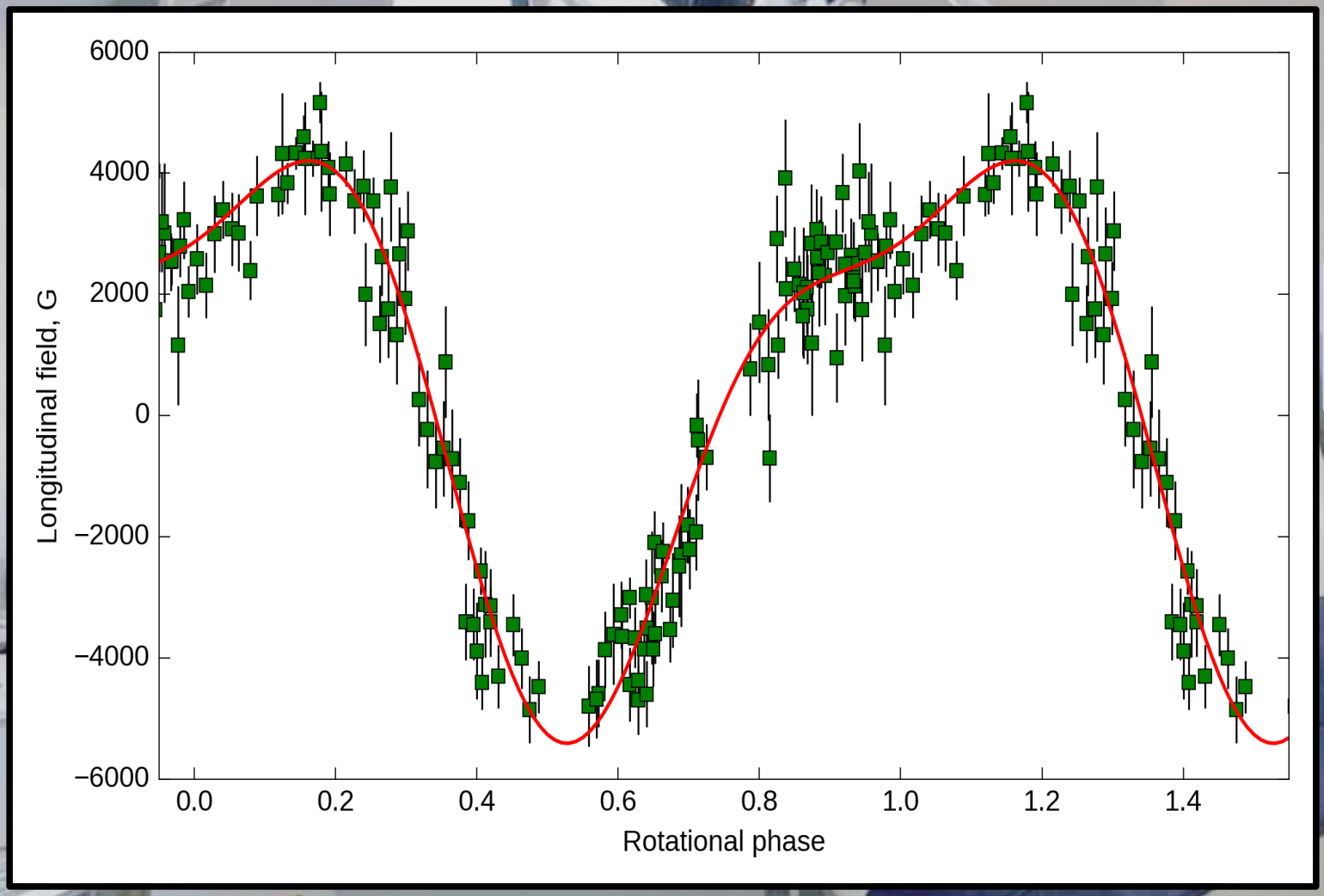
The lines of the primary component are broad with $v_e \sin i$ = 75 km s^{-1}, the secondary component lines are even broader with $v_e \sin i$ > 100 km s^{-1}.

The orbital period is not determined exactly and is within the limits from 80^d to 85^d.

The orbit is very elongated, the eccentricity exceeds e = 0.8.

The main component is magnetic, the secondary is not.

Unique stars. HD 34736



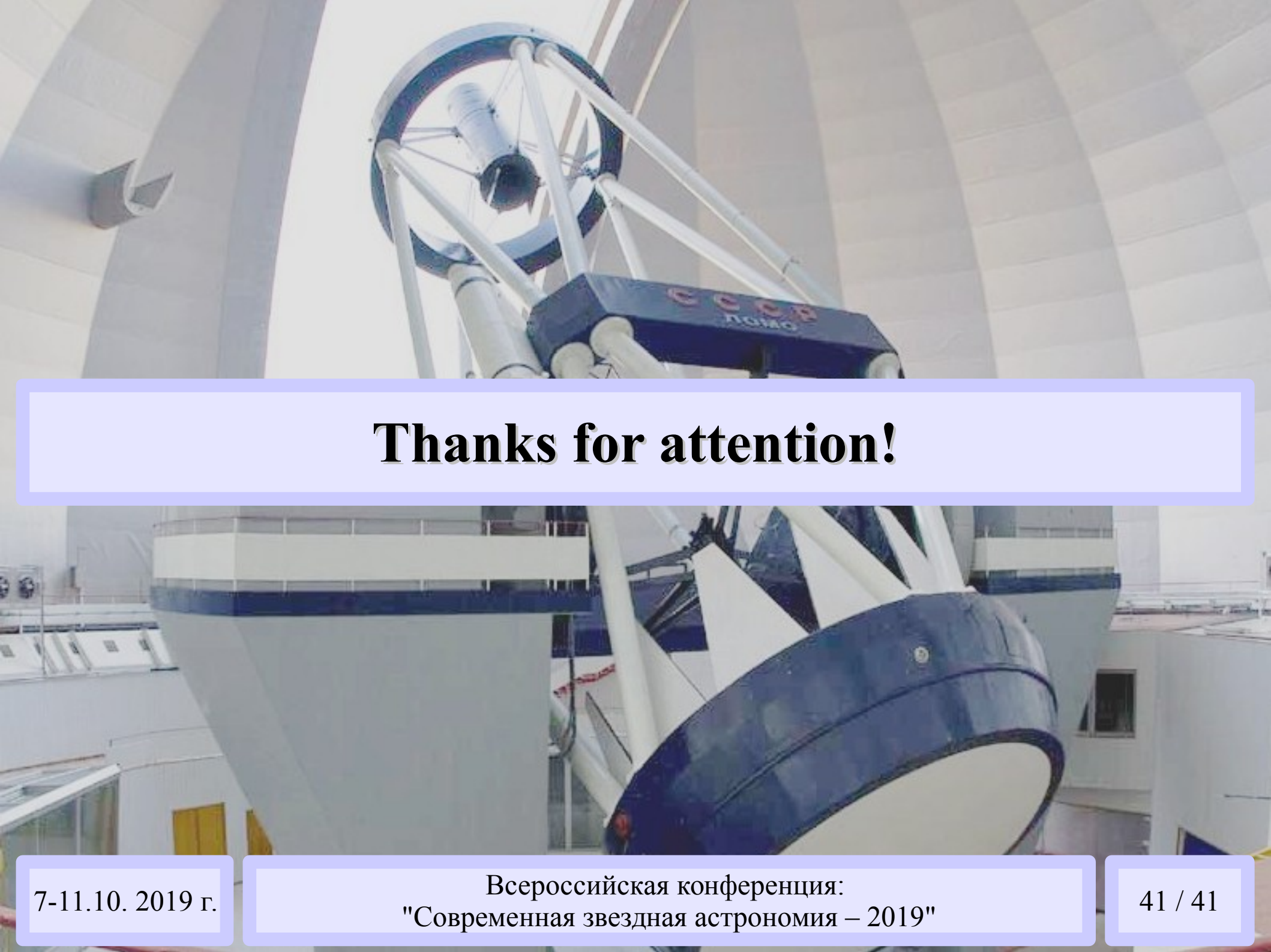
We obtained 130 measurements.

Period of rotation
$P = 1^{d}.29$

Conclusion

The BTA remains one of the main world telescopes, where magnetic fields are measured.

As for CP stars, 200 out of 500 magnetic stars have been discovered with our telescope.



Thanks for attention!