Doppler-Zeeman mapping of the rapidly rotating magnetic CP star HD 37776

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We present the results of our analysis of magnetic field configuration and abundance anomalies on the surface of the rapidly rotating, chemically peculiar helium-strong variable B2 V star HD 37776 with unresolved Zeeman components of spectral lines. Simultaneous inversion of the observed Stokes I and V profiles, which realizes the method of Doppler-Zeeman mapping (Vasil'chenko et al., 1996) has been applied for the first time. Spectroscopic observations were carried out with the Main Stellar Spectrograph of the 6 m Special Astrophysical Observatory telescope equipped with a Zeeman analyzer and a CCD array, which allowed spectra in right- and left-hand circularly polarized light to be taken simultaneously at a signal-to-noise ratio S/N = 150 (Romanyk et al., 1998). The profile width of winged spectral lines (reaching 5 Å) is determined by Zeeman line splitting; however, the observed Zeeman components are blurred and unresolved because of the rapid stellar rotation. When solving the inverse problem, we sought for the magnetic-field configuration in the form of a combination of arbitrarily oriented dipole, quadrupole, and octupole placed at the stellar centre. The observed Stokes I and V profiles for eight spectral lines of He, O II, Al II, Si III, and Fe III were used as input data.

The model of the magnetic field was constructed from the condition of coincidence of magnetic maps obtained from different lines of different chemical elements and from the condition of a minimum profile residual. This analysis leads us to conclude that, within the accuracy of our observational data and the data on the star's physical model and its atmosphere, we must restrict ourselves to the solution with the configuration $(D + Q)$ for $30° < i < 50°$ and a maximum surface field strength H^s = 60 kG. In this case the multipole vectors determined from different lines coincide, but at the same time the directions of the multipoles of different orders also coincide. Thus, we inferred coaxiality of the dipole and the quadrupole from observations and did not confirm the presence of a noticeable, more complex structure. The magnetic axis makes the angle $\beta = 40°$ with the line of sight.

It was found that elements O, Al and Fe are generally underabundant but distributed over the star surface inhomogeneously. A comparison of the maps of chemical anomalies and magnetic field obtained during the solution allows a clear relationship between them to be established. O, Si, and Al are enhanced in the three regions where the magnetic field lines are parallel to the stellar surface, i.e., near the polarity reversal lines ($H^n = 0$). The arch corridors formed by closed field lines lie along these field reversal lines. Interestingly, two such peak abundance spots lie near the points of intersection of arch corridors with the rotation equator.

Only one element (He) exhibits an enhancement on the stellar surface (accessible to observation) near the two regions of maximum of radial field component H^n with opposite polarity. Open field lines appear to emerge from these two regions. The localization of He is consistent with the predictions of Vauclair et al. (1991). Other elements supply a direct observational confirmation of the following idea previously proposed by Odell (1986) and Leone (1993): the stellar wind freely propagates along the open field lines but accumulates matter near closed field lines, producing a ring on the magnetic equator. Clearly, depending on the interaction of centrifugal force and magnetic pressure, two regions located at the points of intersection of the rotation and magnetic equators can exist instead of a solid belt on the magnetic equator.

This idea was proposed on the basis of an analysis of stars with a predominantly dipole field, and it was corroborated by our D-Z mapping of Babcock's star (Khokhlova et al., 1997). Our maps for HD 37776 also confirm the validity of this physical picture for a more complex magnetic configuration. They add a new feature to this picture: there appears to be a third stable region of enhanced elemental abundance in which $H^n = 0$ as well, but it lies at the rotation pole where the centrifugal force is zero.

Our study confirms the futility of attempts to understand the structure of outer layers and the chemical history of CP stars by using the observed magnetic field and elemental abundances averaged over the visible stellar disk. It demonstrates great potentialities of our method of D-Z mapping.

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References

Khokhlova V.L., Vasil'chenko D.V., Stepanov V.V., Tsymbal V.V., 1997, Astronomy Letters 23, No. 4, 465, Translation from "Pis'ma Astron. Zh.", 23, 532 (1997)

Leone F., 1993, Astron. Astrophys., 273, 509

Odell A.P., 1986, Proc. IAU Coll. 87, eds.: K.Hunger et al., Reidel, Dordrecht, 301

Romanyuk I.I., Elkin V.G., Kudryavtsev D.O., et al., 1999, Bull. Spec. Astrophys. Obs., 45, 92

Vasil'chenko D.V., Stepanov V.V., and Khokhlova V.L., 1996, Asronomy Letters, 22, 228, Translation from "Pis'ma Astron. Zh." 22, 924 (1996)

Vauclair S., Dolez N., and Gough D.O., 1991, Astron. Astrophys., 252, 618