ON THE POSSIBLE NATURE OF Bp-Ap STARS: AN APPLICATION TO HD101065 and HR465

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ABSTRACT. We have proposed the new explanation of some magnetic chemically peculiar (MCP) stars anomalies, which is based on assumption that such stars can be the close binary systems with a secondary component being neutron star. Within this hypothesis one can naturally explain the main anomalous features of MCP stars: first of all, an existence of the short-lived radioactive isotopes detected in some stars (like Przybylski's star and HR465), and some others peculiarities (e.g. the behavior of CU Vir in radio range, the phenomenon of the roAp stars).

Key words: Przybylski's star, HR465, close binary system, roAp star, neutron star, pulsar, magnetar.

1. Introduction

It is known that about 10-15% of upper main sequence stars have atmospheres with anomalies in elemental abundance (Bagnulo, 2002). These stars are often classified as magnetic chemically peculiar stars (MCP, or Bp-Ap stars) and nonmagnetic (Hg-Mn and Am-Fm) stars. Hg-Mn stars have a higher temperature than MCP stars and overlap with MCP stars in the region of the higher temperatures, while Am-Fm stars have the lower temperatures than MCP stars.

Among the MCP stars one can select the following subclasses (Kurtz & Martinez, 2000):

1. SrCrEu stars (spectral classes A3-F0).
2. Si stars(B8-A2).
3. He-weak, Si, SrTi stars (B3-B7).
4. He-strong stars (B1-B2).

Some of the peculiarities seen in the chemically peculiar stars can be explained by considering different non-nuclear processes first proposed by Michaud (1970) and then elaborated in a series of the subsequent papers (Turcotte et al., 1998; Turcotte et al., 2000; Richard et al., 2002).

2. MCP stars: the main features

The main characteristics of MCP stars are the following:

1. MCP stars show periodic variations of the light, spectrum and magnetic field. It is believed that these variations are due to the rotation of the star. MCP stars has been regarded as rigid magnetic dipoles with respect to the rotation axis (Babcock, 1949; Stibss, 1950). In the later works it was obtained that MCP stars can be stars with a multi-pole magnetic field (Landstreet, 1990; Mathys, 1991).

2. Some MCP stars are the source of radio emission (Drake et al., 1987). The flat spectra and variability of radio emission on time scales as short as a few hours, as well as the well known strong magnetic field indicate a nontermal gyrosynchrotron emission process (Lynsky et al., 1989). Later Lynsky (Lynsky et al., 1992) remarked, that all observed properties of radio emission from these stars may be understood as optically thick gyrosynchrotron emission from a nonthermal distribution of electron emitters. The radio luminosities of MCP stars are correlated with effective temperature and magnetic field strength (Drake et al., 1994).

3. Some MCP stars are detected as X-ray sources (Drake et al., 1994). They have been investigated during the ROSAT All-Sky Survey. Drake (1998) emphasized that only 10 X-ray sources detected at the positions of 100 magnetic Bp-Ap stars.

4. Shore & Brown (1990) showed that MCP are characterized by an anisotropic stellar wind. MCP stars have been known to have moderate circular polarization (Drake et al., 2002). Trigilio et al. (2000) showed that only CU Vir (Si-star) have a strong 1.4 GHz flux enhancement around phases 0.4 and 0.8, with a right circular polarization of almost 100%. Leto et al., (2007) remarked that only MCP star with a high photospheric temperature develop a radiative-driven stellar wind, which is the cause of the radio emission.

5. Among MCP stars there is known the phenomenon of roAp-stars. roAp stars are the main sequence SrCrEu chemically peculiar stars from mid-A to early-F, which pulsate with periods in the range of 5-16 min and amplitudes > 0.016 mag (Kurtz & Martinez, 2000). The mechanisms responsible for an existent of the roAp star pulsations remain unknown. HD101065 is the first Ap star where pulsations were detected. Kurtz & Wegner (1979) detected the well-defined pulsations with a peak-to-peak amplitude of 0.012 mag and a period of 12.14 min (Kurtz & Wegner, 1979).

6. The most unusual feature is the chemical composition of MCP stars. The first studies of the abundance anomalies in magnetic stars $\alpha 2$ CVn, HD133029, HD151199 showed that there can be the certain nuclear reactions in the star (Burbidge et al., 1958). Now it is accepted that detected over- and/or under-abundance of some elements do not reflect the chemical composition of the entire star, but only its photosphere. There are the most extremal cases among the MCP stars. For example HD101065 with its chemical composition is the most unusual roAp star. The star HD101065 in fact is the unique astrophysical laboratory for understanding and exploring the extreme phenomena of the stellar evolution. This stars shows the high lithium abundance, as well as unusual isotopic lithium ratio (Shavrina et all., 2000). The presence of the short-lived lanthanide promethium $Z = 61$ was noted by Wagner & Petford (1973), Cowley et al. (2004), Fivet et al. (2007). The lines of some short-lived transbismuth isotopes were detected by Gopka et al. (2004), Gopka et al. (2005), Bidelman (2005), Quinet et al. (2007). Cowley & Hubrig (2002), Cowley et al. (2007) found anomalous isotopic ratio of Ca in the HD101065 atmosphere.

3. About nucleosynthesis on the stellar atmosphere

The idea about the possibility of the nucleosynthesis in the stellar atmosphere is not new. In the mid of past century the first papers concerning the chemical composition of Ap stars showed that overabundance of heavy elements really exist. In some cases overabundance of some elements can reach 6 dex and more comparing to the solar abundance. E.M. Burbidge and G.R. Burbidge wrote: "The list of elements with the increased content led us to the thought, that in this case we deal with the nuclear, not with atomic processes and that somewhere and somehow the neutrons take part in them." (Burbidge & Burbidge, 1996).

Nevertheless, the mechanism responsible for such uncommon processes was not identified at that time. Recently, Goriely (2007) showed that nucleosynthesis of heavy (including radioactive) elements can occur in the star's atmosphere due to the high-energy particles entering the atmosphere of the star. At the same time, the origin of such particles was not clearly specified. This idea was also discussed in Arnold et al. (2007).

The r-process has been frequently mentioned in relation to the abundance anomalies observed in Ap stars (Cowley et al., 1973). In particular, Burbidge (1965) indicates the fact that the explosion remnants of a more massive star can be possible explanation of the origin of the peculiarity. For instance, a supernova explosion in the binary system and following contamination of its companion star with freshly synthesized material could, in principle, explain the peculiarity, observed in HD101065. The only problem is that in this case one has to suppose that such an event should have happened not very long ago, since we are observing now the signs of the short-lived isotopes in atmosphere of this star.

4. Possible origin of roAp stars HD101065 and HR465

In order to explain several anomalous features of some MCP stars, and especially their extremely peculiar chemical composition (an existence in atmosphere the short-lived radioactive elements) we propose the following hypothesis. Let us consider an example of HD101065 (Przybylski's star, PS), and assume that PS is a close binary system with a non-seen companion being the neutron star (NS). For this system an orbital plane is near perpendicular to the line of sight (Fig. 1). The rapid wind, generated by NS, which consists of the electron-positron plasma, is accelerated almost to the speed of light and hit the PS atmosphere. The electron-positron plasma falling on the PS must be ultrarelativistic, so that their kinetic energy $E > m_e c^2$. The estimations show that the gamma-factor of the "fast" electrons/positrons, which is necessary for starting the photonuclear reactions, must exceed 20. This estimation is completely realistic, since gamma-factors of the electron-positron plasma in the upper magnetosphere of a radio pulsar can be within 10-10000 (Ruderman & Sutherland, 1975). In the spectrum of one of the most studied pulsar PSR B0531+21 (Crab Nebula pulsar) there really exist the gamma quanta within the required range of energies (Fig. 2).

The high-energy electrons from electron-positron plasma can also generate free neutrons via the direct interaction with hydrogen nuclei in the PS atmosphere ($p + e^- \rightarrow n + \nu$). Such free neutrons are necessary for the r-process to occur in the considered medium.

Thus, the nuclei of heavy elements (including the radioactive isotopes) in the PS atmosphere can be synthesized as a result of two processes: the photonuclear reaction and neutron capture by the seed nuclei of the lighter element. In both cases the source of the en-

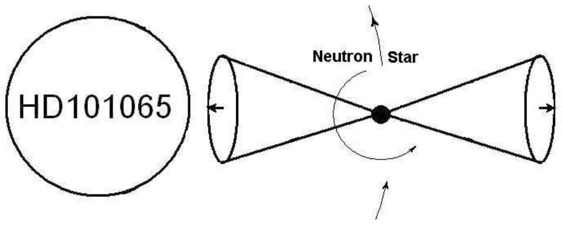

Figure 1: Geometry of the binary system containing Przybylsky's star and neutron star.

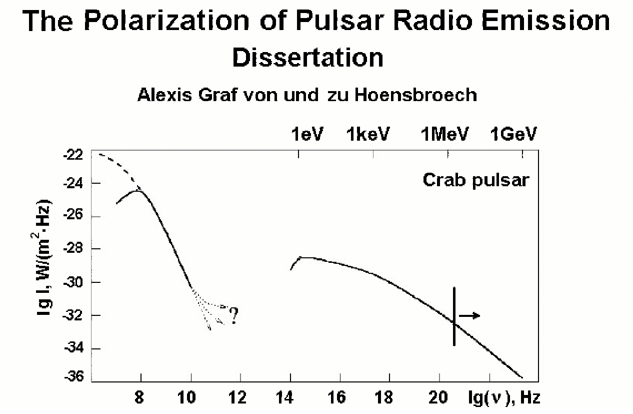

Figure 2: Spectrum of the Crab pulsar.

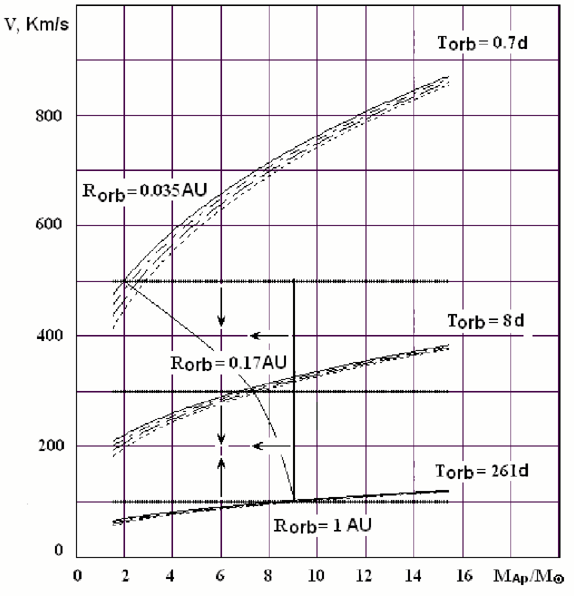

Figure 3: Parameters of a close binary system Ap star - neutron star.

ergetic particles, that trigger the nuclear reactions in the PS atmosphere, is associated with the NS magnetosphere.

Let us show why the binary system PS-NS must be the close one. At present there exist a large uncertainty in the mass estimations of the PS. Thus, if we take one extreme estimate of its effective temperature as 6600° K, and consider another one (spectral class B5, Perryman et al., 1997), then from the spectral class-luminosity relation we obtain that mass of this star falls in the range $M_{PS} \approx 1.5 - 8 \cdot M_\odot$. For the further estimates we assume that masses of the PS and NS are $M_{PS} = (1.5 - 8)M_\odot$ and $M_{NS} = (0.7 - 1.4)M_\odot$ respectively.

It is possible to estimate the parabolic velocity for this system from the main integral of energy: $V_{PAR} = \sqrt{\frac{2G(M_{PS}+M_{NS})}{R}}$ (were R is the distance from the center of mass to the NS). Taking into account that the range of characteristic tangential velocities for the known radio-pulsars is $V_{PSRs} \in \{100 - 500\}$ km/s, and the fact that these velocities must not exceed the parabolic velocity of the considered system, we obtain the range of the most probable parameters (distance, the center of mass of the PS-NS system, the orbital period, the corresponding masses of components). This range is show in Fig. 3. It can be seen that the distances, estimated in that way, ranges from 0.035 AU for a minimum mass M_{PS} to 1.0 AU (for maximum mass). Knowing the parallax of PS $\pi \approx 7.95 \pm 1.07$ mas (Perryman et al., 1997), one can estimate its distance ($D = 125.8 \pm 15.7$) pc and angular size (0.17 mas for minimum mass and 14 mas for maximum mass).

With parameters listed above, the orbital period of PS ranges from 261 days up to 0.7 days. Note that HR465, which has invisible companion (but orbital plane is parallel to the line of sight) has rotation period of 273 days (Scholz, 1978; Fig. 4). At the same time, the spectroscopic, photometrical data and magnetic field measurements could be well represented with a period of 22-23 years (Fuhrhmann, 1989).

Such a long-term variation can be caused by some active region on the stellar surface that changes its position because of the weak precession. In 1996 the magnetic field of this star was 5000 Gs, and the lines of CrII were extremely strong. In 2004 the strong lines of lanthanides and actinides (ThIII, UIII) were seen in the visible part of spectra (Gopka et al., 2007). Magnetic field at that time was 1300-1500 Gs (the estimate of Shavrina). Chromium abundance changed by about 0.7 dex during the period of 8 years. Within our model (MCP star + NS) active region (i.e. local increase of the temperature, in particular) can be formed on the surface of MCP stars as a result of a localized interaction of atmosphere gas with relativistic plasma ejected by NS. To estimate the local temperature increase one can use the value of

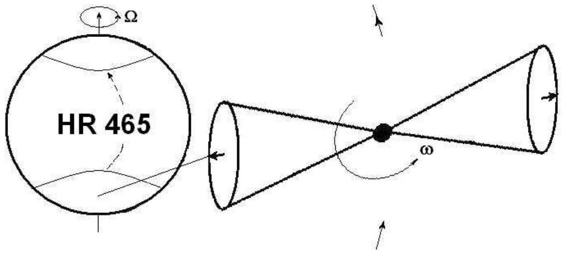

Figure 4: Geometry of HR465 binary system. The position of active area changes with period of 23 years.

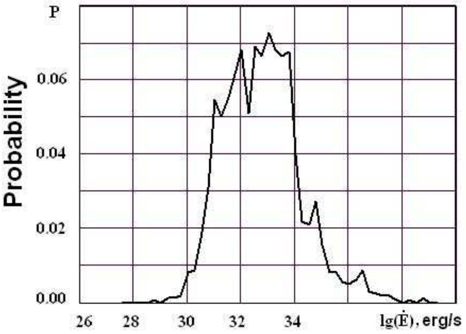

Figure 5: The energy distribution of kinematic losses of 1627 pulsars.

kinematic losses for known pulsars (Fig. 5) Resulting value is close to 3000°- 6000° K. The short-term light variation (roAp phenomenon) can be also explained by such kind of interactions.

5. Conclusions

The proposed hypothesis, which consists in the supposition that some MCP stars can be the binary stellar systems containing as a secondary component neutron star, can be capable in natural explaining of some peculiarities associated with these stars. Among them: anomalous chemical composition, an existence of the short-lived radioactive isotopes, short-time and long-period variations of the light and magnetic field, X-ray and radio-emission detected for some MCP stars.

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