CHEMICAL AND TEMPERATURE INHOMOGENEITIES ON STELLAR SURFACES AS A RESULT OF AN INSTABILITY

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Observations show that chemical anomalies are distributed inhomogeneously on Ap star surfaces. The most elaborated explanation of the observations is based on the fact that different ions and atoms are affected by radiative forces of different strengths and, hence, have different diffusion velocities. The diffusion across the magnetic field is a factor of $(1+\nu_H^2/\nu_C^2)^{-1}$ slower than along the field (ν_H is the gyrofrequency and ν_C is the collision frequency of the ions). It leads to the increasing of the heavy ion number density in regions occupied by magnetic traps.

However, such an explanation meets a number of difficulties: a) the conditions $\nu_H^2 > \nu_C^2$ holds for the most of ion species only in regions where the optical depth is less than 10^{-2} if the field H exceeds 10^5 gs. Although little is known on the depth of the region occupied by the chemical anomalies, there are some indirect indications that it is larger than 10^{-2}; b) The observed dipole field has a value 10^3–10^4 gs and does not form traps corresponding to the observed chemical spots which have very complicated configurations; c) the magnetic trap is imperfect. The separation process in the field is assumed to be produced by the diffusion which needs a long time. However, ions can escape from the trap together with the surrounding hydrogen plasma because of various plasma instablished which take much shorter time; d) observed space distribution of rare elements and also of Fe, Cr, Ti contradicts the predictions of the magnetic separation hypothesis (cf. V. Khohlova IAU Coll. No. 90, this volume).

Thus, new ideas are required to avoid the above difficulties. Dolginov (1984, the workshop paper "Magnetic star" Riga April 1984) has pointed out that some kind of instability can form and support local chemical anomalies. Suppose that in the stellar photosphere ($\tau<1$) there exists even a very small initial excess of atoms or ions which can be easily excited by impacts with surrounding plasma electrons. The energy taken from the electrons is converted into ion excitation energy and then into the energy of radiation, which leaves the star. This leads to the cooling of the surrounding plasma. The cooling results in the shift of the hydrogen ionization equilibrium. The emissivity of neutral hydrogen atoms is much larger than that of free protons and electrons. The pressure inside the cool region is smaller than outside, which leads to the compression of the region. The local cooling leads also to the predominant diffusion of heavy atoms into this region. All these processes result in the cooling continuation. This means that we deal with some instability of the thermal type.

At larger depths thes inverse scenario is possible. If the collisional deactivation of atoms excited by the radiation is large, then the plasma heating occurs instead of the cooling. In this case the energy of stellar radiation is partially recaptured by atoms and then transmitted to the plasma. The realization of the first or second regime depends on the relation between the radiative and collisional transition probabilities. Under the LTE condition and in the case when the radiation has the same temperature as the matter the both processes completely compensate each other and there occurs no cooling or heating. However, the equilibrium is never complete

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in the surface layer.

The local cooling (heating) leads to more intensive horizontal and vertical diffusion of the heavy atoms inward (or outward) the considered region because of the radiative pressure.

Let us impose the following model assumptions: a) the medium consist of hydrogen and a small admixture of the heavy element 10^{-3}; b) spectral lines occupy about 10 - 20% of the continuous spectra; c) the oscillator strengths correspond to the silicon atom transitions; d) in the semi-infinite medium there exists a finite region near the surface with a vertical size $\tau << 1$, and horizontal one $\tau >> 1$, where the number density of the heavy atoms is larger than outside the region.

We need the temperature of this region as a function of the heavy element number density using the obtained temperature gradient, we can determine the diffusion velocity and, hence, the separation rate. To solve this problem quantitatively we have used the energy transfer equation, the continuity equation for particles, and the kinetic equation to describe the atomic level population. The solution of the above equations for the considered model leads to the following conclusions (see A.Z. Dolginov, A.V. Kljachkin Pisma v Ast.J. in press): a) in the region above $\tau \leq 0.1$ the cooling leads to ≃10% temperature decrease; b) below this region there occurs the corresponding heating; c) the separation rate is the same order of magnitude as in the existing theories of the chemical separation by the radiative pressure; d) unlike these theories our approach can explain, not only global but also local chemical anomalies (spots); e) the magnetic field may play an important role suppressing the motions which may destroy the chemical spots;

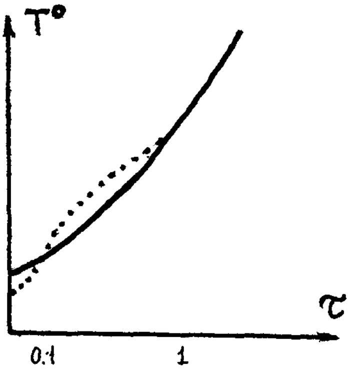

Fig.1

—— without heavy element

•••• with heavy element

f) one should take into account the real level structures of the heavy atoms for precise quantitative predictions, but even the present model shows the important role of this instability in the chemical separation prossess on Ap star surfaces; g) Temperature spots are well known on late-type stars and on the sun. The instability we have considered may play an important role for these cases as well.