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ELECTRON TEMPERATURE IN STELLAR SHELLS CONTAINING HIGH-ENERGY ELECTRONS

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SUMMARY

Attempt is made of determining the electron temperature in stellar shells with the assumption of emergence in the medium of free electrons by photoionization of hydrogen atoms and loss of their energy to recombination processes linked with hydrogen. The case of a bursting star is considered.

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Assume that in the atmosphere of a cold star, above its photosphere, fast electrons emerge in a certain fashion, with energies of the order of $10^6—10^7$ ev. The problem of the interaction of such electrons with the field of photospheric emission of the star itself has been considered in the works [1 - 3]. It was shown, in particular, that fast electrons induce by virtue of the inverse Compton effect the drift of longwave light quanta toward the side of shortwave ones, as a result of which there takes place a sharp enhancement of the shortwave spectrum region of photosphere emission at the expense of partial attenuation of the longwave spectrum. For specific magnitudes of energy of fast electrons there may also emerge the L_c-emission (shorter than 912 A).

Under the influence of the thus emerged L_c-emission (which we shall describe as being of "Compton origin"), the hydrogen, neutral prior to that, will now be ionized. Inasmuch as the possibility of emergence of forbidden lines in the atmosphere of a star is excluded, the electron temperature of such a medium will obviously be determined by the residual energy of electrons, torn off during photoionization of hydrogen.

Our problem resides in the determination of electron temperature of such a medium in the assumption that free electrons emerge by way of photoionization of hydrogen atoms under the influence of L_c-radiation of Compton origin, and lose their energy on the recombination processes linked with hydrogen. It is also postulated that there is established a Maxwellian distribution of velocities between electrons having emerged as a result of photoionization.

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* [Elektronnaya temperature v zvezdnykh obolochkakh soderzhashchikh elektrony vysokoy energii]

The solution of the problem stated is realized by the standard method [4, 5]. To that effect the spectrum of ionizing radiation must be known at the outset.

The Compton emission spectrum is continuous in the 0 to ∞ frequency range, and, depending upon the form of the energy spectrum of fast electrons, it takes various shapes. In particular, when the transformation of longwave quanta to shortwave is materialized by monochromatic fluxes of electrons, the emission intensity in arbitrary frequency (including the frequencies of L_c-emission) is represented by the formula [1]

$$J_\nu(T, \mu, \tau) = B_\nu(T)e^{-\tau} + \frac{\mu^2}{4\pi} B_{\nu'}(T)\tau e^{-\tau}, \tag{1}$$

where $\mu = E / mc^2$; E being the energy of a fast electron; $B_\nu(T)$ and $B_{\nu'}(T)$ are Planck functions, respectively for the effective photosphere temperature T and in the frequencies ν and ν', whereupon in the second case we must postulate $\nu' = \nu/\mu^2$; τ is the optical thickness of the medium on Thomson scattering processes ($\tau = \sigma_e N$, where $\sigma_e = 0.665 \cdot 10^{-24}$ cm^2; N is the effective number of fast electrons inside a column with a 1 cm^2 base).

In order to derive the dependence, searched for, between the electron temperature of the medium and the parameters of radiation field, it is necessary to write the following two equilibrium conditions:

a) condition for stationary state, that is, the number of atoms entering the continuum at photoionization per time unit must be equal to the number of atoms leaving the continuum;

b) condition of radial equilibrium, i. e., the quantity of energy expended per time unit on the photoionization of hydrogen atoms must be equal to the quantity of energy liberated at recombination.

The application of the condition for stationary state gives:

$$n_1 \int_{\nu_0}^{\infty} k_{1\nu} \frac{J_\nu(T, \mu, \tau)}{h\nu} d\nu = 4\pi n^+ n_e \left(\frac{m_e}{2\pi k T_e}\right)^{3/2} \sum_{i=1}^{\infty} \int_0^{\infty} \beta_i(T_e) e^{-m_e v^2/2kT_e} v^3 dv, \tag{2}$$

where the left-hand part of the equality represents the number of ionization events, and the right-hand part — the number of recombination events (see, for example, [5]). In this expression n_1, n^+ and n_e are respectively the concentration of neutral hydrogen atoms, ions and electrons; T_e is the electron temperature of the medium; $\beta_i(T_e)$ is the effective recombination cross-section; $k_{1\nu}$ is the continuous absorption coefficient computed for one neutral hydrogen atom; v is the thermal velocity of the electron.

The condition for radial equilibrium will be written in the form

$$n_1 \int_{\nu_0}^{\infty} k_{1\nu} J_\nu(T, \mu, \tau) d\nu = 4\pi n^+ n_e \left(\frac{m_e}{2\pi k T_e}\right)^{3/2} \sum_{i=1}^{\infty} \int_0^{\infty} \beta_i(T) h\nu e^{-m_e v^2/2kT_e} v^3 dv. \tag{3}$$

For the function $\beta_i(T_e)$ we have [4]

$$\beta_i(T_e) \sim k_{i\nu} \frac{i^2\nu^2}{\nu^2}, \tag{4}$$

and for the factors $k_{1\nu}$ and $k_{i\nu}$ we have, taking into account the influence of negative absorption

$$k_{1\nu} \sim \frac{1}{\nu^3}\left(1 - e^{-h\nu/kT_e}\right); \quad k_{i\nu} \sim \frac{1}{\nu^3 i^5}\left(1 - e^{-h\nu_i/kT_e}\right). \tag{5}$$

Substituting (4) and (5) into (2) and (3), we finally shall find (for details see [5]):

$$\int_{x_0}^{\infty} x^{-4}(1 - e^{-x}) J_x(T, \mu, \tau)\, dx \Big/ \int_{x_0}^{\infty} x^{-3}(1 - e^{-x}) J_x(T, \mu, \tau)\, dx =$$
$$= \sum_{i=1}^{\infty} \frac{e^{x_i}}{i^3}\left[\int_{x_i}^{\infty} \frac{e^{-x}}{x}\, dx - \int_{2x_i}^{\infty} \frac{e^{-x}}{x}\, dx\right] \Big/ \sum_{i=1}^{\infty} \frac{1}{i^3}\left(1 - \frac{1}{2} e^{-x}\right), \tag{6}$$

where we denoted: $x_0 = h\nu_0/kT$; $x_i = h\nu_i/kT_e$; ν_i is the ionization frequency from the i-th state. The value of functions $J_x(T, \mu, \tau)$ is borrowed from (1) posing $\nu = xkT_e/h$.

The only unknown in relation (6) is the electron temperature, which is precisely unilaterally determined as a function of parameters T, μ, τ. The practical determination of T_e from (6) is realized as follows. For given values of T, μ, τ we determine x_0 from (6), and then T_e from

$$T_e = h\nu_0/kx_0. \tag{7}$$

Relation (6) is also valid for the case when the energy spectrum of fast electrons is represented in the form $N_e = KE^{-\gamma}$, with the provision that instead of $J_x(T, \mu, \tau)$ $J_x(T, \gamma, \tau)$ should be placed in (6), of which the form is brought out in [1].

As an example, computations were performed for one particular case, namely T = 2800°K (type-M5 star), τ = 1 and a series of values of μ. The results are compiled in Table 1 hereafter.

As follows from the data brought out in Table 1, the theoretical electron temperature of the atmosphere or part of the atmosphere of a later-type star, where fast electrons (10^6 — 10^7) are present, of which the interaction with thermal quanta leads to the emergence of L_c-radiation of nonthermal nature (Compton origin), is very high, of the order of 150,000 — 200,000°K. It is somewhat higher than the electron temperature of the medium at at synchrotron radiation (100,000°K).

TABLE 1

Electron temperature of the medium in the presence of fast electrons (T = 2800°K, τ = 1)

μ^*	$E \cdot 10^{-6}$, ev	T_e, °K
20	2,1	158 000
50	3,6	175 000
100	5,1	225 000

Attempt was made in [1 - 3] to show that an ultraviolet flare or, generally, the continuous emission in nonstationary (outbursting) stars may be induced by scattering of fast electrons on thermal quanta, at which drift of longwave (infrared) quanta takes place toward the side of high-frequency quanta. In some cases this process may lead to the emergence of hydrogen and even helium emission lines [3]. On the other hand, as seen above, under these conditions the electron temperature in the atmosphere or part of the atmosphere of an outbursting star must be almost 50 times higher than the temperature of the star itself. This is why it would be interesting to verify the possibility of electron temperature increase in the atmosphere of stars during outburst directly by the observation data.

Dzhoy (Joy), having succeeded in obtaining rare spectrograms of outbursting stars, underscored more than once the fact of lines of emission widening with their enhancement during the outburst of the star [1]. He calls attention to one fact also, in which the presence of high temperature in the atmosphere of the star during outburst would be somehow guessed, namely when the Balmer decrement of hydrogen emission lines becomes more slanting in the direction toward shortwaves.

Unfortunately, these conclusions on the widening of emission lines and on character variation of the Balmer decrement are based upon qualitative estimates and are not strengthened by quantitative data. For that reason a careful processing of spectrograms of bursting stars, and also the search for independent ways of determining from observations of the magnitude, or if only of the order of magnitude of electron temperature of a star at time of outburst, must constitute a particular interest.

**** T H E E N D ****

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