ELECTRON TEMPERATURE IN STELLAR ENVELOPES CONTAINING HIGH-ENERGY ELECTRONS

Astronomy

1967

SovietRxiv

Abstract

Full Text

UDC 523.036.51

Astronomy

G. A. GURZADIAN

ELECTRON TEMPERATURE IN STELLAR ENVELOPES CONTAINING HIGH-ENERGY ELECTRONS

(Presented by Academician V. A. Ambartsumian on April 27, 1966)

Suppose that in the atmosphere of a cool star, above its photosphere, fast electrons somehow appear, with energies of the order of 10^6—10^7 eV. The problem of the interaction of such electrons with the field of photospheric radiation of the star itself was considered in ([1–3]). In particular, it was shown that fast electrons, owing to the inverse Compton effect, cause a drift of long-wavelength light quanta toward short wavelengths, as a result of which a sharp enhancement of the short-wavelength region of the photospheric radiation spectrum occurs at the expense of partial weakening of the long-wavelength region. For certain values of the energy of the fast electrons, L_c-radiation may also appear (shorter than 912 Å). Under the influence of the L_c-radiation that has arisen in this way (let us call it "of Compton origin"), hydrogen, which up to this point was neutral, will be ionized. Since the possibility of the occurrence of forbidden lines in the atmosphere of the star is excluded, the electron temperature of such a medium will evidently be determined by the residual energy of the electrons torn off in the photoionization of hydrogen. Our task is to determine the electron temperature of such a medium under the assumption that the free electrons arise through photoionization of hydrogen atoms under the influence of L_c-radiation of Compton origin and lose their energy in recombination processes associated with hydrogen. It is also assumed that a Maxwellian velocity distribution has been established among the electrons of the medium that have arisen as a result of photoionization.

The solution of the problem posed is carried out in the usual way ([4,5]). For this, one must first know the spectrum of the ionizing radiation.

The spectrum of the Compton radiation is continuous in the frequency interval from zero to infinity and, depending on the form of the energy spectrum of the fast electrons, assumes different forms. In particular, when the transformation of long-wavelength quanta into short-wavelength ones is carried out by a flux of monoenergetic electrons, the intensity of the radiation at an arbitrary frequency (including at the frequencies of L_c-radiation) is represented by 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 is the energy of a fast electron; $B_\nu(T)$ and $B_{\nu'}(T)$ are Planck functions at the effective temperature of the photosphere T and at the frequencies ν and ν', respectively, and in the second case one should put $\nu' = \nu/\mu^2$; τ is the optical thickness of the medium for 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 base 1 cm^2).

To derive the desired dependence between the electron temperature of the medium and the parameters of the radiation field, it is necessary to write the following two equilibrium conditions: a) the stationarity condition, i.e., the number of atoms entering the continuum in photoionization per unit time must be equal to the number of atoms leaving the continuum; b) the condition of radi-

of this equilibrium, i.e., the amount of energy expended on the photoionization of hydrogen atoms per unit time must be equal to the amount of energy emitted in recombination.

Application of the stationarity condition 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 side of the equality represents the number of ionization events, and the right-hand side the number of recombination events (see, for example, (5)). In this expression n_1, n^+, and n_e are the concentrations of neutral hydrogen atoms, ions, and electrons, respectively; T_e is the electron temperature of the medium; $\beta_i(T_e)$ is the effective recombination cross section; $k_{1\nu}$ is the coefficient of continuous absorption, calculated per one neutral hydrogen atom; v is the thermal velocity of an electron.

The condition of radiative equilibrium is 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)

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

and for the coefficients $k_{1\nu}$ and $k_{i\nu}$, taking account of the effect of negative absorption, we have

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

Substituting (4) and (5) into (2) and (3), we finally 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 $x_0 = h\nu_0/kT_e$; $x_i = h\nu_i/kT_e$; ν_i is the frequency of ionization from the i-th state. The value of the function $J_x(T,\mu,\tau)$ is taken from (1) with the substitution $\nu = xkT_e/h$.

The only unknown in relation (6) is the electron temperature, which is thereby determined uniquely as a function of the parameters T, μ, and τ. The practical determination of T_e from (6) is carried out as follows. For specified values of T, μ, τ, x_0 is determined 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 $N_e = KE^{-\gamma}$, except that instead of $J_x(T,\mu,\tau)$ one should put $J_x(T,\gamma,\tau)$ in (6), whose form is given in (1).

As an example, calculations are given for one particular case, namely $T = 2800°$K (an M5-type star), $\tau = 1$, and a series of values of μ. The results are presented in Table 1.

As follows from the data given in Table 1, the theoretical electron temperature of the atmosphere, or of part of the atmosphere, of a late-type star where fast electrons are present (10^6—10^7 eV), whose interaction with thermal quanta leads to the appearance of L_c-radiation of nonthermal nature (of 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 in synchrotron radiation, which is of the order of 100 000°K ([5]).

Table 1

Electron temperature of the medium in the presence of fast electrons ($T = 2800°$**K**, $\tau = 1$)

μ^2	$E \cdot 10^{-6}$, eV	T_e, °K
20	2.1	158 000
50	3.6	175 000
100	5.1	225 000

In ([1—3]) an attempt was made to show that an ultraviolet flare, and in general the continuous emission of nonstationary (flaring) stars, may be caused by the scattering of fast electrons by thermal quanta, in which long-wavelength (infrared) quanta drift toward high-frequency quanta. In some cases this process may lead to the appearance of emission lines of hydrogen and even helium ([3]). On the other hand, as we have seen above, under these conditions the electron temperature in the atmosphere, or in part of the atmosphere, of a flaring star must be almost 50 times greater than the temperature of the star itself. It would therefore be of interest to test the possibility of a substantial increase in the electron temperature in the atmospheres of stars during their flare directly from observational data.

Joy, who succeeded in obtaining rare spectrograms of flaring stars, repeatedly emphasizes the fact of the **broadening** of emission lines, along with their strengthening, during a stellar flare ([6]). He also draws attention to another fact in which the presence of a high electron temperature in the stellar atmosphere during flares seems to be discernible, namely, that the Balmer decrement of the hydrogen emission lines in the direction of shorter wavelengths becomes flatter.

Unfortunately, these conclusions concerning the broadening of emission lines and changes in the character of the Balmer decrement are based on qualitative estimates and are not supported by quantitative data. Therefore, careful reduction of spectrograms of flaring stars, as well as the search for independent ways of determining from observations the value, or at least the order of magnitude, of the electron temperature at the moment of a stellar flare, should be of special interest.

Branch of the Byurakan Astrophysical Observatory
of the Academy of Sciences of the Armenian SSR

Received
25 IV 1966

CITED LITERATURE

1. G. A. Gurzadyan, *Astrofizika*, **1**, issue 3, 319 (1965).

2. G. A. Gurzadyan, *DAN*, **166**, No. 1, 53 (1966).

3. G. A. Gurzadyan, *Astrofizika*, **2**, issue 2 (1966).

4. V. A. Ambartsumian, E. R. Mustel and others, *Theoretical Astrophysics*, Moscow, 1952, p. 115.

5. G. A. Gurzadyan, *DAN*, **150**, No. 2, 287 (1960).

6. A. Joy, in: *Stellar Atmospheres*, ed. J. L. Greenstein, IL, 1963, p. 660.

Note: Figure translations are in progress. See original paper for figures.