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On the Heating of the Interstellar Gas

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Supposing that the flux measured by Bunner *et al.* (1971) at 0.26 keV in the galactic plane is due to X-ray sources, it is shown that the energy-input rate of these sources is not enough to heat the interstellar gas.

Supondo-se que o fluxo de raios-X medido por Bunner *et al.* (1971) a 0.26 keV no plano galactico seja devido a fontes discretas, pode-se concluir que o aquecimento do gás interestelar não é devido a estas fontes.

The physical properties of the interstellar gas can be explained with an ionization rate ξ of the order of $10^{-15}\,s^{-1}$ (Pacheco, 1969; Spitzer and Scott, 1969; Field *et al.*, 1969).

Upper limits for the ionization rate of HI regions derived from radio source data are indeed of about $10^{-15}\,s^{-1}$ (Pacheco, 1971). It must be emphasized that these upper limits are obtained directly from observational data such as 21 cm absorption and free-free absorption at lower frequencies.

Upper limits for the ionization rate due to low energy cosmic rays obtained from the production of light nuclei *(Li-Be-B)* by spallation of medium nuclei (C-N-O) in collisions with the atoms of the interstellar gas (Fowler, Reeves and Silk, 1970) and the destruction of H_2 in dense clouds by suprathermal particles (Solomon and Werner, 1971) are orders of magnitude lower than the required ionization rate of $10^{-15}\,s^{-1}$. There are reasons for doubting the validity of these results but it is not our purpose in the present paper to discuss this problem.

If, however, the results of Fowler, Reeves and Silk (1970) and Solomon and Werner (1971) are accepted, then it is difficult to explain the ionization of HI regions by low energy cosmic rays. Silk and Werner (1970) and

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Syunyaev (1970) have therefore proposed that the ionization and the heating of H1 regions may be due to soft X-rays.

In the present paper, we are going to discuss this alternative heating mechanism taking into account the recent measurements of the soft X-ray flux by Bunner *et* al. (1971).

The results of Bunner *et al.* (1971) agree with previous measurements (Bunner *et* al., 1969; Bowyer *et al.*, 1968; Baxter *et* al., 1969) in the sense that at 0.26 keV there is a clear excess over the extrapolated higher energy power law, even taking into account the possible effects of gas clumpiness on the absorption coefficient.

Since the absorption at 0.26 keV in the galactic plane is very important ($\tau \gg 1$), it is likely that the observed flux is galactic in origin.

The bremsstrahlung associated with low energy cosmic rays was considered by the present aiithor (Pacheco, 1970) as a possible mechanism responsible for the emission at 0.26 keV. The X-ray flux at 0.26 keV was calculated to be about 10^4 times smaller than the measured flux. Therefore, this mechanism can be disregarded.

Inverse Compton scattering of optical photons by 10 MeV electrons was considered by Rees and Silk (1969). However, the relativistic electron density N(E > 10 MeV) required to produce the observed X-ray flux is about 10^4 times greater than the value obtained from the measurements of Simnet and MacDonald (1969). Since a demodulation factor of this order of magnitude seems to be excluded at the present, this mechanism can be neglected.

Therefore, it is likely that the observed X-ray flux at 0.26 keV is due to galactic X-ray sources (Bunner et al., 1969; Ryter, 1970; Ilovaisky and Ryter, 1971).

Let us analyse the corisequences for the heating of the interstellar gas if we admit that the obrerved soft X-ray flux in the galactic plane is due to galactic X-ray sources.

Let $L_x(\varepsilon)$ be the photon luminosity per unit energy interval of a typical X-ray source ($L_x(\varepsilon)$ is given in photons per second and per keV). Let N_s be the spatial X-ray source density (we suppose for the sake of simplicity a homogeneous source distribution) and let $\mathscr{H}(\varepsilon)$ and n_H be the photoelectric absorption cross-section and the atomic hydrogen density, respectively.

Then, to a first approximation, the flux $j(\varepsilon)$ produced by the X-ray sources is

$$j(\varepsilon) \approx \frac{N_s L_x(\varepsilon)}{4\pi \mathscr{H}(\varepsilon) n_H} \text{ photons} \cdot \text{cm}^{-2} \cdot \text{s}^{-1} \cdot \text{sr}^{-1} \cdot \text{keV}^{-1}. \tag{1}$$

Using the fiux at 0.26 keV measured by Bunner ***et al.*** (1971) in the galactic plane ($j(0.26) \approx 120$ ph . cm^{-2} . s^{-1} . sr^{-1} . keV^{-1}), we obtain from Eq. (1)

$$N_s L_x(0.26) \sim 4.5 \times 10^{-18} \text{ ph} \cdot \text{cm}^{-3} \cdot \text{s}^{-1} \cdot \text{keV}^{-1}, \tag{2}$$

where we have taken $\mathscr{H}(\varepsilon) \approx \frac{5 \times 10^{-23}}{\varepsilon_{keV}^{3.2}}$ cm^2 (Pacheco, 1970) and an average density $n_H = 0.8$ cm^{-3}.

Let us now calculate the maximum energy rate per unit volume that can be dissipated by the X-ray sources (i.e., the energy input rate per unit volume).

Let us admit that in the energy interval $\overline{\varepsilon_0, \varepsilon_1}$, with $\varepsilon_1 > \varepsilon_0 = 0.26$ keV, the source spectrum can be written as

$$L_x(\varepsilon) = \left[\frac{0.26}{\varepsilon_{keV}}\right]^\alpha L_x(0.26), \tag{3}$$

where α is an effective spectral index in the energy interval considered.

The energy input rate per unit volume Q is then

$$Q = \int_{\varepsilon_0}^{\varepsilon_1} N_s \varepsilon L_x(\varepsilon)\, d\varepsilon. \tag{4}$$

Using Eq. (3), we obtain from Eq. (4)

$$Q \approx \frac{(0.26)^2}{\alpha - 2} N_s L_x(0.26) \text{ keV} \cdot \text{cm}^{-3} \cdot \text{s}^{-1} \tag{5}$$

Substituting the numerical value given by Eq. (2) into (5), we get

$$Q \approx \frac{4.9 \times 10^{-28}}{(\alpha - 2)} \text{ erg} \cdot \text{cm}^{-3} \cdot \text{s}^{-1}. \tag{6}$$

From Eqs. (1) and (3), we obtain $j(\varepsilon) \propto \varepsilon^{-(\alpha-3.2)}$ and, since $j(0.26) > j(0.90)$ from the measurements of Bunner et al. (1969), it follows that a > 3.2. Therefore,

$$Q \lesssim 4.9 \times 10^{-28}\,\mathrm{erg \cdot cm^{-3} \cdot s^{-1}}. \quad (7)$$

This value is about two orders of magnitude lower than the energy input rate per unit volume required to heat the interstellar gas.

Therefore it seems unlikely that soft X-rays with energies $\varepsilon \gtrsim 0.26$ keV due to galactic sources are responsible for the heating of the interstellar gas. A similar result was obtained by Ilovaisky and Ryter (1971) based on X-ray source counts. Photons with energies lower than 0.26 keV will only be efficient at heating the gas near the sources since their mean free path is less than 100 pc.

In conclusion, we can say that since heating by both low energy cosmic rays and soft X-rays present theoretical difficulties, the problem of how the interstellar gas is lieated remains open.

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