Electron-proton temperature equilibration mechanisms in SNRs

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Abstract.
Problem of high electron temperature in SNRs has been discussed in literature for a while ([1],[2],[3]). Despite of this, almost all results in this area are either pure experimental or comes from computer modeling and have no connection with experiment. Simple models preceding our work assumed constant (in both space and time) SNR plasma density profile that contradicts both experimental and theoretical results.
In our work we consider realistic model for SNRs in Sedov phase, take into account Coulomb exchange between electrons and protons and analyze discrepancy with observations.

Model.
Dynamics of supernova remnants after age

$$t_s = \left(\frac{3E}{4\pi\rho v_{sh}^5}\right)^{1/3}$$

where E is explosion energy, ρ -- outer density, v_{sh} -- initial shock speed, could be described with the following set of hydrodynamical equations [1]:

$$\frac{\partial\rho}{\partial t}+v\frac{\partial\rho}{\partial r}+\rho\frac{\partial v}{\partial r}+\frac{2\rho v}{r}=0$$
$$\frac{\partial v}{\partial t}+v\frac{\partial v}{\partial r}+\frac{1}{\rho}\frac{\partial p_t}{\partial r}+\frac{1}{\rho}\frac{\partial p_r}{\partial r}=0$$
$$\frac{\partial p_r}{\partial t}+v\frac{\partial p_r}{\partial r}-\frac{4}{3}\frac{p_r}{\rho}\left(\frac{\partial\rho}{\partial t}+v\frac{\partial\rho}{\partial r}\right)=0$$
$$\frac{\partial p_t}{\partial t}+v\frac{\partial p_t}{\partial r}-\frac{5}{3}\frac{p_t}{\rho}\left(\frac{\partial\rho}{\partial t}+v\frac{\partial\rho}{\partial r}\right)=0$$

where p_t and p_r are pressure of thermal gas and cosmic rays (CR) correspondingly. Boundary conditions to this equations come from mass, momenta and energy conservation at the shock (Rankie-Hugoniot relations):

$$\rho(R_{sh})=\frac{\gamma_s+1}{\gamma_s-1}\rho_0$$
$$v_{r_{sh}}=\frac{2}{\gamma_s+1}v_{sh}$$
$$p_t(r_{sh})=\frac{2(1-w)}{\gamma_s+1}\rho_0 v_{sh}^2$$
$$p_r(r_{sh})=\frac{2w}{\gamma_s+1}\rho_0 v_{sh}^2$$
$$\gamma_s=\frac{5+3w}{3(1+w)}$$

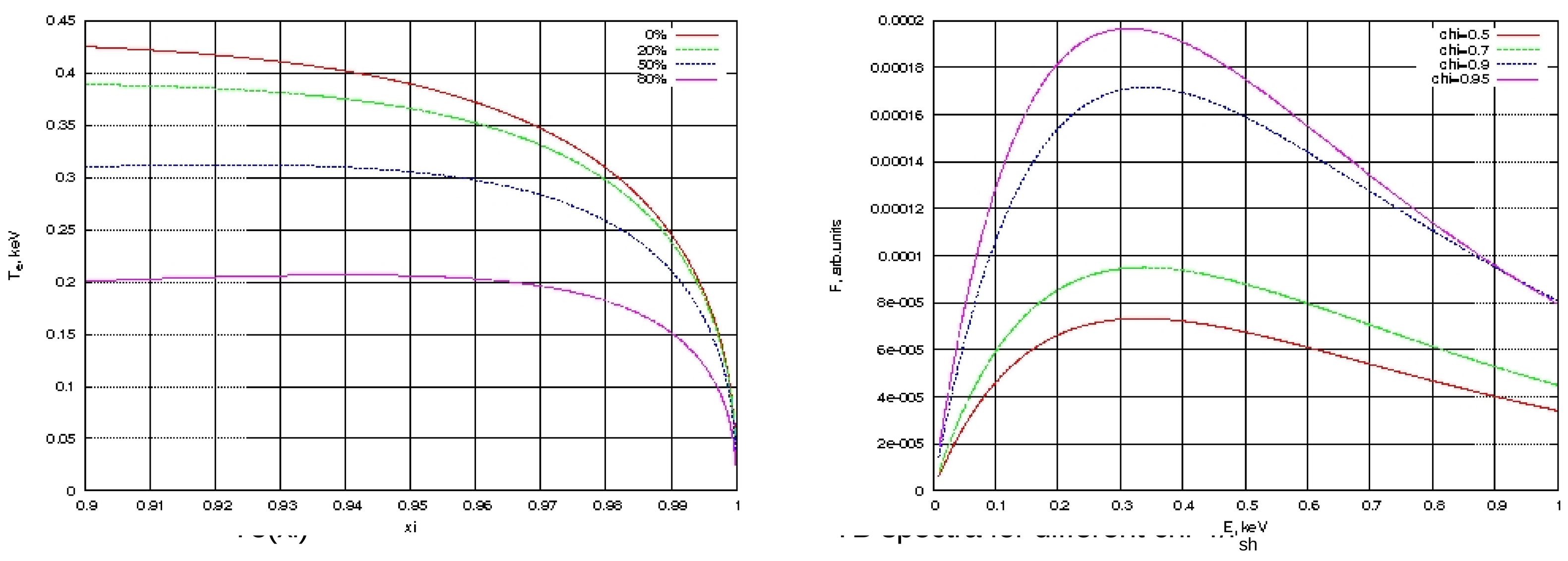
Here w — fraction of pressure that goes to cosmic rays (CR) production i.e.

$$P_r=w(P_t+P_r)$$

Assuming that electrons are heated only due to Coulomb interactions with protons, the electron temperature of adiabatically expanded plasma satisfies[5]:

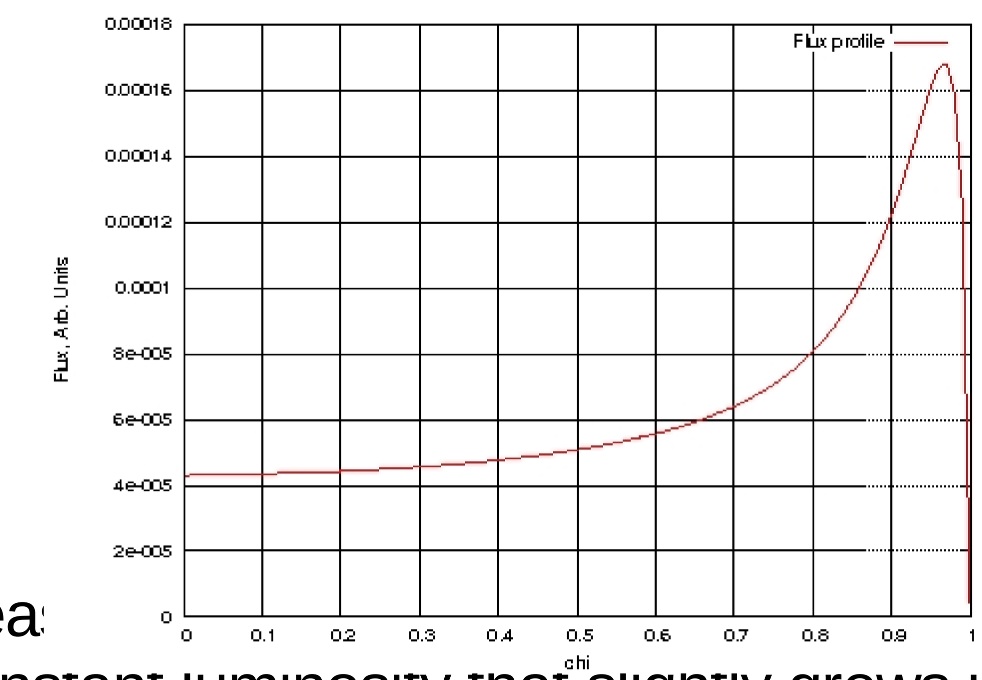
$$\frac{dT_e}{dt}=\frac{T_p-T_e}{t_{eq}}+(\gamma-1)\frac{T_e}{n}\frac{dn}{dt}$$
$$t_{eq}\approx 18616\left(\frac{T_e}{1\mathrm{keV}}\right)^{3/2}\left(\frac{n}{1\mathrm{cm}^{-3}}\right)^{-1}$$

Under assumption that electrons and protons have the same speed at the shock, the following typical dependence T_e(xi), xi=r/r_{sh}, could be obtained (parameters in the fig. correspond to parameters SNR RX J1713)



that gives us thermal bremstrulung (TB) spectra from different parts of SNR.

This figure implies that electron temperature defined as energy at which TB spectra has maximum, almost does not depends on chi=r/r_{sh}.
Typical profile for TB luminosity of SNR in our model is shown in the next figure



that has rea[...]imental data (almost constant luminosity that slightly grows up closer to shock).

Conclusions.
We found that for a large amount of SNRs (SN1006, Tycho, etc.) electron temperature calculated according to our model gives values 4-6 times less than observational ones. To fit the observed temperature we need either assume density 16-36 times higer or that SNRs are 4-6 times older. Assuming non-zero CR-efficiency will make things even worse. So huge discrepancy allows us to conclude that we need some mechanism faster than Coulomb one for electron-proton temperature equilibration.
Only in case of RX J1713 — well known TeV source with lack of keV thermal emission (Te upper limit is below 0.5keV) even Coulomb exchange leads to electron temperatures quite close to this limit.

Literature
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