Cosmic rays estimation

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The total energy rate released in SNR as cosmic rays $\dot{E}_{CR}$ can be estimated as follows. Assuming a Salpeter initial mass function $IMF \propto M^{-7/3}$, we can compute the fraction of stellar mass that finish their lifes as supernovae, $f_{SN} \simeq 7\%$, as well as their average mass, $\bar{M} \simeq 12 M_\odot$. Writing the supernovae formation rate as $f_{SN} SFR/\bar{M}$, the rate of energy released in supernovae as cosmic rays is $\epsilon E_{SN} f_{SN} SFR/\bar{M}$, where $E_{SN} \sim 10^{51} erg$ is the average energy released in a supernova, and ϵ is the fraction of energy which goes into cosmic rays, that we take as $\epsilon \sim 0.1$. Therefore:

$$\dot{E}_{CR} = \epsilon E_{SN} \frac{f_{SN} SFR}{\bar{M}} \simeq 2.0 \times 10^{40} erg \cdot s^{-1} \left(\frac{\epsilon}{0.1}\right) \left(\frac{E_{SN}}{10^{51} erg}\right) \left(\frac{SFR}{M_\odot \cdot yr^{-1}}\right), \tag{1}$$

Furlanetto [1] quotes as a reference value, the X-ray luminosity given by nearby starbust galaxies in the range $0.2 - 10$ keV:

$$L_{0.2-10keV} \simeq 3.4 \times 10^{40} erg \cdot s^{-1} \left(\frac{SFR}{M_\odot \cdot yr^{-1}}\right). \tag{2}$$

However, this value should be translated to the relevant energy range for the IGM heating by X-rays, which lies between $0.3 - 2.5$ keV. Assuming an spectral index of -1.5, it leads to

$$L_{0.3-2.5keV} \simeq 2.1 \times 10^{40} erg \cdot s^{-1} \left(\frac{SFR}{M_\odot \cdot yr^{-1}}\right). \tag{3}$$

Therefore we can see that $\dot{E}_{CR} \simeq L_{0.3-2.5keV}$, so in the most optimistic scenario, cosmic rays could contribute to the heating of the IGM as much as the reference value from X-ray binaries. However, not all this energy would be deposited as heating in the IGM. It is no clear to me which range of energies of cosmic rays could be responsible of heating the gas.

On the other hand, accelerated electrons as cosmic rays could also produce X-rays in supernova remnants. It has been proven [2] that the most efficient process for that (with low enough magnetic fields) is through Inverse Compton scattering, leading to a luminosity dependent on the fraction of energy injected into relativistic electrons ϵ_e. Taking $\epsilon_e \sim 0.1$ as benchmark, we get

$$L^{IC}_{0.3-2.5keV} \simeq 1.3 \times 10^{39} \left(\frac{\epsilon_e}{0.1}\right) erg \cdot s^{-1} \left(\frac{SFR}{M_\odot \cdot yr^{-1}}\right), \tag{4}$$

which is around one order of magnitude lower than Eq. 3. Note that $\epsilon_e \sim 0.1$ could be an overestimation, since the measured ratio of cosmic-ray protons to electrons which get the Earth is ~ 75, which would lead to $\epsilon_e \sim 10^{-3}$. However, the division between electrons and protons near to the source is not well known, and electrons could be influenced by different transport processes and energy loss mechanisms than protons, so the ratio of cosmic-ray protons to electrons close to the sources could be closer to 1 [2].

References

[1] S. Furlanetto. The Global 21 Centimeter Background from High Redshifts. *Mon. Not. Roy. Astron. Soc.*, 371:867–878, 2006.

[2] S. P. Oh. Reionization by hard photons: I. x-rays from the first star clusters. *Astrophys. J.*, 553:499, 2001.