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Neutron production in black hole coronae

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Abstract. We study the injection of neutrons in the corona of Galactic black holes. Since neutrons are not coupled to the magnetic field, a fraction may escape and penetrate the base of the jet, later decaying to create protons. This is a possible mechanism to load Poynting-dominated outflows with protons. Additionally, since neutrons have a mean lifetime of ~ 880 s, the most energetic neutrons can escape the binary system and inject a considerably amount of energy far from the source. We also investigate the fate of those neutrons and their impact on the interstellar medium.

Resumen. Se estudia la producción de neutrones en la corona de agujeros negros galácticos. Los neutrones no están acoplados al campo magnético, por lo que una fracción de neutrones puede escapar y penetrar la base del jet, donde decaen creando protones. Este es un posible mecanismo para cargar flujos de Poynting con protones. Por otro lado, dado que el tiempo de vida medio de los neutrones es de ~ 880 s, los neutrones más energéticos pueden escapar del sistema binario e inyectar energía lejos de la fuente. De esta forma, también se estudia el destino de los neutrones que escapan del sistema y su impacto en el medio interestelar.

1. Introduction

There is clear evidence for the acceleration of relativistic particles in the vicinity of accreting Galactic black holes (Abdo et al. 2009; Tavani et al. 2009; Sabatini et al. 2010; Bodaghee et al. 2013). Some of these black holes are components of microquasars: X-ray binaries with relativistic jets. The content of such jets seems to include protons and nuclei (Migliari et al. 2002; Díaz et al. 2013).

Here, we study the production of neutrons in the corona of Galactic black holes. Since neutrons have not electric charge, they are not coupled to the magnetic field. Then, a fraction of these neutrons may escape and penetrate the base of the jet, later decaying to create protons. This is a possible mechanism to load Poynting-dominated outflows with protons. We study the characteristics of the proton distribution and the impact on the radiative spectrum of the jet. We also investigate the fate of those neutrons that escape the corona into the interstellar medium.

2. Basic scenario

The corona model we adopt is extensively described in Romero et al. (2010); Vieyro & Romero (2012). Table 1 summarizes the values of the relevant parameters of the model.

Table 1. Main parameters of the corona.

Parameter	Value
$R_{\rm c}$: corona radius [cm]	$\sim 10^7$
$\epsilon_{\rm c}$: X-ray spectrum cut-off [keV]	150
α: X-ray spectrum power-law index	1.6
$B_{\rm c}$: magnetic field [G]	5.7×10^5
n_i, ne: plasma density [cm^{-3}]	6.2×10^{13}
kT: disk characteristic temperature [keV]	0.1

3. Neutron injection

We consider that neutrons are injected isotropically by two mechanisms: photohadronic interactions and pp inelastic collisions.

$$Q_n(E) = Q_n^{(pp)}(E) + Q_n^{(p\gamma)}(E). \tag{1}$$

To estimate the neutron injection due to pp inelastic collisions and photohadronic interactions, we use the approximations presented in Sikora et al. (1989) and Atoyan & Dermer (2003), respectively.

The left panel of Fig. 1 shows the injection function of neutrons due to pp and $p\gamma$ interactions. At low energies most neutrons are injected by pp inelastic collisions, whereas $p\gamma$ is the responsible mechanism for the injection of neutrons at higher energies.

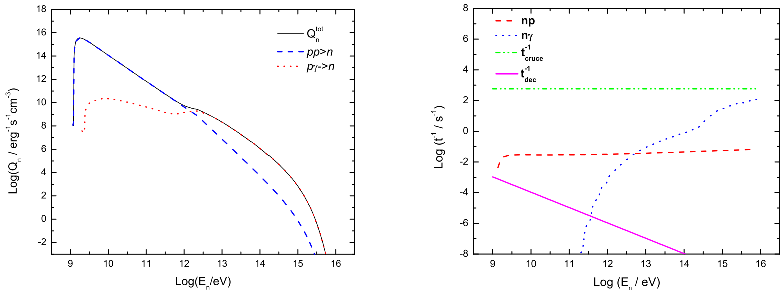
Once neutrons are injected in the corona they can interact, in the same way as protons do, with the ambient material through np inelastic collisions and with the photon field through photomeson production $n\gamma$.

The right panel of Fig. 1 shows the cooling rates together with the decay and escape rates for neutrons, in a medium characterized by the parameters of Table 1. As can be seen in the figure, the escape rate, which is basically the inverse of the crossing time of the corona $t_{\rm cross} = R_{\rm c}/c$, dominates over the radiative losses for neutrons, then radiative losses are not relevant for the transport of neutrons (Sikora et al. 1989).

4. Neutron transport

The mean lifetime of neutrons is $\tau_0 = 881.5 \pm 1.5$ s, and then they decay according to

$$n \to p + e^- + \bar{\nu}_e. \tag{2}$$



(a) Neutron injection.

(b) Radiative losses.

Figure 1. Neutron injection (left panel), and energy losses, decay and escape rate (right panel) in a corona characterized by the parameters on Table 1.

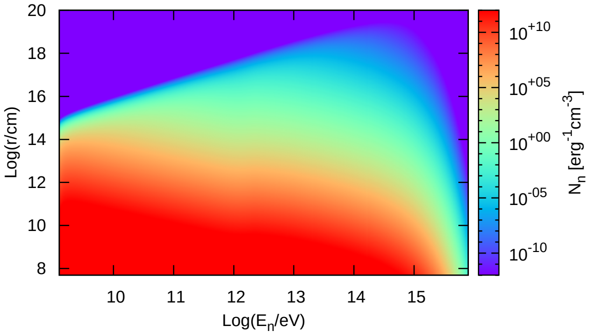


Figure 2. Neutron energy distribution at different values of r.

The distribution of neutron in steady state, $N(E,r)$ (in units $\mathrm{GeV}^{-1}\mathrm{cm}^{-3}$), is governed by an inhomogeneous transport equation:

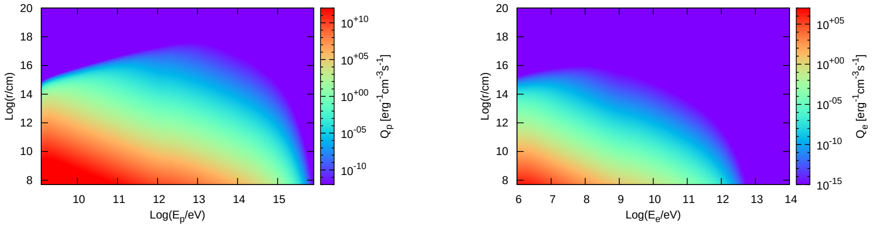
$$\frac{1}{r^2}\frac{\partial(r^2 v(E) N(E,r))}{\partial r} + \frac{\partial(b(E)N(E,r))}{\partial E} + \frac{N(E,r)}{t_{\mathrm{dec}}(E)} = Q(E,r). \tag{3}$$

Here, $v(E)$ is the particle velocity, $b(E)$ contains all the radiative losses and $Q(E,r)$ is the neutron injection obtained in Sect. 3. for $r < R_{\mathrm{c}}$, and $Q(E,r) = 0$ for $r > R_{\mathrm{c}}$.

Figure 2 shows the neutron distribution for different values of the parameter r, where it has been considered that neutrons escape the corona without loosing energy.

5. Results

Figure 3 shows the spectrum of protons and electrons produced by the decay of neutron.



(a) Proton injection.

(b) Electron injection.

Figure 3. Injection function of protons as a result of neutron decay, at different values of z.

Approximately, 99.9% of the neutron energy goes into protons. The power injected in relativistic protons along the jet for our model results in $\sim 10^{34}$ erg s^{-1}. Then, this mechanism can account only partially for the estimated baryon power in the jet of Cygnus X-1 (Gallo et al. 2005).

On the other hand, only 0.01% of the neutron energy goes into electrons and neutrinos; this results in a total power of 10^{30} erg s^{-1} injected in relativistc electrons. Electrons injected within the binary system will interact with the magnetic field and the radiation field of the companion star. For typical values of a massive star, $B \sim 100G$ and $T_* \sim 10^4$ K, we roughly expect the formation of an extended radio synchrotron emission at $\sim$ GHz frequencies. If most of the power injected in electrons were radiated through this channel, the emission would be detectable at the level of the mJy at 1 GHz for a source at 2 kpc. However, the cooling times are very long and the electrons will diffuse far from the site where they were created. A detailed calculation of the radiative spectrum of the electrons and of the morphology of the emission region must be carried out accounting for propagation effects.

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