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Contribution of black hole x-ray binaries in galactic diffuse γ-ray emission at energies above $1MeV$

N. Bhatt, S. Bhattacharyya, A. K. Mitra
Nuclear Research Laboratory, Bhabha Atomic Research Center, Trombay, Mumbai 400 085, India
Presenter: N. Bhatt (nilayb@barc.ernet.in), ind-bhatt-N-abs1-og21-poster

The galactic diffuse γ-ray emission spectrum observed by COMTEL-EGRET can be reproduced by cosmic rays propagation model except the excess in the energy range of $1-30$ MeV. According, to this model discrete sources contribution is required to understand the excess in this energy range. In this work, we estimate the contribution of black hole x-ray binaries in the galactic diffuse γ-ray emission. Following the high energy emission model by Bhattacharyya et al.[1, 2], we give a strong upper limit to the contribution of black hole x-ray binaries to the observed diffuse emission.

1. Introduction

Since its early detection, observation and interpretation of diffuse galactic γ-ray emission is aimed at the unified model for cosmic rays(CRs) and γ-rays in the Galaxy ([3] and references therein). In such models, the discrete sources provide an important contribution. The basic CR propagation processes and diffuse γ-ray emission mechanisms seem to be well understood except few puzzles like excesses in $1-30$ MeV range observed by COMPTEL and above 1 GeV. According to the recent optimized model[4], the diffuse emission spectrum can be reproduced from 30 MeV to 100 GeV, including the ”GeV excess”. But, still the ”MeV” excess remains unexplained by this model. In past, Strong et al.[5] tried to reproduce it, by invoking a steeper electron spectrum below 200 MeV. The problem with this steep spectrum is that it is ad hoc assumption and moreover OSSE-$Ginga$ observations below 500 keV[6] requires even steeper injection spectrum[5]. The MeV excess can be considered as the continuation of the OSSE-$Ginga$ spectrum. Therefore, discrete sources such as supernova remnants possibly contributes to diffuse hard x-ray emission [7]. Evidence for such a contribution at soft γ-ray energies is found recently by $INTEGRAL$[8]. An accretion disk of black hole candidate x-ray binaries (BHXBs) could be a possible site for accelerating electrons/protons to very high energies. This accelerated electrons may have contribution in OSSE range[9] while the accelerated protons will generate pions and $e^{\pm}$ through $p-p$ collisions in the disk. They contribute to MeV energies via π^o decay as well as via IC scattering of disk black body photons by secondary $e^{\pm}$ [1, 2].

2. Luminosity Functions

Grimm et al.[10] produced the x-ray luminosity function (XLF) for High Mass X-ray Binaries(HMXBs) in the Milky way as cut-off power-law. And then the average differential XLF of Low Mass X-ray Binaries (LMXBs) for eleven nearby galaxies including Milky way, as estimated by Gilfanov[11] is a power law with two breaks,

$$\frac{dN_L}{dL_X} = \begin{cases} K_1 \left(\frac{L_X}{L_{b,1}}\right)^{\alpha_1}, & L_X < L_{b,1} \\ K_2 \left(\frac{L_X}{L_{b,2}}\right)^{\alpha_2}, & L_{b,1} < L_X < L_{b,2} \\ K_3 \left(\frac{L_X}{L_c}\right)^{\alpha_3}, & L_{b,2} < L_X < L_c \\ 0, & L_X > L_c \end{cases} \quad (1)$$

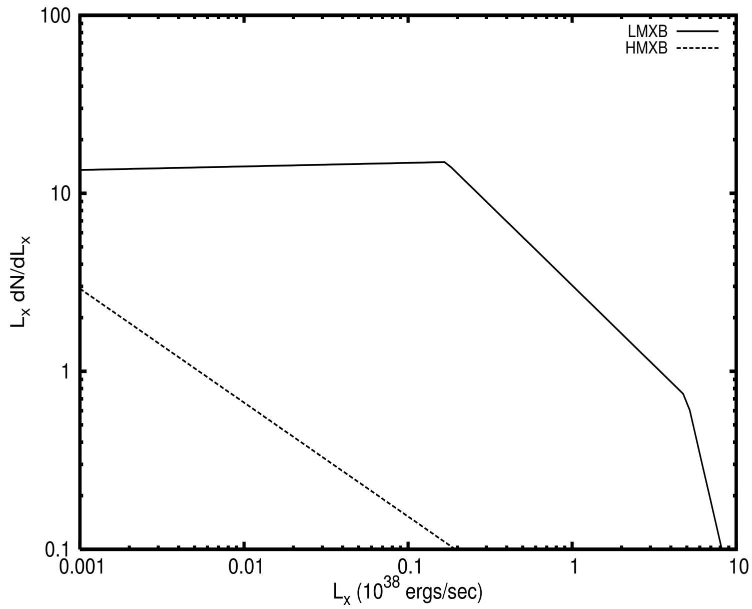

Figure 1. x-ray luminosity functions of BHXBs in the Milky way

$$K_1 = 440.4 \quad \text{per} \;\; 10^{11}\,\mathrm{M}_{\odot}$$
$$K_2 = K_1 \left(\frac{L_{b,1}}{L_{b,2}}\right)^{\alpha_2}, \quad K_3 = K_2 \left(\frac{L_{b,2}}{L_c}\right)^{\alpha_3}$$

The luminosity function is normalised for Milky way using total stellar mass of 4.5×10^{45}[11]. The break luminosities are, $L_{b,1} = 1.7 \times 10^{37} ergs/sec$, $L_{b,2} = 5 \times 10^{38} ergs/sec$. And the indices in three regions are, $\alpha_1 = 0.98$, $\alpha_2 = 1.9$ and $\alpha_3 = 5.0$. Here, we have used $5 \times 10^{35}\ ergs/sec$ as minimum luminosity, L_{min} and the cut-off luminosity, L_c is taken as $10^{39}\ ergs/sec$.

The differential luminosity function of HMXBs[10] is a steep power-law,

$$\frac{dN_H}{dL_X} = K L_X^{-1.64}, \qquad K \approx 0.7 \text{ for Milky way} \tag{2}$$

Based on the catalogue of x-ray binaries by Liu et al.[12, 13], we took the fraction of black hole LMXBs, $f_L = 0.2$ and the fraction of black hole HMXBs, $f_H = 0.05$

3. High energy emission from BHXBs

Photon spectrum of black hole binaries in the soft show a dominant black-body like component ($kT \approx 1$ keV) and a power-law component ($\Gamma \approx 2.5$) which does not show any observable cut-off at energy ≈ 600 keV. Few of them, e.g., Cyg X-1, are observed by COMPTEL in MeV range[14]. The resultant spectrum upto MeV energy is usually fitted with EQPAIR model[15] where it is considered that the black-body like component is produced due to Comptonization of soft photons from the disk by the thermal electrons and the non-thermal component is produced due to the Comptonization by the non-thermal electrons. But this component can not fit the MeV region of the spectrum reasonably well. Bhattacharyya et al.[1, 2] showed that if protons are also accelerated to relativistic energies in the inner region of the accretion disk then energetic protons will produce electrons, positrons and γ-rays through $p-p$ collision with the ambient matter. The resultant electrons and positrons contribute in the $1-50$ MeV range of the spectrum which has broad feature and a cut-off at ≈ 80 MeV due to $\gamma\gamma$ pair production. Their estimates show that the total luminosity of the photons in the $1-80$ MeV band comes nearly 5% of the peak x-ray luminosity of the source.

4. Luminosity Estimates

The bolometric x-ray luminosity derived from the XLFs described in §2 is,

$$L_{X,tot} = \int_{L_{min}}^{L_c} \left[f_L \frac{dN_L}{dL_X} + f_H \frac{dN_H}{dL_X} \right] L_X \, dL_X \approx 6.4 \times 10^{38} \; ergs/sec \tag{3}$$

As described in §3, the estimated total luminosity in the energy band $1-80$ MeV which is 5% of x-ray luminosity, will be,

$$L_{MeV,tot} = 0.05 L_{X,tlot} \approx 3.2 \times 10^{37} \; ergs/sec \tag{4}$$

Using the data given in Strong et al. 2005, the observed luminosity in $1-80$ MeV can be $\approx 10^{39}$ ergs/sec. Hence, the contribution of BHXBs to diffuse γ-ray emission in MeV energy band is expected to be 3.2% of the observed flux.

5. Conclusion

Existing data of diffuse γ-ray emission available in the literature show that the contribution of discrete sources is very important to resolve the 'MeV excess' in the observed spectrum. In this work, an attempt is made to calculate the possible contribution from the BHXBs in their soft state which has a power-law photon spectrum extending upto 1 MeV with no observable cut-off. Considering that the high energy(MeV) power-law component is contributed by the protons accelerated in the inner regions of accretion disk, Bhattacharyya et al. (2003,2005) predicted the spectrum in $1-80$ MeV energy range. Using their estimation, the contribution of BHXBs to galactic diffuse γ-ray emission in $1-80$ MeV energy range is obtained. This preliminary calculation shows that approximately 3.2% of the diffuse γ-ray luminosity may be contributed by BHXBs. This is a strong upper limit for these sources. As BHXBs are not always found in soft state, the calculation with a proper duty cycle will give an estimate less than present upper limit.

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