Time and Space dependent stochastic acceleration model for the Fermi Bubbles

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Abstract

We study the temporal evolution of electron energy distribution in the Fermi Bubbles with a realistic stochastic acceleration model. Our model takes into account the decay of the turbulence. The model spectra well agree with gamma and radio observations, but the profile of surface brightness is yet to be tuned.

Introduction

Gamma ray data from the Fermi-LAT reveal two giant bubbles extending up to 50° above and below the Galactic Center, dubbed the Fermi Bubbles(FB).
The features of the FB are

- extending up to ~10 kpc above and below the GC
- hard energy spectrum($dI/dE \sim E^{-2}$)
- sharp edge(suddenly brighten at the boundary)
- exhibiting an almost constant surface brightness (not constant volume emissivity)

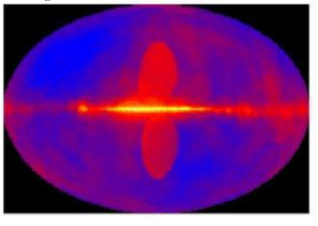

Figure 1:
Gamma-ray data from Fermi-LAT (100-500GeV) without point sources (Ackermann et al.2013)[1]

Model

We consider the space dependent 2nd-order Fermi acceleration like Mertsch et al[2]. In their model, the diffusion coefficient in momentum D_{pp} changes with the distance from the shock front.

$$D_{pp} = p^2 \frac{8\pi D_{xx}(\xi)}{9} \int_{1/L}^{k_d} dk \frac{W(k)k^4}{v_F^2(\xi) + D_{xx}^2(\xi)k^2} \quad \cdots(1)$$

D_{pp} corresponds to an efficiency of the acceleration. ξ is a dimensionless parameter expresses the distance from the shock like ξ= x/L (if L = 2 kpc, ξ = 1.0 correspond to 2 kpc from the shock front).
Figure 2 shows the spatial dependence of D_{pp} .

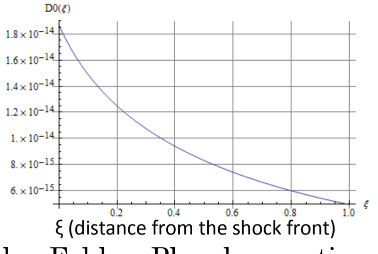

Figure 2:
Plot D_{pp} according to Eq.(1).
This represents the further from the shock, the acceleration efficiency becomes inefficient.

Mertsch et al. solved the Fokker-Planck equation (Eq.(2)) at each ξ until became steady state, and disregarded escaping particles.
We extend this by considering time dependence, at each time ξ=Vt, and escaping particles.

$$\frac{\partial n}{\partial t} - \frac{\partial}{\partial p}\left(p^2 D_{pp} \frac{\partial}{\partial p}\frac{n}{p^2}\right) + \frac{n}{t_{esc}} + \frac{\partial}{\partial p}\left(\frac{dp}{dt} n\right) - Q_{inj} = 0 \quad \cdots(2)$$

Results

We solve the Eq.(2) with three cases.
1.Consider both time dependence and escaping particle(with-escape model, black solid line)
2.Consider time dependence, but neglect escaping particle(cut-escape model, red solid line)
3.Assume there is no escape effect(no-escape model, blue solid line)
The results of fitting are shown in Figure 3.

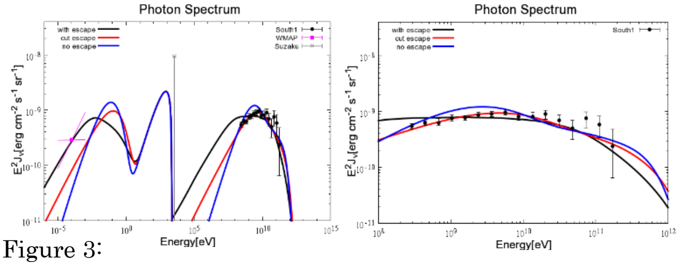

Figure 3:
Fitting with three cases (left:bload band,right:gamma ray)

We assume the uniform magnetic field $B = 4\ \mu$G, the synchrotron and Inverse-Compton cooling, and calculate about 7 Myr. Particles leave the shock front at t =0, and propagate at V = 250 km/s. Diffusive losses from the acceleration region is accounted for by escape on time scale ~ L^2/D_{xx} .
The energy distribution of electrons calculated by 3 models are shown in Figure 4.
We also calculate the surface brightness, but contrary to a previous research, we can't reproduce constant surface brightness(Figure 5).
To solve this problem, now we seek a better tuning of models.

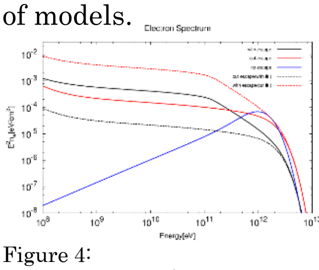

Figure 4:
Electron Spectra(black and red dashed lines are results of other cases at equal parameters)

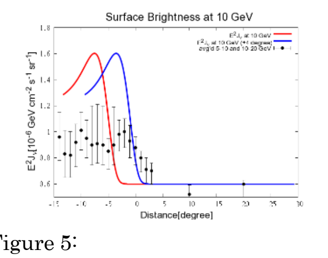

Figure 5:
The gamma ray intensity at 10 GeV (red:with escape model,blue:shock front exists out of edge)

References

[1] Ackermann et al. ApJS 209,34(2013)
[2] P.Mertsch and S.Sarkar, PRL 107,091 101(2011)