CONTRIBUTION FROM STAR-FORMING GALAXIES TO THE COSMIC GAMMA-RAY BACKGROUND RADIATION

Ryu Makiya, Tomonori Totani (Kyoto Univ.), Masakazu Kobayashi (NAOJ)

1. Introduction

- Extragalactic gamma-ray background (EGRB)

Diffuse and stable γ-rays coming from all directions of sky was first observed by SAS-2 satellite (EGRB; Fichtel et al. 1977; Fichtel et al. 1978). The origin of EGRB has been thought that superposition of faint discrete sources, such as active galactic nuclei (AGNs), galaxy clusters, structure formation, and dark matter annihilation. In this work, we calculated the contribution from star-forming galaxies to the EGRB, using the state-of-art model of hierarchical galaxy formation.

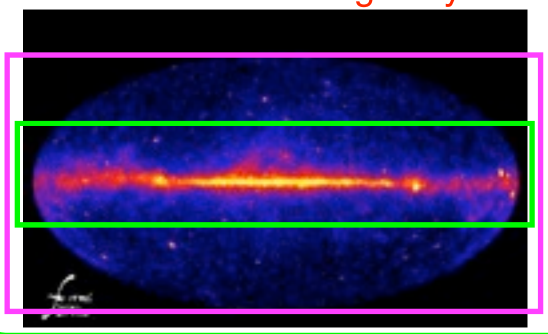

Fig 1. γ-ray all sky map.

Fermi all sky map (1 year)
Credit : NASA/DOE/International LAT Team

- Gamma-rays from star-forming galaxies

Cosmic-rays accelerated by supernova remnants (SNR) are interacted with interstellar gas and radiation field, and emit γ-rays via bremsstrahlung, inverse Compton (IC), and π_0 decay process. Diffuse gamma-rays from our galaxy and large magellanic cloud (LMC) has been observed, and recently, small magellanic cloud (SMC), M82 and NGC253 are detected in γ-rays for the first time by H.E.S.S. (Acero et al. 2009), VERITAS (VERITAS Collaboration 2010), and *Fermi* (Abdo et al 2010, The Fermi/LAT Collaboration 2010).

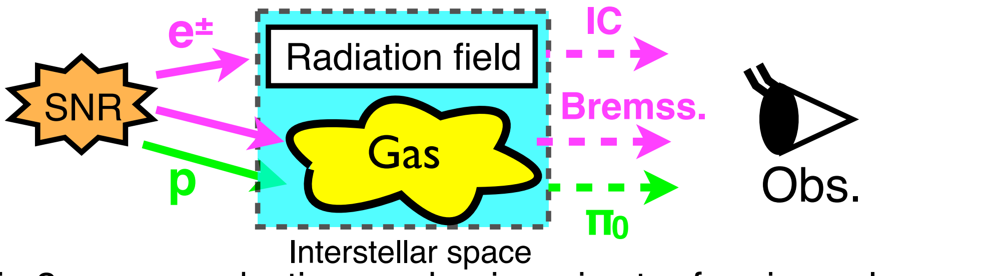

Fig 2. γ-ray production mechanisms in star-forming galaxy

2. Model

• Galaxy formation model

To calculate the contribution from star-forming galaxies to the EGRB, we need a γ-ray luminosity function (LF) of galaxies (comoving number density of galaxies per unit γ-ray luminosity). We use a mock numerical galaxy catalog produced by one of the latest semi-analytic models of hierarchical galaxy formation [the Mitaka model (Nagashima & Yoshii 2004; Nagashima et al. 2005)] to construct the LF. The Mitaka model can quantitatively reproduce a wide variety of observed characteristics of galaxies. Moreover, it also can reproduce well the cosmic star formation history.

• Gamma-ray emission from galaxies

We estimated the γ-ray luminosity of galaxies using star formation rate (SFR) and gas mass. SFR is an indicator of the cosmic-ray luminosity, while gas mass account for the amount of target atom. In Fig. 3 it is clearly seen that there is a good correlation between the γ-ray luminosity and SFR × gas mass. We fitted these data to power-law function, and the result is

$$L_\gamma = 0.28 \times \left(\frac{\mathrm{SFR}}{M_\odot \mathrm{yr}^{-1}} \times \frac{M_{\mathrm{gas}}}{10^9 M_\odot}\right)^{0.86} [10^{39}\mathrm{erg/s}],$$

where L_γ is γ-ray luminosity in 100 MeV - 5 GeV.

We also need to model the γ-ray spectrum of galaxies. We simply assumed that all quiescent galaxies have the same spectral shape as the MW. For starburst galaxies, spectrum could become harder than quiescent galaxies, therefore we consider another model that MW-like spectrum plus hard power-law component.

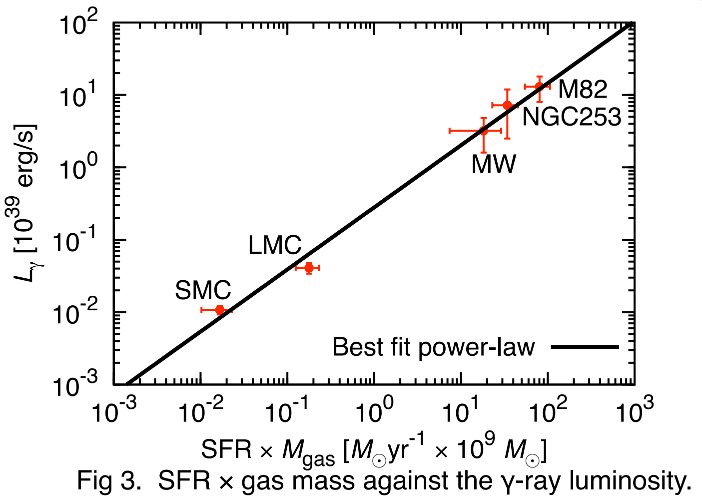

Fig 3. SFR × gas mass against the γ-ray luminosity.

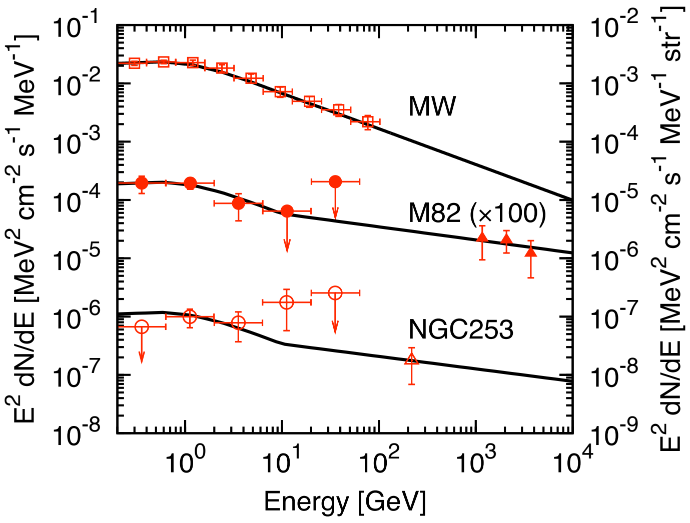

Fig.4 γ-ray spectrum of galaxies. MW is in units shown on the right ordinate, while the others are in left ordinate.

• The EGRB calculation

Using the mock numerical galaxy catalog including the SFR and gas mass of each galaxies and the modeling of γ-ray luminosity, we constructed the γ-ray LF of galaxies. The EGRB flux and spectrum can be calculated by integrating the γ-ray LF.

We also calculated the attenuation of γ-rays by cosmic infrared background (CIB) photons, and reprocessed cascade emission.

3. Results

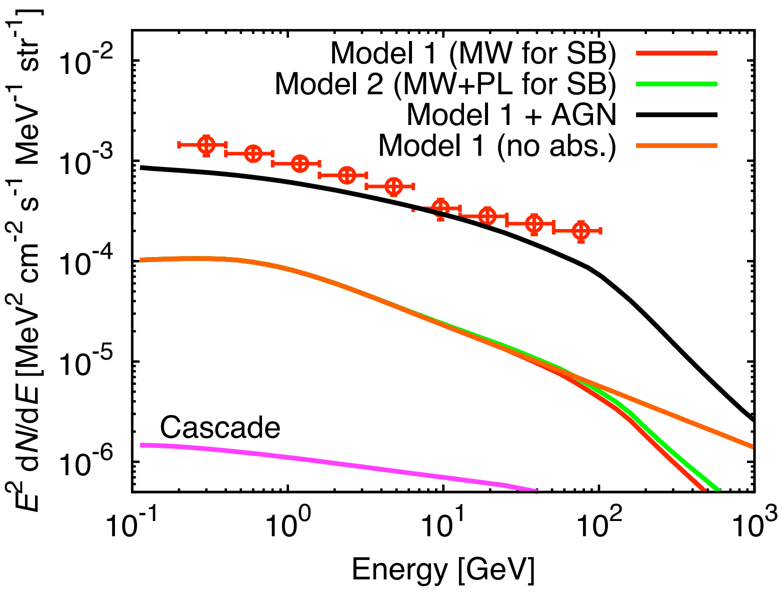

Fig.5 The EGRB spectrum.

In Fig.5 the predictions of total EGRB flux from all star-forming galaxies (quiescent +starburst), as well as the total prediction including AGNs, are plotted. Model 1 and 2 correspond to two cases of spectrum of starburst galaxies. For the model of the AGN contribution we used Inoue & Totani (2009). The data points are the *Fermi* measurements of the EGRB including the contribution from resolved sources (Abdo et al. 2010). To show the effect of absorption, Model 1 with no-absorption and the flux of cascade emission are also plotted. As a result, the EGRB photon flux from all star-forming galaxies become 8.7% of the total EGRB, and the sum of the contributions from AGNs and star-forming galaxies account for the ~65% of the total EGRB. It should also be noted that the combined spectrum by AGNs and star-forming galaxies is remarkably similar to the observed EGRB spectrum. Further examination is required to see whether the ~35% residual of the EGRB is mainly a result of modeling uncertainty, experimental uncertainty, or significant contributions from other sources, e.g., dark matter annihilation. Please see arXiv:1005.1390 for more detailed discussions.