PROCEEDINGS OF SCIENCE

An MeV gamma-ray all-sky simulation

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The MeV gamma-ray domain is the only unexplored window among recent multiwavelength observations in astrophysics, and is often referred to as the "MeV gap". To bridge this gap, there are several ongoing and planned projects of MeV gamma-ray telescopes. The measurement of MeV gamma rays (both continuum and line emission) would give us new insight into many topics in astrophysics, such as studies of relativistic jets, particle acceleration, and origin of dark matter. In advance of future missions, we have been working on prediction of the MeV gamma-ray sky, which is helpful to determine what kinds of sources can be detectable with the future telescopes. In order to explore MeV gamma-ray sources, we performed a catalog cross-matching between the hard X-ray (*Swift*-BAT) and GeV gamma-ray (*Fermi*-LAT) catalogs, resulting in 145 firmly cross-matched sources. Most of the sources are brighter than 10^{-11} erg cm^{-2} s^{-1} in the 1–10 MeV band and thus promising targets for future observations. Combined with the Galactic diffuse and extragalactic emissions, the all-sky maps in the MeV gamma-ray band can be produced. We find that it is dominated by the Galactic diffuse emission at lower latitudes, while the extragalactic component becomes dominant at higher latitudes. This all-sky study is also used to investigate a long-standing problem in MeV gamma-ray astrophysics: the origin of the diffuse emission from the inner Galaxy, measured by COMPTEL.

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1. Introduction

The sky in the MeV gamma-ray energy band was explored almost 30 years ago by the Imaging Compton Telescope COMPTEL on board the Compton Gamma-Ray Observatory (CGRO) mission. Using the first 5-yr data of COMPTEL in the 0.75–30 MeV range, a source catalog was [8] produced, which included 25 steady sources, seven line gamma-ray sources, and 31 GRBs. COMPTEL also measured the Galactic Diffuse Emission (GDE) and the extragalactic emission (e.g., [10, 16]). However, there have been no devoted detectors in this band since the era of COMPTEL.

Although this "MeV gap" in the gamma-ray energy domain has remained uninvestigated in recent multi-wavelength astronomy, there are promising discoveries to be made in this energy band. There are currently several ongoing and planned projects of MeV gamma-ray detectors to achieve sensitive and improved observations in the next decades. In advance of these next-generation missions, an all-sky projection of MeV sources, using the latest results in the hard X-ray and GeV gamma-ray bands, will be useful. This study would be helpful to build an observational strategy for the future missions.

In this proceeding, we present a predicted all-sky map in the MeV gamma-ray energy range based on currently available source catalogs and models of Galactic and extragalactic diffuse emission. Details of each component are given in Section 2 (MeV gamma-ray sources) and Section 3 (diffuse emission), and the simulated all sky is presented in Section 4.

2. MeV gamma-ray source candidates

This section presents individual sources in the MeV gamma-ray band. These sources were obtained from a MeV gamma-ray source catalog [13], which was constructed by cross-matching the latest hard X-ray and GeV gamma-ray catalogs, the 105-month *Swift*-BAT catalog [6] and the 4FGL-DR2 [3], respectively. This resulted in 145 firmly matched sources (i.e., both hard X-ray and GeV gamma-ray emitters), which would be potential MeV gamma-ray sources. The firmly matched sources consist of mostly AGN (fraction of 65%), and pulsars/PWNe (12%), HMXBs (3%), and SNRs (3%).

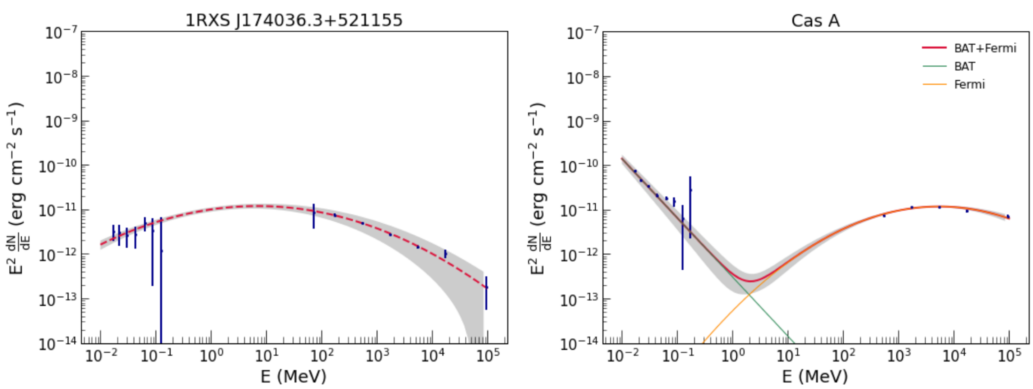

Figure 1: Spectral energy distributions (SEDs) of FSRQ RXS J174036.3+521155 (left) and SNR Cassiopeia A (right).

We estimated flux in the MeV gamma-ray range by interpolating the hard X-ray and GeV gamma-ray spectra, respectively provided by [6] and [3]. Figure 1 show example spectral energy distributions (SEDs) of two candidate sources, FSRQ RXS J174036.3+521155 and SNR Cassiopeia A. For a fitting model of the SED, we adopt a log-parabola model as default. This model is applicable to sources, for which radiation from the X-ray to gamma-ray energy bands is originated from one population, such as inverse Compton (IC) scattering in FSRQs. If the log-parabola model is not appropriate, we made use of a two-component model (i.e., sum of the best-fit X-ray model from [6] and gamma-ray model from [3]). An example of application of the two-component model is Cassiopeia A, for which X-ray and gamma-ray emission would have different origins. Based on the best-fit models, we calculated the projected 1–10 MeV flux for each source.

Figure 2 illustrates an all-sky map of the projected source flux, obtained from the aforementioned way. While there are many extragalactic sources which are AGN (i.e., the majority sources in the catalog), there exist several Galactic sources at the low-latitude region. We found 30 sources have flux higher than 10^{-10} erg cm^{-2} s^{-1}, roughly corresponding to the number of sources detected by COMPTEL [8]. If the sensitivity of future detectors improves by one order of magnitude, 125 sources are expected to be detectable. These bright sources will be good targets for future missions in the MeV gamma-ray domain.

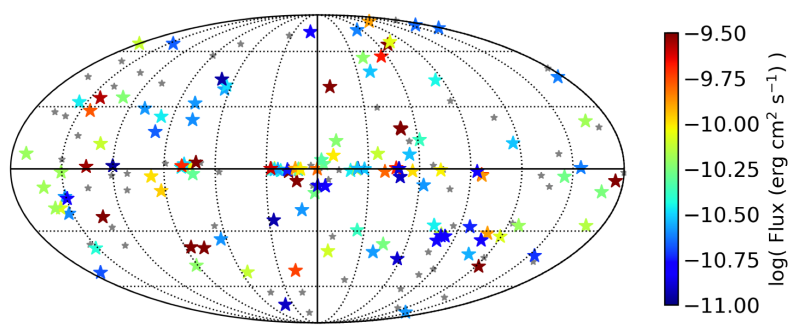

Figure 2: Source map. The 1–10 MeV flux is shown in color, and sources with flux lower than 10^{-11} erg cm^{-2} s^{-1} are shown with small grey stars.

3. MeV gamma-ray diffuse emission

3.1 Galactic diffuse emission

We made use of Galactic Diffuse Emission (GDE) models of [1] and [7], which were mainly elaborated to be reconciled with the observed GeV gamma-ray data by *Fermi*-LAT and cosmic ray (CR) spectra. Among their models, we adopted for $^{S}S^{Z}4^{R}20^{T}150^{C}5$[1] model from [1] (referred to as Model 1 in our study) and DRE and DRELowV models from [7] (Model 2 and 3, respectively). Note that difference of these three models is a factor of a few.

[1]This model assumes that the source distribution of CRs is SNRs, the Galactic disk is characterized by the height of $z = 4$ kpc and the galactocentric radius of $R = 20$ kpc, and $T_s = 150$ K and $E(B-V) = 5$ mag cut is adopted for determining the gas-to-dust ratio (see [1] for details).

3.2 Extragalactic emission

Extragalactic emission in the MeV gamma-ray energy band was investigated by COMPTEL [16] and Gamma-Ray Spectrometer (GRS) onboard the Solar Maximum Mission (SMM) [15]. The difference of the extragalactic emission reported by these instruments is a factor of 2–3 in the 1–10 MeV band. We assumed an isotropic spatial distribution in this proceeding. It should be noted that the measurements by COMPTEL and SMM were conducted in 0.8–30 MeV and 0.3–8 MeV, respectively, thus the extrapolation to the outside of these energy bands needs caution.

4. MeV gamma-ray all-sky simulation

Figure 3 illustrates an example of 1–10 MeV gamma-ray all-sky map, consisting of individual sources and Galactic [1] and extragalactic [16] diffuse emission. All-sky maps at different energy bands, including the energy band of COSI [12] of 0.2–5 MeV, and with different models of GDE and extragalactic component are preliminarily available in our webpage[2].

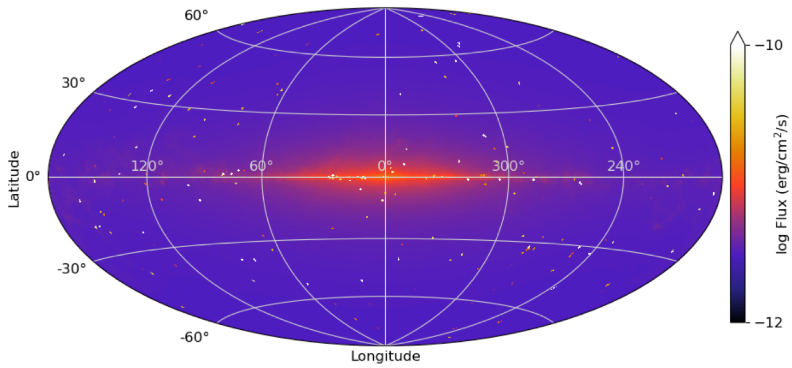

Figure 3: Predicted all-sky map in the 1–10 MeV band, using the GDE model of [1] and the extragalactic model of [16].

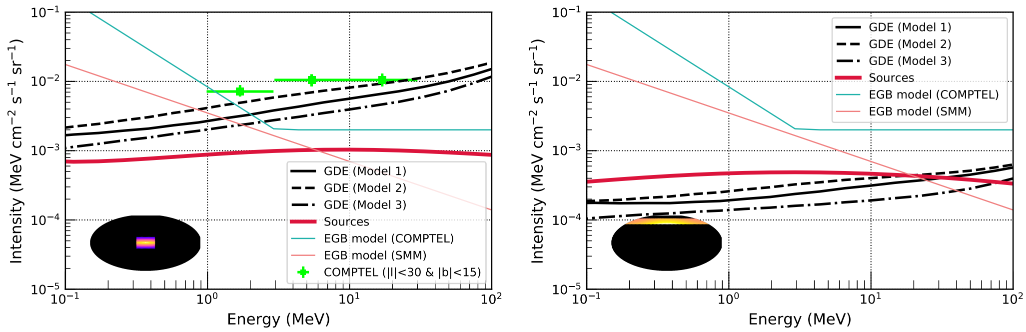

Figure 4: SEDs of the low-latitude sky (left; $|l| < 30°$ and $|b| < 15°$) and the high-latitude sky (right; $50° < b < 70°$)

We present a spectrum from the inner Galactic region, $|l| < 30°$ and $|b| < 15°$, in Figure 4, showing that the GDE dominates above ∼2 MeV. COMPTEL measured the flux from this region,

[2]https://tsuji703.github.io/MeV-All-Sky/

shown with light green plots in Figure 4 (e.g., [4, 9, 10]), the origin of which has been unveiled since its discovery, often referred to as COMPTEL excess. The accumulated flux of sources located within this region, indicated by a red line in Figure 4, inferred that individual sources contributed to the COMPTEL emission by ~20%. Combined with GDE, the COMPTEL emission might be roughly reproduced, depending on choices of the GDE models (see also [14]).

In contrast to the inner Galactic region, the high-latitude sky (e.g., $50° < b < 70°$) is dominated by the extragalactic emission, as shown in Figure 4. The accumulated source flux is roughly comparable to GDE.

5. Summary

We constructed a simulated all-sky map in the MeV gamma-ray range, based on the projected MeV gamma-ray source catalog [13], the measured galactic diffuse [1, 7] and extragalactic emissions [15, 16]. The predicted map shows that (1) many sources can be bright against the diffuse emission, suggesting they could be good targets for future missions, (2) the low-latitude sky is dominated by the GDE component, and (3) the high-latitude region is dominated by the extragalactic radiation. The prediction of the MeV gamma-ray all sky would be helpful for building an observational strategy for future missions, such as GRAMS [2], COSI [12], AMEGO-X [5], and SMILE [11].

Acknowledgments

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