Contribution to the cosmic γ-ray background radiation from star-forming galaxies

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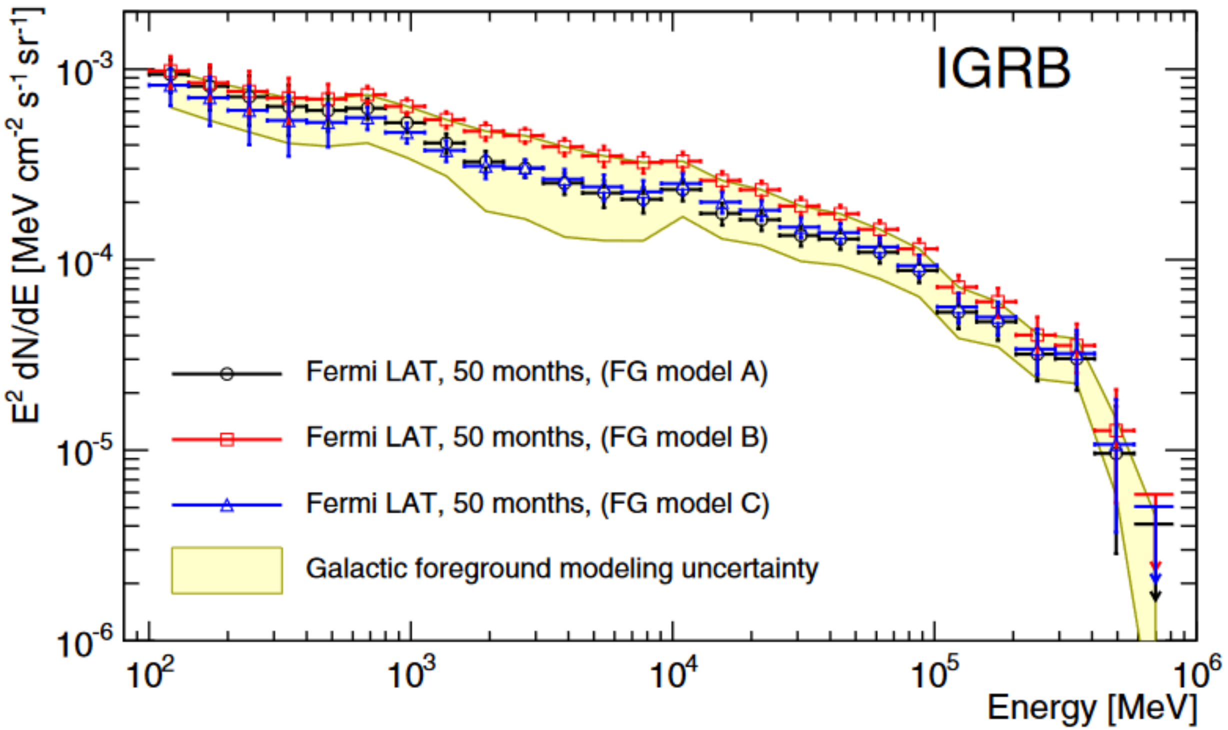
Unresolved Isotropic Diffuse γ-ray Background(IGRB)

- Extragalactic γ-ray background(EGB or IGRB): contains both resolved and unresolved γ-ray sources, which is a constant.
- Unresolved IGRB: only contains the diffuse unresolved sources.

Unresolved Isotropic Diffuse γ-ray Background(IGRB)



Ackermann et al. (2015)

Integrated LAT counts above 100MeV that used for the analysis of IGRB

Spectrum of derived IGRB by Fermi LAT

Candidate Sources

- Star-forming galaxies ← What we are interested in
- Active galactic nuclei
- Millisecond pulsars
- Dark matter annihilation

Review of Previous Works

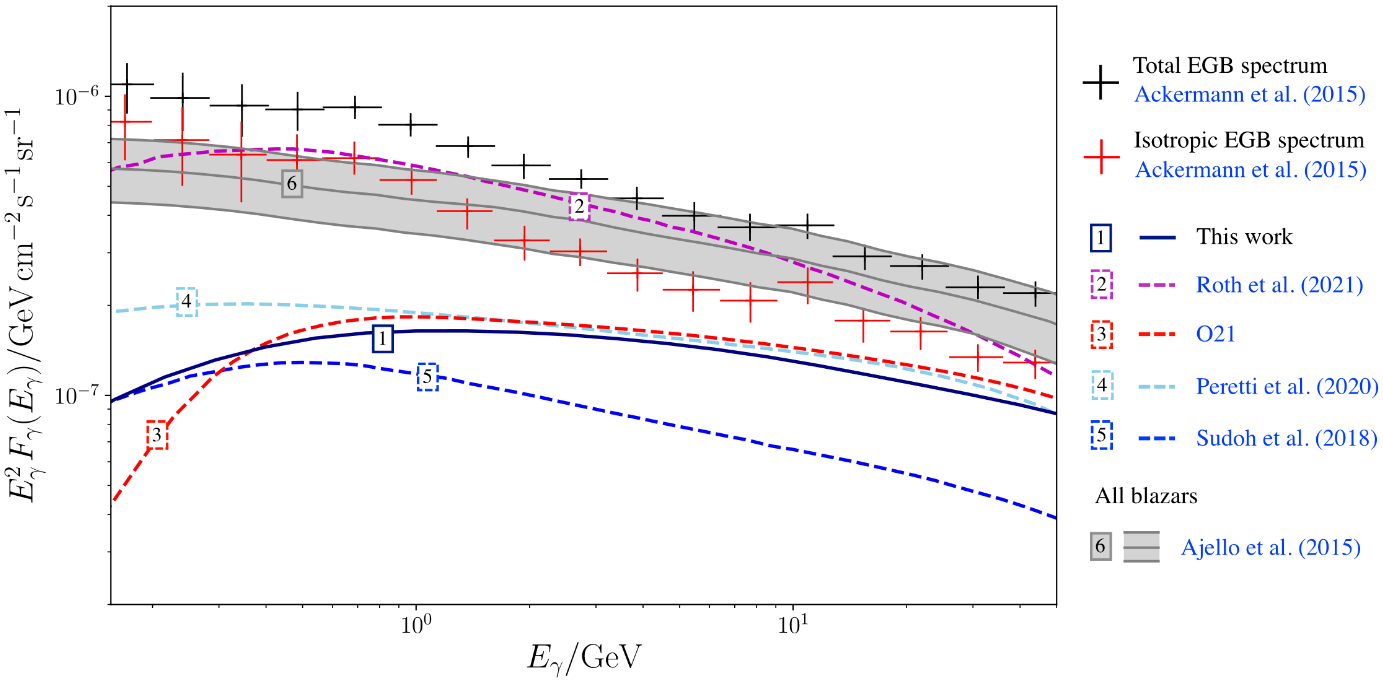


Figure A1. Total contribution from SFGs (starburst and main sequence) to the isotropic EGB, between 0.1 and 50 GeV. The fiducial result from this work is given by line 1, which is in agreement with the constraint imparted by the contribution from resolved and unresolved blazars (grey band, denoting the three models of Ajello et al. 2015) and the observed EGB with 50 months of *Fermi*-LAT data (Ackermann et al. 2015), determined using their foreground model A. Comparison is made with four recent works; Roth et al. 2021 (line 2), O21 (line 3), Peretti et al. 2020 (line 4), and Sudoh et al. 2018 (line 5).

25%

ound (EGB

ed by

Owen et al. (2022)

The Aim of this Work

- Investigate the origin of discrepancy between the previous studies, especially Roth et al.(2021), which is significantly higher than others.
- Provide the best estimate for the contribution from star-forming galaxies to the background.

Our Advantages

- In this work, we made some improvement compared with previous ones:

1. Use galaxy parameters of CANDELS (improvement compared with Sudoh et al. (2018)).
2. Base on careful normalization to nearby galaxies (improvement compared with Roth et al. (2021)).
3. Keep consistency of initial mass function(IMF).
4. Examine model dependence by trying Sudoh vs. Roth models.

Basic Mechanism

Objects	D^a (Mpc)	L_γ (0.1–800 GeV)^b (10^{39} erg s^{-1})	ψ^c ($M_\odot$ yr^{-1})	M^d_{gas} (10^9 $M_\odot$)	M^e_{star} (10^9 $M_\odot$)	R^f_{eff} kpc
MW		0.82 ± 0.27	2.6	4.9	50	6.0
LMC	0.05	0.032 ± 0.001	0.3	0.59	1.8	2.2
SMC	0.06	0.0125 ± 0.0005	0.043	0.46	0.3	0.7
NGC 253	3.5	13 ± 1	3.3	3.2	54.4	0.5
M82	3.3	14.7 ± 0.7	4.4	4.7	21.9	0.3
NGC 2146	17.2	81.4 ± 14.2	11.4	10.4	87.1	1.7

Physical properties of GeV-detected galaxies

Shimono et al. (2021)

Production of Cosmic Rays

- Cosmic rays luminosity

$$\frac{dN_p}{dtdE_p} = C(\frac{SFR}{M_{\odot}yr^{-1}})(\frac{E_p}{GeV})^{-\Gamma_{inj}}$$

- $C_{fit} = 2.6\times10^{45}s^{-1}erg^{-1}$
- $C_{theory} = 3.2\times10^{45}s^{-1}erg^{-1}$
- $\Gamma_{inj} = 2.2$ (from observation)

Propagation and Interaction of Cosmic Rays

- Fraction of cosmic rays interacting with ISM

$$f_{cal}(E_p) = 1 - exp(-t_{esc}/t_{pp})$$

- $t_{esc}(E_p) = min[t_{diff}, t_{adv}]$
- $t_{pp}(E_p) = (n_{gas}\sigma_{pp}c)^{-1}$

γ-ray Flux at Earth

- γ-ray luminosity from galaxies:

$$\frac{dL_{N,\gamma}}{dE_\gamma} = \int_{E_\gamma}^{\infty} f_{cal} \frac{dN_p}{dtdE_p} \frac{dn_\gamma}{dE_\gamma} dE_p$$

- γ-ray flux at earth:

$$\frac{dF_\gamma}{dE_\gamma} = \frac{(1+z)^2}{4\pi d_L^2(z)} \frac{dL_{N,\gamma}}{dE_\gamma} |_{E_\gamma(1+z)} e^{-\tau_{EBL}(E_\gamma,z)}$$

Application to Galaxy Samples

- We use the CANDELS GOODS-S sample from Roth et al. (2021). They select 22279 galaxies from 34930 galaxies in the full sample.
- Divide the sky into some slides ($\Delta z = 0.1$)
- Sum all fluxes of galaxies in the slide j

$$\sum_{i=1}^{n_{S,j}} \left(\frac{dF_{\gamma,i}}{dE_\gamma}\right)_{i,j}$$

- Here the $n_{S,j}$ is the number of CANDELS galaxies in the redshift bin
- Cosmic SFR best fitting function

$$\psi_{cosmic}(z) = 0.015 \frac{(1+z)^{2.7}}{1 + [(1+z)/2.9]^{5.6}} M_\odot year^{-1} Mpc^{-3}$$

Application to Galaxy Samples

- γ-ray flux from SFGs in the whole sky

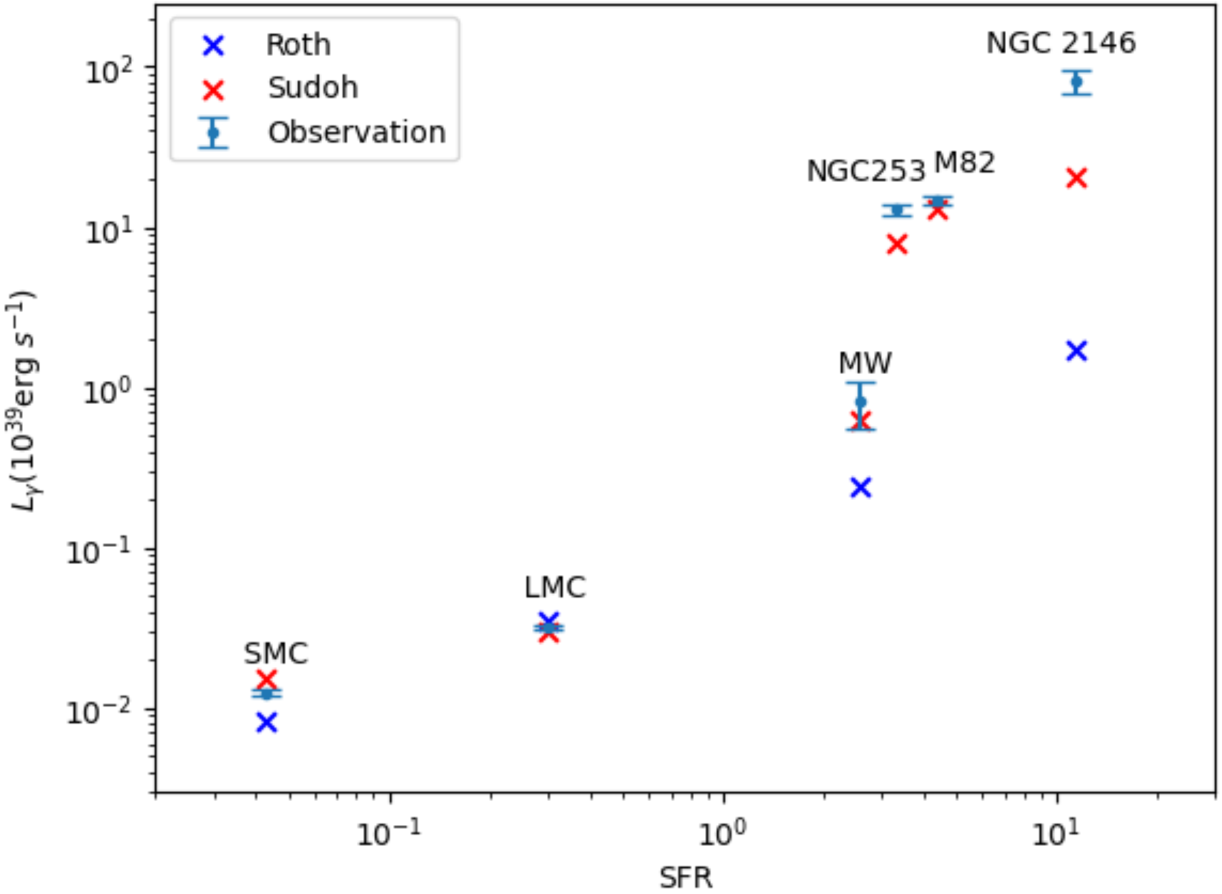
$$\Phi(E_\gamma) = \frac{1}{\Omega_S} \sum_{j=1}^{n_{zbin}} f_{corr,j} \sum_{i=1}^{n_{S,j}} \left(\frac{dF_{\gamma,i}}{dE_\gamma}\right)_{i,j}$$

- $\Omega_S = 173 arcmin^2$ is the solid angle surveyed by CANDELS
- $f_{corr,j}$ is the ratio of total SFR to SFRs of CANDELS in a redshift bin

$$f_{corr,j} = \frac{\frac{4\pi}{3}\left(x^3(z+0.1) - x^3(z)\right)\psi_{cosmic}(z)}{\sum_{i=1}^{n_{S,j}} \psi_{i,j}}$$

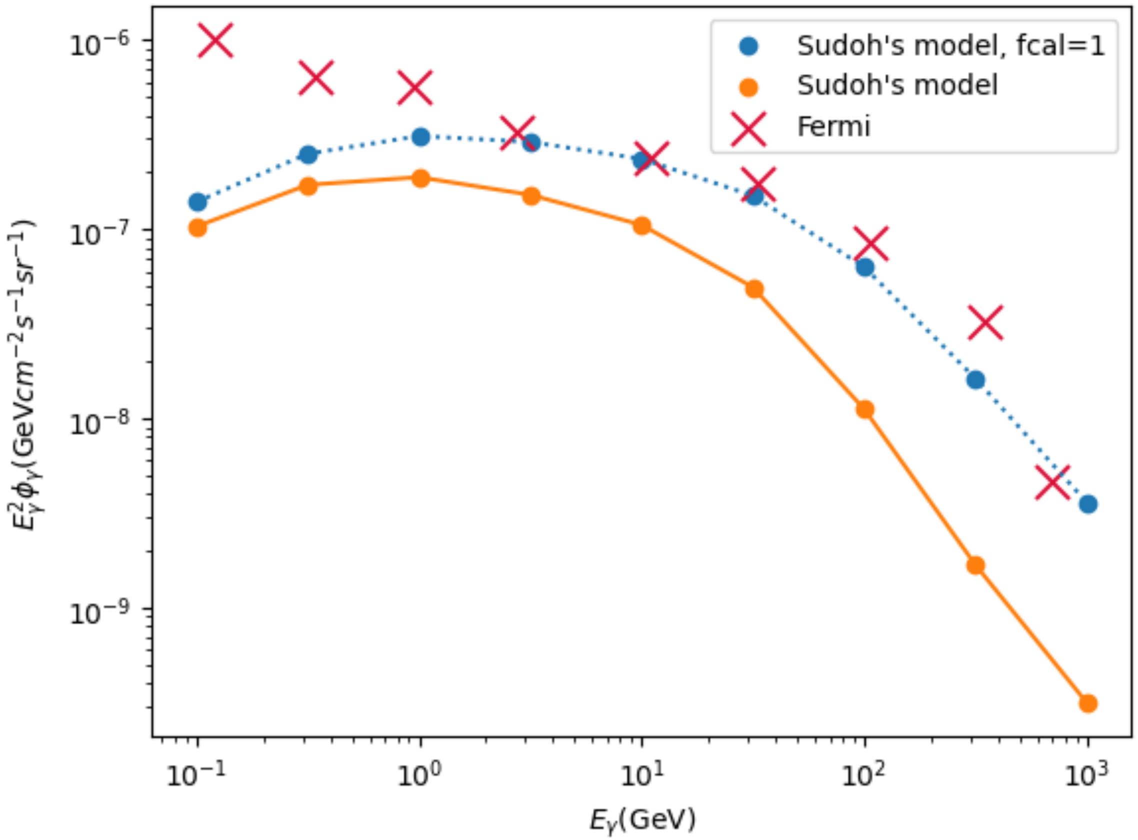
Verify models with nearby galaxies

- The γ- … So we can apply t … e their validity
- The pr … stence with the obs



Our Result

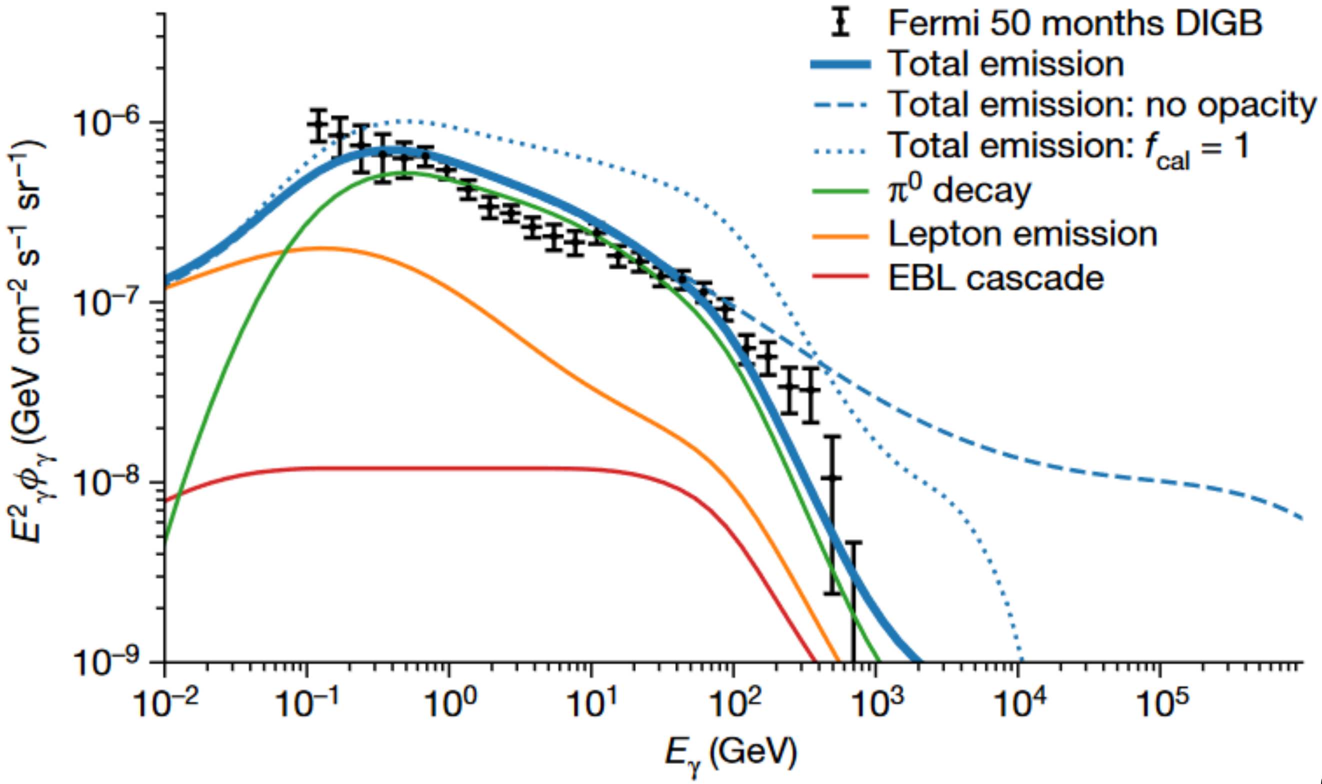
Our Result



We use Sudoh+ model for gamma-ray luminosity from an SFG

SFGs cannot explain the total unresolved background alone!

Research by Roth et al.



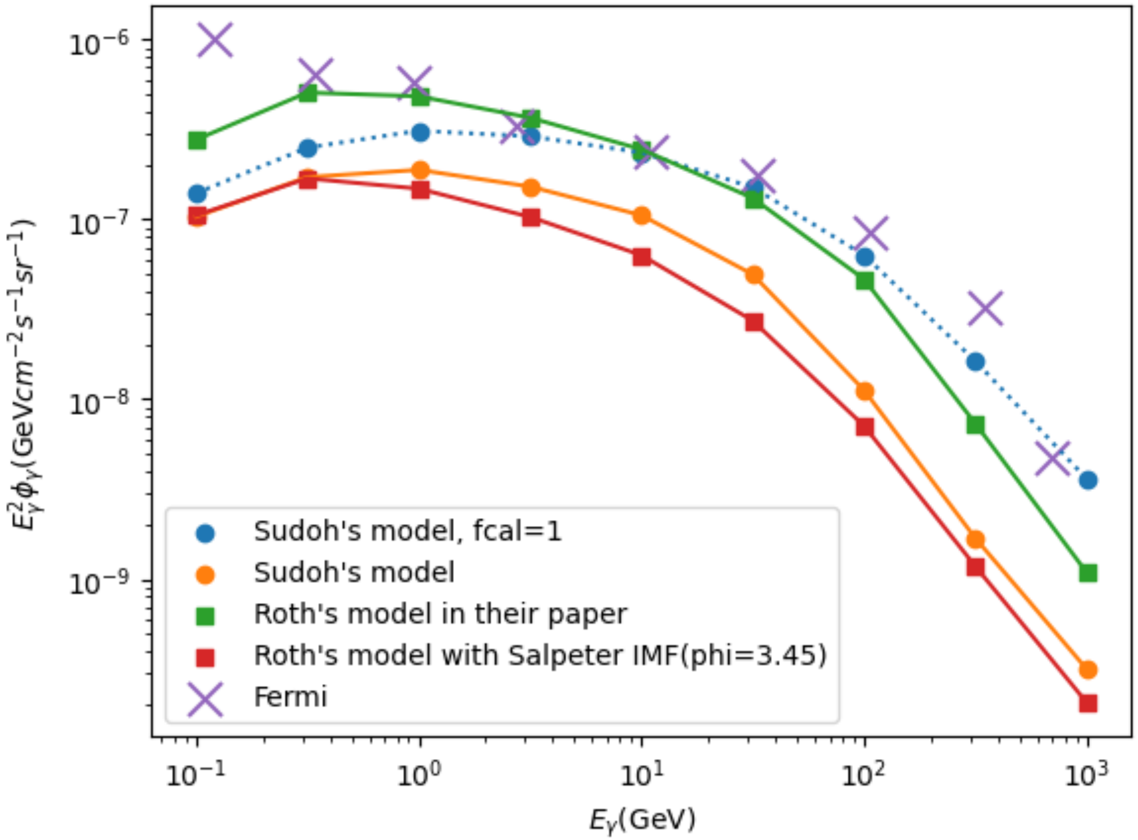
ELS, instead of

Roth et al. (2021), implies SFGs can explain the IGRB alone

What is the origin of the difference?

- In Roth+, the model flux is normalized by the factor "ϕ", converting SFR into cosmic-ray production rate
  - $\phi = 7.15\times10^{42} GeV^{-1} s^{-1} (M_\odot/yr)^{-1}$ in their paper
  - depends on IMF
    - their gamma-ray emission model uses Chabrier IMF
    - but their final background flux is re-calibrated by cosmic SFR evolution of Madau & Dickinson '14, which assumes Salpeter IMF
- We cannot reproduce the Roth+ ϕ value. By our own estimate,
  - $\phi = 5.40\times10^{42}$ assuming Chabrier IMF
  - $\phi = 3.45\times10^{42}$ assuming Salpeter IMF
- But we could reproduce the Roth+ background flux if we assume:
  - $\phi = 7.15\times10^{42}$ (the value in Roth+ paper)
  - cosmic SFR evolution assuming Salpeter
  - In the case of $f_{cal} = 1$ (calorimetric limit, ignoring cosmic-ray escape, so the background flux is determined only by phi and cosmic SFR history)
- However, the correct value of phi should be 3.45×10^{42}, according to our calculation
  - So the background flux should be reduced by 3.45/7.15 = 0.48, roughly.

Comparison



Using the correct normalization factor (that we believe), Roth+ model flux is reduced, which becomes similar with our own background model flux using the Sudoh+ emission model.

Conclusion

- The normalization factor used in the Roth+ model is somehow higher than our own estimate by a factor of 2.07
- With our own estimate of the normalization factor, the Roth+ model gives a similar background flux with other previous studies including our own.
- The difference between Sudoh+ and Roth+ gamma-ray emission models does not significantly change the background flux.
- It is unlikely that the background flux is explained 100% only by star-forming galaxies.
- Spectrum of the remaining components will be examined in future work

Thank you for listening!