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Diffuse Neutrino Flux from Star-Forming Galaxies

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Outline

- ★ High-energy IceCube neutrino flux
- ★ Gamma-ray and neutrino backgrounds from star-forming galaxies
- ★ Implications for the starburst history
- ★ Conclusions

This talk is mainly based on work in collaboration with S. Ando and K. Murase
[arXiv: 1404.1189].

IceCube high-energy excess

★ IceCube observed 37 events over three years
(~ 10 events expected from conventional atmospheric contributions).

★ Mostly showers. 3 events with energy above 1 PeV, 12 above 100 TeV.

★ Zenith Distribution compatible with isotropic flux.

★ Energy spectrum harder than any expected atmospheric background.
E^(-2) spectrum with potential cutoff around 2-5 PeV.

★ Flavor distribution consistent with $\nu_e : \nu_\mu : \nu_\tau = 1 : 1 : 1.$

$5.7\ \sigma$ evidence for astrophysical flux

[Talk by E. Resconi]

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[*] IceCube Collaboration, Science 342 (2013) 6161, arXiv: 1405.5303.

Where are these neutrinos coming from?

Where are these neutrinos coming from?

★ Galactic origin [Talks by M. Ahlers, V. Niro].

★ **Extragalactic origin**:
- Gamma-ray bursts, blazars
- Active galactic nuclei
- Newborn pulsars
- **Star-forming galaxies**

[See also talk by M. Bustamante, J. Tjus].

★ New physics processes (i.e., superheavy dark matter, exotic neutrino models, Planck scale phenomena).

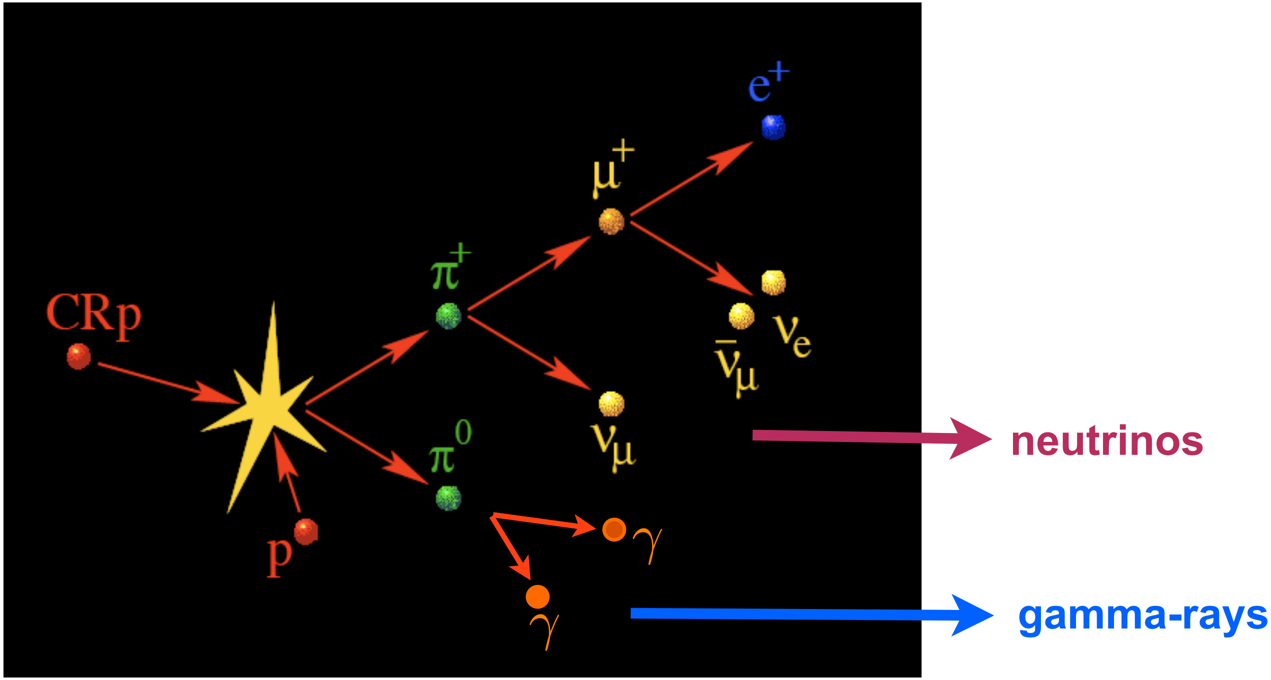
Warning: More statistics needed! No strong preference so far.

* L. A. Anchordoqui et al., JHEAp 1-2 (2014) 1.

Diffuse flux from star-forming galaxies

p-p interactions in star-forming galaxies

Star-forming galaxies produce neutrinos by cosmic rays colliding with the dense interstellar medium. These p-p collisions also produce high-energy gamma rays.

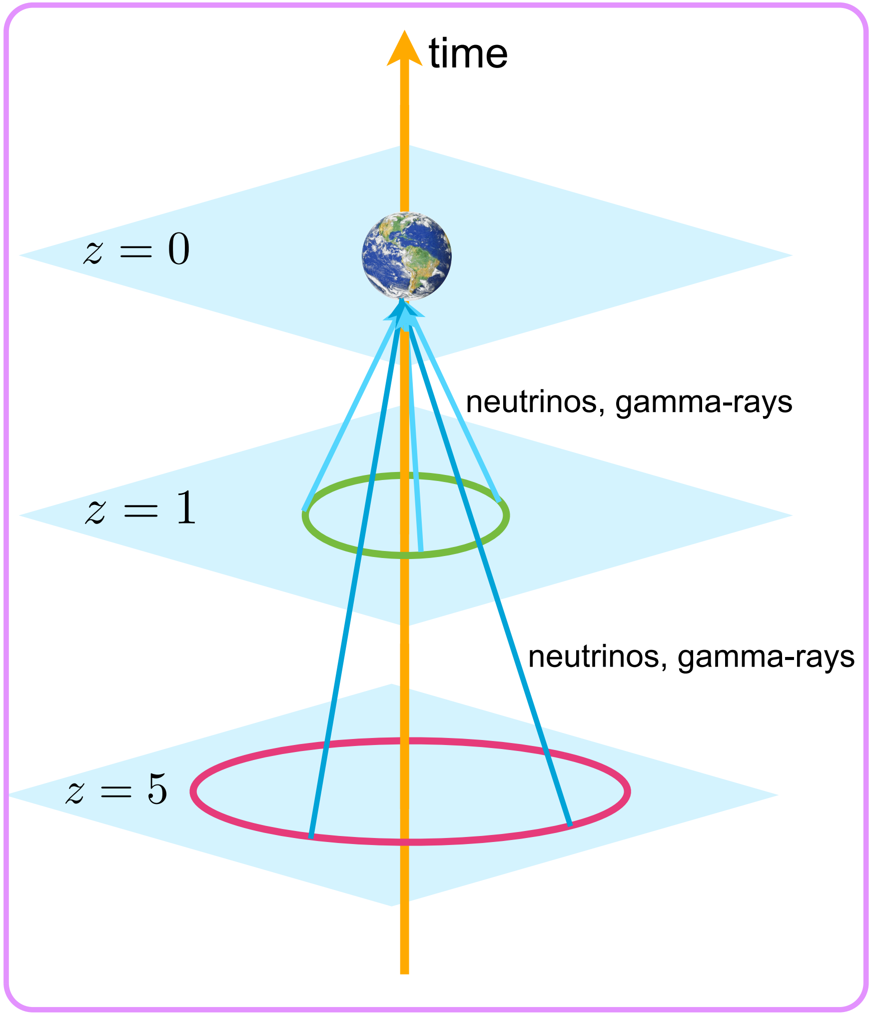


Gamma-ray and neutrino intensities are related by a simple relation.

$$\boxed{\sum_\alpha I_{\nu_\alpha}(E_\nu) \simeq 6\ I_\gamma(E_\gamma)}$$

with $E_\gamma \simeq 2E_\nu$

Diffuse background ingredients



- Gamma-ray and neutrino energy fluxes
- Distribution of star-forming galaxies with redshift
- Comoving volume (cosmology)

Gamma-ray background from star-forming galaxies

$$I(E_\gamma) = \int_0^{z_{\max}} dz \int_{L_{\gamma,\min}}^{L_{\gamma,\max}} dL_\gamma \underbrace{\boxed{\frac{d^2V}{d\Omega dz}}}_{\text{comoving volume}} \sum_X \underbrace{\boxed{\Phi_X(L_\gamma, z)}}_{\text{luminosity function}} \underbrace{\boxed{\frac{dN_X(L_\gamma,(1+z)E_\gamma)}{dE_\gamma}}}_{\text{gamma-ray flux}} \underbrace{\boxed{e^{-\tau(E_\gamma,z)}}}_{\text{EBL correction}}$$

comoving volume

luminosity function

$$\Phi_X(L_\gamma, z) = d^2N_X/dV\,dL_\gamma$$

gamma-ray flux

EBL correction

Herschel PEP/HerMES survey provides IR luminosity function for each population X of star-forming galaxies (up to z > 4).

$$\boxed{\log\left(\frac{L_\gamma}{\text{erg s}^{-1}}\right) = \alpha \log\left(\frac{L_{\text{IR}}}{10^{10} L_\odot}\right) + \beta}$$

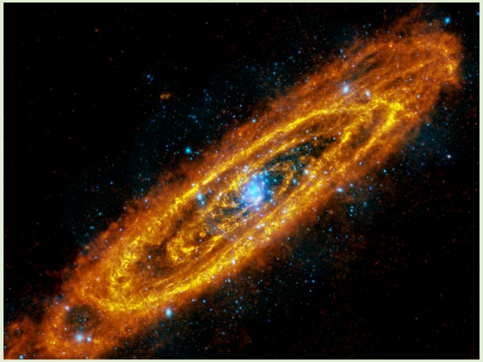
Gamma-ray-IR linear relation from Fermi data.

* C. Gruppioni et al., MNRAS 432 (2013) 23. M. Ackermann et al., Astrophys. J. 755 (2012) 164.

Gamma-ray diffuse background from star-forming galaxies

Herschel provides IR luminosity function for each population X of star-forming galaxies.

Normal galaxies
(i.e., Milky Way, Andromeda)



Injection spectral index in our canonical model (E> 600 MeV):

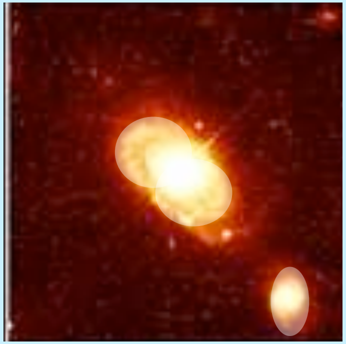
$$\Gamma_{\mathrm{NG}} = 2.7$$

Starburst galaxies
(i.e., M82, NGC 253)

Injection spectral index in our canonical model (E > 600 MeV):

$$\Gamma_{\mathrm{SB}} = 2.2$$

SF-AGN
(galaxies with
dim/low-luminosity AGN)

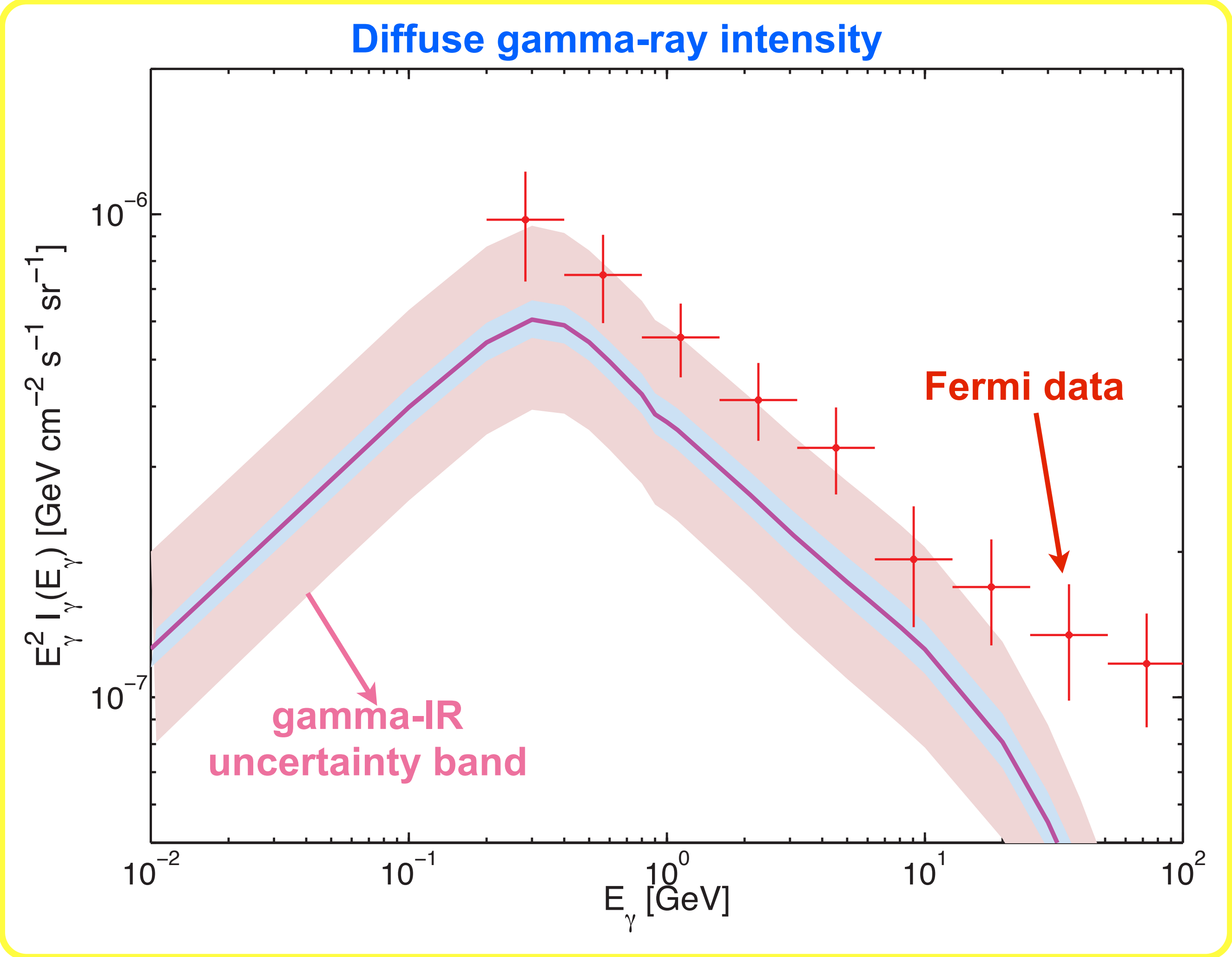


Injection spectral index in our canonical model (E > 600 MeV):

$$\Gamma_{\mathrm{SF-AGN}} = 2.7 \text{ for } z \leq 1.5$$
$$\Gamma_{\mathrm{SF-AGN}} = 2.2 \text{ for } z > 1.5$$

* C. Gruppioni et al., MNRAS 432 (2013) 23. Credits for images: ESA, Hubble, NASA web-sites.

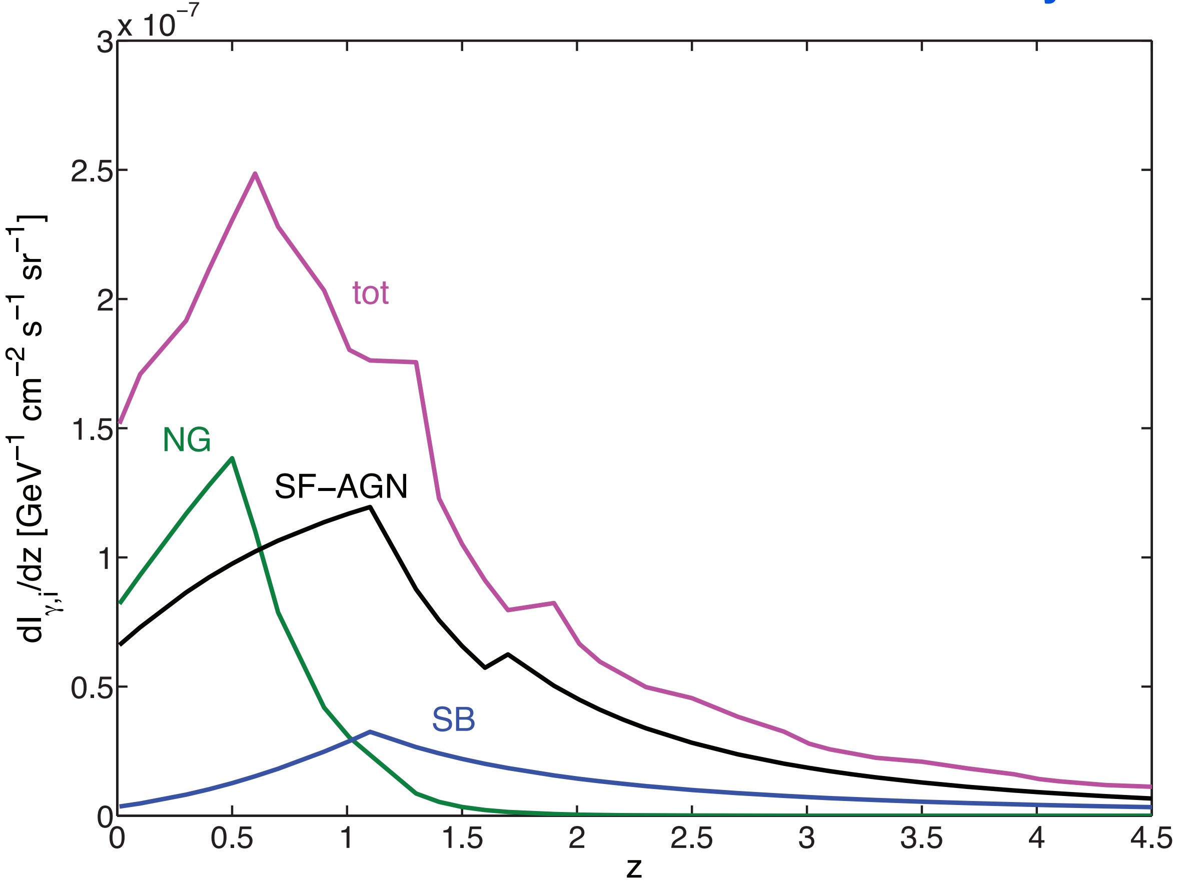
Gamma-ray diffuse background from star-forming galaxies



* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189.

Gamma-ray diffuse background from star-forming galaxies

Differential contributions to the EGRB intensity

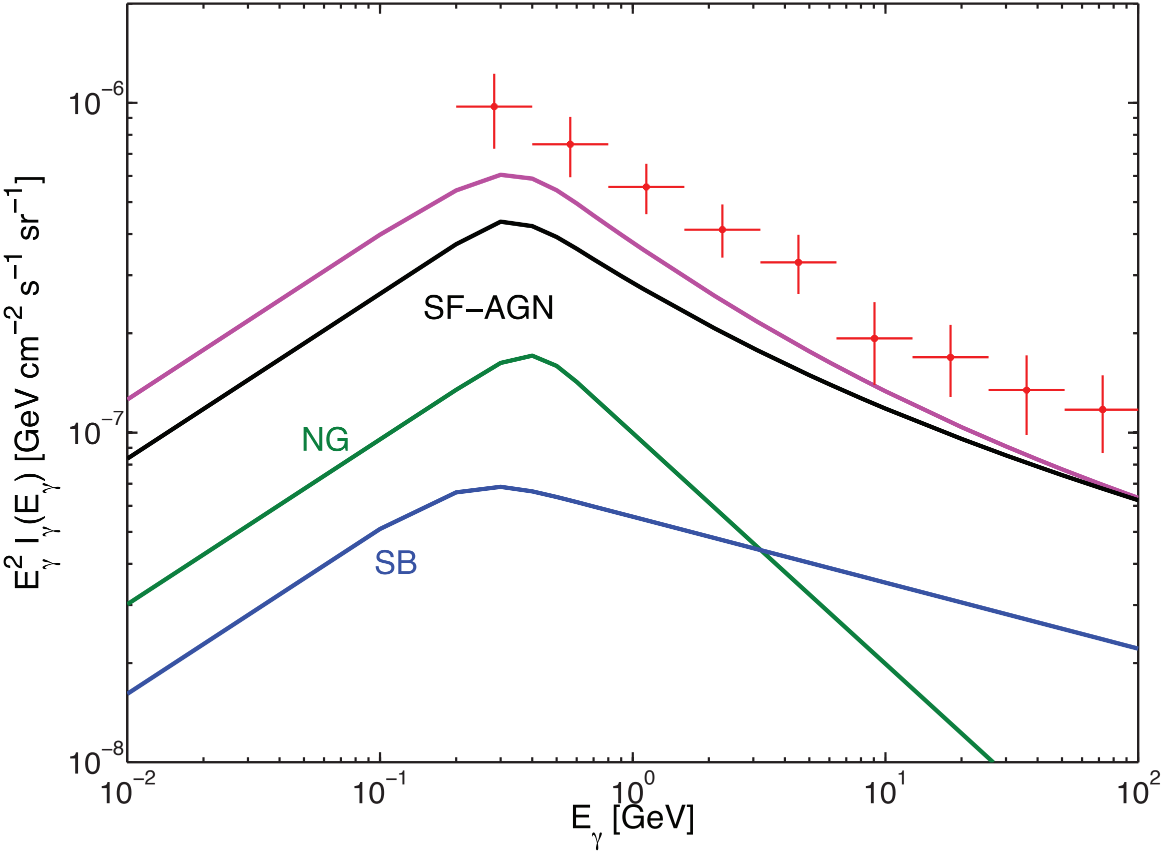


Normal galaxies leading contribution up to z=0.5. SF-AGN and SB dominate at higher z.

* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189.

Gamma-ray diffuse background from star-forming galaxies

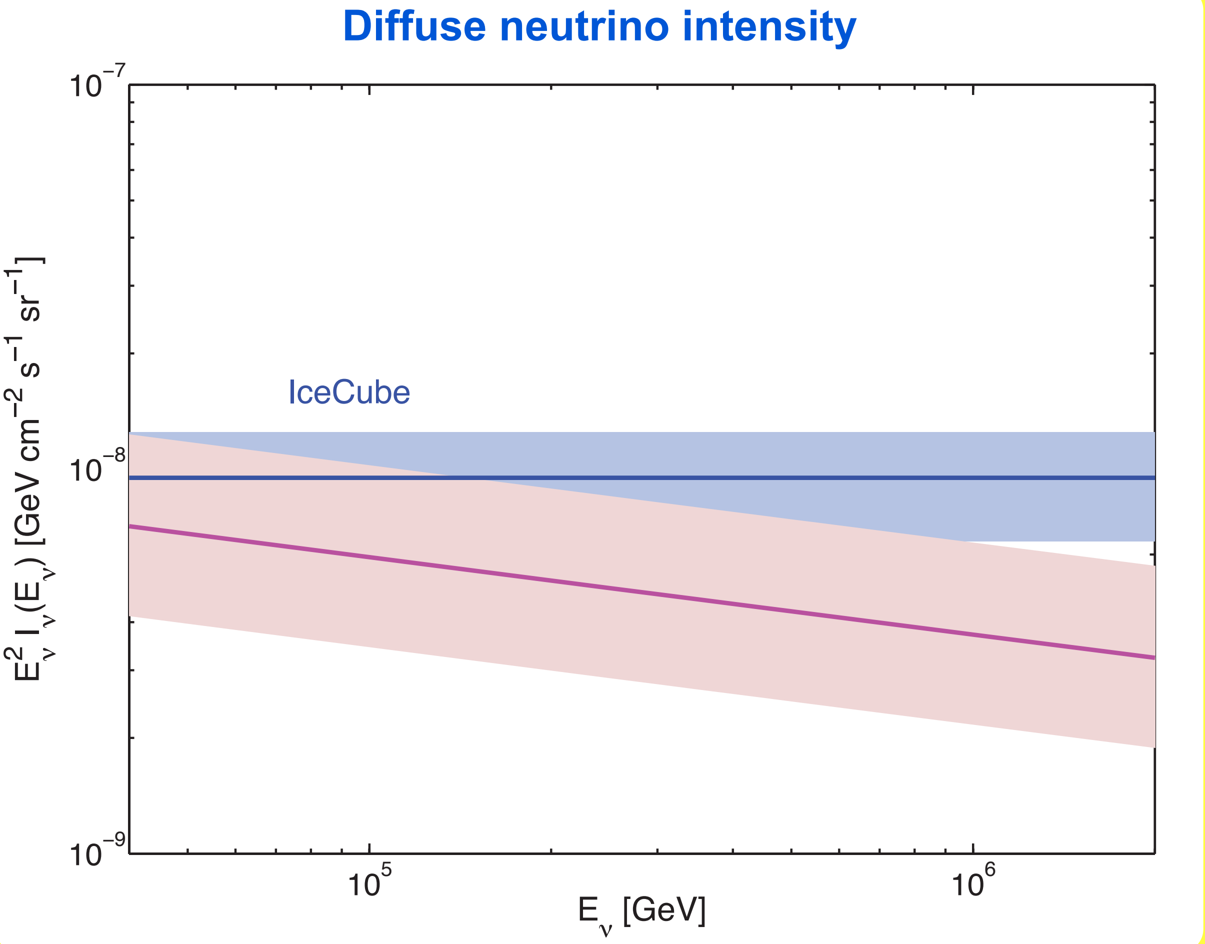
Diffuse gamma-ray intensity for all EGRB components



SF-AGN give the larger contribution to the total EGRB intensity.

* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189.

Neutrino diffuse background from star-forming galaxies



Neutrino intensity with its astrophysical uncertainty band within IceCube band for E<0.5 PeV.

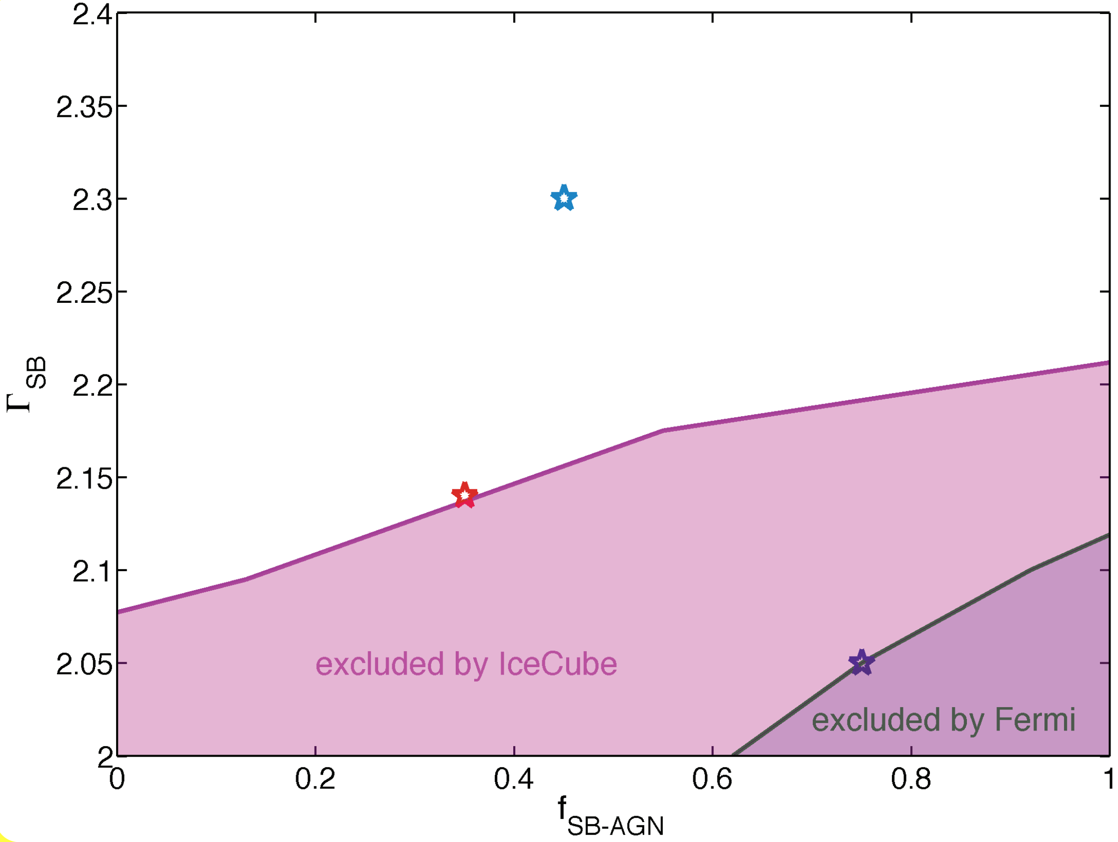
* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189. See also A. Loeb, E. Waxman, JCAP 0605 (2006) 003.

Constraints from Fermi and IceCube data

Fermi and IceCube data can constrain starburst abundance and their injection spectral index.

$$I_\gamma(E_\gamma) = I_{\gamma,\mathrm{NG}}(E_\gamma) + I_{\gamma,\mathrm{SB}}(E_\gamma,\Gamma_{\mathrm{SB}}) + [f_{\mathrm{SB-AGN}}\ I_{\gamma,\mathrm{SB}}(E_\gamma,\Gamma_{\mathrm{SB}}) + (1 - f_{\mathrm{SB-AGN}})\ I_{\gamma,\mathrm{NG}}(E_\gamma)]$$

SB spectral index and SB-AGN fraction compatible with Fermi and IceCube data



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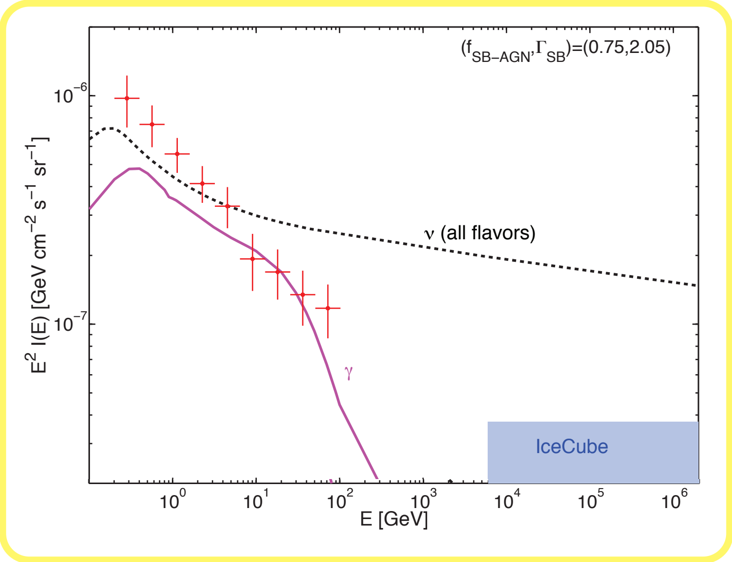
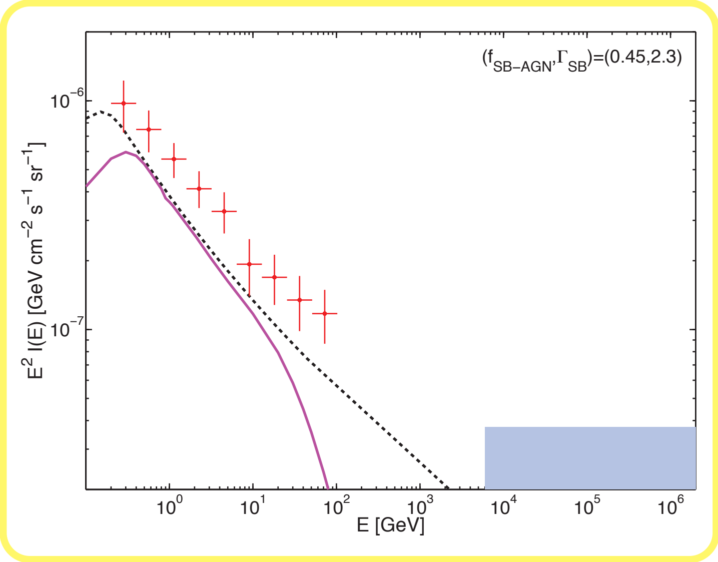
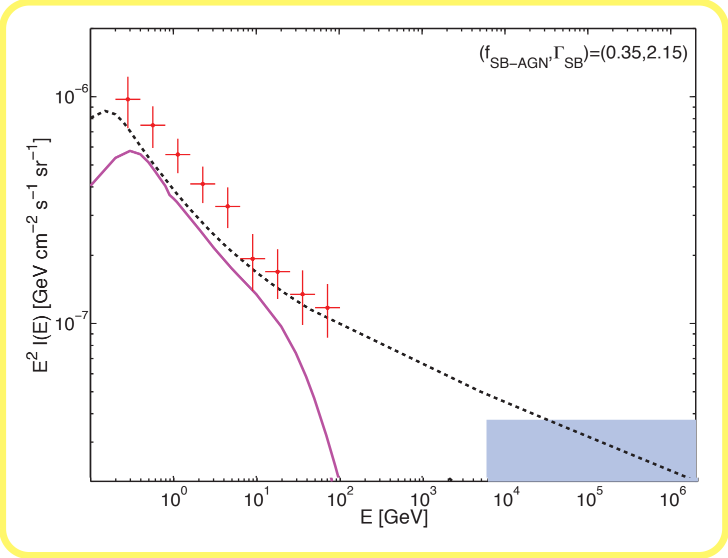
* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189.

Constraints from Fermi and IceCube data







The SB spectral index matching **simultaneously** Fermi and IceCube data is $\Gamma_{SB} \simeq 2.15$.

* I. Tamborra, S. Ando, K. Murase, arXiv: 1404.1189.
See also A. Loeb, E. Waxman, JCAP 0605 (2006) 003, K. Murase, M. Ahlers, B. Lacki, PRD 88 (2013) 12, 121301.

Conclusions

★ Origin of IceCube high-energy neutrinos unknown.

★ Diffuse neutrino flux from star-forming galaxies is one natural possibility.

★ Multi-messenger approach: Starburst spectral index matching **simultaneously** Fermi and IceCube data close to $\Gamma_{\mathrm{S}B} \simeq 2.15$.

Thank you

for your attention!