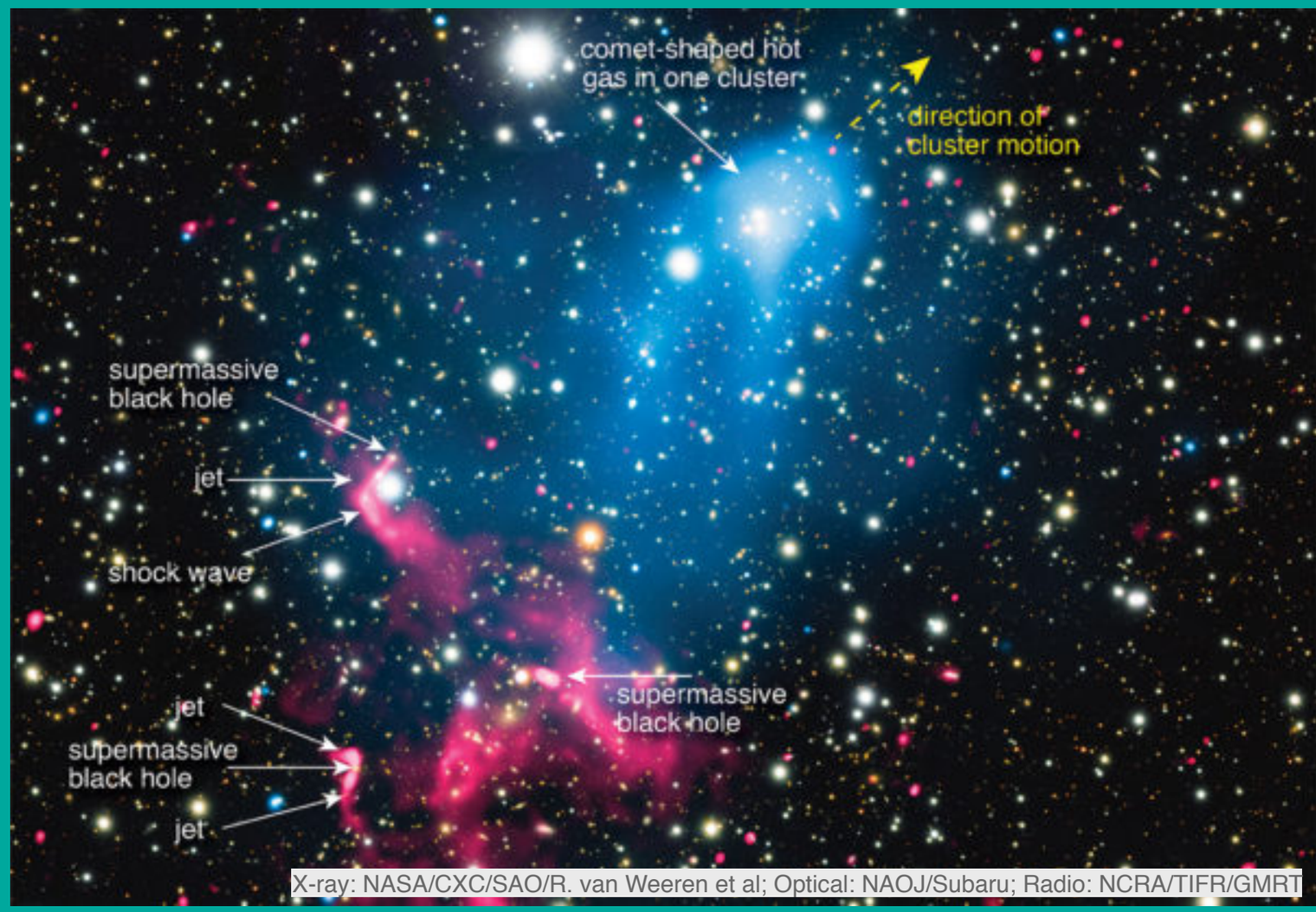
A Time-independent Search for Neutrinos from Galaxy Clusters with IceCube

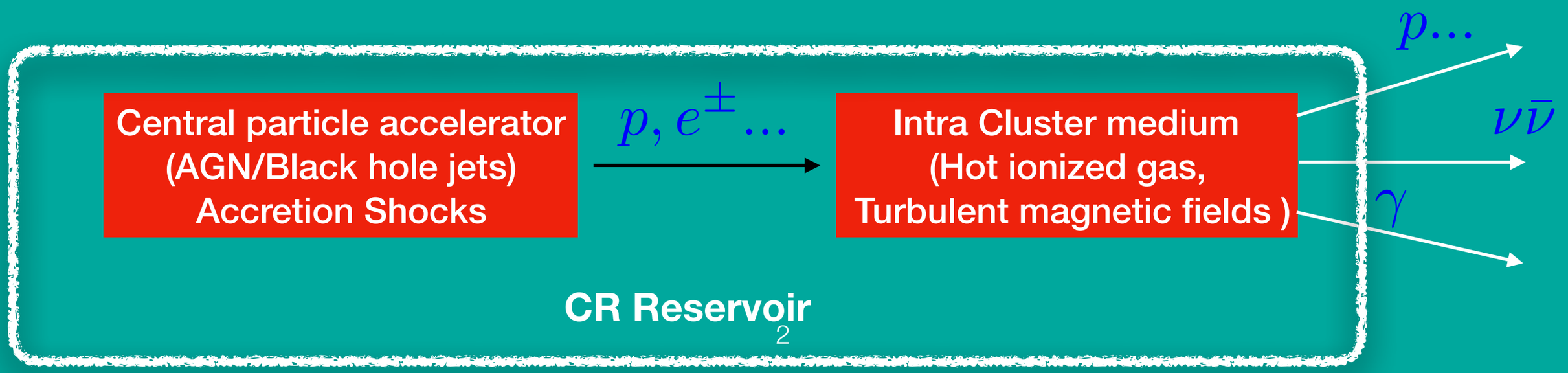
Mehr Un Nisa, Andrew Ludwig (MSU)
Srini Raghunathan (UCLA)

ICRC 2021

Overview

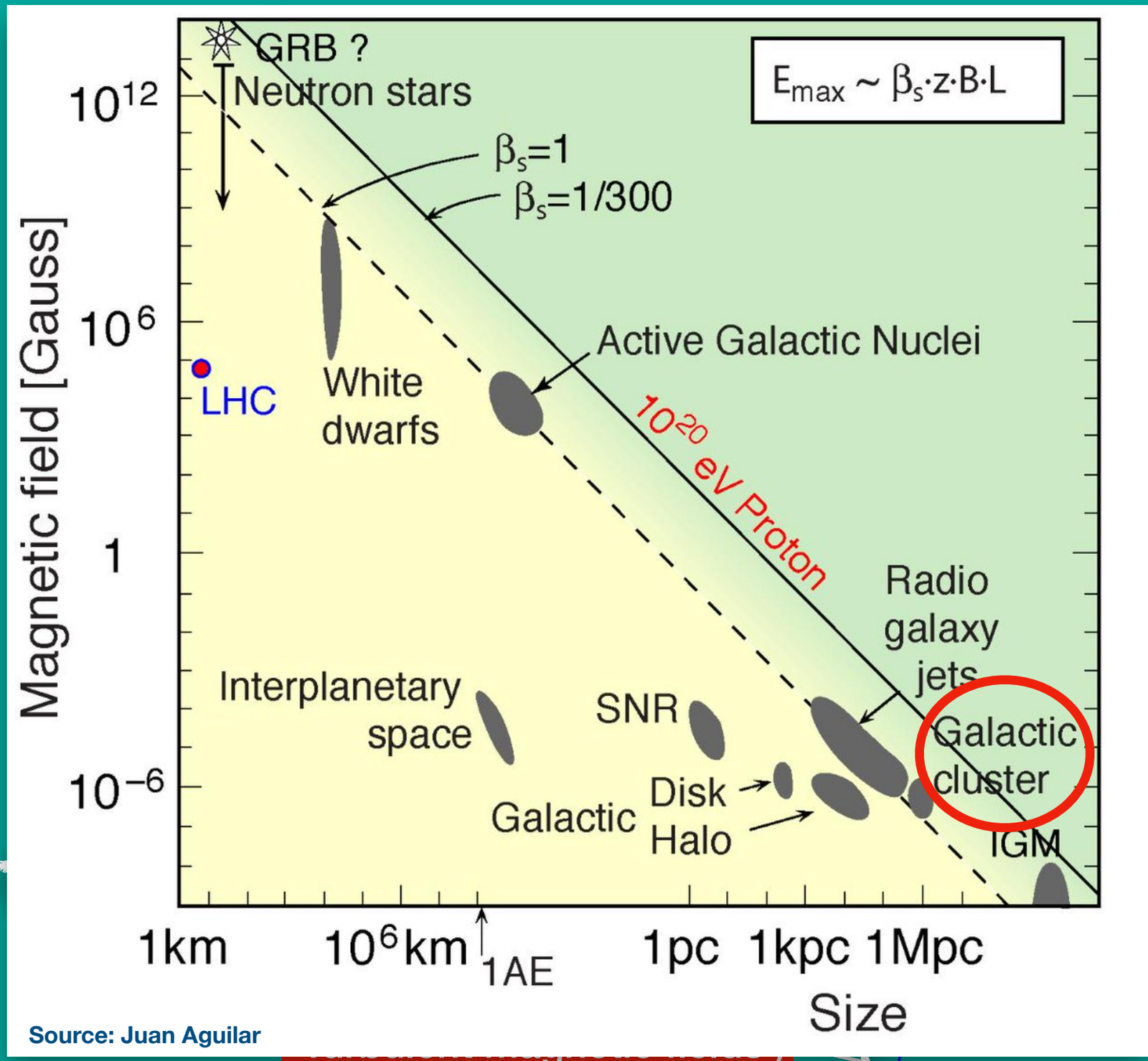
- **CR acceleration and confinement in GC.**
- **Neutrino production via charged pion decay.**
- **We're testing the contribution to the diffuse neutrino flux by stacking a catalog of galaxy clusters.**





Overview

- **CR acceleration and confinement in GC.**
- **Neutrino production via charged pion decay.**
- **We're testing the contribution to the diffuse neutrino flux by stacking a catalog of galaxy clusters.**

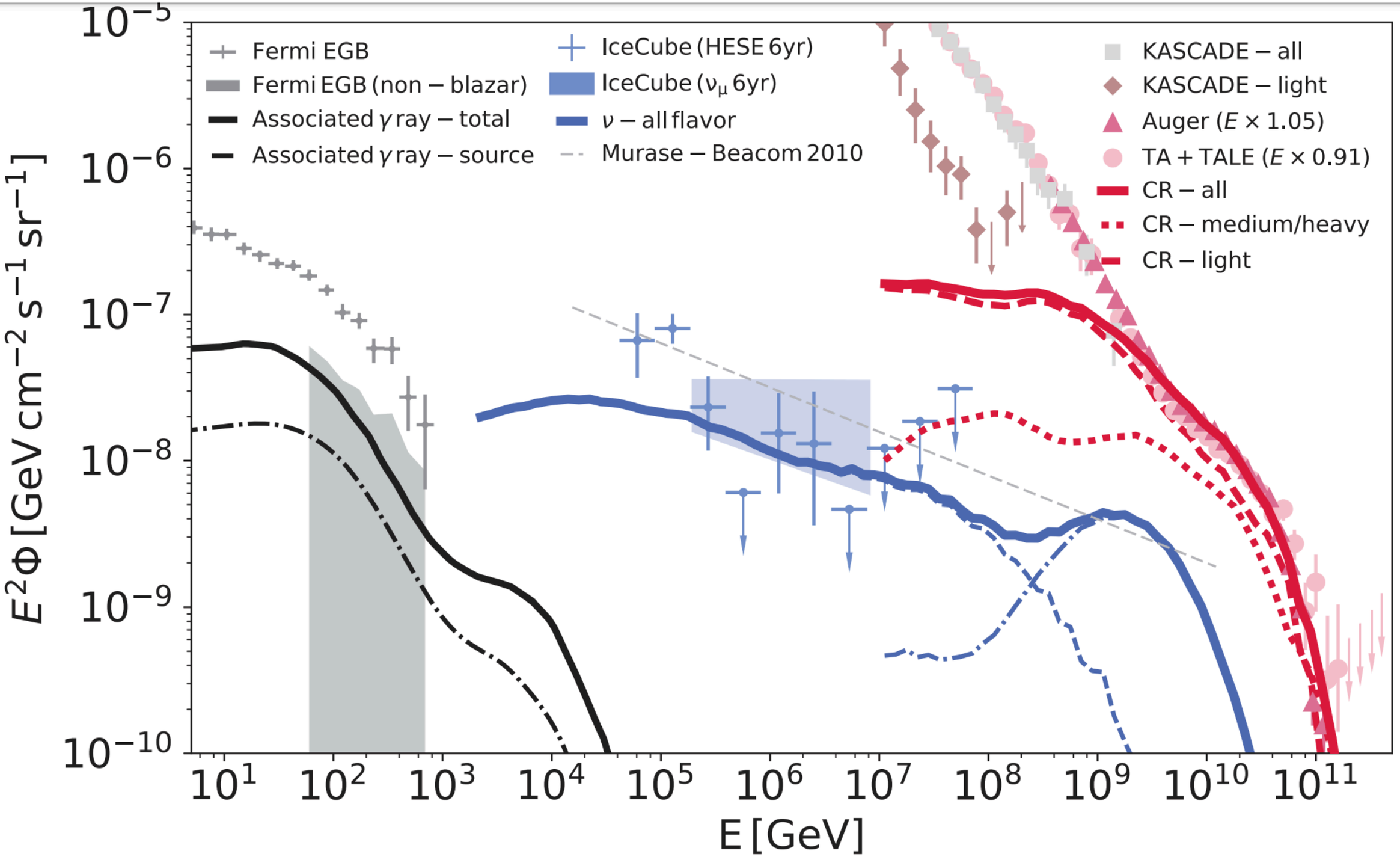


Source: Juan Aguilar

Central particle accelerator (AGN/Black hole jets) Accretion Shocks

CR Reservoir

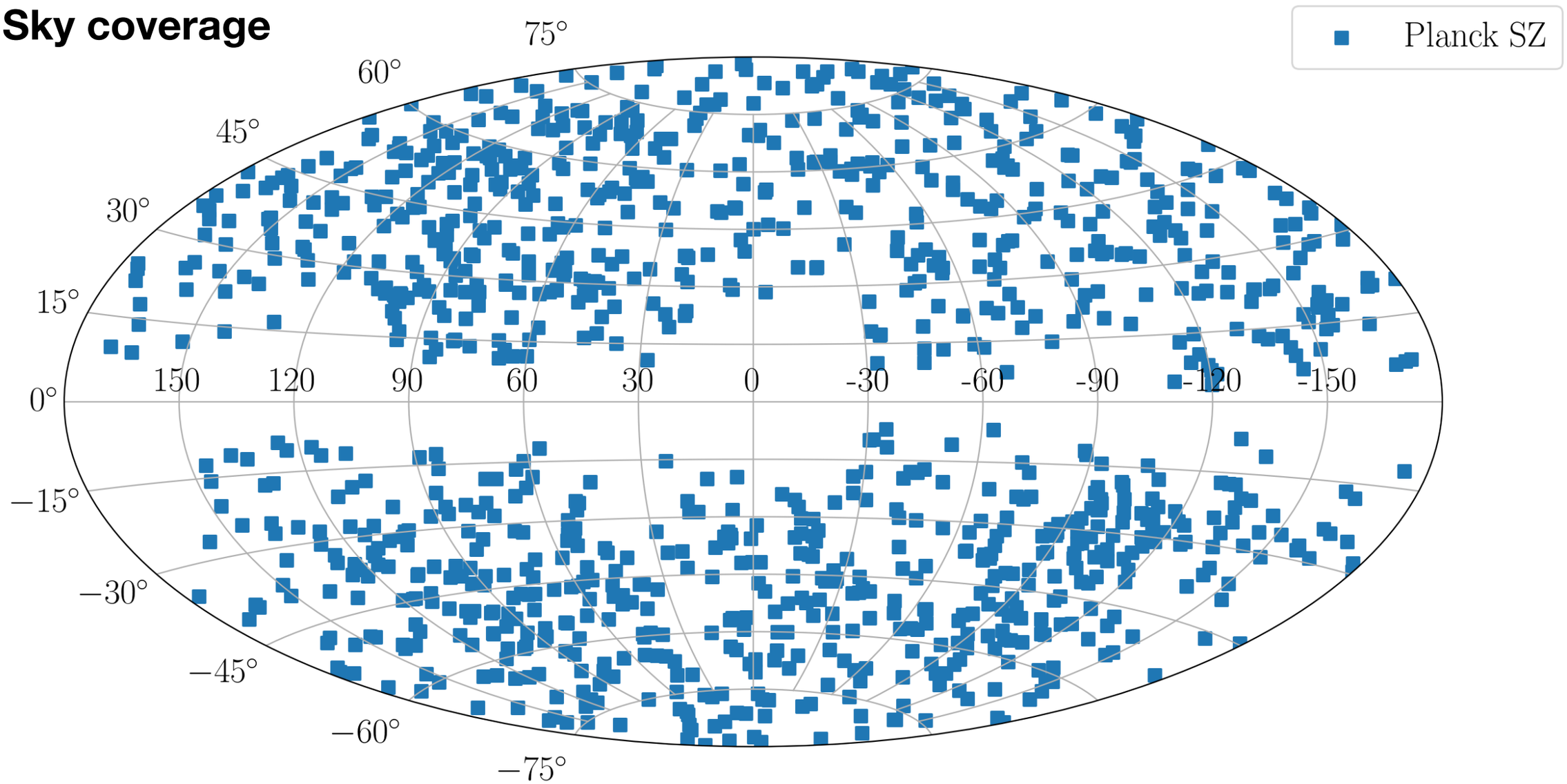
Neutrinos from Galaxy clusters



Fang & Murase *Nature Phys. 14 (2018) 396*

The Planck SZ Catalog of Galaxy Clusters

- **The ICM can be robustly detected either in X rays or, by CMB telescopes via the Sunyaev–Zel'dovich (SZ) effect**
- **We use the 2015 Planck survey (PSZ2): 1094 clusters up to a redshift of 0.97**
- **83% Sky coverage**



Stacking Analysis

$$\log \mathcal{L} = \sum_{i=1}^{N} \log \left(\frac{n_s}{N} \cdot S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) + \left(1 - \frac{n_s}{N}\right) B(\delta_i, E_i) \right)$$

Stacking *M* sources with weights

$$S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) = \sum_{k=1}^{M} w_k S_k(\delta_i, \alpha_i, \sigma_i, E_i; \gamma)$$

Weighting Schemes

1. $w_k = 1$
2. w_k **proportional to inverse distance-squared**
3. w_k **proportional to mass/distance-squared (Proxy for X-ray flux obtained from the MCXC catalog of X-ray clusters)**

Stacking Analysis

$$\log \mathcal{L} = \sum_{i=1}^{N} \log \left(\frac{n_s}{N} \cdot S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) + \left(1 - \frac{n_s}{N}\right) B(\delta_i, E_i) \right)$$

Signal events

Total events

Background PDF

Stacking *M* sources with weights

$$S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) = \sum_{k=1}^{M} w_k S_k(\delta_i, \alpha_i, \sigma_i, E_i; \gamma)$$

Signal PDF

Weighting Schemes

1. $w_k = 1$
2. w_k **proportional to inverse distance-squared**
3. w_k **proportional to mass/distance-squared (Proxy for X-ray flux obtained from the MCXC catalog of X-ray clusters)**

Stacking Analysis

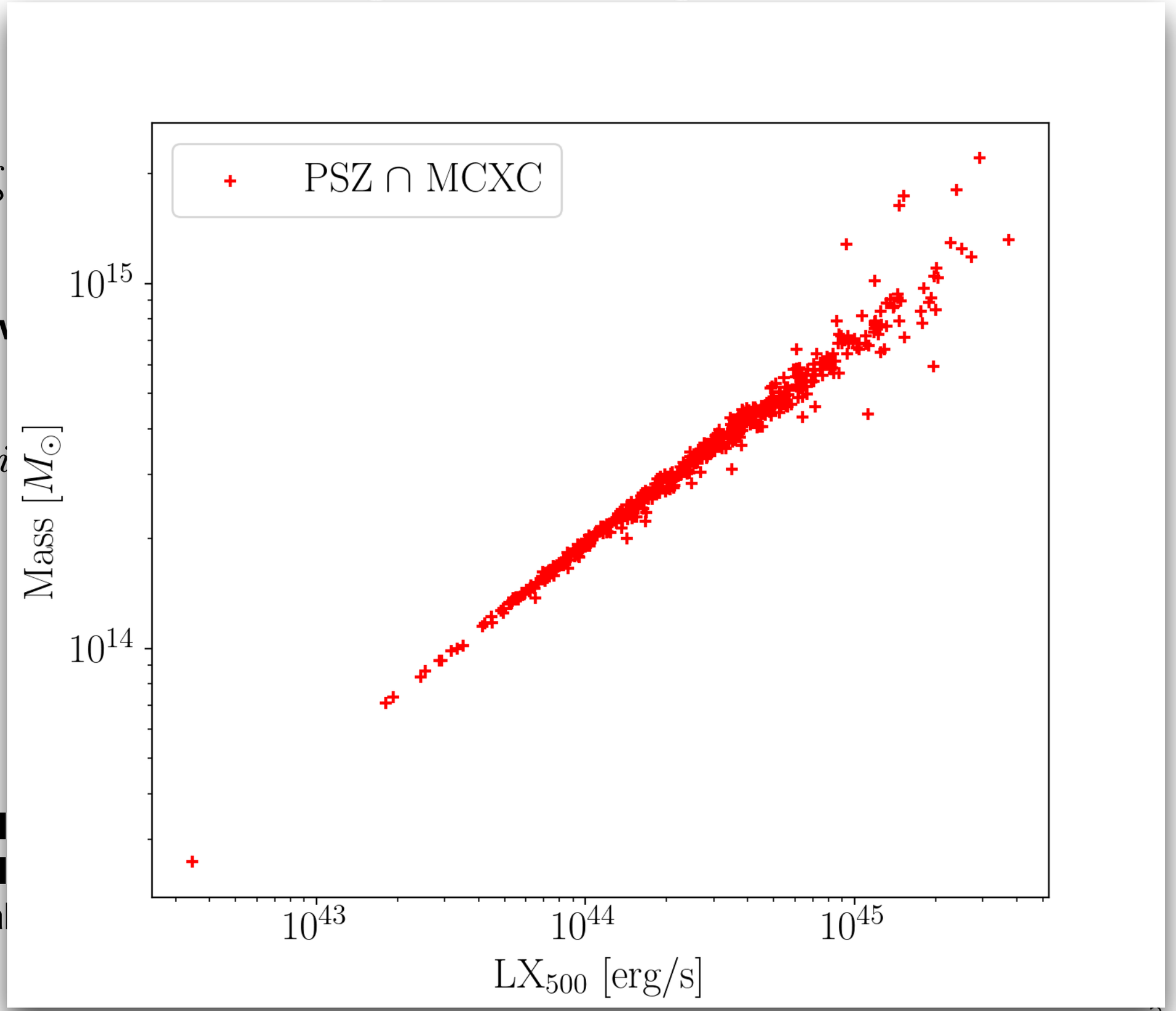
$$\log \mathcal{L} = \sum_{i=1}^{N} \log$$

Stacking *M* sources v

$$S(\delta_i, \alpha_i, \sigma_i, E_i$$

Weighting Schemes

1. $w_k = 1$
2. w_k proportional
3. w_k proportional
   the MCXC catal



Stacking Analysis

$$\log \mathcal{L} = \sum_{i=1}^{N} \log \left(\frac{n_s}{N} \cdot S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) + \left(1 - \frac{n_s}{N}\right) B(\delta_i, E_i) \right)$$

Signal events

Total events

Background PDF

Stacking *M* sources with weights

$$S(\delta_i, \alpha_i, \sigma_i, E_i; \gamma) = \sum_{k=1}^{M} w_k S_k(\delta_i, \alpha_i, \sigma_i, E_i; \gamma)$$

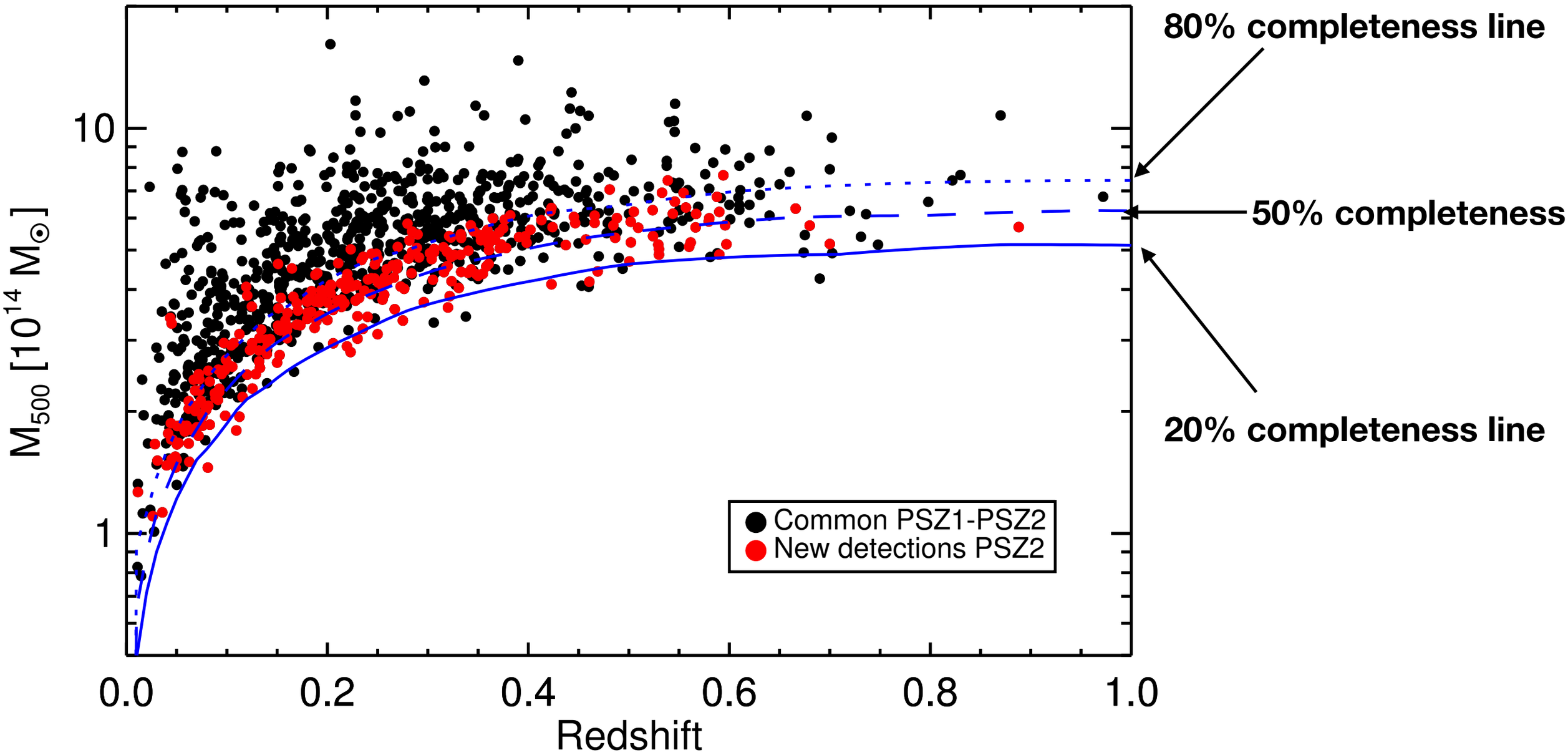
Signal PDF

Weighting Schemes

1. $w_k = 1$
2. w_k **proportional to inverse distance-squared**
3. w_k **proportional to mass/distance-squared (Proxy for X-ray flux obtained from the MCXC catalog of X-ray clusters)**

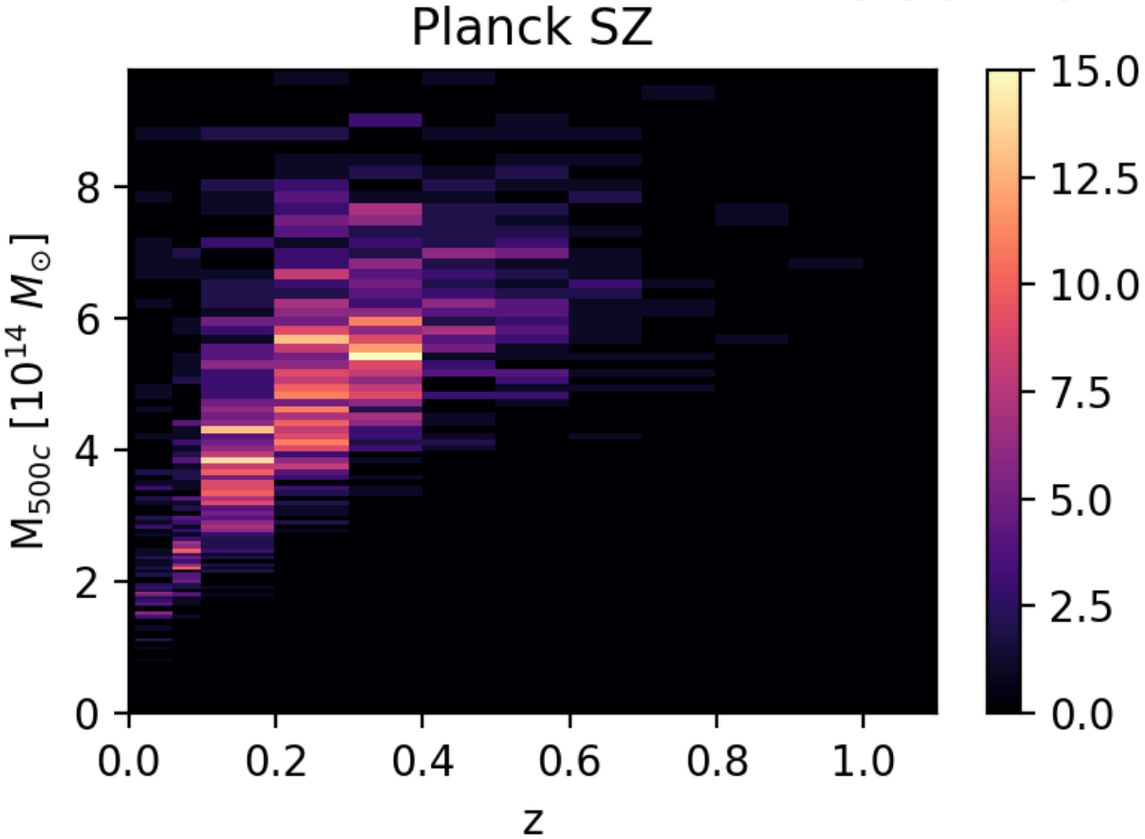
Estimating the Completeness of the Catalog

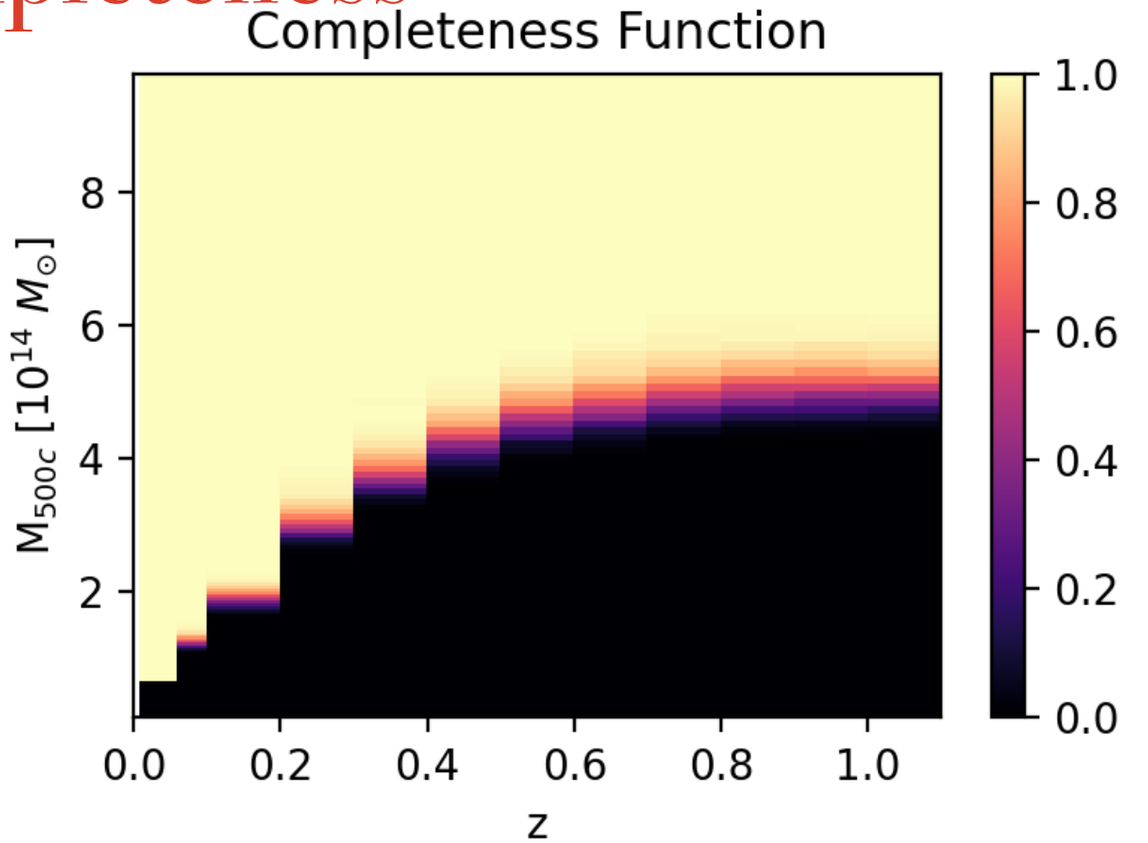
- Completeness is a function of cluster mass and redshift.
- Need to compare with the distribution of clusters in nature.
- Use the Tinker 2010 halo-mass function for the theoretical distribution of clusters.

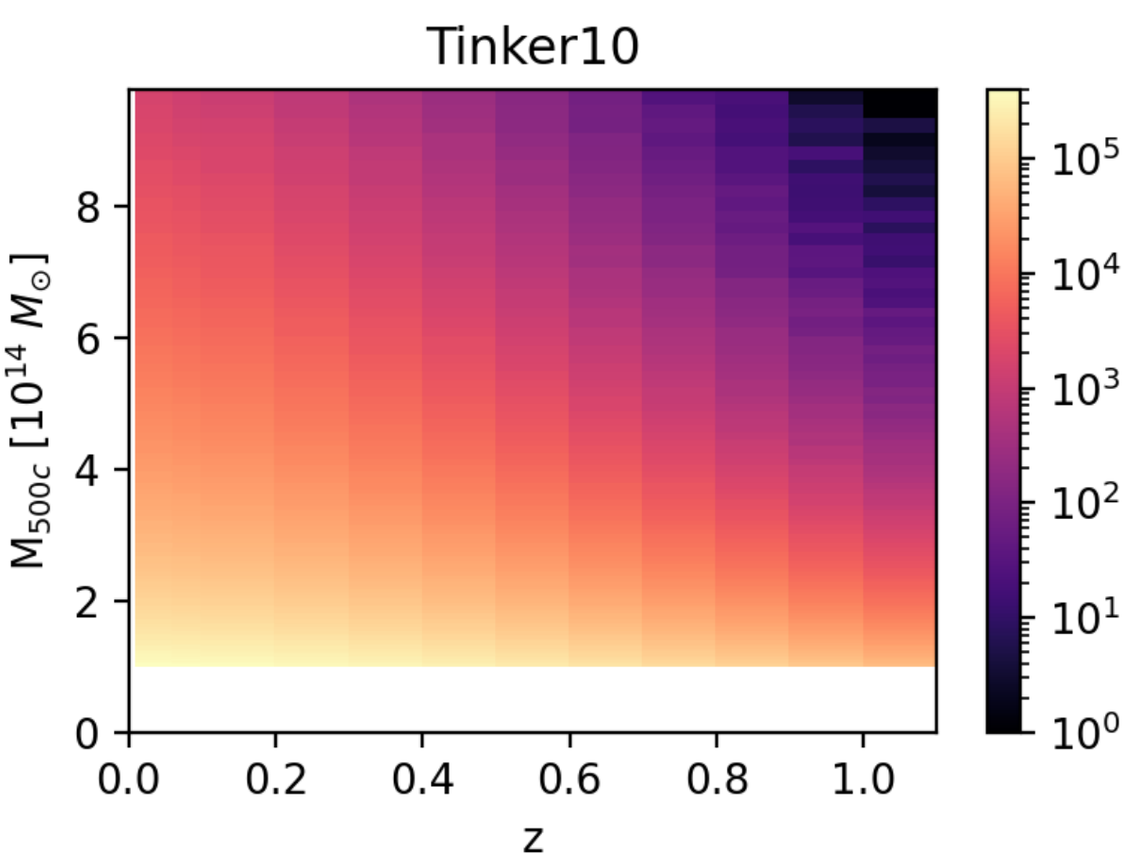


https://arxiv.org/pdf/1502.01598.pdf

Effective Completeness





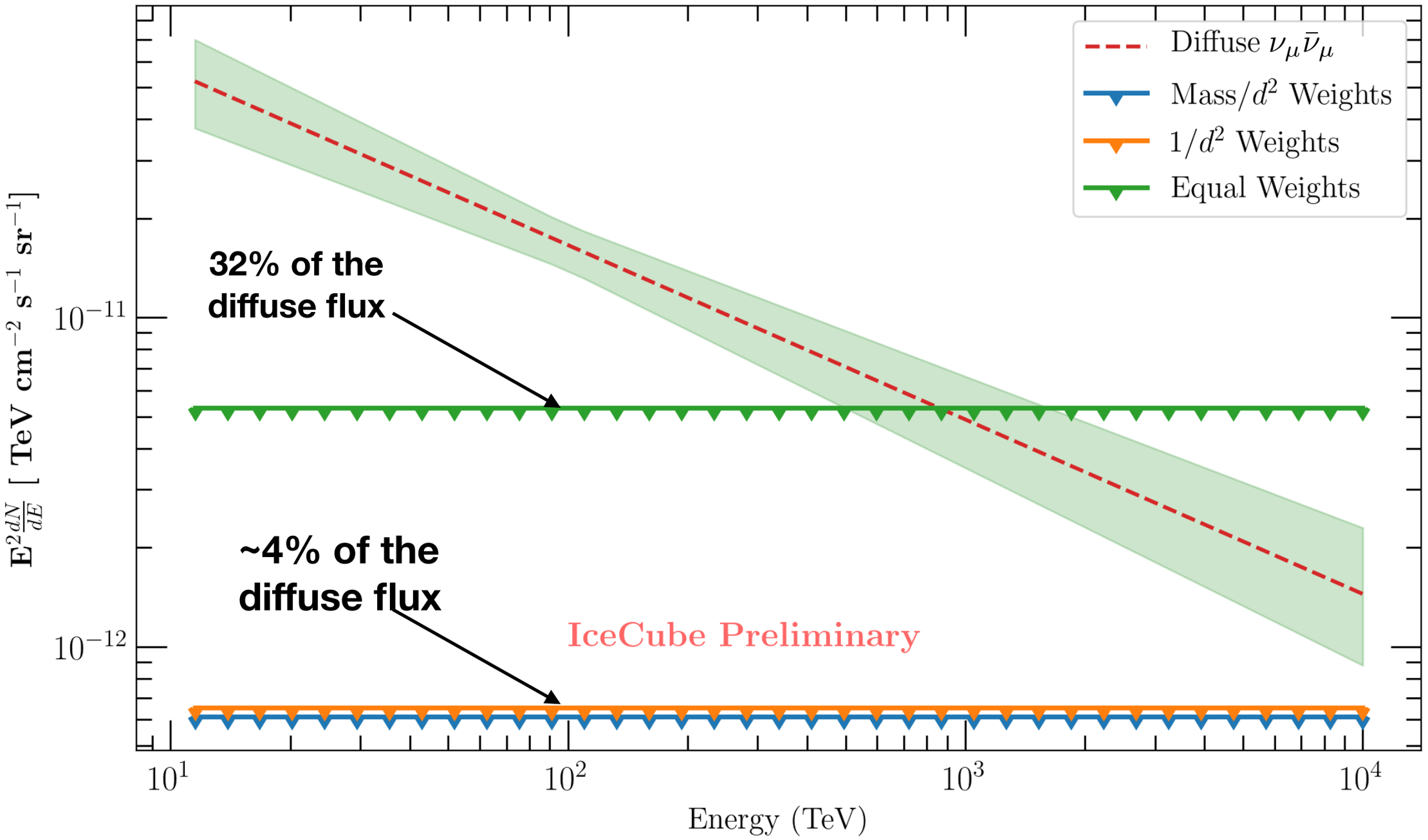


- Sampled O(10^6) clusters from the halo mass function in the M-z plane.
- Take product with the completeness function, and with the stacking weights in each M-z bin, sum over all M-z bins and divide by the total number of simulated clusters.
- Gives an overall completeness fraction of **17%** for equal weights.
- $1/d^2$ weights: **53%**
- M/d^2 weights: **66%**

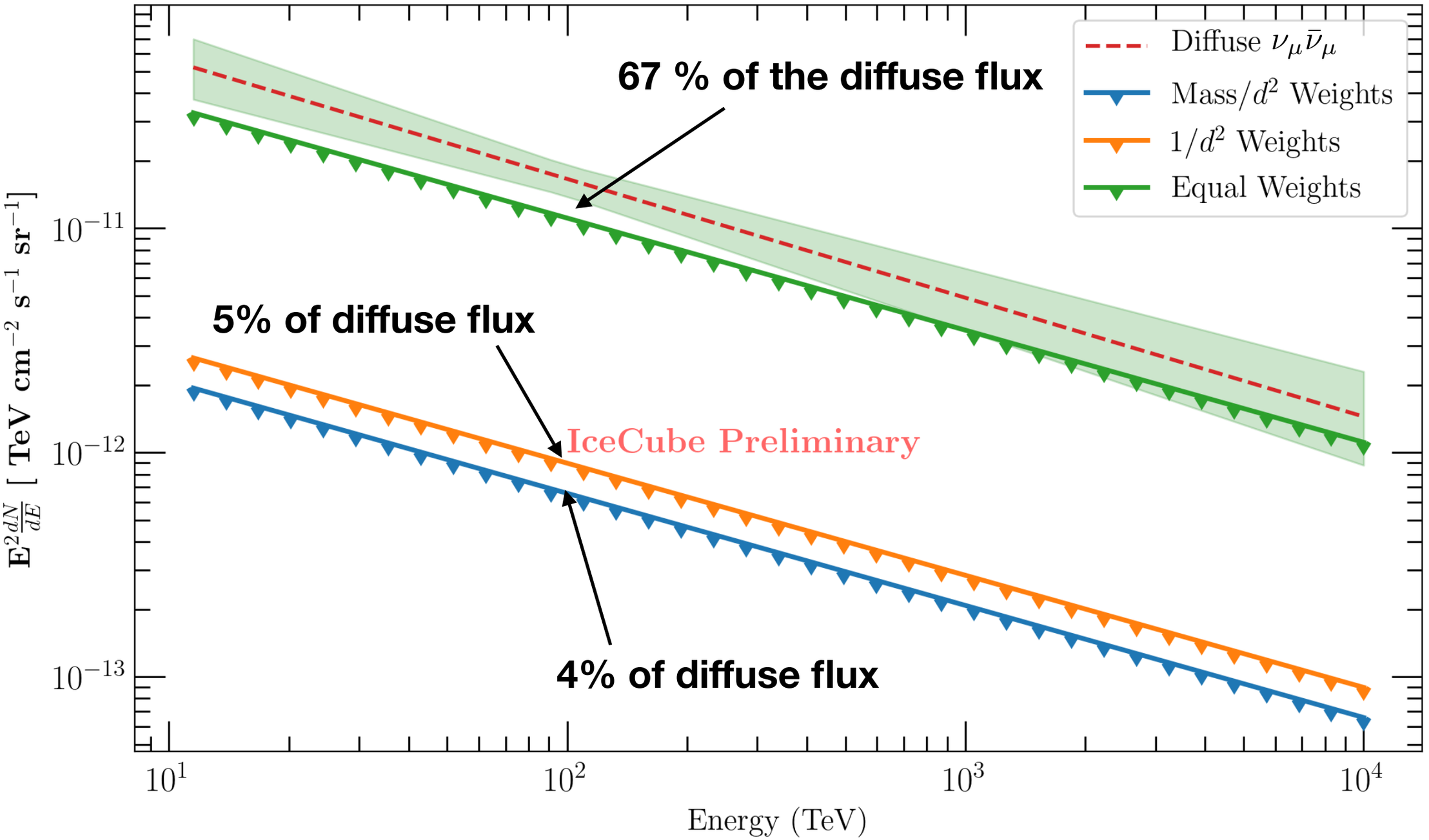
Stacking Fits Results

- Perform likelihood fits for three weighting schemes: Unweighted, inverse distance-squared weighting, and mass/distance-squared.
- No significant emission observed: ns = TS = 0 for all three weighting schemes
- Report 90% CL upper limits on the flux assuming spectral indices of 2.0, 2.5 and 3.0
- Report 90% CL upper limits on in one-decade differential energy bins assuming an index of 2.0.
- Scale by effective completeness of the catalog and report 90% CL contribution to the diffuse neutrino flux at 100 TeV assuming the three spectral indices mentioned above.

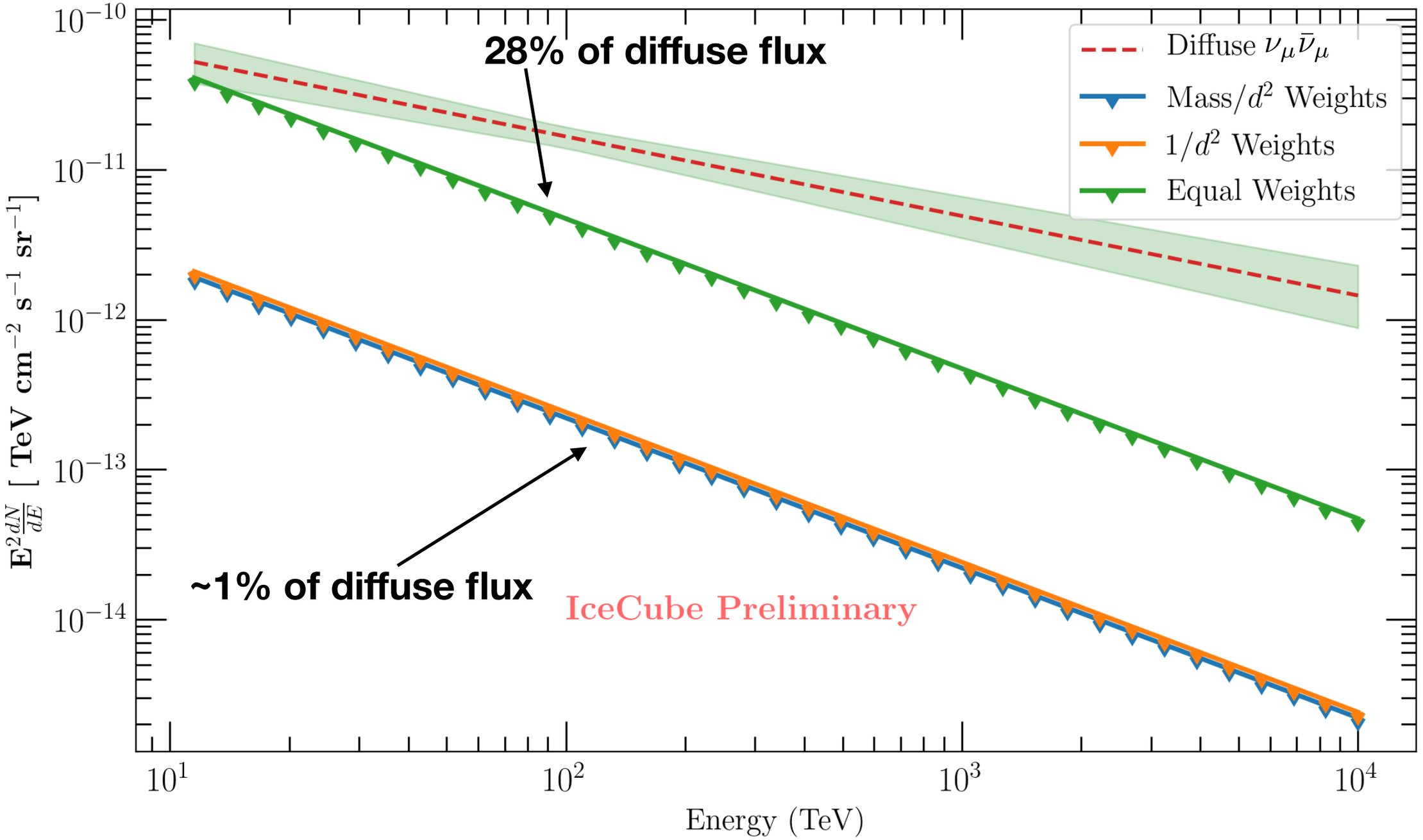
Integrated Results: $\gamma = 2.0$



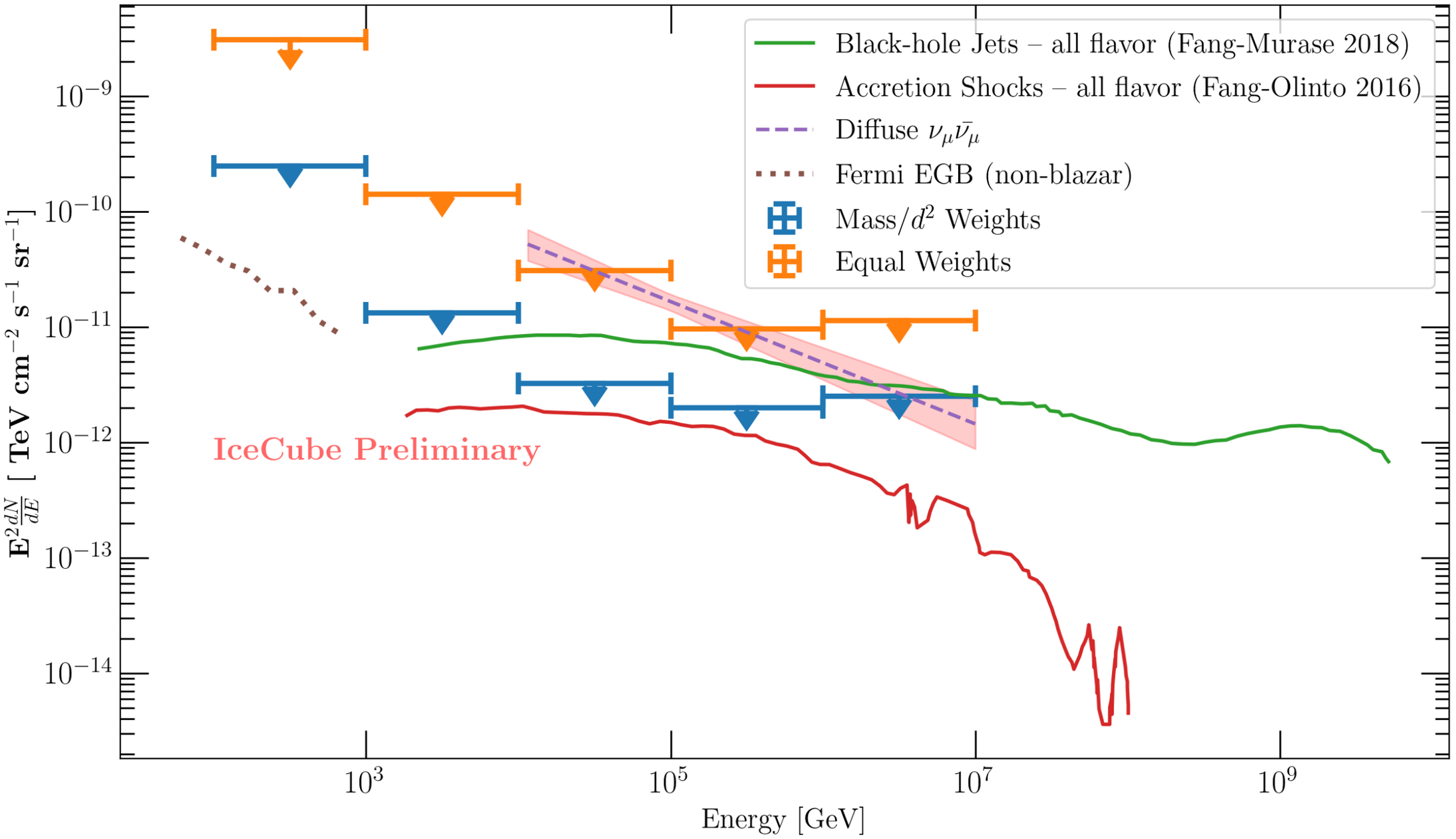
Integrated Results: $\gamma = 2.5$



Integrated Results: $\gamma = 3.0$



Differential Results



Summary

- **No significant emission observed from a stacked analysis of over 1000 galaxy clusters from the Planck survey.**

- **We can constrain the contribution of GC's with masses above 10^{14} solar masses ($0.01 < z < 2.0$) to the diffuse nu-mu flux down to ~4% for an index of 2.5 assuming the flux is proportional to cluster mass (proxy for X-ray luminosity).**

- **We can constrain the contribution of the aforementioned GC's to the diffuse nu-mu flux down to 67% in the most conservative (equal weights) scenario.**

- **In the distance weighted scenario, we can also exclude the Fang-Murase model above 10 TeV.**

Thanks!