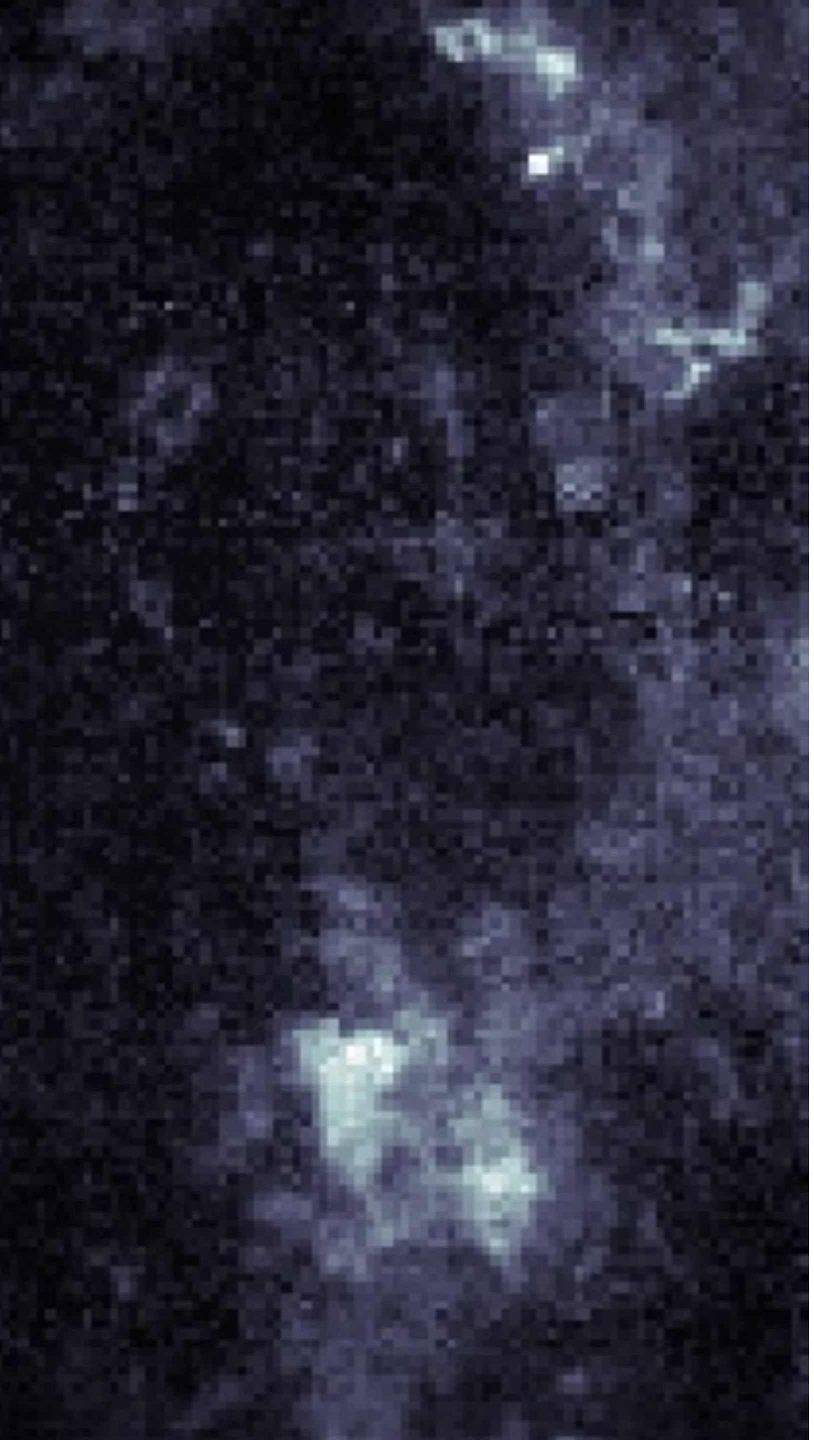

Gamma-ray and Neutrino Emission from Supernova Remnants and Molecular Clouds

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24th Australian Institute of Physics Congress

THE UNIVERSITY of ADELAIDE

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Motivation

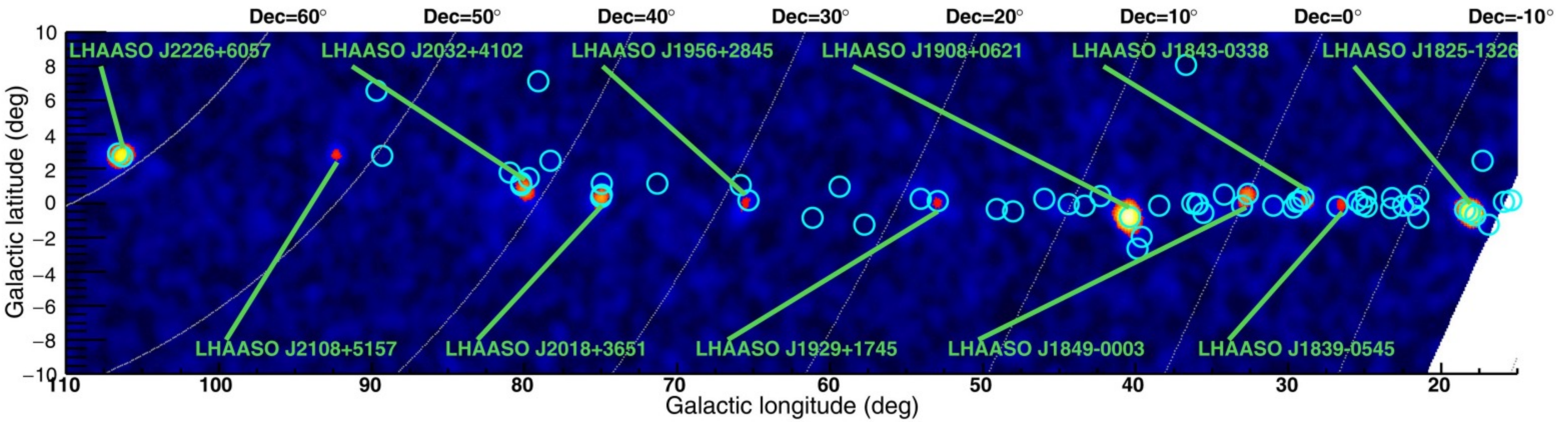
Many gamma-ray sources identified

- A lot of these sources are unresolved
- Recent LHAASO results are especially interesting

Astrophysical neutrinos have been observed

- Currently no identified Galactic sources for any of these

Is there a common source for these particles?

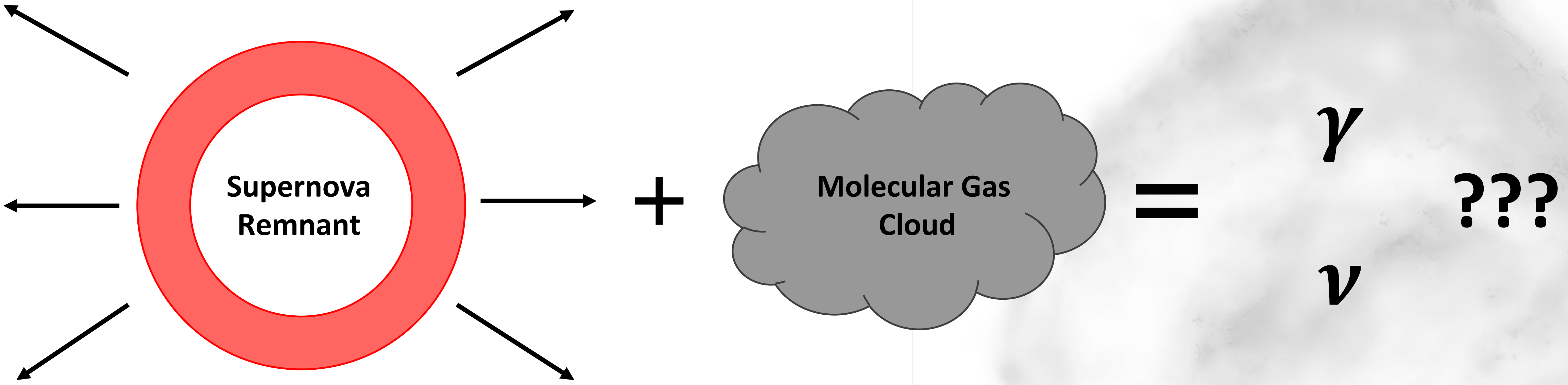


*LHAASO Collaboration, Nature, **594** (2021)*

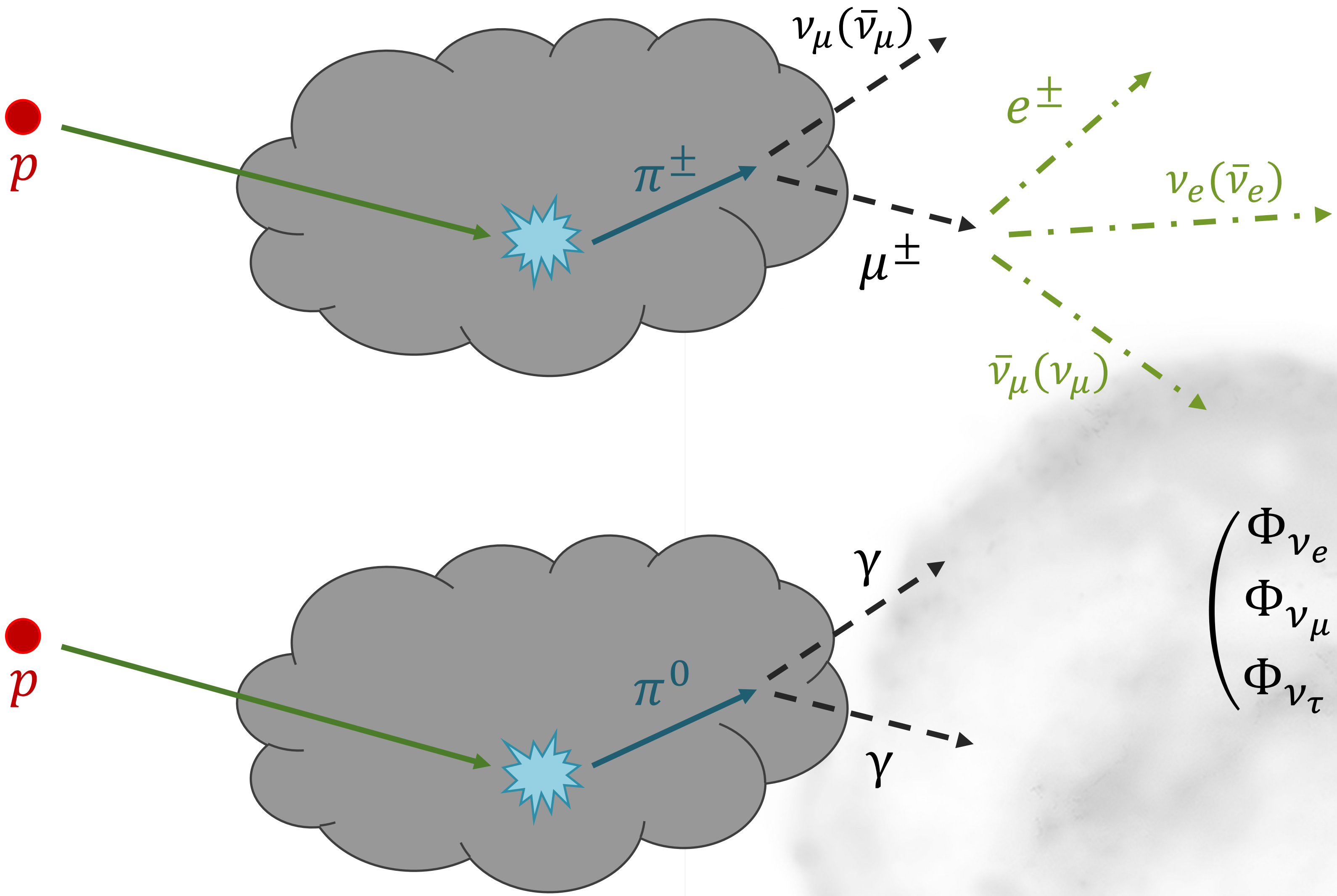
Motivation

Supernova remnants (SNRs) could be responsible for these particles

- Cosmic rays from SNRs interact with molecular gas to make gamma rays and neutrinos
- We can model SNR and cloud combinations to find regions of interest
- Look at these regions in more detail with other data



Gamma-ray and Neutrino Production



$$\begin{pmatrix}\Phi_{\nu_e}\\ \Phi_{\nu_\mu}\\ \Phi_{\nu_\tau}\end{pmatrix} = \begin{pmatrix}1\\ 2\\ 0\end{pmatrix}$$

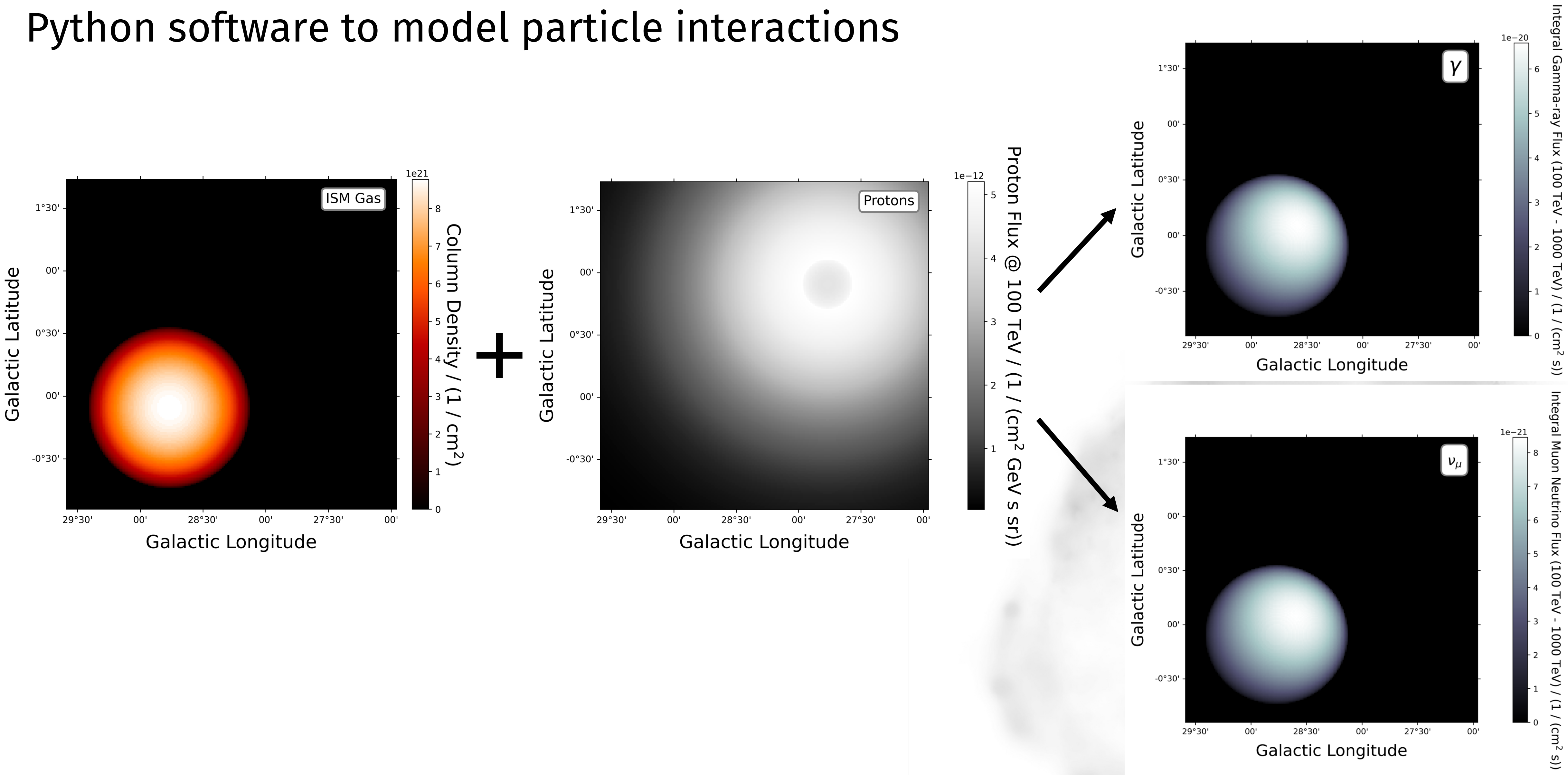
Gamma-ray and Neutrino Flux

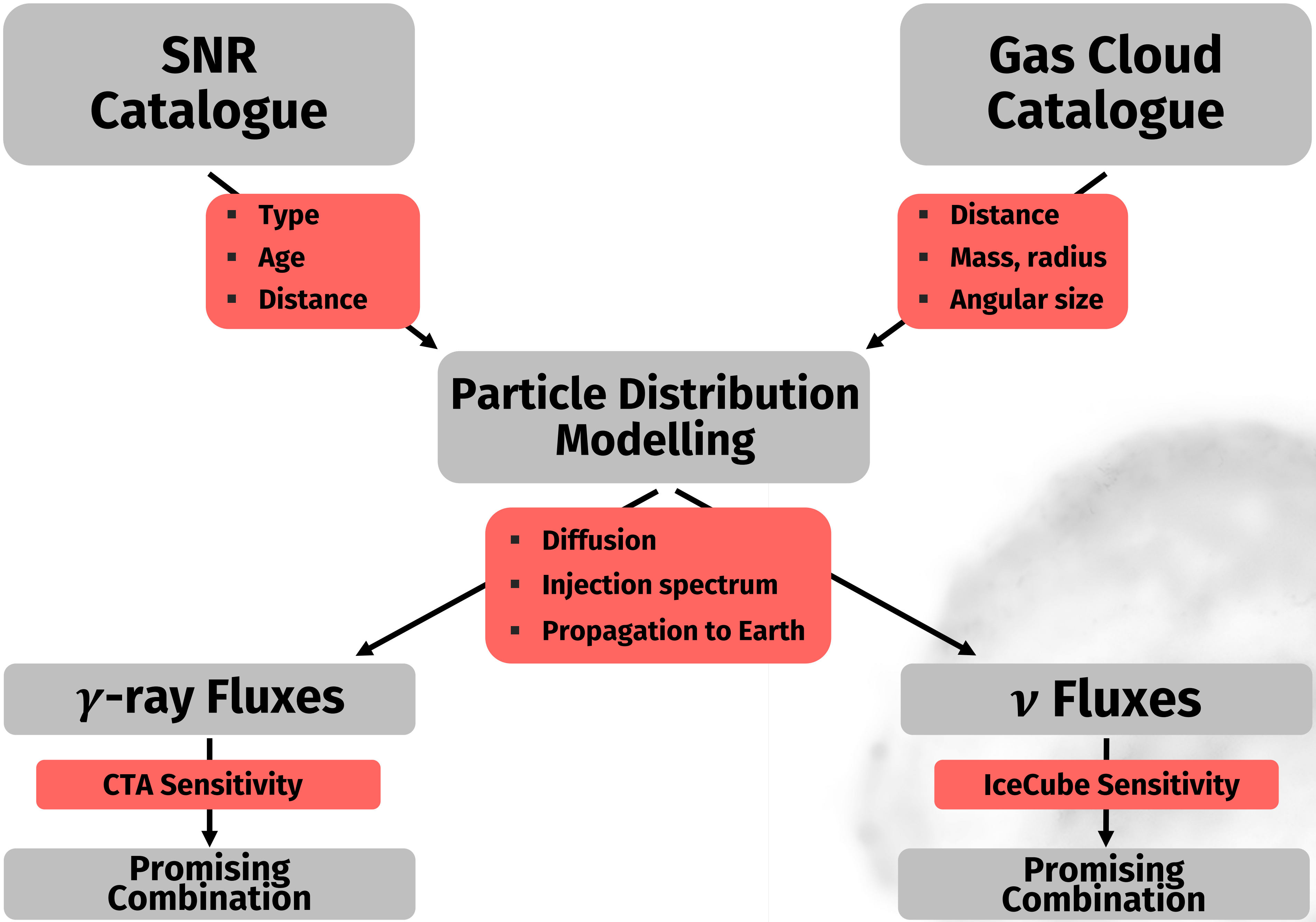
$$\Phi_j(E_j) \equiv \frac{dN_j}{dE_j} = \frac{c n_H V}{4\pi D^2} \int_{E_j}^{\infty} \sigma_{inel}(E_p) J_p(E_p) F_j\left(\frac{E_j}{E_p}, E_p\right) \frac{dE_p}{E_p}$$

- Particle flux → $\Phi_j(E_j)$
- Number density of ISM → n_H
- Volume of ISM → V
- Volume distribution of protons (*Aharonian & Atoyan, A&A*, ***309*** (1996)) → $J_p(E_p)$
- Distance from production site to Earth → D
- Inelastic cross-section for p-p interaction → σ_{inel}
- Number of gamma rays/neutrinos per proton collision (*Kelner et al., Phys. Rev. D.*, ***74*** (2006)) → F_j

partISM – modelling **part**icles in the **ISM**

Python software to model particle interactions




SNR Catalogue
Type
Age
Distance
Gas Cloud Catalogue
Distance
Mass, radius
Angular size
Particle Distribution Modelling
Diffusion
Injection spectrum
Propagation to Earth
γ-ray Fluxes
CTA Sensitivity
Promising Combination
ν Fluxes
IceCube Sensitivity
Promising Combination

Top Combinations

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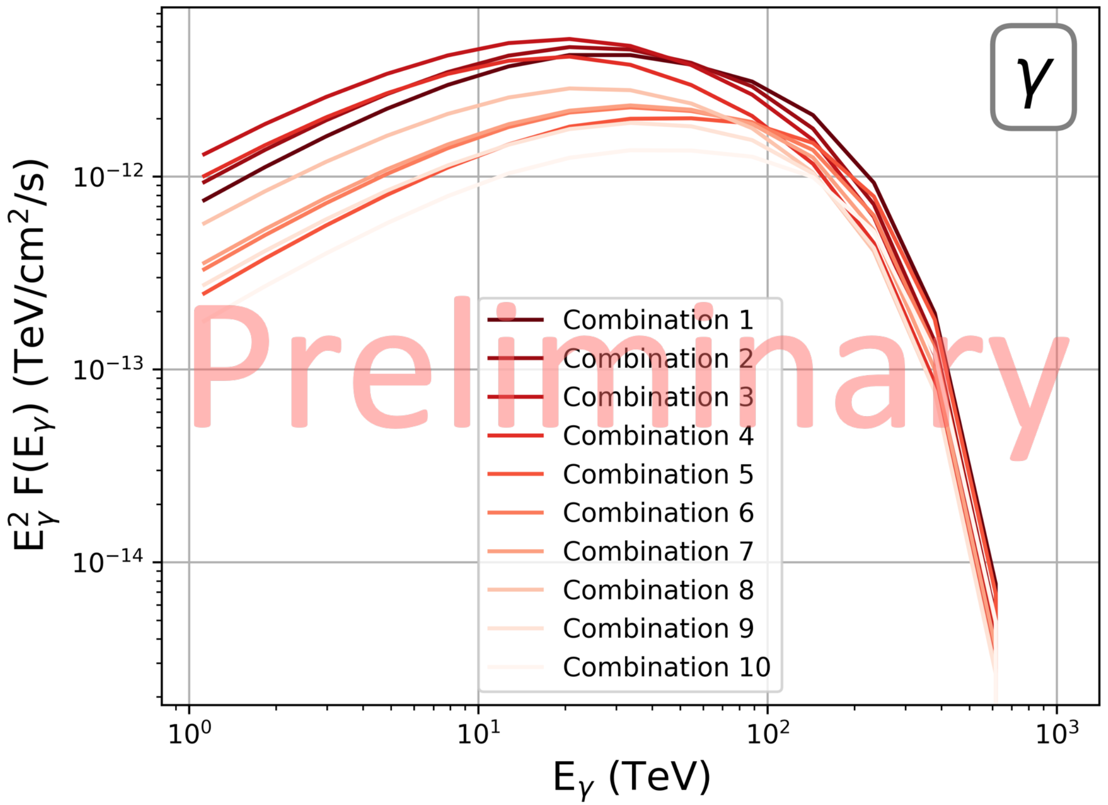
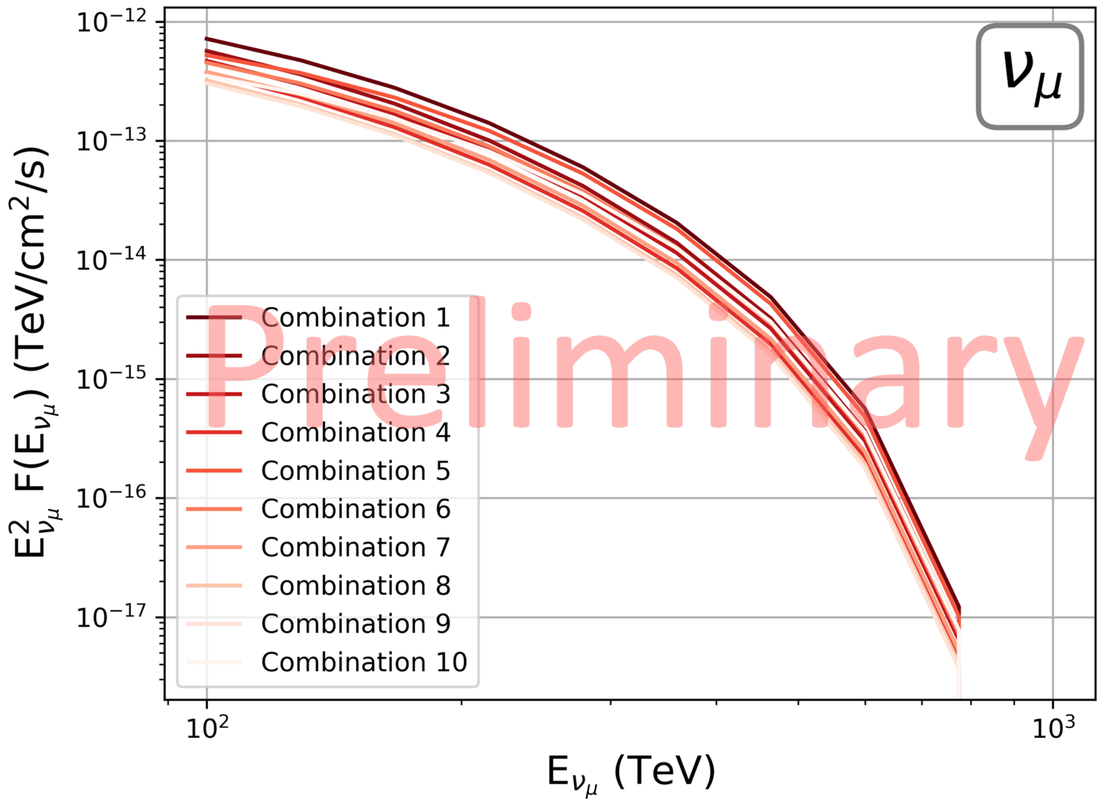
Energy flux spectra over the respective ranges we are interested in:

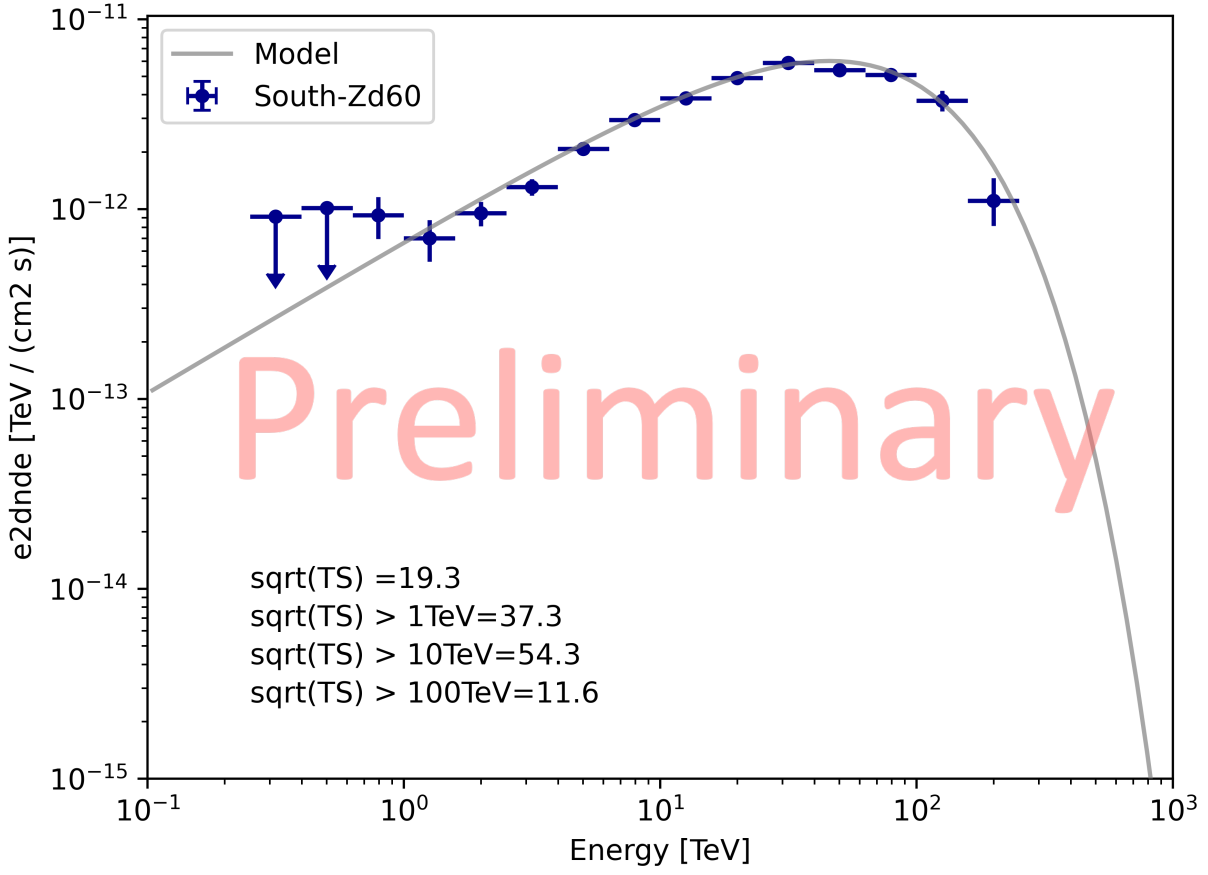




CTA Consideration

Simulate how CTA would see our gamma-ray spectra, considering:

- Extension of source
- Zenith dependence
- Source visibility



We use the CTA instrument response functions *(CTA Consortium and Observatory, doi: 10.5281/zenodo5499840 (2021))*

IceCube Consideration

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Neutrino signalness

- Represents the probability the neutrino is from the cloud, rather than the background

$$\text{signalness} = \frac{N_{\nu_\mu+\bar{\nu}_\mu,\text{cloud, astro}}}{N_{\nu_\mu+\bar{\nu}_\mu,\text{cloud, astro}} + N_{\nu_\mu+\bar{\nu}_\mu,\text{diffuse, astro}} + N_{\nu_\mu+\bar{\nu}_\mu,\text{atmos}}}$$

Dependencies:

- Effective area of the IceCube detector *(IceCube Collaboration, doi: 10.21234/CPKQ-K003 (2021))*
- Atmospheric muon neutrino flux *(Petrova et al., Phys. Part. Nucl. Lett., **9** (2014))*
- Diffuse astrophysical muon neutrino flux *(IceCube Collaboration, Astrophys. J., **928** (2022))*

Top Combinations

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Combo	Cloud Coordinates (l, b) (deg)	Cloud Dist (kpc)	Cloud Radius (deg)	SNR	SNR Age (kyr)	CTA Sig. > 100 (σ)	F_γ @ 100 TeV (TeV cm^{-2} s^{-1})	Signalness	F_{ν_μ} @ 100 TeV (TeV cm^{-2} s^{-1})
1	(333.46, -0.31)	**3.37**	0.630	**G332.4-00.4**	**3.20**	11.6 (60Z)	3.82e-12	0.39e-8	7.07e-13
2	(341.34, 0.21)	**2.41**	0.285	G341.2+00.9	2.14	10.7 (40Z)	2.14e-12	1.48e-8	4.90e-13
3	(337.84, -0.40)	**2.91**	0.467	**G337.2-00.7**	**2.58**	9.5 (60Z)	2.08e-12	0.45e-8	4.10e-13
4	(30.73, 0.03)	2.62	0.689	G030.7+01.0	3.39	9 (60Z)	2.84e-12	0.67e-8	4.65e-13
5	(337.78, -0.02)	3.87	0.262	G338.1+00.4	3.87	8.1 (60Z)	1.79e-12	1.05e-8	2.75e-13
6	(14.14, -0.59)	**2.09**	0.334	**G015.1-01.6**	3.61	7.4 (60Z)	1.12e-12	0.67e-8	1.87e-13
7	(30.73, 0.03)	2.62	0.689	G031.5-00.6	2.30	6.9 (40Z)	1.65e-12	0.47e-8	3.75e-13
8	(337.10, 0.01)	4.67	0.238	G336.7+00.5	3.54	6.8 (60Z)	1.06e-12	0.74e-8	1.81e-13
9	(41.24, -0.07)	2.50	0.414	**G040.5-00.5**	3.38	6.6 (60Z)	1.60e-12	1.07e-8	2.52e-13
10	(318.07, -0.21)	2.77	0.617	G318.9+00.4	4.37	6.4 (40Z)	2.28e-12	0.25e-8	3.68e-13
11	(16.24, -1.02)	**4.33**	0.330	G016.4-00.5	3.58	6.1 (60Z)	1.13e-12	0.72e-8	1.76e-13
12	(316.45, -0.09)	3.01	0.550	G315.4-00.3	3.49	5.9 (60Z)	1.37e-12	0.19e-8	2.39e-13
13	(16.24, -1.02)	**4.33**	0.330	G016.0-00.5	3.25	5.8 (40Z)	1.23e-12	0.80e-8	2.02e-13
14	(35.64, 0.01)	**1.86**	0.695	G036.6-00.7	2.22	5.8 (60Z)	1.10e-12	0.34e-8	2.53e-13

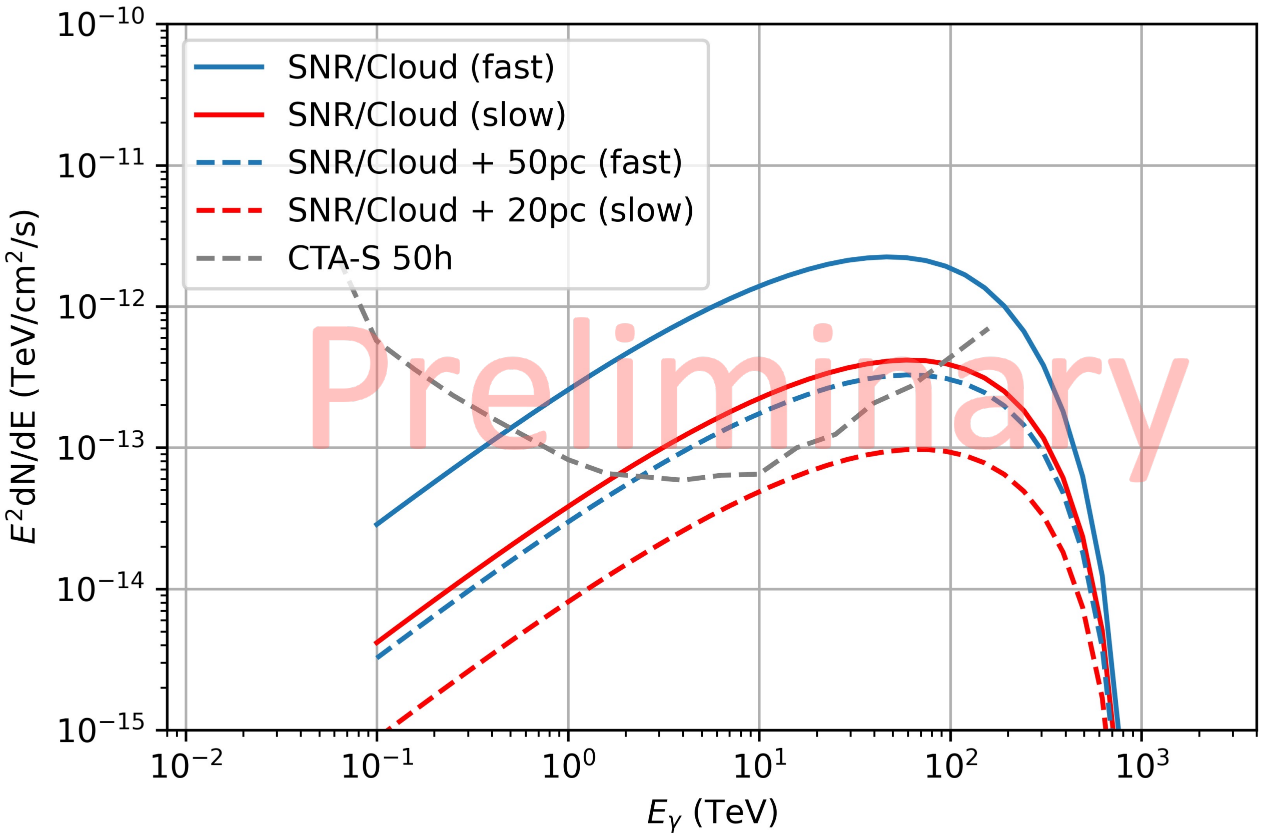
Preliminary

Top combinations ranked in order of significance if simulated flux is observed for 50 hours with CTA-South.

Assumptions

Number of assumptions in this study:

- Spherical clouds
- SNR ages and distances
- Diffusion



Why haven't they been seen already?

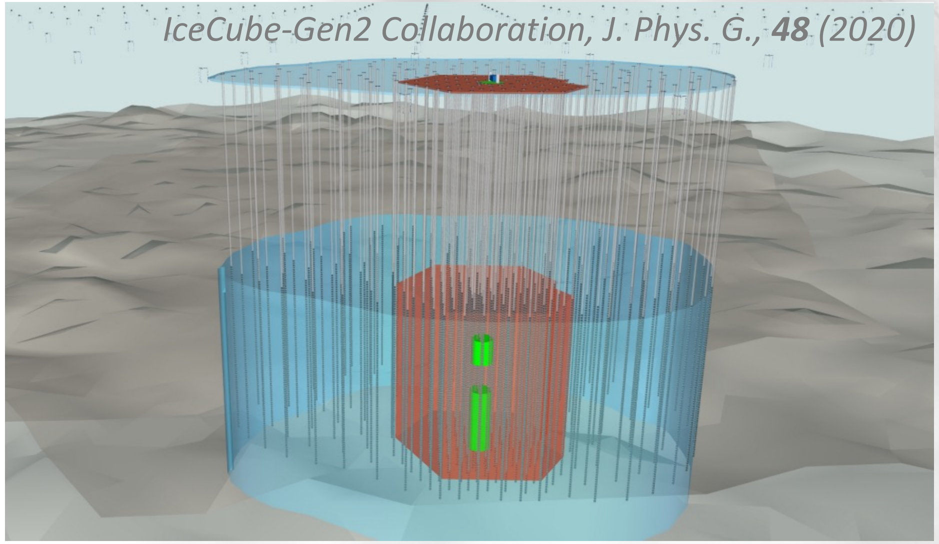
- Our assumptions
- Looking for promising combinations

Conclusions and Further Work

Many combinations of supernova remnants and molecular gas clouds could be responsible for unresolved gamma-ray sources and astrophysical neutrinos

- We aim to find the most promising combinations
- This work will provide a selection of promising targets that will be valuable for many studies
- Interesting follow-up opportunities for the top candidates from this study

Diaz & Besel, CTAO (2020)



*IceCube-Gen2 Collaboration, J. Phys. G., **48** (2020)*