Constraining neutrino-DM interaction with IceCube170922A

[work on progress with Carsten Rott and Jongkuk Kim]

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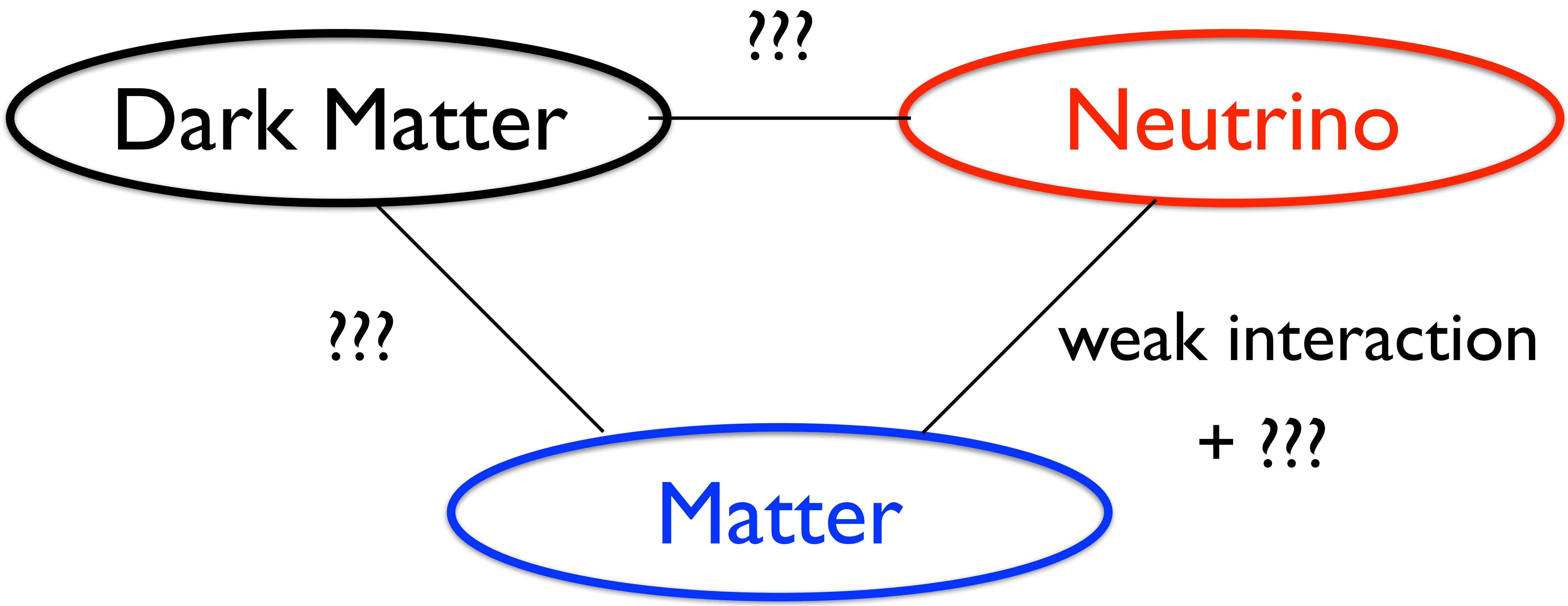
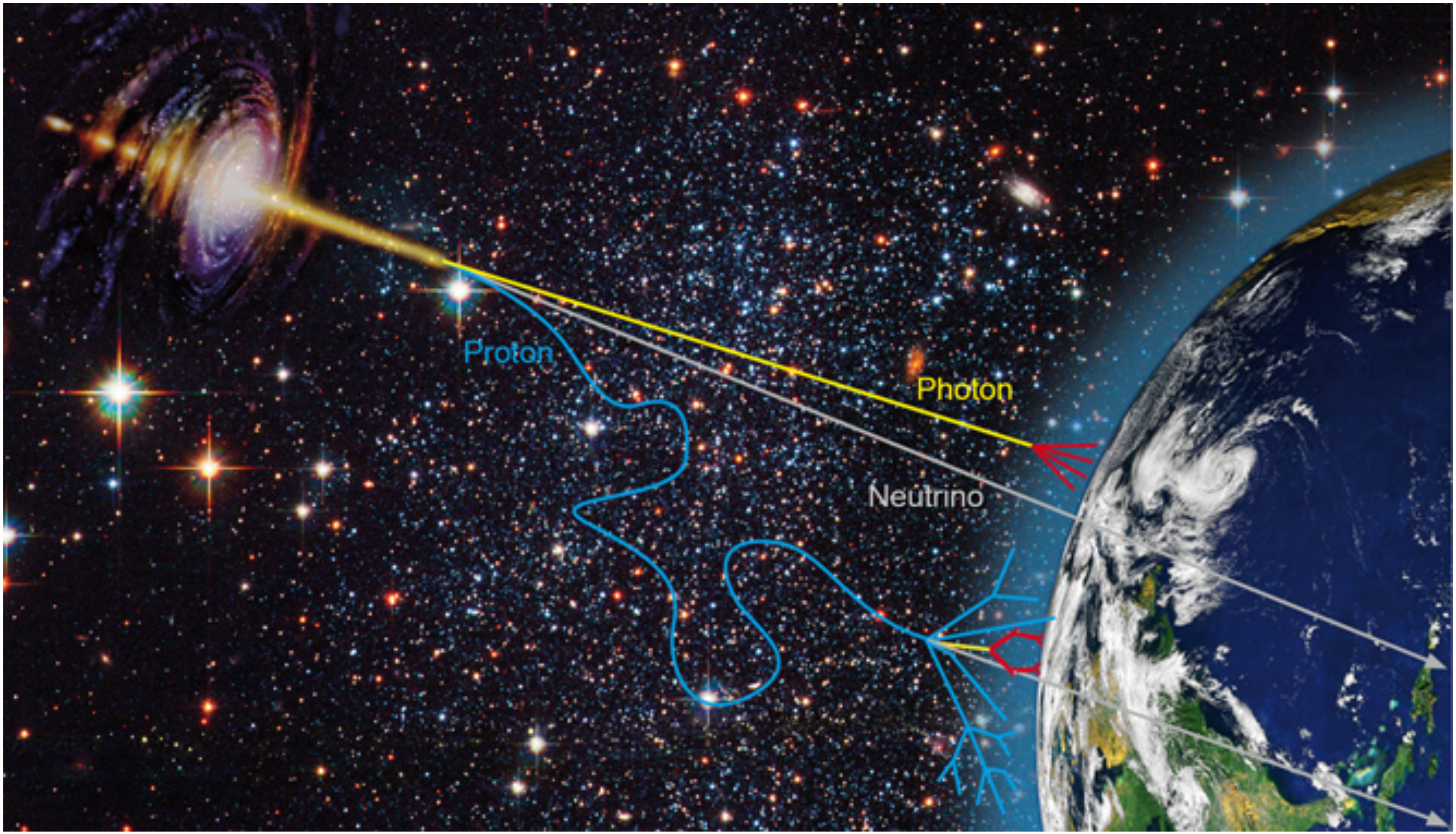
Interaction between Matters



Astrophysical Neutrinos



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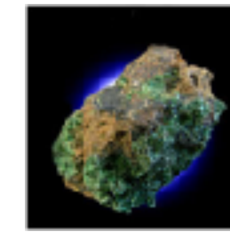
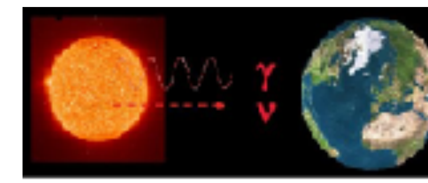
Neutrinos Observations

- The neutrinos discovered are

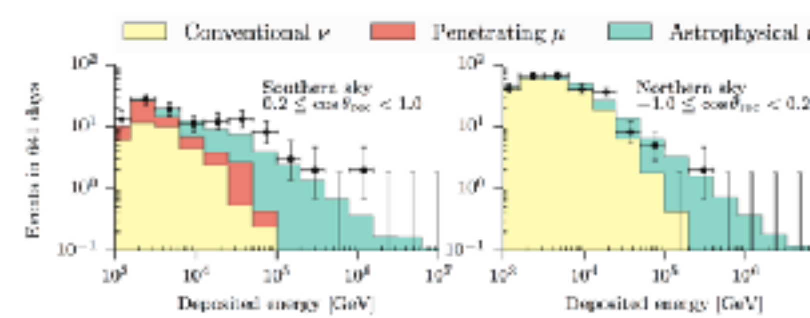


  - Terrestrial neutrinos from rock, nuclear reactor, and collider



  - Solar neutrinos and atmospheric neutrinos
  - Supernova 1987A: Large Magellanic Cloud, galaxy satellite of Milky Way
  - Unidentified astrophysical neutrino at TeV - PeV with IceCube
  - Multi-messenger observation of IceCube170922A

- The neutrinos un-discovered yet are



  - GZK neutrinos
  - Cosmic Neutrino Background from Big Bang

$$\Omega_\nu h^2 \simeq \frac{m_\nu}{93\,\mathrm{eV}}$$

IceCube-170922A

RESEARCH ARTICLE

NEUTRINO ASTROPHYSICS

Multimessenger observations of a flaring blazar coincident with high-energy neutrino IceCube-170922A

The IceCube Collaboration, *Fermi*-LAT, MAGIC, *AGILE*, ASAS-SN, HAWC, H.E.S.S., *INTEGRAL*, Kanata, Kiso, Kapteyn, Liverpool Telescope, Subaru, *Swift/NuSTAR*, VERITAS, and VLA/17B-403 teams*†

Previous detections of individual astrophysical sources of neutrinos are limited to the Sun and the supernova 1987A, whereas the origins of the diffuse flux of high-energy cosmic neutrinos remain unidentified. On 22 September 2017, we detected a high-energy neutrino, IceCube-170922A, with an energy of ~290 tera–electron volts. Its arrival direction was consistent with the location of a known γ-ray blazar, TXS 0506+056, observed to be in a flaring state. An extensive multiwavelength campaign followed, ranging from radio frequencies to γ-rays. These observations characterize the variability and energetics of the blazar and include the detection of TXS 0506+056 in very-high-energy γ-rays. This observation of a neutrino in spatial coincidence with a γ-ray–emitting blazar during an active phase suggests that blazars may be a source of high-energy neutrinos.

evaluated below, associating neutrino and γ-ray production.

The neutrino alert

IceCube is a neutrino observatory with more than 5000 optical sensors embedded in 1 km^3 of the Antarctic ice-sheet close to the Amundsen-Scott South Pole Station. The detector consists of 86 vertical strings frozen into the ice 125 m apart, each equipped with 60 digital optical modules (DOMs) at depths between 1450 and 2450 m. When a high-energy muon-neutrino interacts with an atomic nucleus in or close to the detector array, a muon is produced moving through the ice at superluminal speed and creating Cherenkov radiation detected by the DOMs. On 22 September 2017 at 20:54:30.43 Coordinated Universal Time (UTC), a high-energy neutrino-induced muon track event was detected in an automated analysis that is part of IceCube's real-time alert system. An automated alert was distributed (*17*) to observers 43 s later, providing an initial estimate of the direction and energy of the event. A sequence of refined reconstruction algorithms was automatically started at the same time, using the full event information. A representation of this neutrino event with the best-fitting reconstructed direction is shown in Fig. 1. Monitoring data from IceCube indicate that the observatory was functioning normally at the time

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IceCube-170922A : blazar TXS 0506+056

Redshift: $z = 0.3365 \pm 0.0010$ → $1421^{+1425}_{-1416}\ \mathrm{Mpc}$

right ascension (RA) $77.42^{+0.95}_{-0.65}$ Declination (Dec) $+5.72^{+0.50}_{-0.30}$

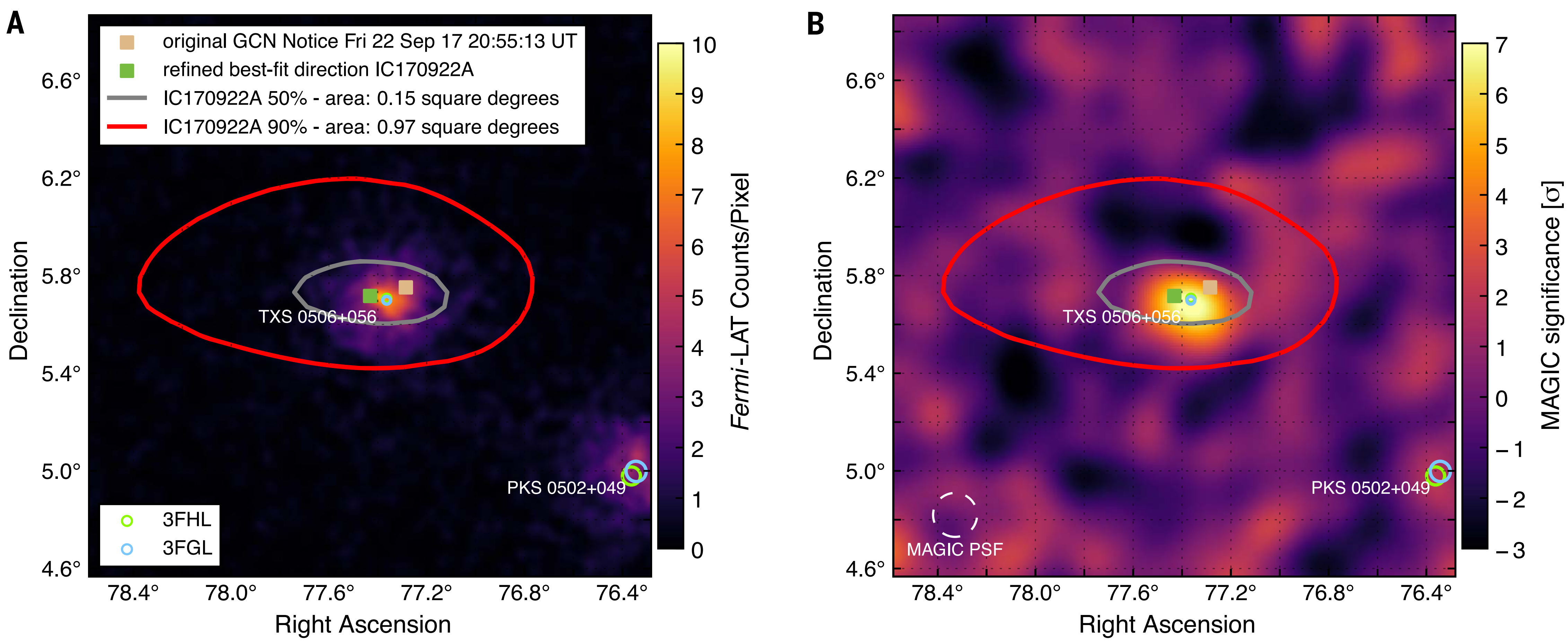

Fig. 2. ***Fermi*-LAT and MAGIC observations of IceCube-170922A's location.** Sky position of IceCube-170922A in J2000 equatorial coordinates pixel, using detected photons with energy of 1 to 300 GeV in a 2° by 2° region around TXS0506+056. The map has a pixel size of 0.02° and was

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Change of Coordinates

From equatorial coordinates to Galactic coordinates

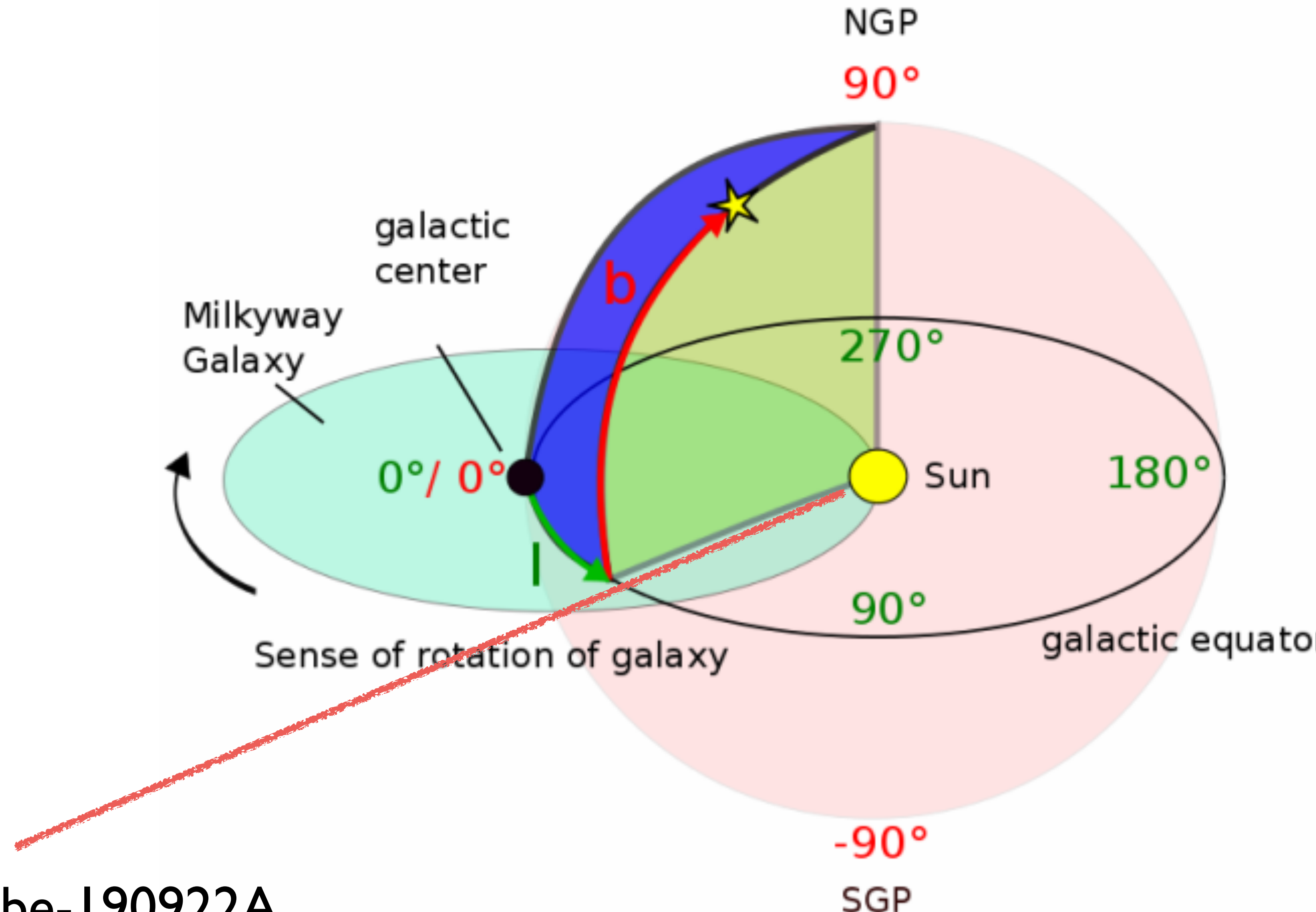
$$\tan(l_0 - l) = \frac{\cos(\delta)\sin(\alpha - \alpha_0)}{\sin(\delta)\cos(\delta_0) - \cos(\delta)\sin(\delta_0)\cos(\alpha - \alpha_0)}$$

$$\sin(b) = \sin(\delta)\sin(\delta_0) + \cos(\delta)\cos(\delta_0)\cos(\alpha - \alpha_0)$$

the equatorial coordinates of the Galactic north pole $\alpha_0 \approx 192.8595^\circ$, $\delta_0 \approx 27.1284^\circ$

Galactic longitude of the equatorial north pole $l_0 \approx 122.9320^\circ$

Galactic Coordinate



IceCube-190922A

b=-19.6 degree

l=15.4 degree

Dissipation of Neutrino flux

The interaction of neutrinos with dark matter in the Universe can suppress the flux of neutrinos along the path from the source to Earth

$$\Phi = \Phi_0 e^{-\int_{\rm path} \sigma n(\mathbf{x}) dl}$$

The suppression depends on the scattering cross section between DM and neutrinos and as well as the DM number density along the path.

The observation of neutrinos imply that

$$\int_{\rm path} \sigma n(\mathbf{x}) dl \lesssim 1$$

Dissipation of Neutrino flux
from IC170922A

$$\int_{\rm path} \sigma n(\mathbf{x}) dl = n_0 \sigma L + \int_{los} \sigma n_{\rm gal}(\mathbf{x}) dl,$$

$$= \frac{\sigma}{M_{\rm dm}} \left(\rho_0 L + \int_{los} \rho_{\rm gal}(\mathbf{x}) dl \right).$$

DM is non-relativistic
sigma is constant

cosmological DM

Galactic DM

$$\rho_0 \simeq 1.3 \times 10^{-6}\, {\rm GeV/\,cm^3}$$

$$L = 1420\, {\rm Mpc}$$

$$\rho_{\rm gal}(\mathbf{x}) = \frac{\rho_s}{\frac{r}{r_s}\left(1 + \frac{r}{r_s}\right)^2}$$

$$\rho_s = 0.184\, {\rm GeV/\,cm^3}$$
$$r_s = 24.42\, {\rm kpc}$$

$$\rho_0 L \simeq 5.7 \times 10^{21}\, {\rm GeV/\,cm^2}$$

$$\int_{los} \rho_{\rm gal}(\mathbf{x}) dl \simeq 3.8 \times 10^{22}\, {\rm GeV/\,cm^2}$$

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Constraint on the DM-neutrino interaction

Requiring less than 90% suppression of the flux $\int \sigma n dl \lesssim 2.3$

$$\frac{\sigma}{M_{\rm dm}} \lesssim \left(\rho_0 L + \int_{los} \rho_{\rm gal}(\mathbf{x}) dl\right)^{-1} \times 2.3$$

We obtain the upper bound on the cross section/mass as

$$\sigma/M_{\rm dm} \lesssim 5.3 \times 10^{-23}\,{\rm cm}^2/\,{\rm GeV} \quad \text{at} \quad E_\nu = 290\,{\rm TeV}$$

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Interaction between DM and neutrinos

From Early Universe

- DM annihilation into neutrinos: DM relic density, BBN, Neff
- Suppression of the small scale perturbations
  : CMB anisotropy, LSS, R. J. Wilkinson, C. Boehm and J. Lesgourgues, JCAP **1405** (2014) 011 doi:10.1088/1475-7516/2014/05/011

From Present Universe

G. Mangano, A. Melchiorri, P. Serra, A. Cooray and M. Kamionkowski, Phys. Rev. D **74** (2006) 043517

- Neutrino flux suppression from SN1987A
- Deviation of the HE neutrino isotropy C. A. Argelles, A. Kheirandish and A. C. Vincent, Phys. Rev. Lett. **119** (2017) no.20, 201801
- Flavor changes due to lepton gauge symmetry
- HE neutrino flux suppression

P. F. de Salas, R. A. Lineros and M. Tortola, Phys. Rev. D **94** (2016) no.12, 123001

S. Pandey, S. Karmakar and S. Rakshit, JHEP **1901** (2019) 095 doi:10.1007/JHEP01(2019)095

Suppression of small scales

From Lyman-alpha, (similar from CMB too)

for constant cross section,

$$\sigma_{\rm el} < 10^{-36} \left(\frac{m_{\rm DM}}{\rm MeV}\right) \ {\rm cm}^2 \ ,$$

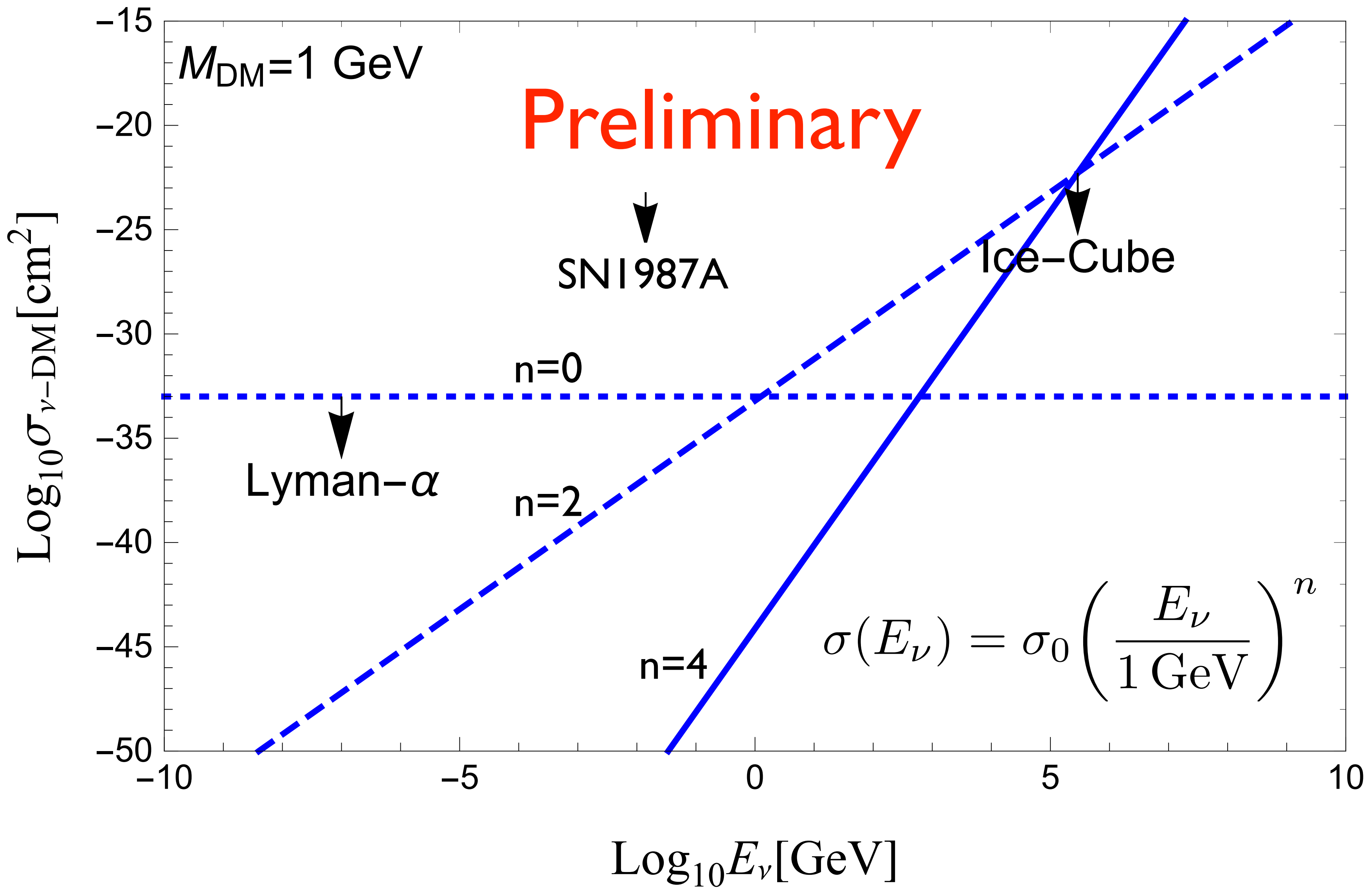
for temperature-dependent cross section,

$$\sigma_{\rm el} < 10^{-48} \left(\frac{m_{\rm DM}}{\rm MeV}\right) \left(\frac{T_\nu}{T_0}\right)^2 \ {\rm cm}^2$$

$$T_0 = 2.35 \times 10^{-4} \ {\rm eV}$$

This bound is applied for neutrino energy at around eV-100 eV.

Energy dependence of the constraint

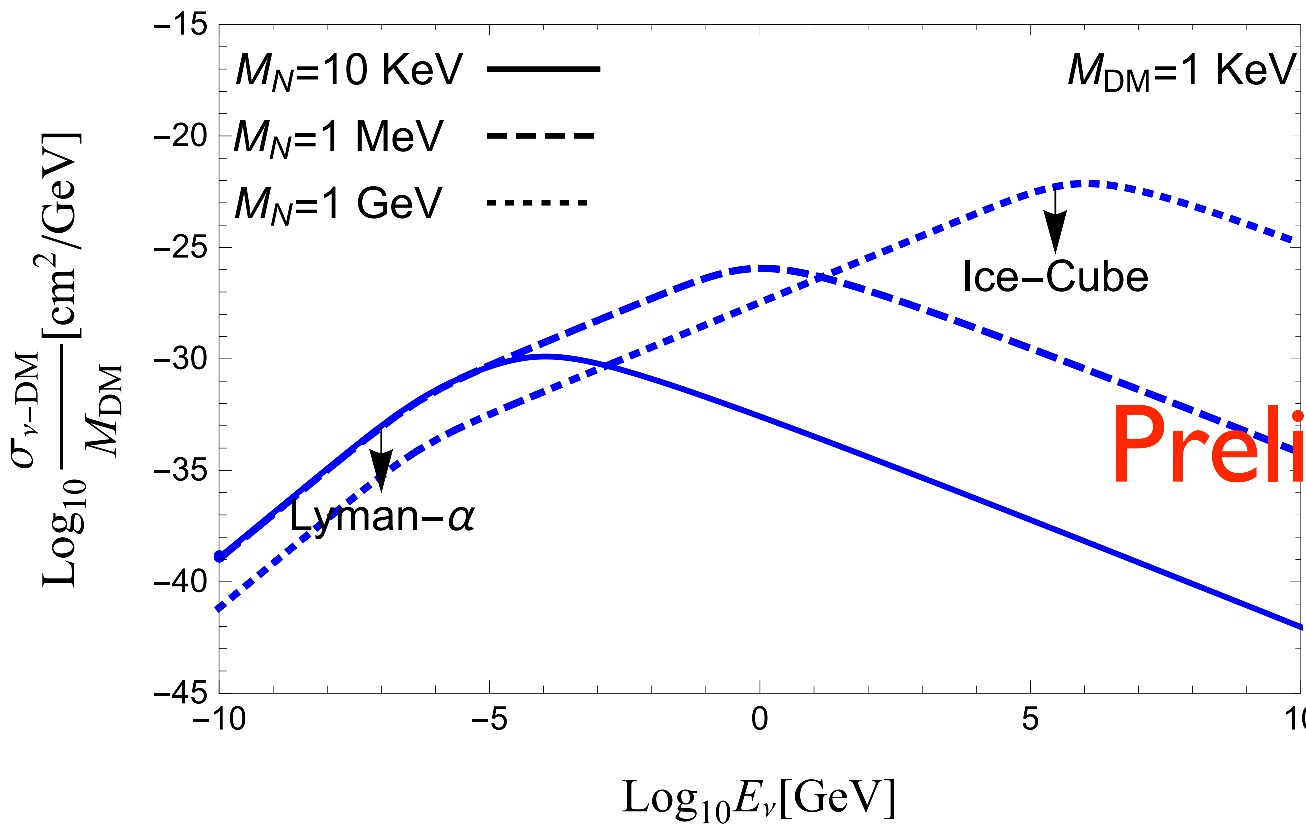


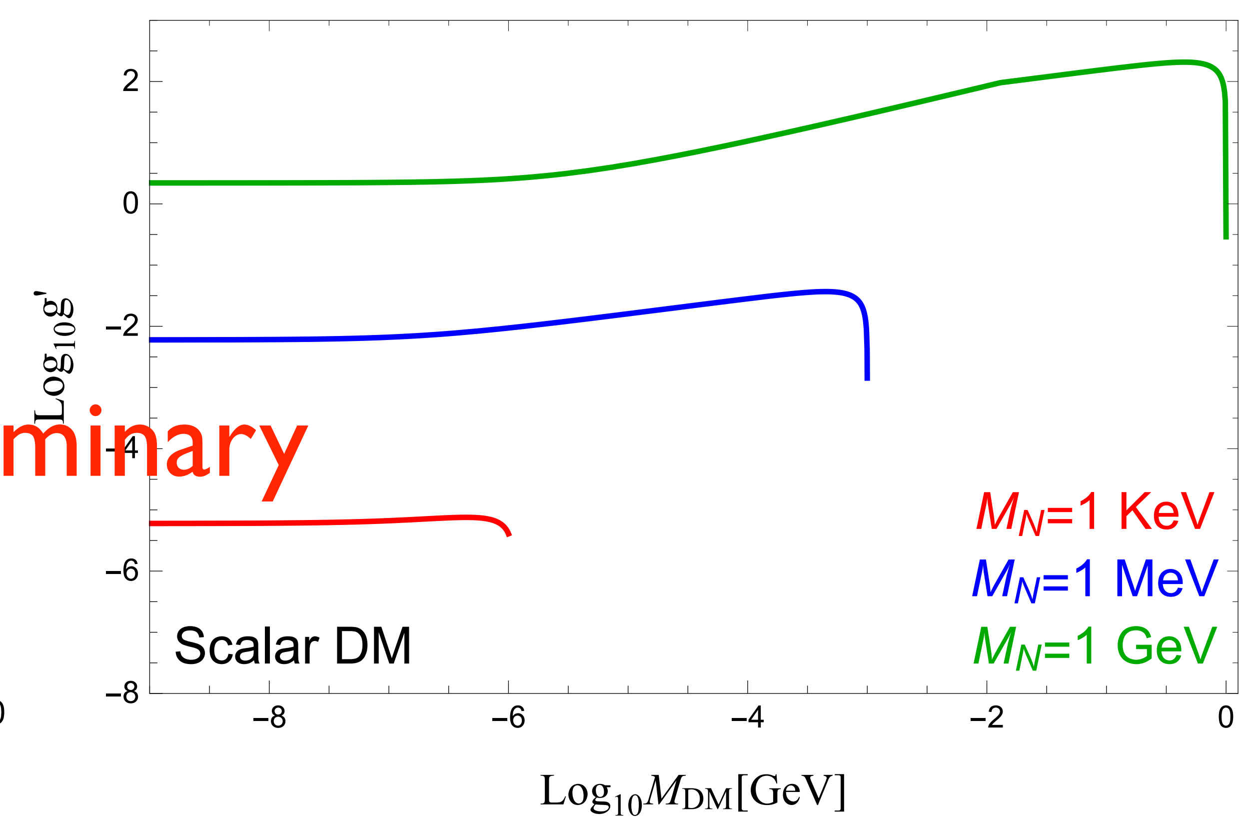
The strongest constraint depends on the form of cross section.

$$\sigma_0/M_{\rm dm} \lesssim 10^{-33}\,{\rm cm}^2/\,{\rm GeV} \quad {\rm for} \quad n=0,$$
$$\sigma_0/M_{\rm dm} \lesssim 6.3\times10^{-34}\,{\rm cm}^2/\,{\rm GeV} \quad {\rm for} \quad n=2,$$
$$\sigma_0/M_{\rm dm} \lesssim 7.5\times10^{-45}\,{\rm cm}^2/\,{\rm GeV} \quad {\rm for} \quad n=4.$$

Complex Scalar DM with fermion mediator

$$\mathcal{L}_{\rm int} = -g\chi\overline{N}\nu_L + {\rm h.c.}$$





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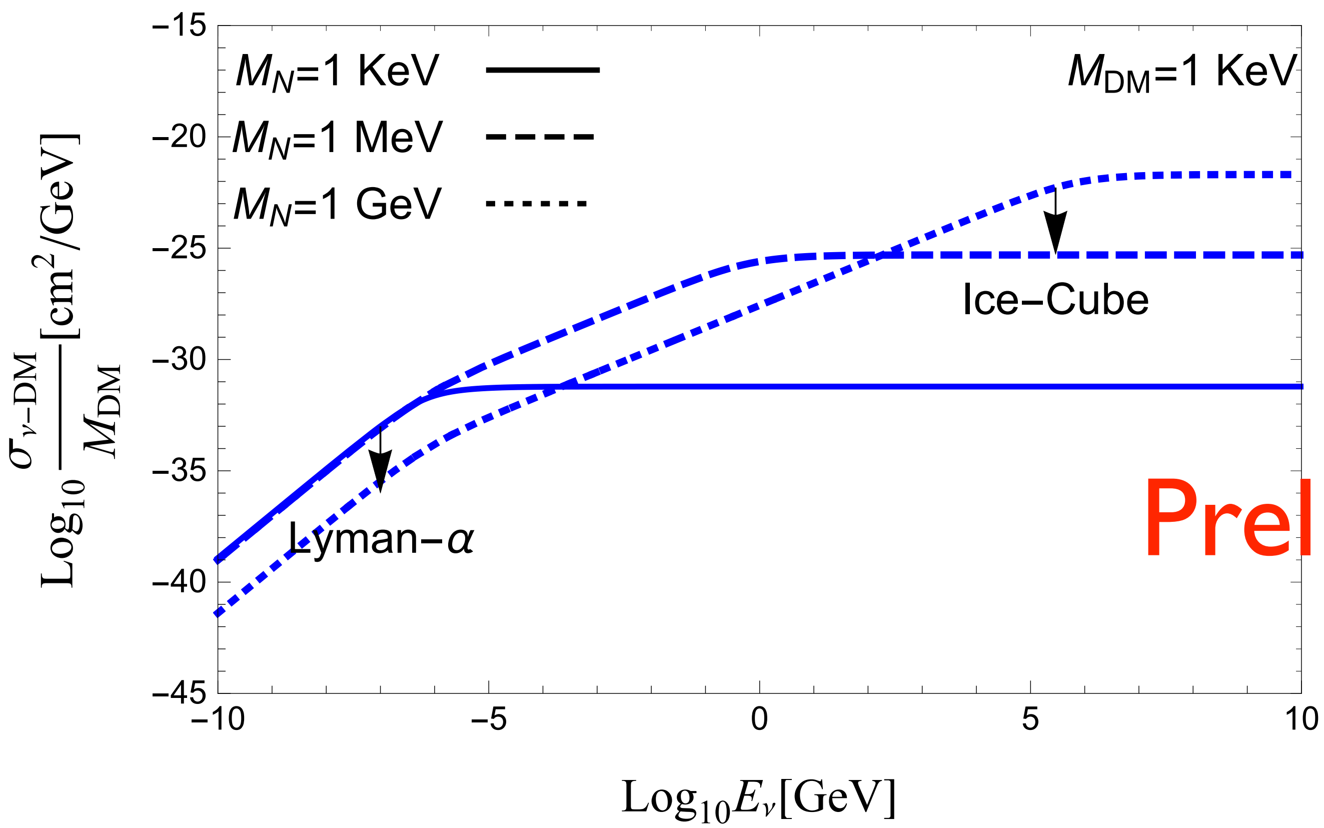
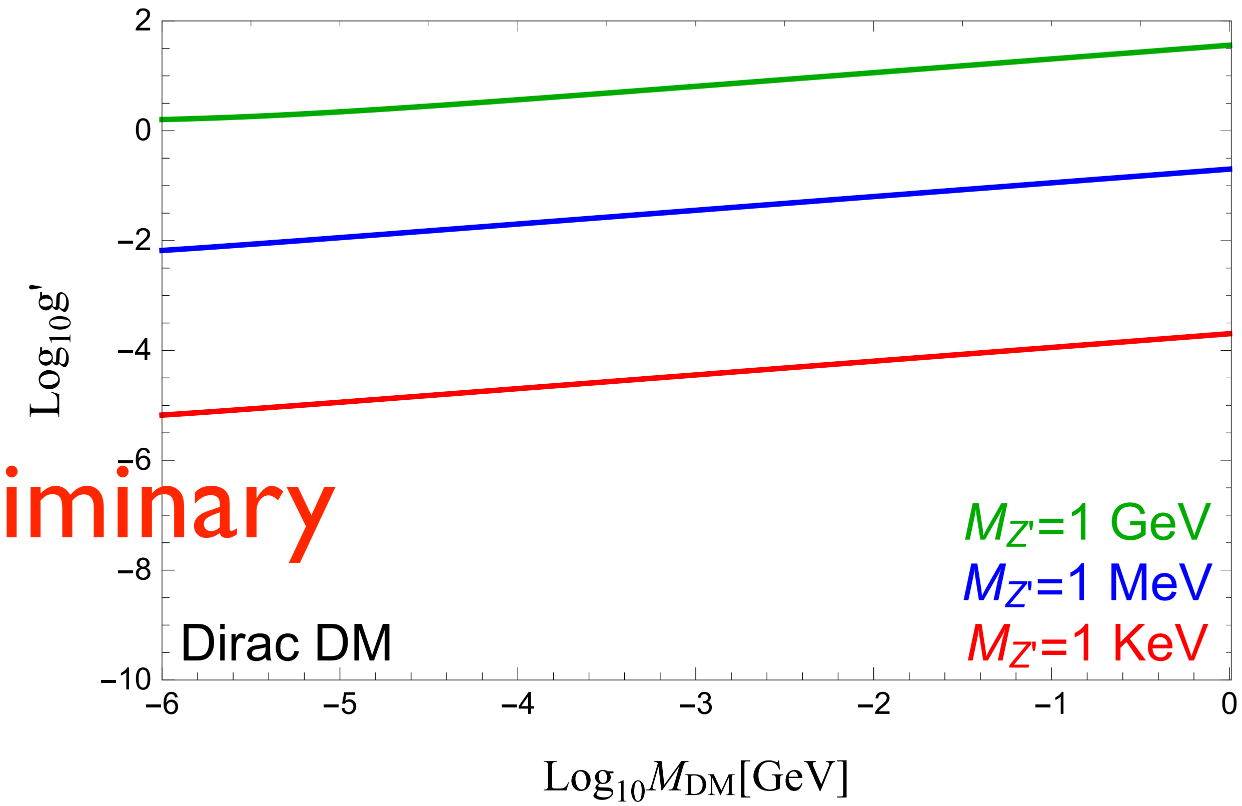
Fermion DM with vector mediator

$$\mathcal{L}_{\rm int} = -g_\nu \overline{\nu_L}\gamma^\mu Z'_\mu \nu_L - g_\chi \overline{\chi}\gamma^\mu Z'_\mu \chi$$





Preliminary

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Conclusion

• The recent multi-messenger observations of IceCube170922A determine its source with definite distance and direction.

• The identification of the source gives us the precise calculation of the neutrino flux change due to the DM and neutrinos and the constraint on the scattering cross section

$$\sigma/M_{\rm dm} \lesssim 5.3 \times 10^{-23}\,{\rm cm}^2/\,{\rm GeV} \qquad {\rm at} \quad E_\nu = 290\,{\rm TeV}$$

• The strongest constraint on the interaction depends on the neutrino energy and the parameters in the model.

Thank You!