Constraining DM-neutrino interactions with IceCube-170922A

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In collaboration with Prof. Ki-Young Choi, Prof. Carsten Rott

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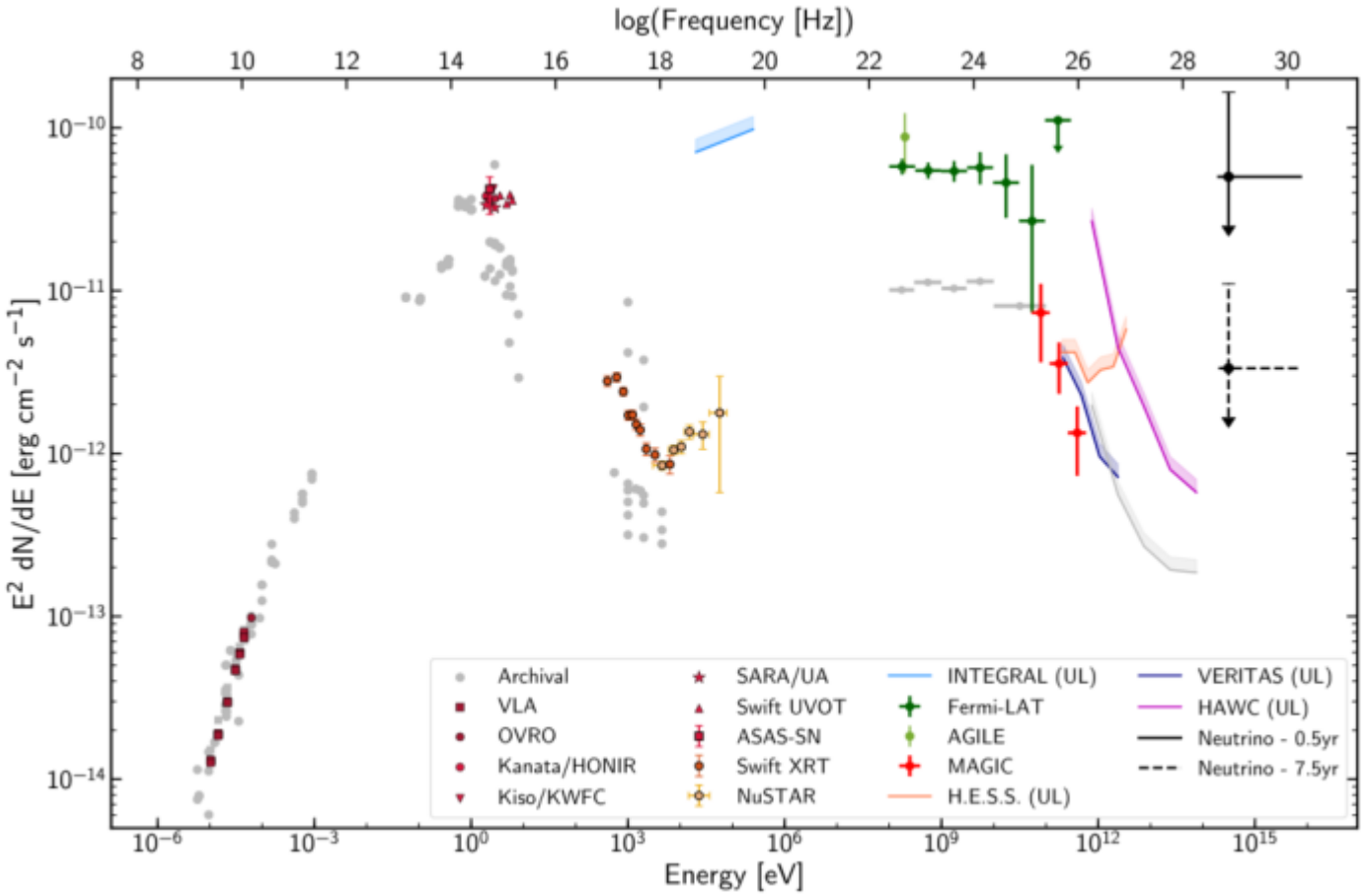
IceCube-170922A

- Fermi-LAT and MAGIC identify a spatially coincident **flaring blazar** (TXS 0506+056)

IceCube 2018 Science



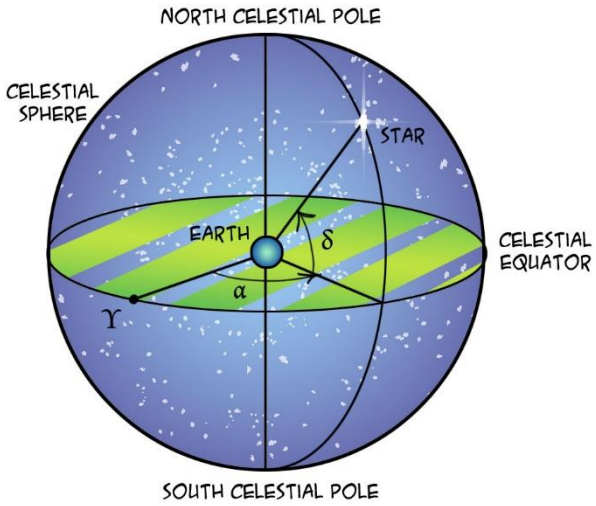
IceCube-170922A

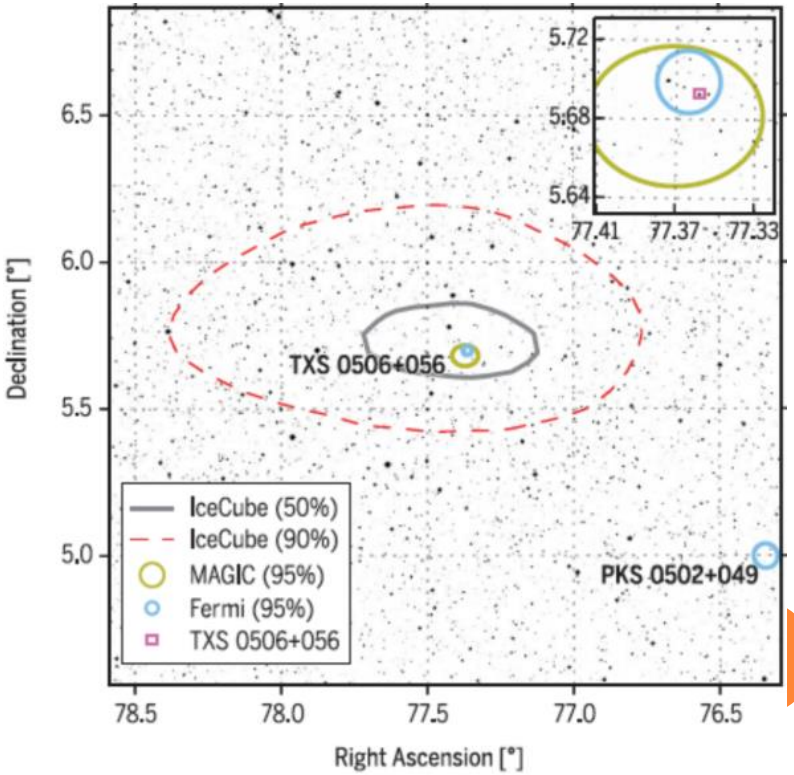
- Icecube-170922A
  - TXS 0506+056 determined to be z = 0.3365
  - 1421 Mpc
  - Right ascension: 77.42, Declination: 5.72

IceCube 2018 Science

S. Paiano et al, ApJL 2018

- Equatorial coordinate system





Mean free-path for a neutrino

- How far a neutrino can travel without any scattering process
- The definition of the mean free-path
  - $\lambda_{\mathrm{MFP}} = \dfrac{1}{n_X \sigma(\nu X \to Y)}$
  - X can be DM
- A new physics model can be constrained

Dissipation of neutrino flux

- The interaction of neutrinos with DM can suppress the flux of neutrinos along the path from the source to Earth
  - Scattering cross section → constant

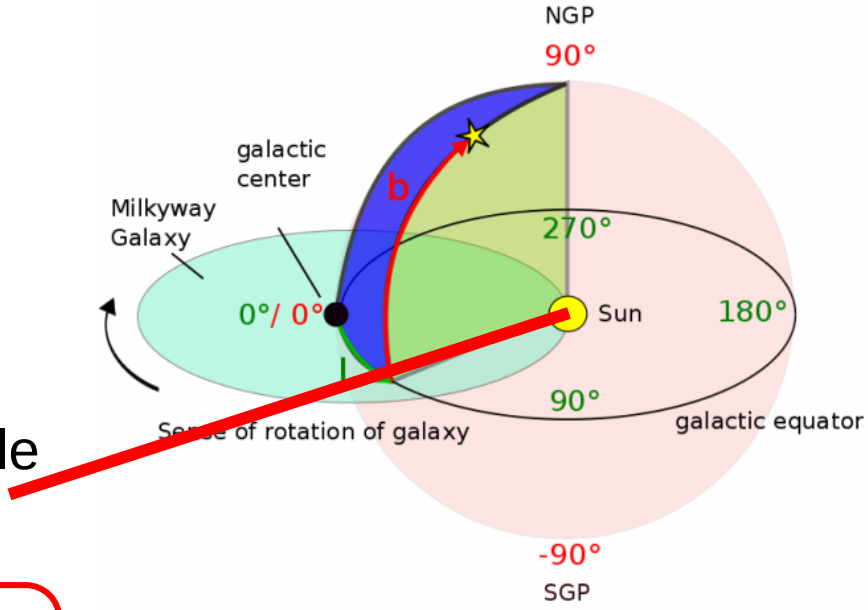
$$\Phi = \Phi_0 e^{-\int_{\text{path}} \sigma n(\mathbf{x}) dl}$$

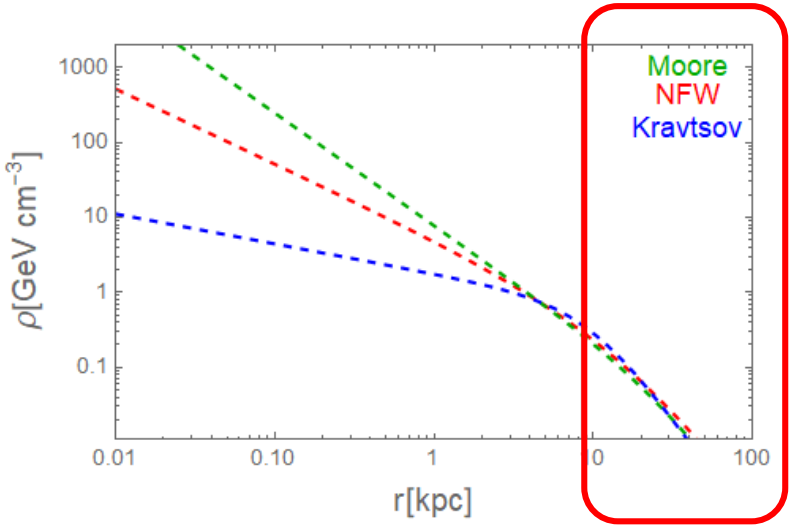
- The suppression depends on the DM-v scattering cross section as well as the DM number density along the path

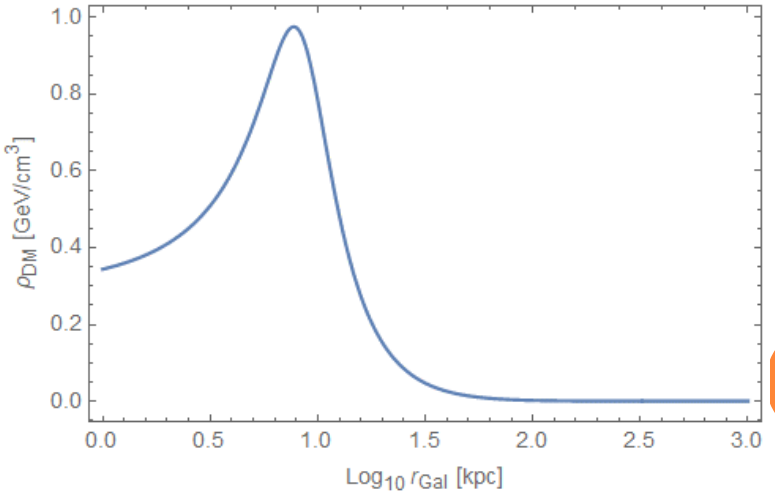
- $\int \sigma n dl \lesssim 2.3$

Galactic coordinate

- Icecube-170922A
  - b = -19.6 degree
  - l = 15.4 degree
- Not travel through GC
  - Not depends on DM profile







Dissipation of neutrino flux

- The suppression can be divide into two contributions

$$\int_{\text{path}} \sigma n(\mathbf{x}) dl = \int_{\text{los}} n(z)\sigma dl + \int_{\text{los}} \sigma n_{\text{gal}}(\mathbf{x}) dl,$$

$$= \frac{\sigma}{M_{\text{dm}}} \left(\int_{\text{los}} \rho(z) dl + \int_{\text{los}} \rho_{\text{gal}}(\mathbf{x}) dl \right)$$

- Suppression from the cosmological DM
  - Cosmological DM energy density is determined by Planck 2018 data
    - $\rho_{\text{dm}}(z) = 1.3 \times 10^{-6} (1+z)^3 \,\text{GeV/cm}^3$ Planck 2018
  - $$\int_{los} \rho(z)\, dl = \int \rho(z) \frac{cdt}{dz} dz,$$
    $$\simeq 7.2 \times 10^{21}\,\text{GeV/cm}^2.$$

Dissipation of neutrino flux

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$$\int_{\text{path}} \sigma n(\mathbf{x}) dl = \int_{\text{los}} n(z)\sigma dl + \int_{\text{los}} \sigma n_{\text{gal}}(\mathbf{x}) dl,$$

$$= \frac{\sigma}{M_{\text{dm}}} \left(\int_{\text{los}} \rho(z) dl + \int_{\text{los}} \rho_{\text{gal}}(\mathbf{x}) dl \right)$$

- Galactic DM
  - NFW DM profile
  - $\int_{los} \rho_{\text{gal}}(\mathbf{x}) dl \simeq 3.8 \times 10^{22}\,\text{GeV}/\,\text{cm}^2$

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

- Incidentally both contributions from cosmological DM and Milky Way DM are very comparable
  - Very tiny cosmological DM density is compensated by the long distance

New constraint

- Demand less than 90% suppression of the flux
  - $\int \sigma n dl \lesssim 2.3$
- DM-ν scattering cross section
  - The identification of the source can allow the precise evaluation of the neutrino flux change due to DM- ν scattering cross section

- $\sigma / M_{\rm dm} \leq 5.1 \times 10^{-23} {\rm cm}^2/{\rm GeV}$
  - @ $E_\nu = 290$ TeV

Known constraints

- Lyman-alpha

C. Boehm, R. Wilkinson arXiv: 1401.7597

  - WIMP DM stays in equilibrium with primordial plasma for longer time due to elastic scattering and undergoes acoustic oscillations
  - Suppresses matter perturbations and reduces the amount of small scale structures today
  - constant cross section: $\sigma_{\rm el} < 10^{-36} \left(\frac{m_{\rm DM}}{\rm MeV}\right) \ {\rm cm}^2$
  - T-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 constraint can be applied for neutrino energy at around 100 eV.

Known constraints

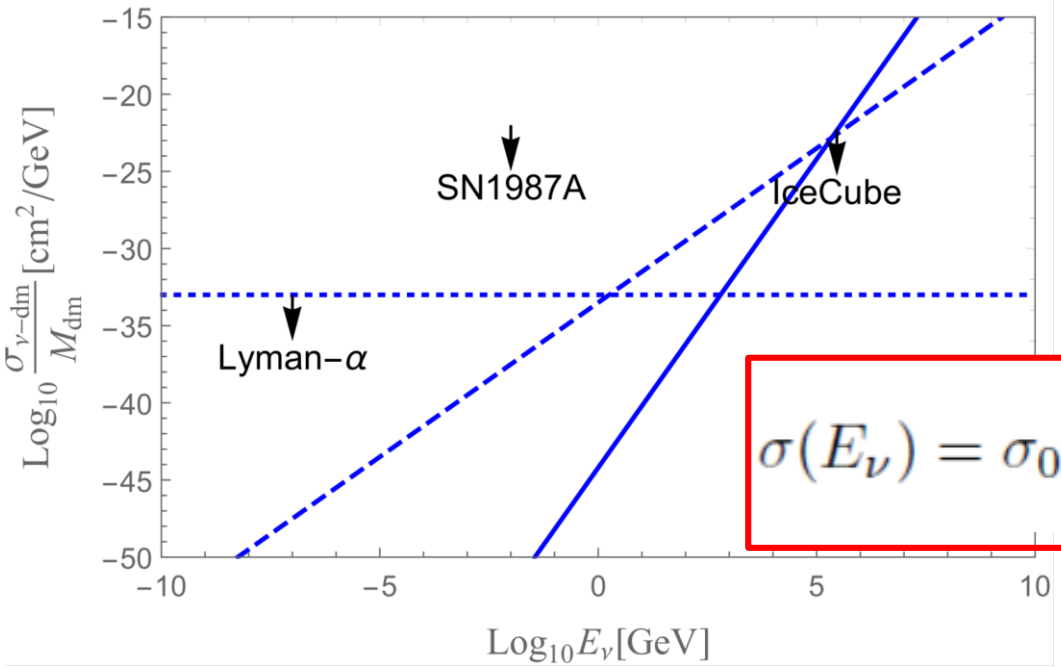
G. Barbiellini, G. Cocconi, 1987

- SN1987A
  - Neutrino energies ~ 10 MeV
  - Distance ~ 50 kpc

- v-DM interaction can be constrained
- This constraint can be applied for neutrino energy at around 10 MeV.

Neutrino energy	$\sigma / M_{\mathrm{dm}} [\mathrm{cm}^2 / \mathrm{GeV}]$
~ 100 eV	6×10^{-31}
~ 100 eV	10^{-33}
10 MeV	10^{-22}

Scattering cross section



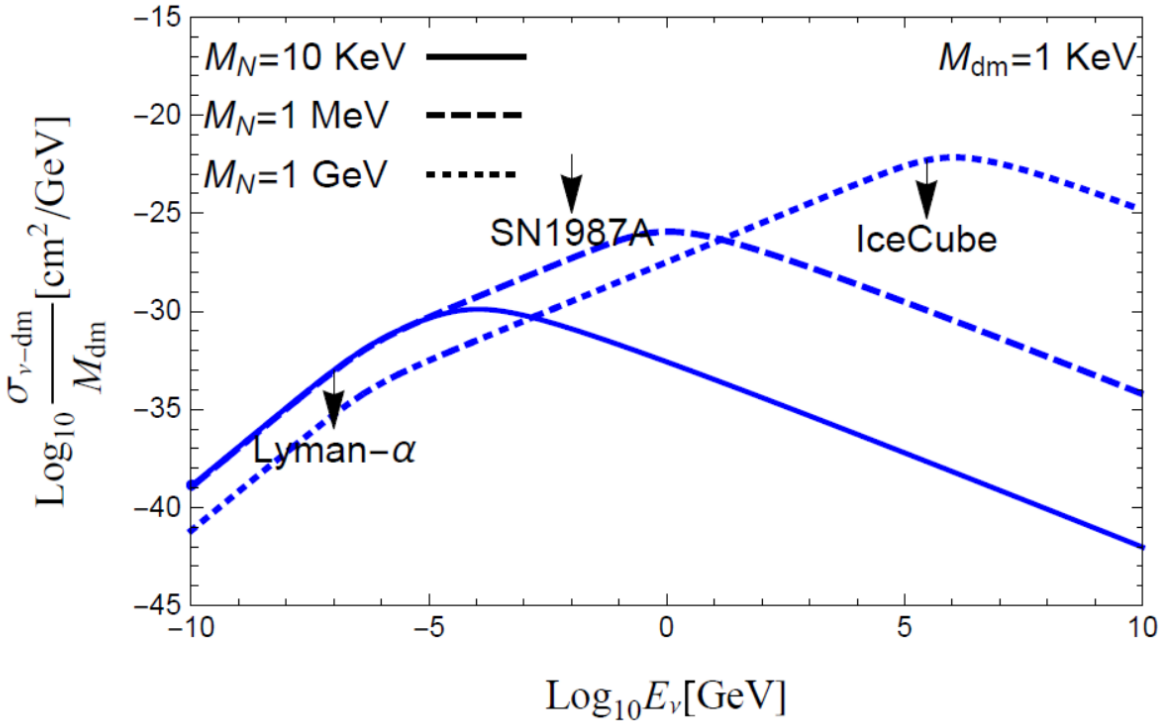
$$\sigma(E_\nu) = \sigma_0 \left(\frac{E_\nu}{1\,\mathrm{GeV}} \right)^n$$

- $\sigma_0/M_{\mathrm{dm}} \lesssim 10^{-33}\,\mathrm{cm}^2/\,\mathrm{GeV} \quad \text{for} \quad n = 0,$
  $\sigma_0/M_{\mathrm{dm}} \lesssim 6.3 \times 10^{-34}\,\mathrm{cm}^2/\,\mathrm{GeV} \quad \text{for} \quad n = 2,$
  $\sigma_0/M_{\mathrm{dm}} \lesssim 7.5 \times 10^{-45}\,\mathrm{cm}^2/\,\mathrm{GeV} \quad \text{for} \quad n = 4.$
- Stringent constraint depends on the upper bound on DM-neutrino scattering cross section

Complex scalar DM model

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

- Scattering cross section vs neutrino energy



Conclusion

- Identifying sources of astrophysical neutrinos gives us additional information

- We find new constraint on DM-ν scattering
  - Obtained from Icecube-170922A

- $\sigma/M_{\rm dm} \leq 5.1 \times 10^{-23} {\rm cm}^2/{\rm GeV}$
  - @ $E_\nu = 290$ TeV

- Certain classes of new physics models can be probed by high energy neutrinos travelling very long distances
  - Light DM model

Conclusion

- Identifying sources of astrophysical neutrinos gives us additional information

Thank you.

  - @ $E_\nu = 290\ \mathrm{TeV}$

- Certain classes of new physics models can be probed by high energy neutrinos travelling very long distances
  - Light DM model