Constraining DM-neutrino interactions with IceCube-170922A

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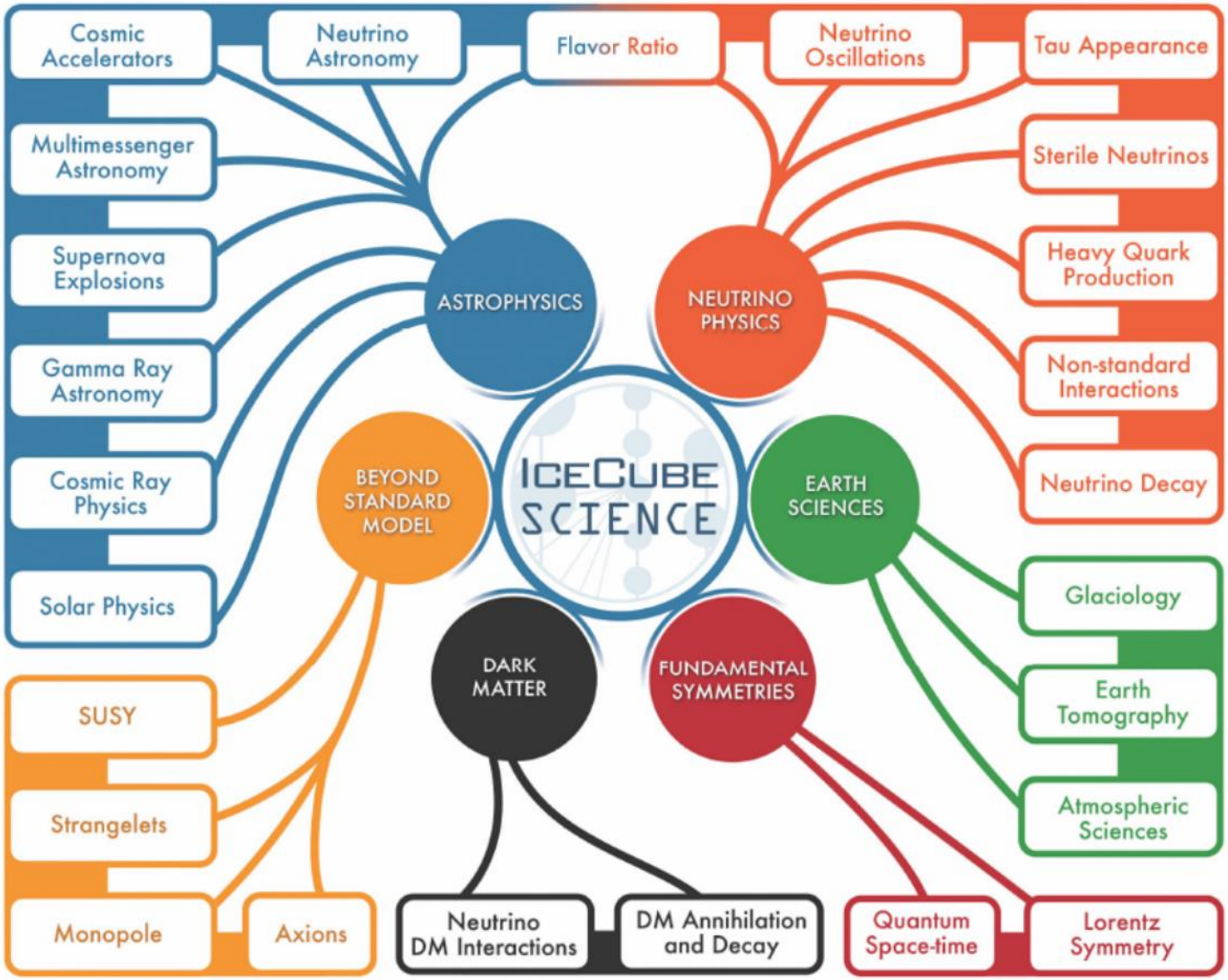
In collaboration with Prof. Ki-Young Choi, Prof. Carsten Rott

2019. 8. 14 @ Quy Nhon, Vietnam

New Physics?


IceCube Science
Astrophysics
Neutrino Physics
Beyond Standard Model
Earth Sciences
Dark Matter
Fundamental Symmetries
Cosmic Accelerators
Neutrino Astronomy
Multimessenger Astronomy
Supernova Explosions
Gamma Ray Astronomy
Cosmic Ray Physics
Solar Physics
Flavor Ratio
Neutrino Oscillations
Tau Appearance
Sterile Neutrinos
Heavy Quark Production
Non-standard Interactions
Neutrino Decay
Glaciology
Earth Tomography
Atmospheric Sciences
SUSY
Strangelets
Monopole
Axions
Neutrino DM Interactions
DM Annihilation and Decay
Quantum Space-time
Lorentz Symmetry

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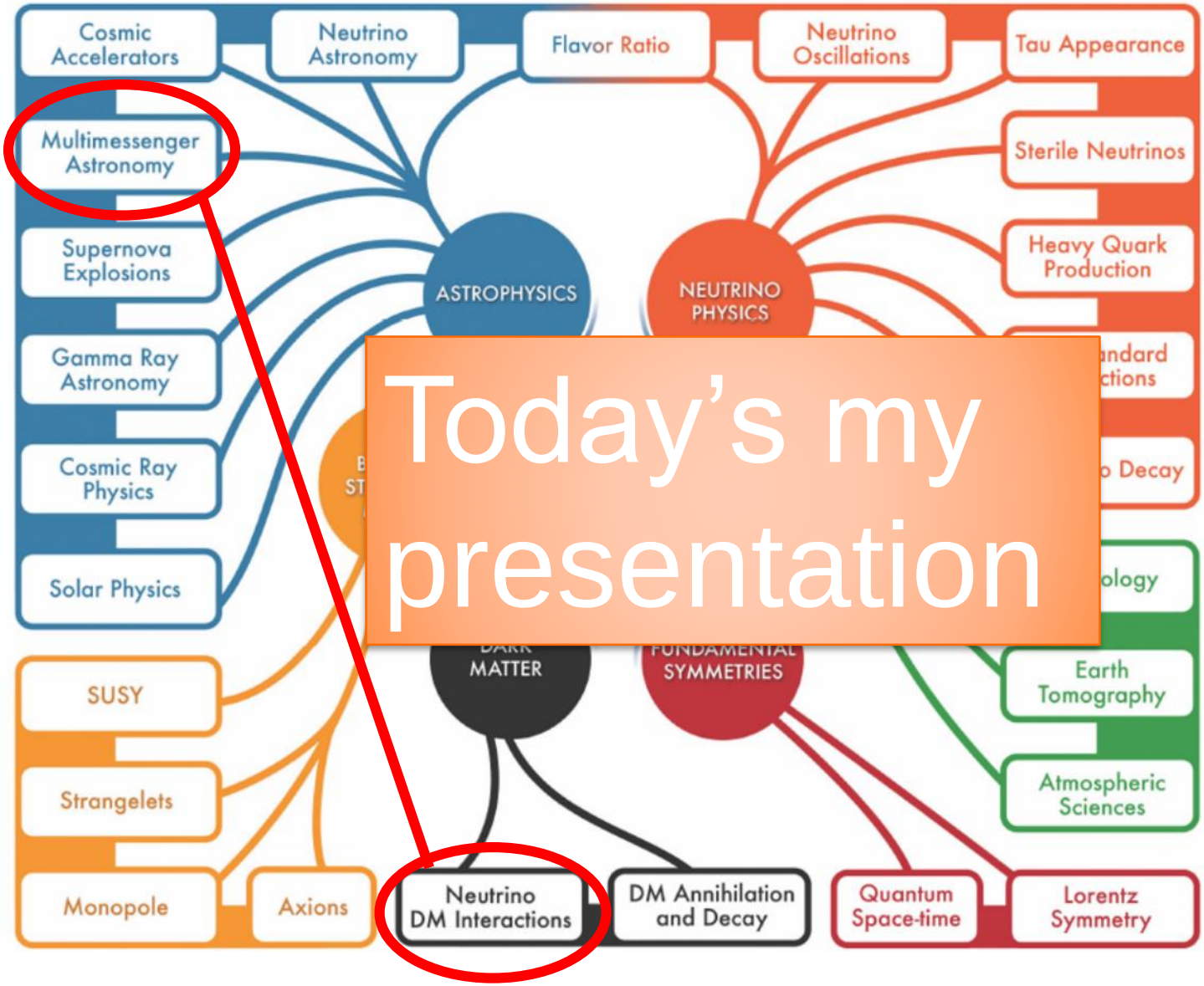
- 
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Today's my presentation
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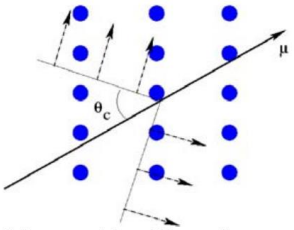
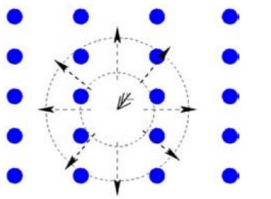
IceCube Telescope

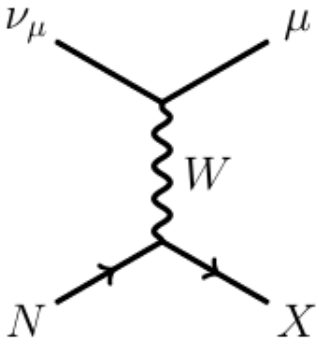
- Neutrinos might interact in or near the detector
- Neutrinos are identified through Cherenkov light emission from secondary particles produced in the neutrino interaction with the ice

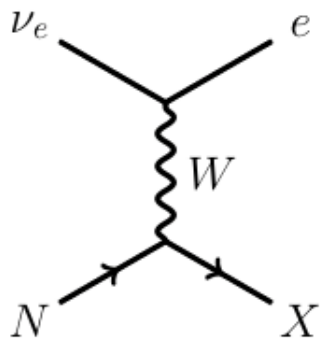


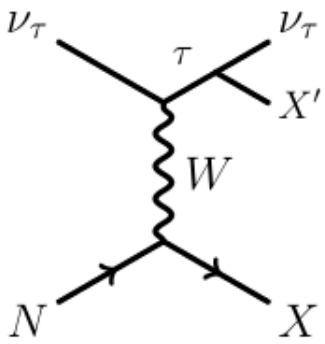
Muon, with a Cherenkov cone



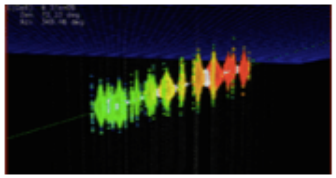
Electromagnetic cascade, spherical Cherenkov front.



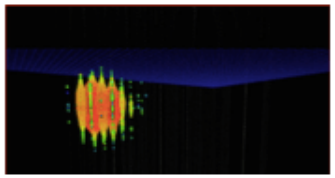




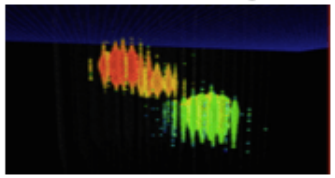
track

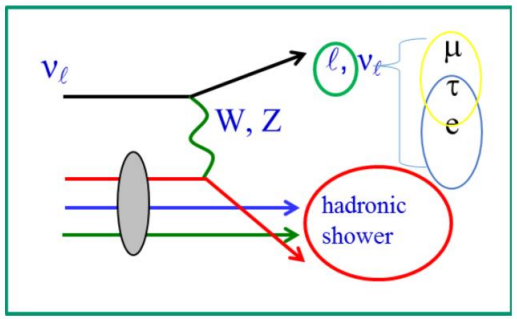


shower



double bang*

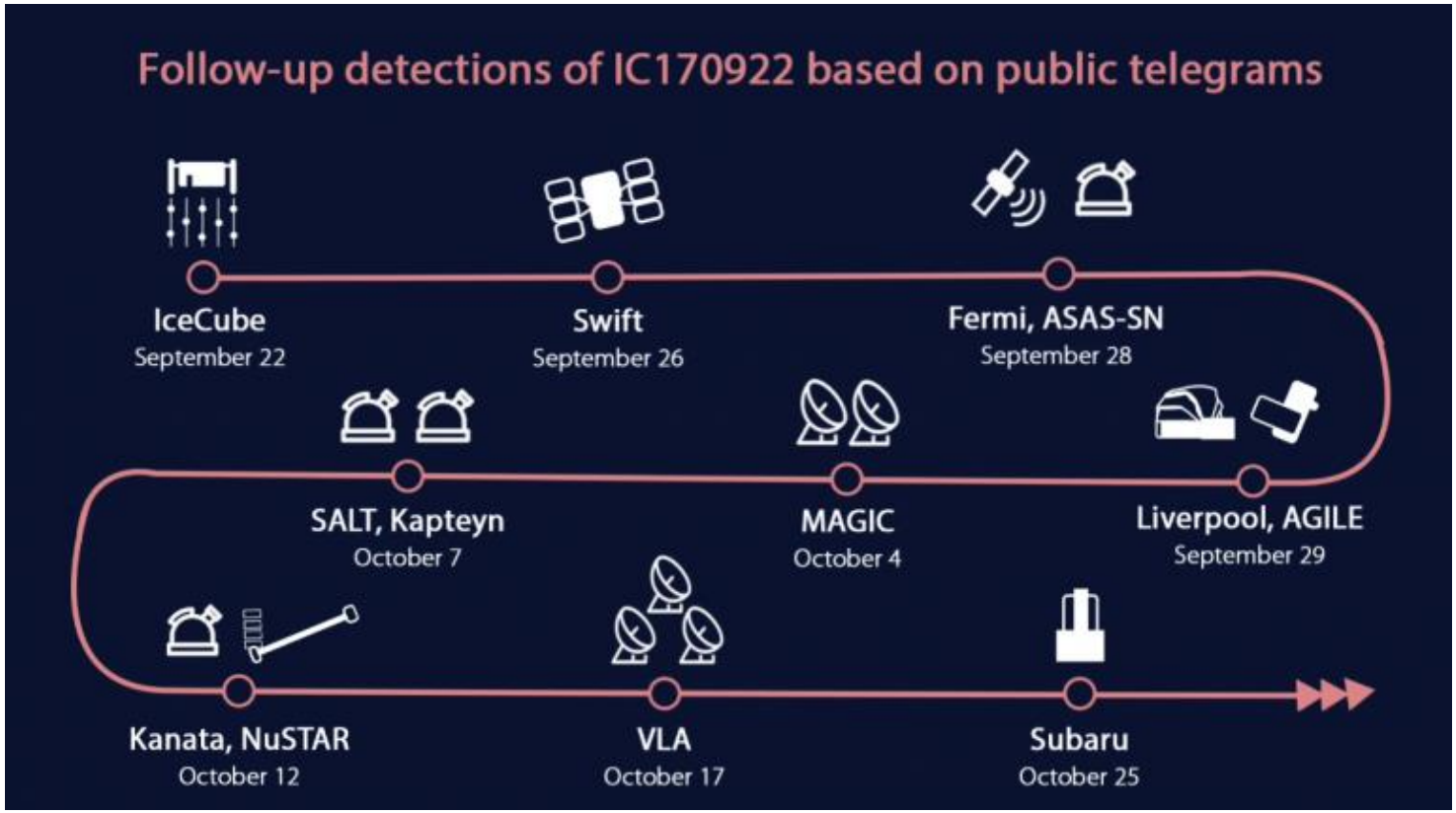




IceCube-170922A

IceCube 2018 Science

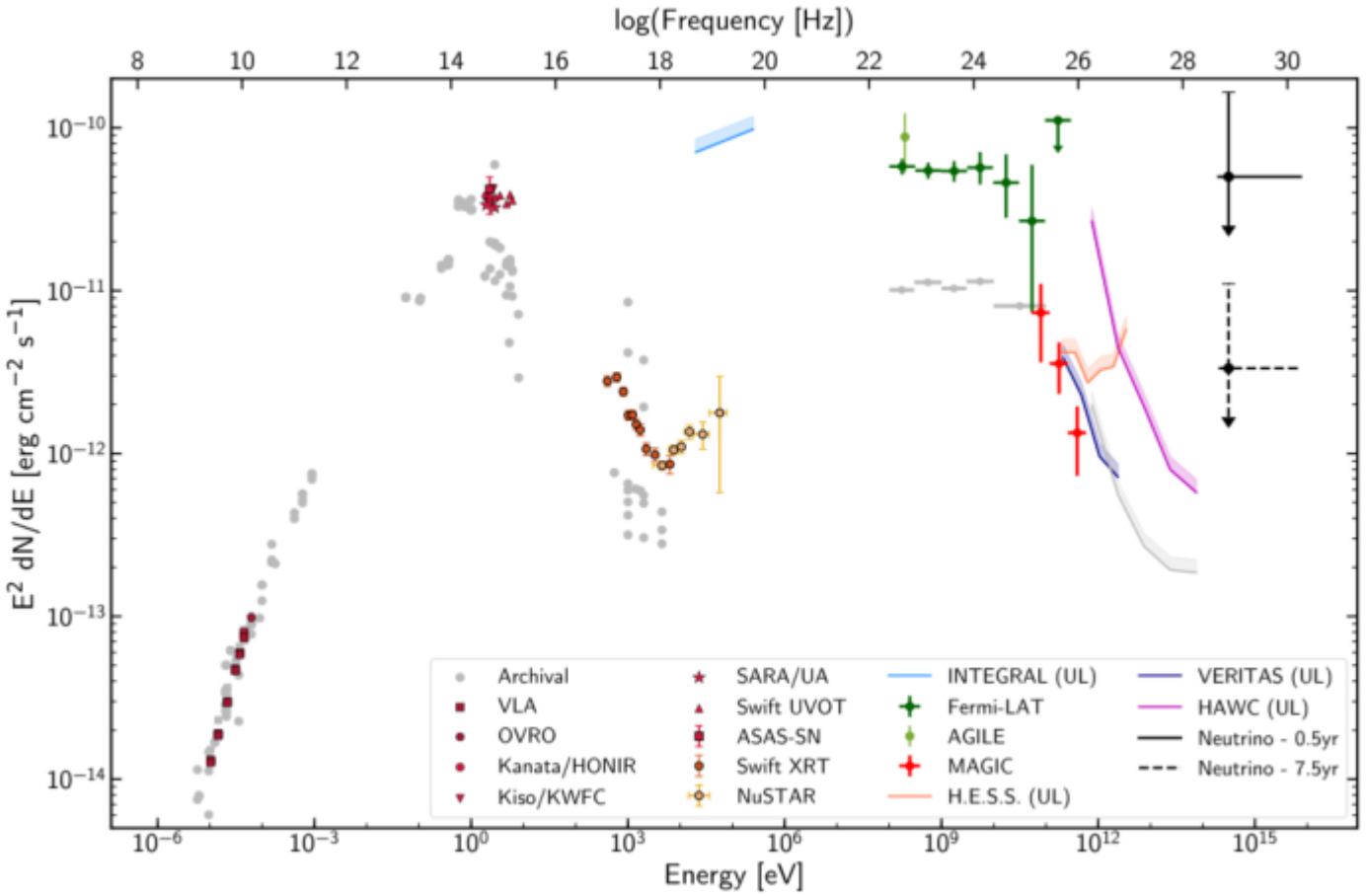
- September 22, 2017
  - A neutrino alert issued by IceCube



IceCube-170922A

IceCube 2018 Science

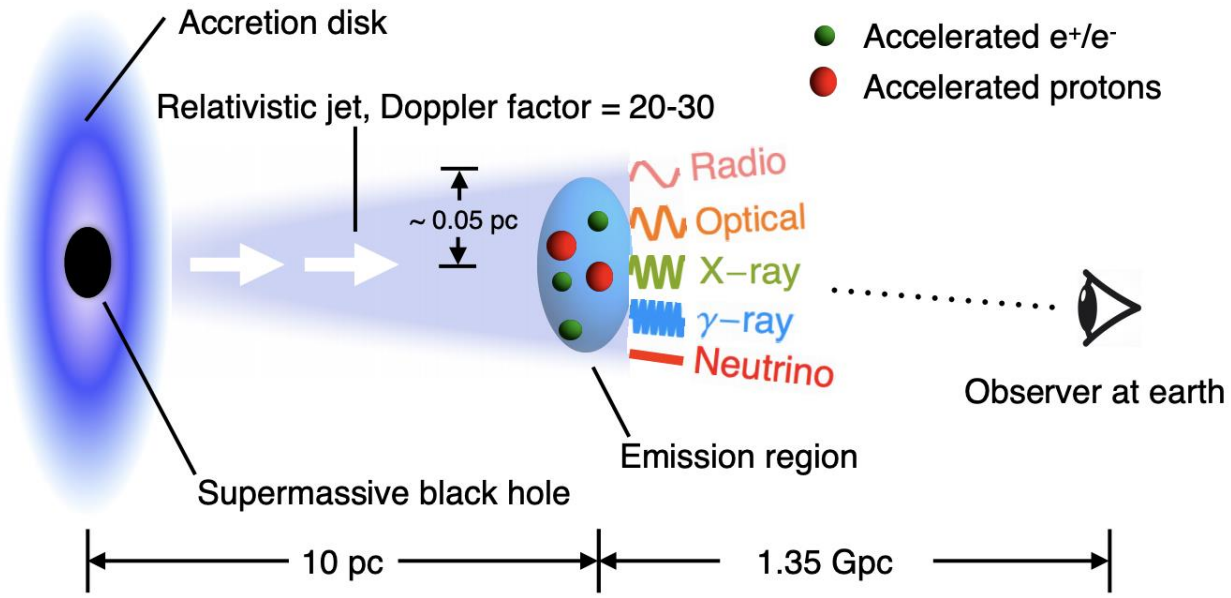
- Fermi-LAT and MAGIC identify a spatially coincident **flaring blazar** (TXS 0506+056)



Flaring blazar

Shan Gao et al, 2018
Lots of Astrophysics papers

- Blazar model
  - In the center, supermassive black hole
  - Emit relativistic jets → electron, positron, proton



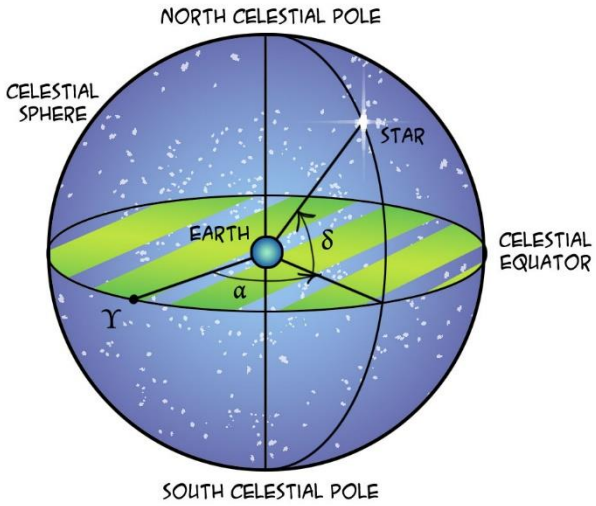
IceCube-170922A

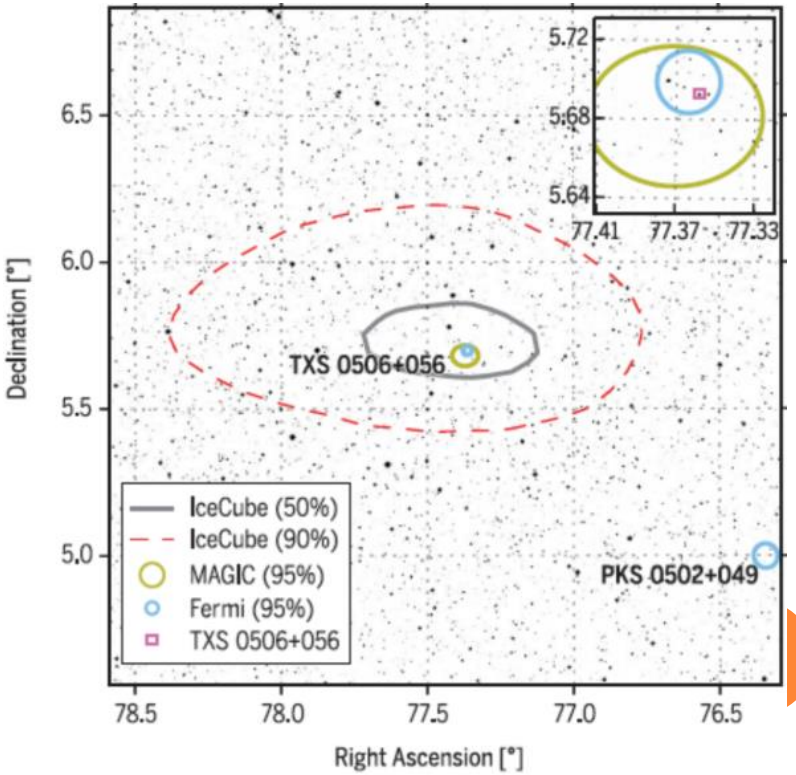
- Icecube-170922A
  - TXS 0506+056 determined to be z = 0.3365
  - 1421 Mpc
  - Right ascension: 77.42, Declination: 5.72

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 a neutrino/anti-neutrino or DM

- A new physics model can be constrained

Coordinate transformation

- From equatorial coordinates to Galactic coordinates

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

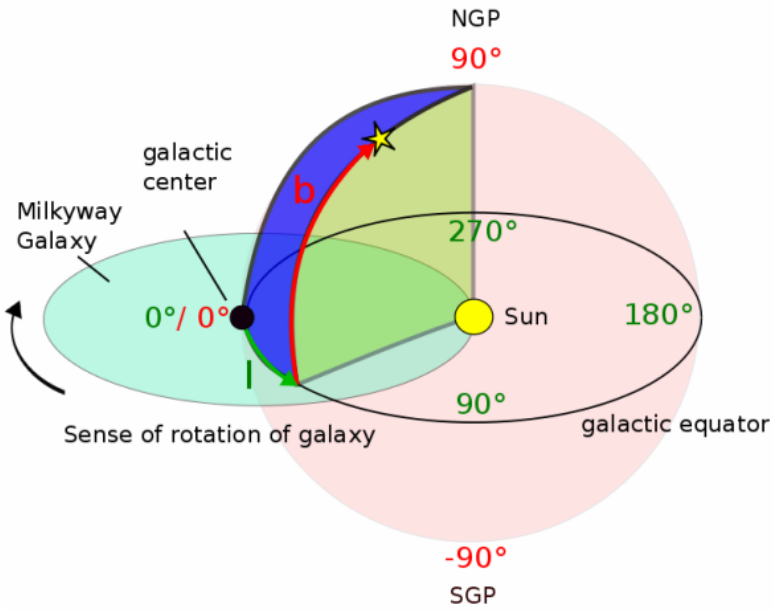
$$\sin(b) = \sin(\delta)\sin(\delta_0) + \cos(\delta)\cos(\delta_0)\cos(\alpha - \alpha_0)$$

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-170922A
  - b = -19.6 degree
  - l = 15.4 degree



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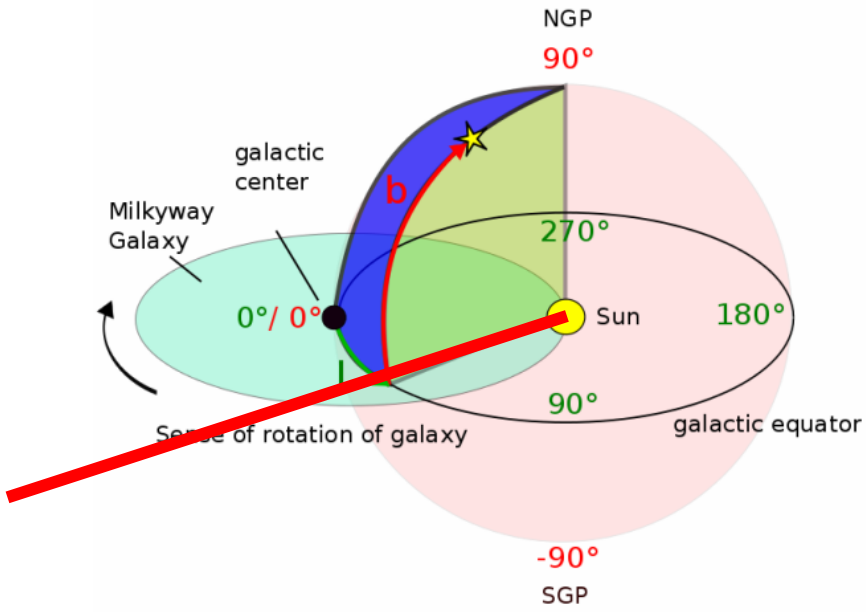

Galactic coordinate

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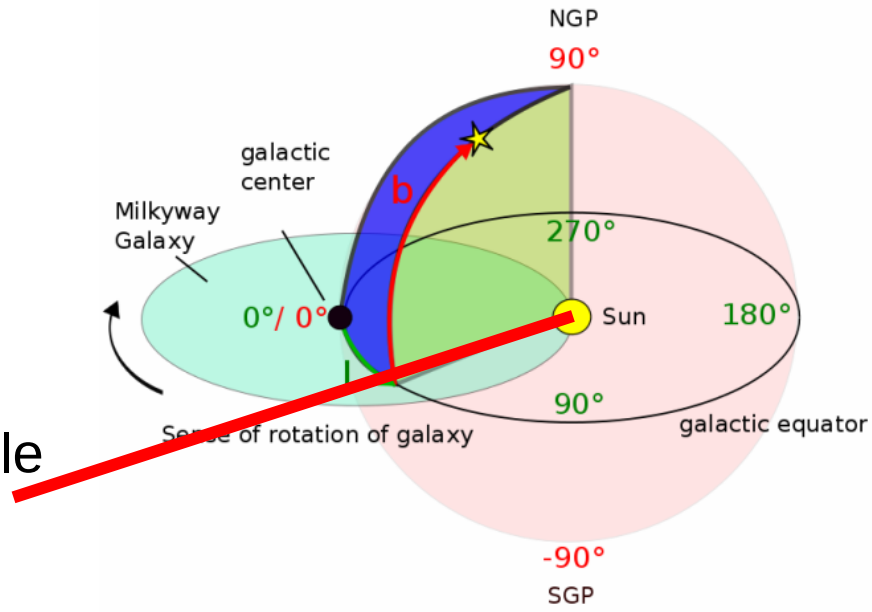
- Not travel through GC
  - Not depends on DM profile



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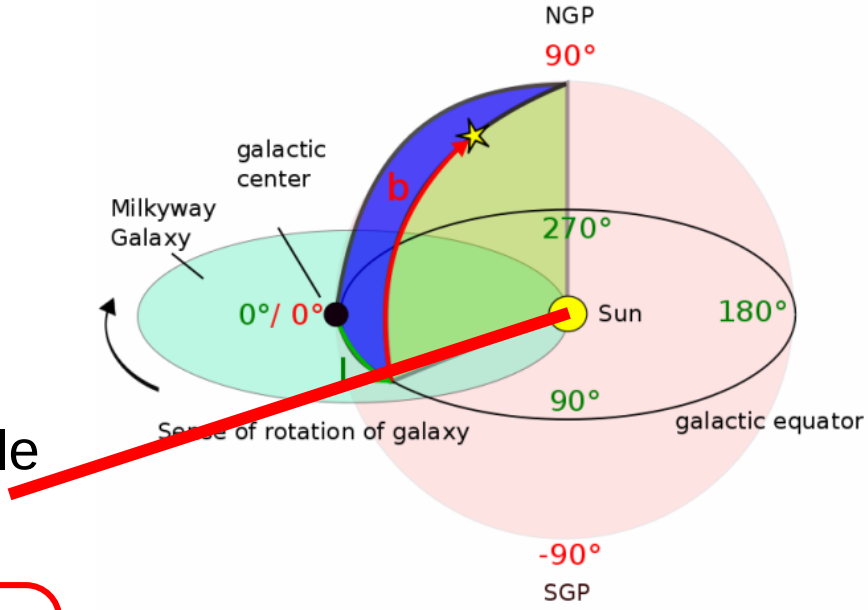

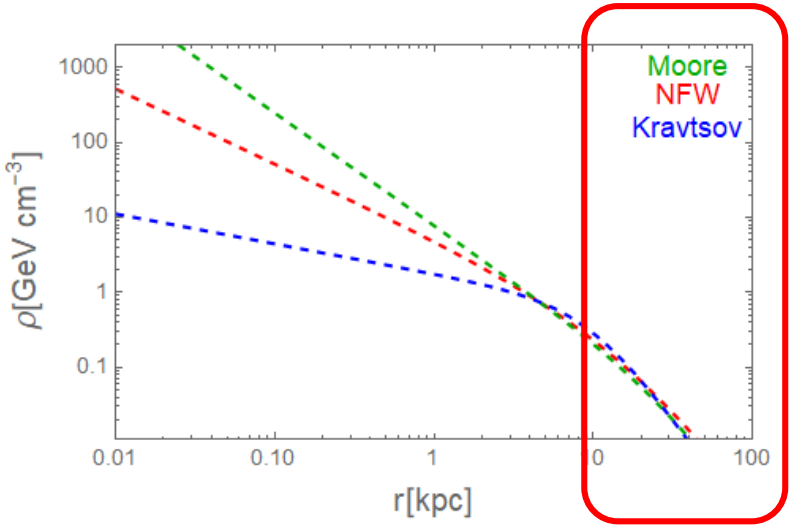

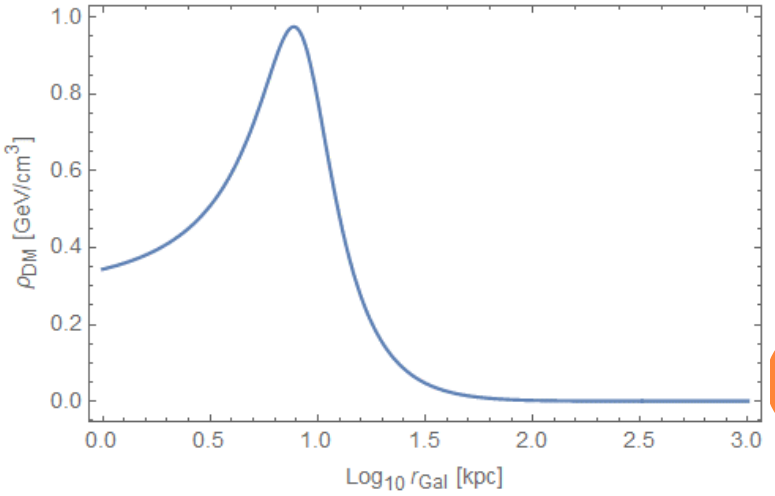

Cosmic neutrino background

- If sizable v-CvB interaction exists, scattering off the v-CvB can cause a depletion of the detected neutrino events

- Scattering cross section between
  - Icecube-19022A neutrino and Cosmic neutrino background
  - Number density of the CvB: 340/cm^3

- Mean free-path of a 290 TeV neutrino
  - O(10^11) Gpc
  - Negligible effect in the SM
  - New neutrino self-interactions can be tested

K. J. Kelly & P. A. Machado, arXiv:1808.02889

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

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

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

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

Dissipation of neutrino flux

- The suppression can be divide into two contributions

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

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

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- 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
  - $$\int_{los} \rho(z)\, dl = \int \rho(z) \frac{cdt}{dz} dz,$$
    $$\simeq 7.2 \times 10^{21}\,\text{GeV/cm}^2.$$

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

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

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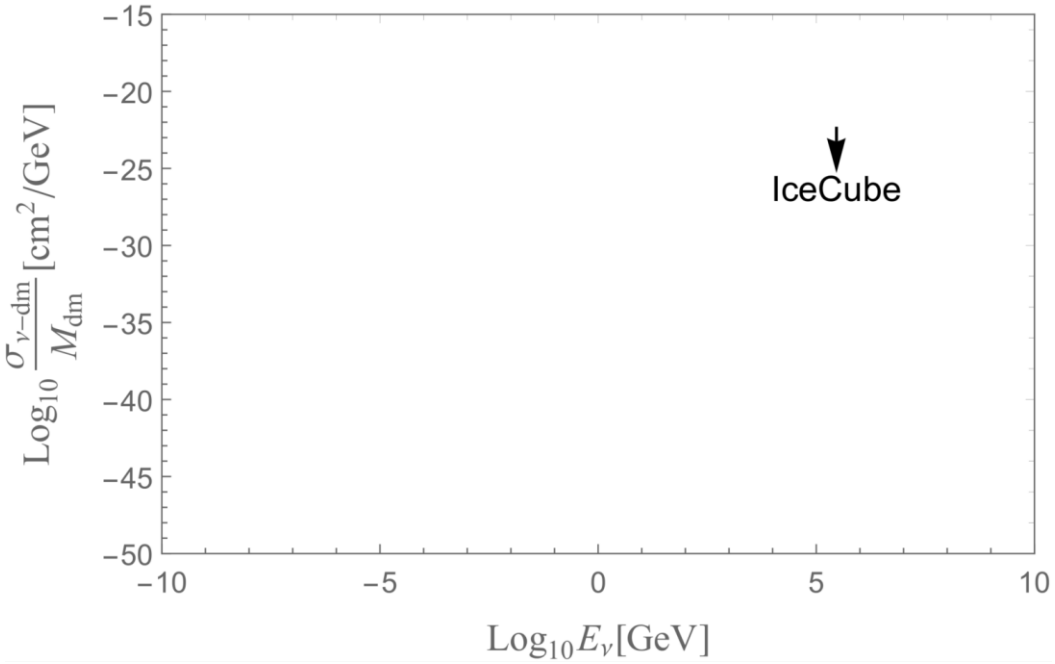
- Incidentally both contributions from cosmological DM and Milky Way DM are very comparable
  - Very tiny cosmological DM density is compensated by the long distance

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

New constraint



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

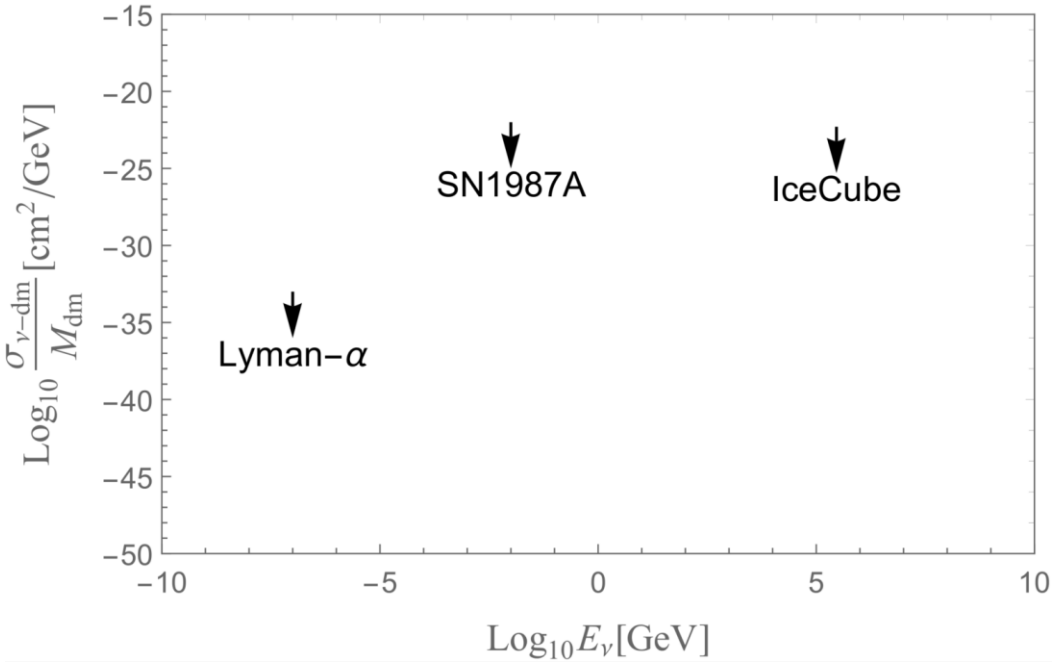
G. Barbiellini, G. Cocconi, 1987

- 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



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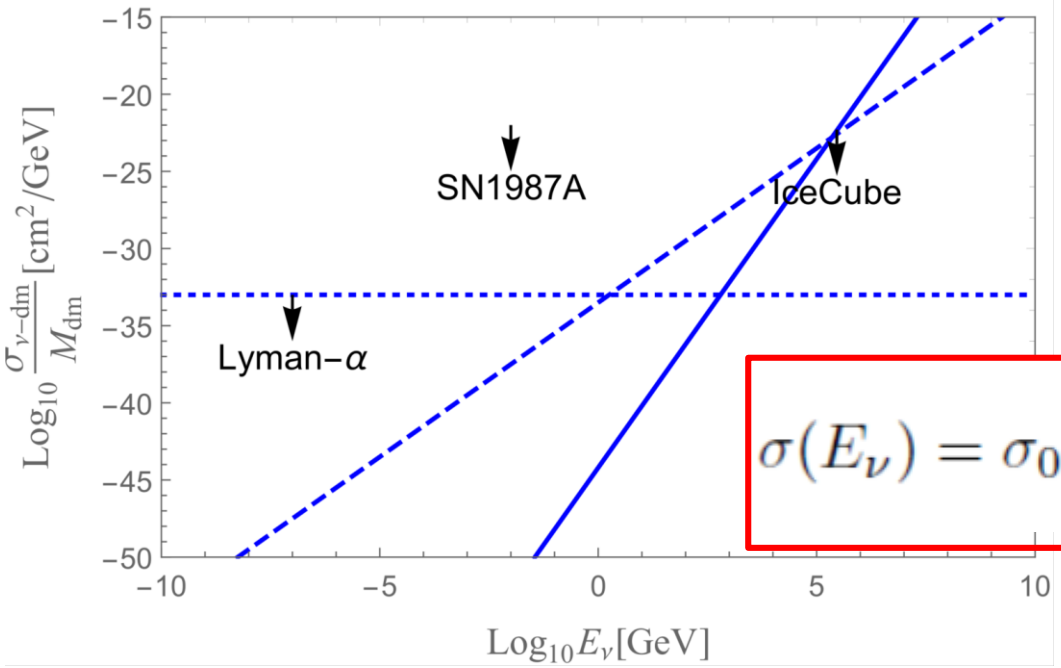


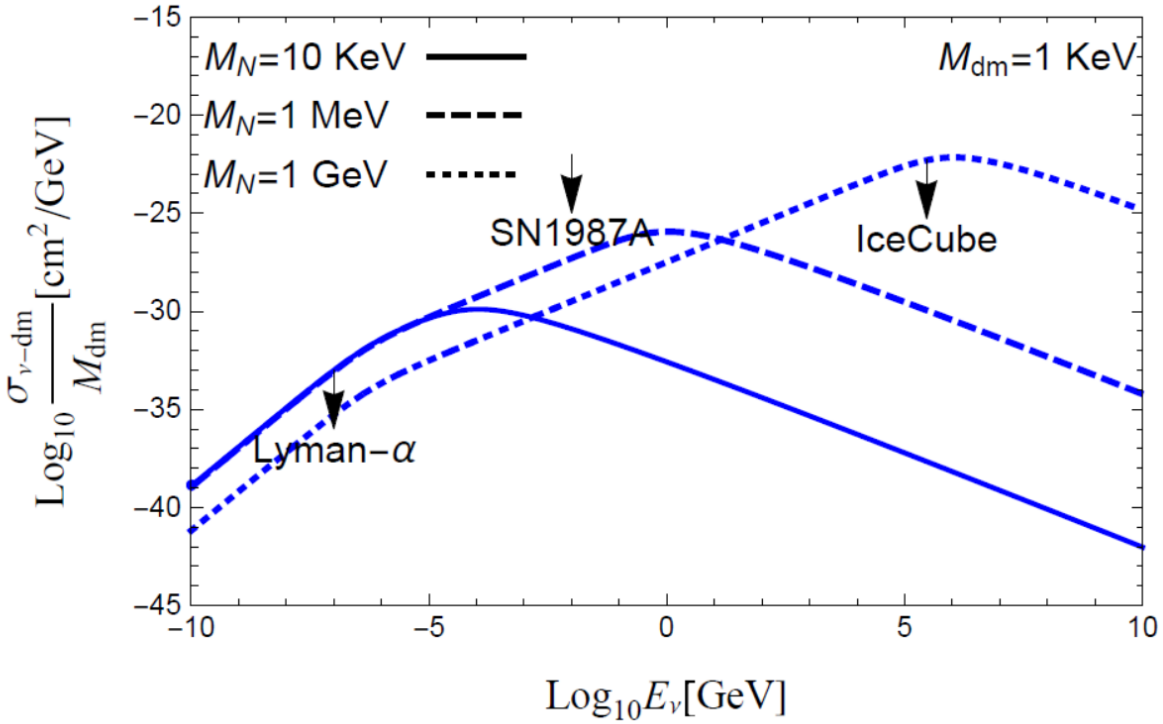
$$\sigma(E_\nu) = \sigma_0 \left(\frac{E_\nu}{1\,\mathrm{GeV}} \right)^n$$

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

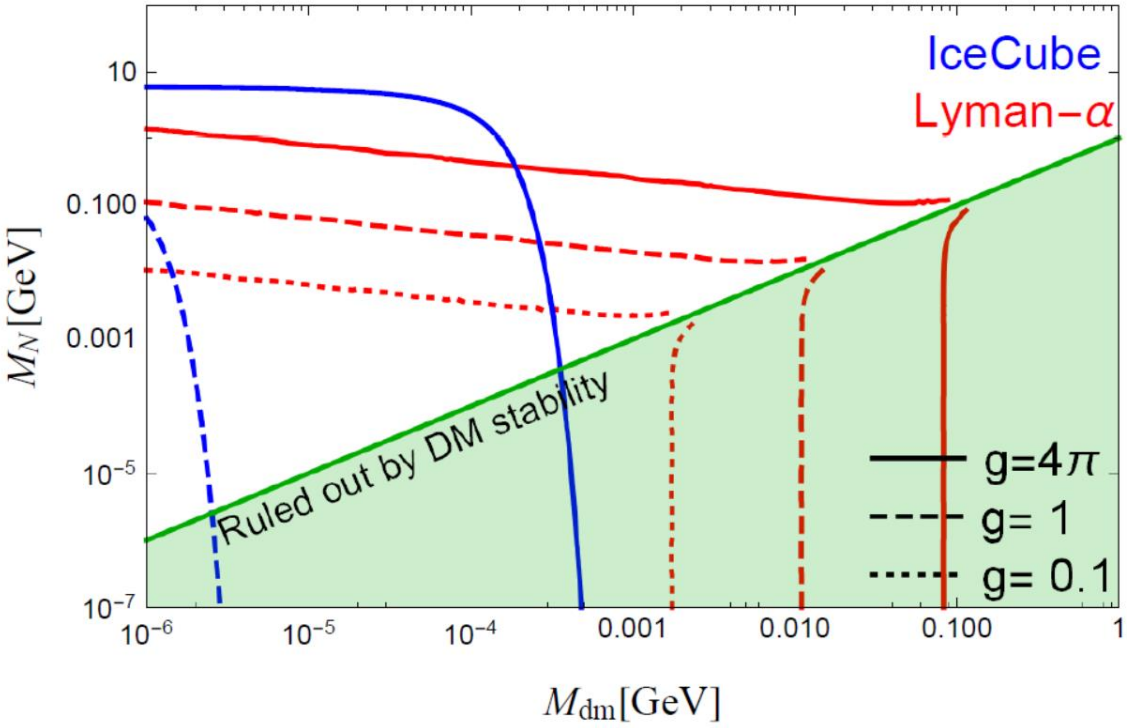
Complex scalar DM model

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

- Scattering cross section vs neutrino energy

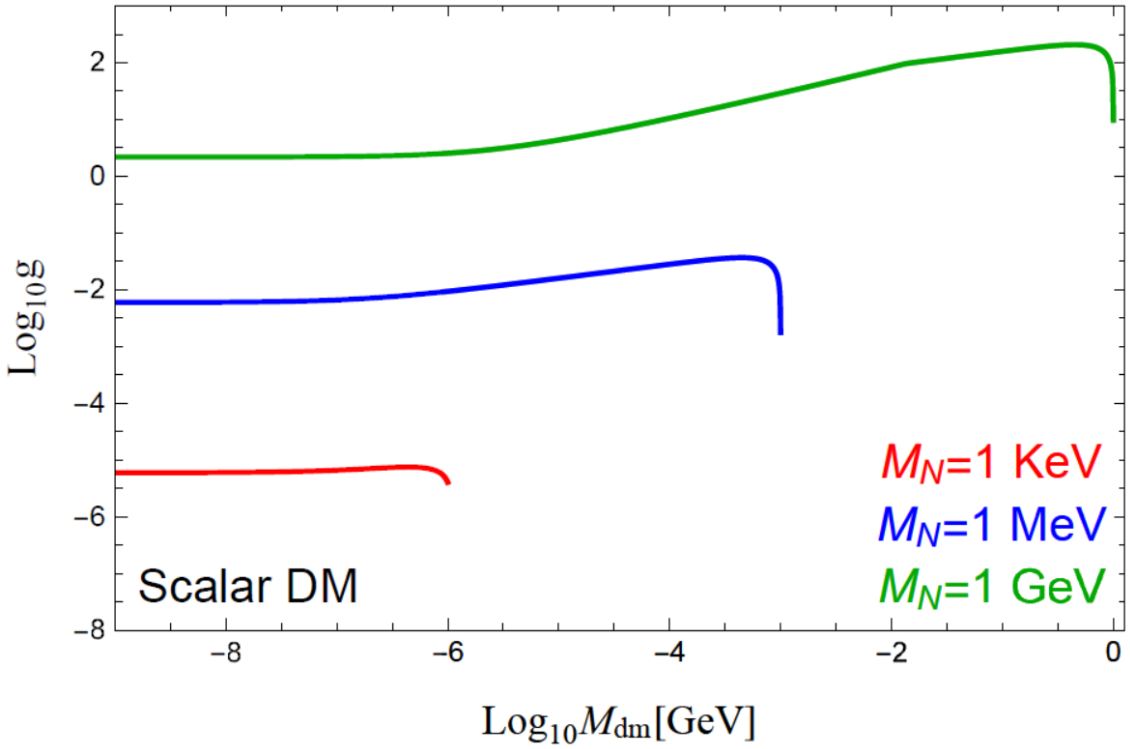


Complex scalar DM model



- Upper & right region are allowed
  - Blue: IceCube-170922A
  - Red: Lyman alpha
- Green region: ruled out by DM stability

Complex scalar DM model



- Maximum values of (g vs M_{dm})

Conclusions

- 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