Neutrino self-interaction effect in signals from Blazar TXS 0506+056

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Collaboration with
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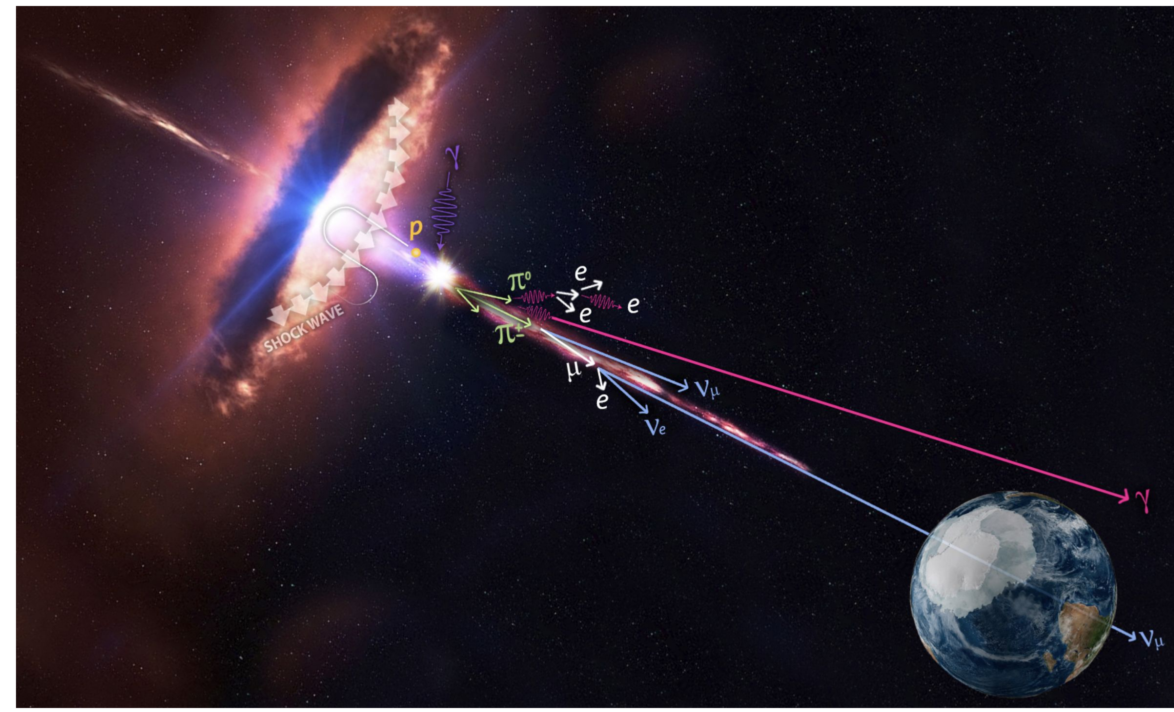
Multi-messenger observation from Blazar TXS 0506+056

- Blazar : AGN w/ a relativistic jets (mostly energetic p^+, e^- above PeV scale)



- By the scatterings with X-ray photons or synchrotron radiations,
  - photopion prod. $p\gamma_{\rm bkg} \to p\pi^0, n\pi^+$

    $\pi^0 \to \gamma\gamma$ $\quad \pi^+ \to \mu^+\nu_\mu$ $\quad n \to pe\nu_e$

    $\mu \to e\nu\bar{\nu}$
  - inverse compton $e\gamma_{\rm bkg} \to e\gamma$

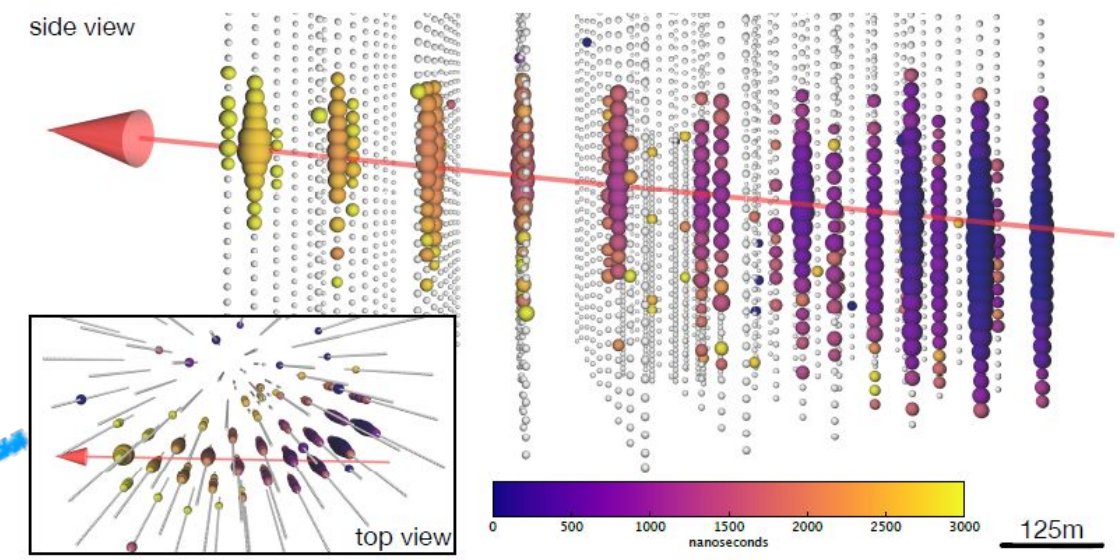
- Usually both energetic neutrino around O(100) TeV - O(100) PeV and multi-wavelength (from optical to gamma-rays) photon fluxes are expected.

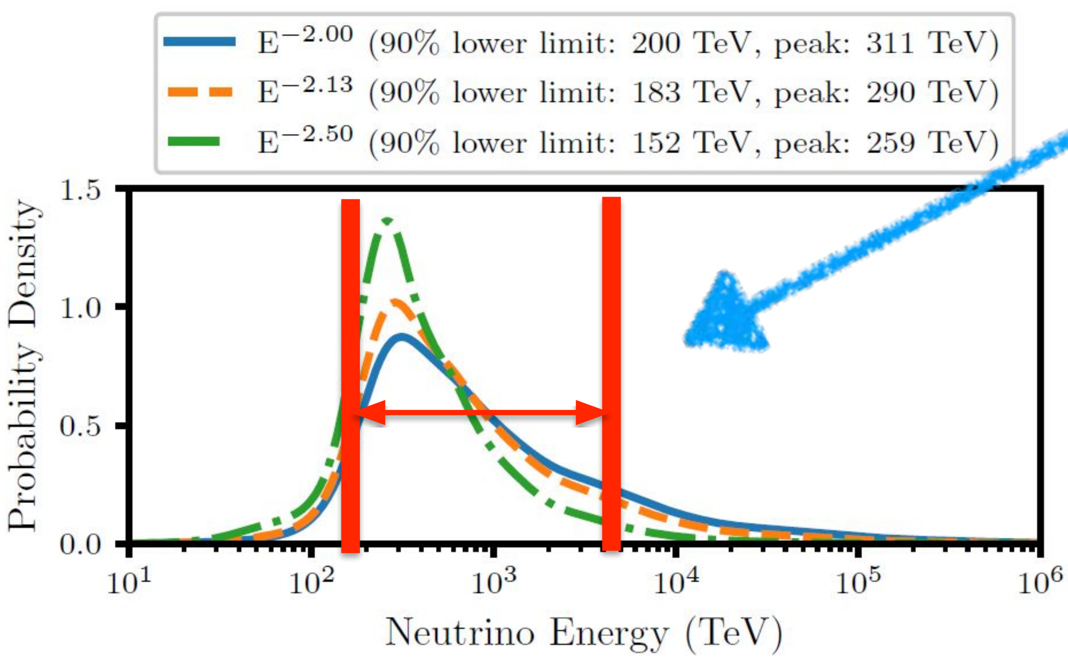
Multi-messenger observation from Blazar TXS 0506+056

- ν flare in TXS 0506+056 (2017) : the first complete set of multi-messenger observation including **both photon and neutrinos** from the **same astrophysical source**.

Science 361 (2018) eaat1378 [1807.08816]

O(100) TeV high E neutrino IceCube

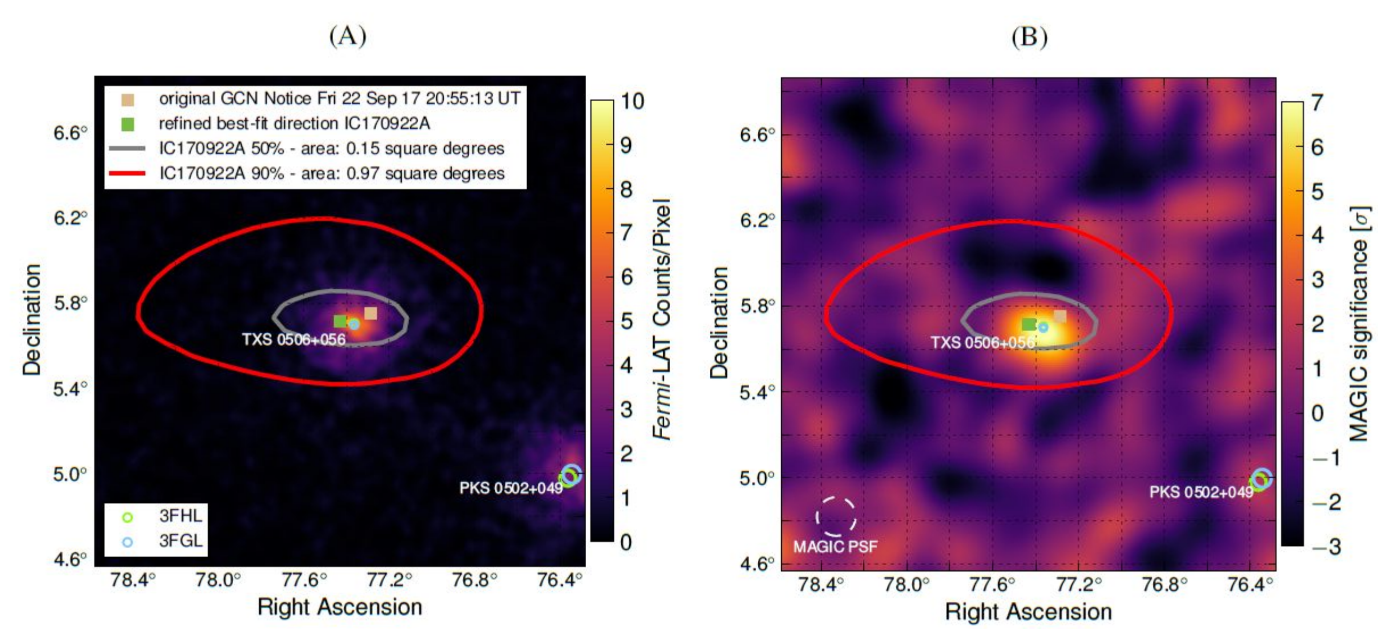




$E_\nu = 290\ \mathrm{TeV}$ **high E muon neutrino**

$183\ \mathrm{TeV} \le E_\nu \le 4.3\ \mathrm{PeV}$ at 90% C.L.

Gamma rays O(1-100) GeV



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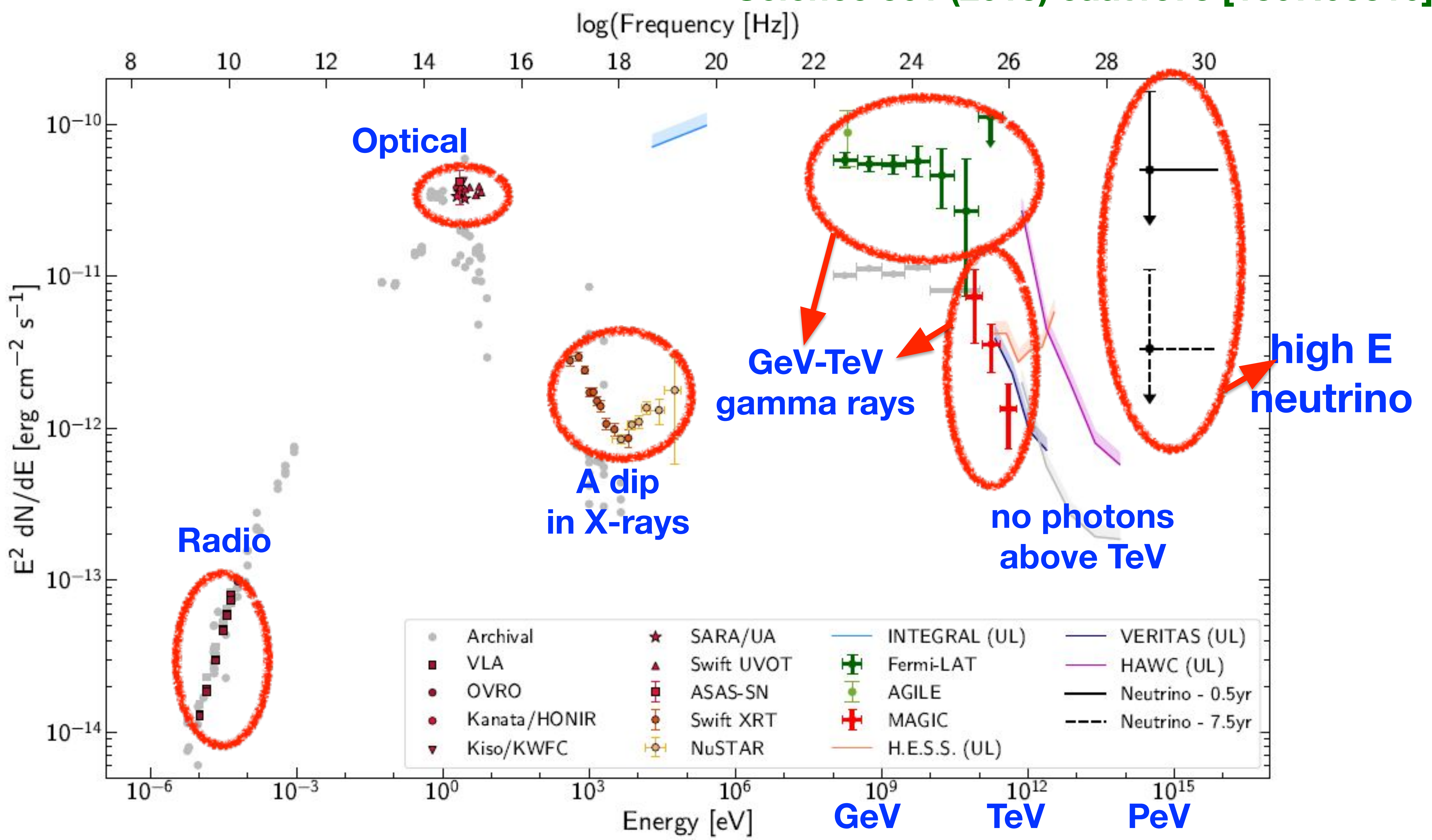
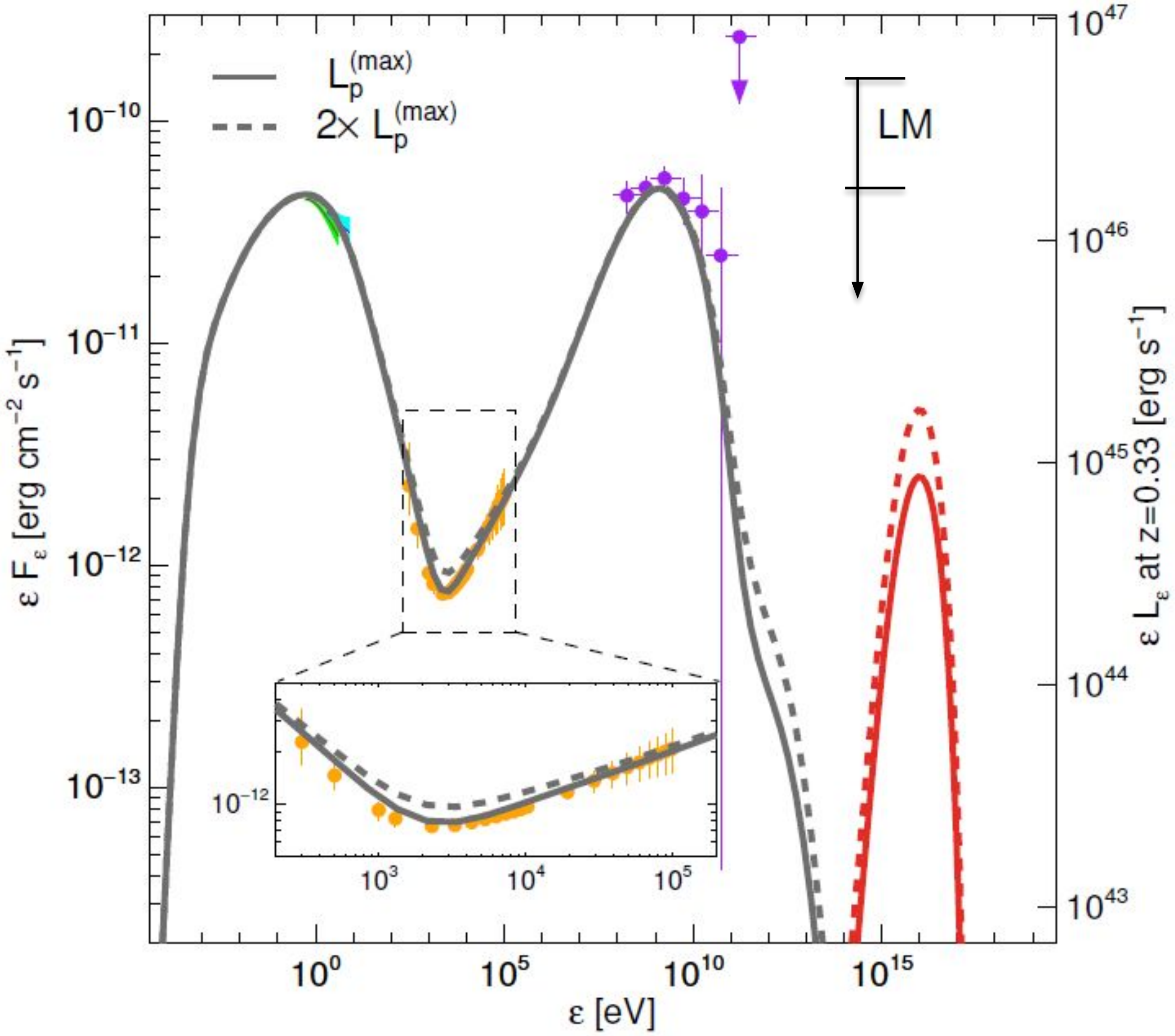
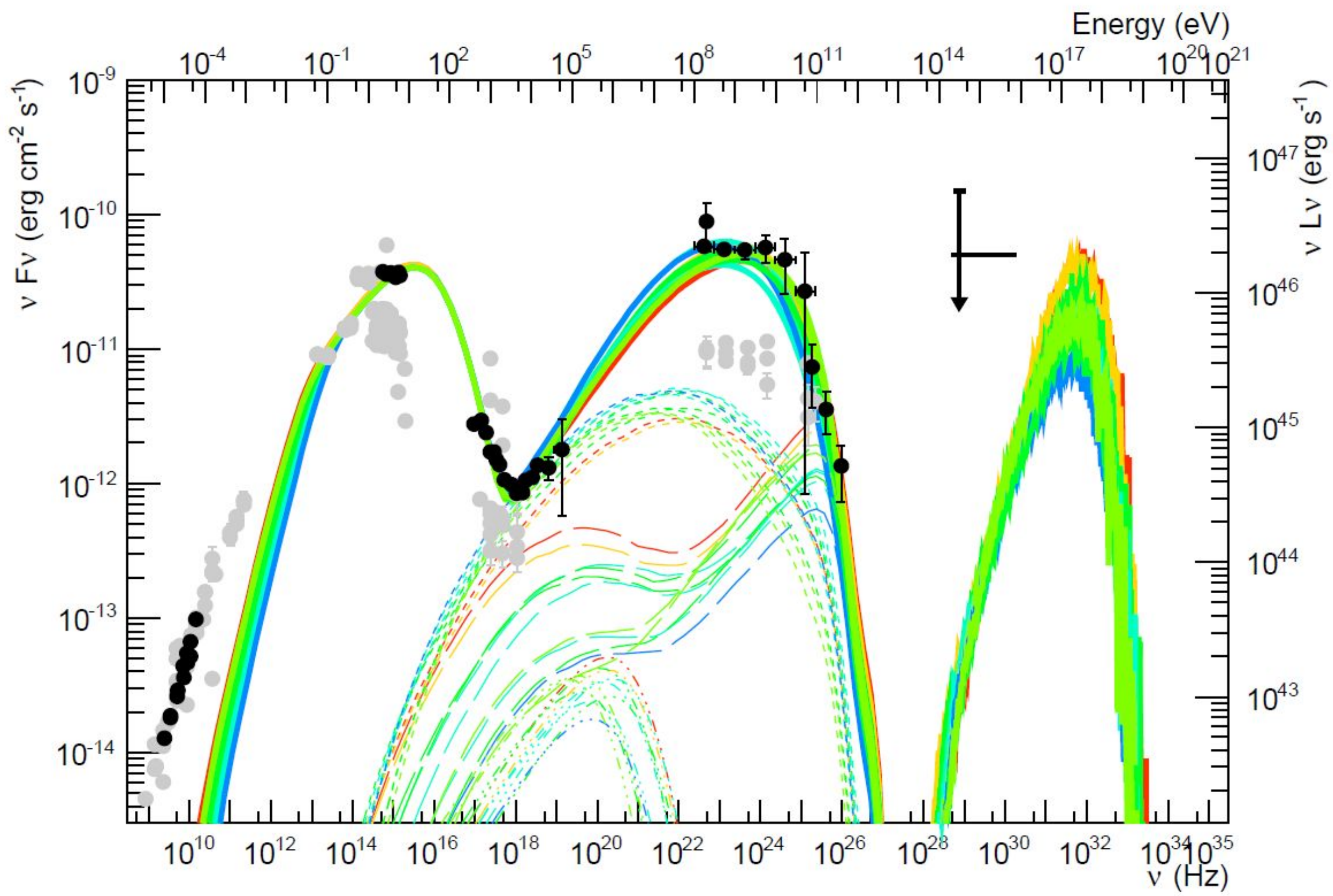


Astrophysical models for Blazar



A. Keivani et al. [1807.04537]



M. Cerruti et al. [1807.04335]

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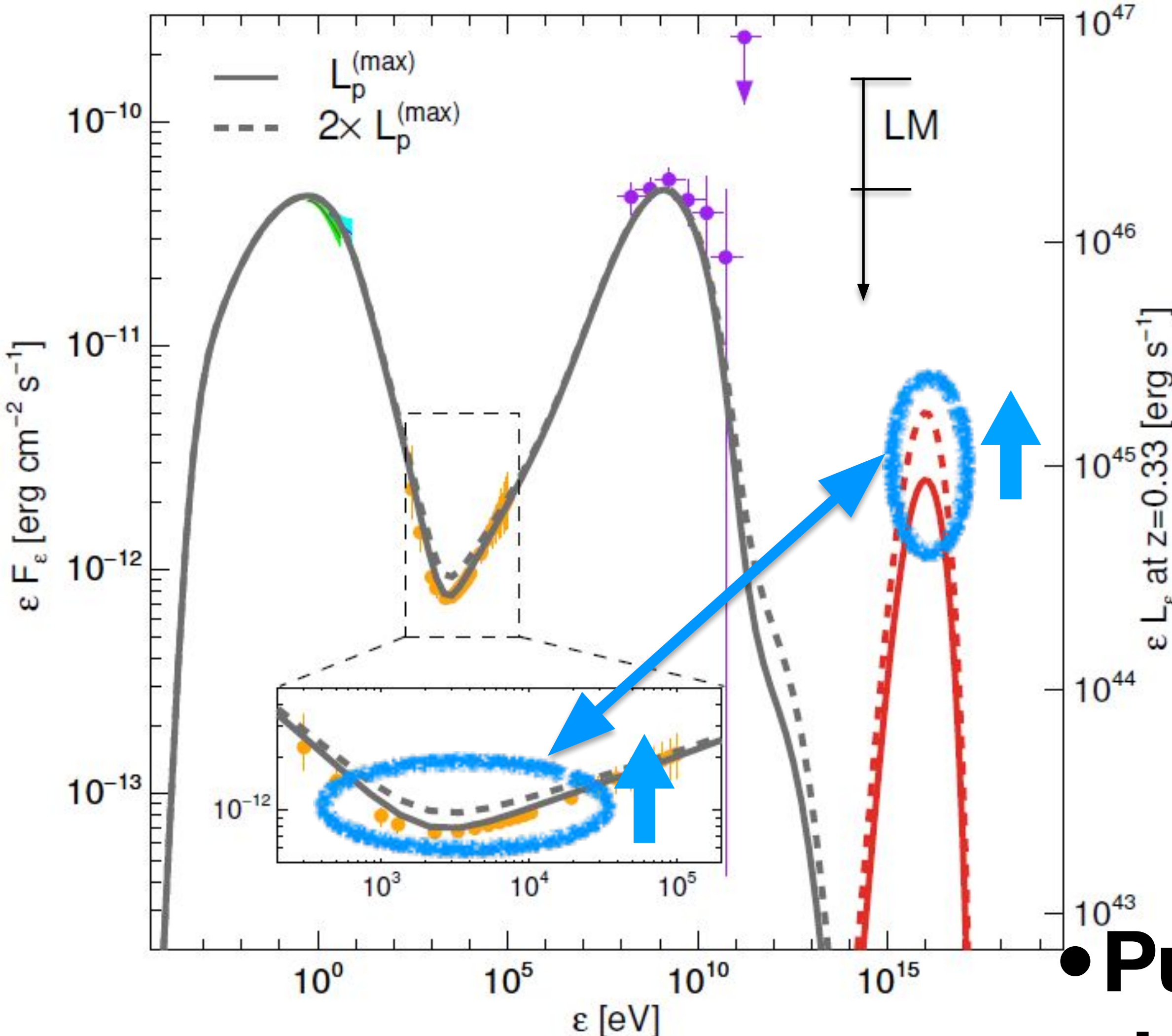

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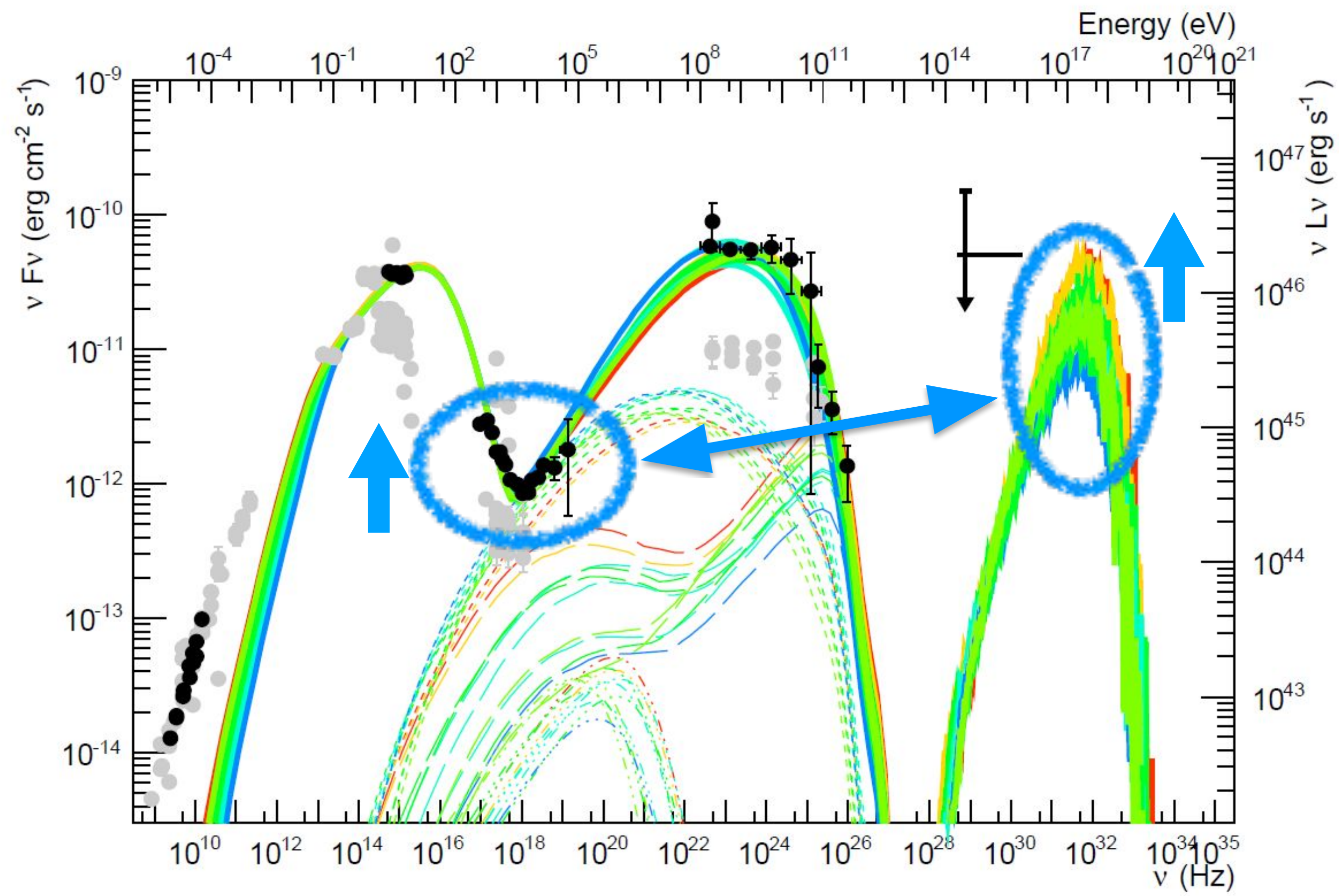

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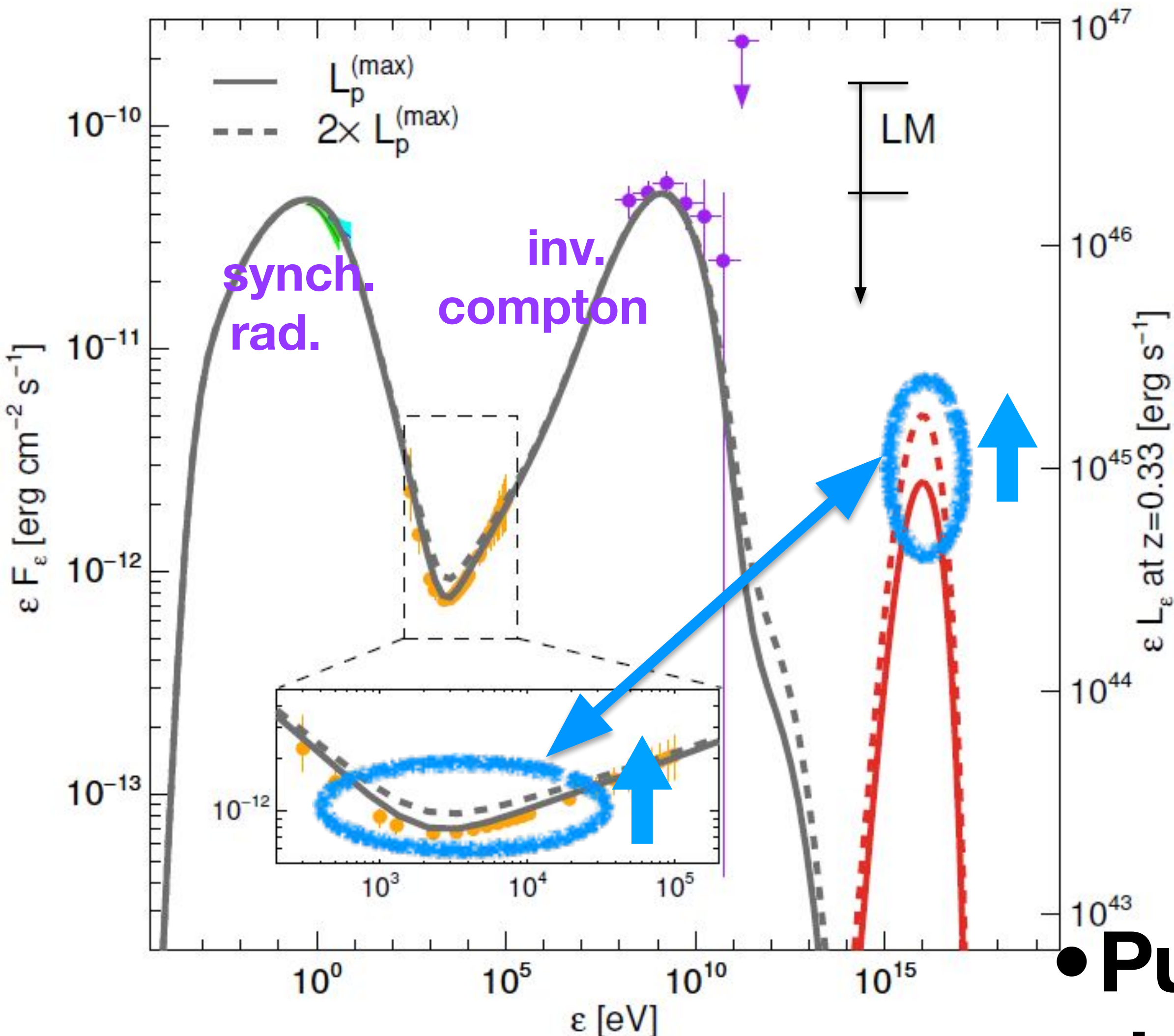

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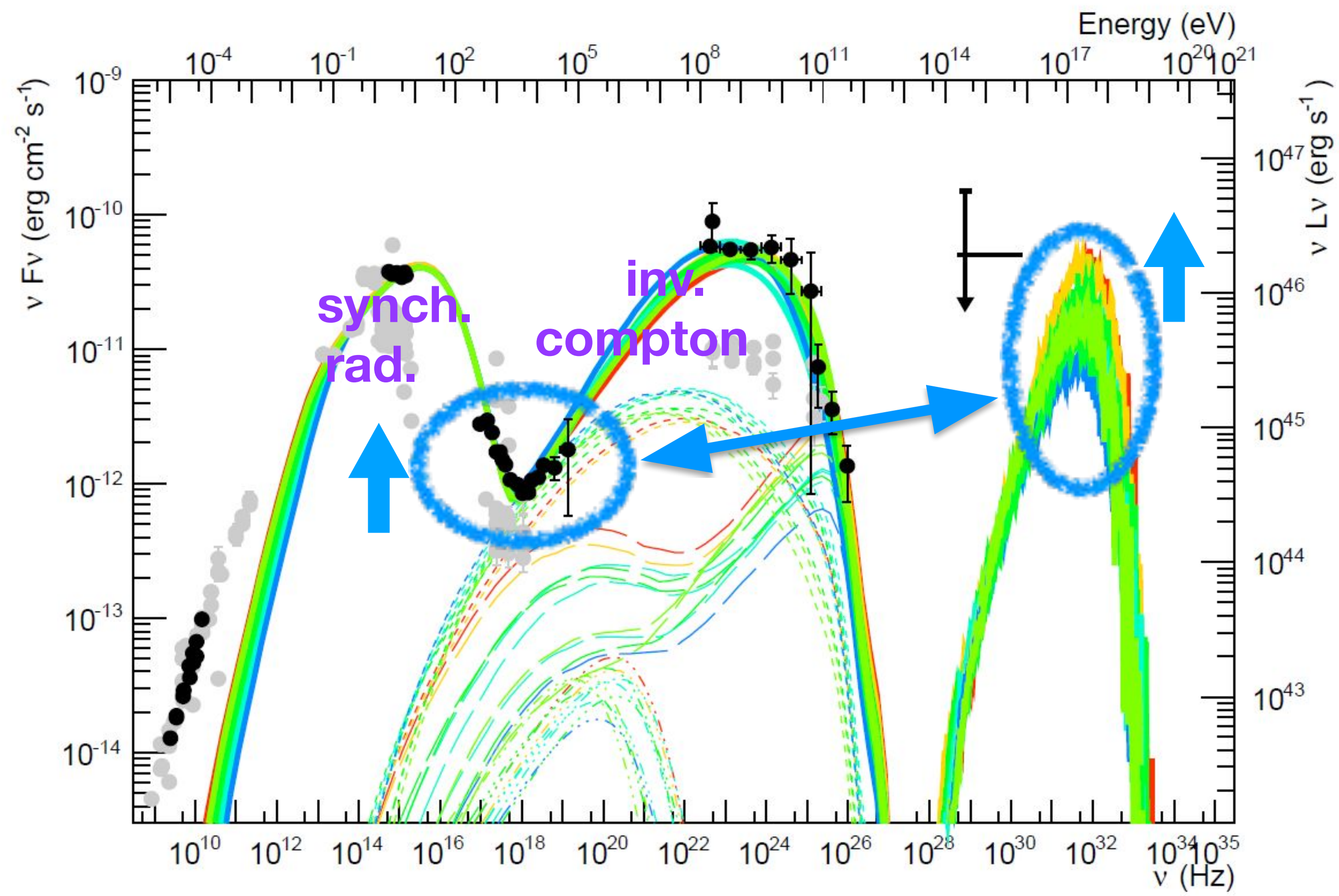

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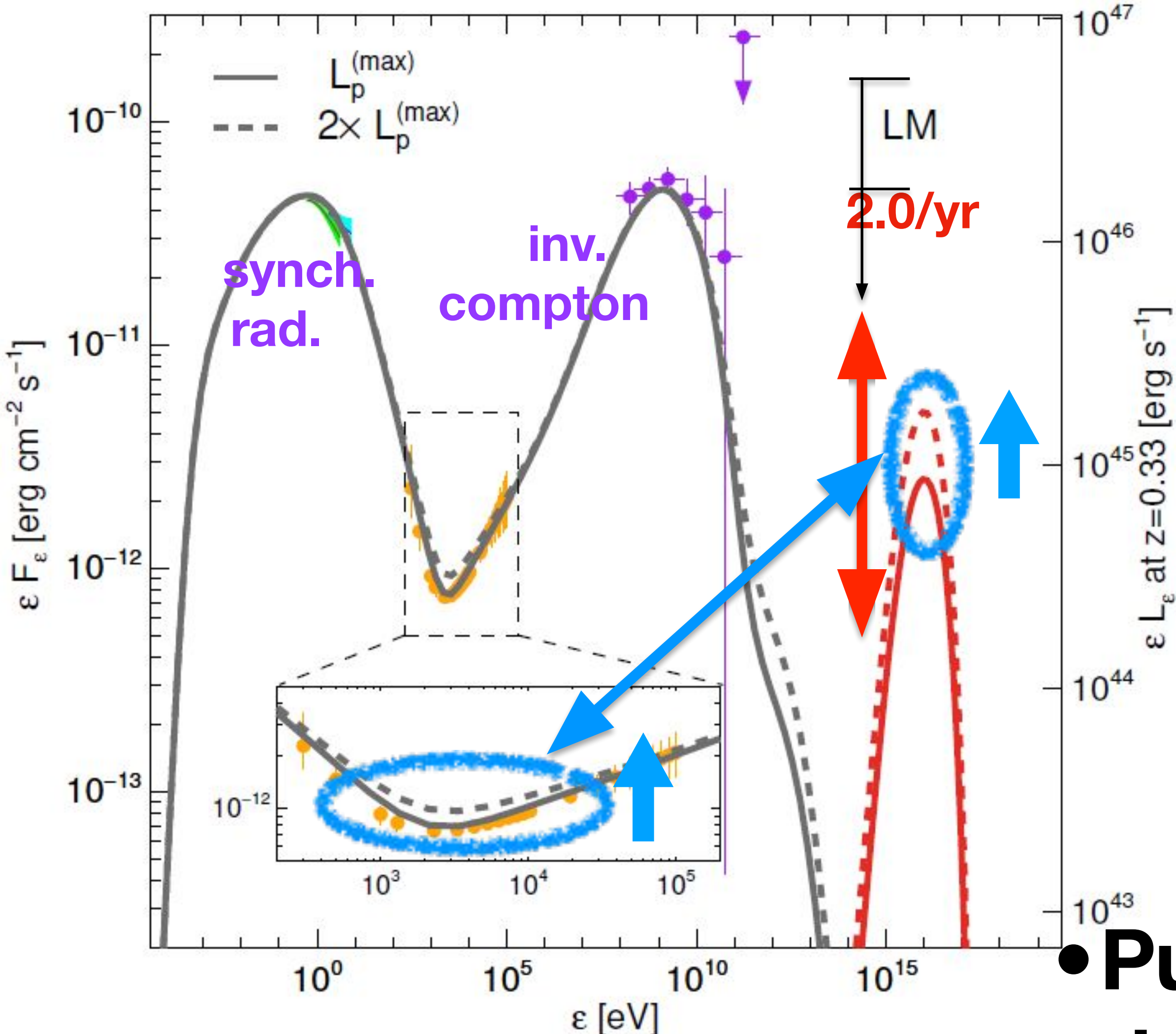

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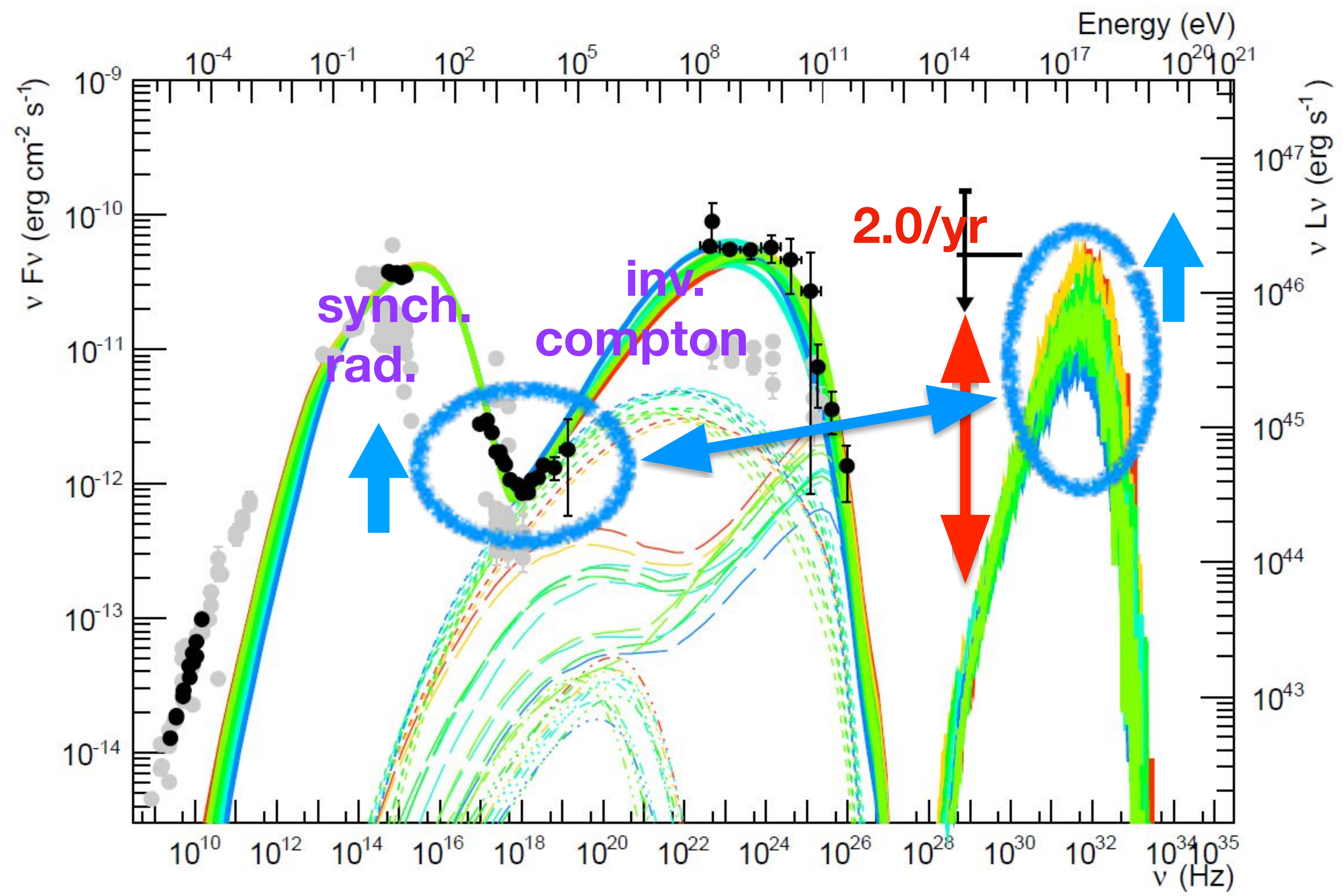

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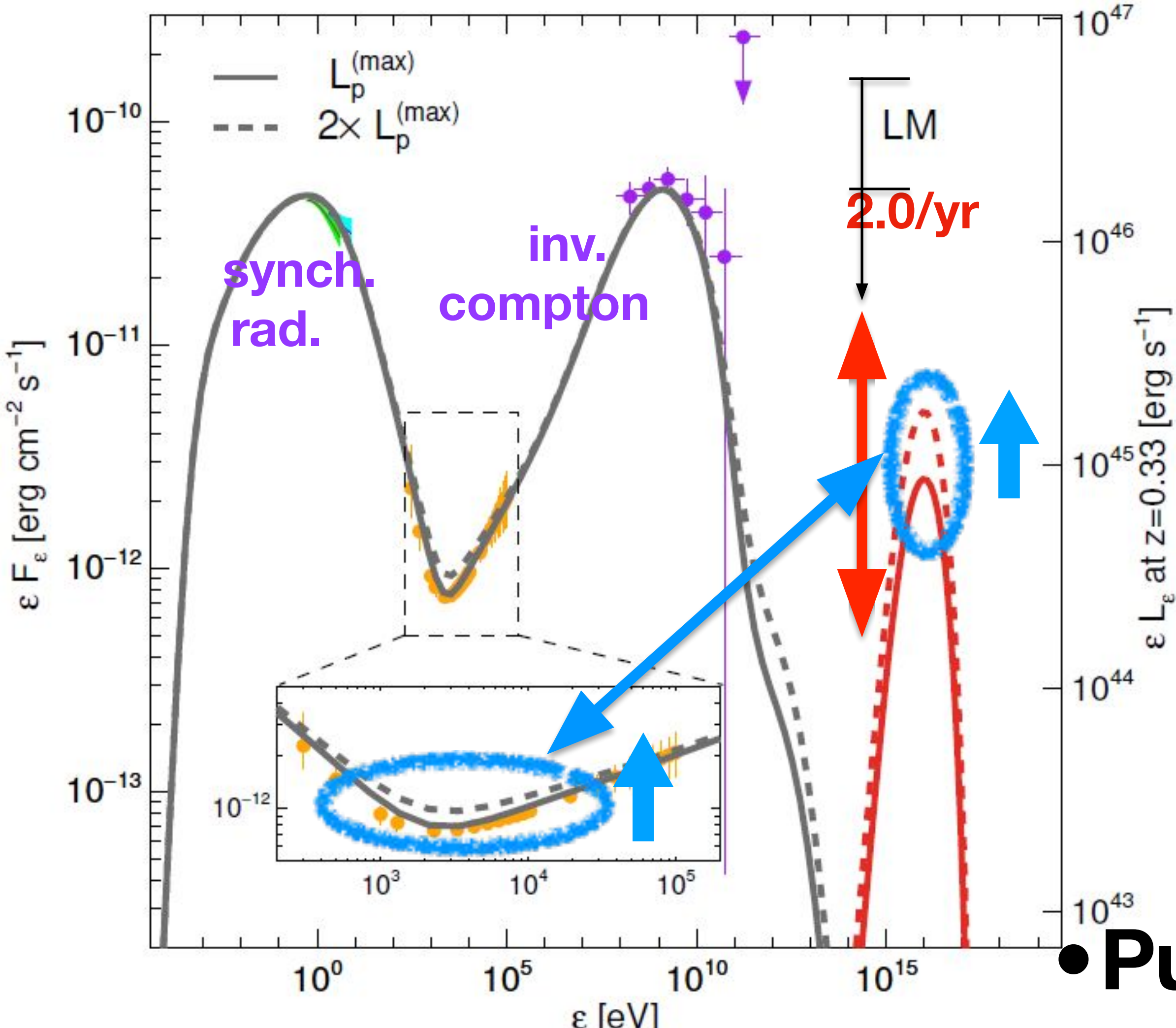

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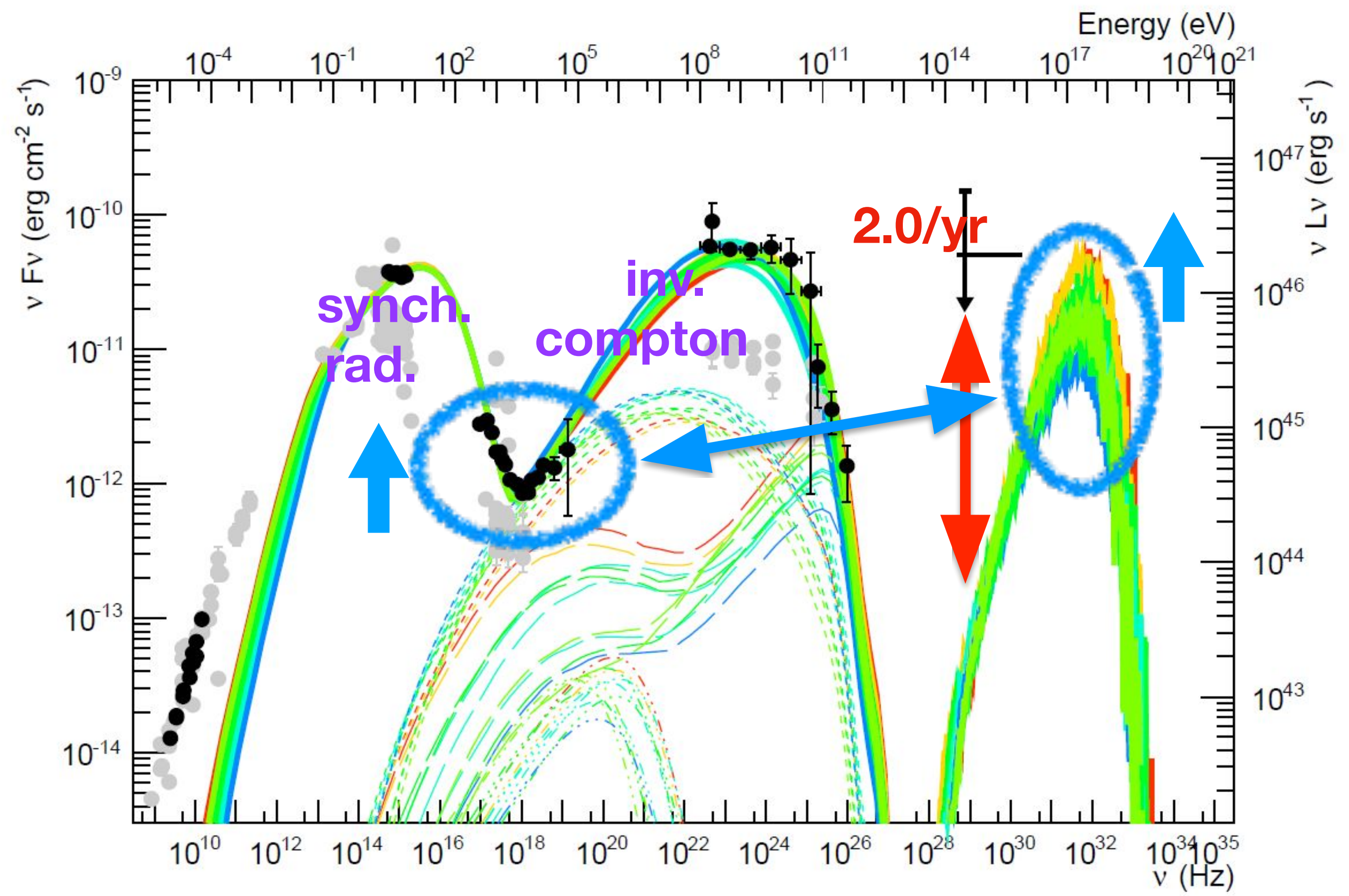

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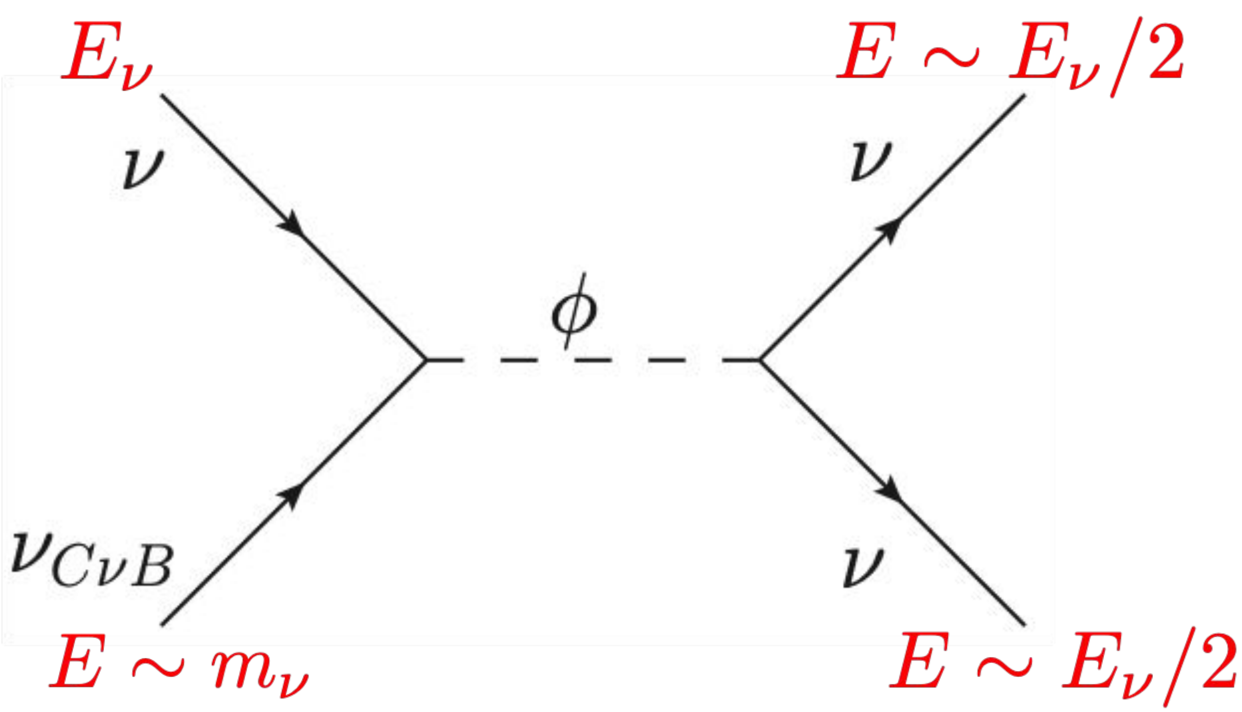
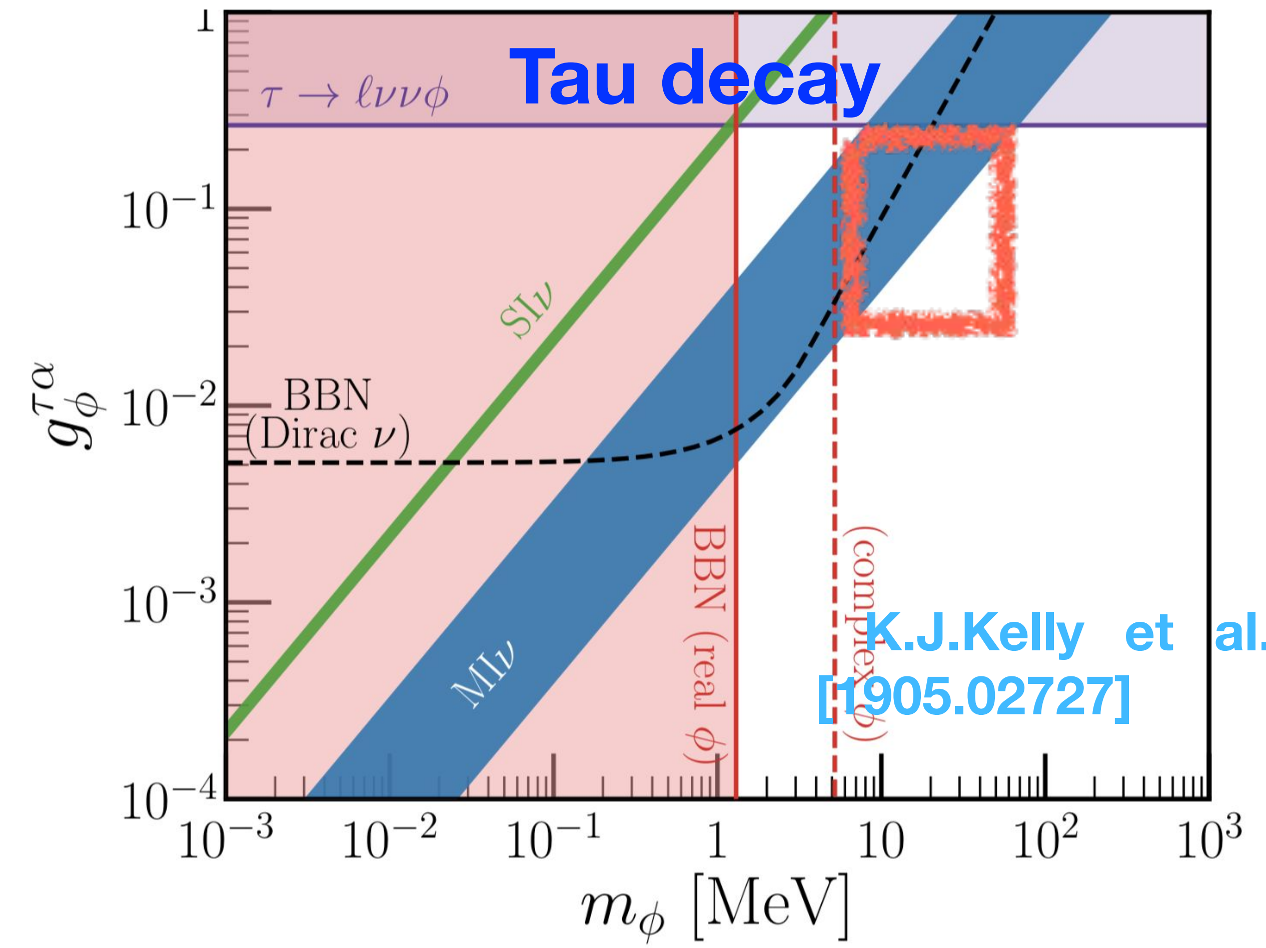
- **Most events are expected at O(100) PeV energies and Event rate at 100 TeV - 1 PeV energy is suppressed as ~** $10^{-3} - 10^{-2}/\mathrm{yr}$
  - **Obtaining O(1)/yr event rate at IceCube is very tough within simplest astrophysical models.**

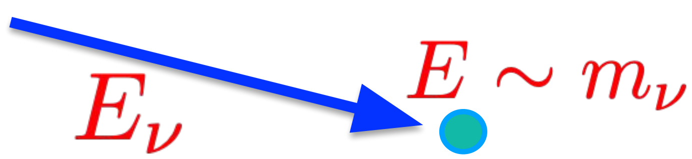
New self-interaction of neutrinos and neutrino cascade during propagation

- ν **self-interaction with light mediator**

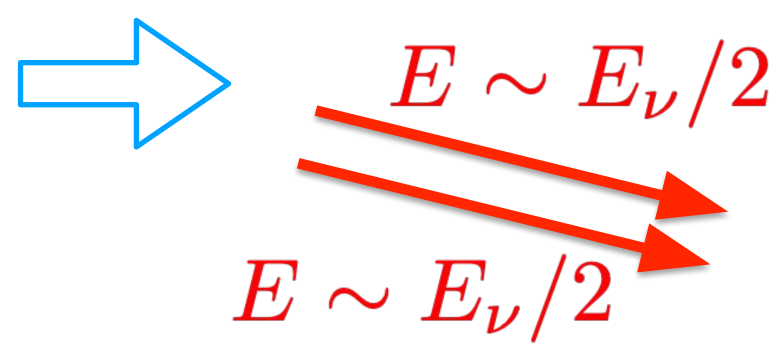
$$\mathcal{L}_{\rm eff} \supset -g_\phi \bar{\nu^c_\tau}\nu_\tau \phi + {\rm h.c.}$$







neutrino cascade can occur during propagation with MFP ~ O(200-1000) Mpc



New self-interaction of neutrinos and neutrino cascade during propagation

- **Obtaining the modified flux with simple neutrino cascades**

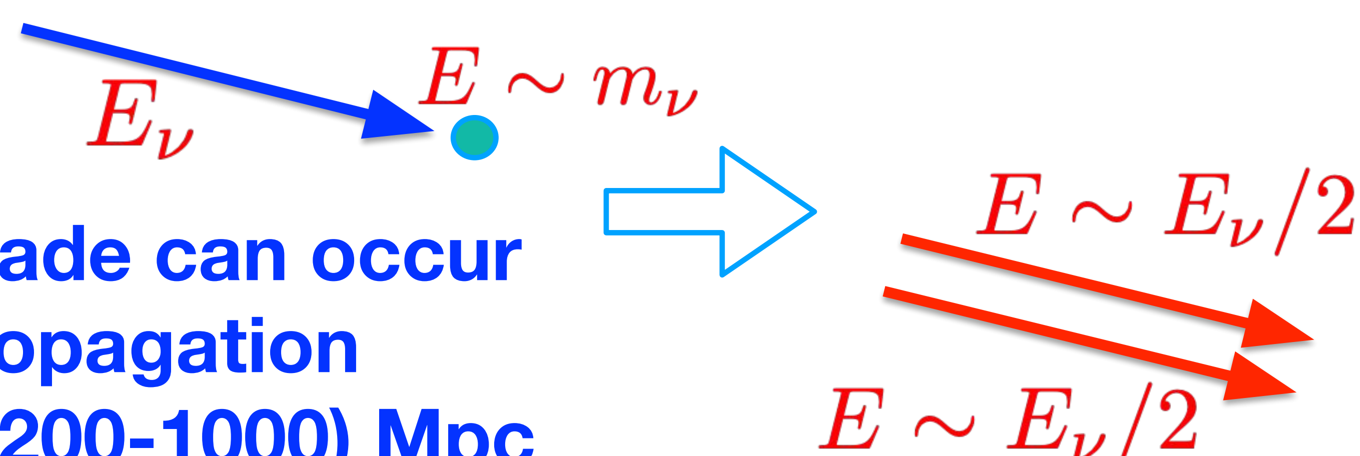
$$\frac{\partial f_\nu(\epsilon_\nu^{\rm obs}, z)}{\partial t} = -\frac{c}{\lambda_\nu(\epsilon_\nu, z)} f_\nu(\epsilon_\nu^{\rm obs}, z) + \frac{4c}{\lambda_\nu(2\epsilon_\nu, z)} f_\nu(2\epsilon_\nu^{\rm obs}, z)$$

Absorption of energetic neutrino by neutrino cascades

Production of down-scattered secondary neutrinos

$$\lambda_\nu(\epsilon_\nu, z) = \frac{1}{n_\nu^{\rm C\nu B}(z) \cdot \sigma_\nu^{\nu {\rm SI}}(\epsilon_\nu)}$$

$$\sigma_\nu^{\nu{\rm SI}}(\epsilon_\nu) \simeq \frac{g_\phi^4}{16\pi} \frac{s}{(s - m_\phi^2)^2 + m_\phi^2 \Gamma_\phi^2}$$

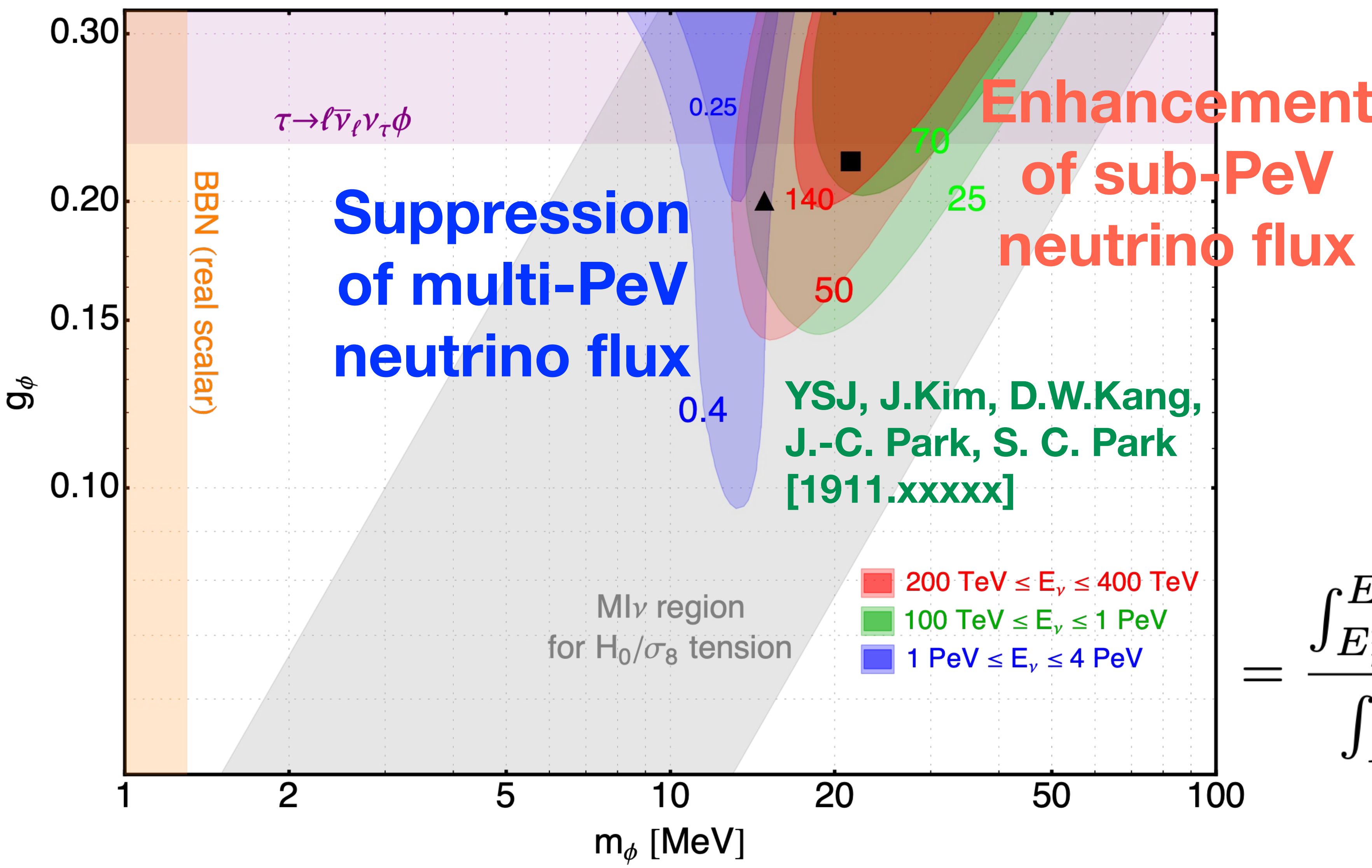


neutrino cascade can occur during propagation with MFP ~ O(200-1000) Mpc

Event spectrum at IceCube

- **Enhancement of neutrino flux at 100 TeV - 1 PeV** $\simeq \mathcal{O}(10-100)$ **without changing any EM component spectrum**
- **Suppression of neutrino flux at ~ 3-10 PeV by resonance**

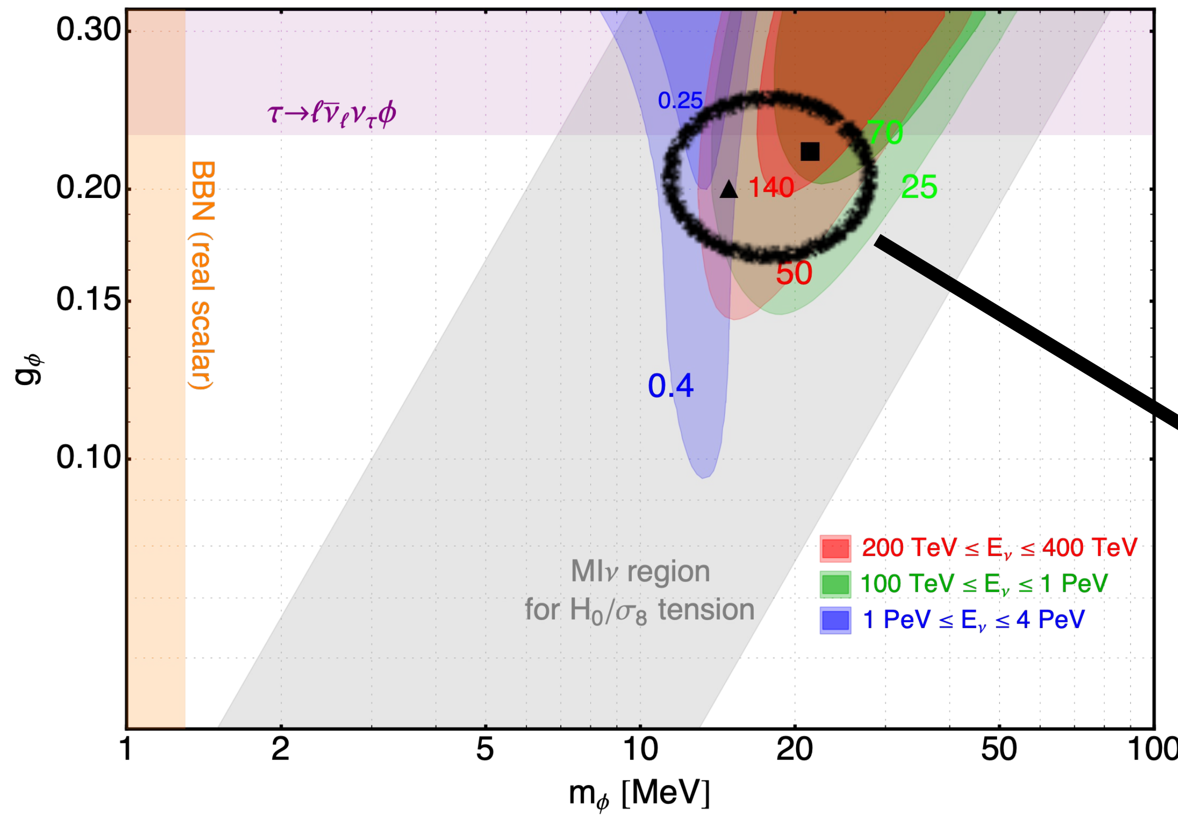
➡ **The absence (or suppression) of multi-PeV neutrino events**



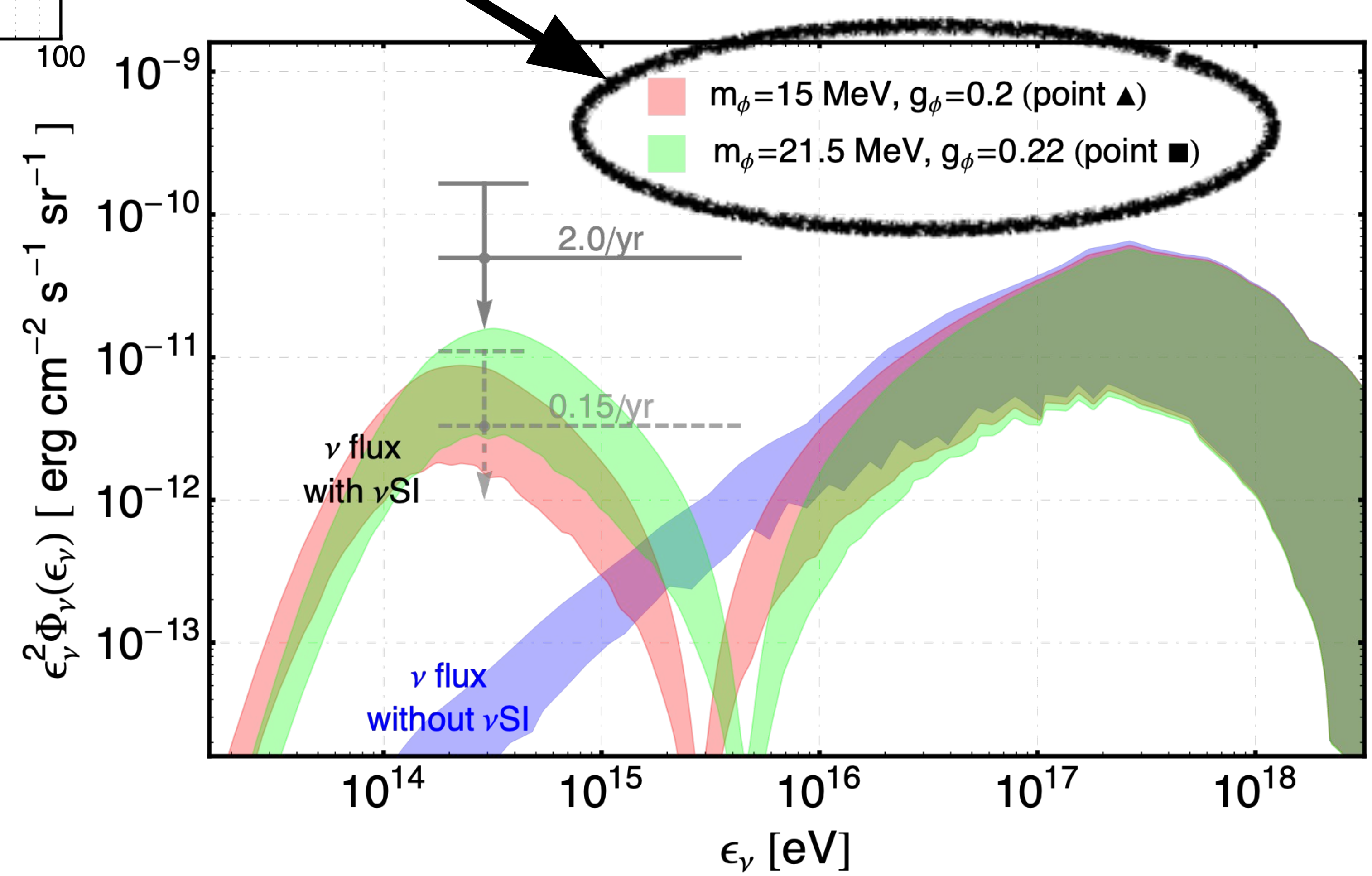
Enhanced # of events

$$R_\nu(E_\nu^{\rm min}, E_\nu^{\rm max}, m_\phi, g_\phi) \equiv \left.\frac{N_\nu^{\rm SM+\phi}}{N_\nu^{\rm SM}}\right|_{E_\nu^{\rm min} \le E_\nu \le E_\nu^{\rm max}} = \frac{\int_{E_\nu^{\rm min}}^{E_\nu^{\rm max}} A_{\rm eff}(E_\nu)\Phi_\nu^{\rm SM+\phi}(E_\nu)dE_\nu}{\int_{E_\nu^{\rm min}}^{E_\nu^{\rm max}} A_{\rm eff}(E_\nu)\Phi_\nu^{\rm SM}(E_\nu)dE_\nu}$$

Event spectrum at IceCube



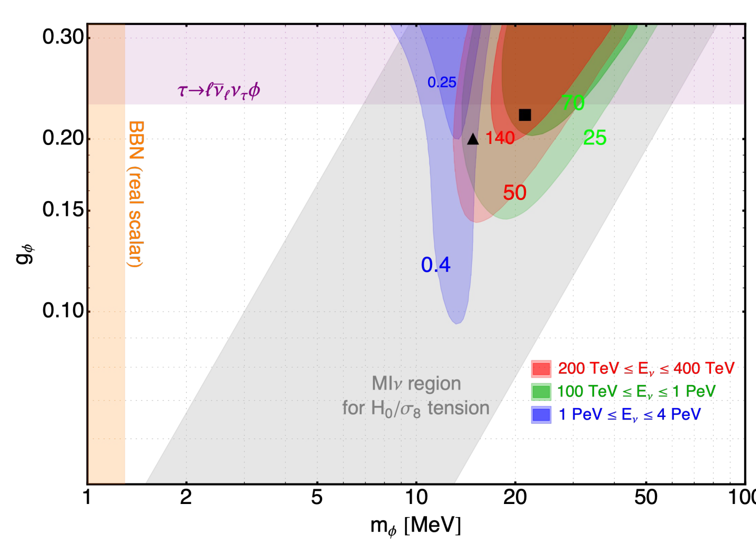
YSJ, J.Kim, D.W.Kang, J.-C. Park, S. C. Park [1911.xxxxx]

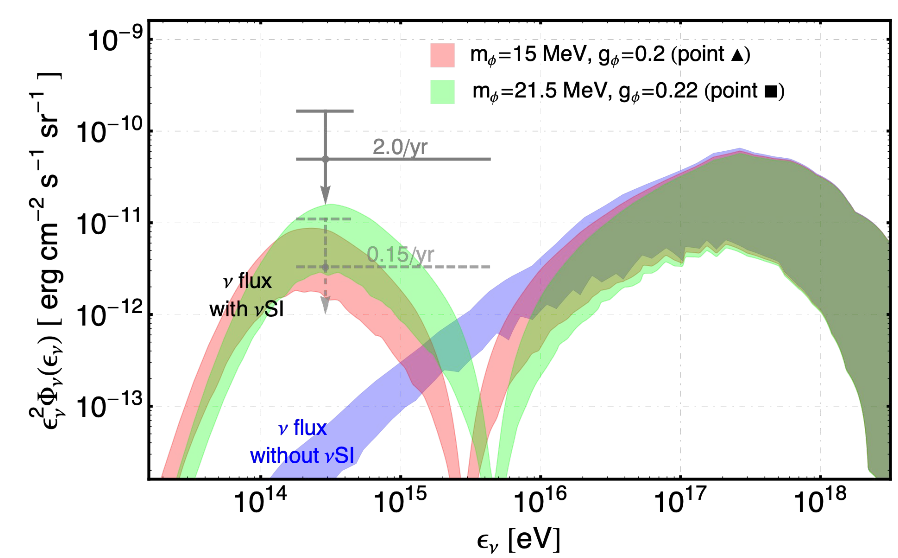


- **Observation of multi-PeV neutrinos from distant sources (> O(1) Gpc) can constrain this scenario in future.**

Conclusion

- The neutrino flare at TXS 0506+056 provides the **first complete set of multi-messenger observation** including **photons** and **neutrinos**.
- Pure hadronic models are disfavored and
Leptonic models are suffered from the explanation of IceCube neutrino obs.
- **neutrino self-interaction** with a light mediator (m ~ 10-50 MeV) **enhances in O(100) TeV neutrinos** and **suppresses O(1-10) PeV neutrinos** due to the neutrino cascade during propagation that can explain the observed anomaly.
- Future multi-messenger observation will increase the statistics for the test of this scenarios, providing the detailed features of low energy neutrino sector.





Thank you
for your attention