Light Curves of BSM-Induced Neutrino Echoes in the Optically Thin Limit

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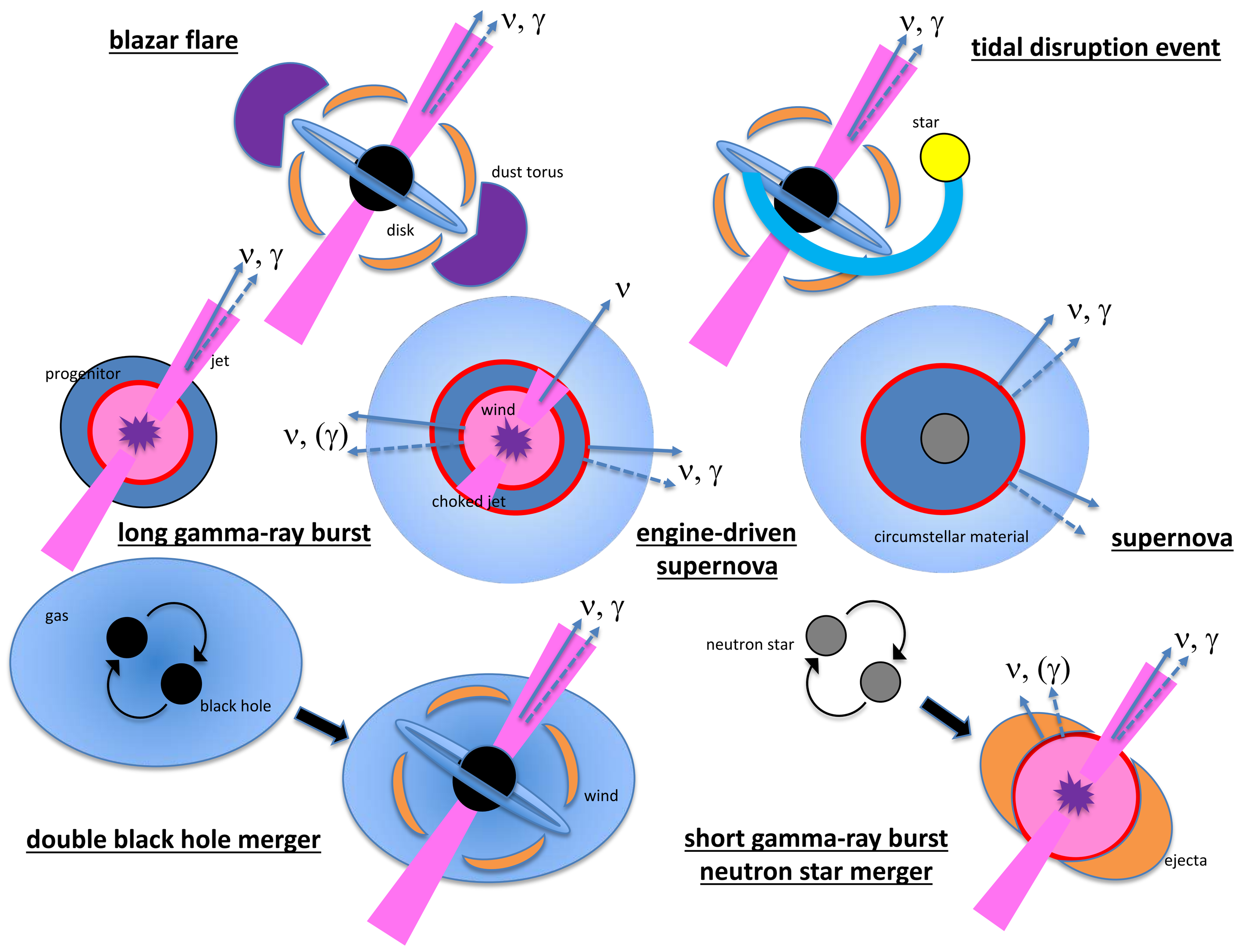
Transients offer powerful probes of new physics in neutrino sector

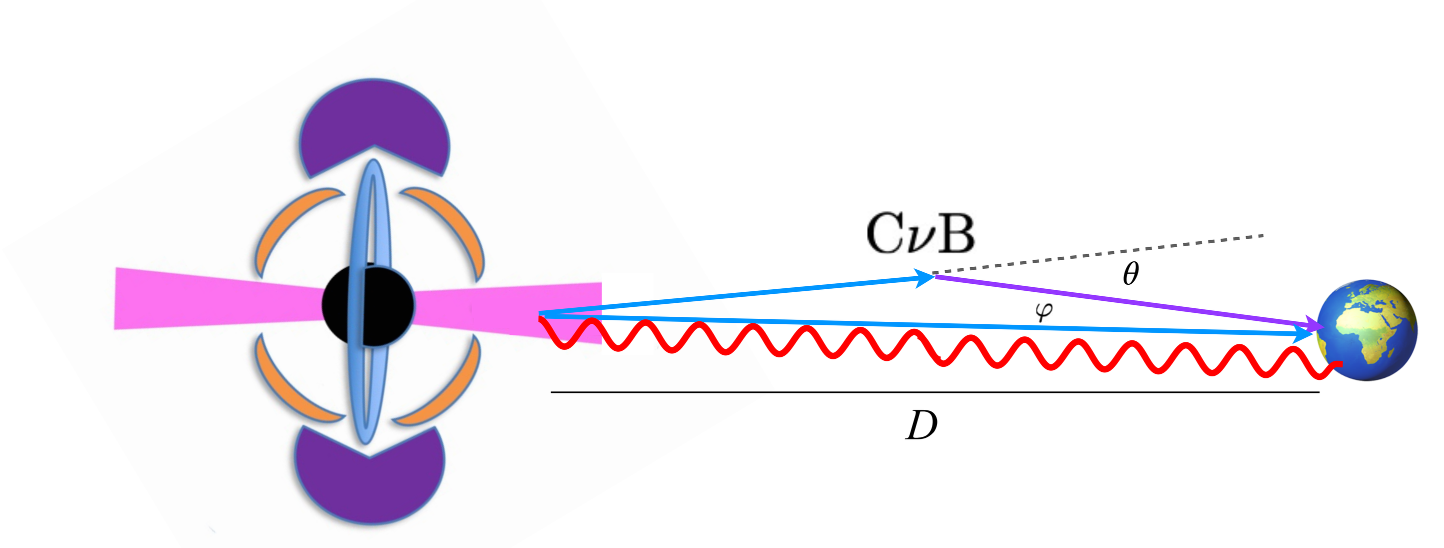
- High-energy cosmic neutrinos present a unique opportunity to search for physics beyond Standard Model (BSM) thanks to their reach to the highest energies and longest baseline.
- BSM induced interactions of high-energy neutrinos during their propagation yield distinct signatures in their observables in neutrino telescopes: energy, arrival direction, flavor, and time [1].
- Transient astrophysical phenomena are among the primary candidates for the origin of high-energy cosmic neutrinos discovered by IceCube [2].
- Evidence for neutrino emission from flaring blazar, TXS 0506+056 [3], demonstrated the feasibility of BSM searches with time-domain multi messenger astrophysics.



Examples of transient astrophysical phenomena that serve as primary candidates for high-energy cosmic neutrinos. Figure from [2].

Time-delay induced by *secret* neutrino interactions

- BSM induced neutrino self interaction is predicted in "scotogenic models" and are particularly interesting as they can explain neutrino mass generation.
- Time delay between neutrinos and other cosmic messengers, such as gamma rays, is expected in the presence of secret neutrino interactions [4].



- High-energy cosmic neutrinos interact with CνB.
- The time difference can be estimated by evaluating the extra distance neutrino has to travel.
- In the optically thin limit for $\nu\nu$ interaction, $\tau = n_\nu \sigma_{\nu\nu} D < 1$, the average scattering angle can be approximate as:

$$\theta = \varphi + \frac{2ct}{D\varphi}$$

- The time-delay can be approximated as [4]

$$t \approx \frac{1}{2}\frac{\langle\theta^2\rangle}{4} D \simeq 77\ \mathrm{s}\left(\frac{D}{3\ \mathrm{Gpc}}\right)\left(\frac{C}{0.6}\right)^2\left(\frac{m_\nu}{0.1\ \mathrm{eV}}\right)\left(\frac{0.1\ \mathrm{PeV}}{E_\nu}\right).$$

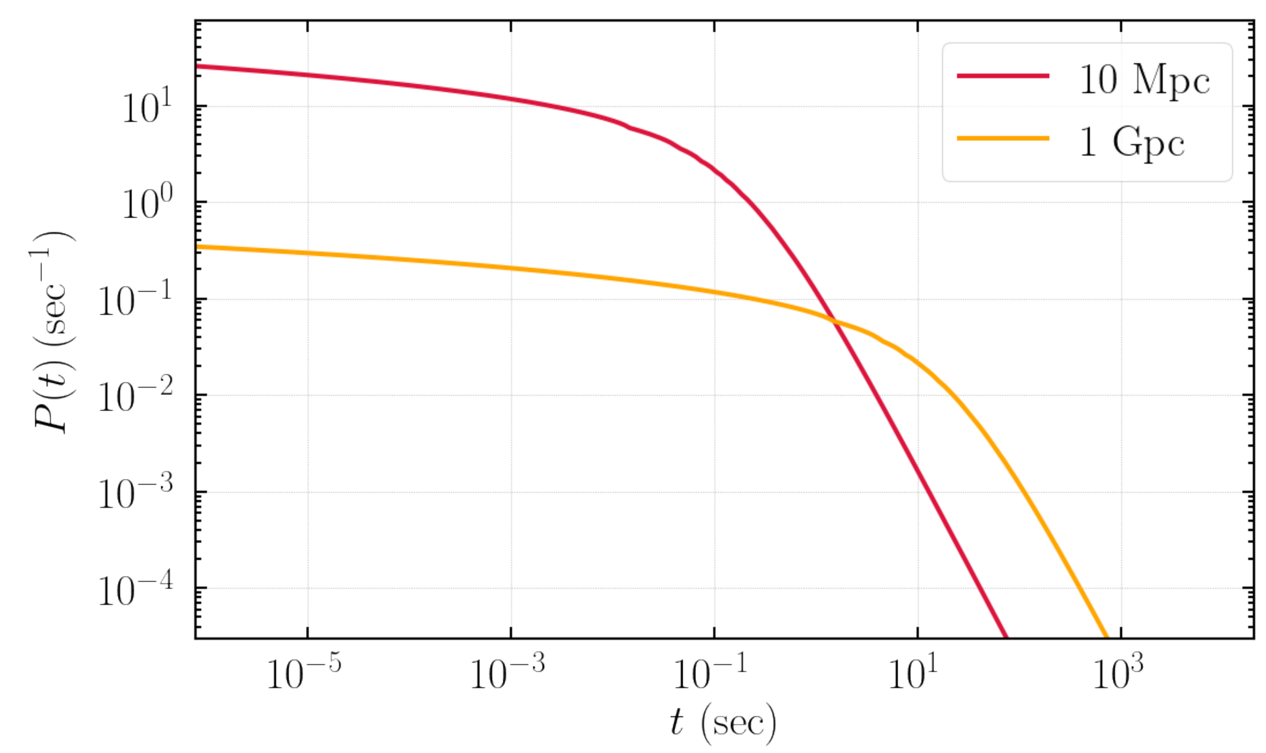
- Absence of time-delay is observed for neutrinos from a transient will provide upper limit on the strength of neutrino secret interactions:

$$\sigma_{\nu\nu} \leq \frac{2.3}{N_{\mathrm{sig}} n_\nu D}$$

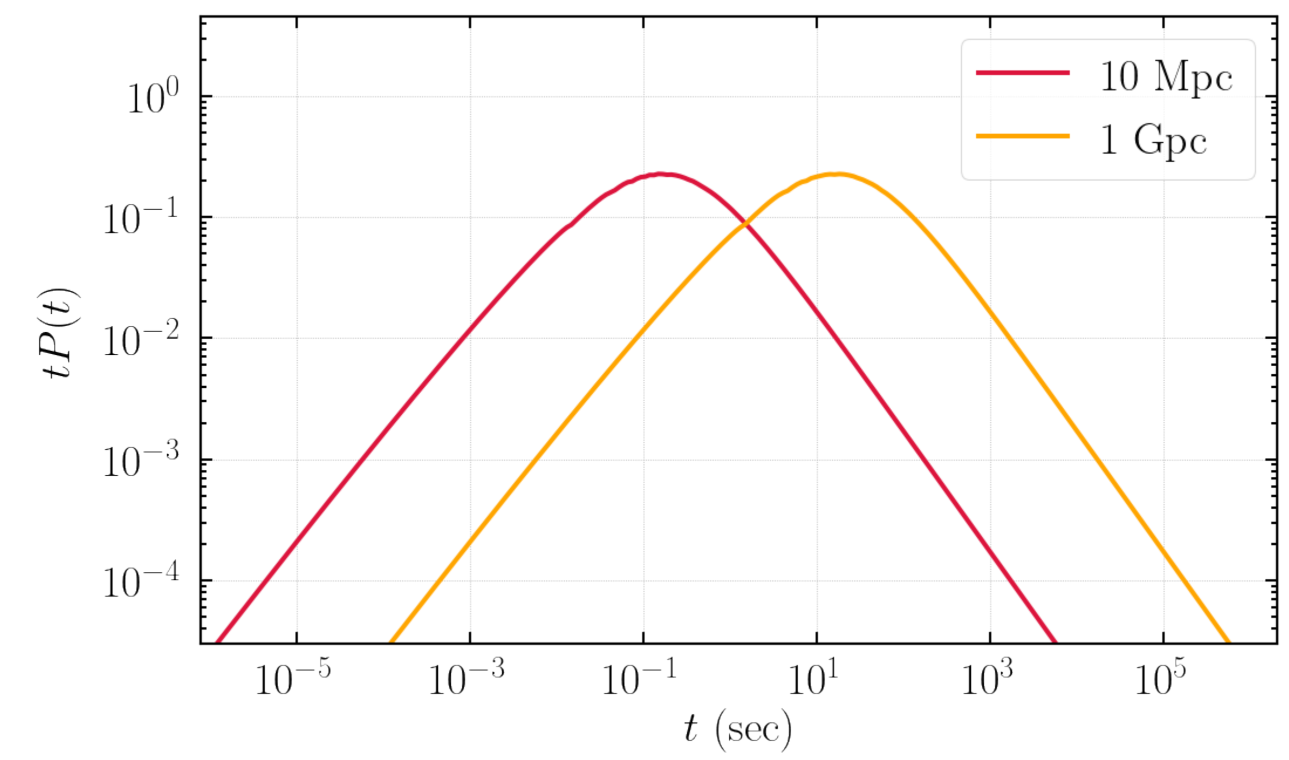
Neutrino Light Curves

- The probability distribution for the time delay projects the differential cross section of the secret interactions.

$$P(t,\varphi;D) \approx \frac{1}{[t + (D\varphi^2/2)]}\frac{1}{\sigma_{\nu\nu}}\left(\frac{d\sigma_{\nu\nu}}{d\theta}\right)$$



The probability distribution of the time delay for 100 TeV neutrinos scattering off CvB for a close by (10 Mpc) and distant (1 Gpc) transient. We assume a coupling of 0.1, a scalar mediator of 10 MeV, and neutrino mass of 0.1 eV.



Light curve for 100 TeV neutrino from transients for a close by (10 Mpc) and distant (1 Gpc) transient. Parameters are same as top figure.

- Neutrino-dark matter interaction is another potential BSM scenario that would alter neutrino observables [4,5]. Stay tuned for neutrino light curves from neutrino-dark matter.

Refrences:

[1] Argüelles, Bustamante, Kheirandish, Parlomares-Ruiz, Salvado, & Vincent, PoS ICRC2019 (2020) 849

[2] Murase & Bartos, Ann.Rev.Nucl.Part.Sci. 69 (2019) 477-506

[3] IceCube Collaboration+, Science 361 (2018) 6398

[4] Shoemaker & Murase, Phys.Rev.Lett. 123 (2019) 24, 241102

[5] Arguelles, Kheirandish, & Vincent, *Phys.Rev.Lett.* 119 (2017) 20, 201801

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