Neutrinos and gamma rays from long-lived mediator decays in the Sun

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Motivation

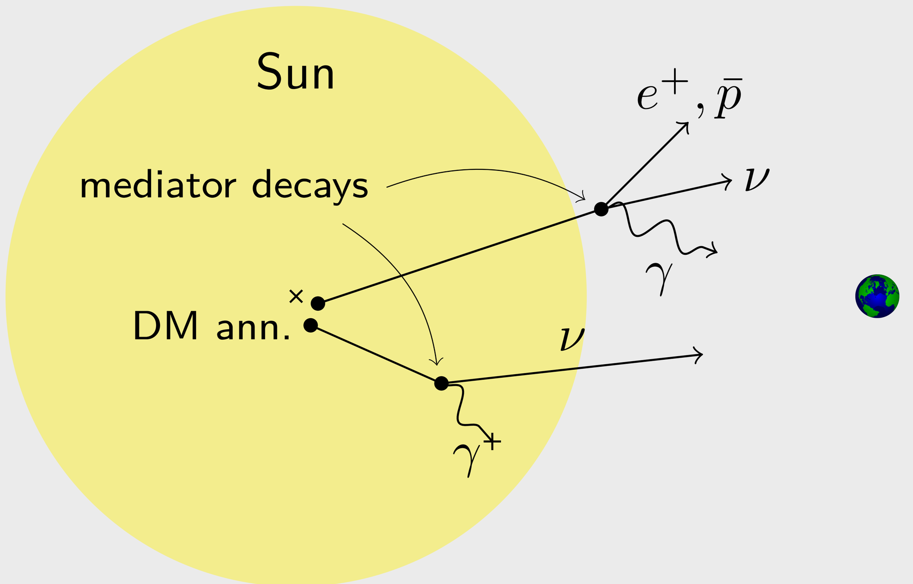
- Indirect searches for WIMP annihilation in the Sun using ν telescopes.
- ν-nucleon electroweak interactions $\implies$ traditional ν searches (e.g., IceCube) limited to $E_\nu \in [1, 1000]$ GeV.
- *Long-lived mediators* improve the situation $\rightarrow$ νs produced further out from solar core.
- Mediator decays outside Sun $\rightarrow$ γ ray and charged cosmic ray fluxes.

Long-lived mediator scenario

- DM χ annihilates into long-lived mediators Y, Y subsequently decays into SM particles:

$$\chi\chi \rightarrow YY \rightarrow (2 \times \text{SM})\ (2 \times \text{SM}). \quad (1)$$

- Typical phenomenology ~ secluded DM models, e.g., dark photon.
- Long lifetime $\implies$ Y decays away from χ annihilation point.



- Solar DM density falls exponentially with r $\rightarrow$ less attenuation of ν fluxes from electroweak interactions, c.f., standard scenario.
- Decays outside Sun $\rightarrow$ γ rays and charged cosmic ray fluxes, c.f., absorption in standard scenario.

Parameters and Constraints

Parameters	Description
m_χ	DM mass [GeV]
m_Y	Mediator mass [GeV]
γL	Boosted mediator decay length, $\gamma = m_\chi/m_Y$
–	Mediator decay channel
Γ_A	DM annihilation rate [s^{-1}]

Table 1: Relevant parameters of interest.

Methodology

- Use WimpSim v5.0: a fully-event based Monte Carlo code for simulating νs from WIMP annihilation in the Sun/Earth. Code publicly available at:

  http://wimpsim.astroparticle.se.

- Simulation of χ annihilation, subsequent decay and/or hadronisation of SM products using Pythia v6.4.26; ν propagation to Earth (including matter + vacuum oscillations).
- Assume 100% branching ratio into $b\bar{b}$ (soft) and $\tau^+\tau^-$ (hard) channels.
- Assume some cross section gives a DM signal with rate Γ_A.

Constraints

1. *ν and γ ray searches*: Impose limits on Γ_A from IceCube and Super-K data (for νs), and *Fermi*-LAT, HAWC and ARGO observations (for γ rays).
2. *Big Bang Nucleosynthesis (BBN)*: long lifetimes $\rightarrow$ affects primordial abundance of light elements. Limit varies with Y decay channel and its abundance. We require

$$\gamma L = \frac{m_\chi}{m_Y} c\tau_0 \lesssim \frac{m_\chi}{m_Y} c\tau^*, \qquad \tau^* = 1\,\text{s}. \quad (2)$$

3. *LHC searches for long-lived mediators*: expect small mediator-SM coupling $\rightarrow$ small production cross section $\rightarrow$ mediator escapes detection.
4. *Indirect searches and Cosmic Microwave Background*: $\Gamma_\text{A} \leftrightarrow \langle\sigma v_\text{rel}\rangle$ relationship *not* 1:1.

Results

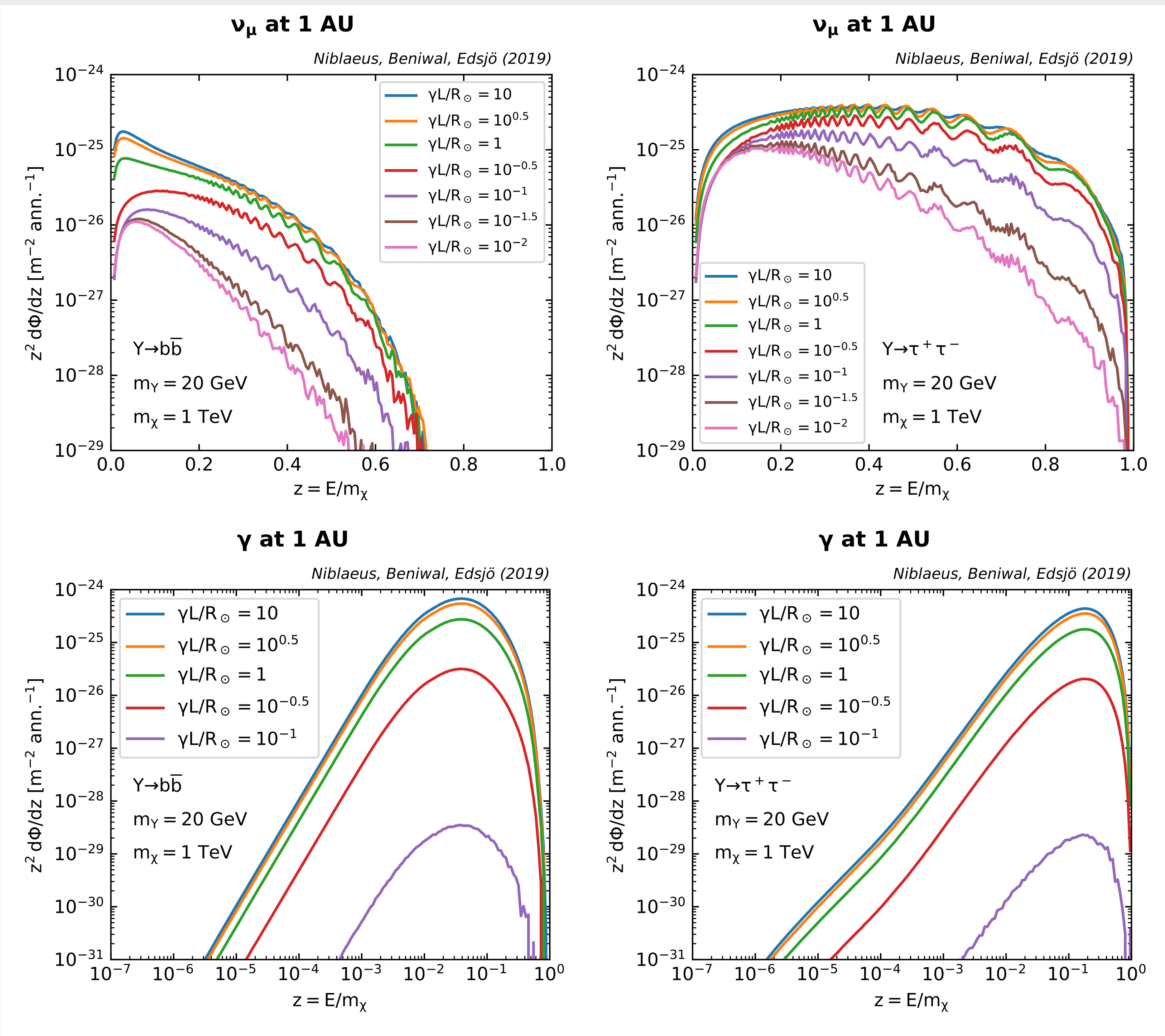


Fig. 1: Effect of varying the mediator decay length γL on ν (*top panel*) and γ ray (*bottom panel*) fluxes at 1 AU.

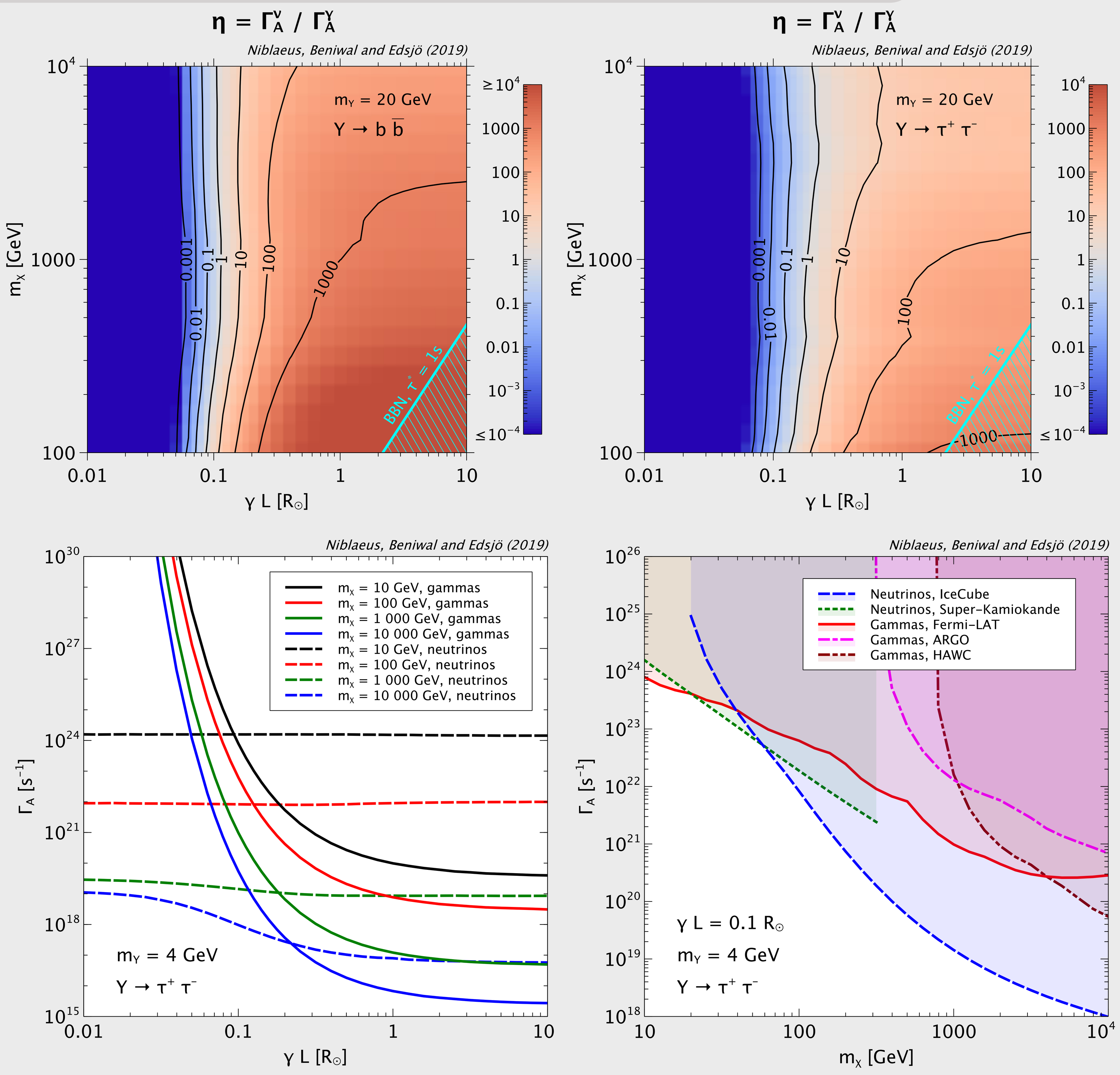


Fig. 2: Complementarity between ν and γ ray searches.

Summary

- Predicted energy spectra of ν and γ rays from mediator decays using WimpSim v5.0.
- Harder ν spectra in long-lived mediator scenario $\rightarrow$ ν fluxes less attenuated.
- ν and γ ray fluxes depend on m_χ, γL and decay channel; less sensitive to m_Y.
- Imposed upper limits on Γ_A from ν (IceCube, Super-K) and γ ray (*Fermi*-LAT, HAWC, ARGO) searches.
- γ ray searches more constraining than νs for $\gamma L \gtrsim 0.1\, R_\odot$.