Heavy decaying dark matter at future neutrino radio telescopes

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Here, There & Everywhere Neutrino School

Rasmi Hajjar

Scuola Superiore Meridionale (IT)
Università degli Studi di Napoli Federico II

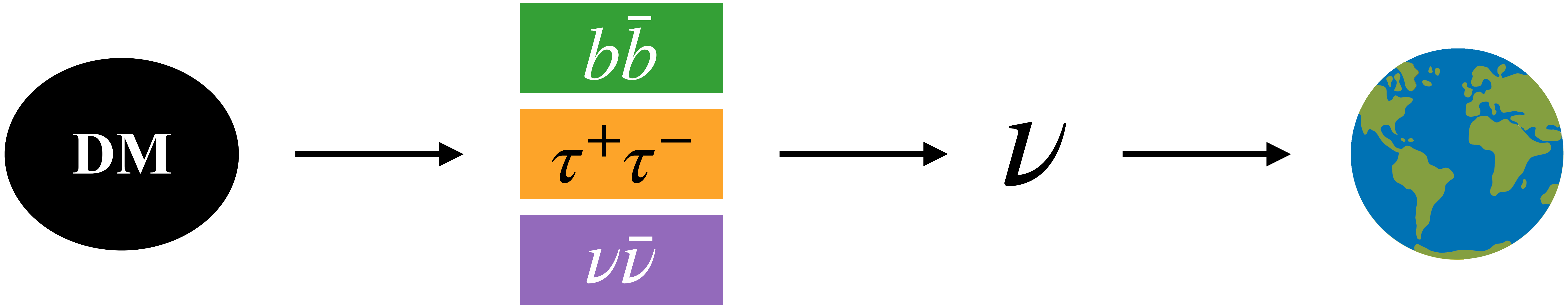
rasmienrique.hajjarmunoz@unina.it

based on M. Chianese, D. Fiorillo, RH, G. Miele, S. Morisi and N. Saviano JCAP05(2021)074 arXiv: [2103.03254]

Main goal of this work

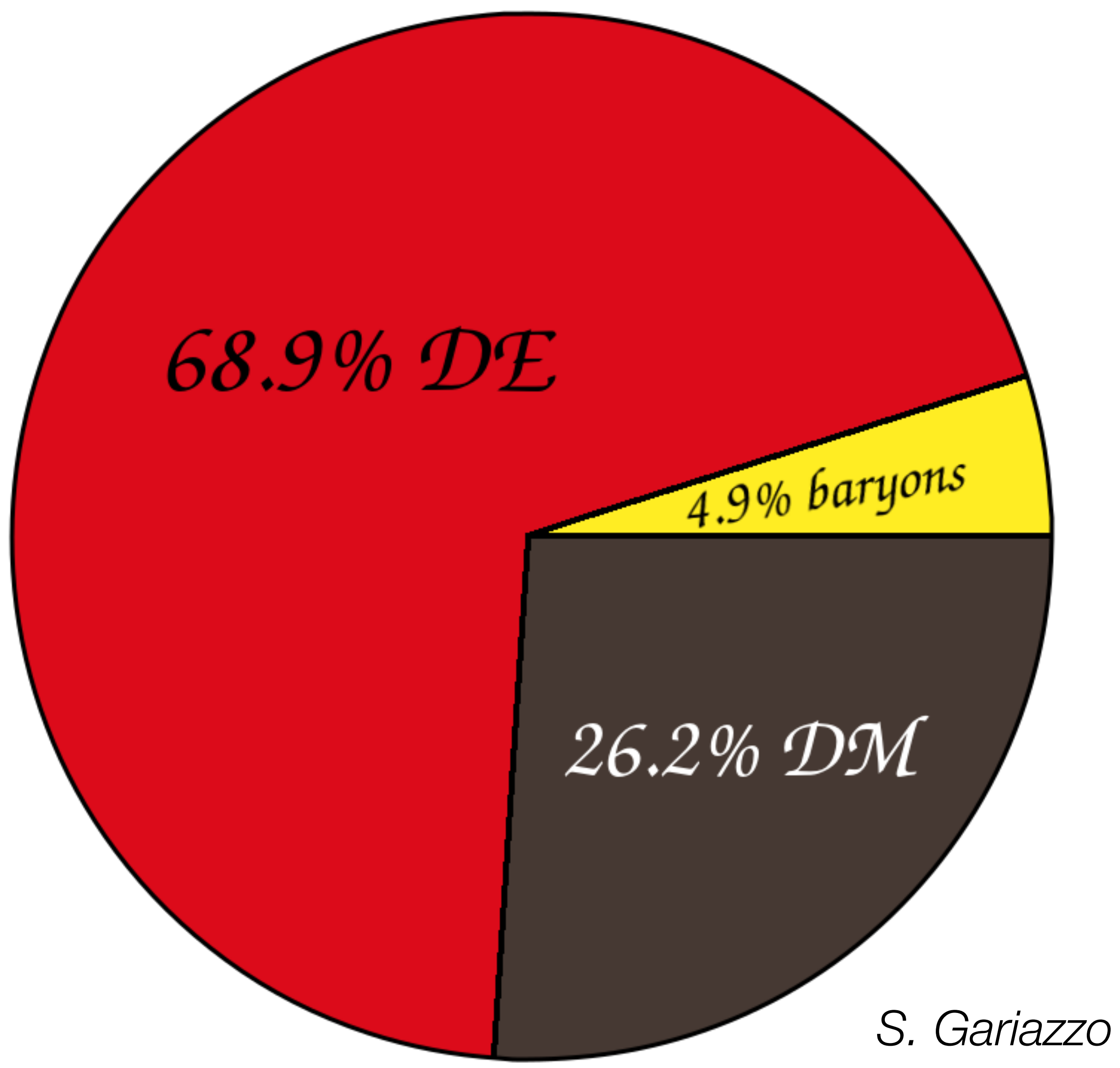
- The main goal of this work is to forecast the limits that we can place on the lifetime of Heavy Dark Matter (HDM) particles using future neutrino radio telescopes.

- We assume that the DM particles decay to a pair of SM particles and the minimal decaying DM scenario with only two parameters: $(m_{\rm DM}\,,\ \tau_{\rm DM})$



Introduction

- DM is one of the pillars of the standard cosmological model.
- We have only seen DM interacting gravitationally, no other direct observations.
- Indirect DM detection via CRs, gamma rays and neutrinos emitted by annihilation or decay of the DM particles (multi-messenger astronomy)



S. Gariazzo (2018)

- We focus on the neutrino detection, where $E_\nu > 10\ \mathrm{PeV}$ is observationally unexplored.

Neutrino fluxes from DM

- Indirect DM detection via neutrinos
- Minimal Decaying Dark Matter model: $(m_{\rm DM}\,,\ \tau_{\rm DM})$
- Assume DM decay into a pair of SM particles: $(\,{\rm DM} \to f\bar{f}\,)$
- Decaying DM expected fluxes:

$b\bar{b}$

$\tau^+\tau^-$

$\nu\bar{\nu}$

NFW profile

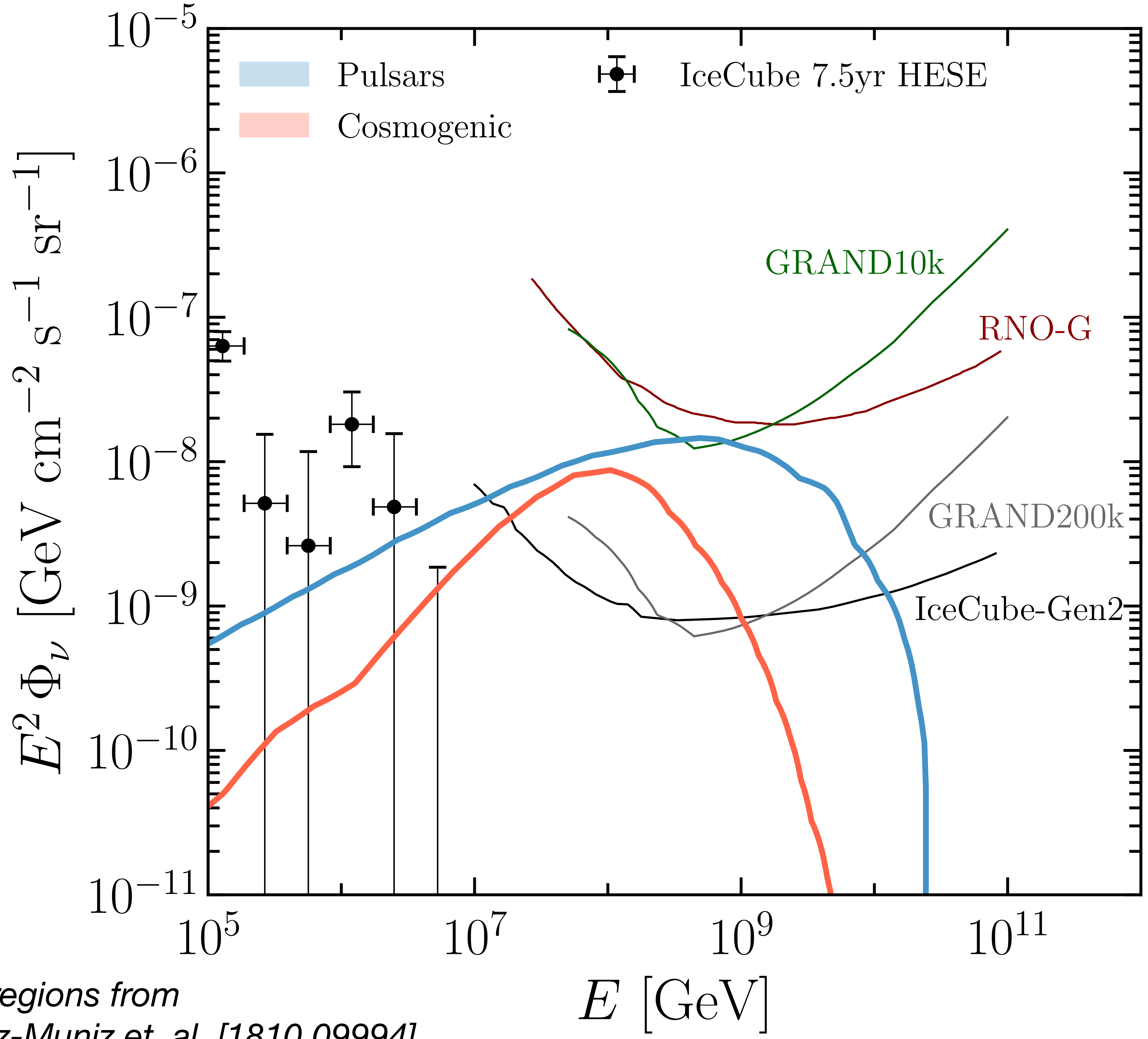
$$\frac{{\rm d}\Phi^{\rm gal.}_{\nu_\alpha+\bar{\nu}_\alpha}}{{\rm d}E_\nu {\rm d}\Omega} = \frac{1}{4\pi m_{\rm DM}\tau_{\rm DM}} \frac{{\rm d}N_\alpha}{{\rm d}E_\nu} \int_0^\infty {\rm d}s\, \rho_{\rm DM}[r(s,\ell,b)]$$

$$\frac{{\rm d}\Phi^{\rm ext.gal.}_{\nu_\alpha+\bar{\nu}_\alpha}}{{\rm d}E_\nu {\rm d}\Omega} = \frac{\Omega_{\rm DM}\rho_c}{4\pi m_{\rm DM}\tau_{\rm DM}} \int_0^\infty \frac{{\rm d}z}{H(z)} \frac{{\rm d}N_\alpha}{{\rm d}E'_\nu}\bigg|_{E'_\nu = E_\nu(1+z)}$$

$$\frac{{\rm d}\Phi^{\rm DM}_{3\nu}}{{\rm d}E_\nu} = \sum_\alpha \int {\rm d}\Omega \left[\frac{{\rm d}\Phi^{\rm gal.}_{\nu_\alpha+\bar{\nu}_\alpha}}{{\rm d}E_\nu {\rm d}\Omega} + \frac{{\rm d}\Phi^{\rm ext.gal.}_{\nu_\alpha+\bar{\nu}_\alpha}}{{\rm d}E_\nu {\rm d}\Omega}\right]$$

Neutrino fluxes from DM

- High energy ν flux is unknown. Other possible contributions:



colored regions from
J. Álvarez-Muniz et. al. [1810.09994]

Cosmogenic

guaranteed but uncertain magnitude, come from CRs interacting with CMB

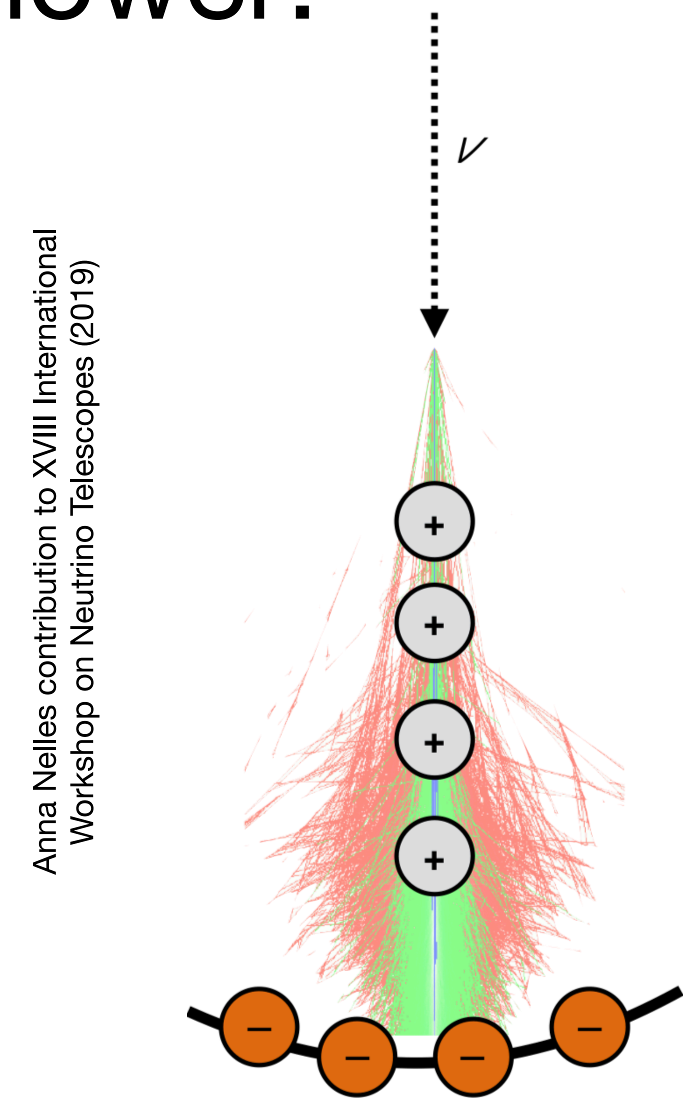
Newborn Pulsars

higher expected astrophysical contribution in literature for neutrino radio telescopes

- Active Galactic Nuclei
- Gamma-ray bursts
- Flat-spectrum radio Quasars
- Black Hole jets embedded in large structures

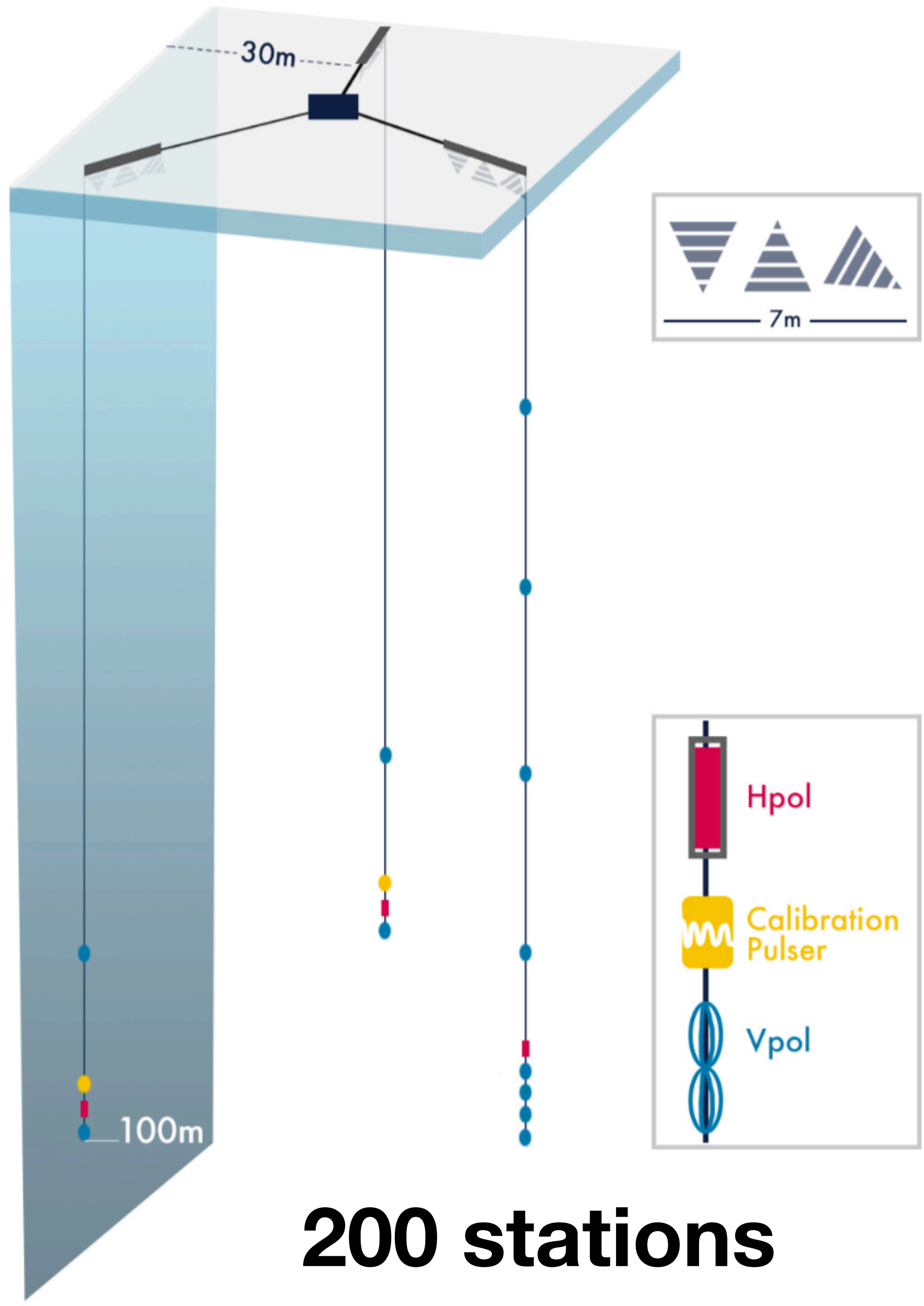
Future radio ν telescopes

Radio emission from hadronic/EM shower:



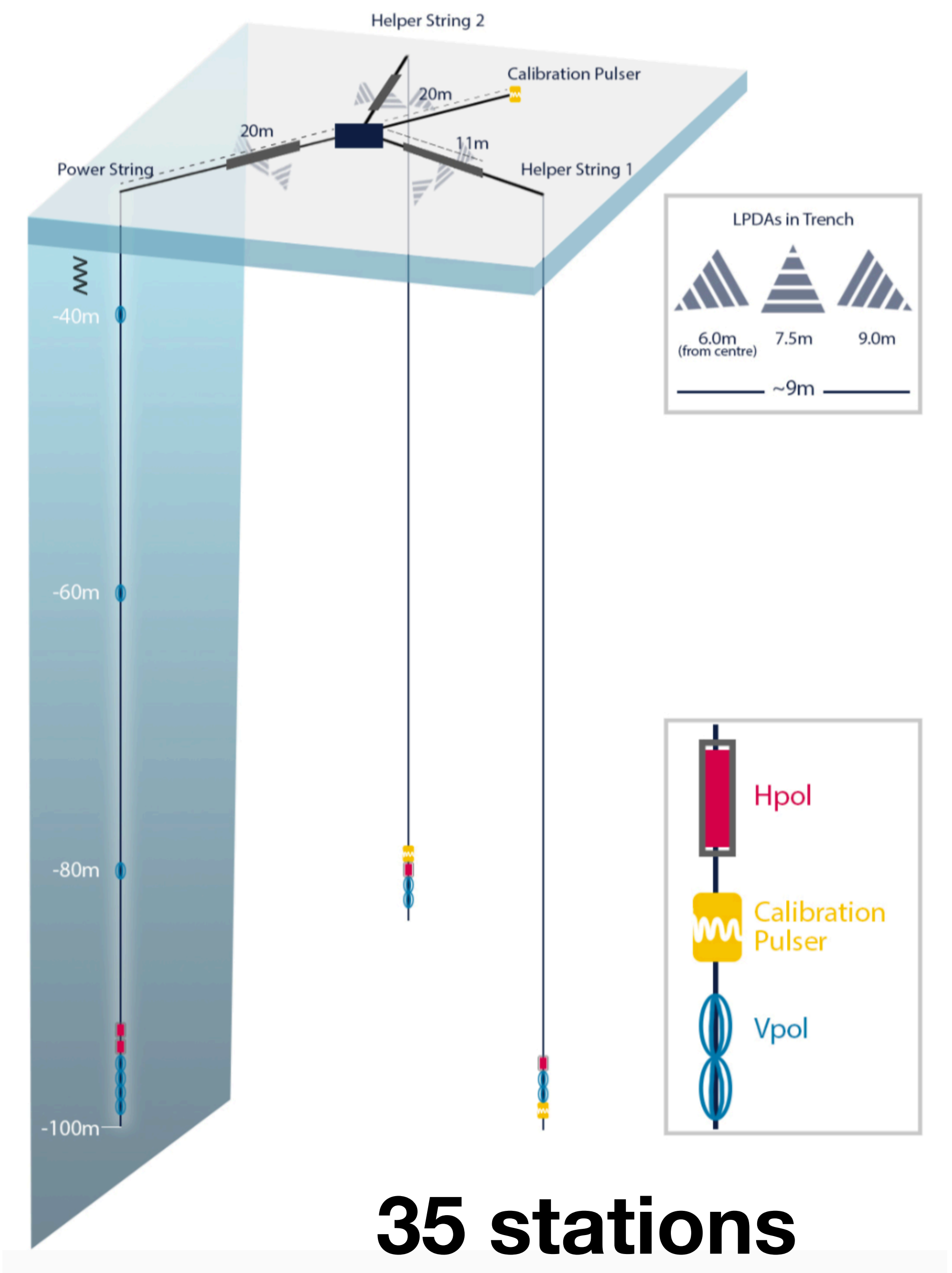
IceCube gen-2 radio

M.G. Aartsen et. al. [2008.04323]



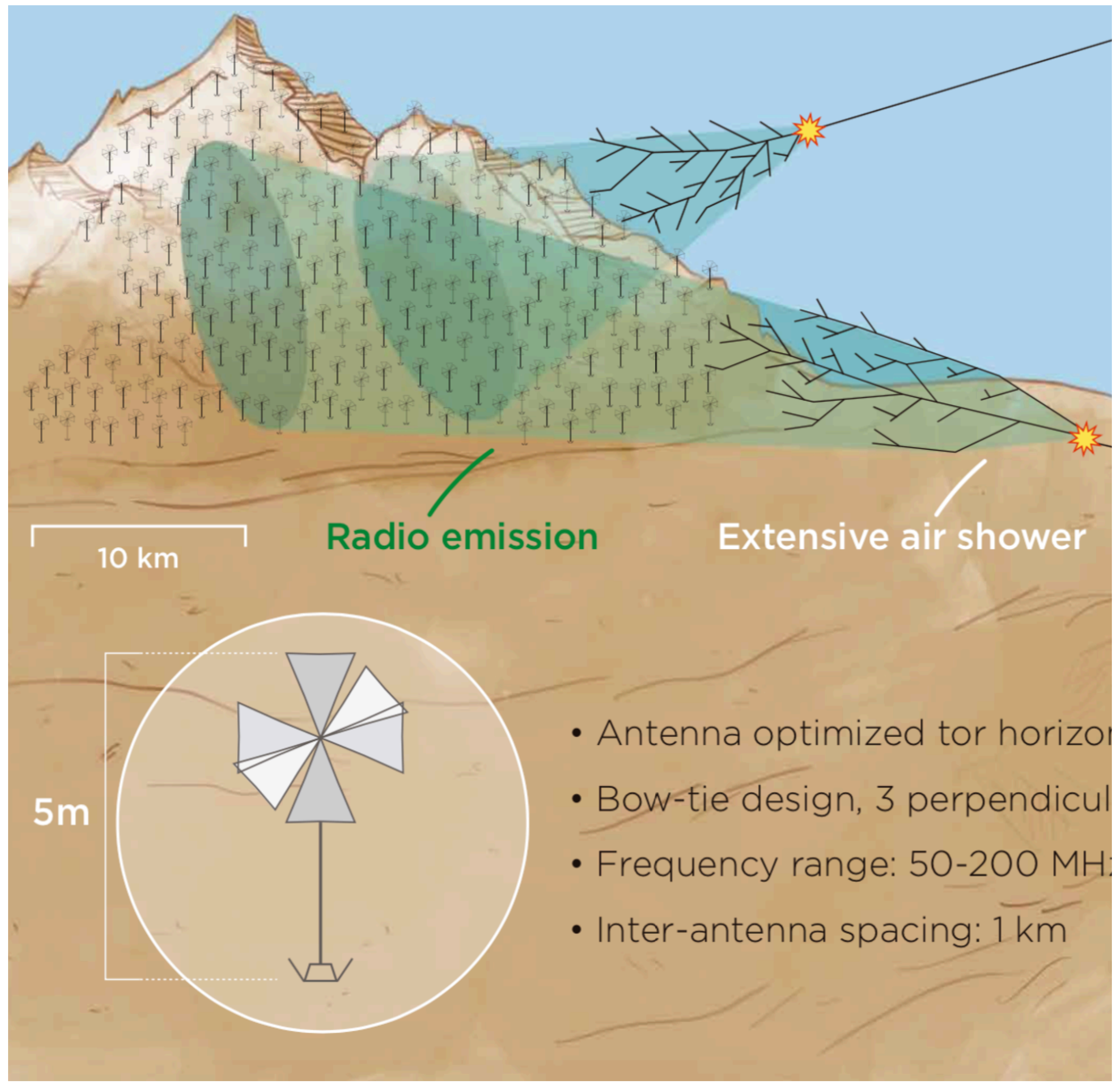
RNO-G

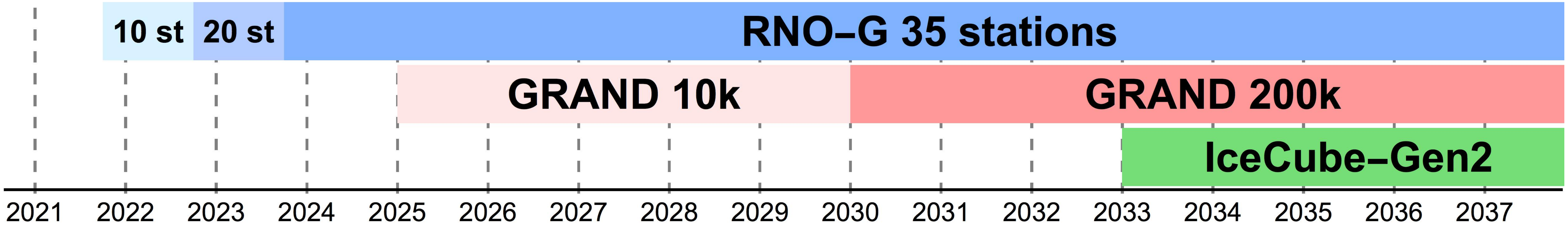
J.A. Aguilar et. al. [2010.12279]



GRAND

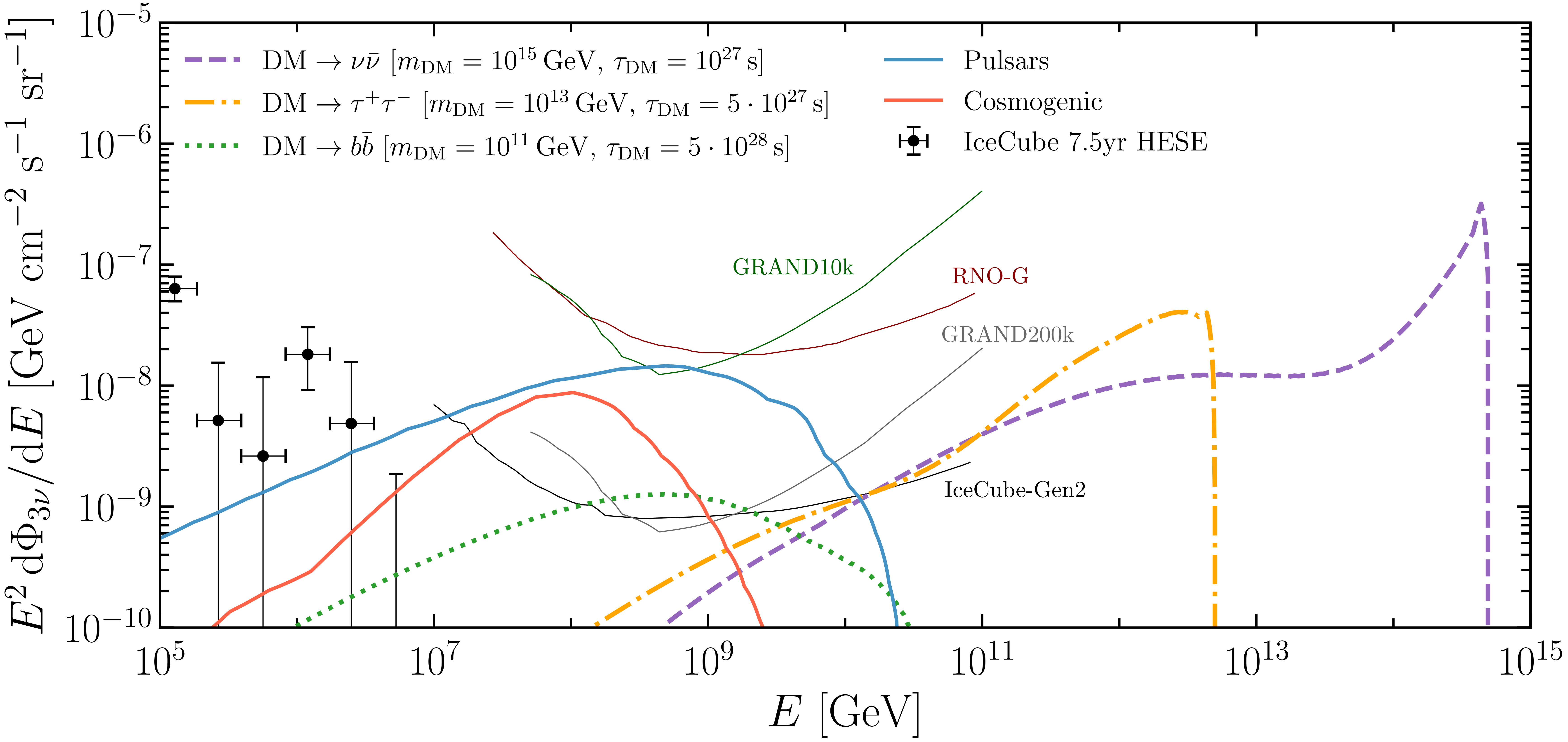
J. Álvarez-Muniz et. al. [1810.09994]





Methodology

- HDMSpectra to generate DM fluxes: *C. W. Bauer et. al. [2007.15001]*
- Astrophysical neutrinos act as a background.
- Conservative choice: highest theoretical astro fluxes.



Methodology

- For each astrophysical scenario the probability to observe $N_{\rm obs}$ events is

$$p\left(N_{\rm obs}\,|\,N_{\rm astro}\right) = \frac{\left(N_{\rm astro}\right)^{N_{\rm obs}} e^{-N_{\rm astro}}}{N_{\rm obs}\,!}$$

N_{obs} stochastic random variable
N_{astro} expected astrophysical events

- Conservative choice: constrain signals $N_{\rm events}$ of DM > $N_{\rm events}$ observed.
- Test statistic: ($\mathscr{L}$ assumed Poisson)

$$\mathrm{TS}(m_{\rm DM}, \tau_{\rm DM}) = \begin{cases} 0 & \text{for} \quad n_{\rm DM} < N_{\rm obs} \\ -2\ln\left(\dfrac{\mathscr{L}(N_{\rm obs}\,|\,n_{\rm DM})}{\mathscr{L}(N_{\rm obs}\,|\,N_{\rm obs})}\right) & \text{for} \quad n_{\rm DM} \geq N_{\rm obs} \end{cases}$$

- For $m_{\rm DM}$ and $N_{\rm astro}$ we can determine the lifetime limits.

New limits on HDDM

$N_{\text{astro}} = 0$

Cosmogenic

Pulsars

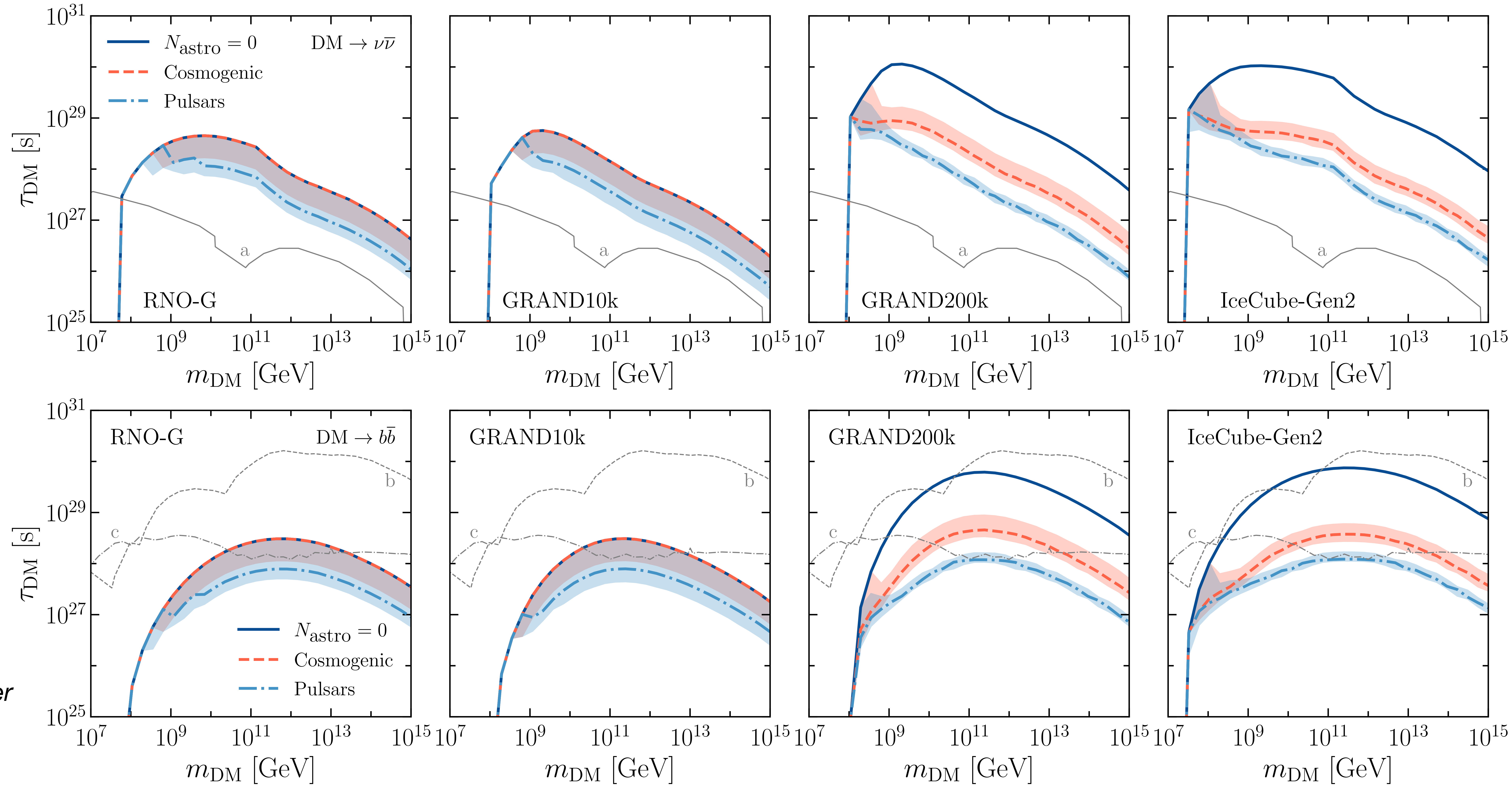
T_{obs} = 3 years

$$\text{DM} \rightarrow \nu\bar{\nu}$$

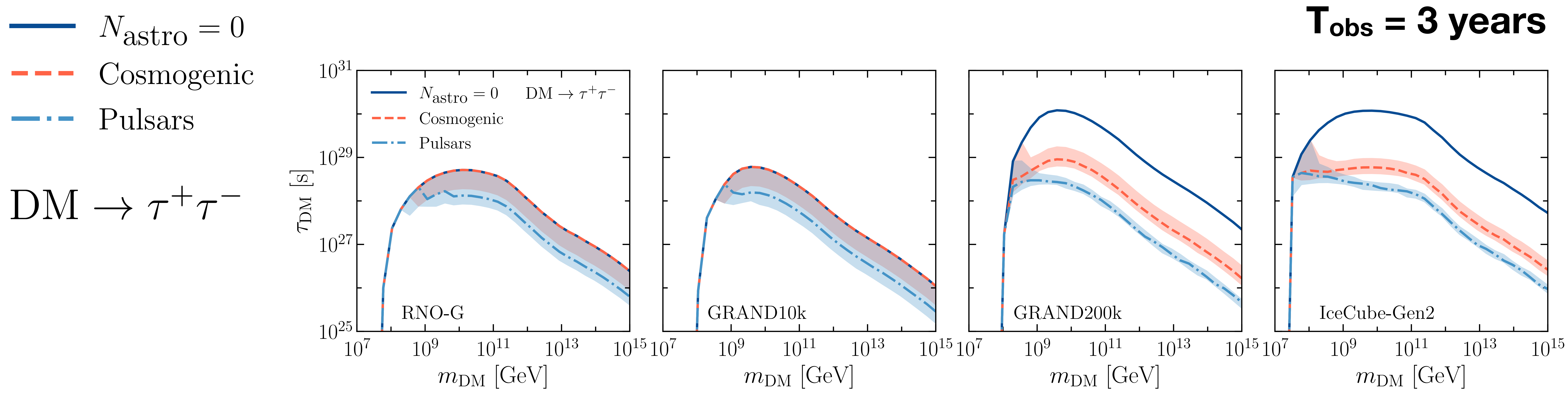
a) IceCube + PAO + ANITA
A. Esmaili et. al. [1205.5281]

$$\text{DM} \rightarrow b\bar{b}$$

b) galactic Multi-Messenger K. Ishiwata et. al. [1907.11671]
c) extragalactic Multi-Messenger K. Ishiwata et. al. [1907.11671]



New limits on HDDM



- New limits with upcoming neutrino radio telescopes.
    - Neutrino channel: higher constraints.
    - Tau channel: new constraints.
    - b channel: complementary constraints to gamma rays.

Conclusions

- Radio neutrino telescopes will have potential to detect a contribution coming from DM.
- Forecast analysis in order to set conservative bounds on the lifetime of HDM particles with $m_{DM} = 10^7 - 10^{15}$ GeV.
- 3 channels, 4 experiments and 2 different astrophysical signals.
- Future work: obtain limits using the current gamma-ray measurements for all channels.

Thank you for your attention