Astrophysical constraints on the non-standard coherent neutrino-nucleus scattering

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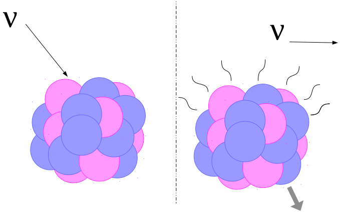
Main ingridients for calculating the sensitivities



$$\nu + T(A,Z) \rightarrow \nu + T(A,Z)$$

Astrophysical neutrino fluxes

- Galactic supernova neutrinos
- Solar neutrinos
- Atmospheric neutrinos

Reaction

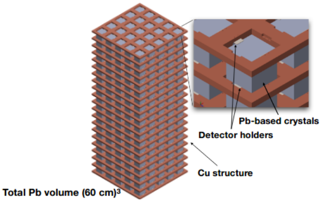
- Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)
  (D. Z. Freedman, (1973), COHERENT Collaboration)

New physics

- non-standard scalar and vector mediators coupling to neutrinos and quarks
  (R. Harnik, D. G. Cerdeno et al. (2016), Y. Farzan et al.(2018) ,...)

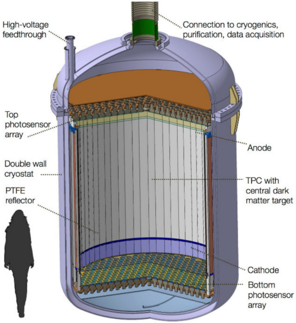
Future generation CEνNS detectors

RES-NOVA (L. Pattavina et al. (2020))



fiducial volume: 2.4 - 456 ton
target material: Pb
threshold: 1 keV

DARWIN (J. Aalbers et al. (2016))



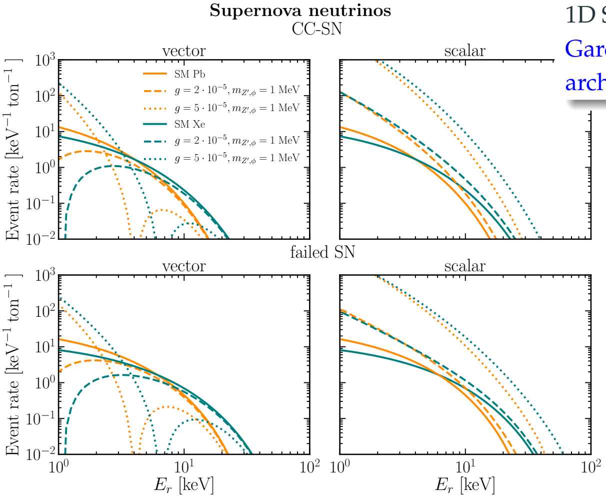
fiducial volume: 40 ton
target material: Xe
threshold: 1 keV
efficiency: XENON1T - 100%

Scattering rate

$$\frac{dR_{\nu N}}{dE_r dt} = N_T \, \epsilon(E_r) \int dE_\nu \, \frac{d\sigma_{\nu N}}{dE_r} \, \psi(E_\nu, t) \, \Theta(E_r^{\max} - E_r)$$

$$E_r^{\max} = \frac{2E_\nu^2}{m_T + 2E_\nu}$$

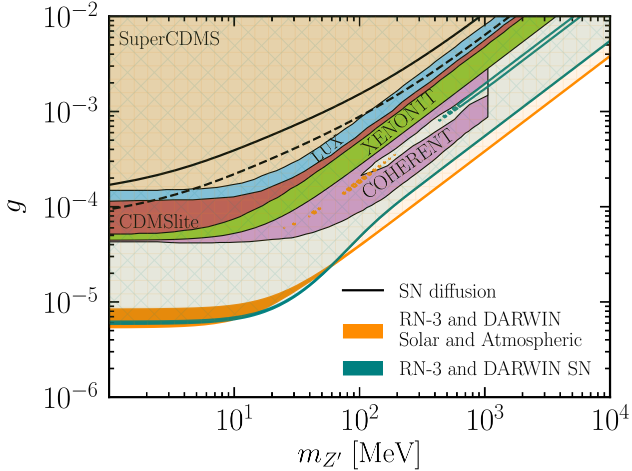
Event rates for supernova neutrinos



1D SN models
Garching group archive

- Failed SN: hotter neutrino spectrum → longer recoil spectrum
- Heavier target: higher number of events but shorter recoil spectrum

Sensitivity bounds on the new non-standard mediators



- Detection of solar and supernova neutrinos → most competitive bounds
- WIMP bound can be translated to a limit on non-standard mediators
- Static picture: non-standard mediators inside the SN place weak bounds

Conclusions

Future dark matter (CEνNS) detectors

- sensitive to astrophysical neutrinos
- flavor insensitive neutrino channel
- high cross section & low thresholds
- open an extra window to probe new physics
- promise to place most competitive bounds on new mediators

Thank you!

Core-collapse supernovae

- non-standard mediators affect the diffusion time of neutrinos
- scalar LNC mediator $\rightarrow$ new cooling channel

Backup slides

Astrophysical neutrino fluxes

Supernova neutrinos

- large flux for Galactic SN
- transient event

Solar neutrinos

$^{8}\text{B} \rightarrow {}^{8}\text{Be}^{*} + e^{+} + \nu_e$

$^{3}\text{He} + p \rightarrow {}^{4}\text{He} + e^{+} + \nu_e$

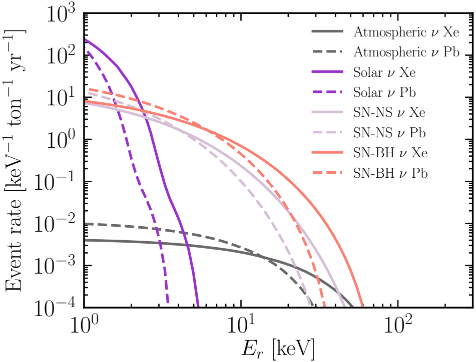
- neutrino energies up to $\sim$15 MeV

Atmospheric neutrinos

$\pi^{+} \rightarrow \mu^{+} + \nu_\mu$ and $\pi^{-} \rightarrow \mu^{-} + \bar{\nu}_\mu$

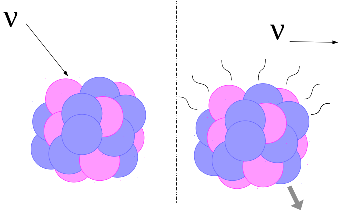
$\mu^{+} \rightarrow e^{+} + \bar{\nu}_\mu + \nu_e$ and $\mu^{-} \rightarrow e^{-} + \nu_\mu + \bar{\nu}_e$

- the highest neutrino energies among the considered sources
- high uncertainty $\sim 20\%$

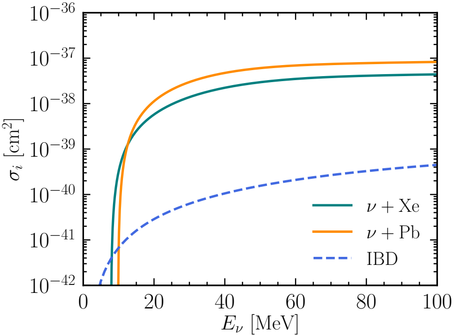


E. Vitagliano et al. (2019), M. Honda et al. (2011), J. L. Newstead et al. (2020)

Coherent elastic neutrino-nucleus scatterings (CEνNS)



$$\nu + T(A, Z) \to \nu + T(A, Z)$$



Cross section

$$\frac{d\sigma_{\rm SM}}{dE_r} = \frac{G_F^2 m_T}{4\pi} Q_w^2 \left(1 - \frac{m_T E_r}{2E_\nu^2}\right) F^2(Q),\ \ Q_w = \left[N - Z(1 - 4\sin^2\theta_W)\right]$$

- coherently enhanced by the square of the neutron number
- flavor insensitive
- coherent up to $\sim$ 50 MeV

D. Z. Freedman

Non-standard coherent neutrino-nucleus scatterings

$g = \sqrt{|g_{q,i} g_{\nu,i}|},\ g_{q,i} g_{\nu,i} > 0$

new vector mediator

Z'

new scalar mediator

ϕ

Lagrangian terms

$$\mathcal{L}^{Z'} = g_{\nu,Z'} Z'_\mu \bar{\nu}_L \gamma^\mu \nu_L + Z'_\mu \bar{q} \gamma^\mu g_{q,Z'} q$$

$$\mathcal{L}^{\phi}_{\text{LNC}} = g_{\nu,\phi} \phi \bar{\nu}_R \nu_L + \phi \bar{q} g_{q,\phi} q$$

$$\mathcal{L}^{\phi}_{\text{LNV}} = g_{\nu,\phi} \phi \nu^c_L \nu_L + \phi \bar{q} g_{q,\phi} q$$

Cross sections

$$\frac{d\sigma_{\nu N}}{dE_r} = \frac{G_F^2 m_T}{\pi} |\xi|^2 \left(1 - \frac{m_T E_r}{2E_\nu^2}\right) F^2(Q)$$

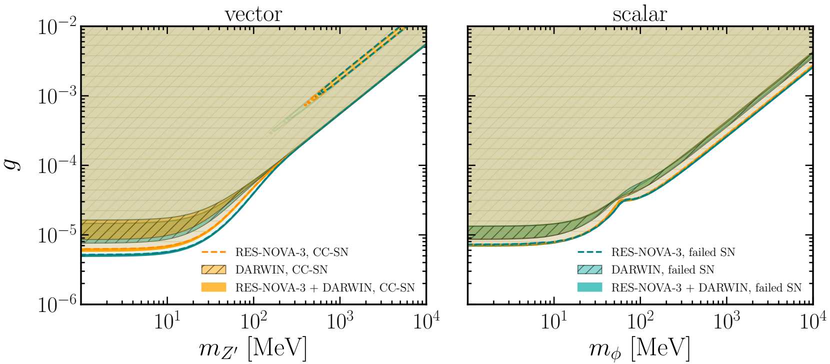
$$\xi = -\frac{Q_w}{2} + \frac{g_{\nu,Z'} Q'_w}{\sqrt{2} G_F (2 m_T E_r + m_{Z'}^2)}$$

$$\frac{d\sigma_{\nu N}}{dE_r} = \frac{d\sigma_{\text{SM}}}{dE_r} + \frac{d\sigma_\phi}{dE_r}$$

$$\frac{d\sigma_\phi}{dE_r} = \frac{(g_{\nu,\phi} g_{q,\phi} Q_s)^2}{2\pi (2 E_r m_T + m_\phi^2)^2} \frac{m_T^2 E_r}{2E_\nu^2} F^2(Q)$$

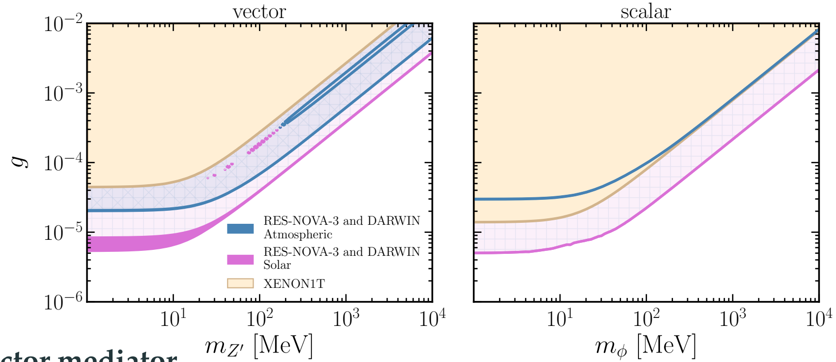
D. G. Cerdeno et al. (2016), Y. Farzan et al.(2018), D. Aristizabal Sierra et al. (2019)

Results supernova neutrinos



- failed SN: higher number of events → better constraints
- RES-NOVA-3 drives the limits due to to higher volume
- vector mediator small unconstrained region due to the interference term
- limits on the vector mediator better for low mediator masses

Results solar and atmospheric neutrinos



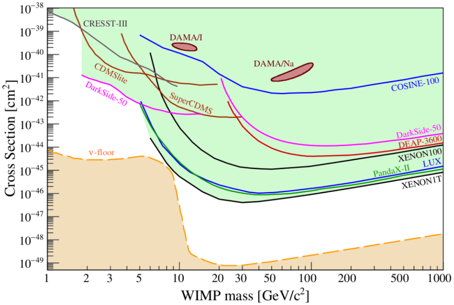
Vector mediator

- Solar neutrinos: bounds driven by Xe based detector
- Atmospheric neutrinos: bounds driven by Pb detector

Scalar mediator

- Bounds driven by Pb detector

XENON1T results



M. Schumann (2019)

neutrino floor

unavoidable background

in the future dark matter detectors

WIMP's limits

on the mass and cross section

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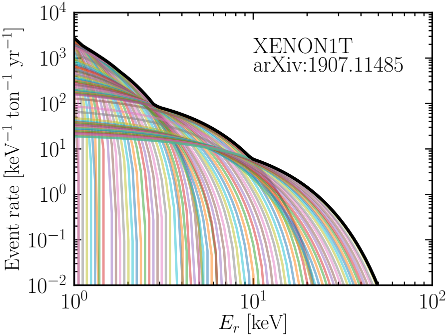
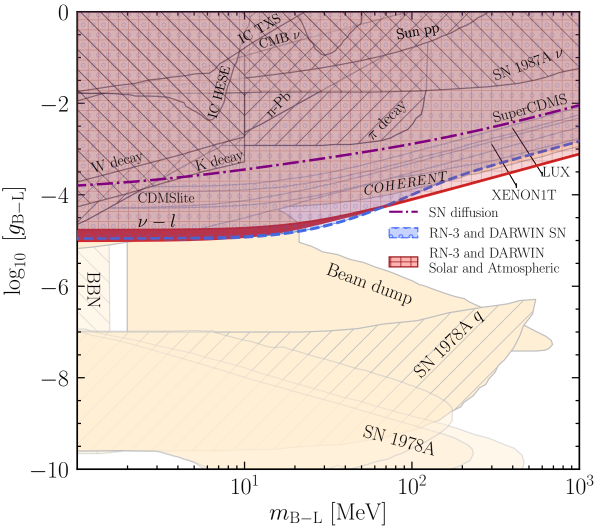
limits on the mass and coupling

of the non-standard mediators

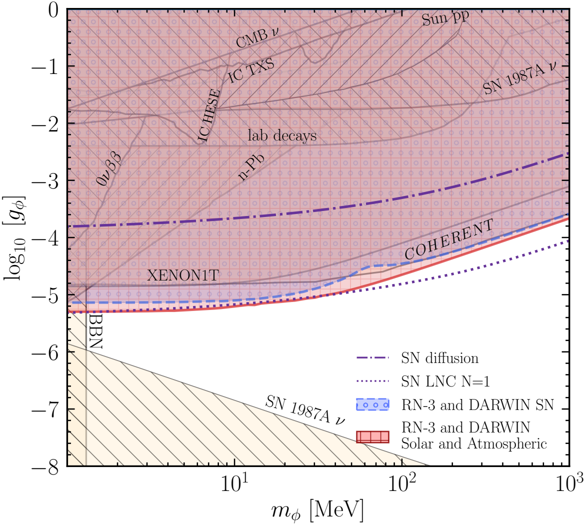


J. Aalbers et al. wimprates, E. Aprile et al. (2019)

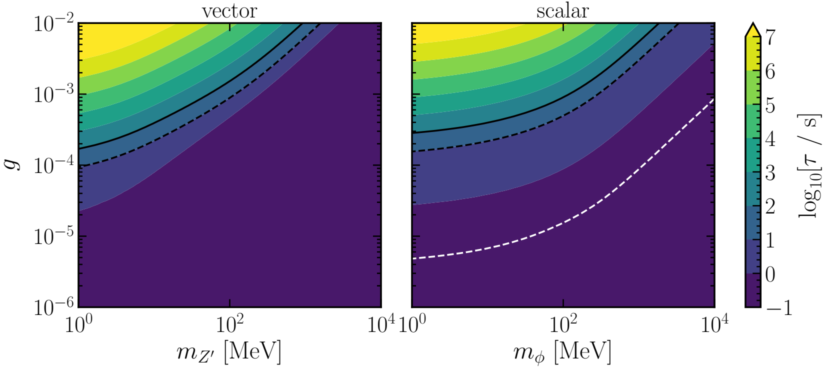
Comparision of limits from specific new physics models



Comparision of limits from specific new physics models

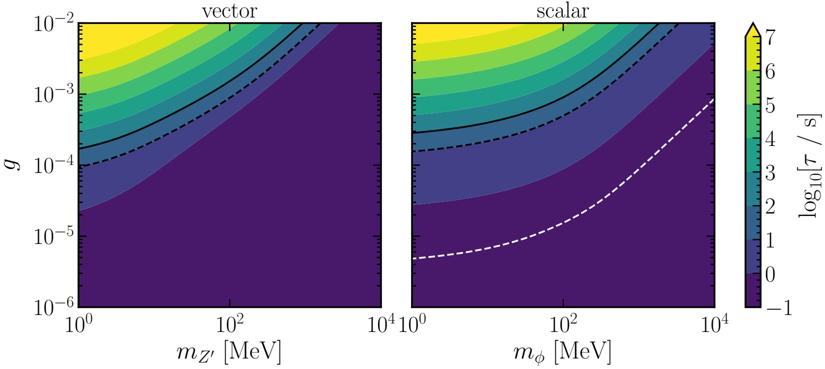


Non-standard coherent scattering in the supernova core



- prolonged diffusion time → possible change in the star's fate
- prolonged diffusion time → changed duration of the neutrino signal
- LNC scalar mediator → new cooling channel due to ν_R

Non-standard coherent scattering in the supernova core



- mean-free path

$$\lambda_{\nu_\beta} = \sum_{\text{CC,NC}} \frac{\int dE_{\nu_\beta} f(E_{\nu_\beta}) E^2_{\nu_\beta}}{n_t \int dE_{\nu_\beta} f(E_{\nu_\beta}) E^2_{\nu_\beta} \sigma_i(E_{\nu_\beta})}$$

- diffusion time

$$\tau_{\nu_\beta} = \int_{R_1}^{R_2} dr \frac{r}{\lambda_{\nu_\beta}(r)}$$

- number of scatters

$$N = \int_0^{R_2} \frac{2r}{\lambda(r)^2} \, dr$$

$R_1 = 10$ km

$R_2 = 40$ km