# Supernova Bounds on a Neutrinophilic Dark Sector

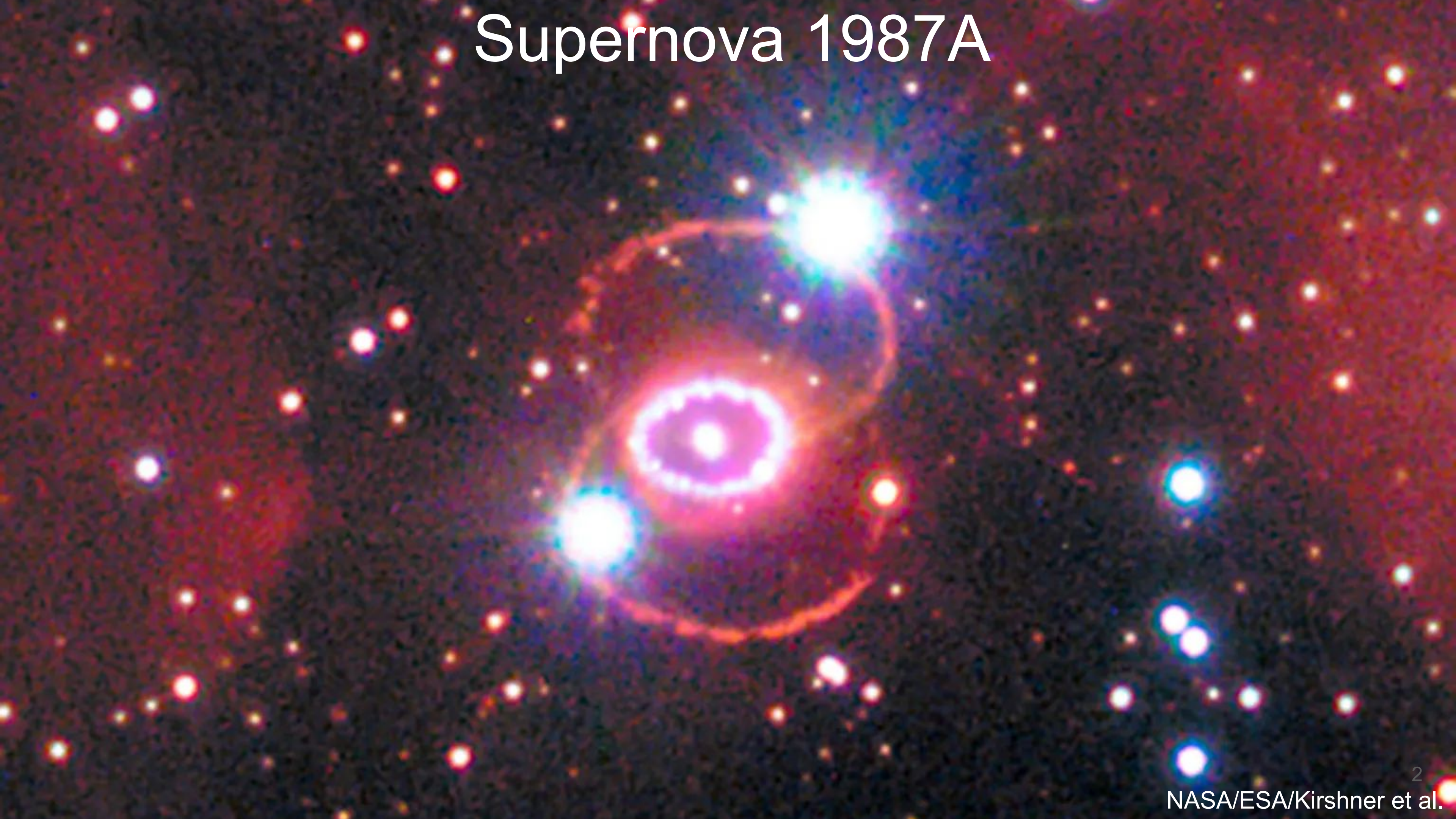
Christopher Cappiello

Based on:
arXiv:2503.09691 + upcoming work
CC, Bhupal Dev, Amol Patwardhan

CETUP*, July 13, 2026

WashU

# Supernova 1987A



NASA/ESA/Kirshner et al.

# Supernova 1987A Constraints on New Particles

Volume 193, number 4 PHYSICS LETTERS B 23 July 1987

## CONSTRAINTS ON LIGHT PARTICLES FROM SUPERNOVA SN 1987A

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Received 23 April 1987

We show how the recent observations of neutrinos from SN 1987A can be used to constrain the properties of light particles, including the number of neutrino species $N_\nu$ and the coupling strength of a light pseudoscalar boson such as the axion. First we demonstrate the consistency of Kamiokande II and IMB III data with each other and with the standard theory of neutrino emission from a supernova core of radius $R \simeq 20$ km and effective temperature $T \simeq 5$ to 6 MeV. The total amount of energy emission by neutrinos is compatble with the binding energy of a neutron star only if $N_\nu \leqslant 6$. The upper limit on the difference between the binding energy and the energy lost via $N_\nu = 3$ neutrino species excludes light pseudoscalar bosons with couplings to electrons in the range $10^{-27} \leqslant \alpha_e \leqslant 10^{-24}$, which enables one to extend astrophysical bounds on the axion decay constant to $f_a \geqslant 4 \times 10^9$ GeV.

VOLUME 60, NUMBER 18 PHYSICAL REVIEW LETTERS 2 MAY 1988

## Axions from SN1987A

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(Received 12 November 1987)

Axion emission from SN1987A by nucleon-nucleon axion bremsstrahlung is considered. On the basis of the neutrino observations the axion luminosity must be $\lesssim 10^{53}$ erg s$^{-1}$. This occurs if (1) axions couple very weakly: $m_a \lesssim 0.75 \times 10^{-3}$ eV; or (2) axions couple strongly enough to be "trapped" and radiated from an "axion sphere" with $T_a \lesssim 8$ MeV: $m_a \gtrsim 2.2$ eV. In general, "axion trapping" occurs for $m_a \gtrsim 0.016$ eV. These mass constraints are at best reliable to within a factor of $\simeq 3$.

PACS numbers: 97.60.Bw, 14.80.Gt, 97.60.Jd

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## CONSTRAINTS ON AXIONS FROM SN 1987A

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Received 23 December 1987

We argue that the detection of neutrinos from SN 1987A implies that axion emission from the collapsing star must not have been significant. The best axion supernova limits come from nucleon bremsstrahlung processes which involve axion–quark couplings rather than the electron or photon couplings used in obtaining axion limits from red giants. The axion–quark couplings are less sensitive to specific axion model parameters and therefore are capable of yielding a model independent lower bound on $f_a$. Quantitatively this yields an axion coupling limit of $f_a \gtrsim 8 \times 10^{11}$ GeV (or equivalently $m_a \lesssim 9 \times 10^{-5}$ eV). This approaches the upper bound on $f_a \lesssim 4 \times 10^{12}$ GeV from cosmological density arguments. While the bounds do not exclude the axion, if the axion exists, it must dominate the cosmological mass density. This same argument can also be applied to analogous couplings for any particle with $m \lesssim 50$ MeV.

VOLUME 60, NUMBER 18 PHYSICAL REVIEW LETTERS 2 MAY 1988

## Bounds on Exotic-Particle Interactions from SN1987A

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(Received 26 October 1987)

The observation of a neutrino pulse from the supernova SN1987A constrains the production of light exotic particles in the proto neutron star. We derive a new bound on the axion decay constant, $f_a \gtrsim 10^{10}$ GeV. If right-handed (RH) neutrinos exist, the "RH Fermi constant" is $G_{RH} \lesssim 10^{-4} G_F$, 2 orders of magnitude below laboratory bounds. The Dirac mass of $\nu_\mu$ can be constrained below laboratory limits.

PACS numbers: 97.60.Bw, 14.60.Gh, 14.80.Gt, 97.60.Jd



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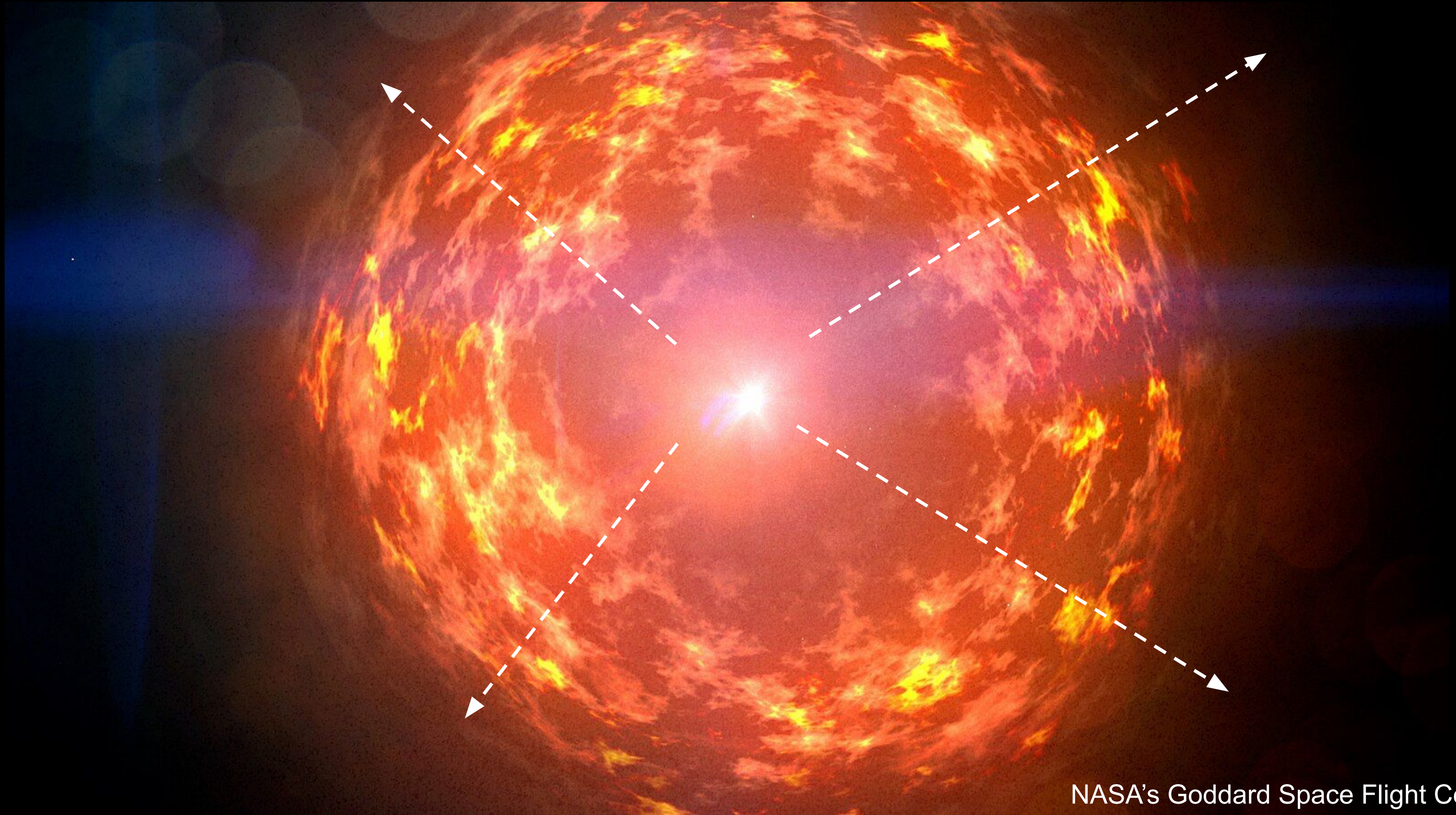
# Supernova 1987A Constraints on New Particles



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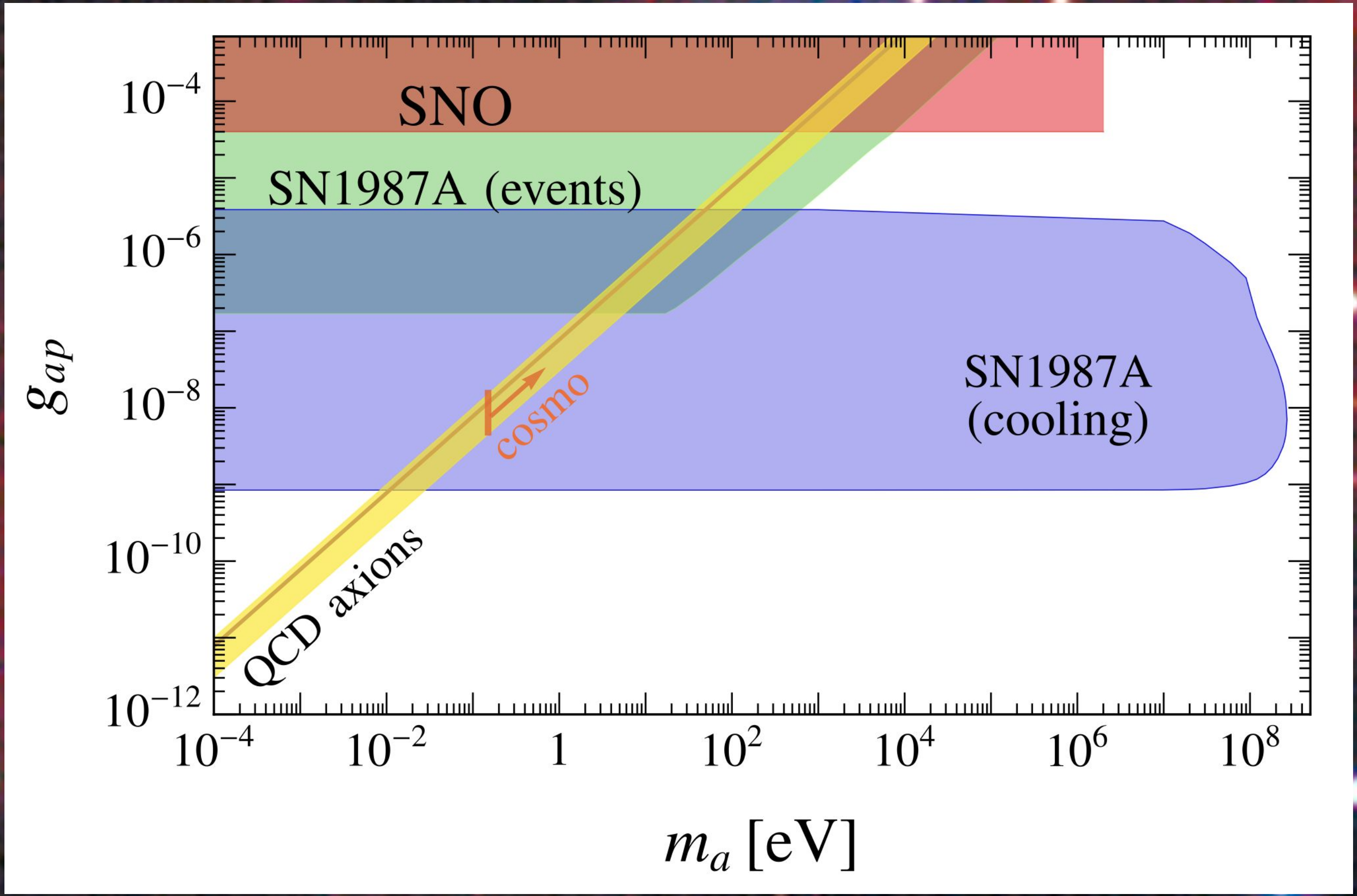


https://arxiv.org/pdf/2309.14798

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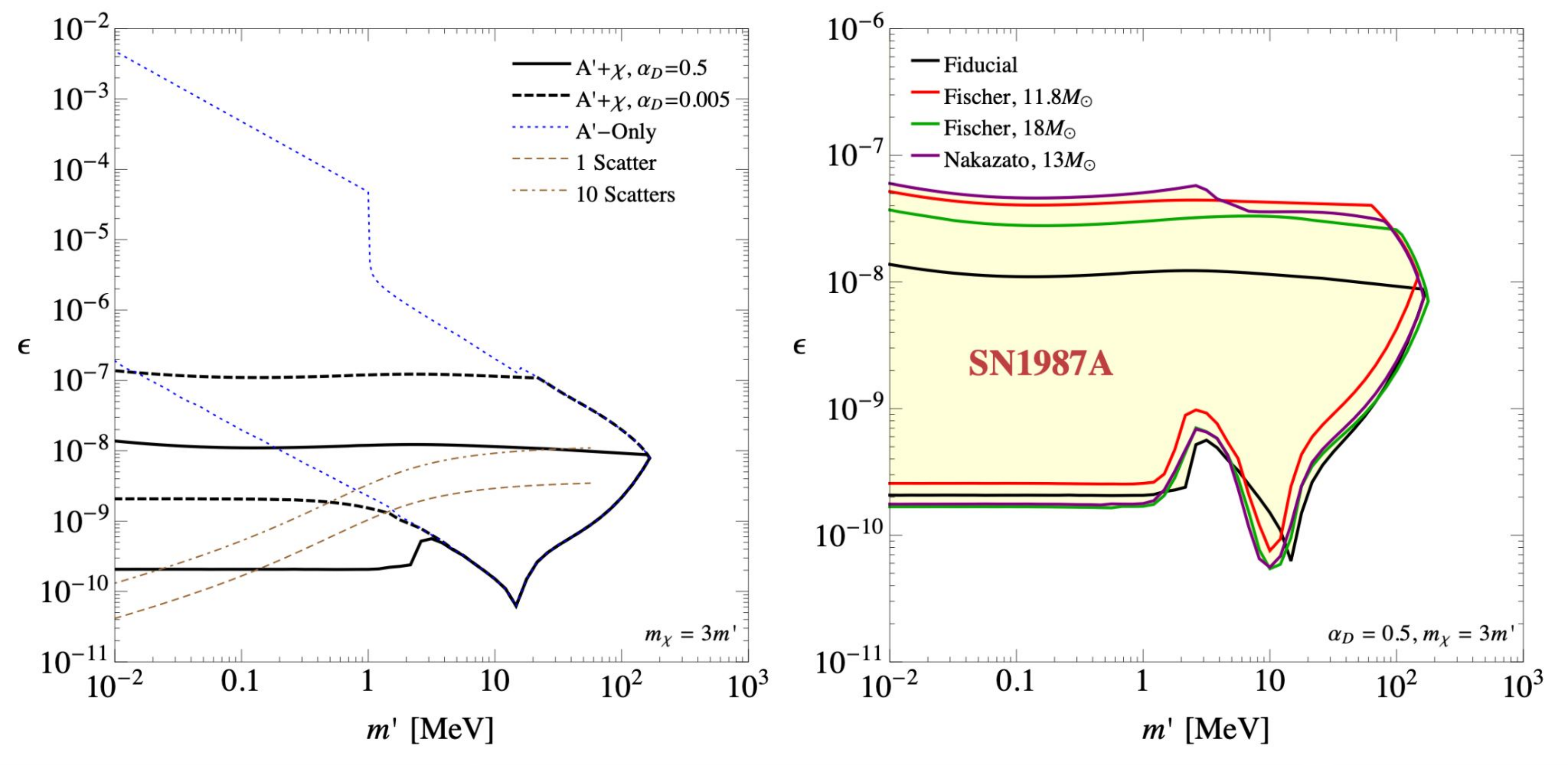


https://arxiv.org/pdf/1803.00993



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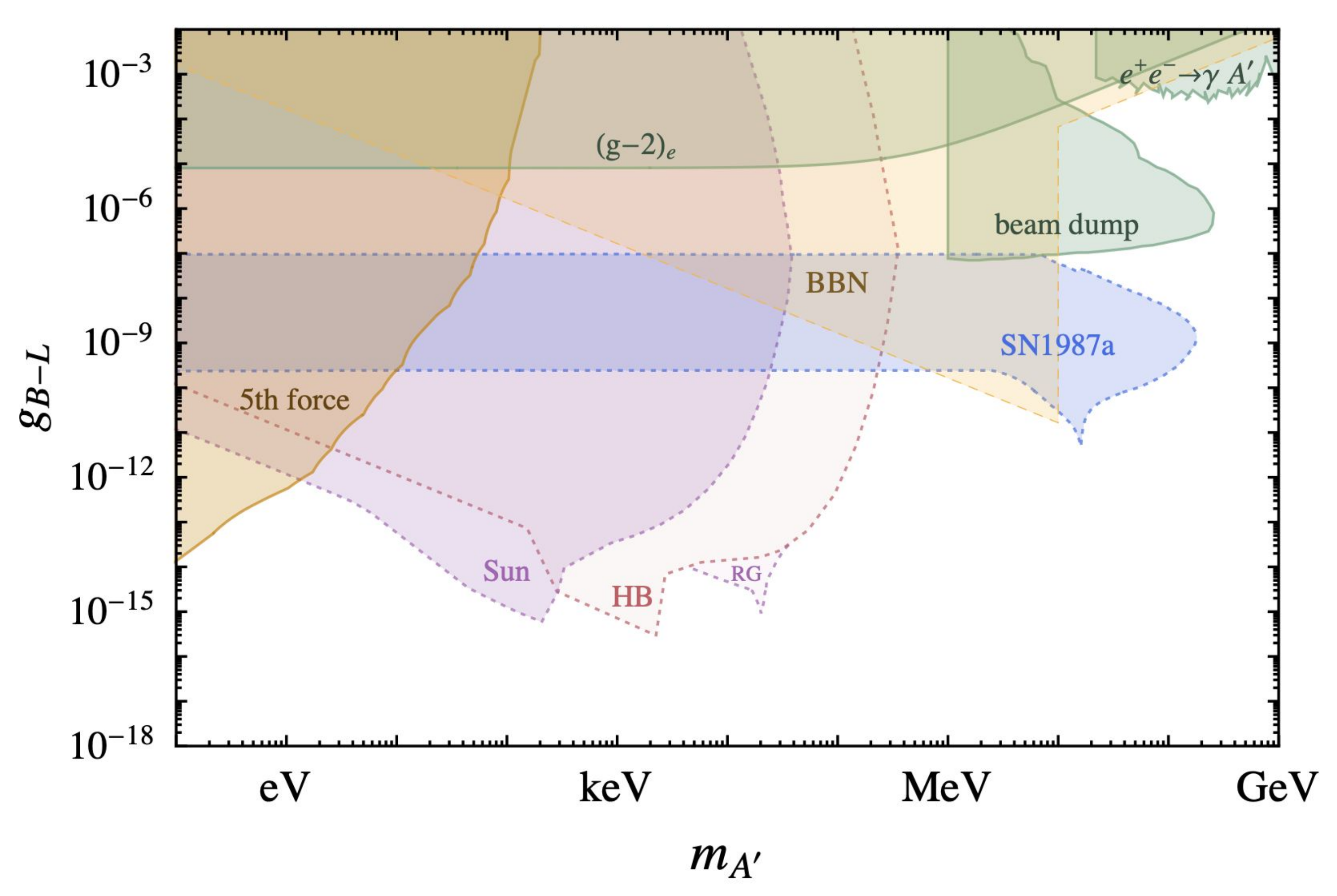


https://arxiv.org/pdf/1709.07882

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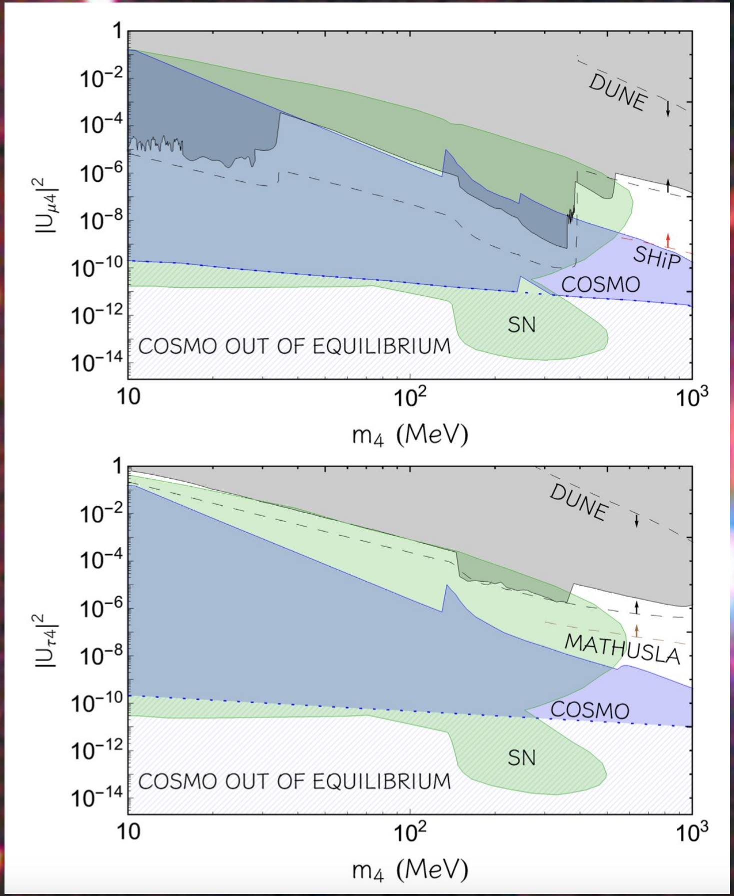
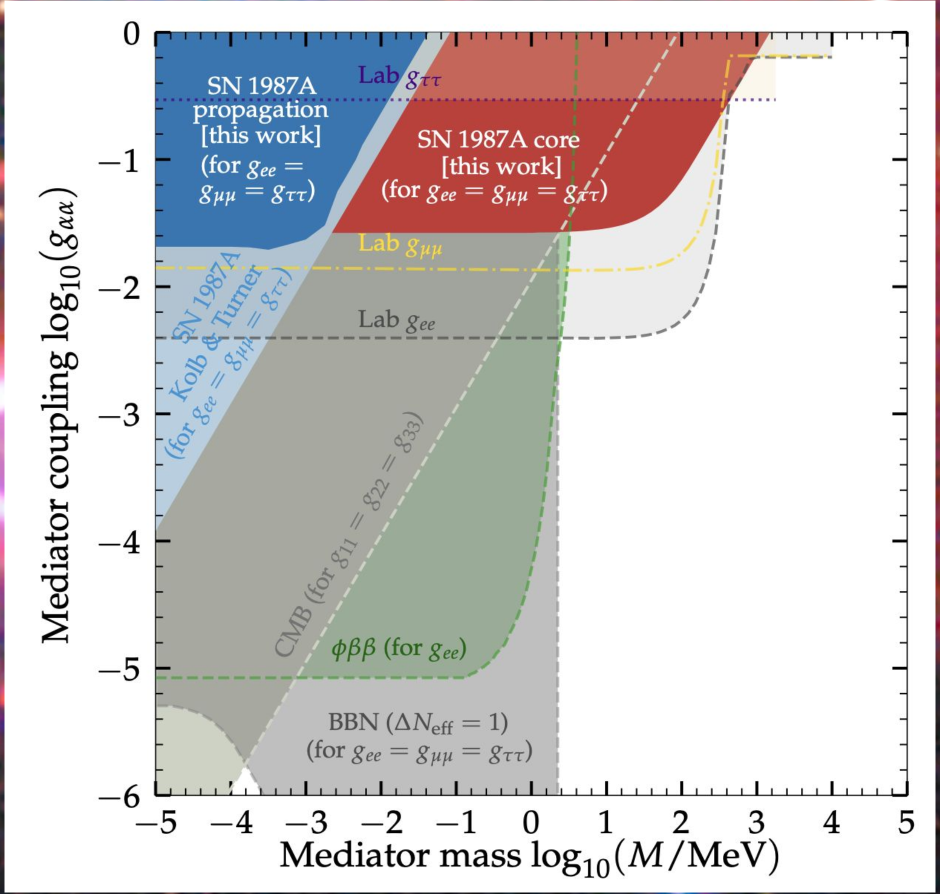
# Supernova 1987A and Neutrino Physics




https://arxiv.org/pdf/2311.00033




https://arxiv.org/pdf/1912.09115

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# Neutrinophilic Dark Matter

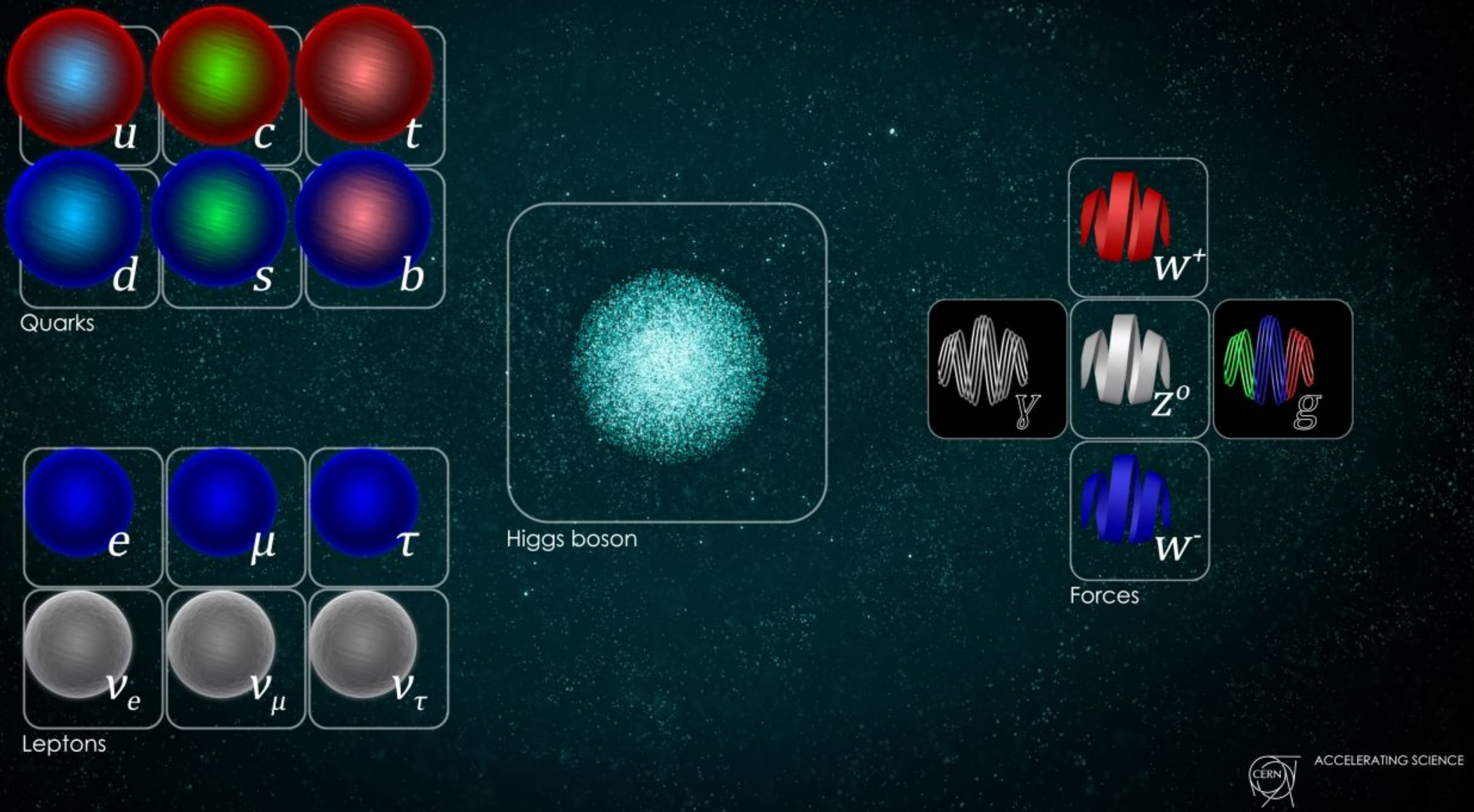


Image: Daniel Dominguez/CERN

# Neutrinophilic Dark Matter

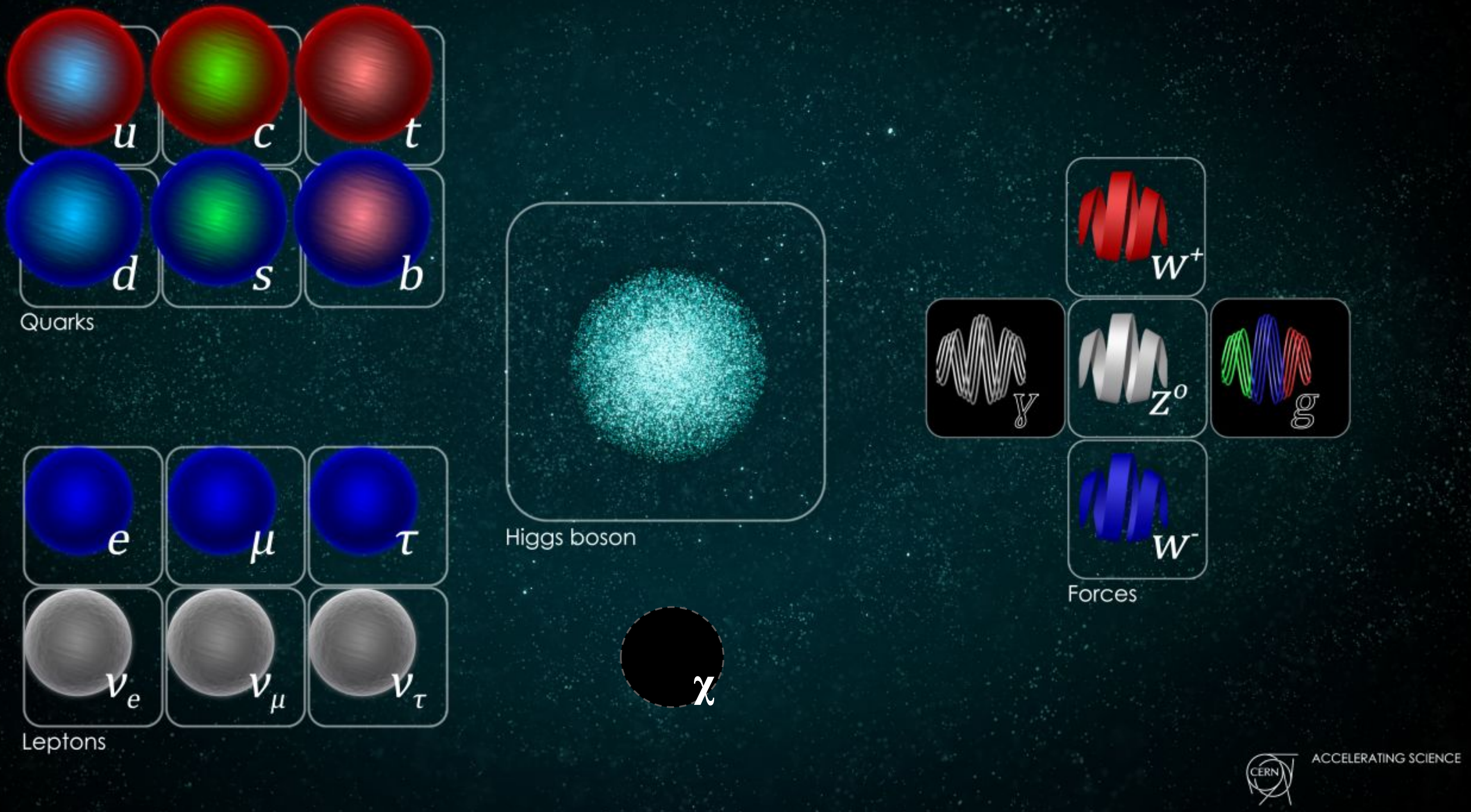


Image: Daniel Dominguez/CERN

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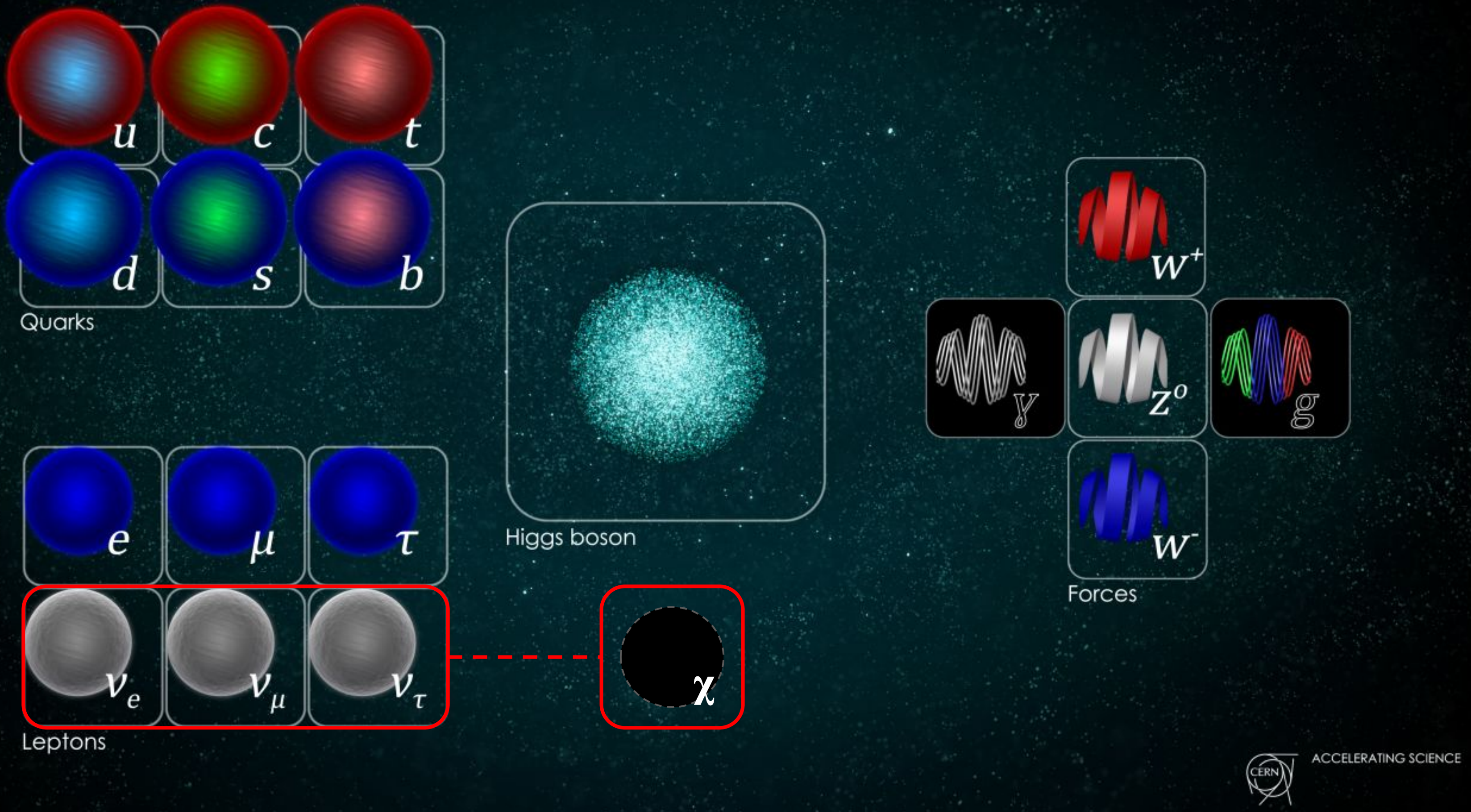
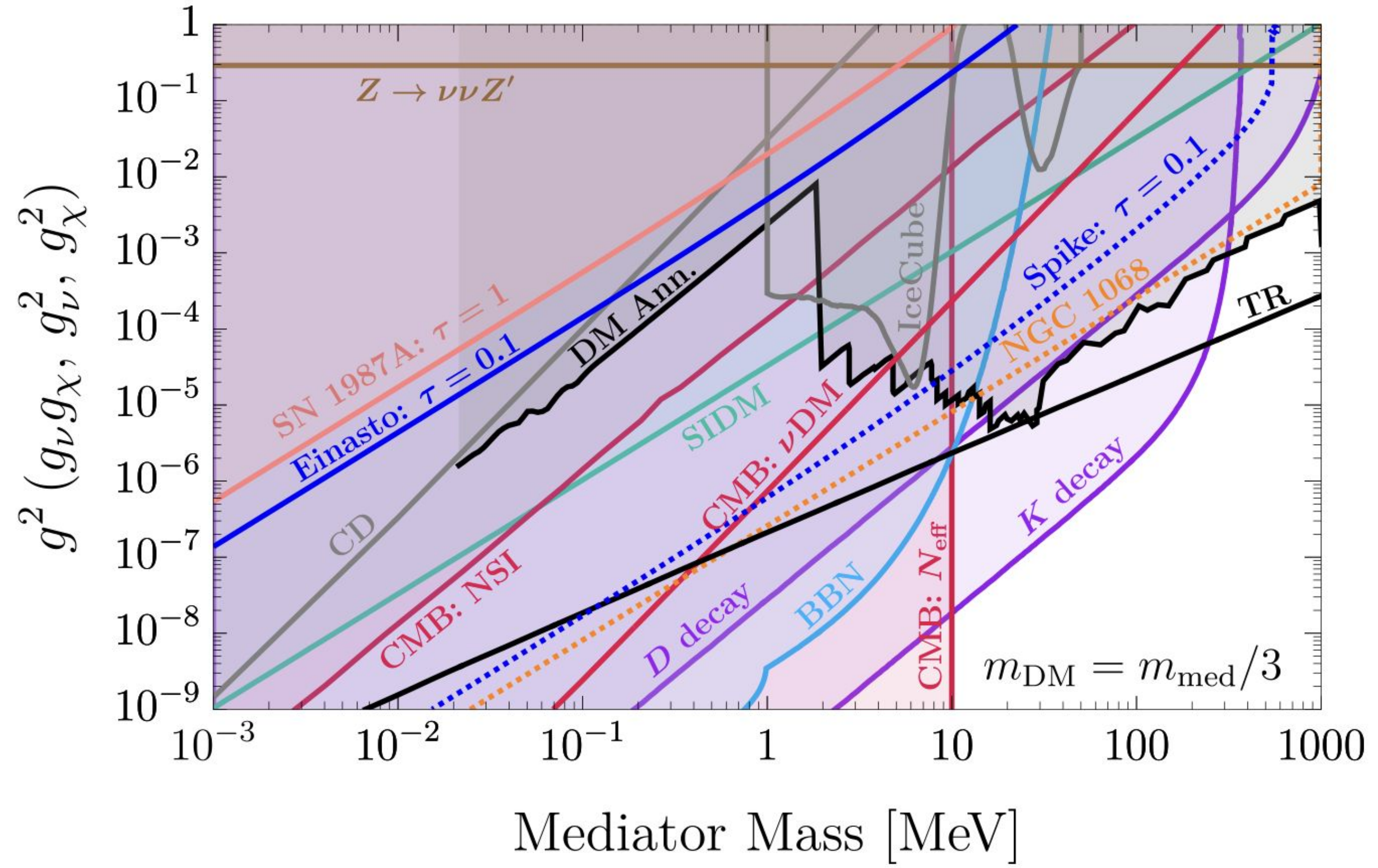



Image: Daniel Dominguez/CERN

# Neutrinophilic Dark Matter




https://arxiv.org/pdf/2507.01000

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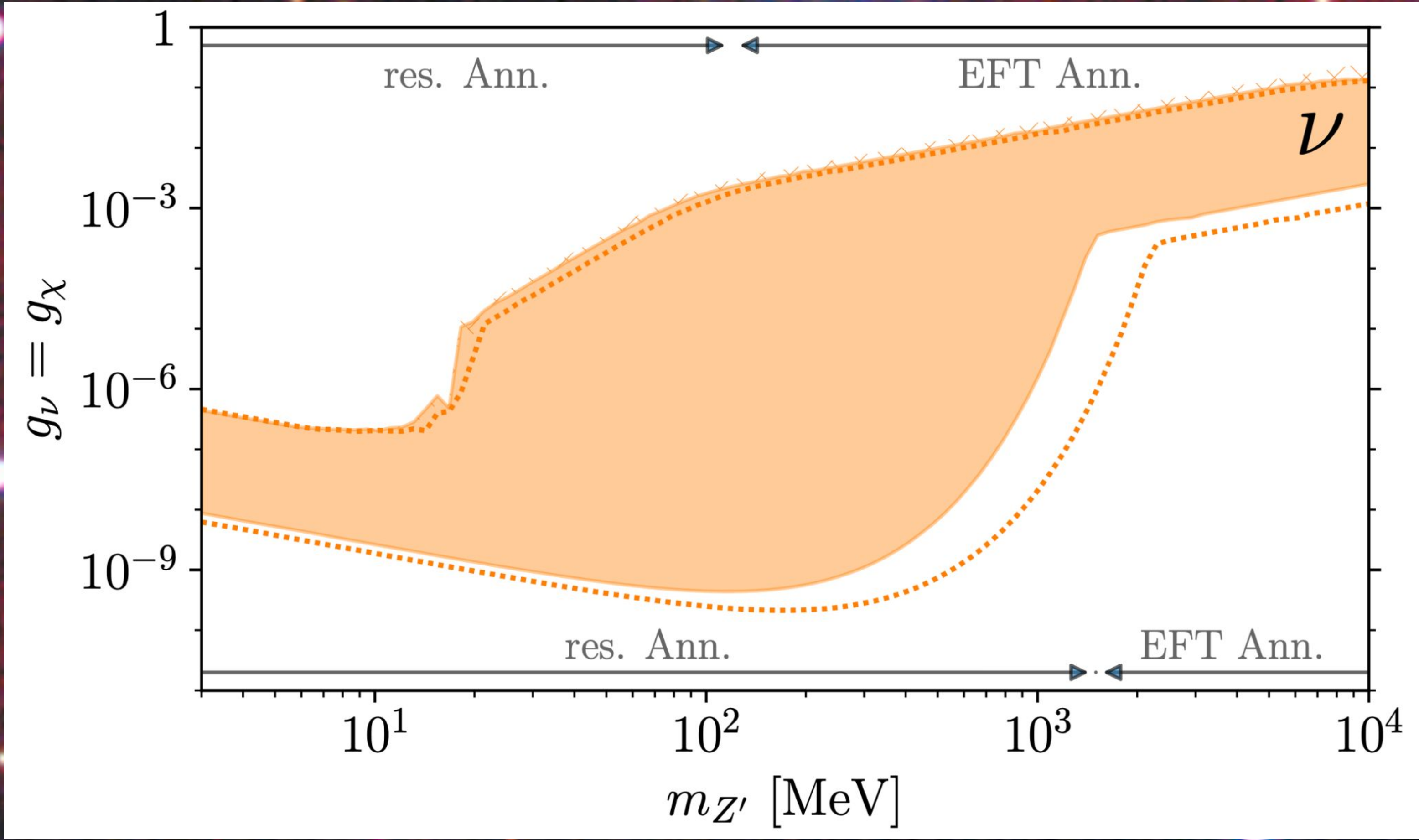
# SN Bounds on DM-Neutrino Interactions




https://arxiv.org/pdf/2307.03143

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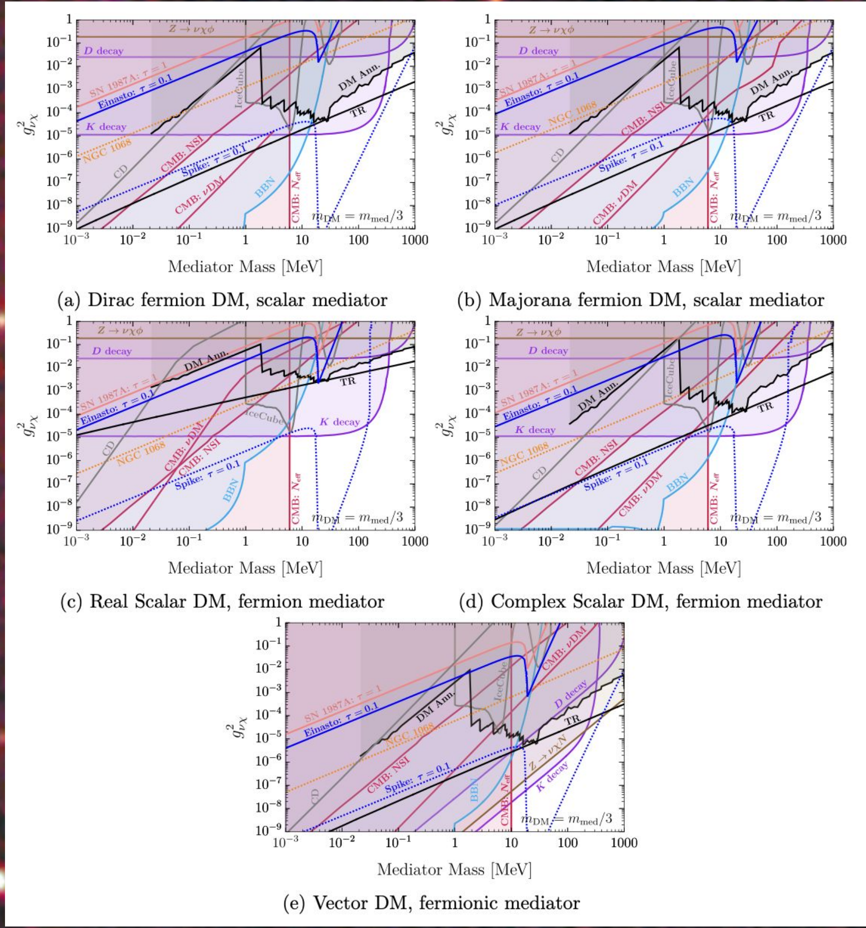
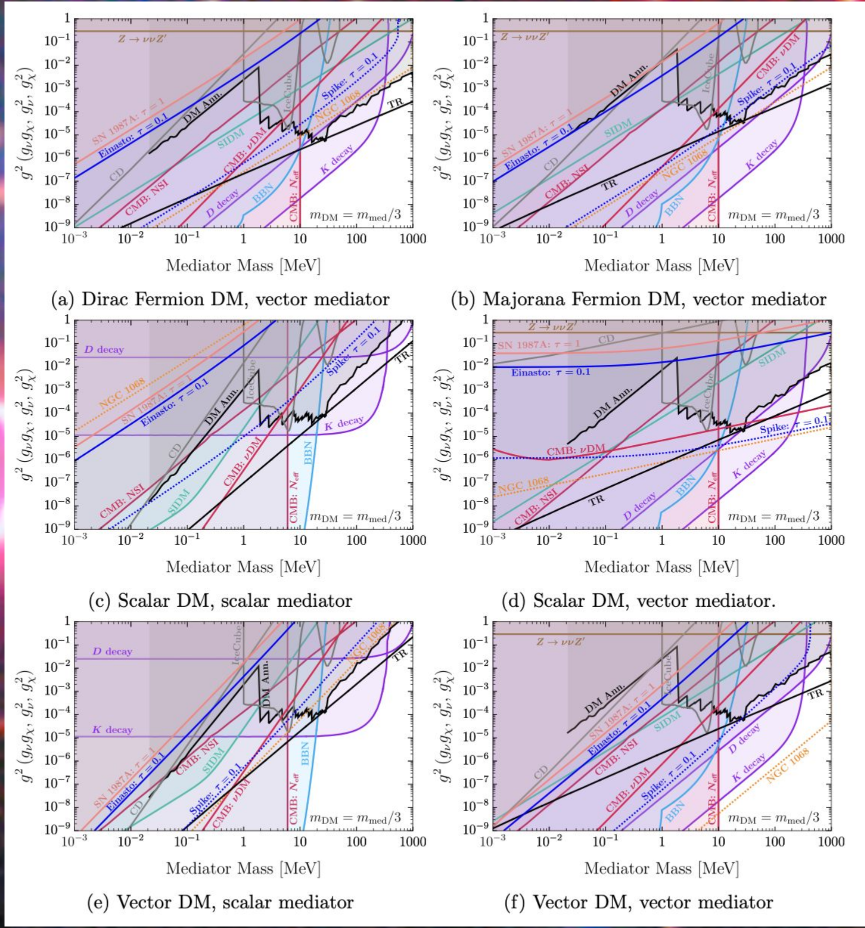
# Many Models for DM-Neutrino Interactions!



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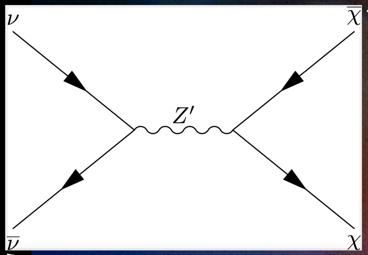
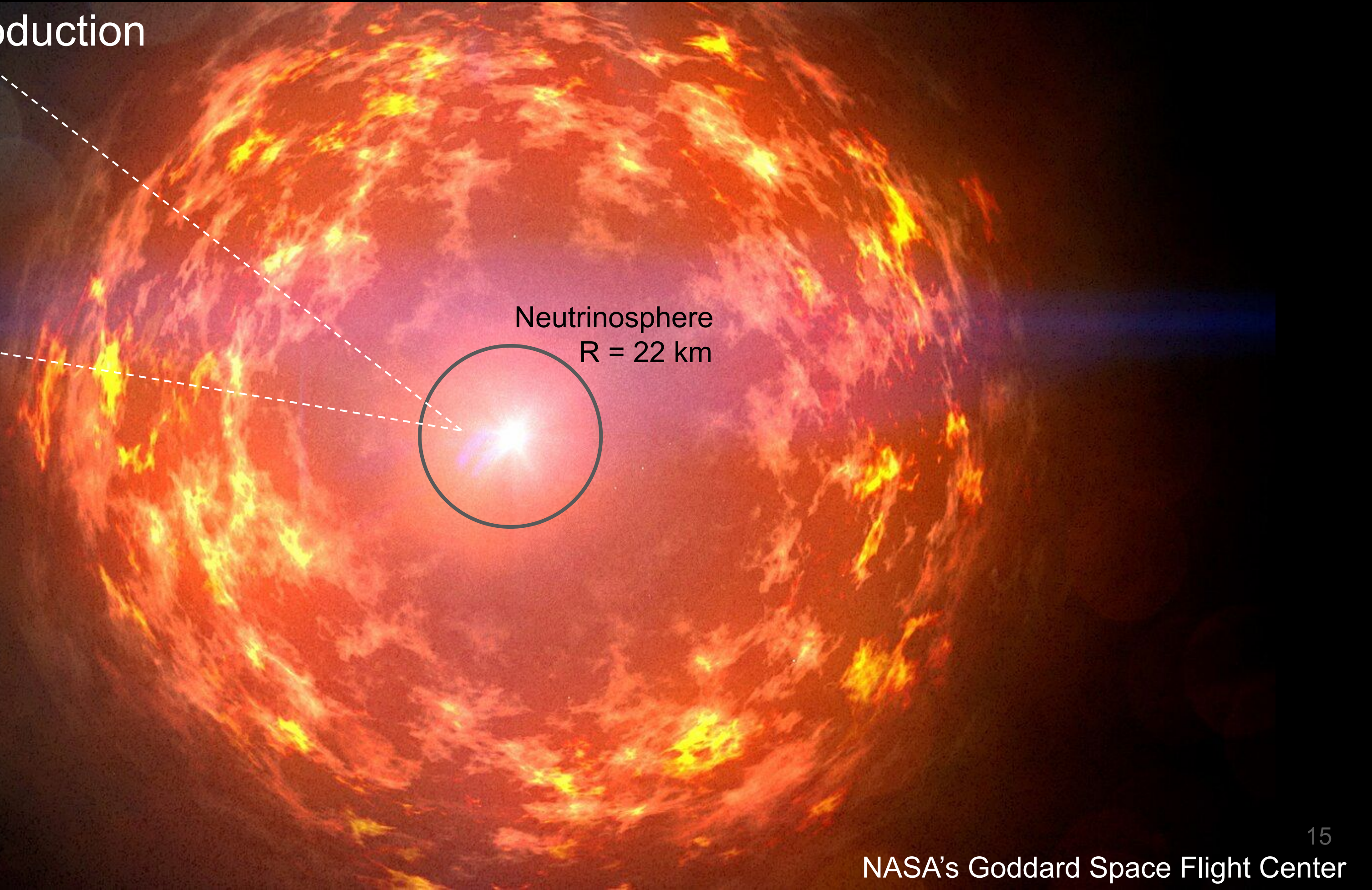
# Constraining Neutrinophilic Dark Sector

## 1. Dark Matter Production

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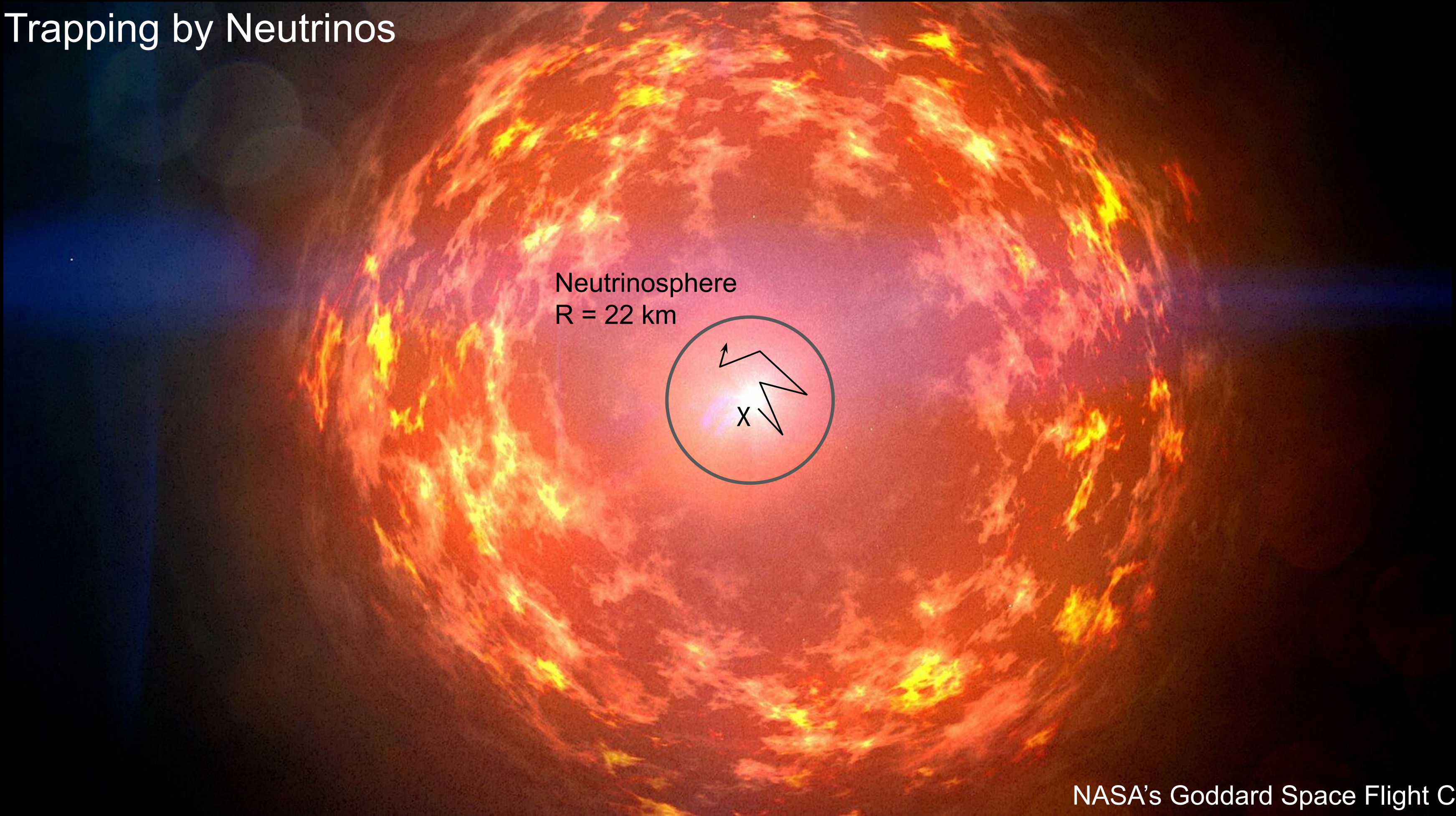
# Constraining Neutrinophilic Dark Sector

2. Trapping by Neutrinos



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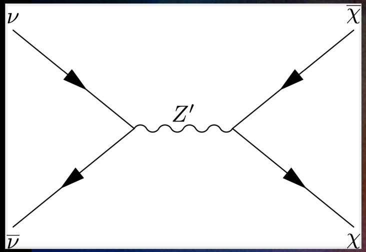
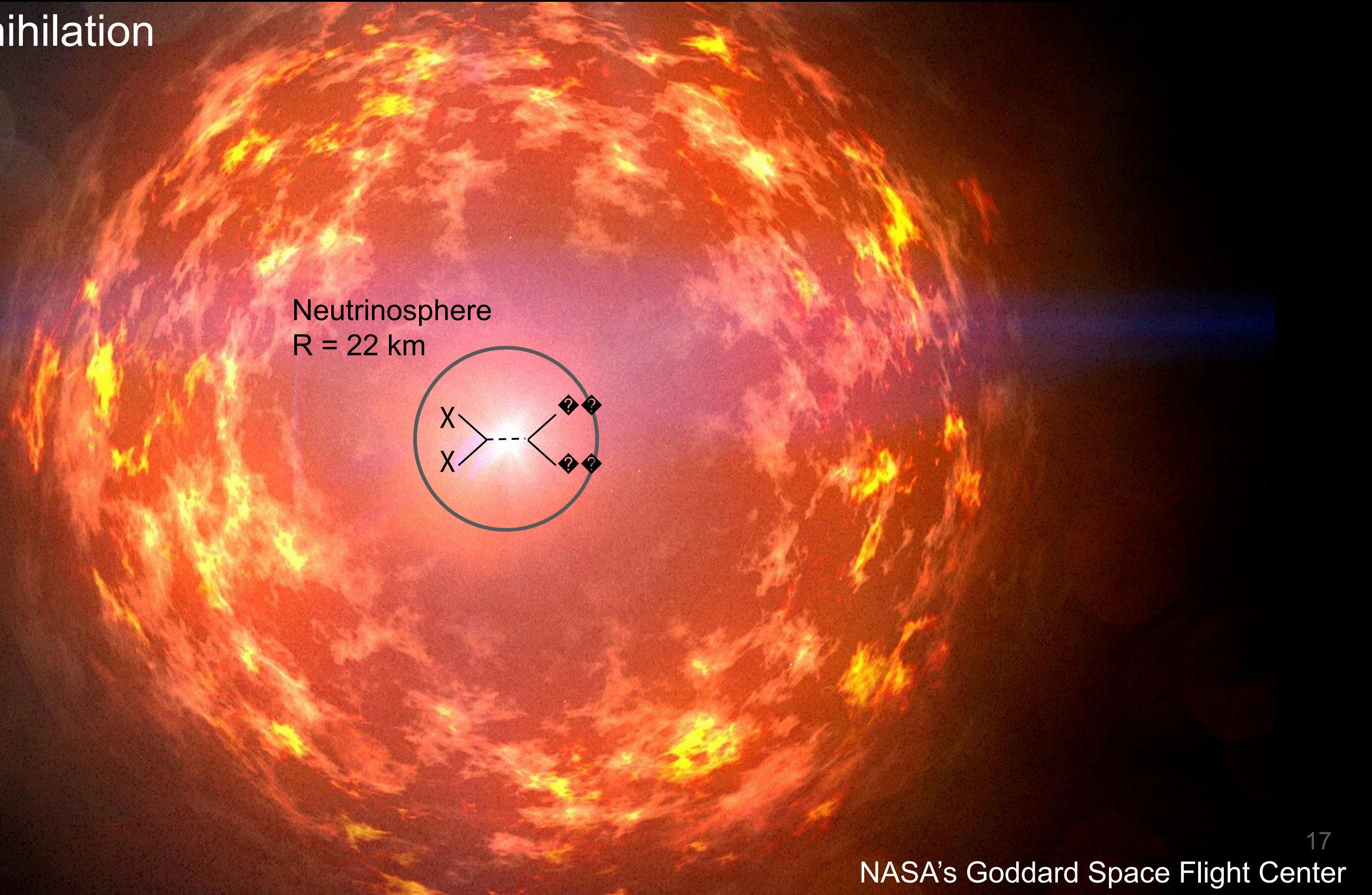
# Constraining Neutrinophilic Dark Sector

## 3. Trapping by Annihilation



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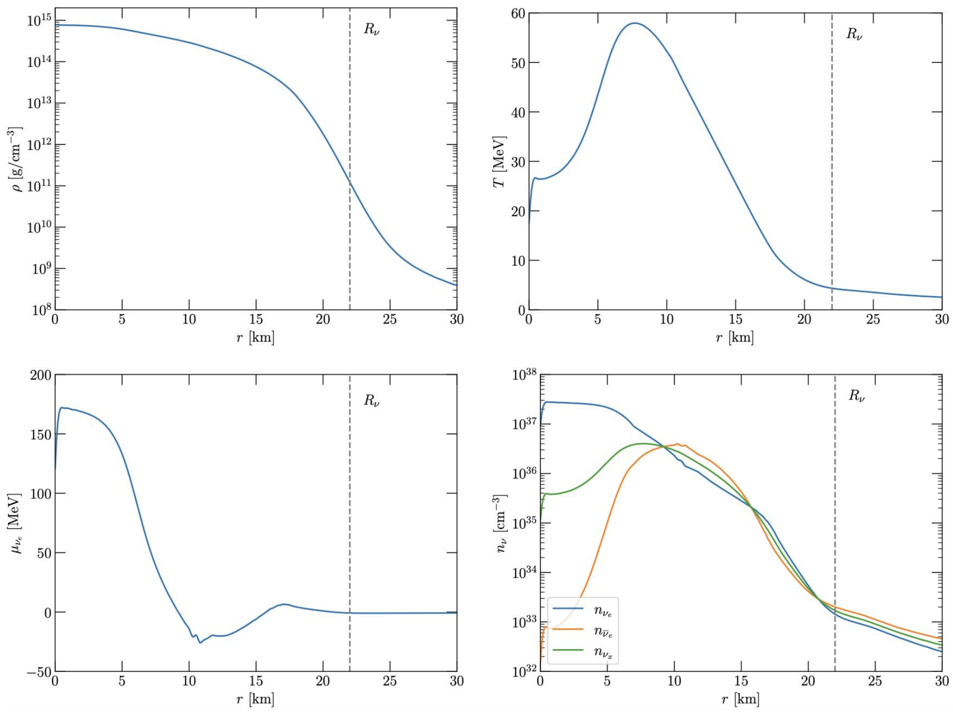
# Constraints for a Heavy Mediator

$$-\mathcal{L}_{\text{int}} \supset g_\nu Z'_\mu \bar{\nu}\gamma^\mu P_L \nu + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$

Simulation Inputs: Garching Core Collapse Supernova Archive

- Credit: Hans-Thomas Janka, Robert Bollig and Lorenz Hüdepohl
- https://wwwmpa.mpa-garching.mpg.de/ccsnarchive/archive.html
- We use a CCSN simulation for 20 solar mass progenitor, snapshot at 1 second post core bounce (PROMETHEUS-VERTEX)

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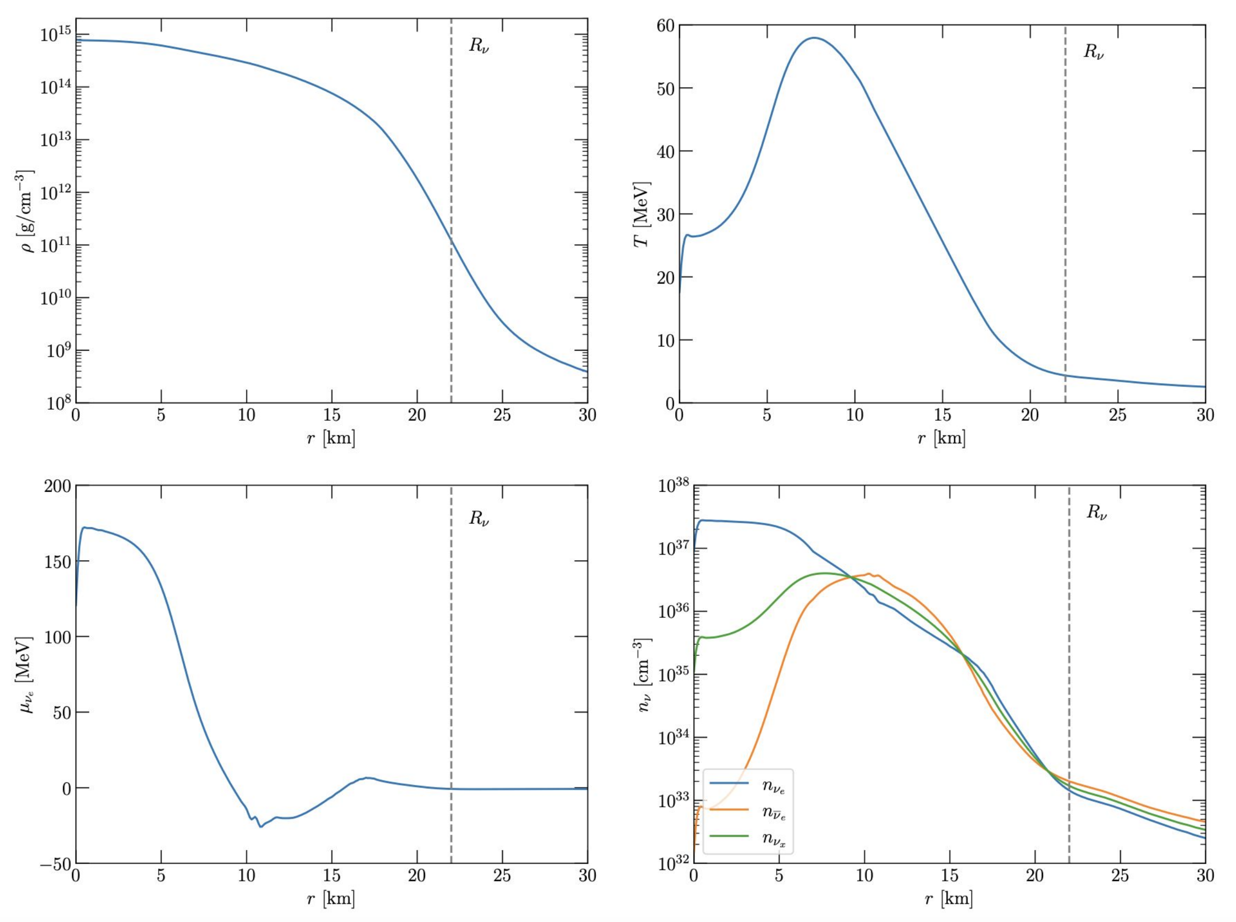




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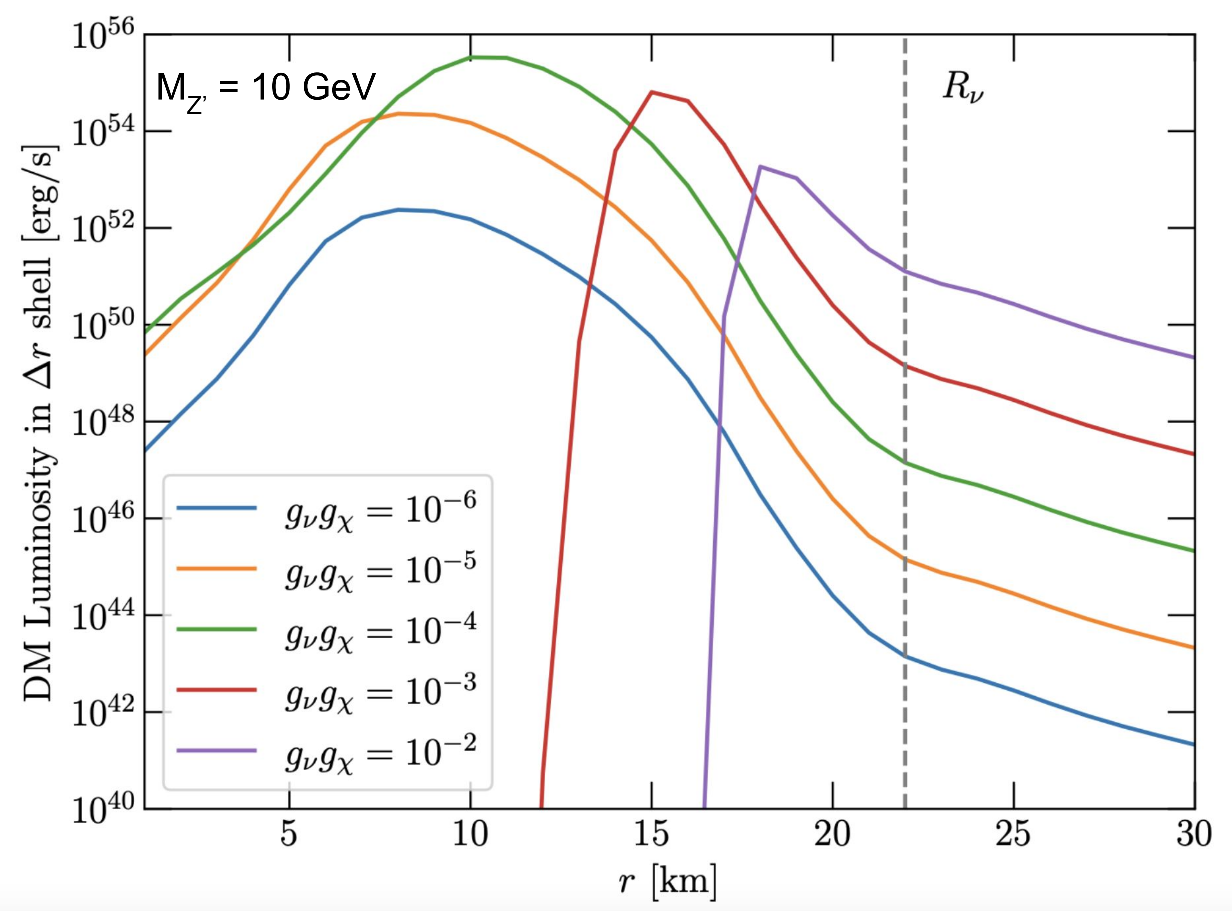




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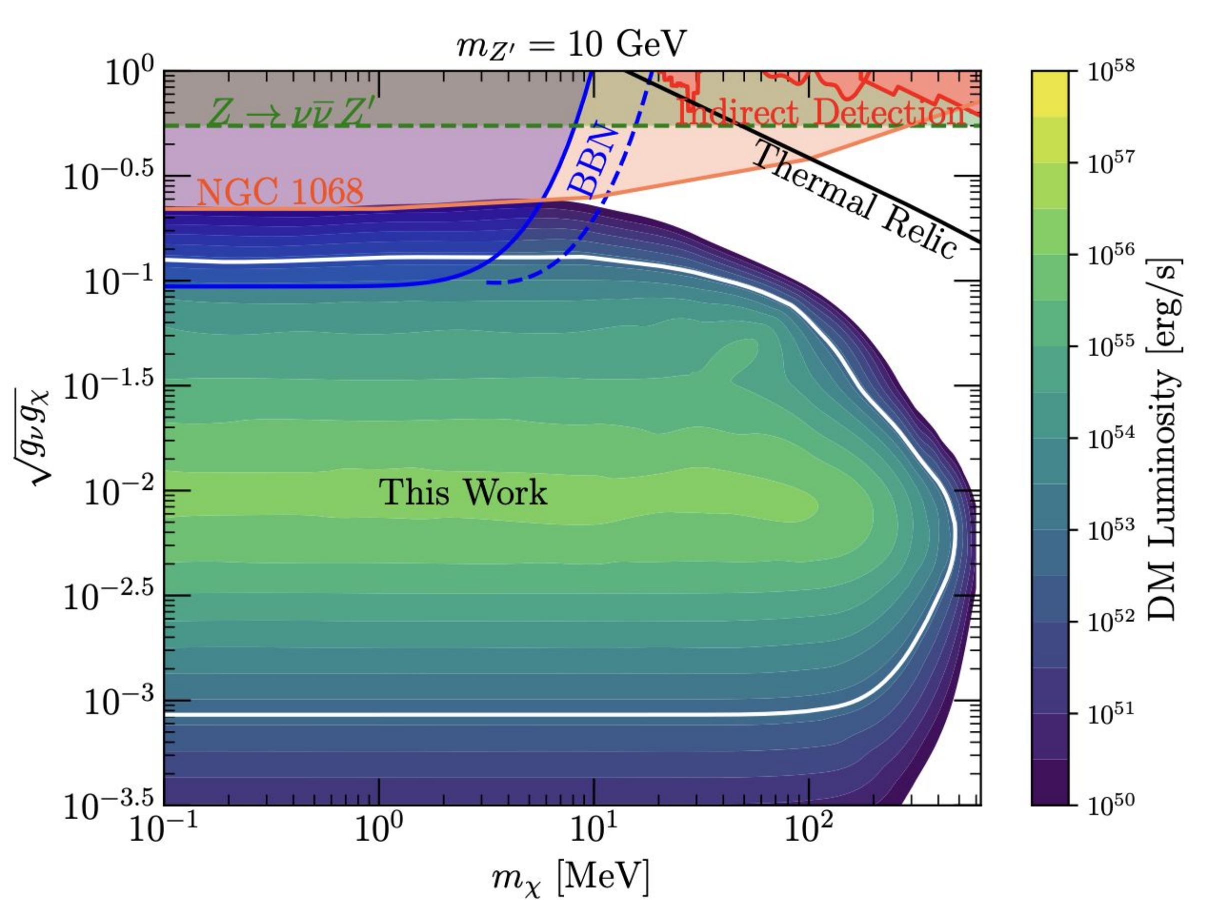




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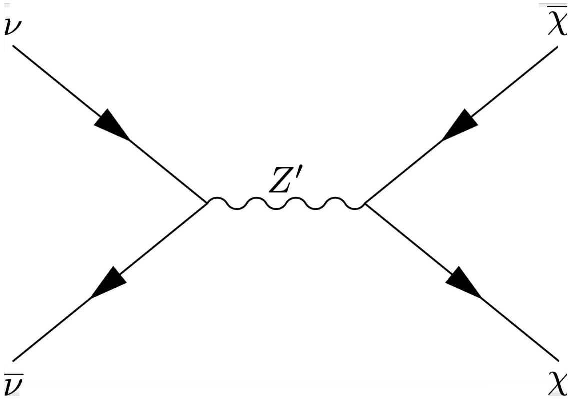
# Resonant Dark Matter Production

$$-\mathcal{L}_{\text{int}} \supset g_\nu Z'_\mu \bar{\nu}\gamma^\mu P_L \nu + g_\chi Z'_\mu \bar{\chi}\gamma^\mu \chi$$

$$\sigma_{\nu_\alpha\bar{\nu}_\alpha\to\chi\bar{\chi}} = \frac{g_\nu^2 g_\chi^2 (s+2m_\chi^2)(s-m_\nu^2)}{6\pi s[(s-m_{Z'}^2)^2 + m_{Z'}^2\Gamma_{Z'}^2]}\sqrt{\frac{s-4m_\chi^2}{s-4m_\nu^2}}$$




Resonant production

→ Enhanced production rate

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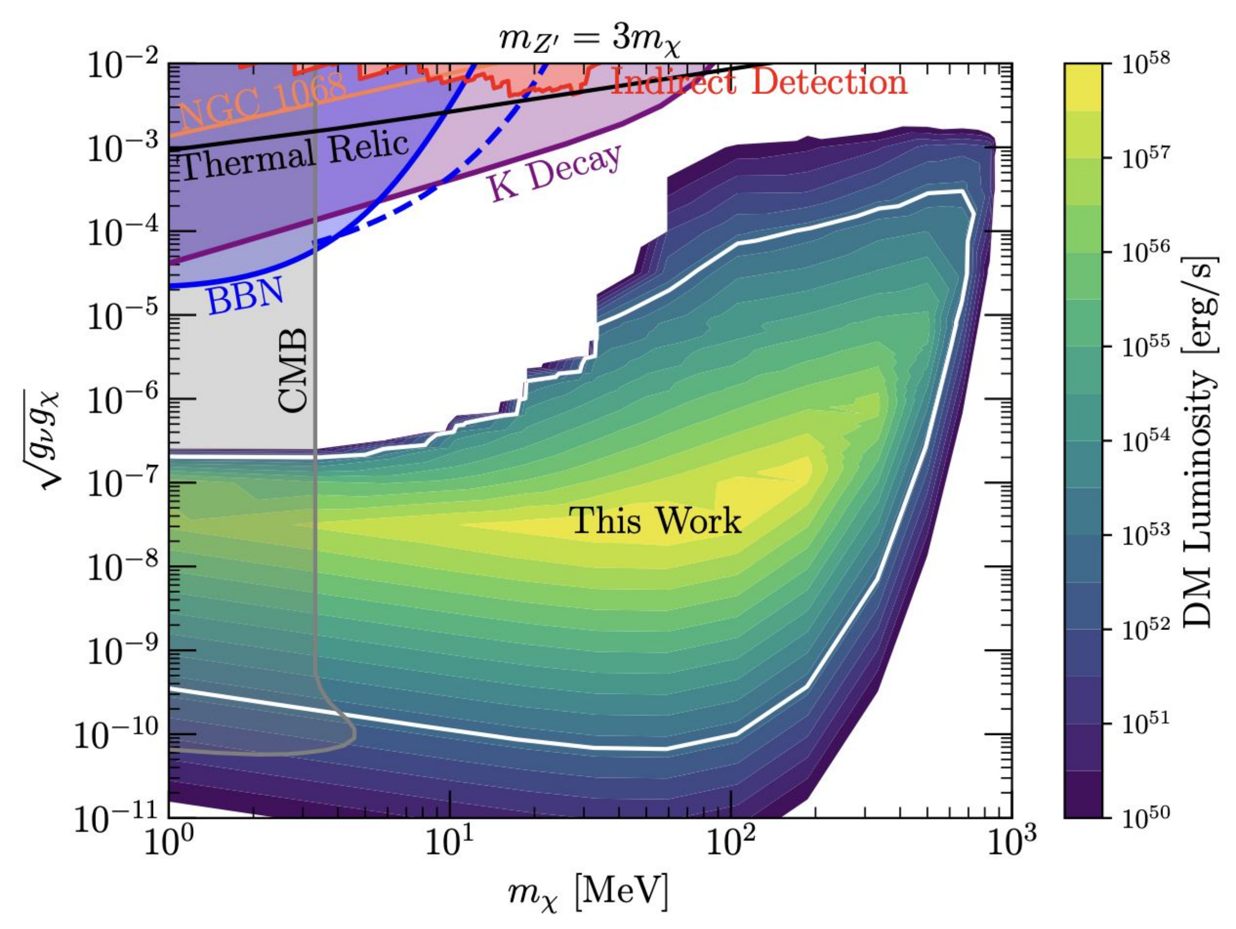
# Constraints for a Light Mediator



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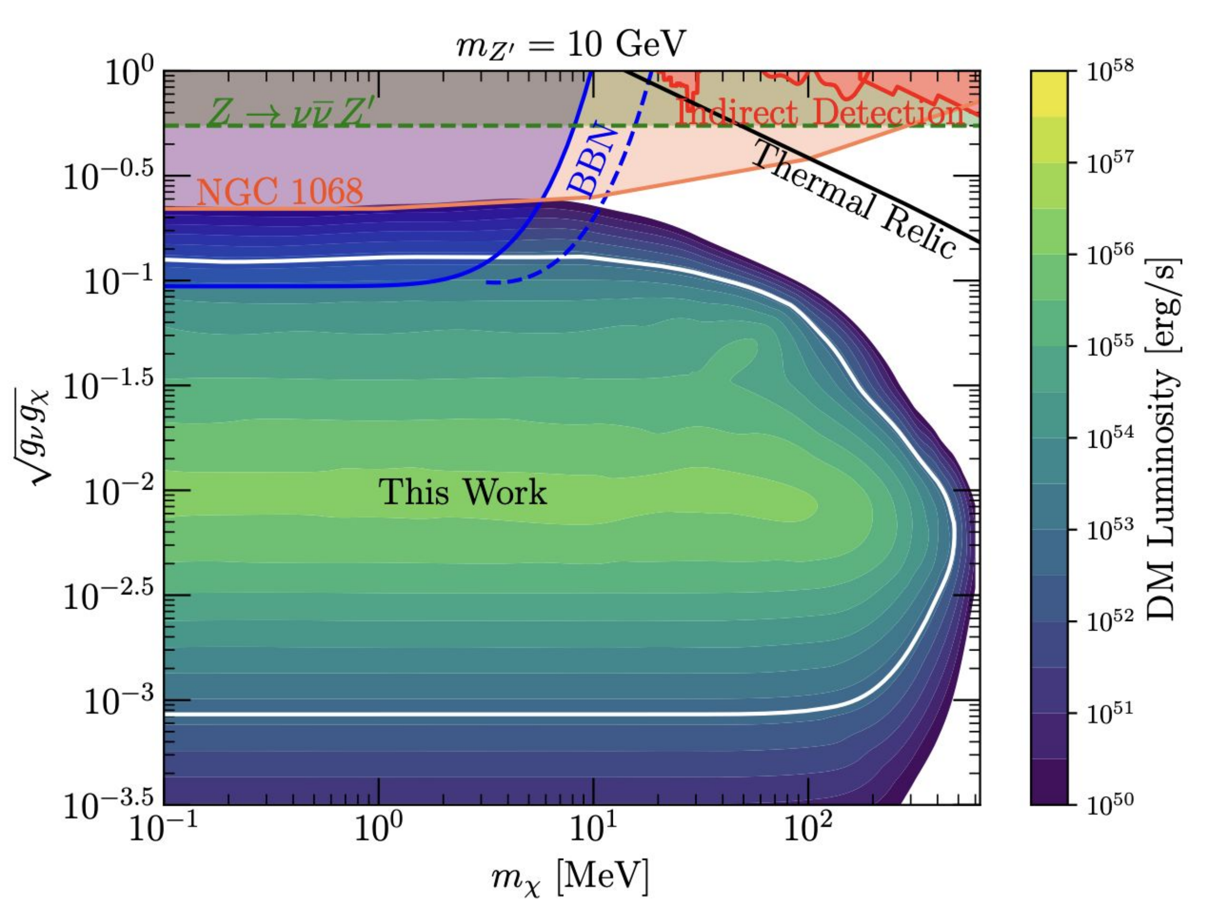




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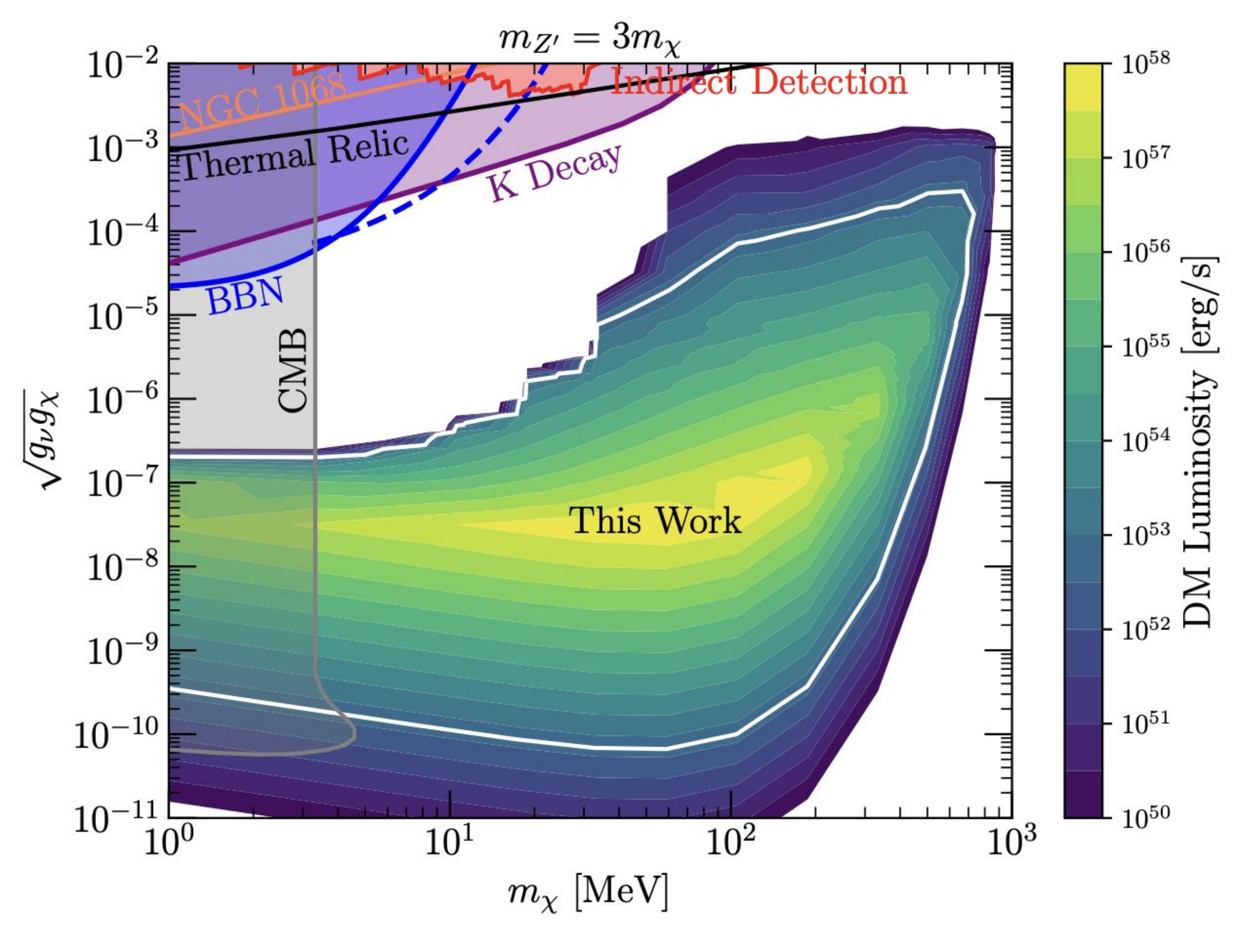




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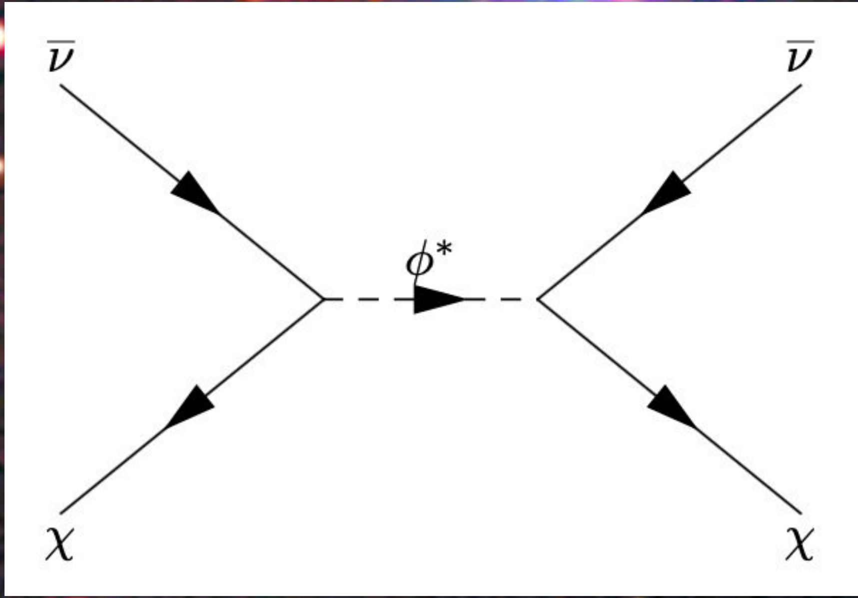
# s-channel Models

$$\mathcal{L}_{\text{int}} \supset -g\phi^* \bar{\chi} P_L \nu + \text{h.c.}$$



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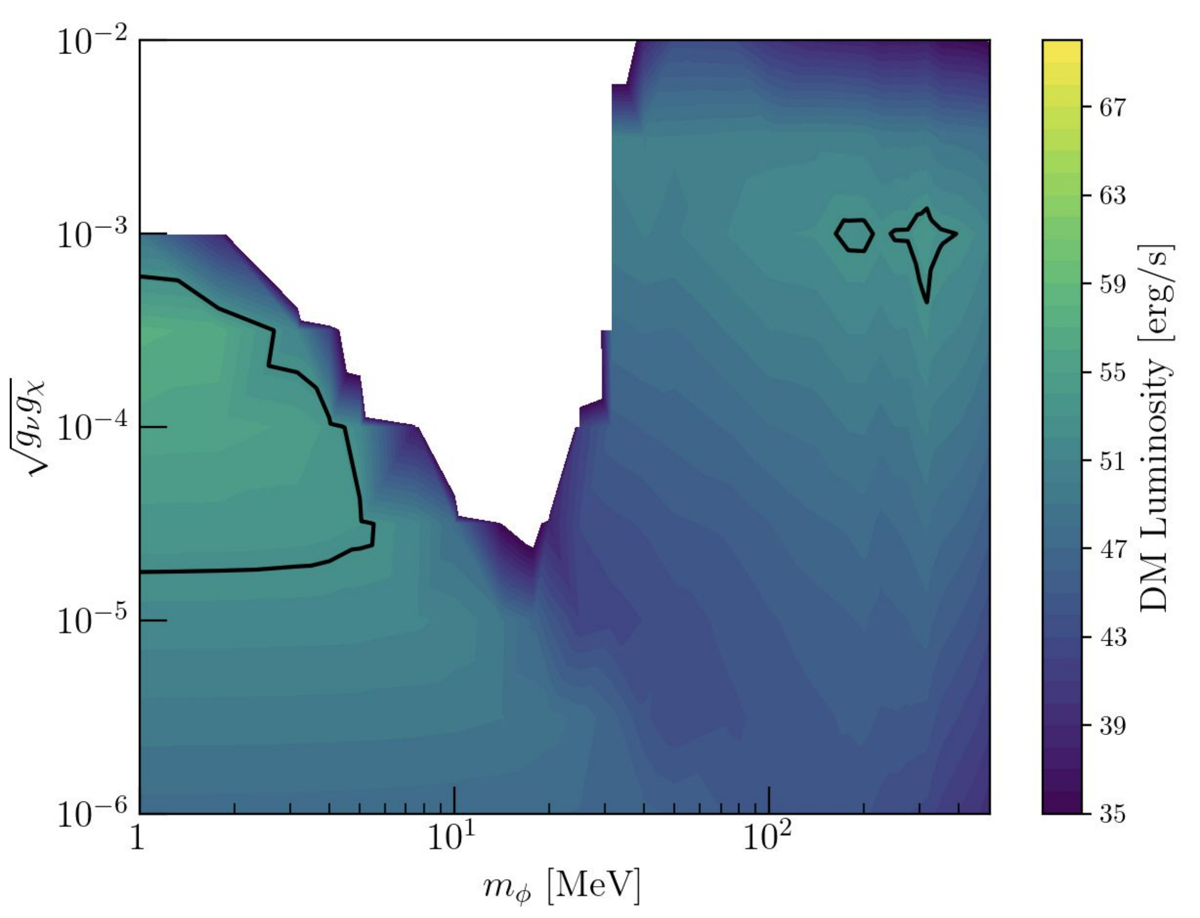
# s-channel Models



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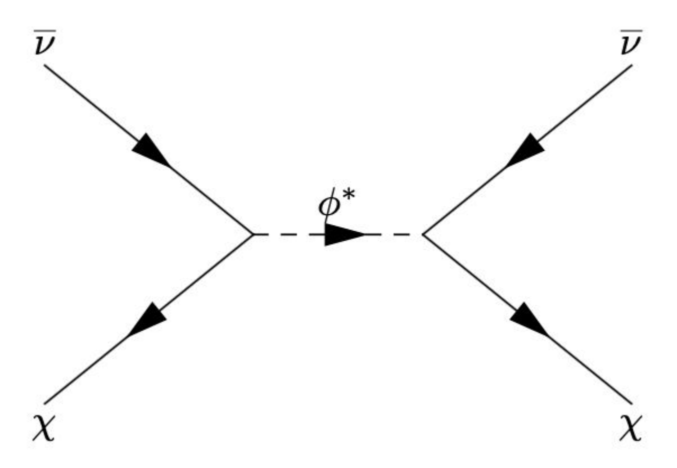
# s-channel Models

$$\mathcal{L}_{\rm int} \supset -g\phi^* \bar{\chi} P_L \nu + \text{h.c.}$$

$$\frac{d\sigma_{\bar{\nu}\chi\to\bar{\nu}\chi}}{dt} = \frac{g^4}{32\pi(s-m_\chi^2)^2}\frac{(s-m_\chi^2)^2}{(s-m_\phi^2)^2+m_\phi^2\Gamma_\phi^2}$$



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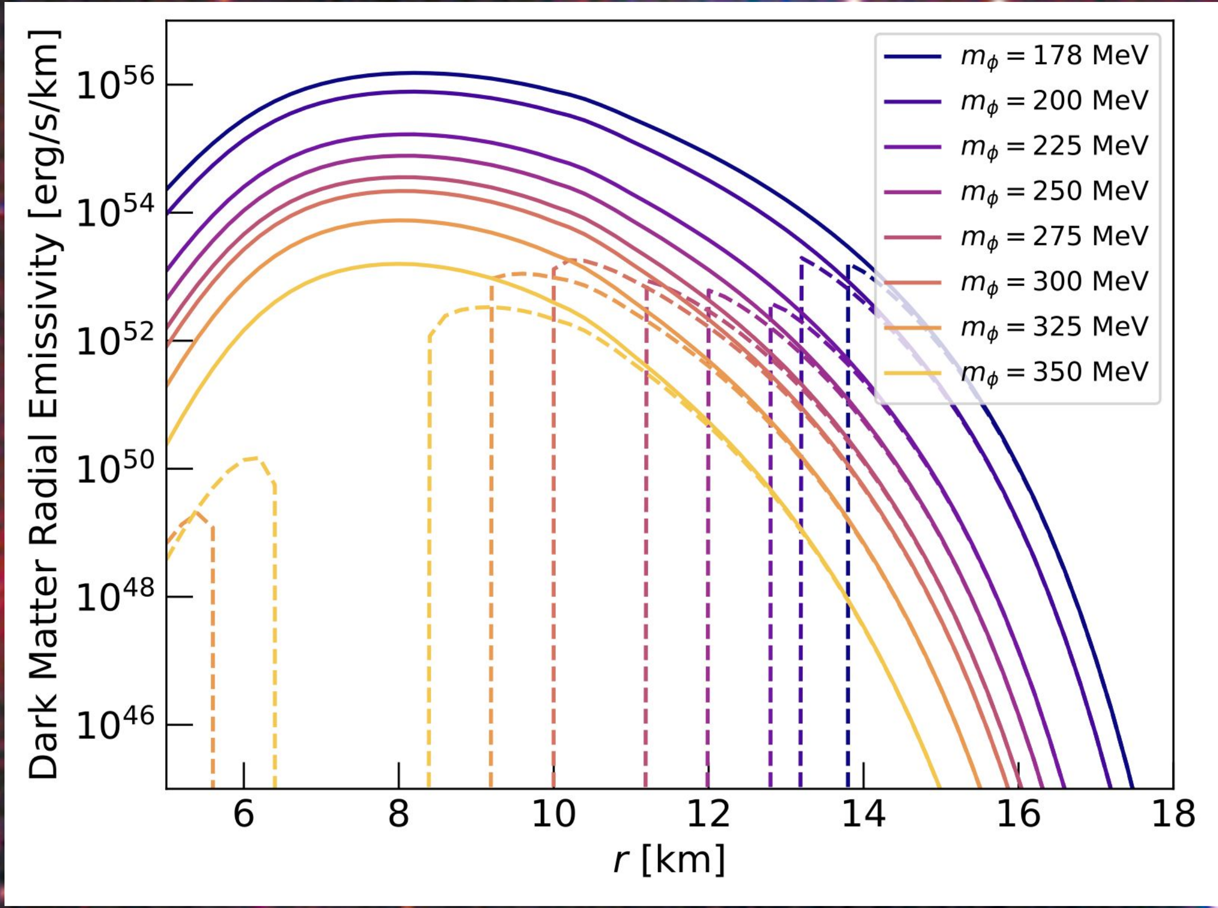




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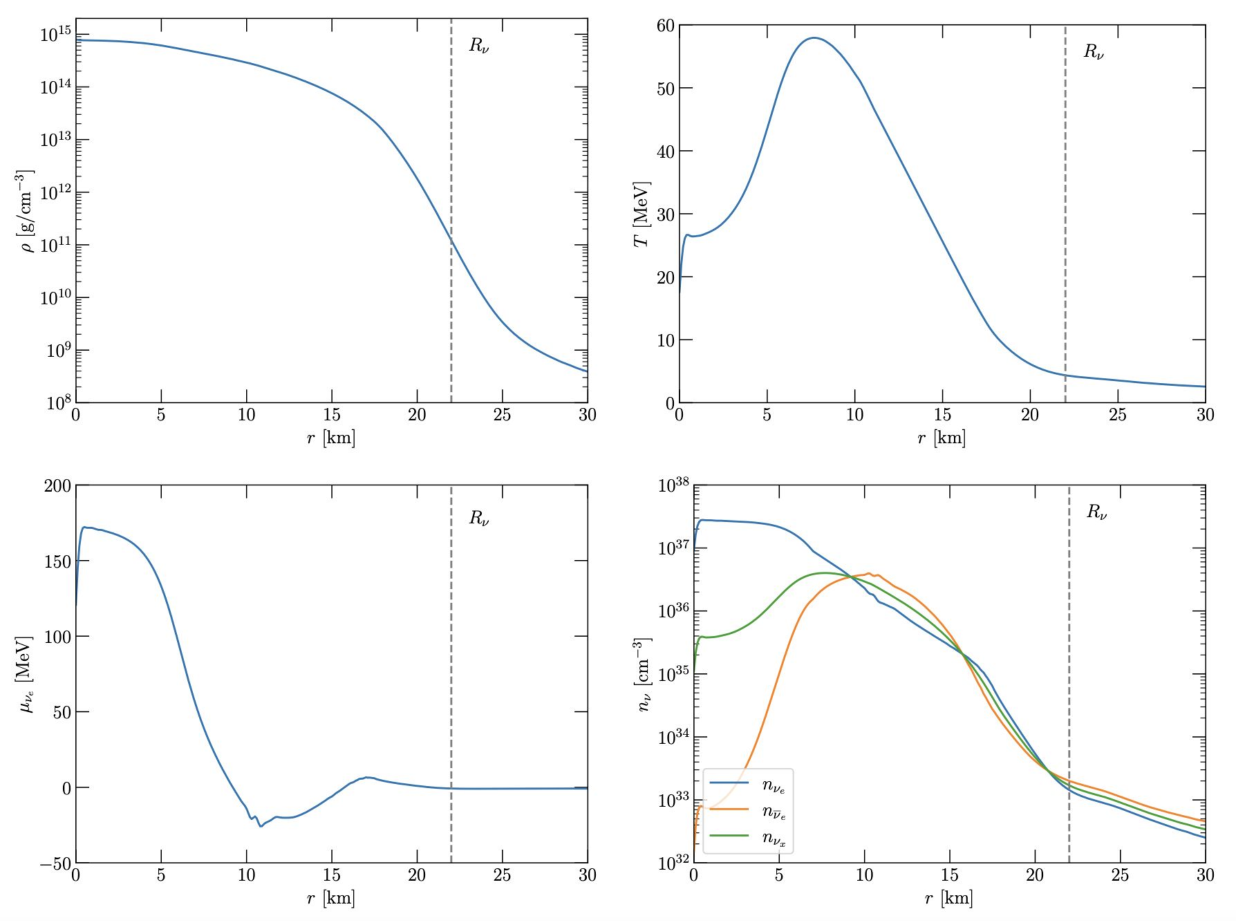
# Constraints for a Heavy Mediator



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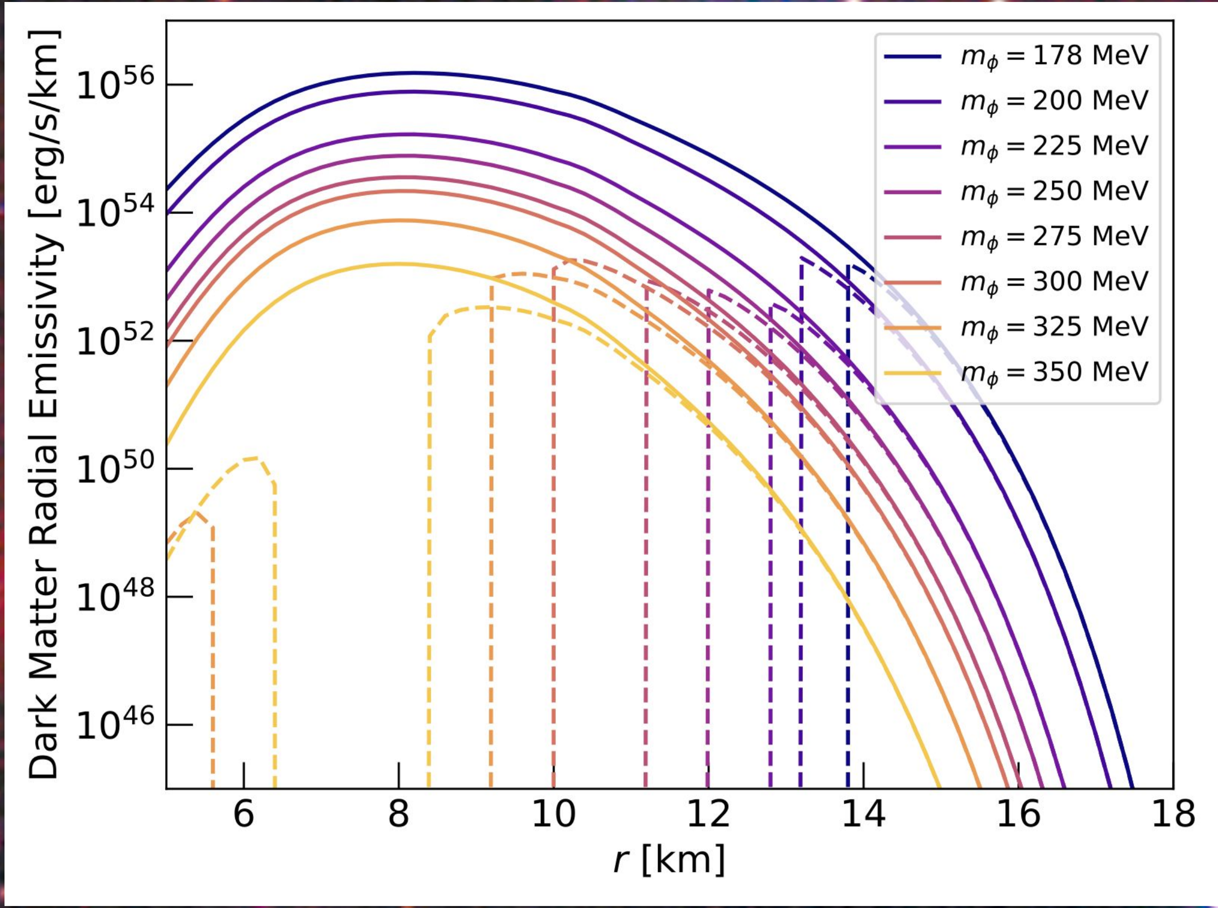




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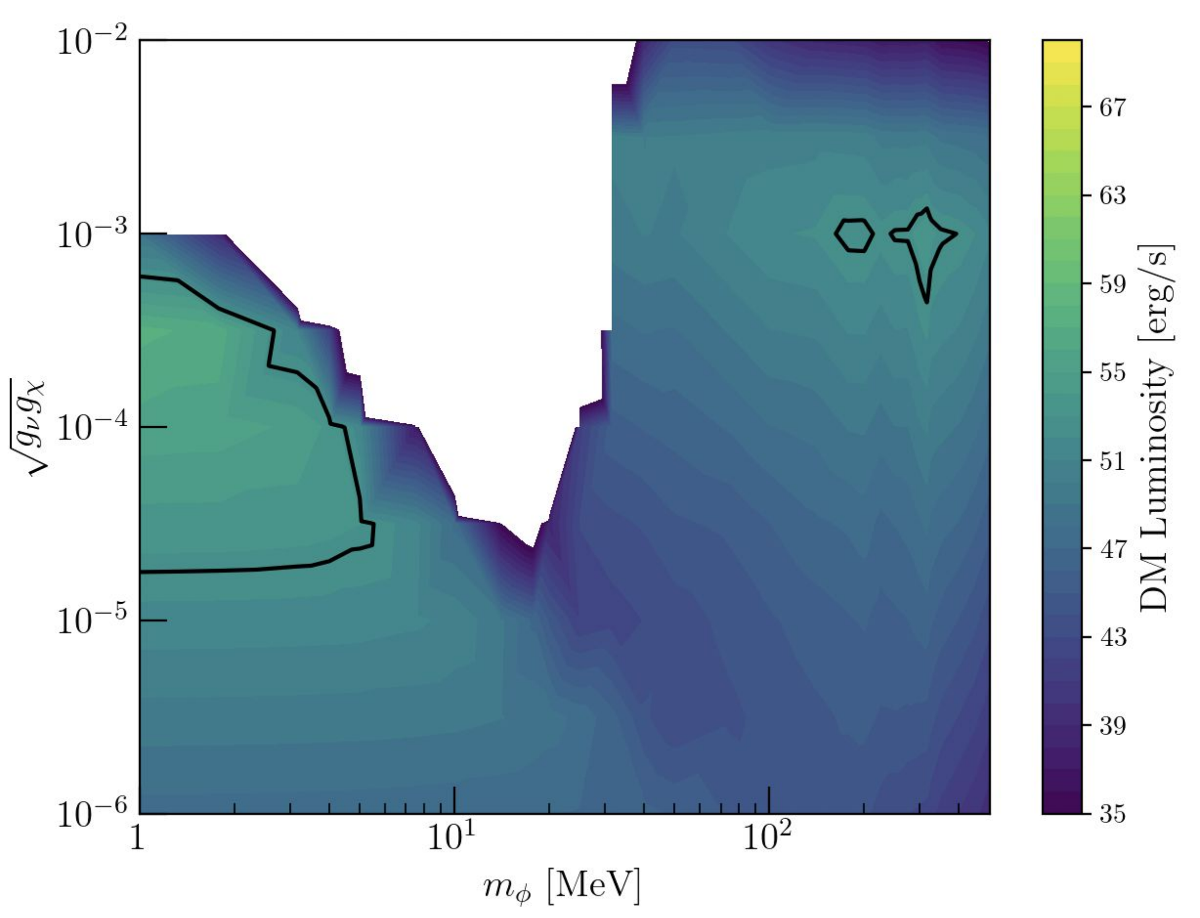




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