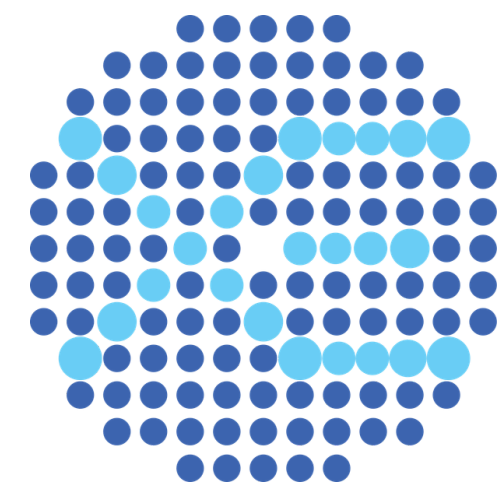
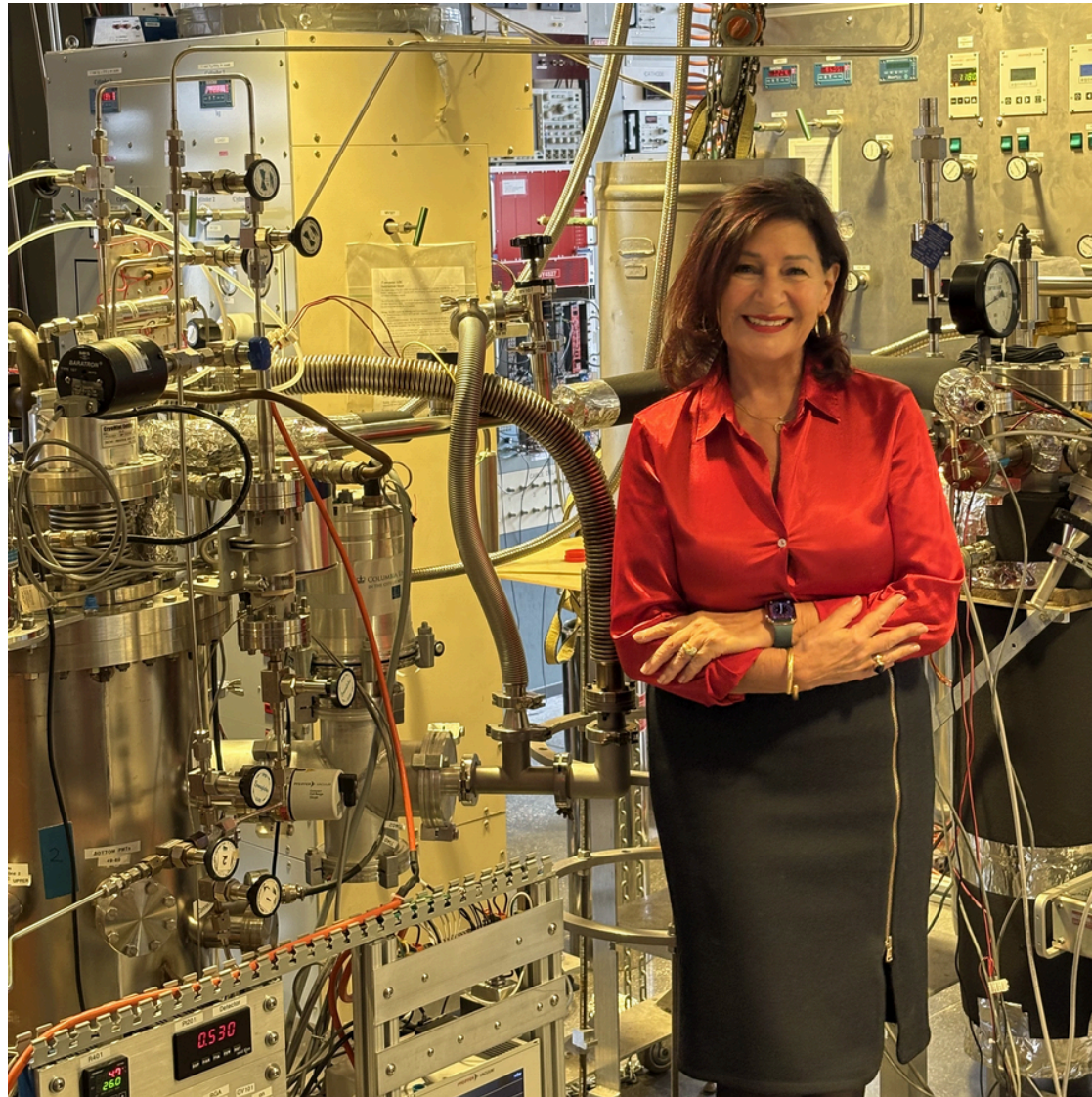
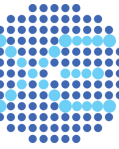


Beyond the Neutrino Fog: Dark Matter Discovery Limits with the Full XENONnT Background Model

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Nevis Labs REU
July 30, 2026





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Physics



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Postdoctoral Research
Scientist



I. Introduction to XENONnT

II. Background Modeling

III. Statistical Framework and Fog

IV. Results and Conclusion



I. Introduction to XENONnT

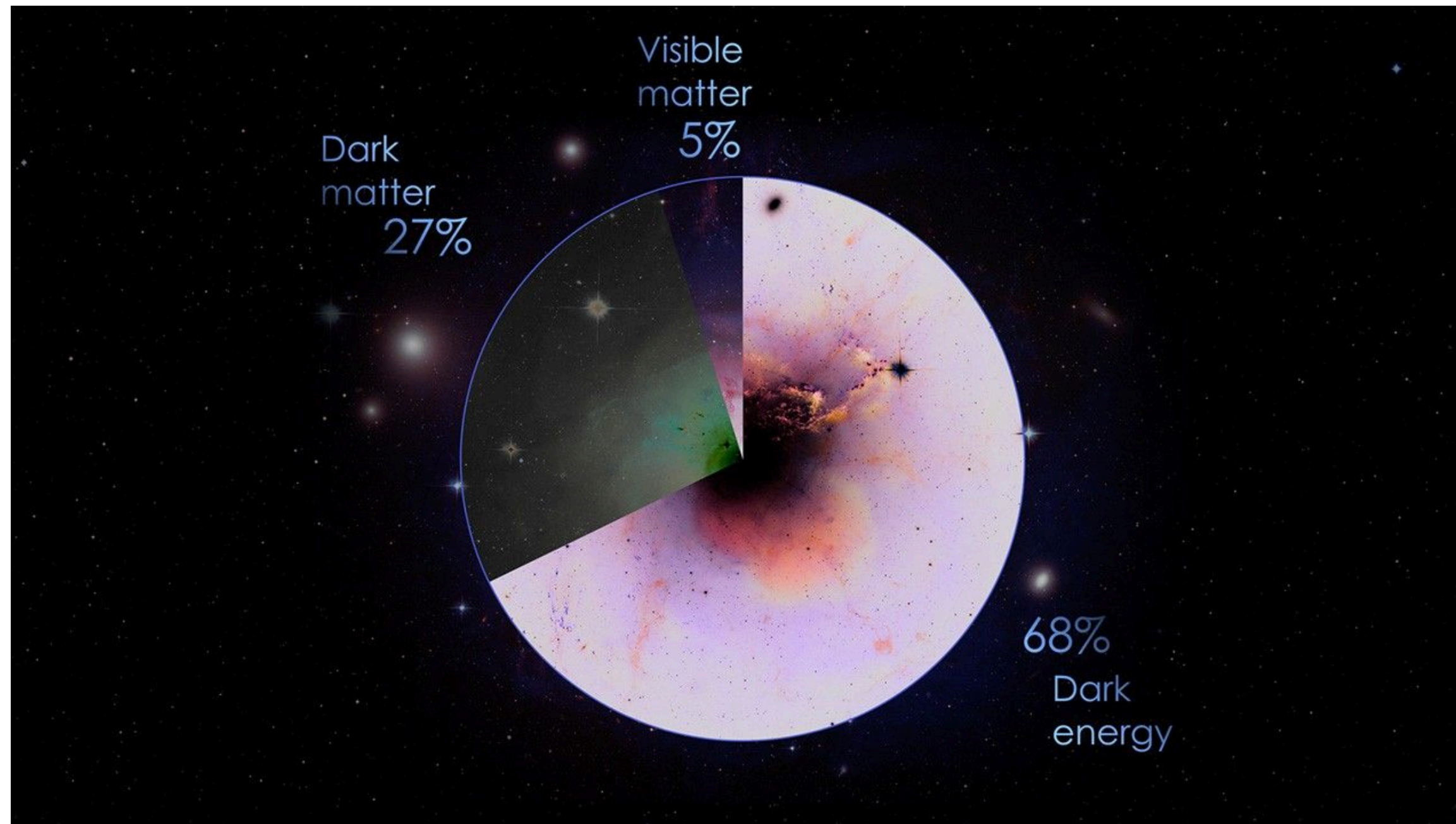


What is dark matter?

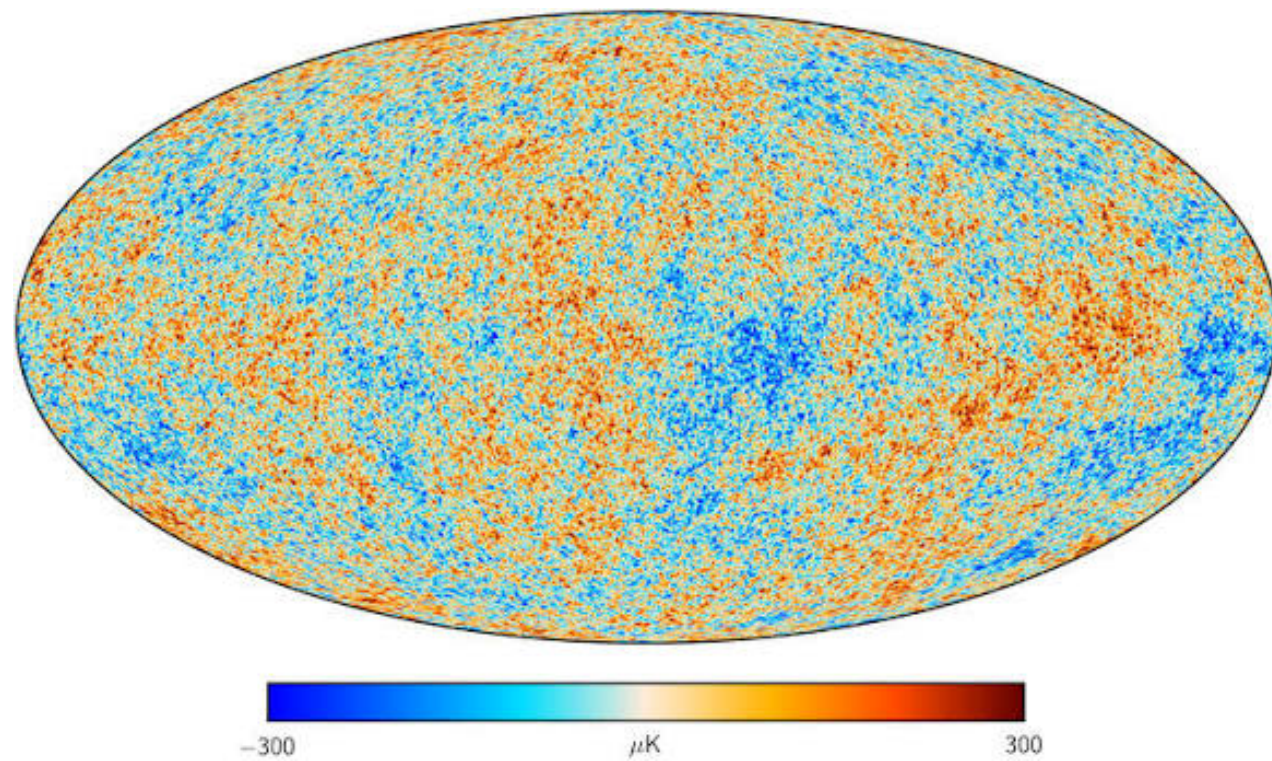
The Dark Matter Problem



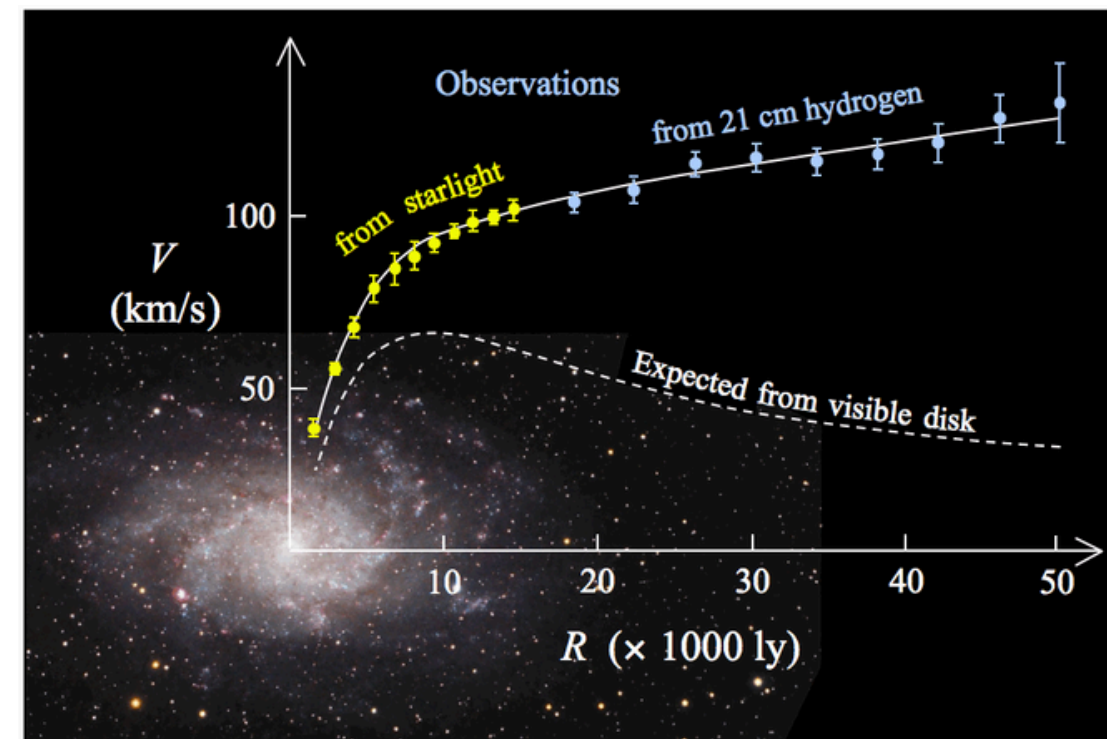
- Makes up 27% of the mass-energy in the universe, visible matter only takes up 5%
- It is non-luminous matter that is imperceivable via any interaction except gravity



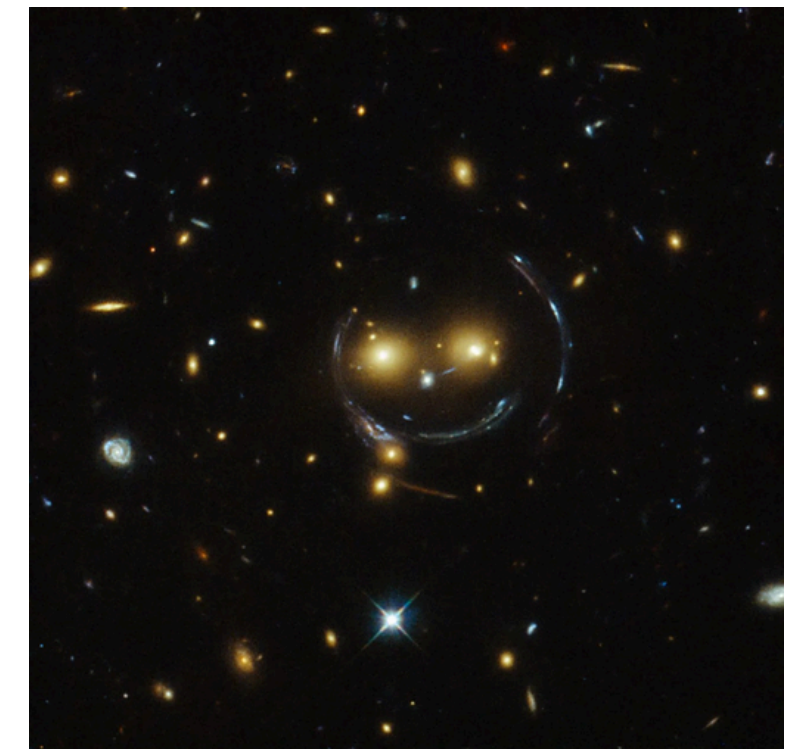
The Dark Matter Problem: Evidence



Temperature
Fluctuations in CMB

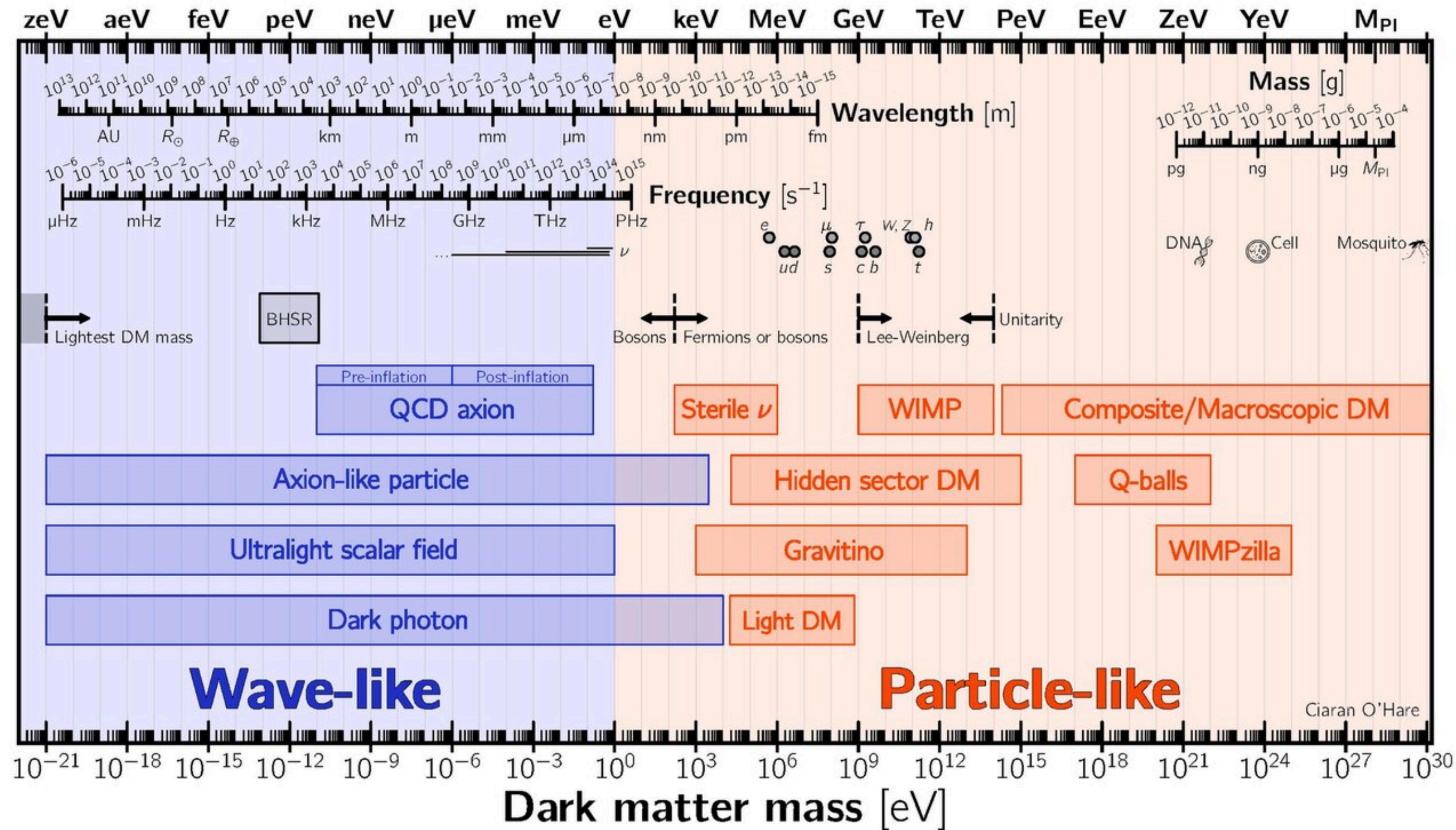


Galaxy rotation curve

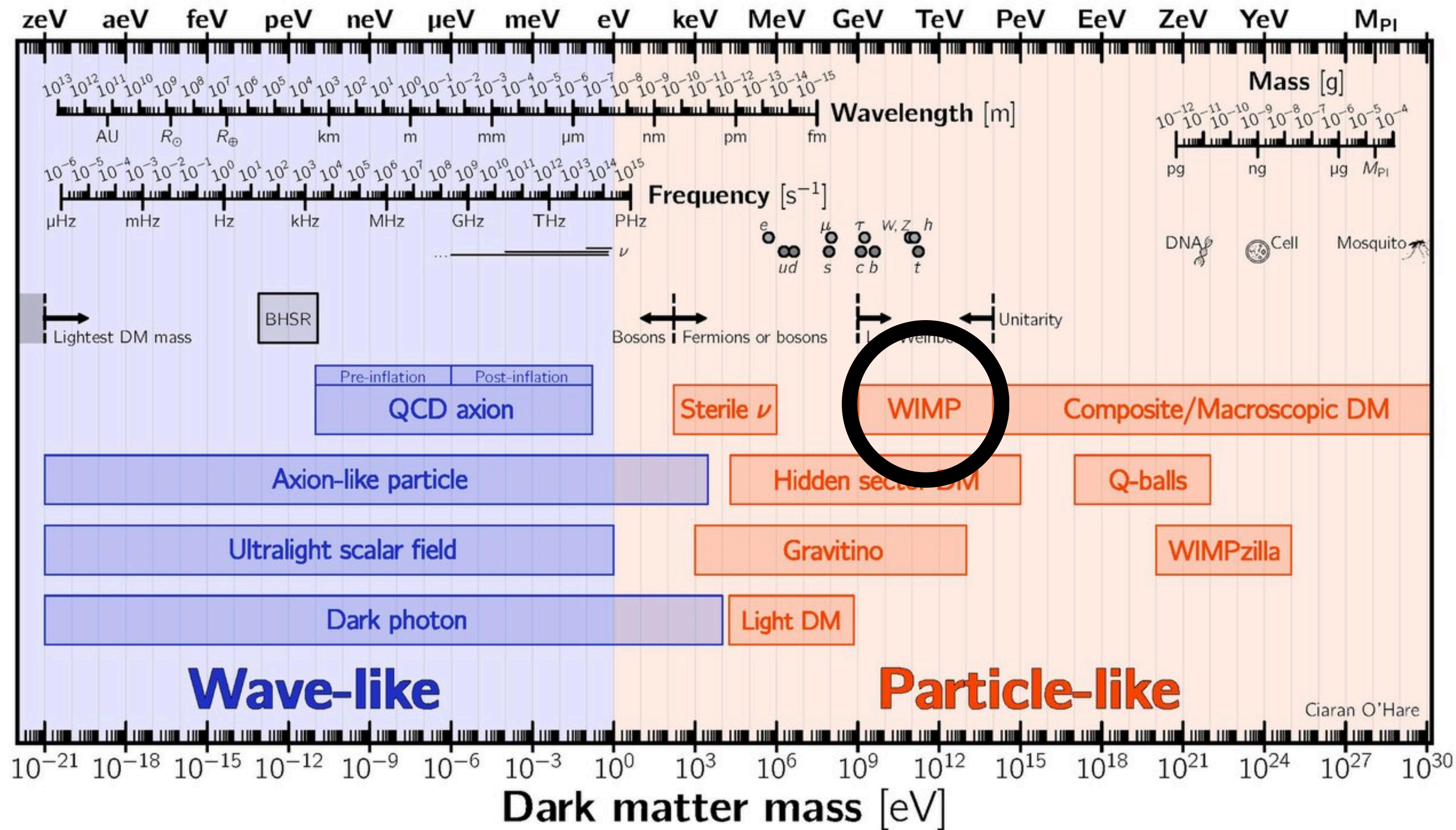


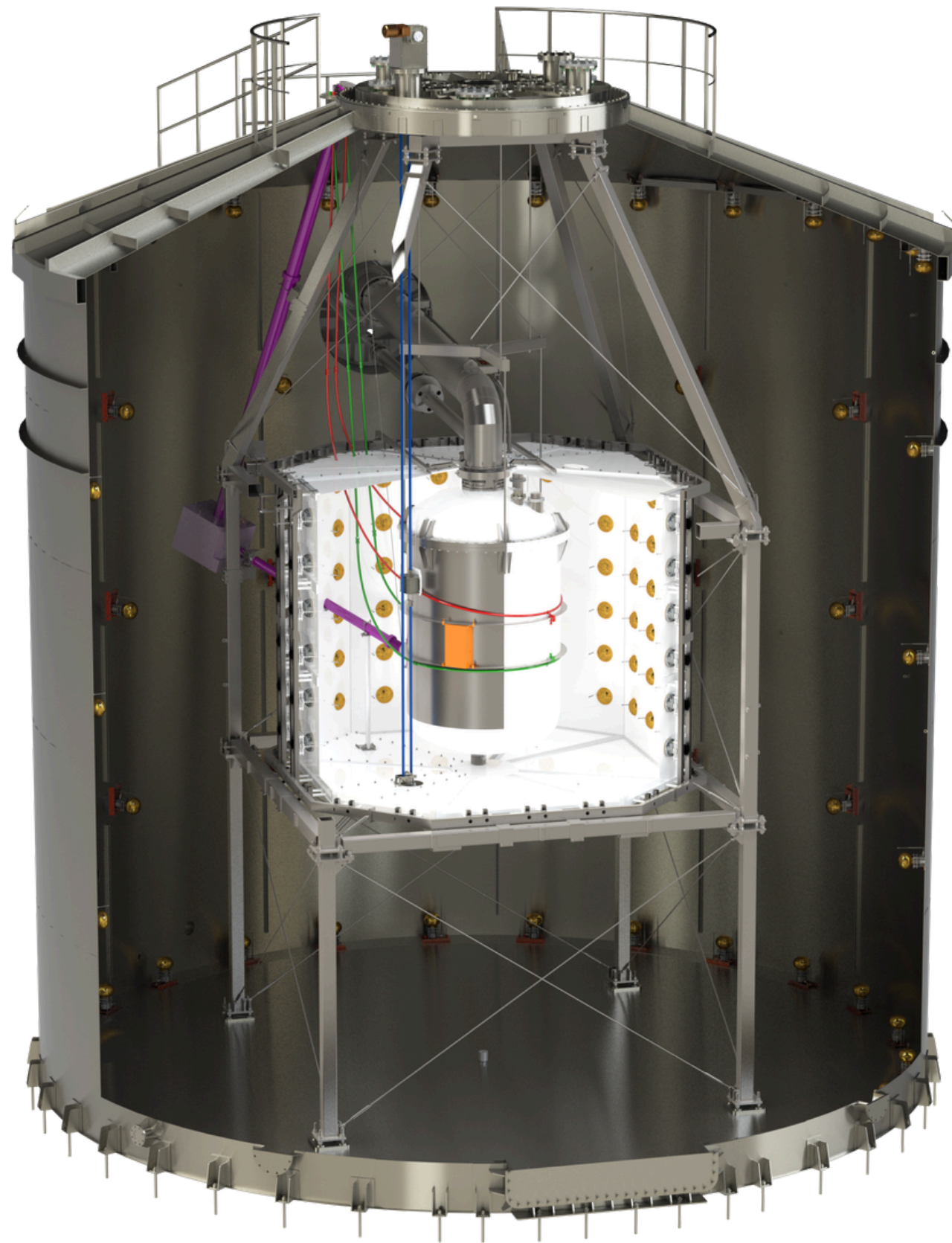
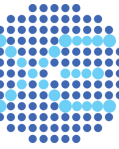
Gravitational Lensing

The Dark Matter Problem: Candidates

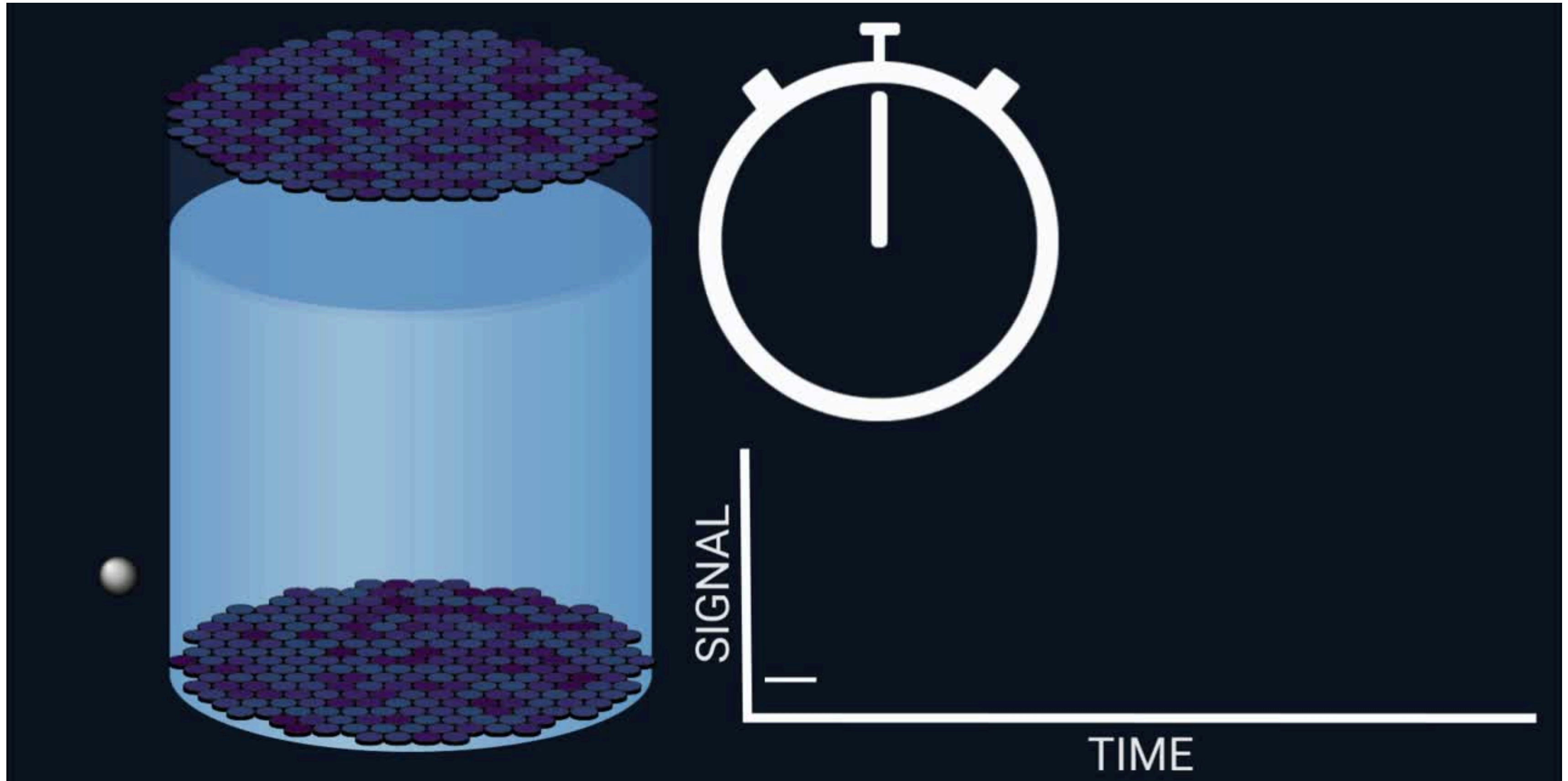
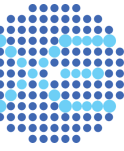


The Dark Matter Problem: Candidates



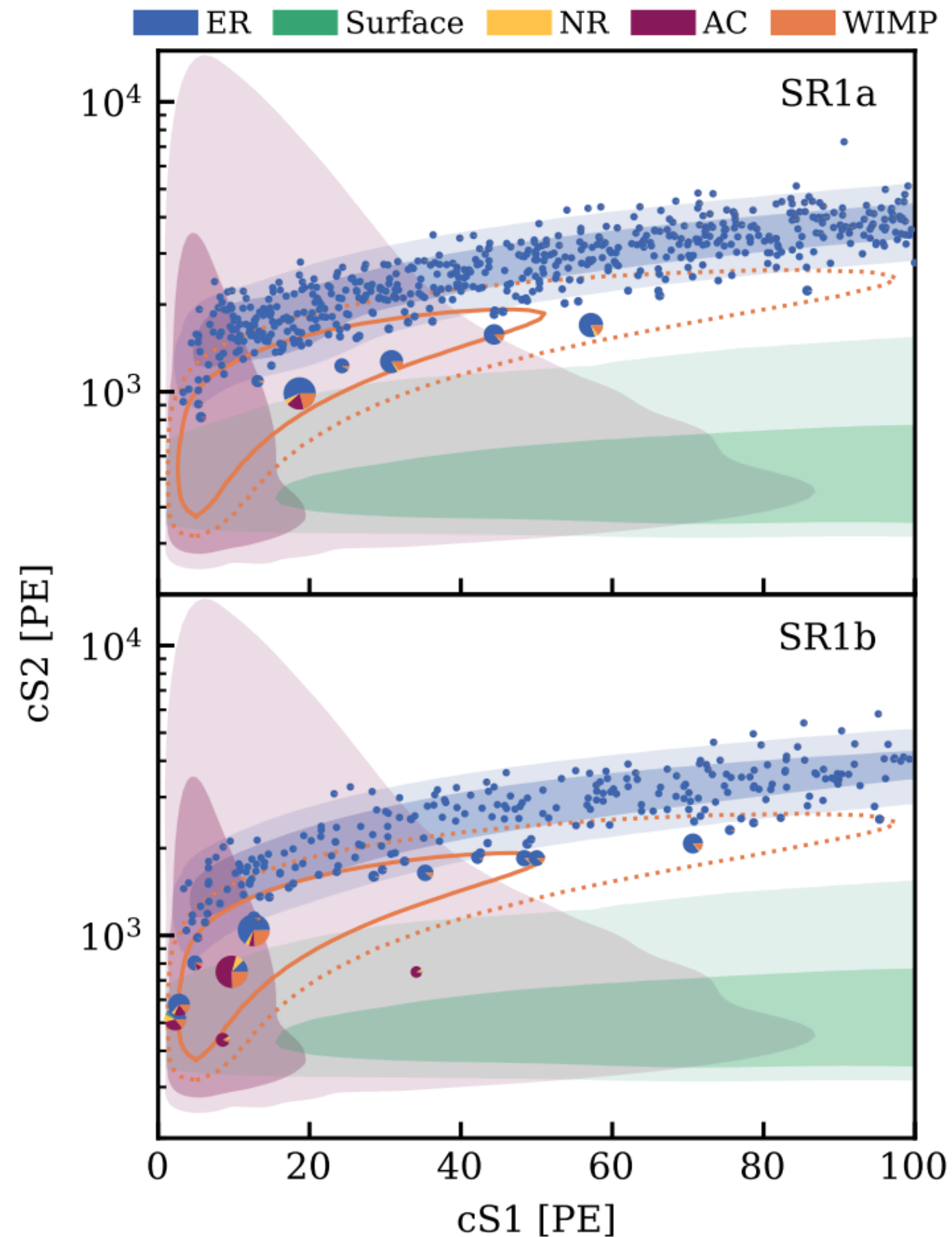


- Situated in INFN Gran Sasso National Laboratory
- 8.6 tonnes of xenon
- Muon veto
 - Tags muon events
- Neutron Veto
 - Tags radiogenic neutrons
- Xenon dual-phase time projection chamber





II. Background Modeling



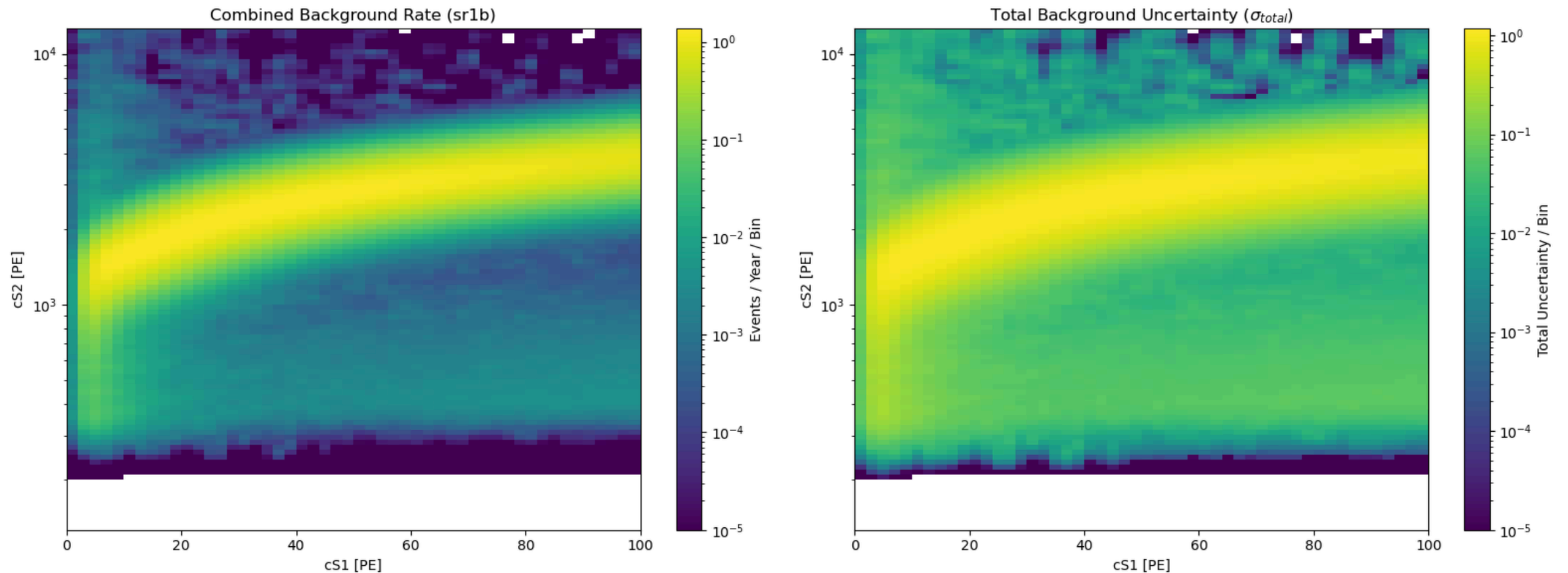
- ER background
 - β -decays of ^{214}Pb , ^{85}Kr and γ -rays from detector material
 - β decays of ^3H
- Surface events
 - β -decay events in the ^{210}Pb decay chain on the surface of the TPC wall.
- NR background
 - radiogenic neutrons produced by spontaneous fission and (α, n) reactions in detector materials near the LXe target
 - coherent elastic neutrino-nucleus scattering (CEvNS) of ^8B solar
 - diffuse supernova neutrino background (DSNB)
- Accidental Coincidences (AC)
 - Wrongly paired S1 and S2

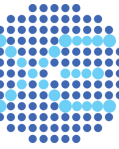
XENONnT Background Models



XENONnT science runs:

- normalized to events/year/bin
- defined in the space of cS1-cS2-radius





Neutrino fog: Recoil signatures of DM and neutrinos look similar

- Different sources of neutrino imitate DM of varying masses and cross sections

1 Solar (^8B)

Dominant at low recoil energy, primary source of CEvNS events for most DM detectors

2 Atmospheric

Cosmic-ray-induced neutrinos that are dominant background at high recoil energies.

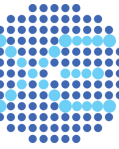
3 DSNB

Cumulative flux of neutrinos from the cosmological history of core-collapse supernovae

Why "fog," not "floor": unlike a hard limit, this background can be pushed through with greater exposure and discrimination power — the boundary is defined by systematics, not a wall.



III. Statistical Framework and Fog



Fog: Parameter space where a clear distinction between signal and background is challenging, but not impossible

- Binned likelihood written as the product of the Poisson probability multiplied by Gaussian likelihood functions

$$\mathcal{L}(\sigma, \Phi) = \prod_{i=1}^{N_{\text{bins}}} \text{Poisson}(n_{\text{obs},i} | n_{\text{exp},i}) \times C(\Phi)$$



1. Found test statistic, q , using Asimov dataset ($n_{\text{obs}}^i = n_{\text{exp}}^i$)

$$q_0 = \begin{cases} -2 \ln \left[\frac{\mathcal{L}(0, \hat{\Phi} | \mathcal{M}_{\sigma=0})}{\mathcal{L}(\hat{\sigma}, \hat{\Phi} | \mathcal{M})} \right] & \hat{\sigma} > 0 \\ 0 & \hat{\sigma} \leq 0, \end{cases}$$

2. Explored the 3σ discovery limit as a function of detector exposure by solving for the exposure at which the profile-likelihood test statistic satisfies $\sqrt{q} = 3$

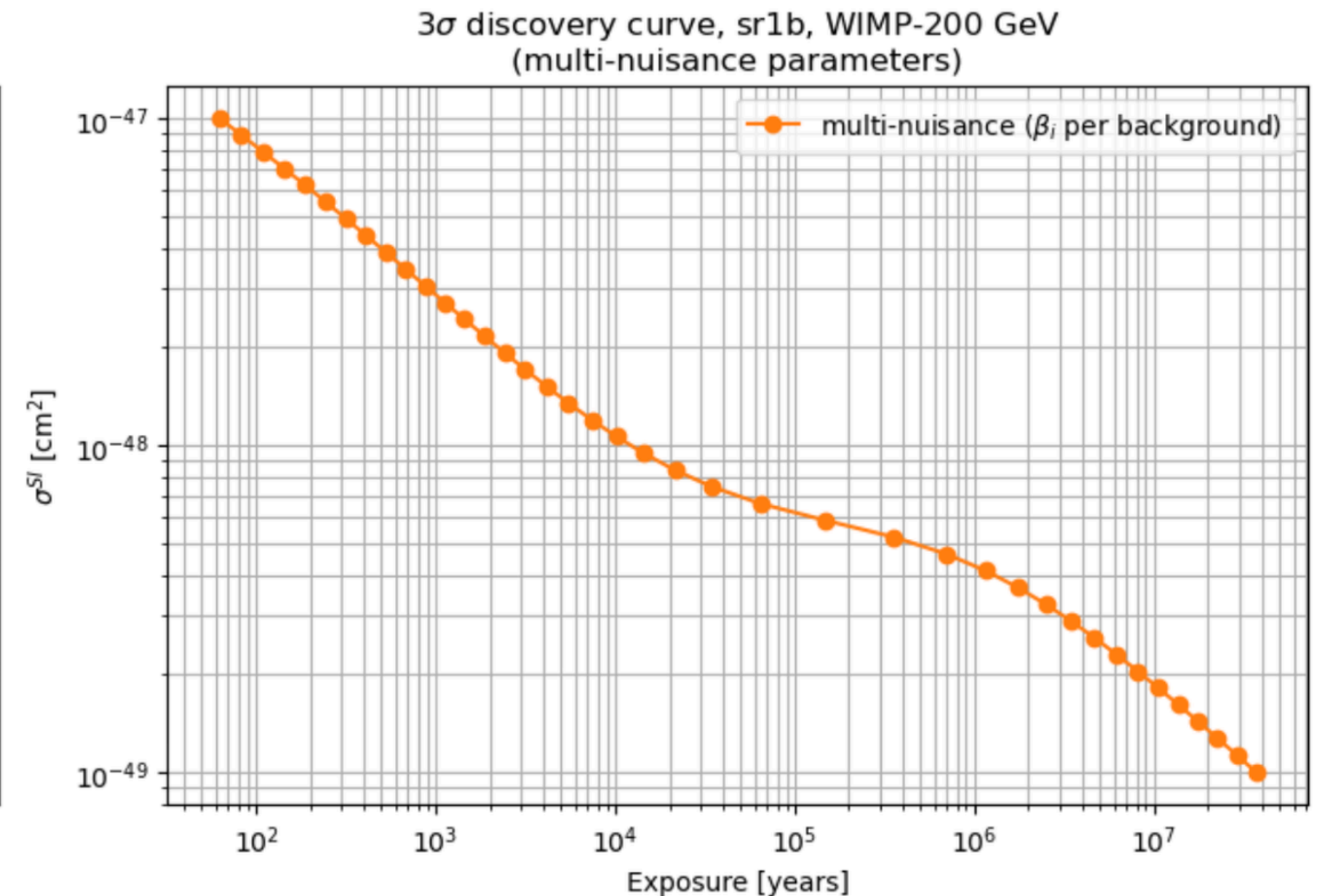
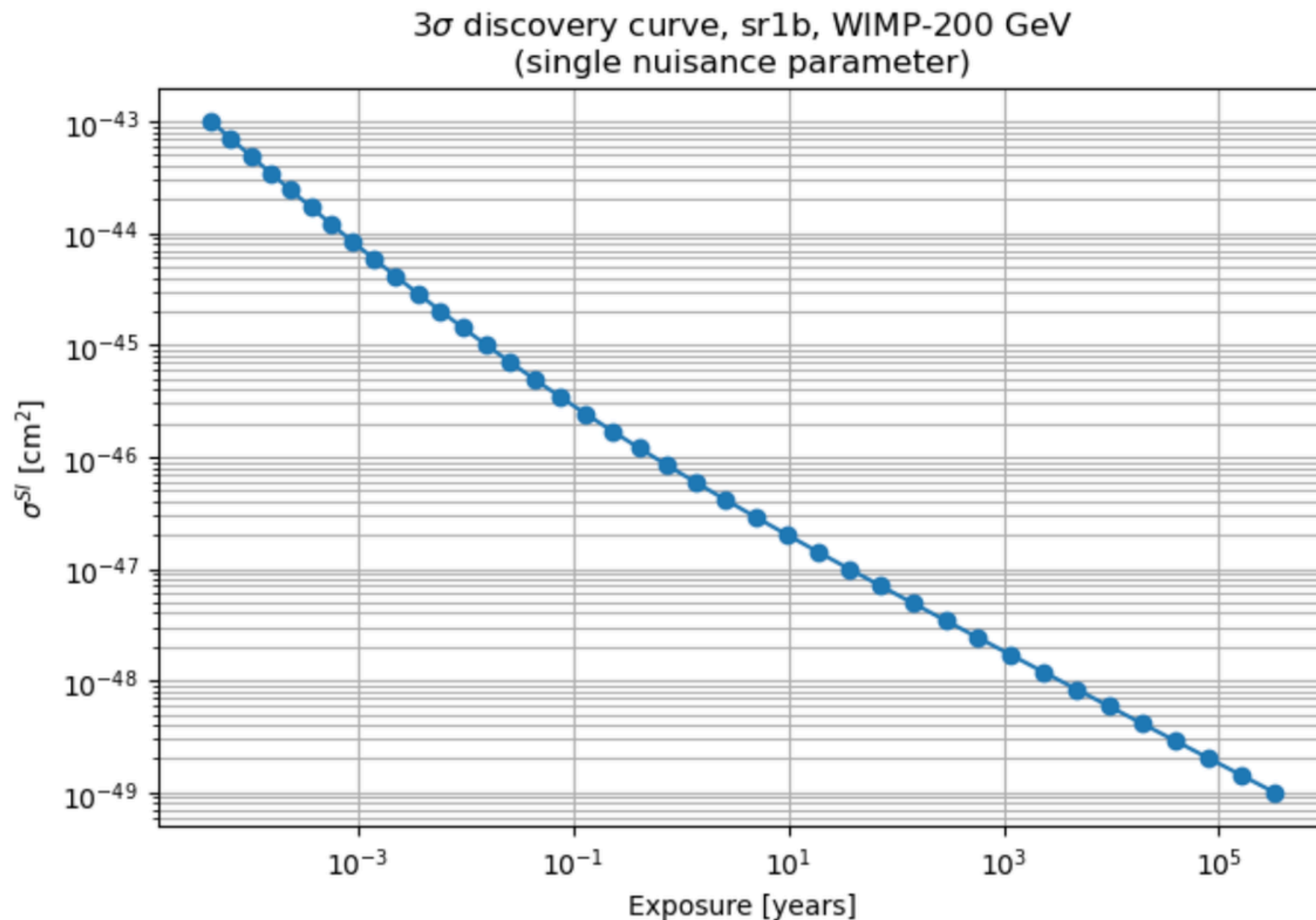
Opacity n

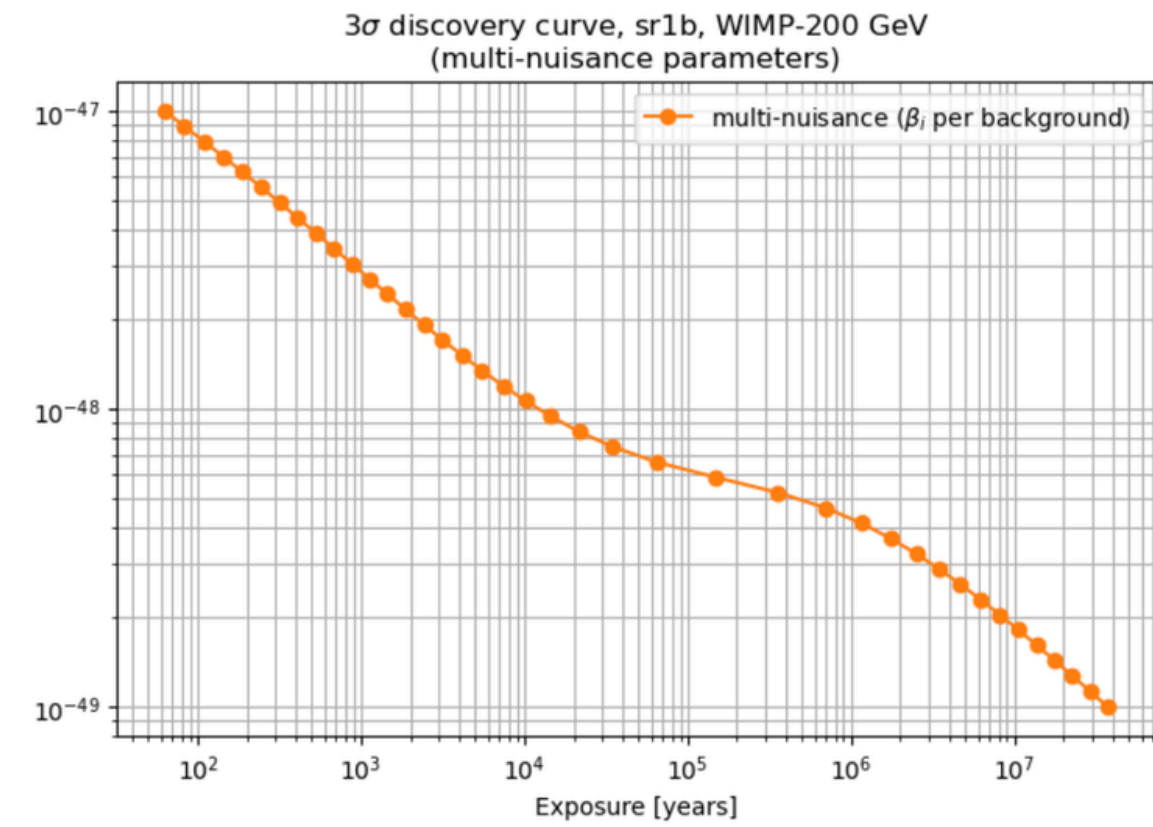
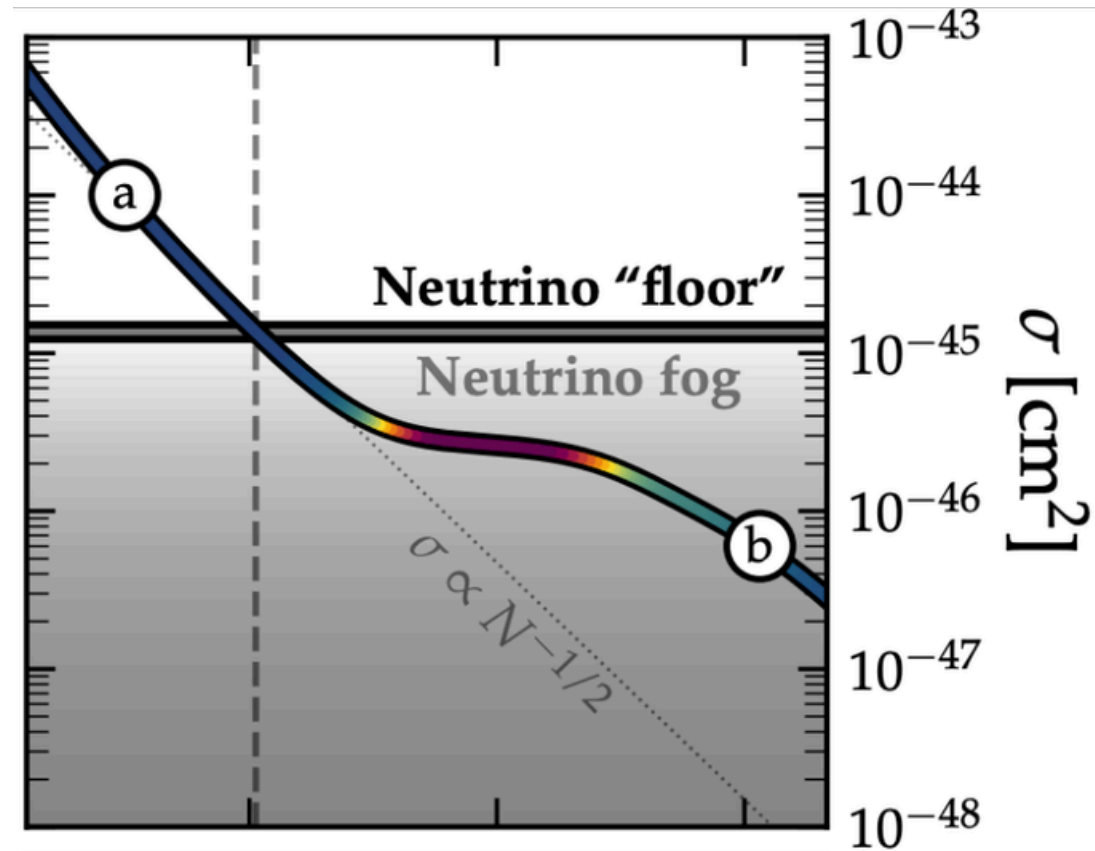
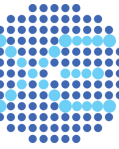
- $n = 2$ under normal Poissonian subtraction

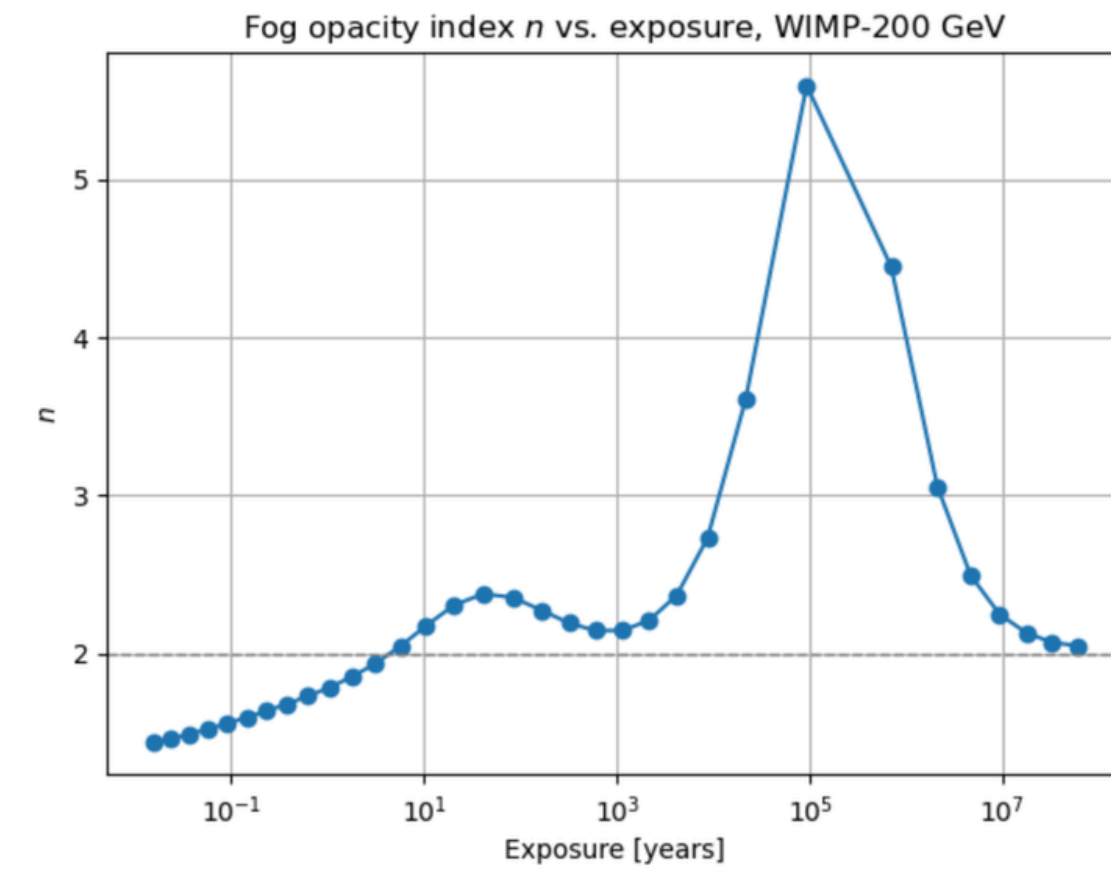
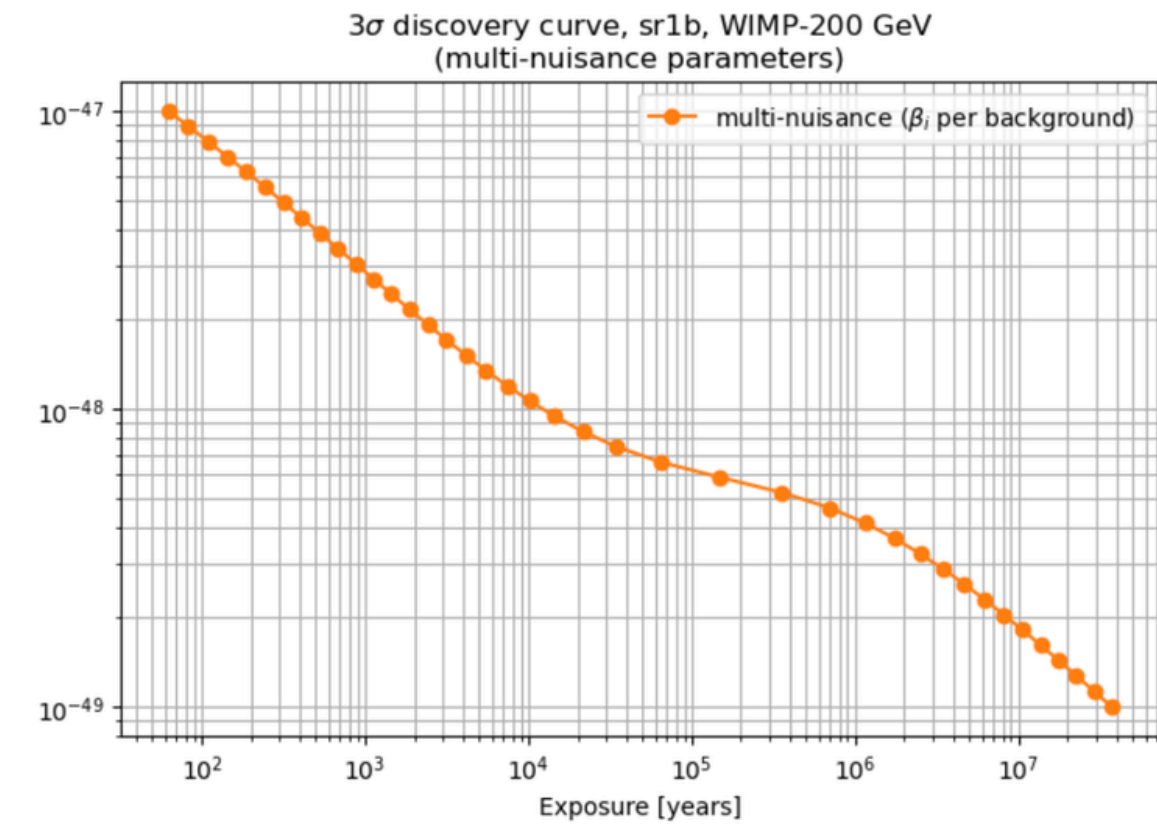
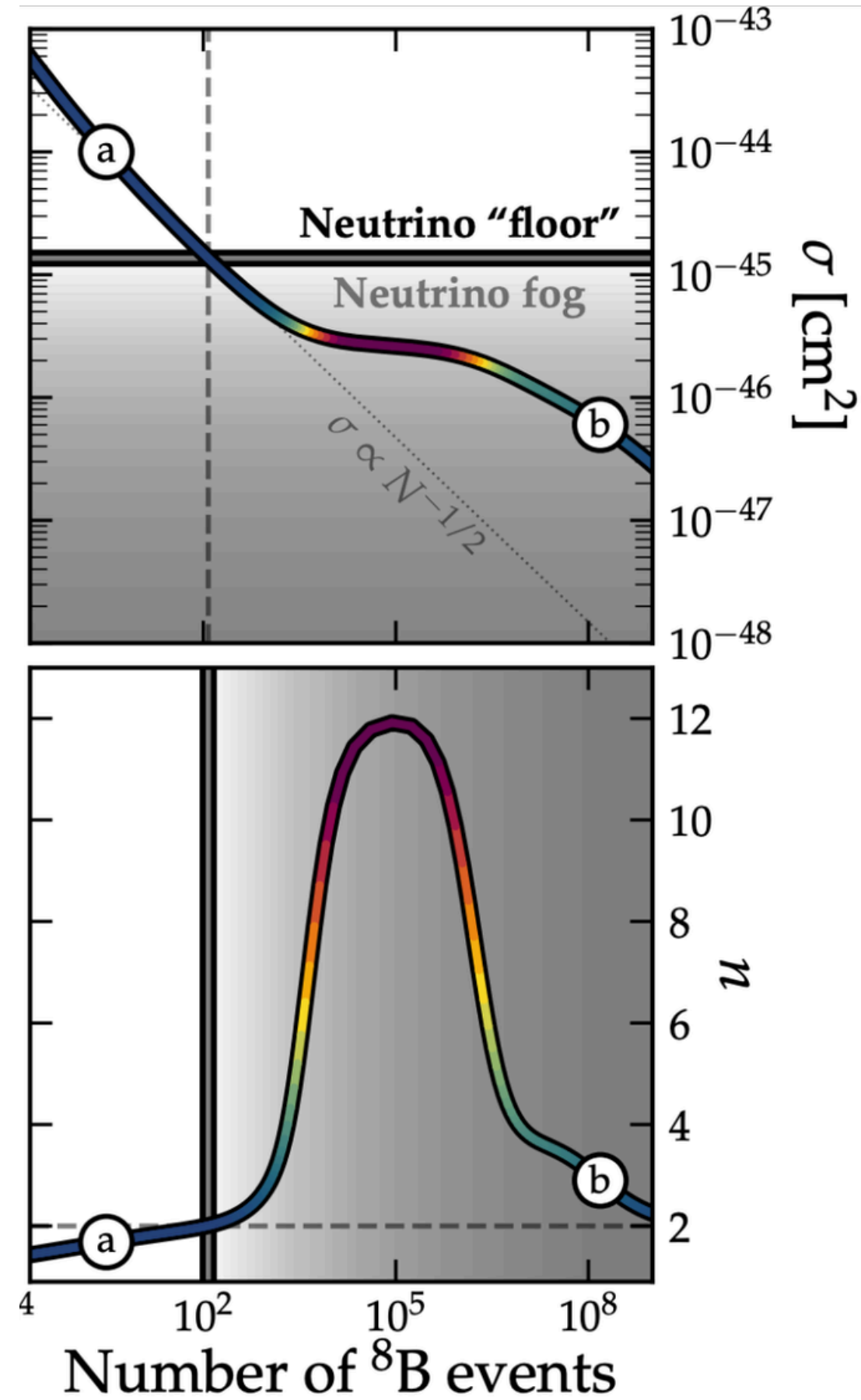
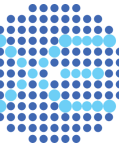
$$n = - \left(\frac{d \ln \sigma}{d \ln N} \right)^{-1}$$



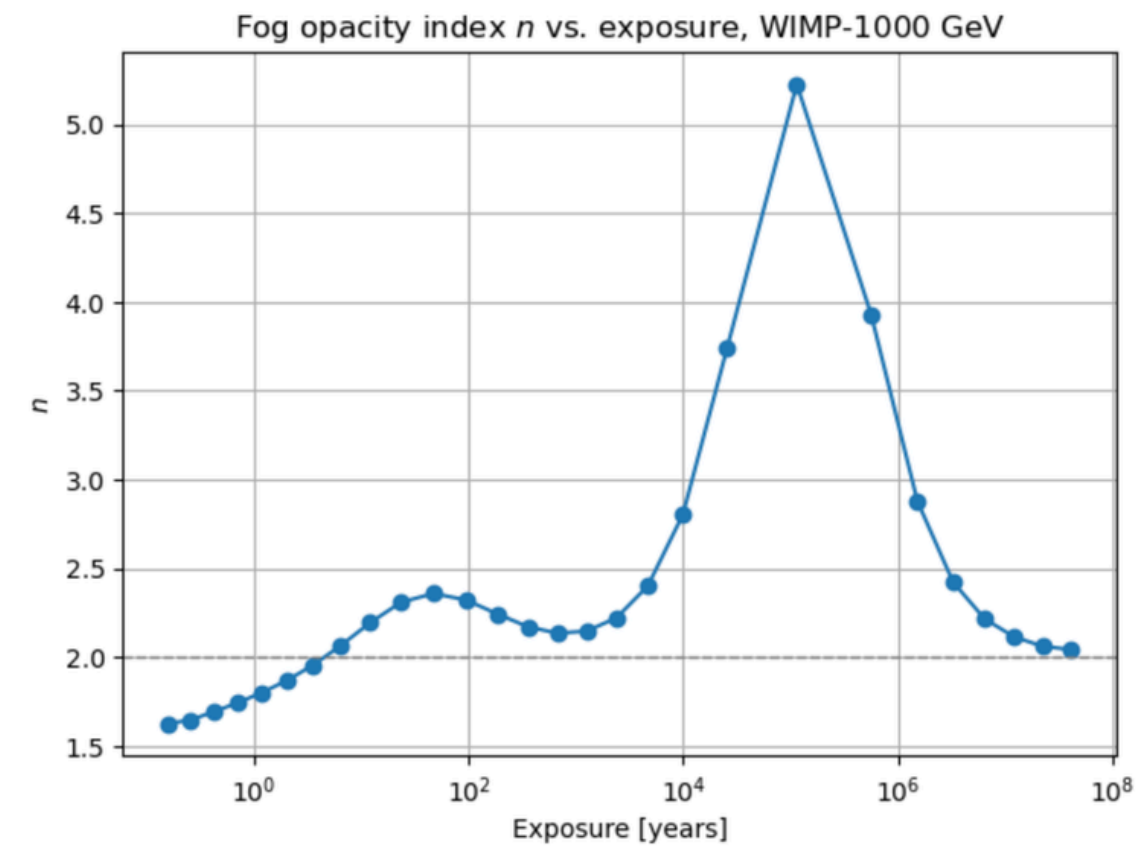
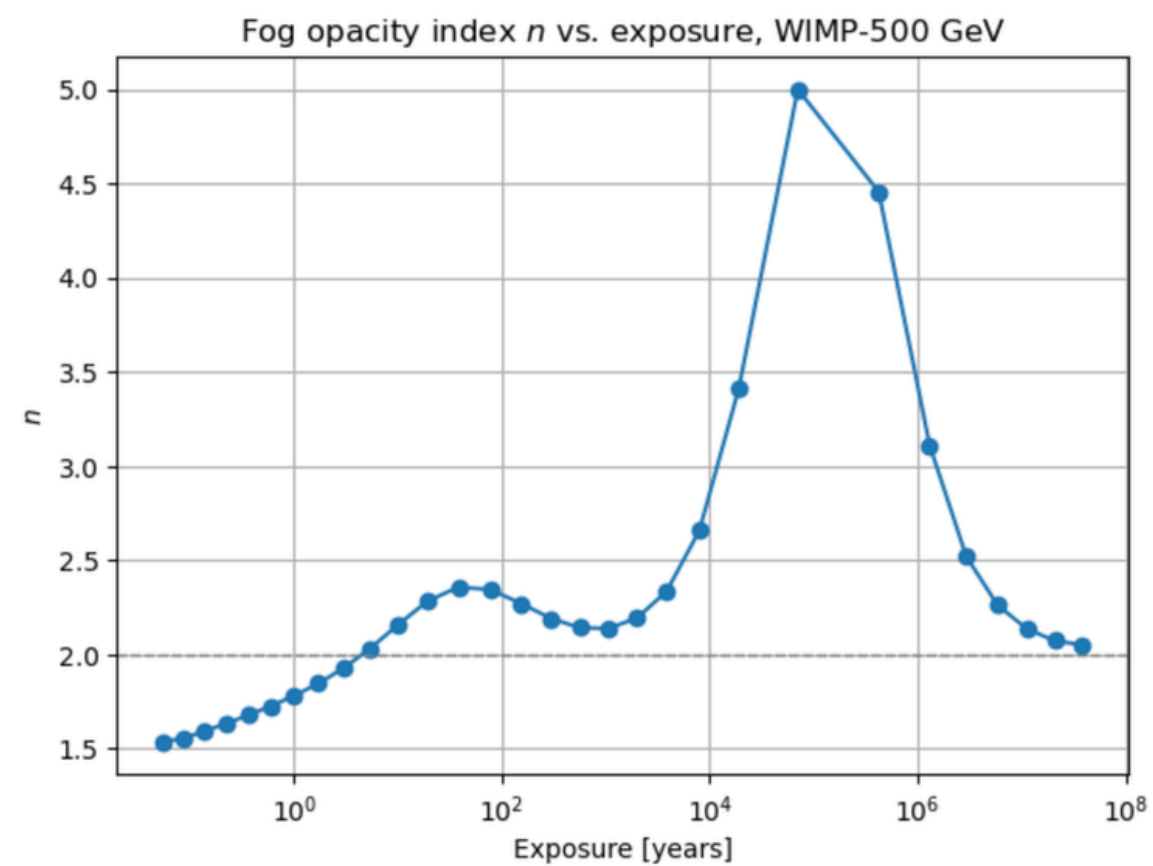
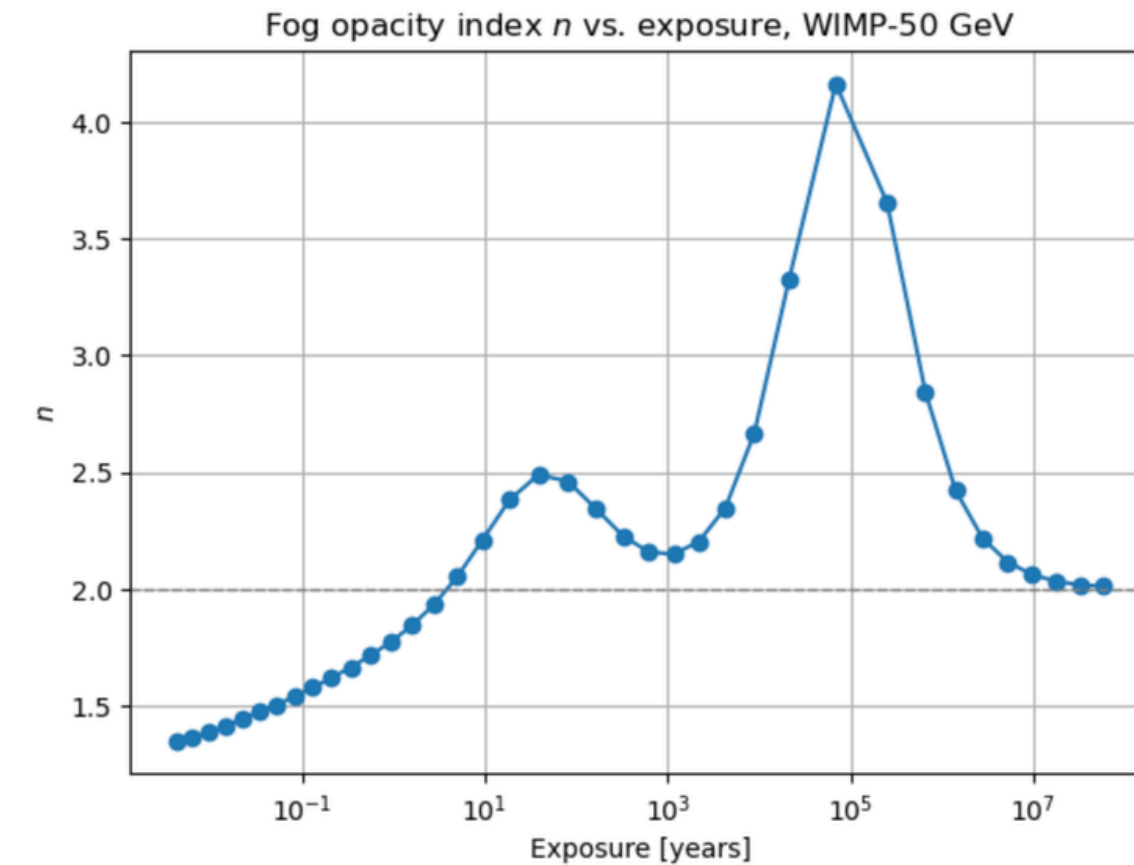
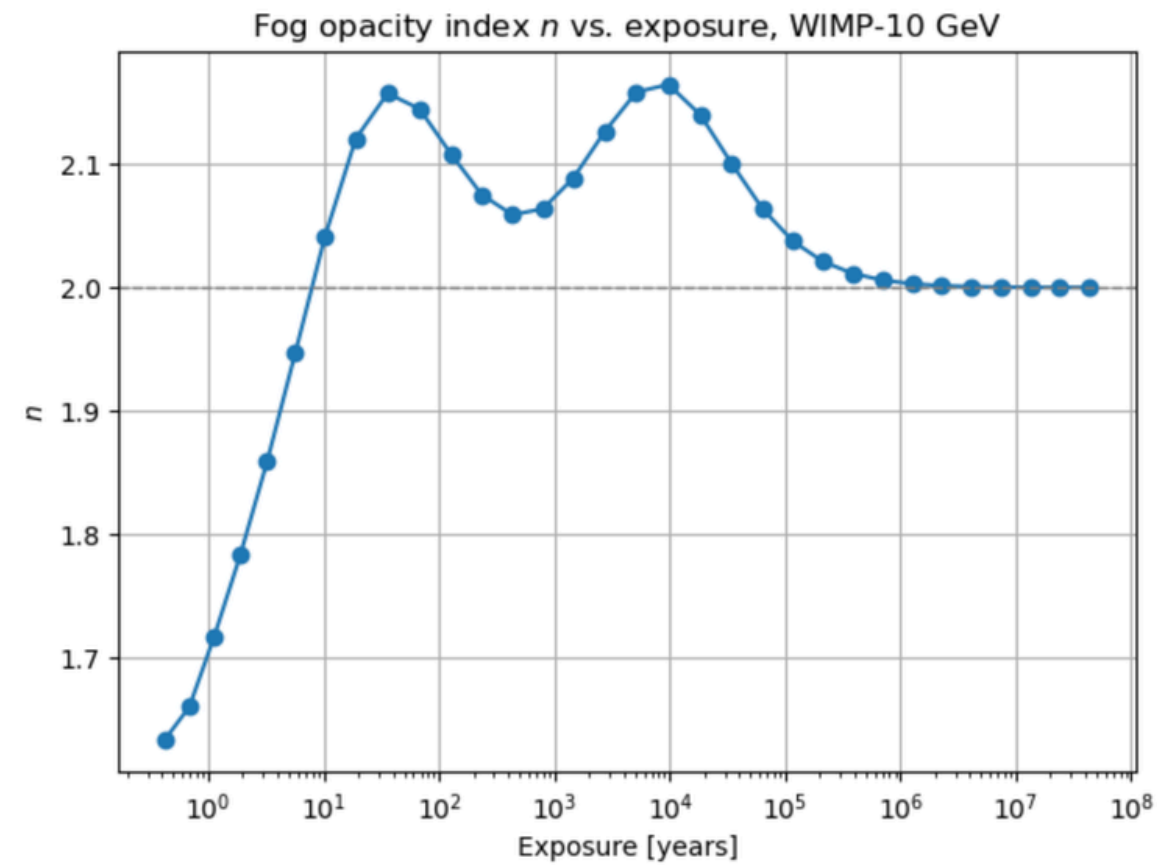
1. Generate an Asimov dataset
2. Calculate the discovery significance
3. Determine the exposure required to achieve a 3σ discovery for each cross section (σ^{SI})
4. Plot the spin-independent WIMP–nucleon cross section versus exposure.





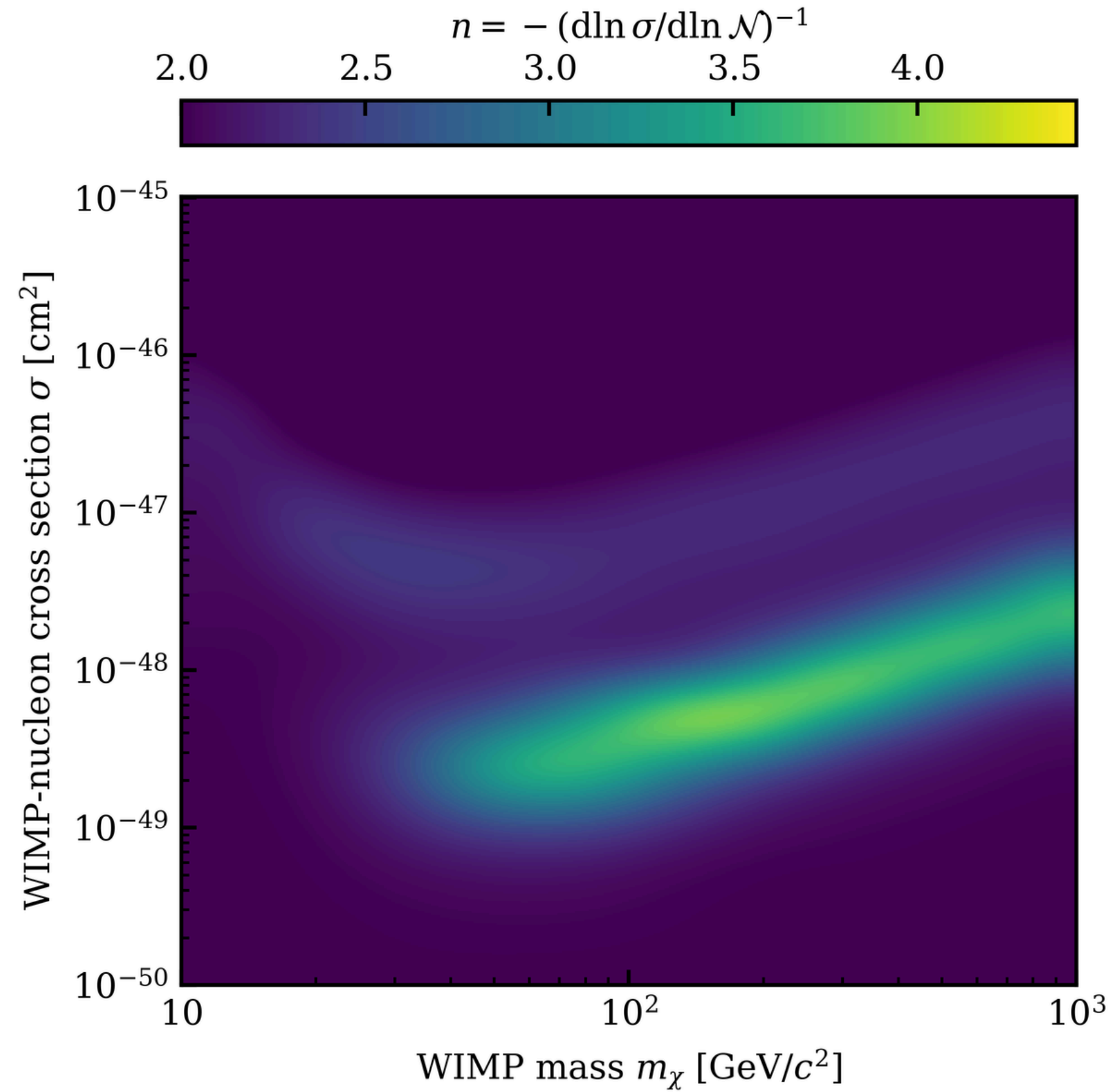


10 - 1000 GeV Opacity Graphs



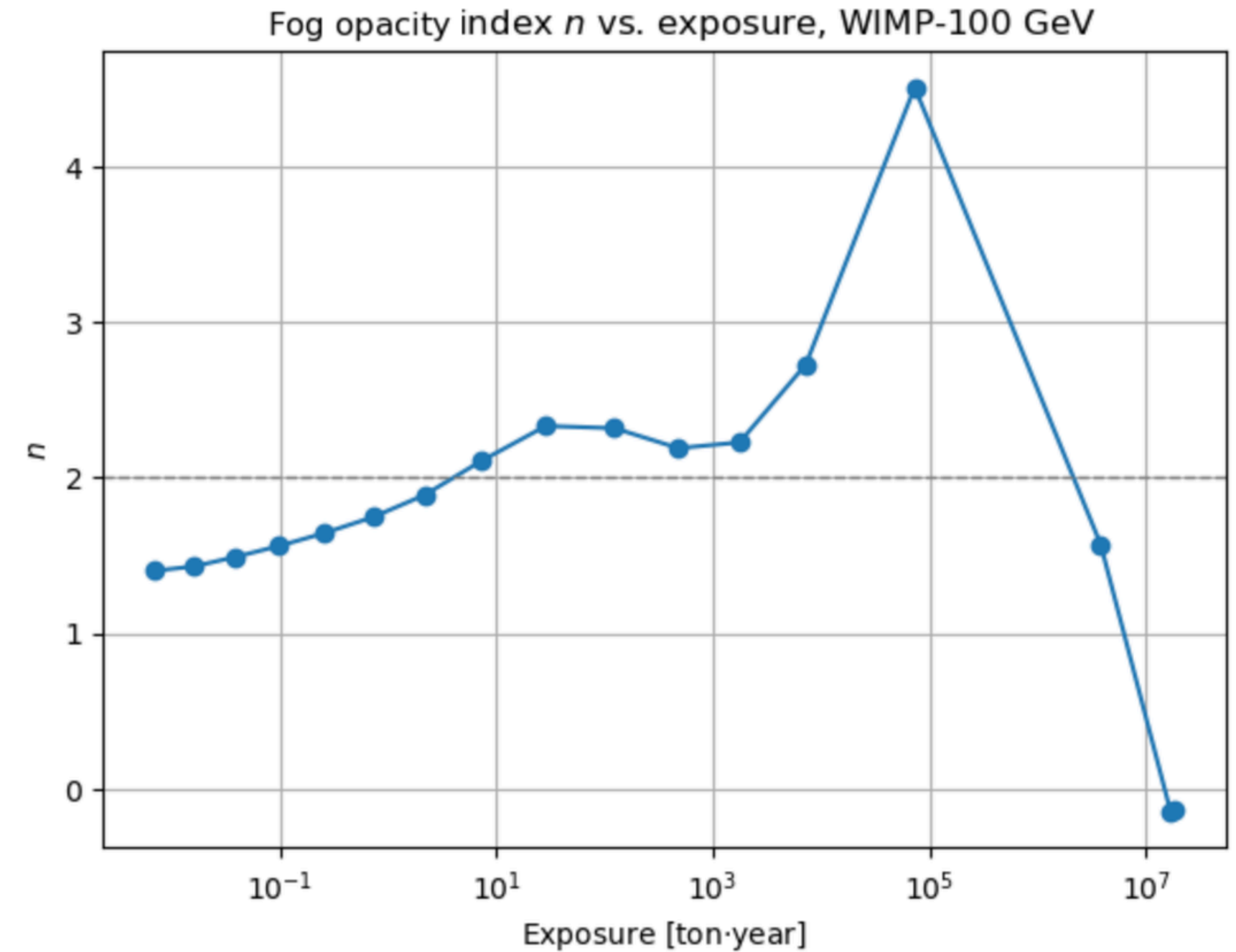


IV. Results and Conclusion



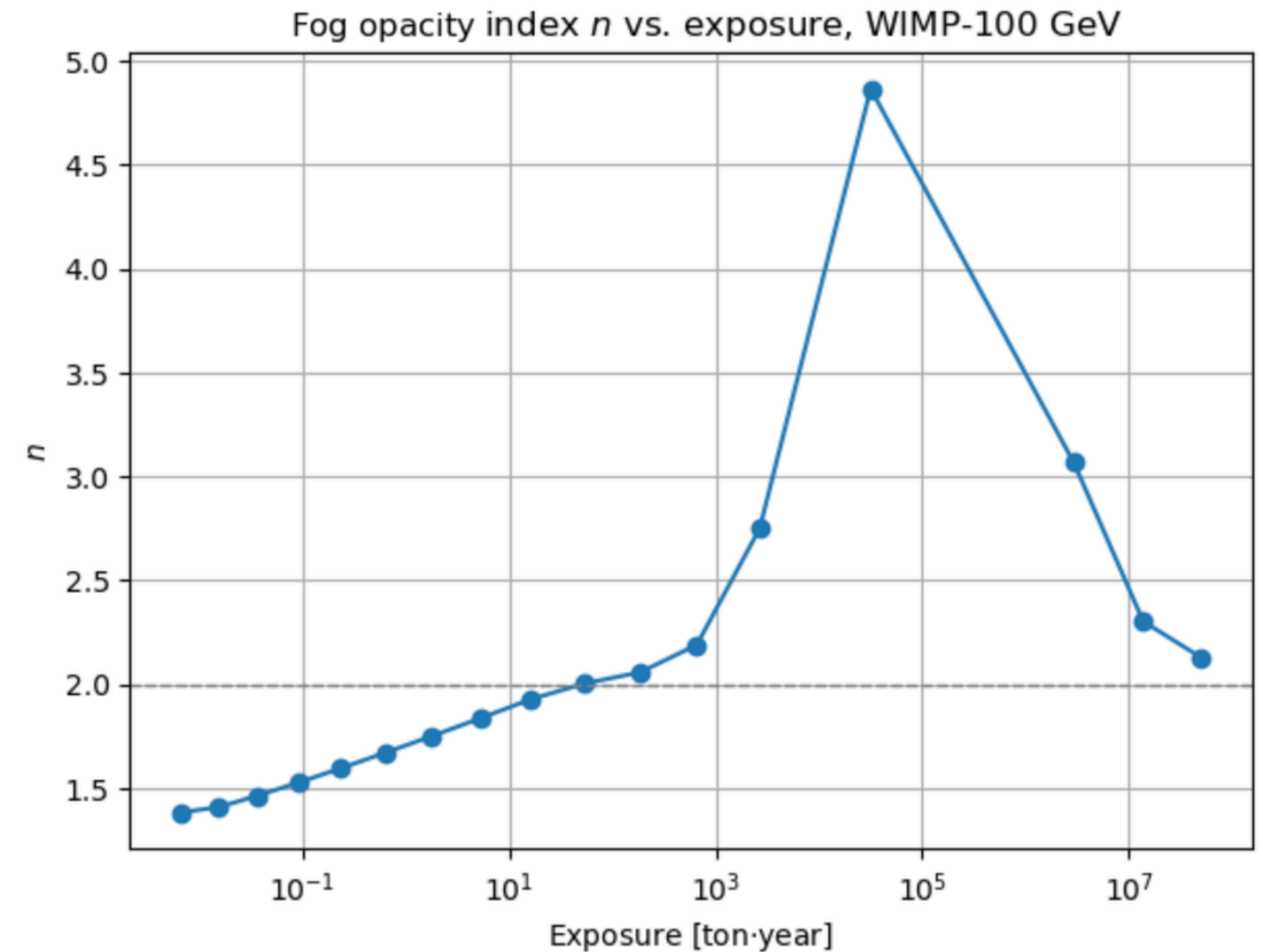


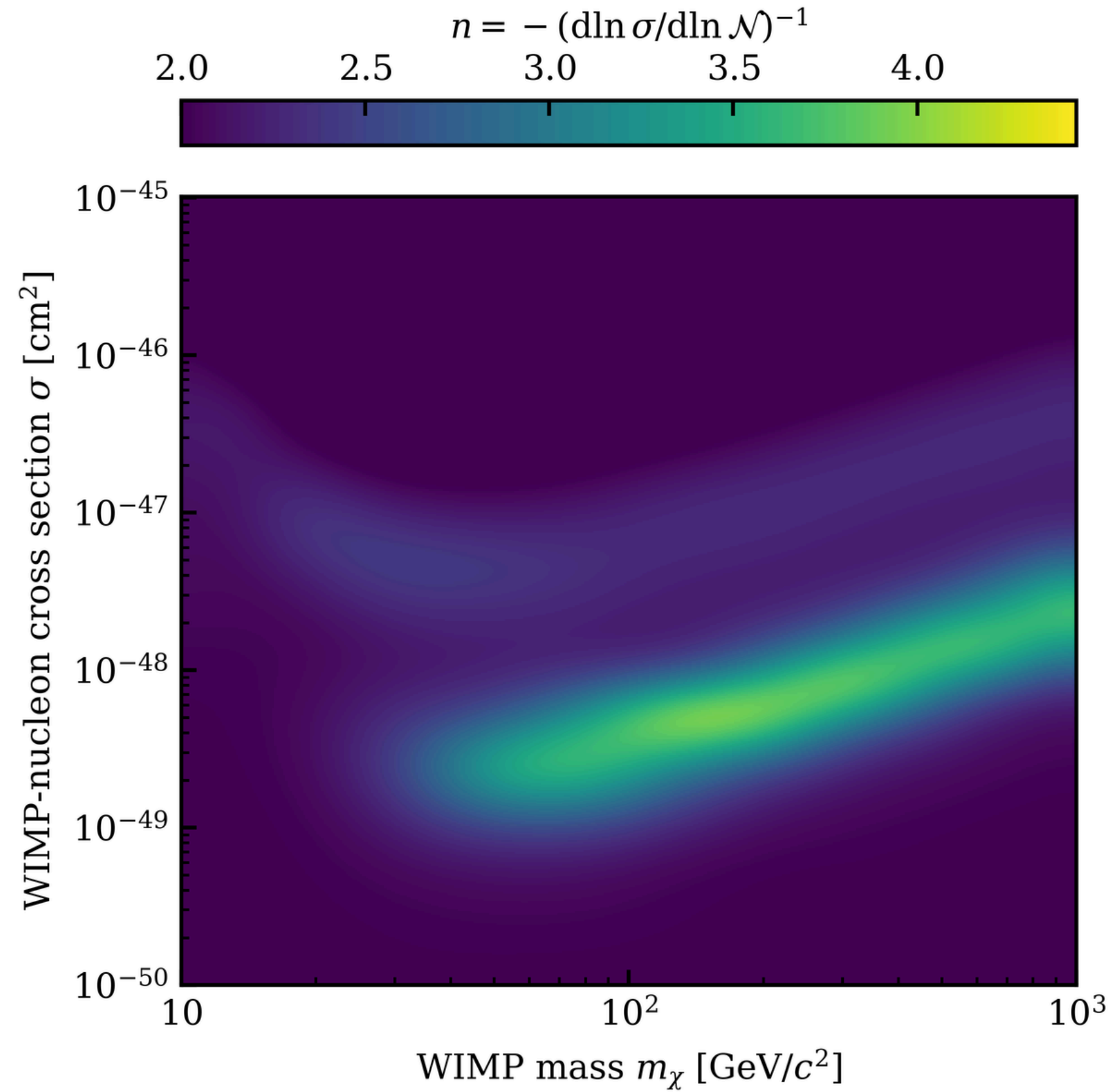
```
templates = np.load("templates.npy", allow_pickle=True).item()
sr = "sr1b"
signal_name = "wimp-100gev"
background_names = [
    "er_flat_pca_0_0",
    "er_h3_pca_0_0",
    "radiogenic",
    "solar_cevns",
    "atnu_cevns",
    "ac",
    "surface",
]
```

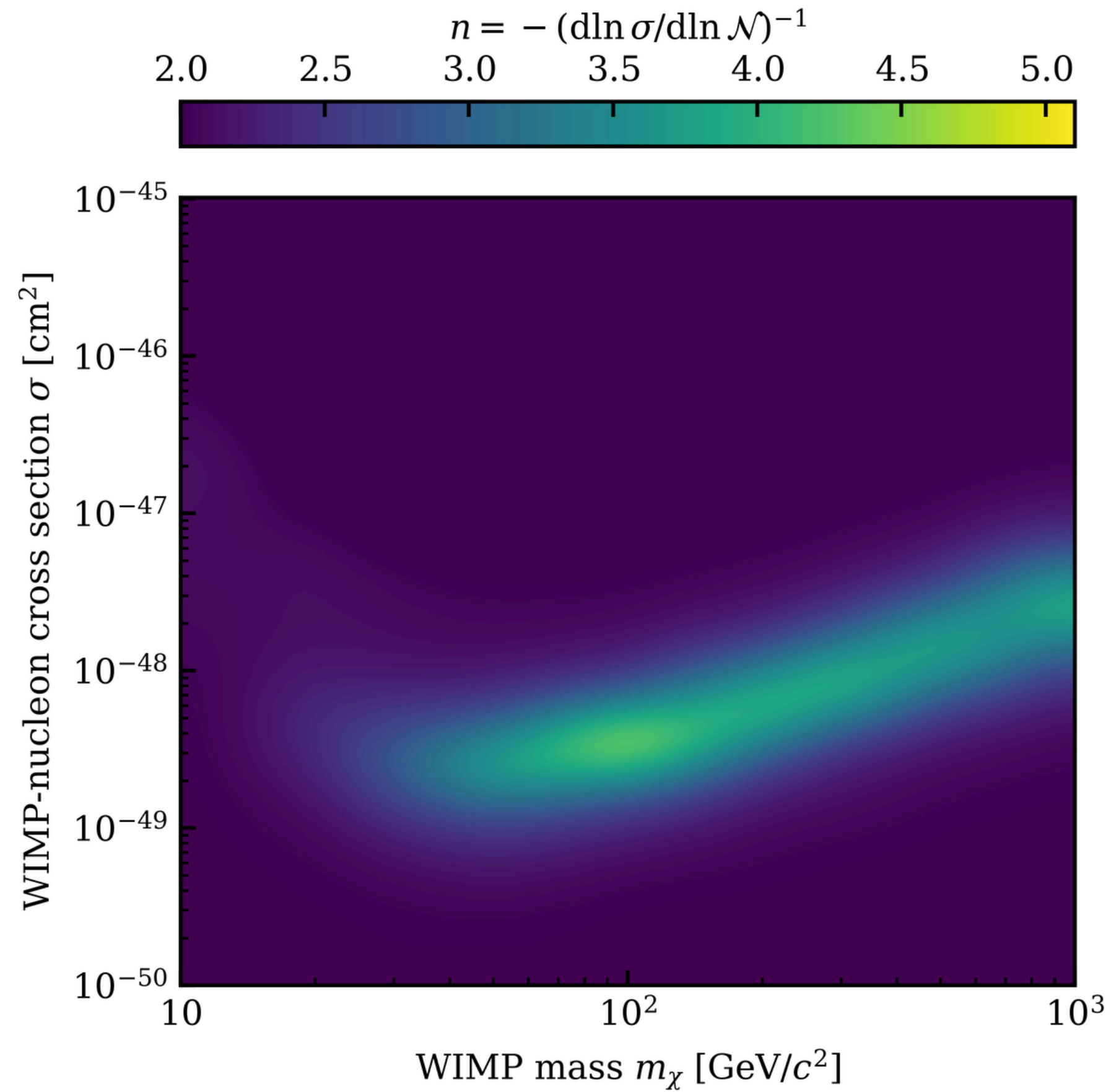


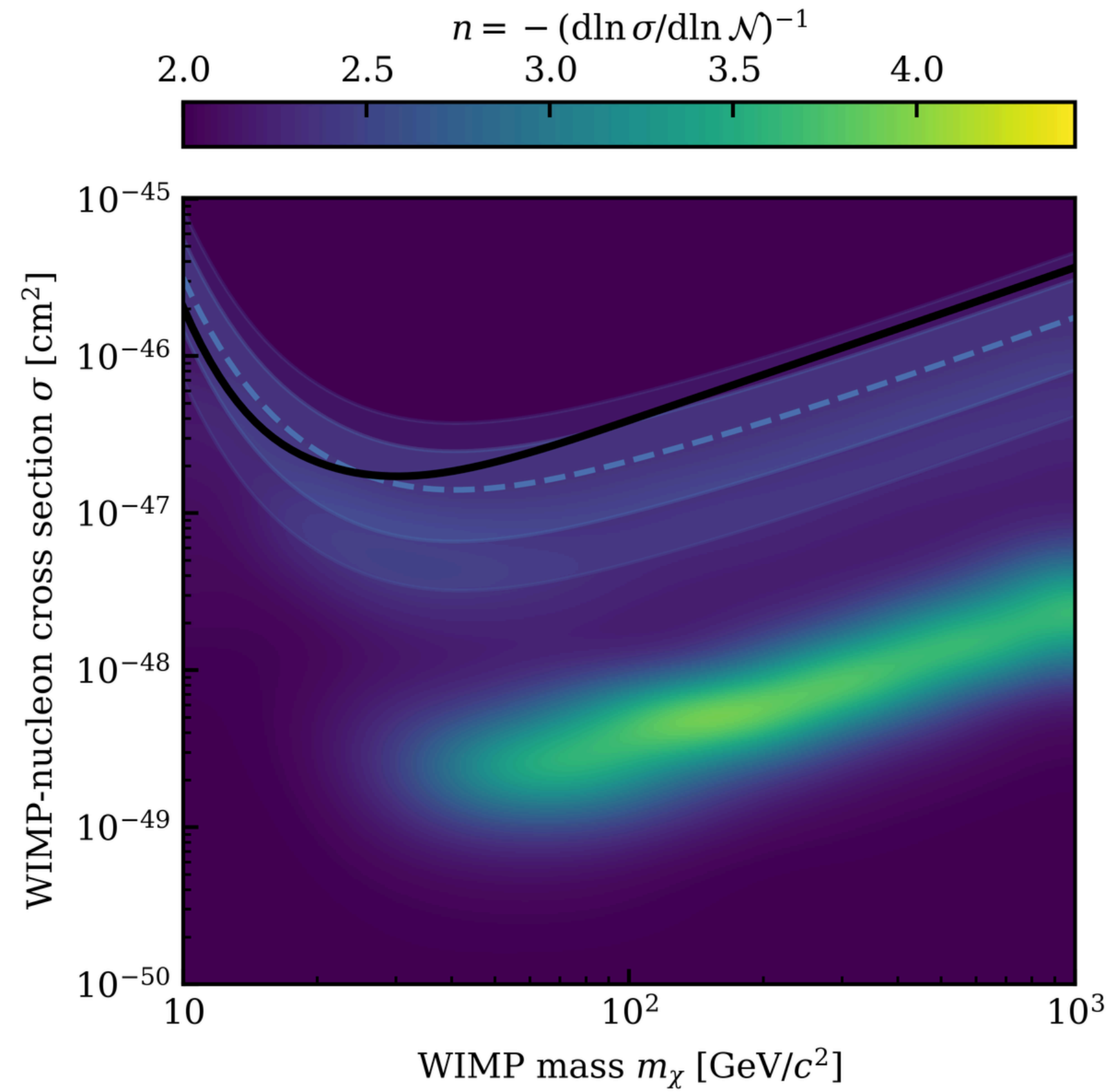


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    "solar_cevns",
    "atnu_cevns",
    "ac",
    "surface",
]
```











- XENONnT does experience fog from radiogenic neutrinos that is not very dense, making it easier to penetrate than other background sources.
- Better constrained thanks to improved discrimination power

