Which dark matter topic do you want to hear about?

Freeze-in of asymmetric dark matter via scatterings

- Model building
- Feynman diagrams
- Lagrangian

Dark matter induced airglow in the Solar System giant planets

- Phenomenology
- Cute planet pictures

Freeze-in of asymmetric dark matter via scatterings

Marianne Moore

work with Pouya Asadi, David Morrissey, And Michael Shamma

241X.XXXXX

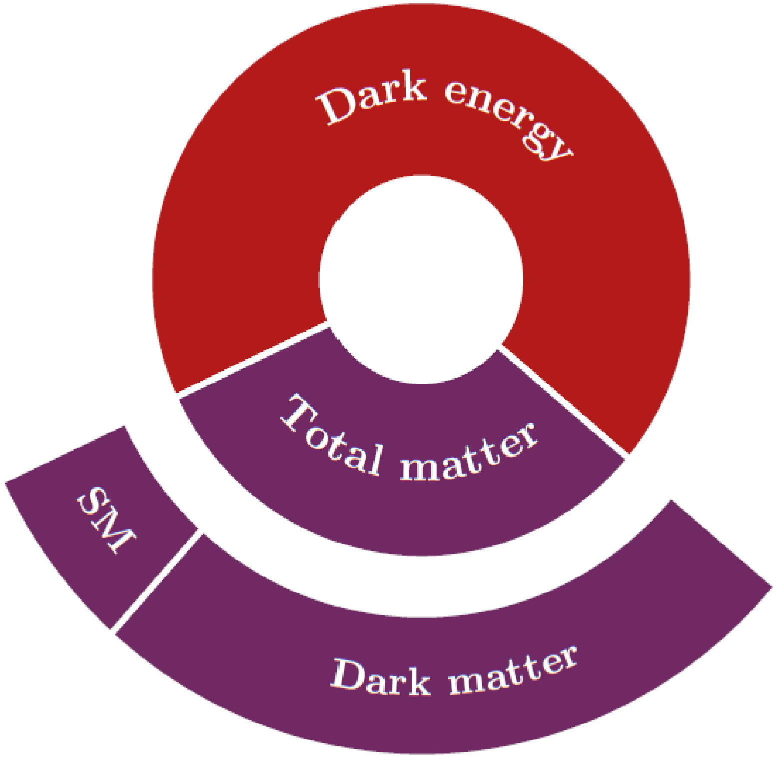
September 12, 2024

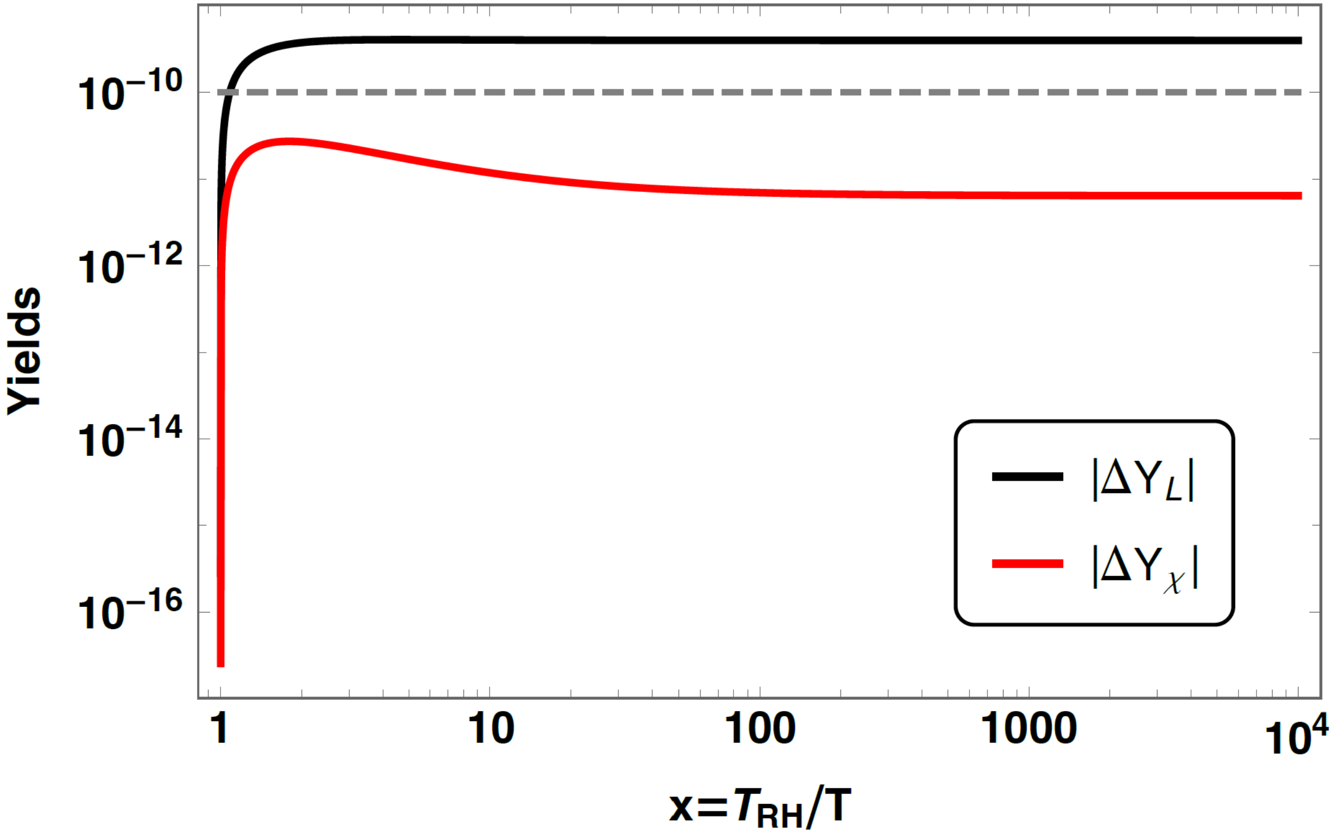
Outline

- Terminology
  - Cogenesis
  - Freeze-in
- The model
- How is the model interesting
  - Constraints
- Summary

Cogenesis

The only hint of SM ↔ DM connection

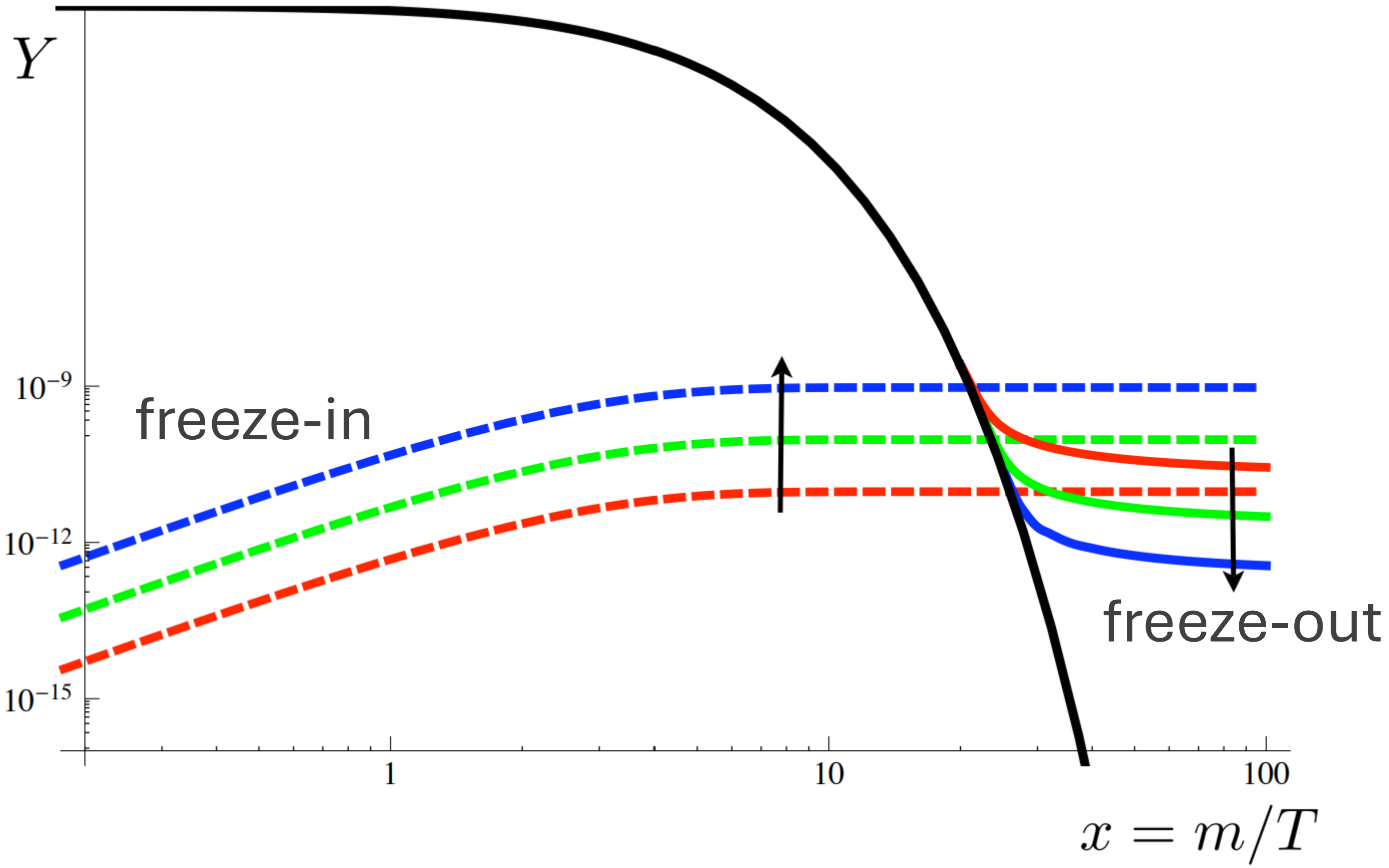




Freeze-in

UV freeze-in: ~ T_{RH}

IR freeze-in: ~$m_{decaying}$



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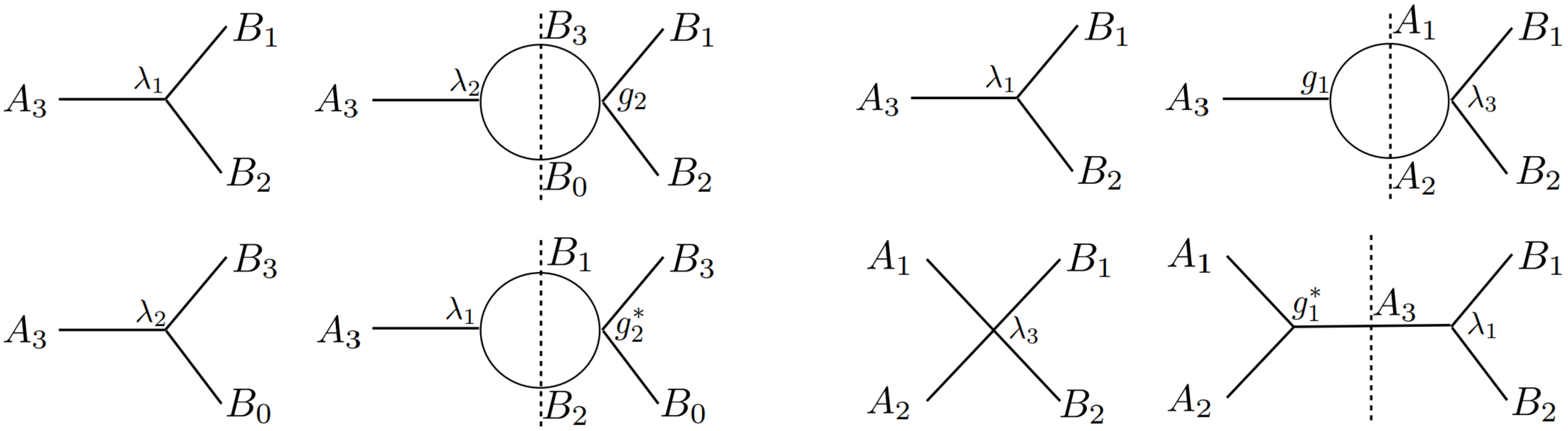
Unitarity constraints on asymmetric freeze-in

It is difficult to do asymmetric freeze-in (e.g. not possible at $\mathcal{O}(\lambda^2)$)



interference of decay and scattering

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The model

$$\mathcal{L} \supset y_{ia} H \ell_i N_a + \lambda_{\beta a} \phi \chi_\beta N_a + m_\chi \chi \chi^c + m_\phi \phi^\dagger \phi + M_a N_a N_a + \text{h.c.}$$

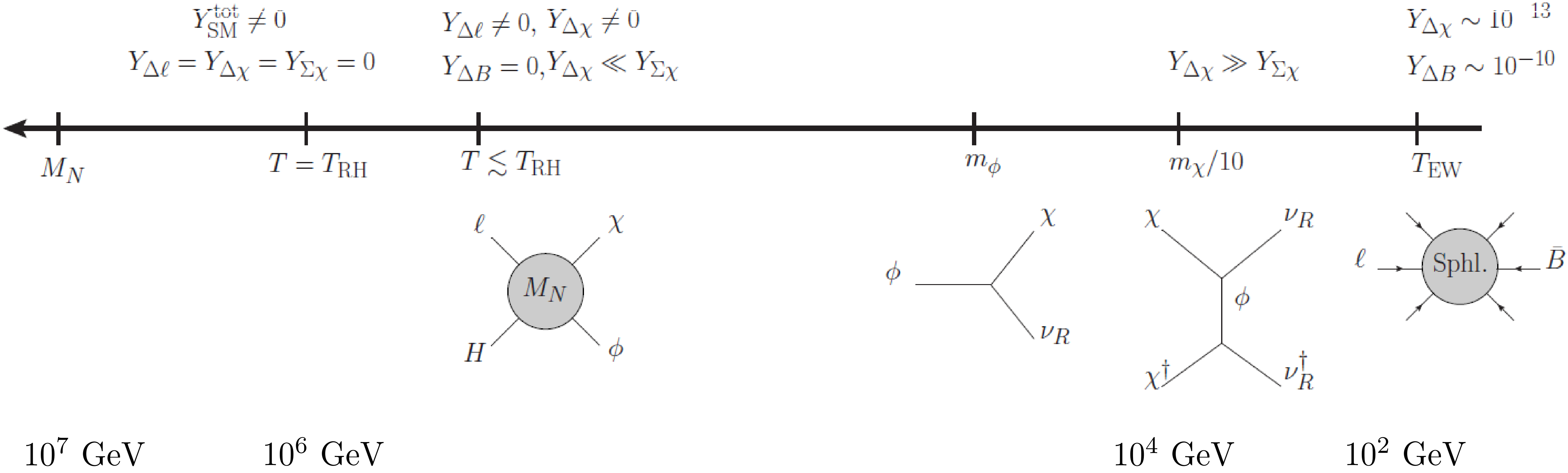
$a = \{1, 2\}$ or more!

$i, \beta = 1$

M_a is real and positive

$$M_a \gg T_{\text{RH}} > m_\phi > m_\chi$$

Cosmological history



The model (schematically)

Asymmetry source (tree x loop)

$$\ell H \to \chi\phi$$
$$\ell^\dagger H^\dagger \to \chi\phi$$
$$\ell H \to \ell^\dagger H^\dagger$$
$$\chi\phi \to \chi^\dagger\phi^\dagger$$

Symmetric source (tree)

$$\ell H \to \chi\phi$$
$$\ell^\dagger H^\dagger \to \chi\phi$$

Washout (tree)

$$\ell\phi \to \chi^\dagger H^\dagger$$
$$\ell\chi \to \phi^\dagger H^\dagger$$
$$\chi\chi \to \phi^\dagger\phi^\dagger$$
$$\ldots$$

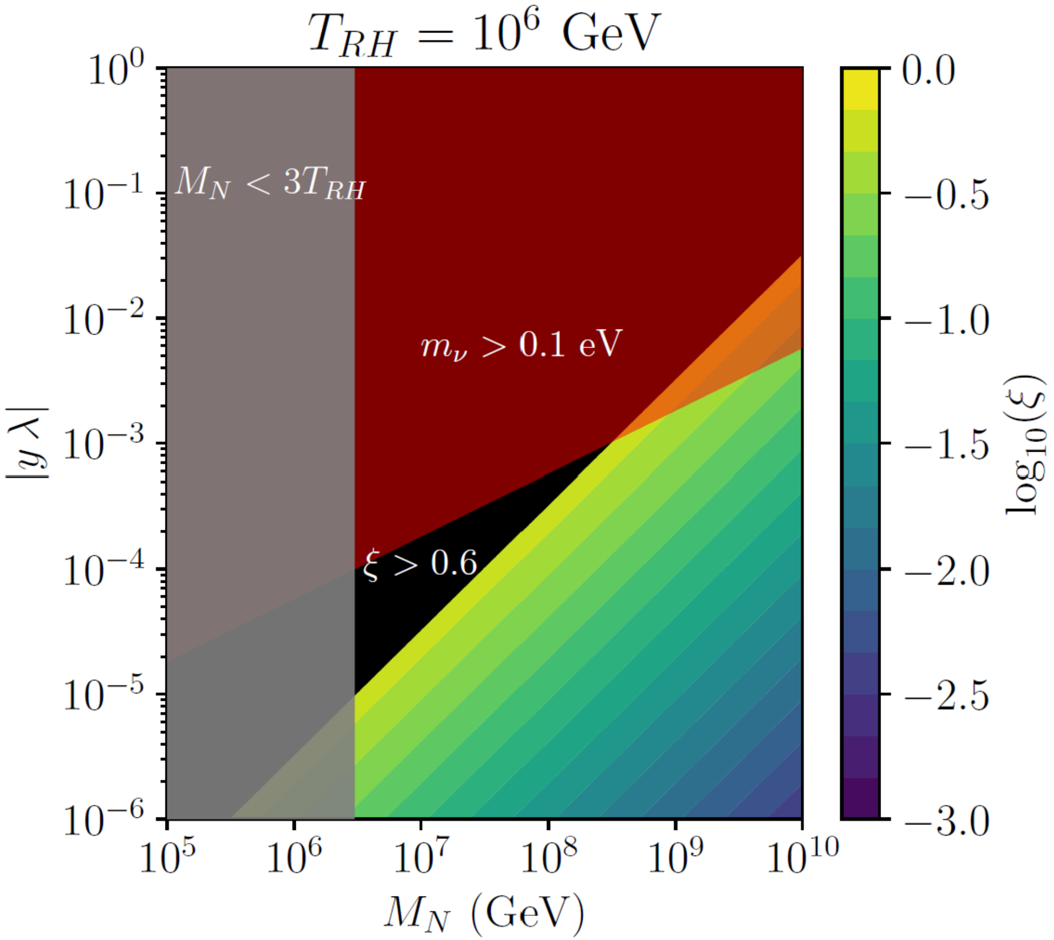
plus terms which separately keep each sector in equilibrium

Constraints on the model

$$\xi = T_{\text{dark}}/T_{\text{SM}} \ll 1$$

$$m_\nu^{\text{SM}} = \frac{|y^2|v_h^2}{M_N} > 0.1 \text{ eV}$$

We can get viable χ with mass ~0.1 GeV to 10^7 GeV



Sakharov condition

1. C and CP violation
   - Chiral interactions
   - Complex couplings y, λ
2. Baryon number violation
   - $M_a \neq 0$
3. Deviation from thermal equilibrium
   - $\xi = T_{\rm dark}/T_{\rm SM} \ll 1$

Davidson-Ibarra bound

Typically:

Models where the lepton asymmetry is generated via the decay of a heavy Majorana neutrino can only give rise to the observed asymmetry if

$$T_{\mathrm{RH}} \gtrsim 10^9\ \mathrm{GeV}$$

Washout (tree)

$$\ell\phi \to \chi^\dagger H^\dagger$$

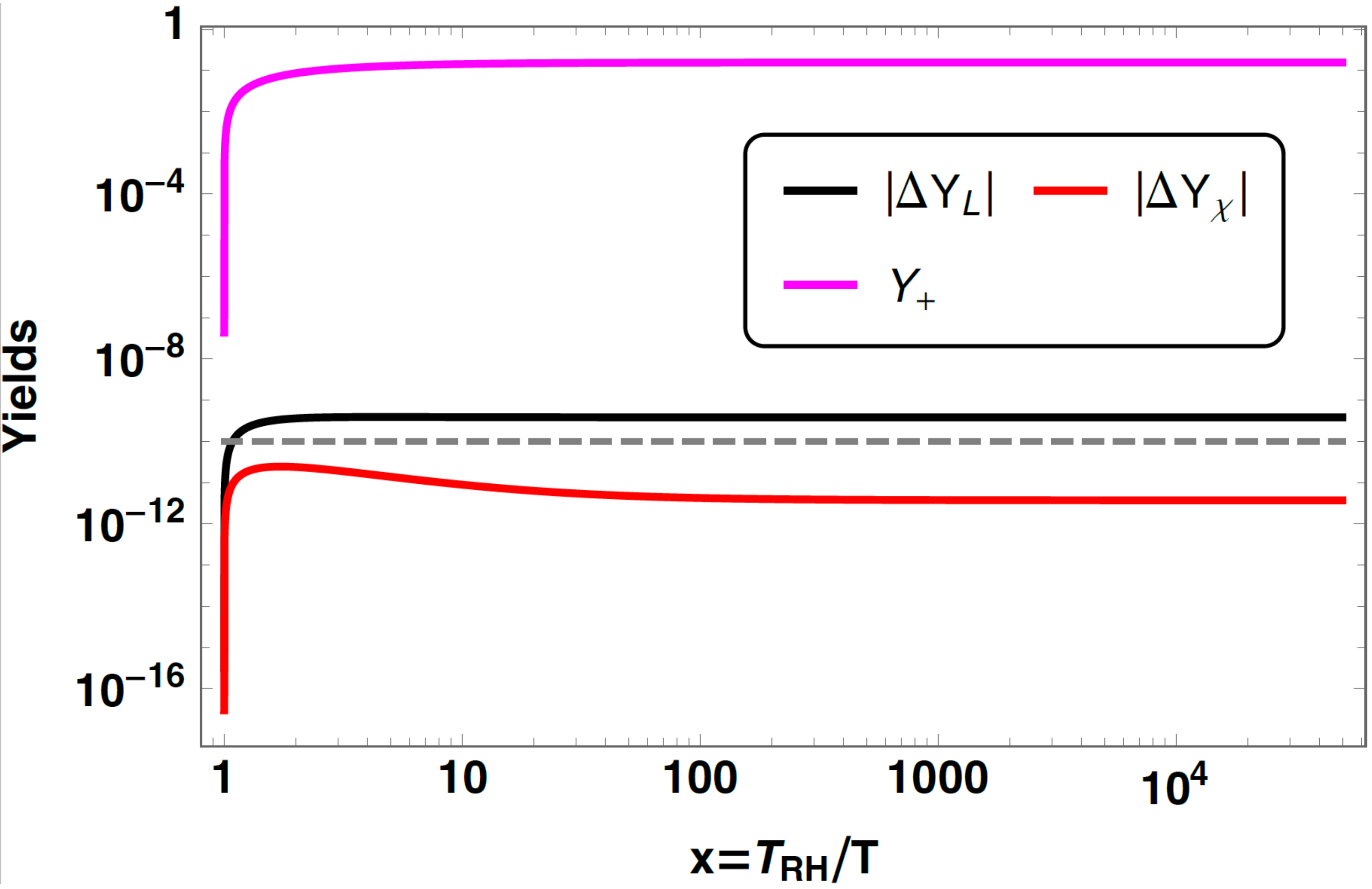
$$\ell\chi \to \phi^\dagger H^\dagger$$

$$\chi\chi \to \phi^\dagger \phi^\dagger$$

$$\ldots$$

hep-ph/0202239

Dark sink



We need to get rid of this symmetric population

2312.14152

Summary

What is this model?

- UV freeze-in dark matter
- Cogenesis via scattering

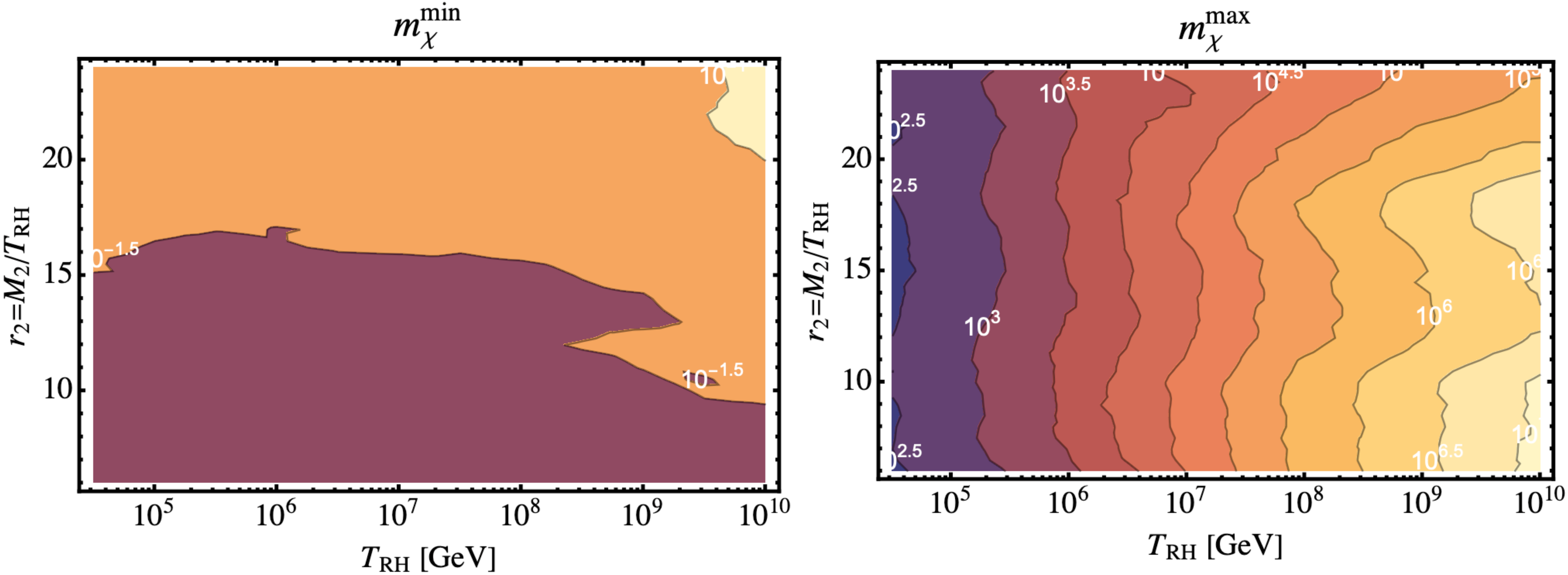
Why is this model interesting?

- Generates dark matter
- Generates the lepton asymmetry
- Is the first case of evading the Davidson-Ibarra bound

Backup slides

$$
\begin{aligned}
\dot{n}_\chi + 3\mathbf{H}n_\chi \;=\; & \int \Pi_{\chi\phi}^{\ell H}\left[|\mathcal{M}_{\chi\phi}^{\ell H}|^2 f_\ell f_H(1-f_\chi)(1+f_\phi) - |\mathcal{M}_{\ell H}^{\chi\phi}|^2 f_\chi f_\phi(1-f_\ell)(1+f_H)\right] \qquad (53)\\
+ & \int \Pi_{\chi\phi}^{\ell^\dagger H^\dagger}\left[|\mathcal{M}_{\chi\phi}^{\ell^\dagger H^\dagger}|^2 f_{\ell^\dagger} f_{H^\dagger}(1-f_\chi)(1+f_\phi) - |\mathcal{M}_{\ell^\dagger H^\dagger}^{\chi\phi}|^2 f_\chi f_\phi(1-f_{\ell^\dagger})(1+f_{H^\dagger})\right]\\
+ & \int \Pi_{\chi\phi}^{\chi^\dagger \phi^\dagger}\left[|\mathcal{M}_{\chi\phi}^{\chi^\dagger\phi^\dagger}|^2 f_{\chi^\dagger} f_{\phi^\dagger}(1-f_\chi)(1+f_\phi) - |\mathcal{M}_{\chi^\dagger\phi^\dagger}^{\chi\phi}|^2 f_\chi f_\phi(1-f_{\chi^\dagger})(1+f_{\phi^\dagger})\right]\\
+ & \; 2\int \Pi_{\chi\chi}^{\phi^\dagger\phi^\dagger}\left[|\mathcal{M}_{\chi\chi}^{\phi^\dagger\phi^\dagger}|^2 f_{\phi^\dagger}^2(1-f_\chi)^2 - |\mathcal{M}_{\phi^\dagger\phi^\dagger}^{\chi\chi}|^2 f_\chi^2(1+f_{\phi^\dagger})^2\right]\\
+ & \int \Pi_{\chi H^\dagger}^{\ell\phi^\dagger}\left[|\mathcal{M}_{\chi H^\dagger}^{\ell\phi^\dagger}|^2 f_\ell f_{\phi^\dagger}(1-f_\chi)(1+f_{H^\dagger}) - |\mathcal{M}_{\ell\phi^\dagger}^{\chi H^\dagger}|^2 f_\chi f_{H^\dagger}(1-f_\ell)(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi H}^{\ell^\dagger\phi^\dagger}\left[|\mathcal{M}_{\chi H}^{\ell^\dagger\phi^\dagger}|^2 f_{\ell^\dagger} f_{\phi^\dagger}(1-f_\chi)(1+f_H) - |\mathcal{M}_{\ell^\dagger\phi^\dagger}^{\chi H}|^2 f_\chi f_H(1-f_{\ell^\dagger})(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi\ell}^{H^\dagger\phi^\dagger}\left[|\mathcal{M}_{\chi\ell}^{H^\dagger\phi^\dagger}|^2 f_{H^\dagger} f_{\phi^\dagger}(1-f_\chi)(1-f_\ell) - |\mathcal{M}_{H^\dagger\phi^\dagger}^{\chi\ell}|^2 f_\chi f_\ell(1+f_{H^\dagger})(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi\ell^\dagger}^{H\phi^\dagger}\left[|\mathcal{M}_{\chi\ell^\dagger}^{H\phi^\dagger}|^2 f_H f_{\phi^\dagger}(1-f_\chi)(1-f_{\ell^\dagger}) - |\mathcal{M}_{H\phi^\dagger}^{\chi\ell^\dagger}|^2 f_\chi f_{\ell^\dagger}(1+f_H)(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi\chi^\dagger}^{\phi\phi^\dagger}\left[|\mathcal{M}_{\chi\chi^\dagger}^{\phi\phi^\dagger}|^2 f_\phi f_{\phi\dagger}(1-f_\chi)(1-f_{\chi^\dagger}) - |\mathcal{M}_{\phi\phi^\dagger}^{\chi\chi^\dagger}|^2 f_\chi f_{\chi^\dagger}(1+f_\phi)(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi\chi^\dagger}^{\nu\nu^\dagger}\left[|\mathcal{M}_{\chi\chi^\dagger}^{\nu\nu^\dagger}|^2 f_\nu f_{\nu\dagger}(1-f_\chi)(1-f_{\chi^\dagger}) - |\mathcal{M}_{\nu\nu^\dagger}^{\chi\chi^\dagger}|^2 f_\chi f_{\chi^\dagger}(1+f_\nu)(1+f_{\nu^\dagger})\right]\\
+ & \int \Pi_{\chi\nu_R^\dagger}^{\phi^\dagger}\left[|\mathcal{M}_{\chi\nu_R^\dagger}^{\phi^\dagger}|^2 f_{\phi^\dagger}(1-f_\chi)(1-f_{\nu_R^\dagger}) - |\mathcal{M}_{\phi^\dagger}^{\chi\nu_R^\dagger}|^2 f_\chi f_{\nu_R^\dagger}(1+f_{\phi^\dagger})\right]\\
+ & \int \Pi_{\chi\nu}^{\phi^\dagger}\left[|\mathcal{M}_{\chi\nu}^{\phi^\dagger}|^2 f_{\phi^\dagger}(1-f_\chi)(1-f_\nu) - |\mathcal{M}_{\phi^\dagger}^{\chi\nu}|^2 f_\chi f_\nu(1+f_{\phi^\dagger})\right],
\end{aligned}
$$

Available dark matter masses



Dark matter induced airglow in the Solar System giant planets

Marianne Moore

2408.15318

with Carlos Blanco, Rebecca Leane, and Joshua Tong

September 12, 2024

SUBMIT NSERC CRSNG Fonds de recherche Québec

Outline

Dark matter accumulation

Ultraviolet airglow

Dark matter-induced airglow

Results

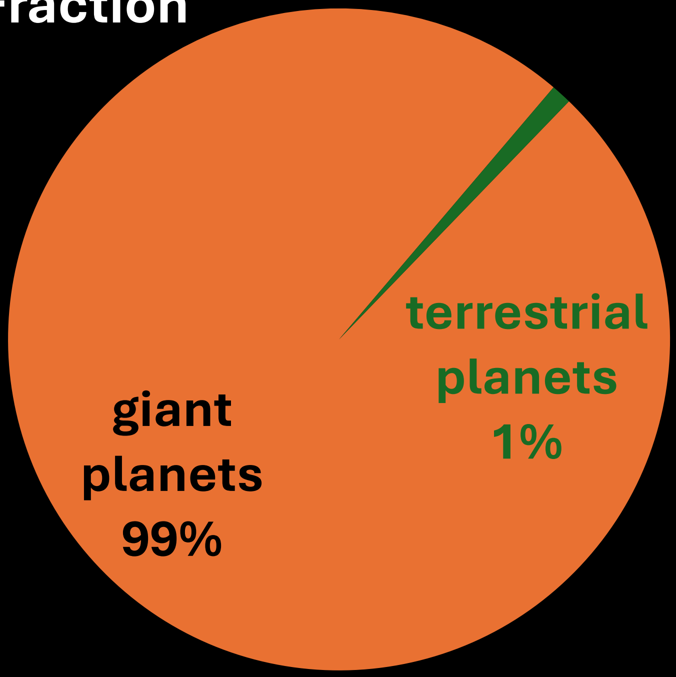
Previous constraints

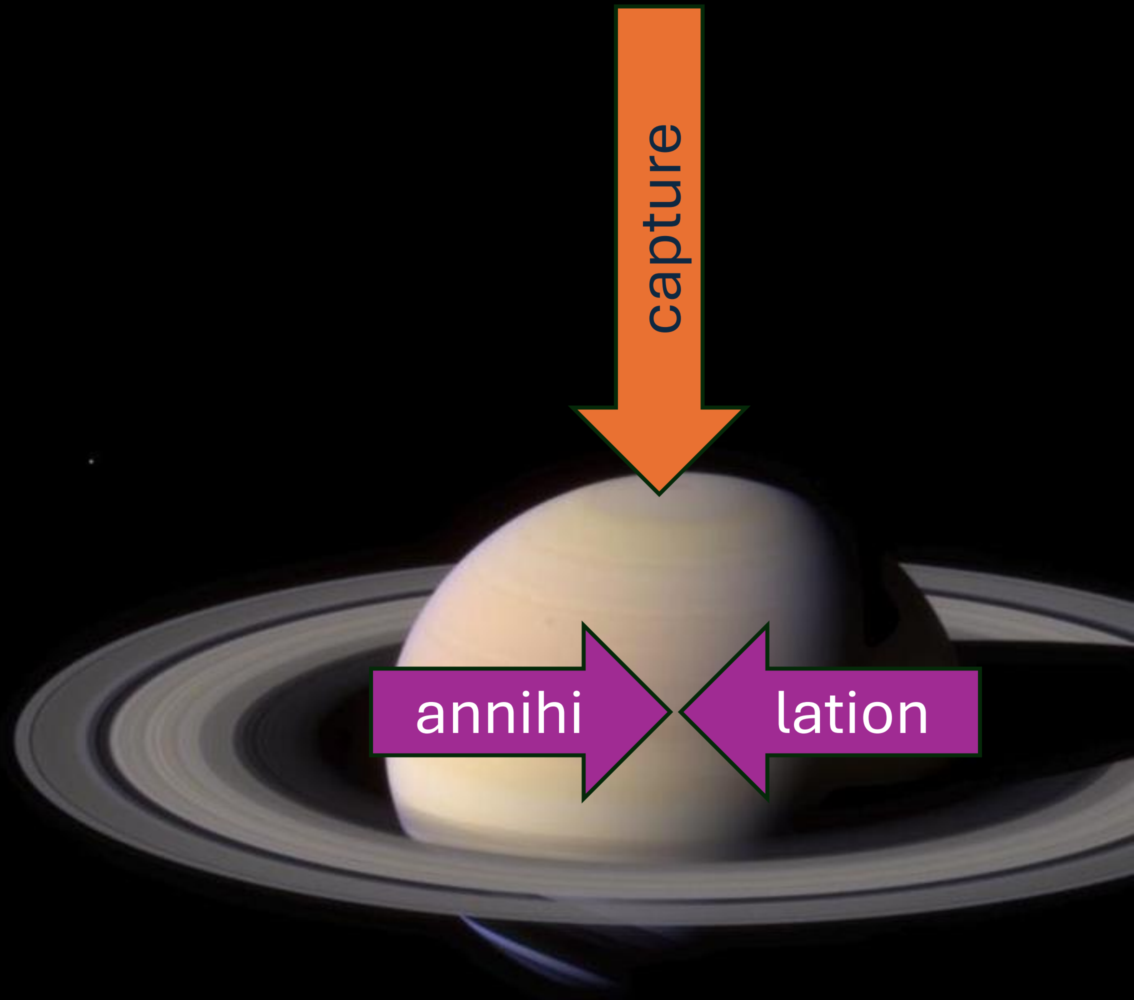
Summary

Dark matter accumulation in planets

$$\frac{\mathrm{d}N_\chi}{\mathrm{d}t} = \Gamma_{\mathrm{capture}} - N_\chi^2 \Gamma_{\mathrm{annihilation}}$$

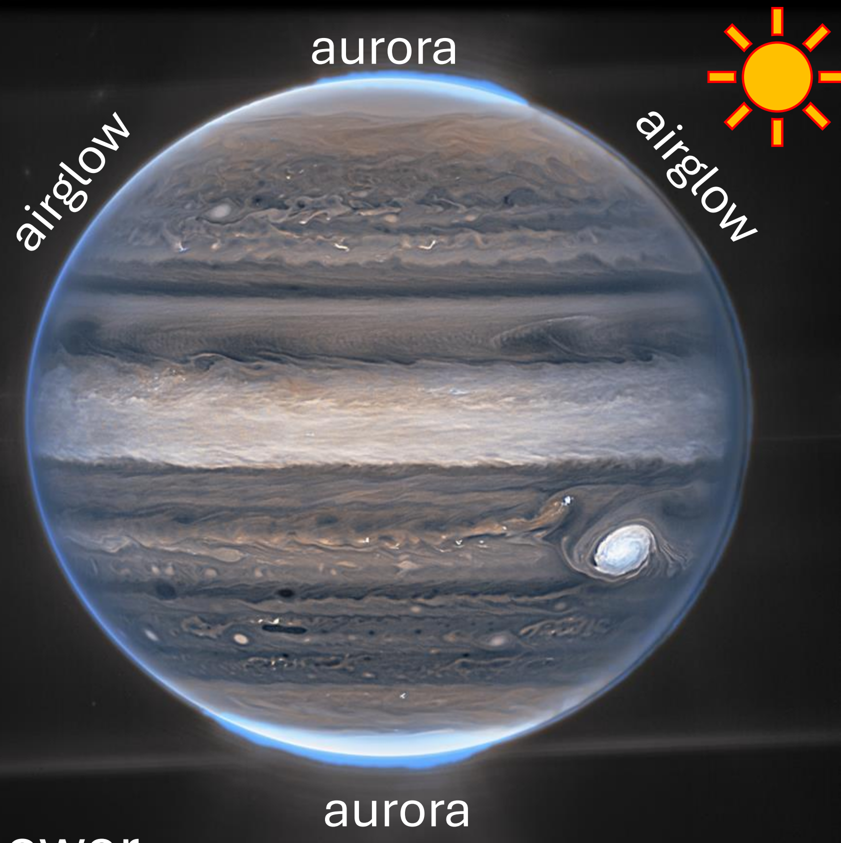
Mass Fraction





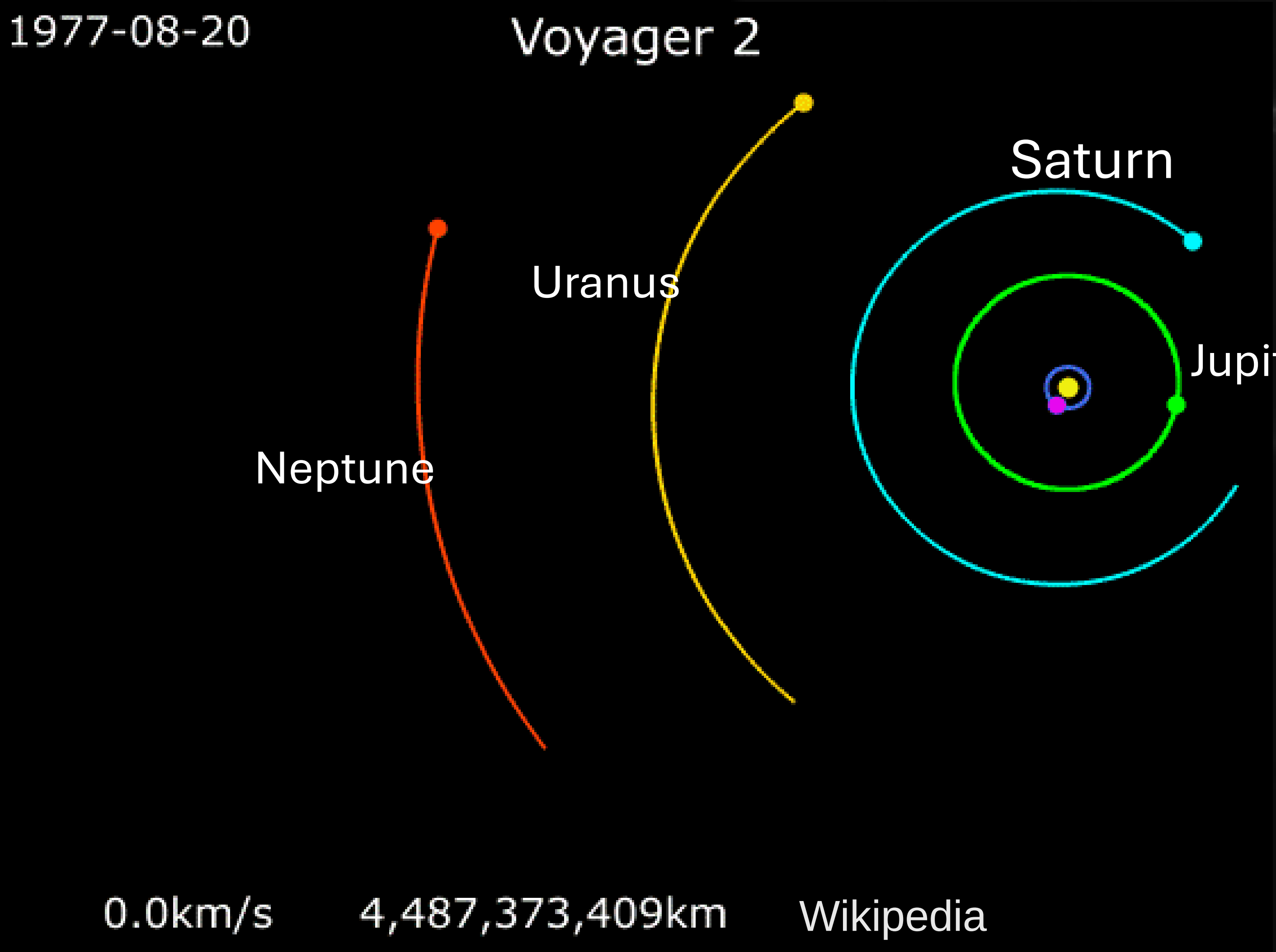
Ultraviolet airglow

- The giant planets emit an isotropic airglow and auroras
- Mostly produced by electron precipitation
  - With contamination by solar radiation on dayside
- Focus on molecular hydrogen lines
  - Clear relationship observed flux ⇔ input electron power



$$H_2^* \rightarrow H_2 + h\nu$$

Ultraviolet airglow



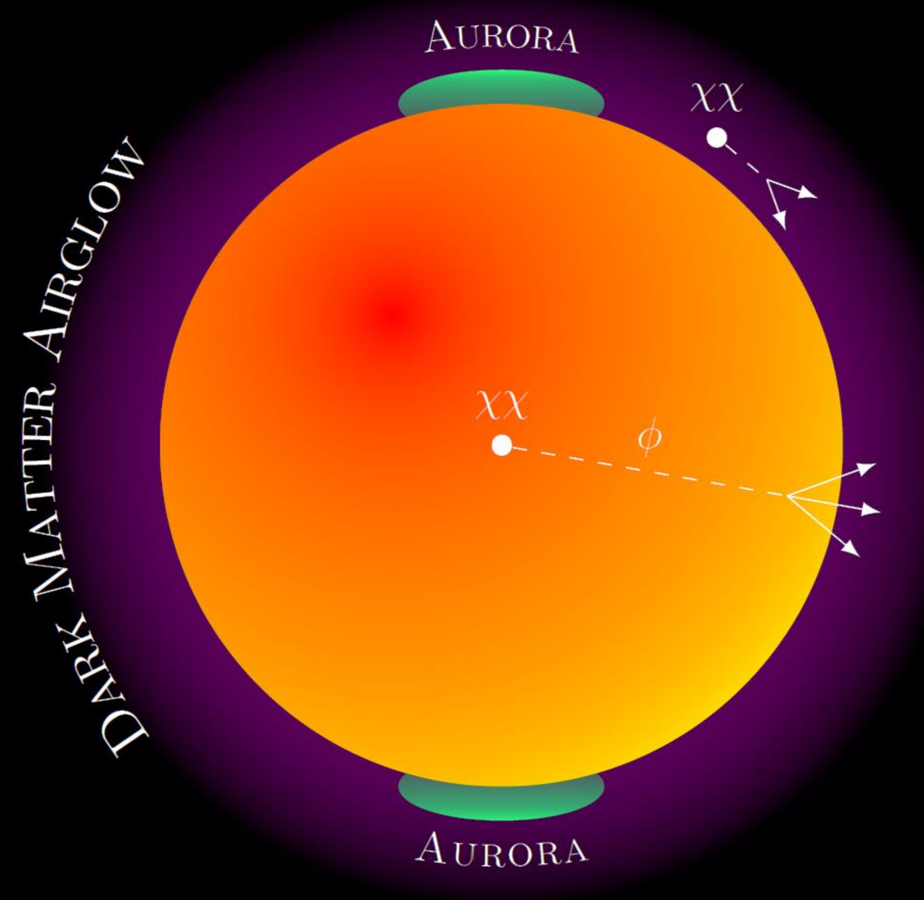
Dark matter-induced airglow

If dark matter annihilates to

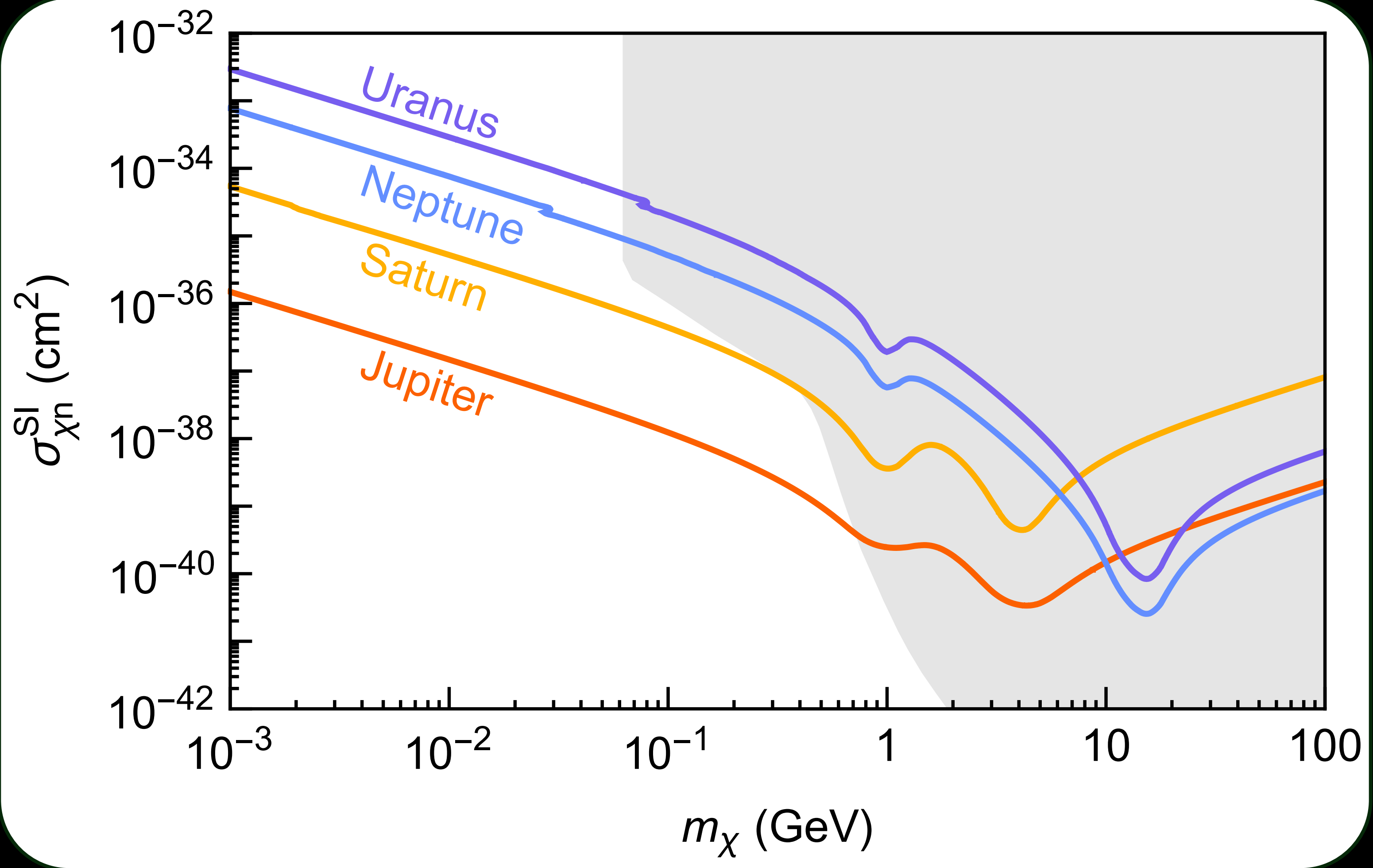
- electrons
  - $P_{\mathrm{DM}}^{\mathrm{airglow}} \leq P_{\mathrm{observed}}^{\mathrm{airglow}}$
- other charged final states
  - The limit is reduced by a factor of a few

➢ both can also lead to internal heating

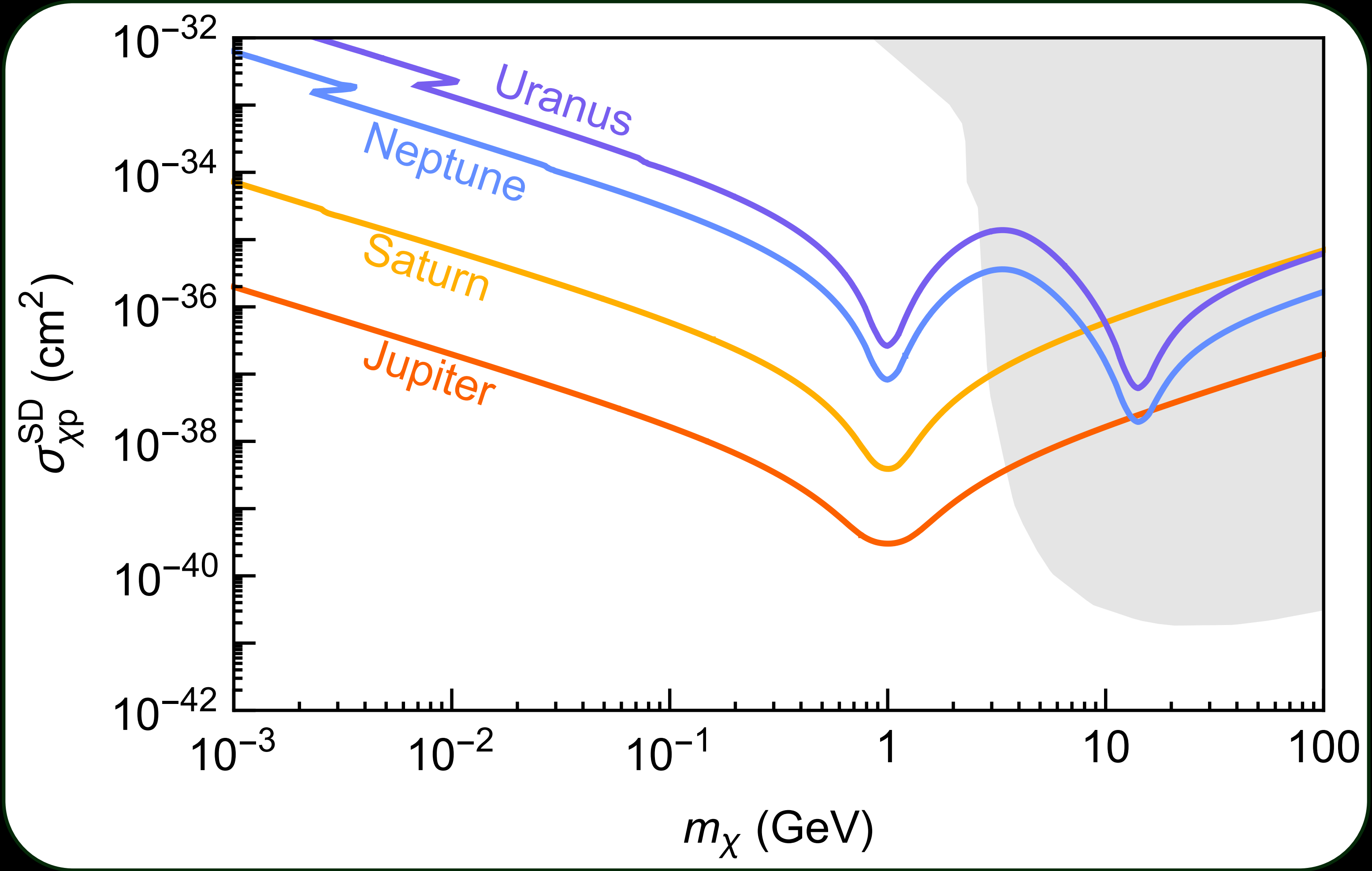
- neutrinos
  - no airglow, but IceCube limits from the Sun exist (see Aaron Vincent's talk)



Results: spin-independent

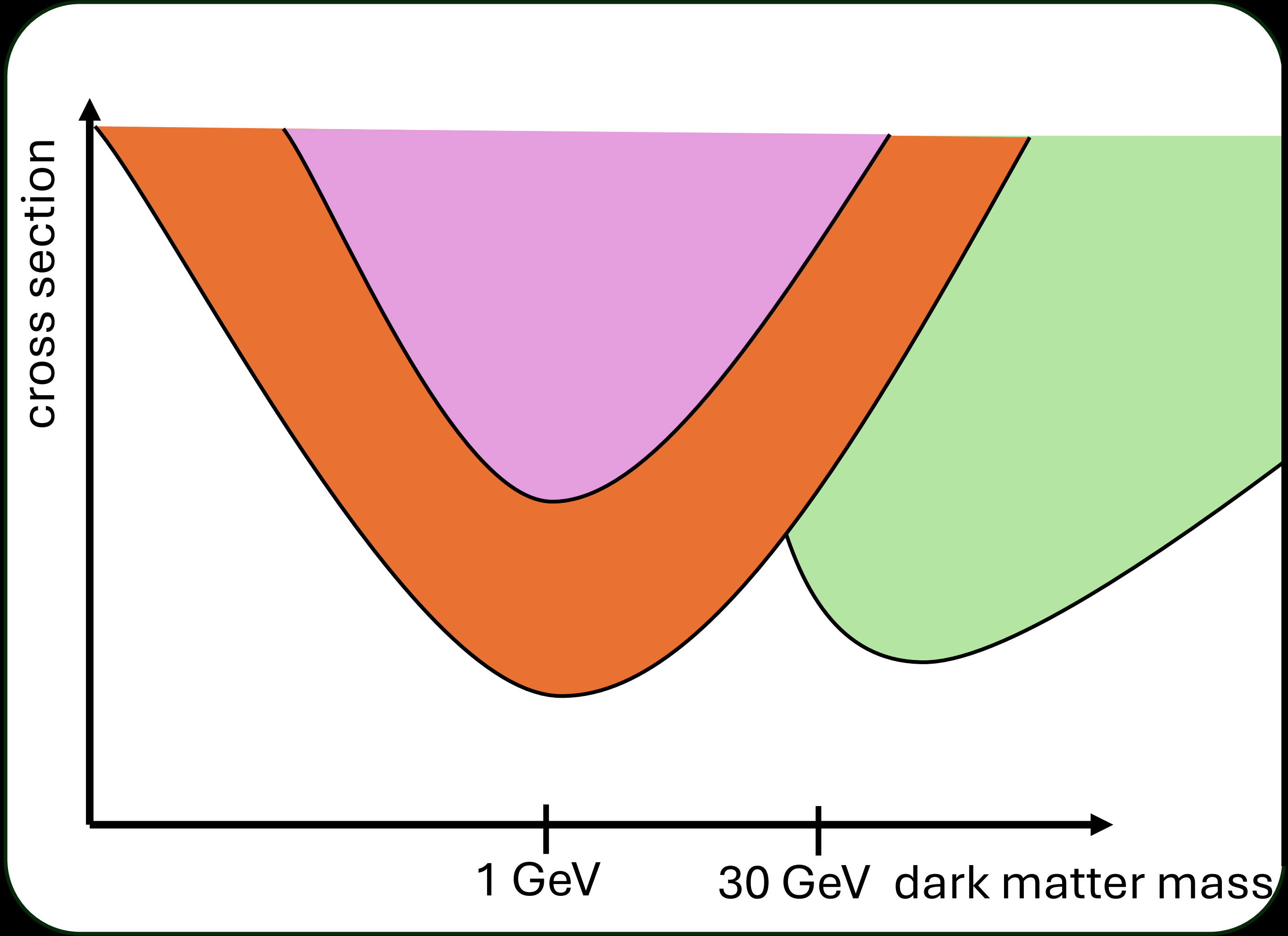


Results: spin-dependent proton



Our results vs previous constraints

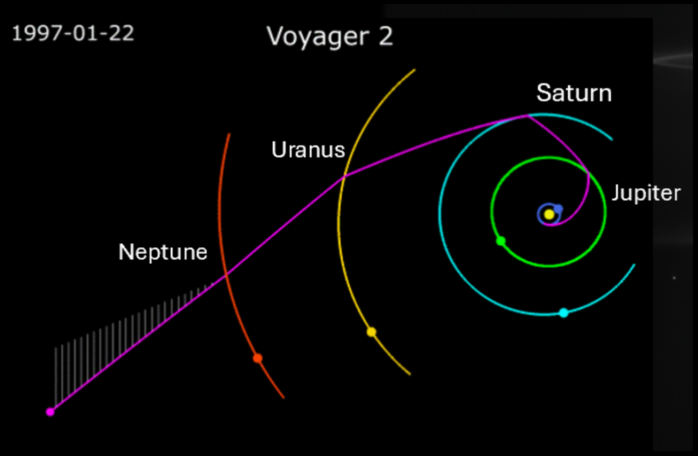
- Atmospheric cooling by H_3^+ (2312.06758)
- Anomalous heating of the planetary interior (e.g. 0705.4298, 0808.2823, 1909.11683, 2210.01812)
- Limits from the Galactic center



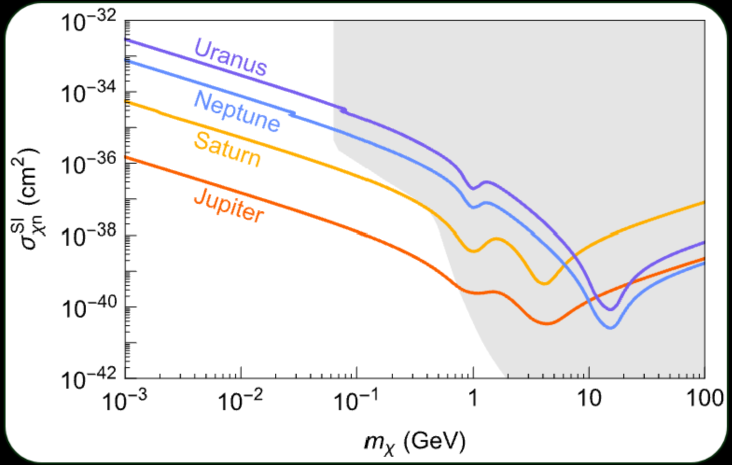
Summary

Signal

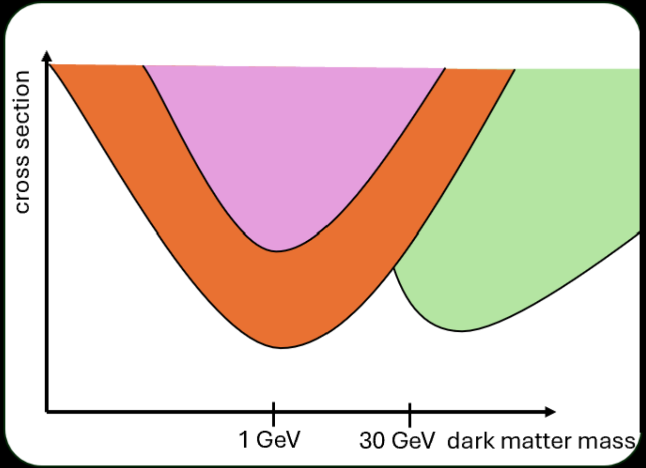
Data



Our constraints

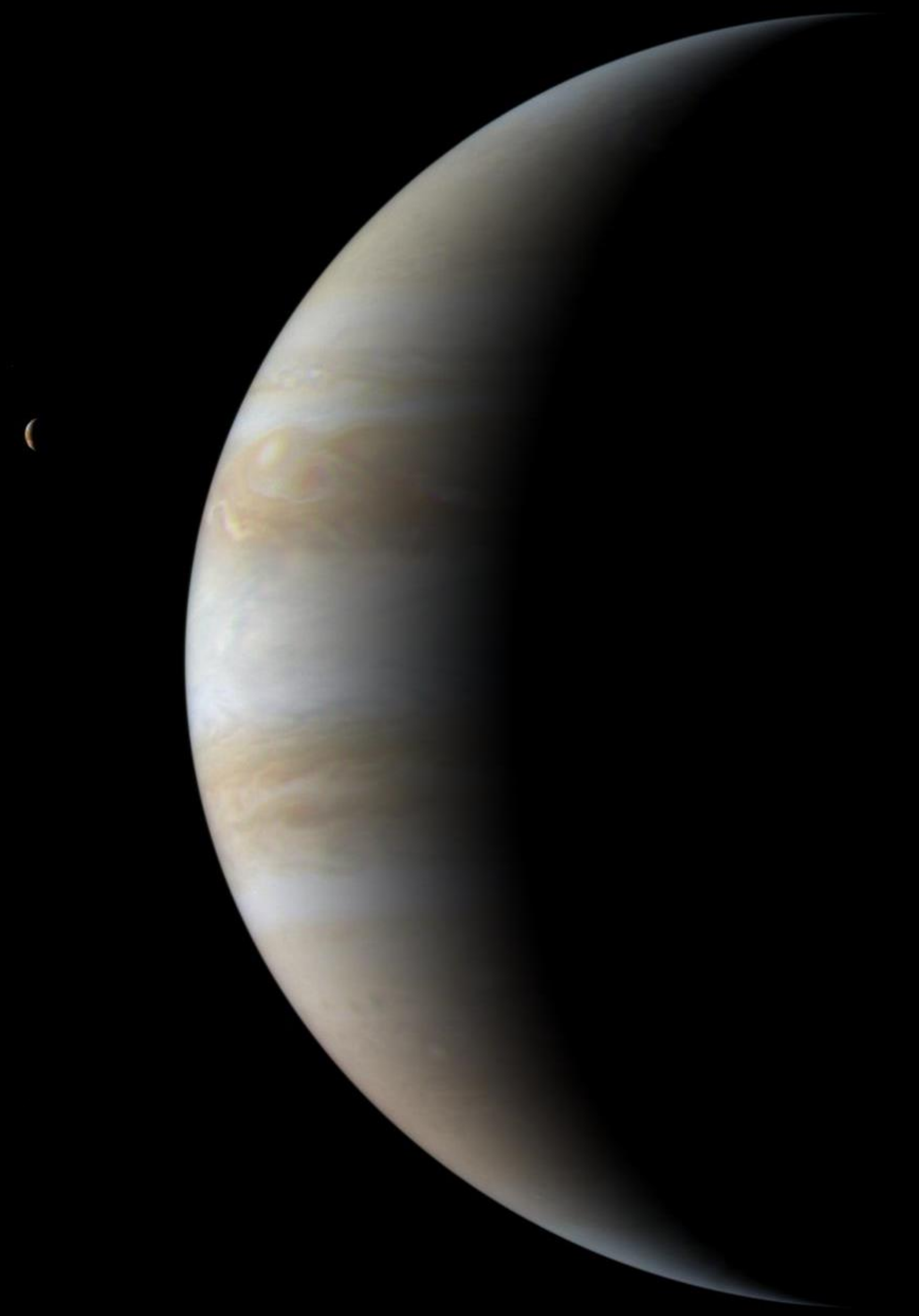


Competing constraints



Summary

UV airglow is a promising ave
to search for dark matter

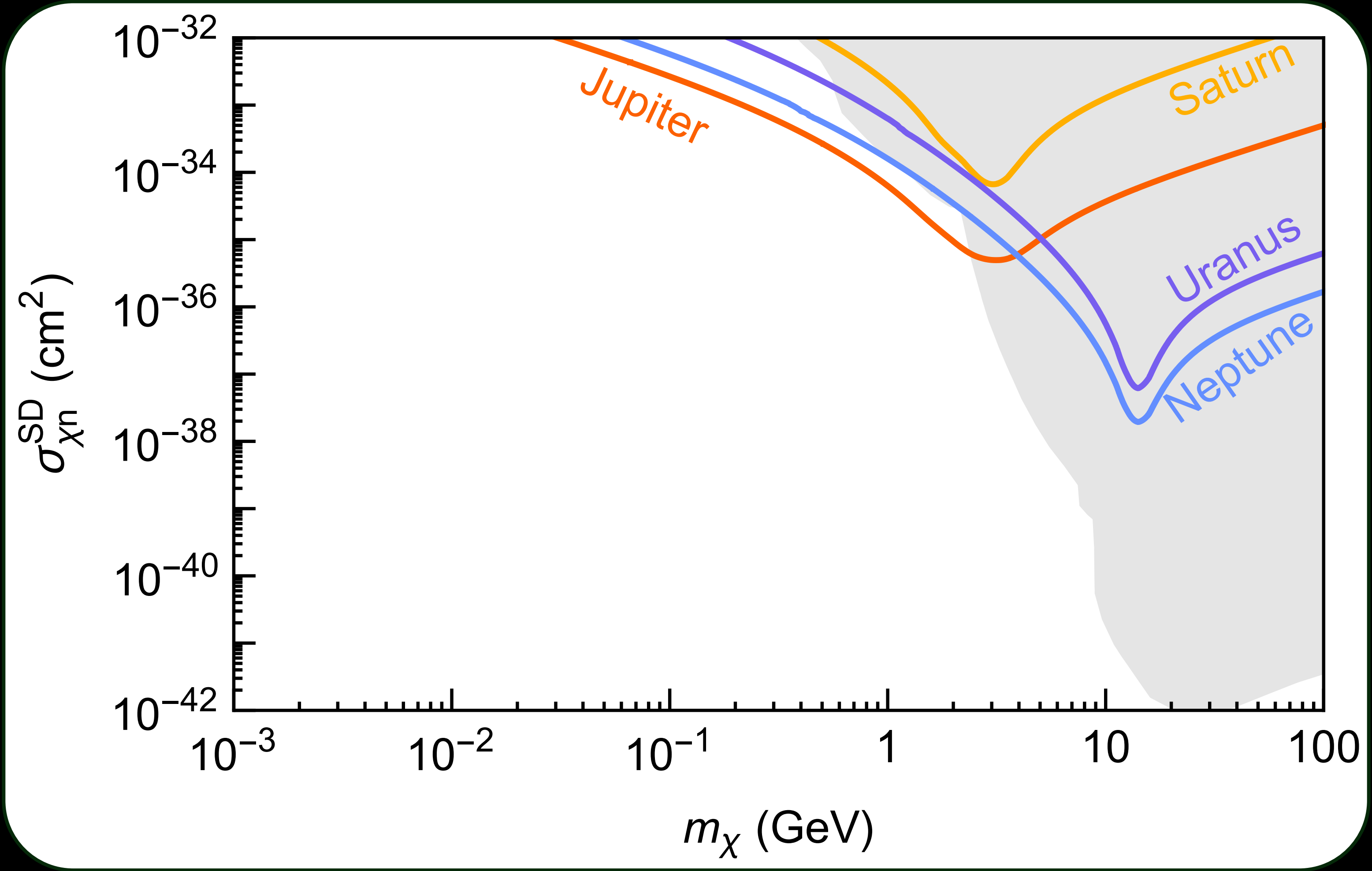


Backup slides

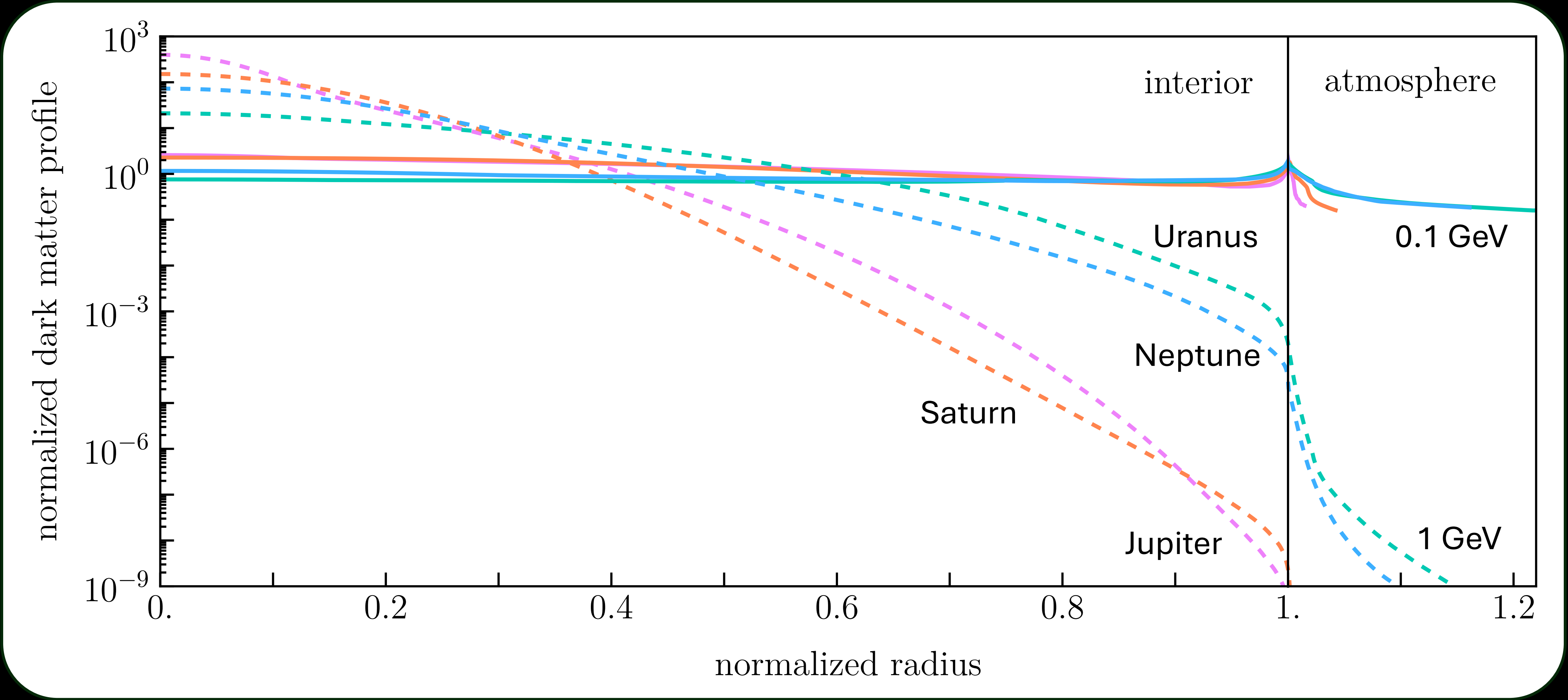
UV airglow values

Planet	$P_{observed}^{airglow}$ (μW/m²)	Space probe
Jupiter	$0.31^{+0.19}_{-0.15}$	New Horizons
Saturn	<1	Voyager 1
Uranus	4.6	Voyager 2
Neptune	1.9 ± 0.3	Voyager 2

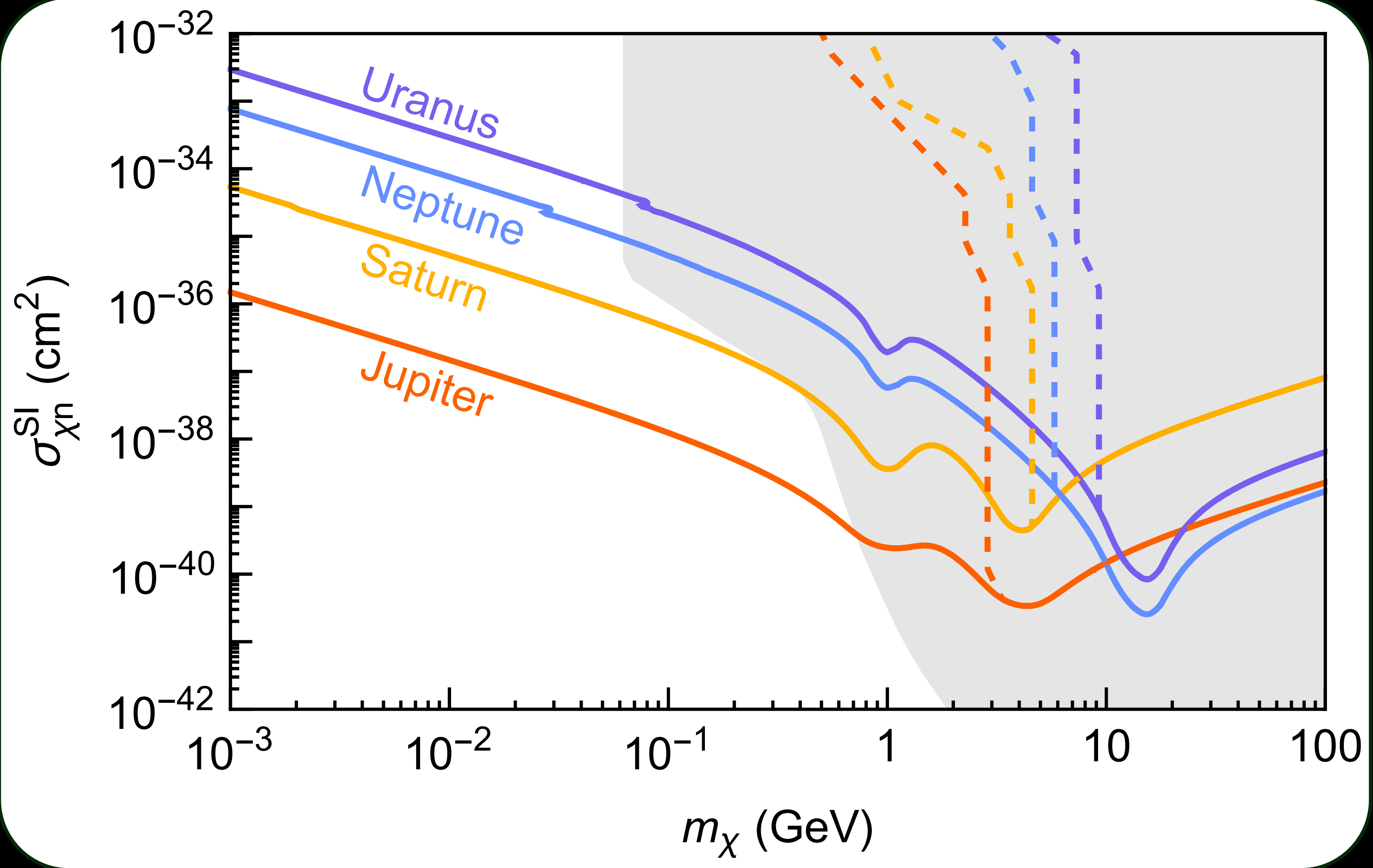
Results: spin-dependent neutron



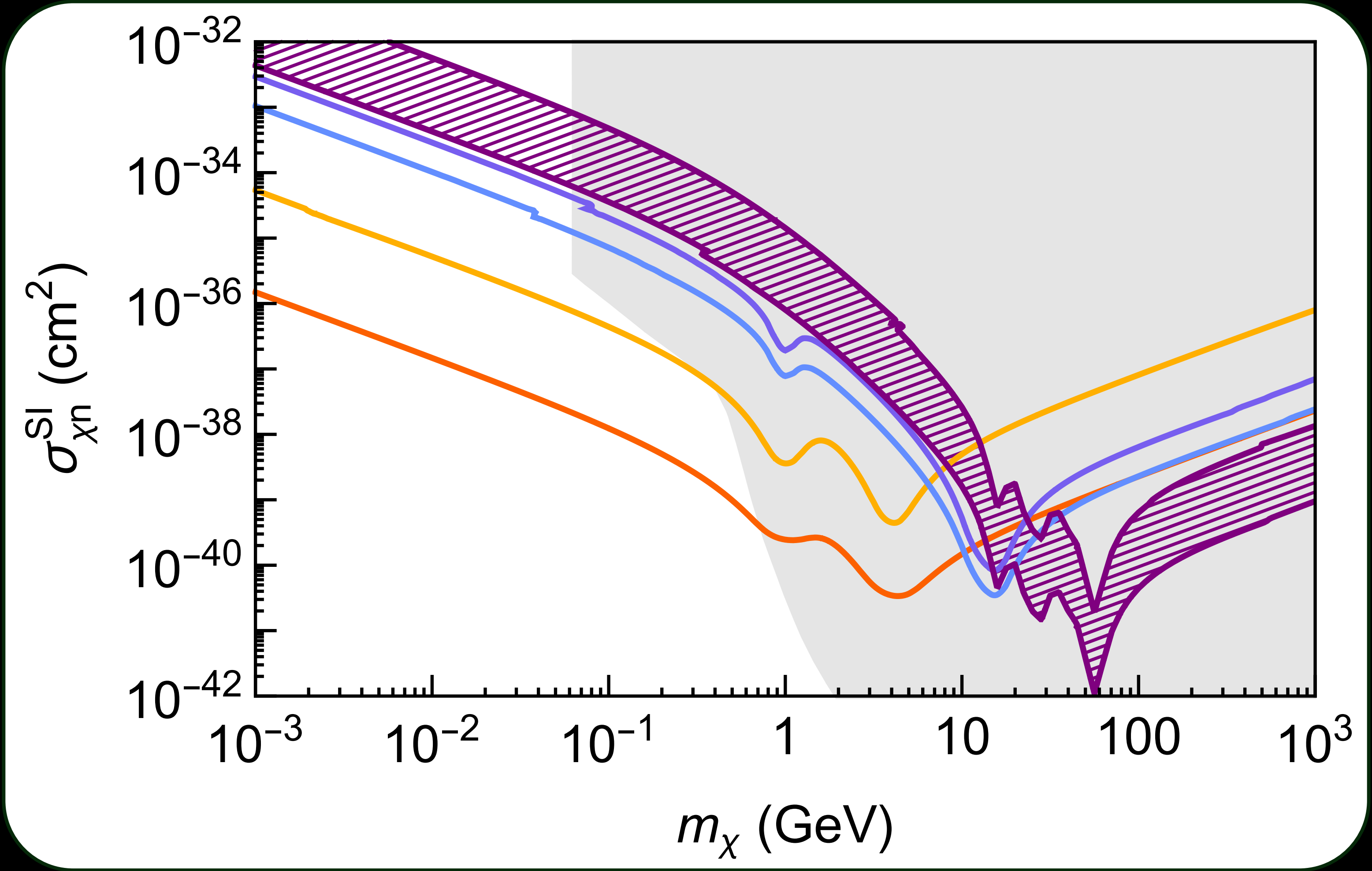
Preliminary results: dark matter radial profile



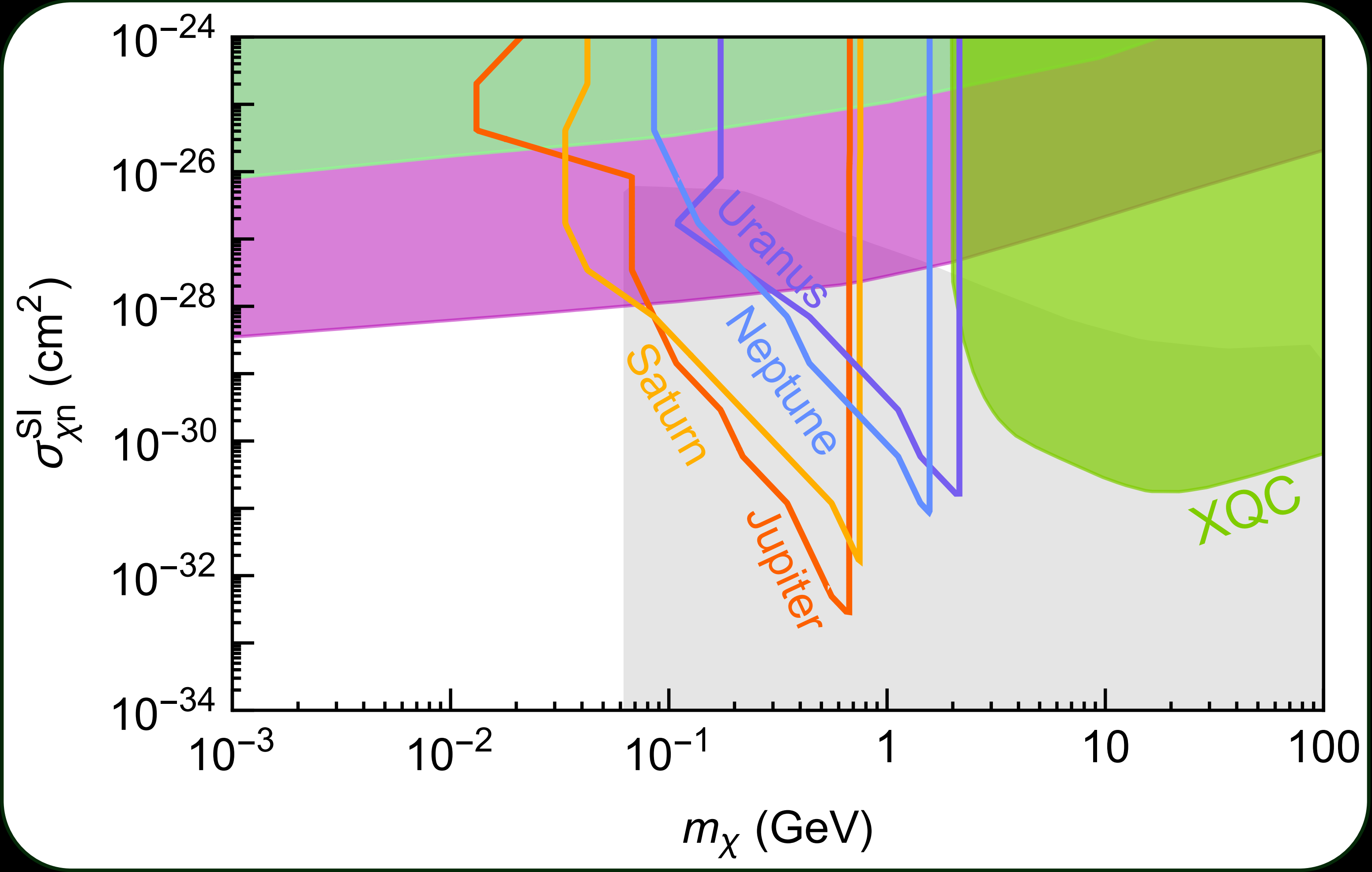
Preliminary results: evaporation



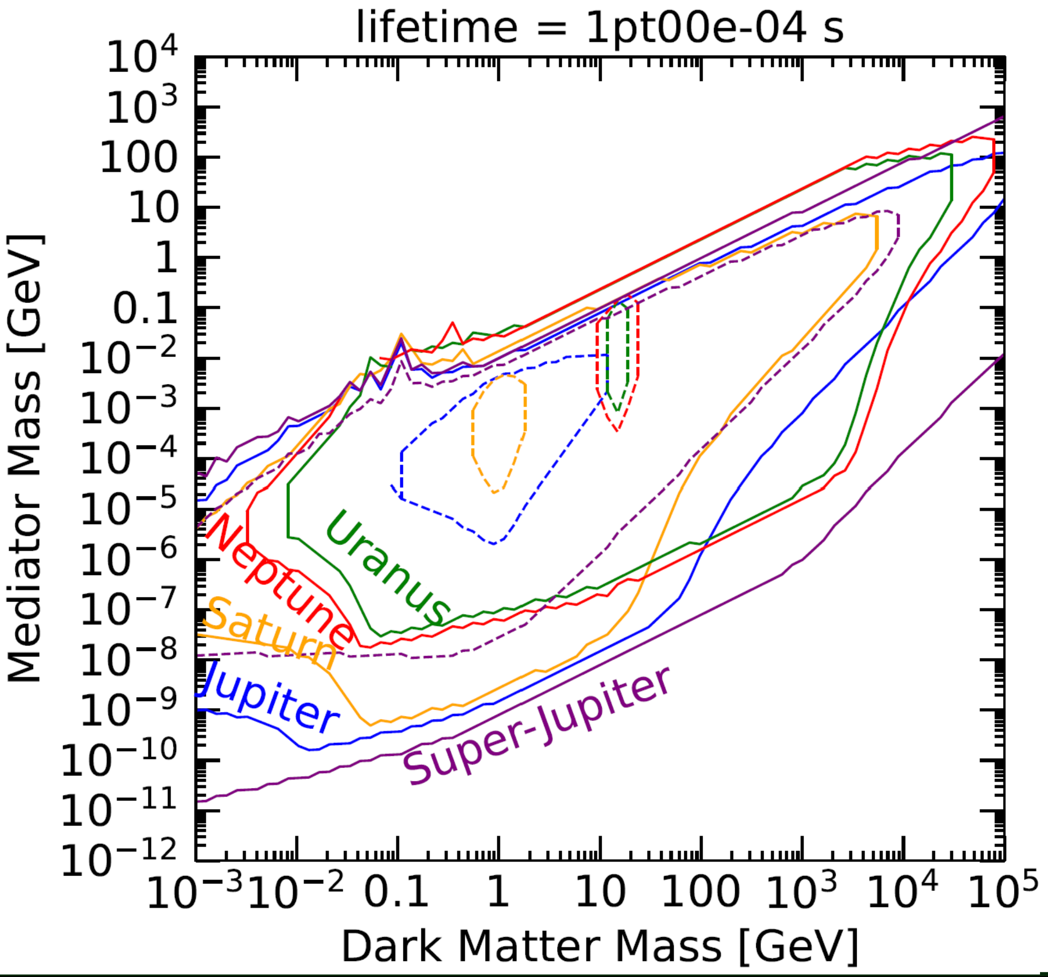
Preliminary results: what about Earth?



Preliminary results: heavy mediator annihilation

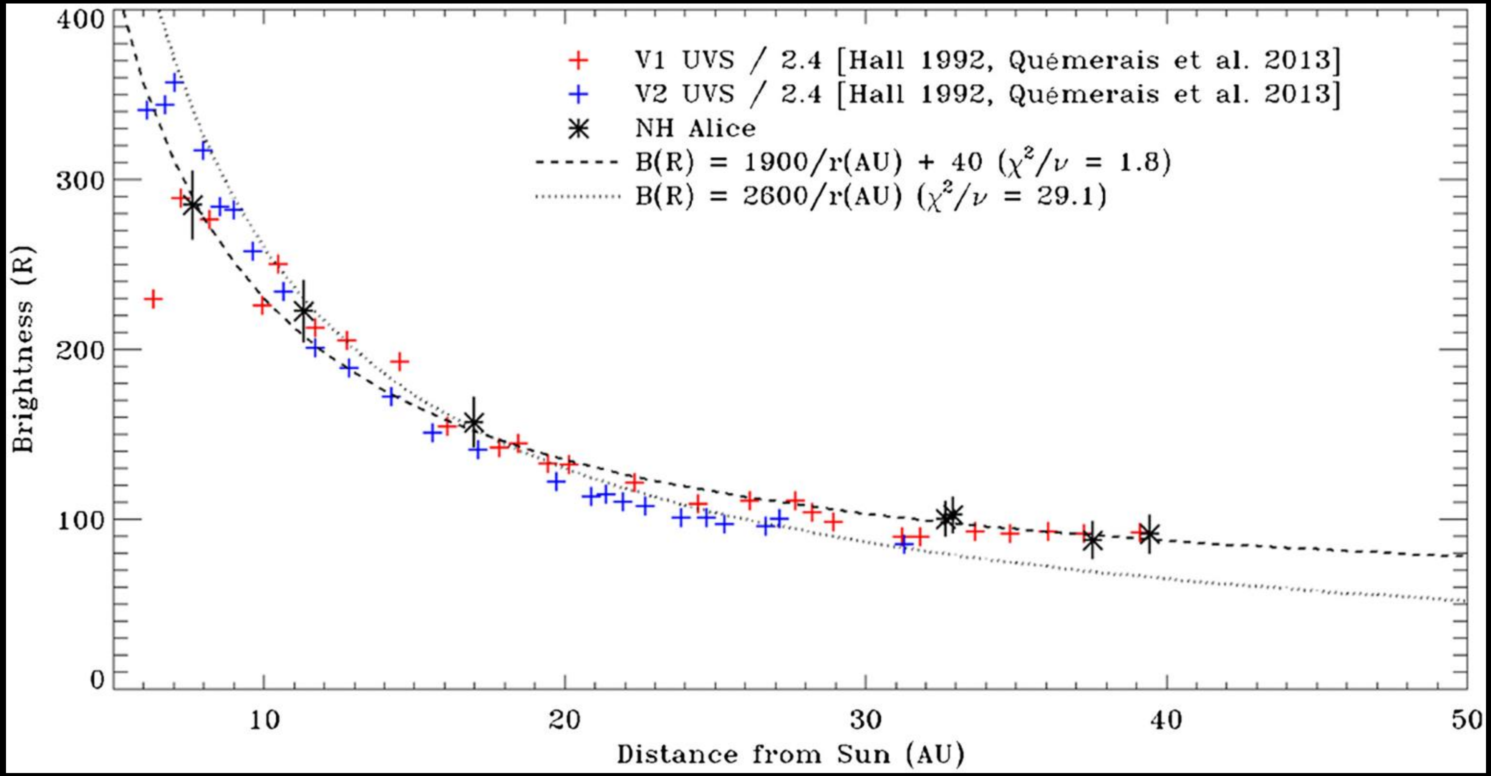


Preliminary results: light mediator annihilation



Why not Lyman-alpha?

Non-negligible background on the nightside due to the interplanetary medium



Gladstone *et al.*, GRL 2018