

# Probing dark matter annihilation through planetary airglow and internal heat flow

Marianne Moore

2408.15318 *Search for dark matter induced airglow in planetary atmospheres*

25XX.XXXXX *Complementary planetary spectroscopy probes of dark matter*

with Carlos Blanco, Rebecca Leane, and Joshua Tong

July 15, 2025



Fonds  
de recherche

Québec



# Outline

A person is silhouetted against a vibrant, multi-colored view of the Milky Way galaxy in a dark night sky. The galaxy's core is bright yellow and orange, transitioning through green and blue to a deep purple and pink at the top. The person stands on a dark, rocky ridge in the foreground, looking up at the starry expanse.

Signatures of accumulated dark matter

Ultraviolet airglow

Dark matter-induced airglow

Capture-annihilation equilibrium

Fraction of annihilation energy

Internal heat flow

Summary

# Why consider planets?

Planets are ...

less massive



smaller



colder



... than stars

# Signatures of accumulated dark matter

## Asymmetric (scattering)

- Thermal conduction  
(Spergel+Press 1985 and others)
- Formation of a black hole at the core  
(Goldman+Nussinov 1989 and others)
- Upscattering  
(McKeen, MM+ 2022 and others)

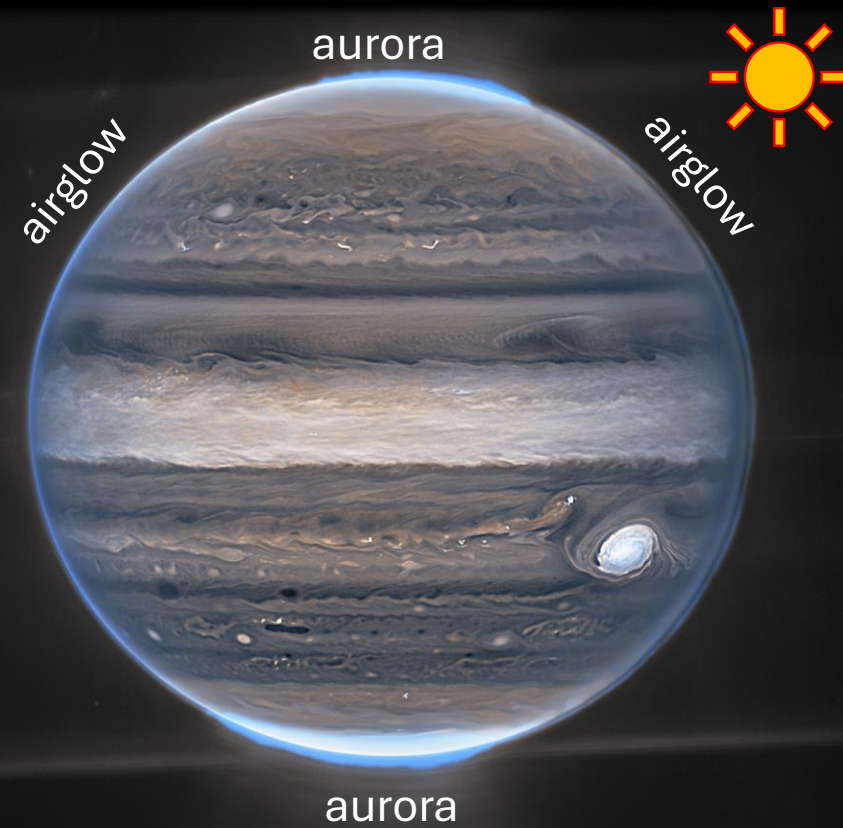
# Signatures of accumulated dark matter

## Symmetric (annihilation)

- to neutrinos: visible with SK, IceCube  
(Griest+Seckel 1987 and others)
- to visible particles that
  - do not escape: heating (and melting!)  
(Kawasaki 1991 and others)
  - escape:
    - $\gamma$ -rays (Leane+Linden 2021)
    - electrons (Li+Fan 2022)
  - almost escape: airglow

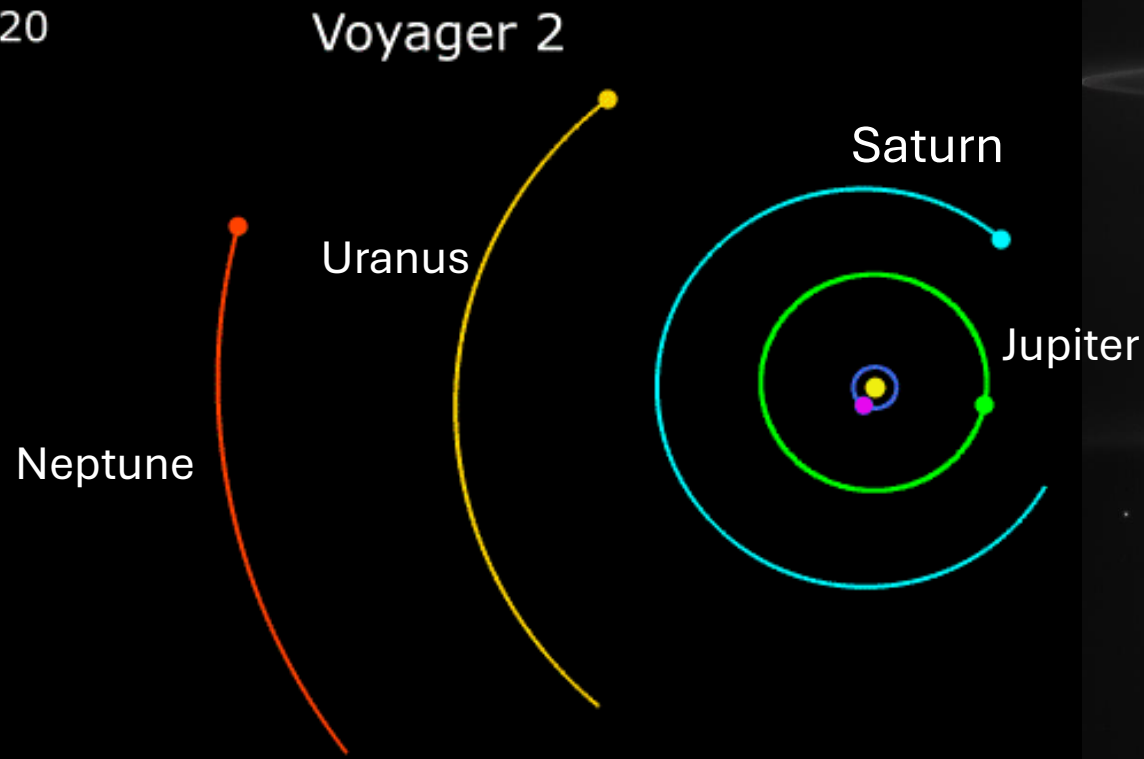
# Ultraviolet airglow

- 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  $\Leftrightarrow$  input electron power



# Ultraviolet airglow

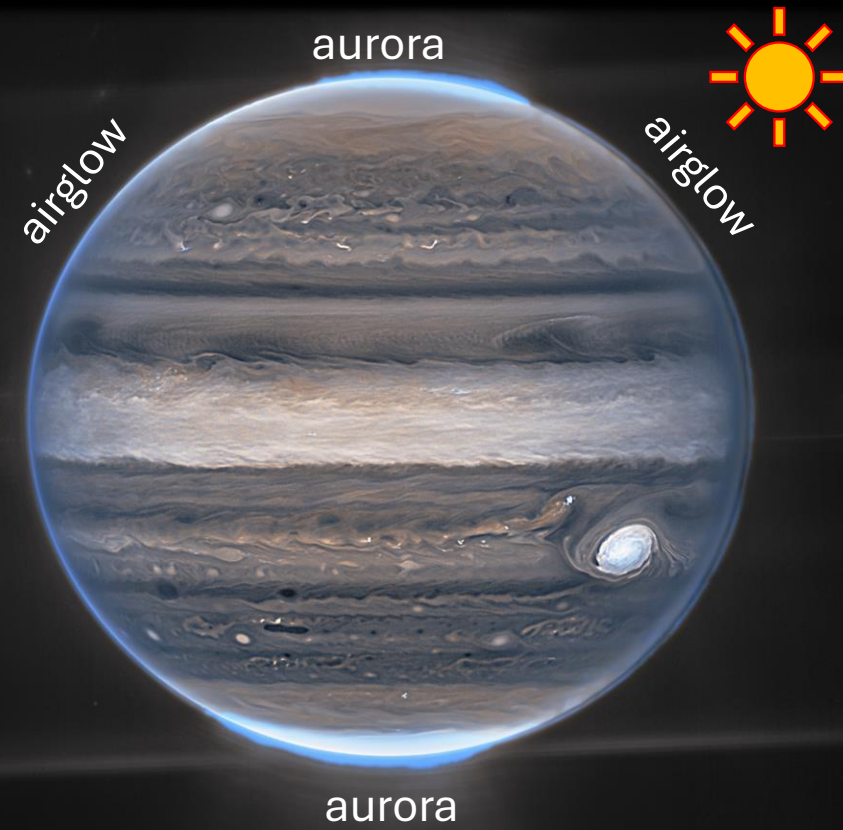
1977-08-20



0.0km/s

4,487,373,409km

Wikipedia



# Earth's precipitating electrons



Marianne Moore (MIT)



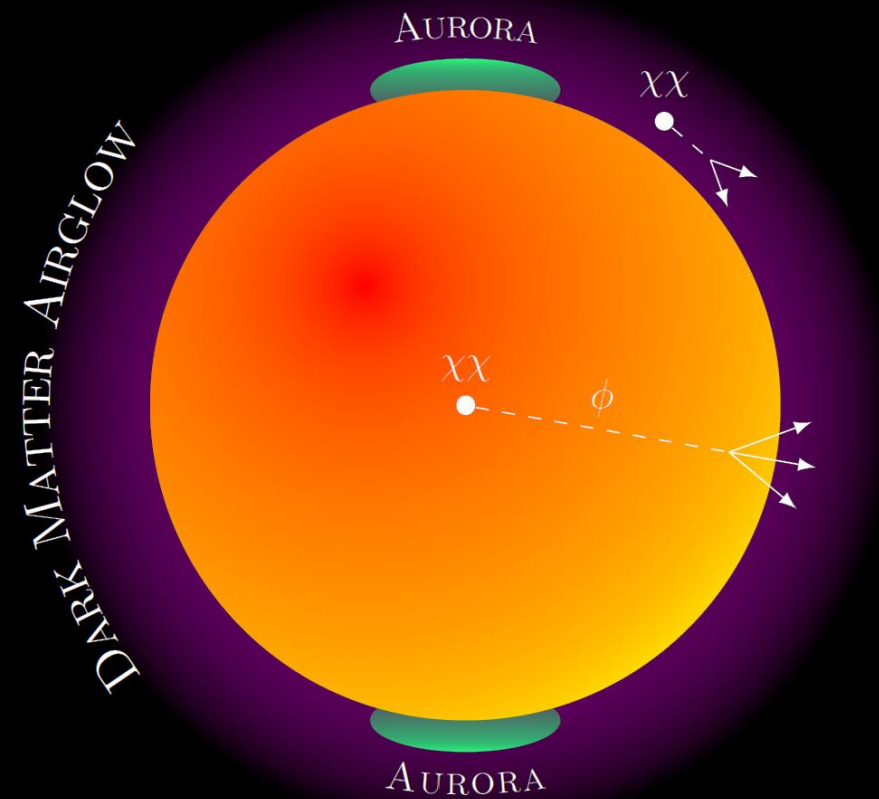
# Dark matter-induced airglow

Assuming

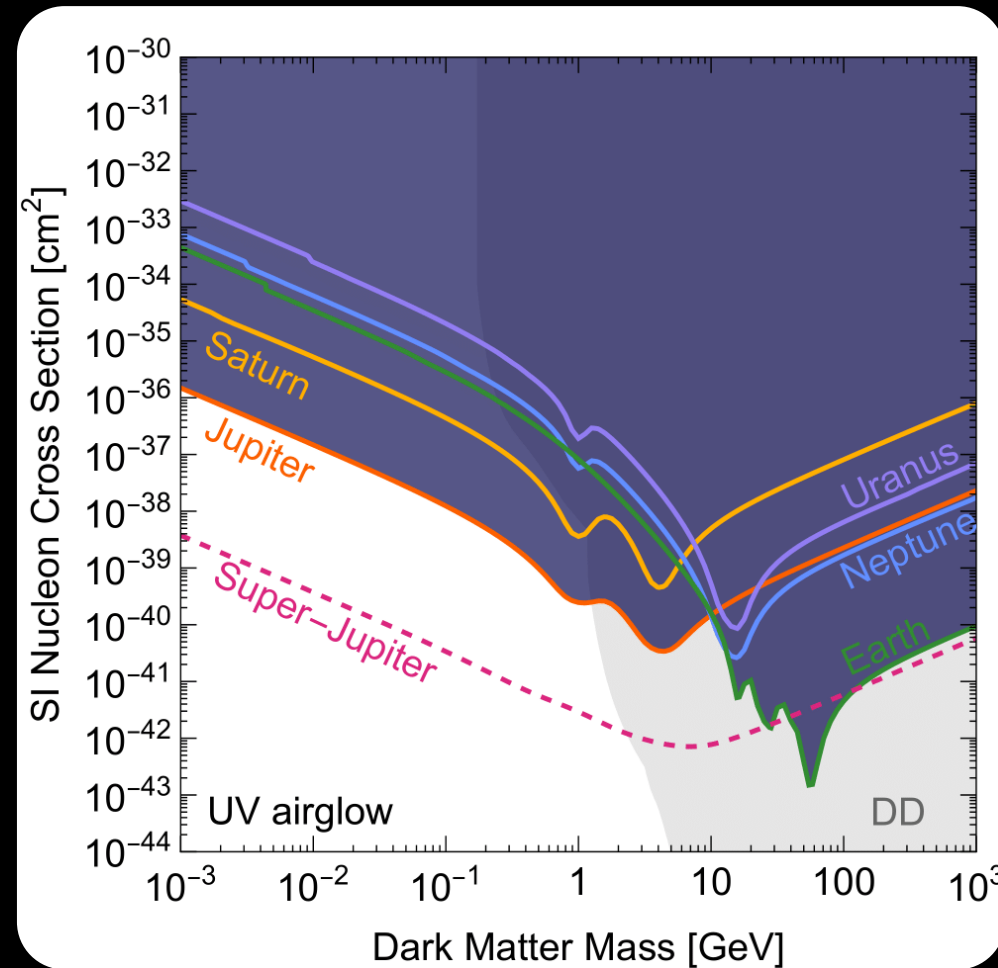
- dark matter annihilates to electrons

$$P_{\text{DM}}^{\text{airglow}} \leq P_{\text{observed}}^{\text{airglow}}$$

- dark matter annihilates to other final states
  - The limit is reduced by a factor of a few



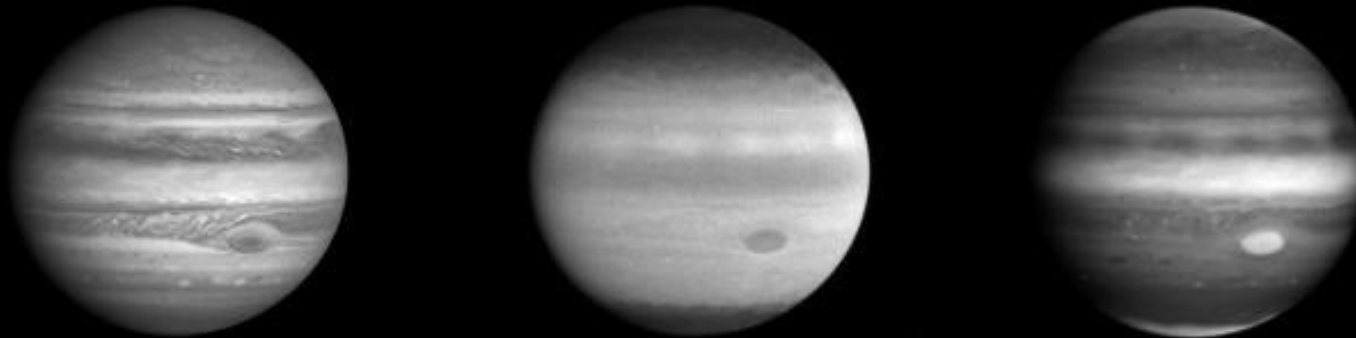
# Parameter space ruled out from non-observation of dark matter airglow



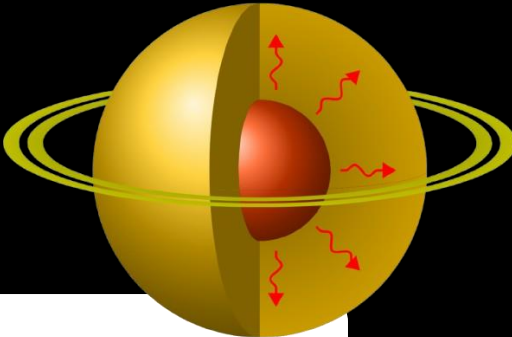
# Internal heat flow of planets

- data from Cassini (Jupiter and Saturn), Voyager (Uranus and Neptune), and boreholes (Earth)

Jupiter in blue, ultraviolet and near infrared



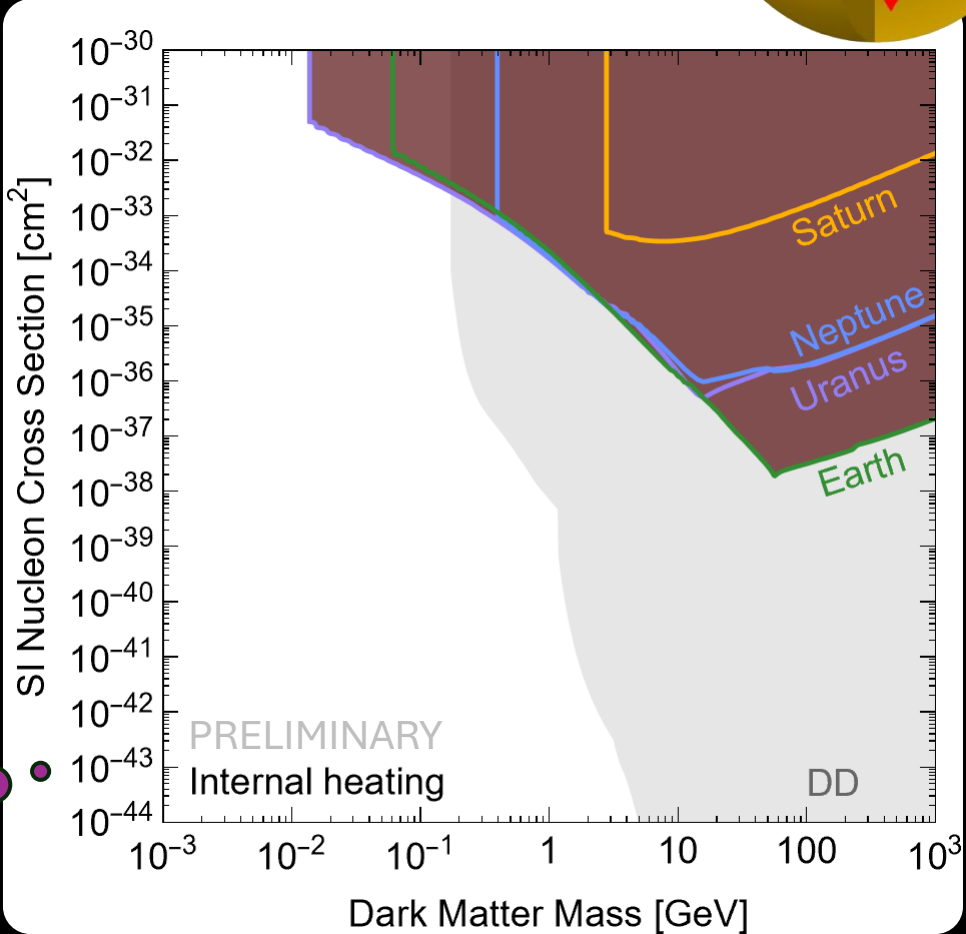
credits: JPL Cassini



# Internal heat flow in planets

- see works by Joe Bramante and others e.g. [0705.4298](#), [0808.2823](#), [1909.11683](#), [2210.01812](#)
- heating power is 4 – 7 orders of magnitude larger than UV airglow

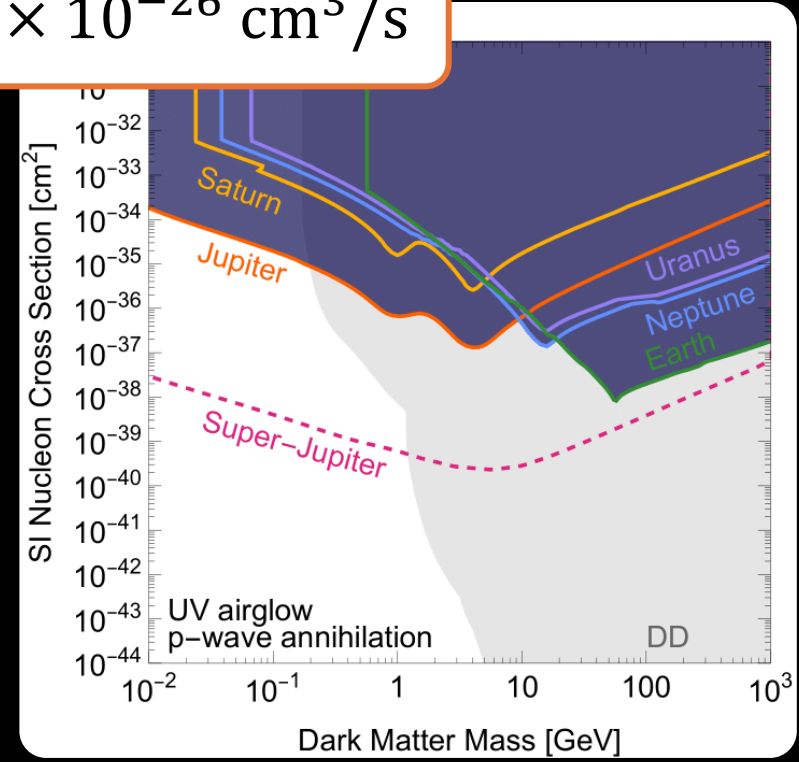
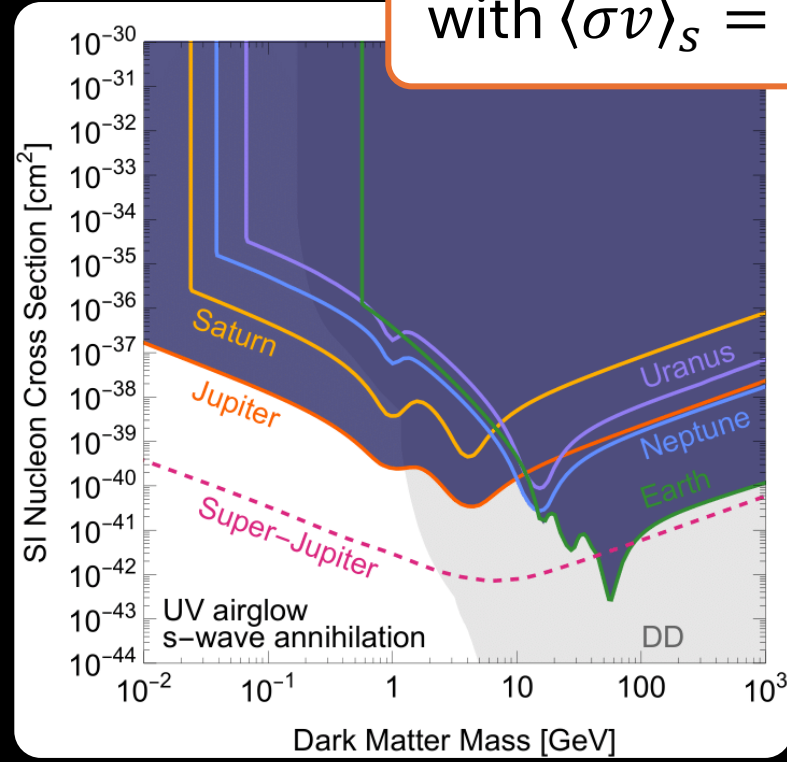
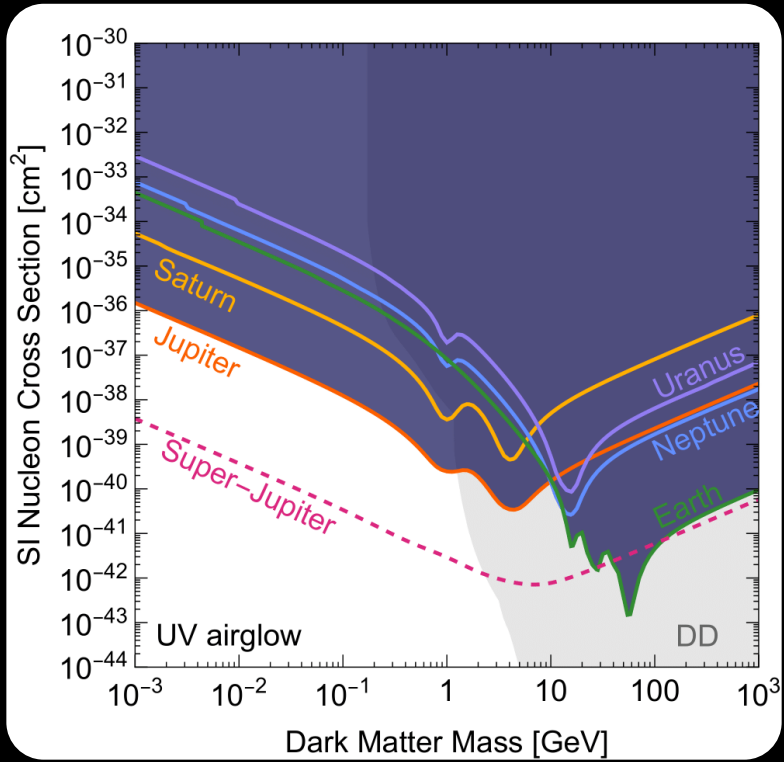
no bound from Jupiter



These constraints assume capture – annihilation equilibrium *has been reached*

# These constraints assume capture – annihilation equilibrium *has been reached*

with  $\langle\sigma v\rangle_s = 3 \times 10^{-26} \text{ cm}^3/\text{s}$

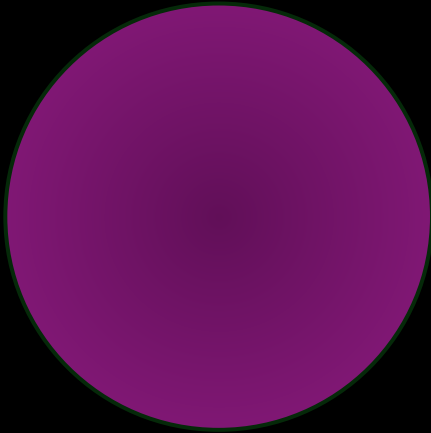


These constraints assume *all* annihilation energy goes into the spectroscopic signature

# Where does dark matter settle in a planet?

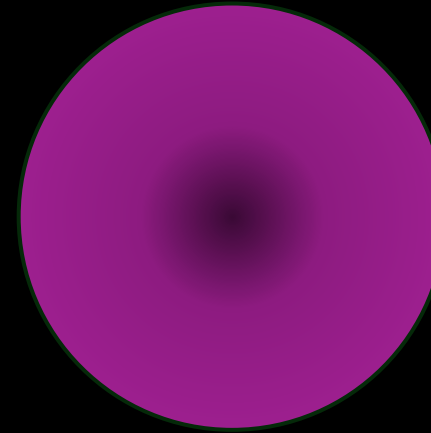
## Light dark matter

- Uniformly distributed in the interior and atmosphere



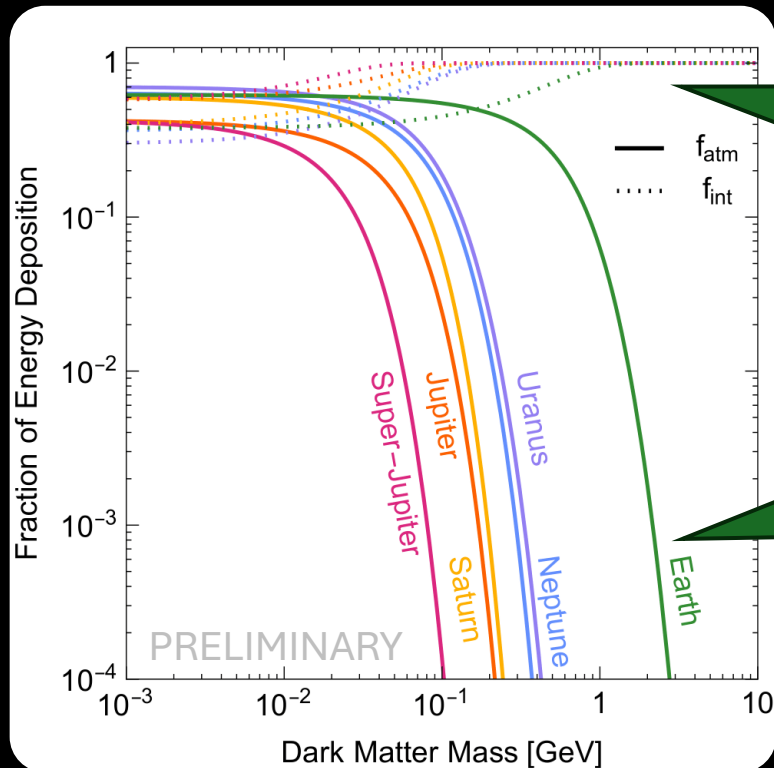
## Heavy dark matter

- Almost exclusively in the core



# ... and inject annihilation energy in a planet?

annihilation through  
a **heavy** mediator

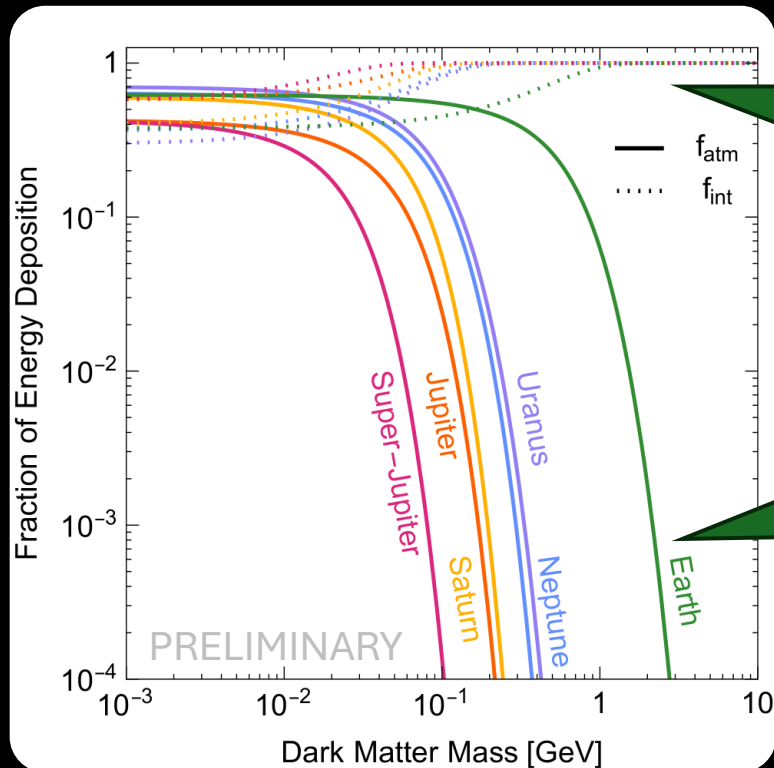


energy deposited in  
the interior

energy deposited in  
the atmosphere

# ... and inject annihilation energy in a planet?

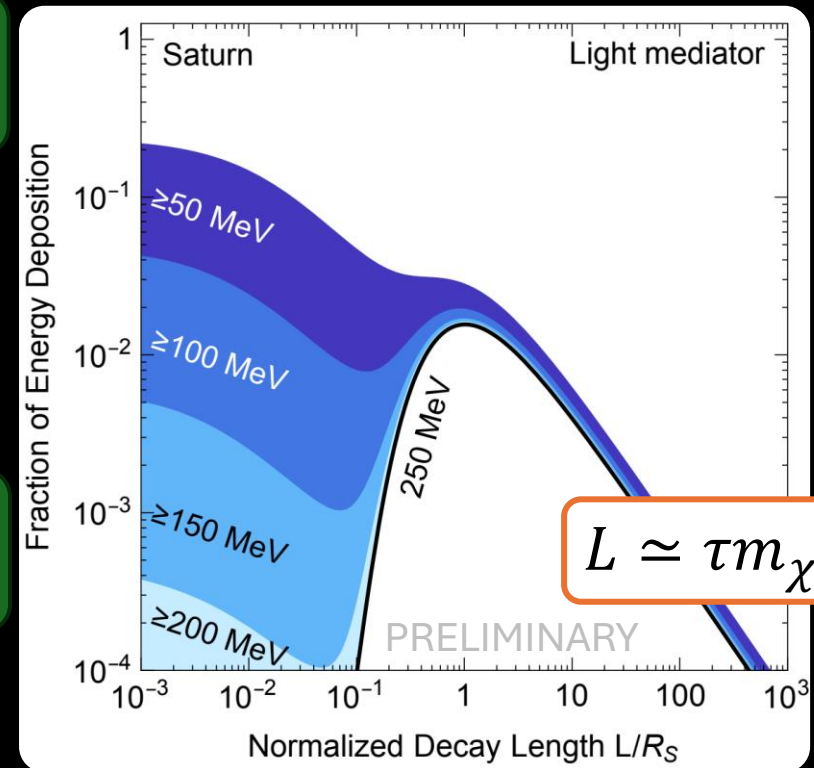
annihilation through  
a **heavy** mediator



energy deposited in  
the interior

energy deposited in  
the atmosphere

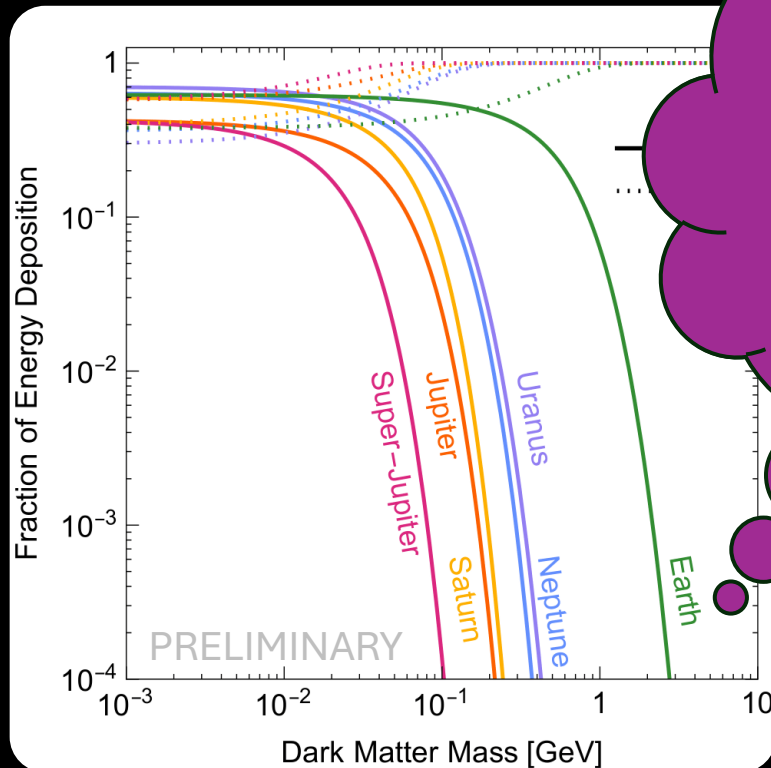
annihilation through  
a **light** mediator



$$L \approx \tau m_\chi / m_\phi$$

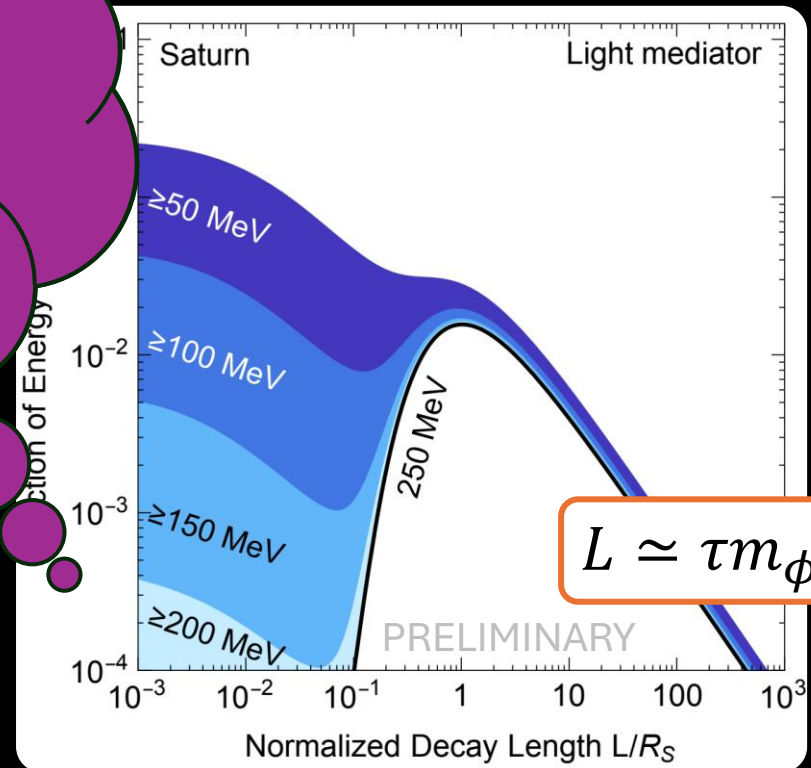
# ... and inject annihilation energy in a planet?

annihilation through  
a **heavy** mediator



non-negligible  
even if the  
atmosphere is  
small compared  
to the planet!

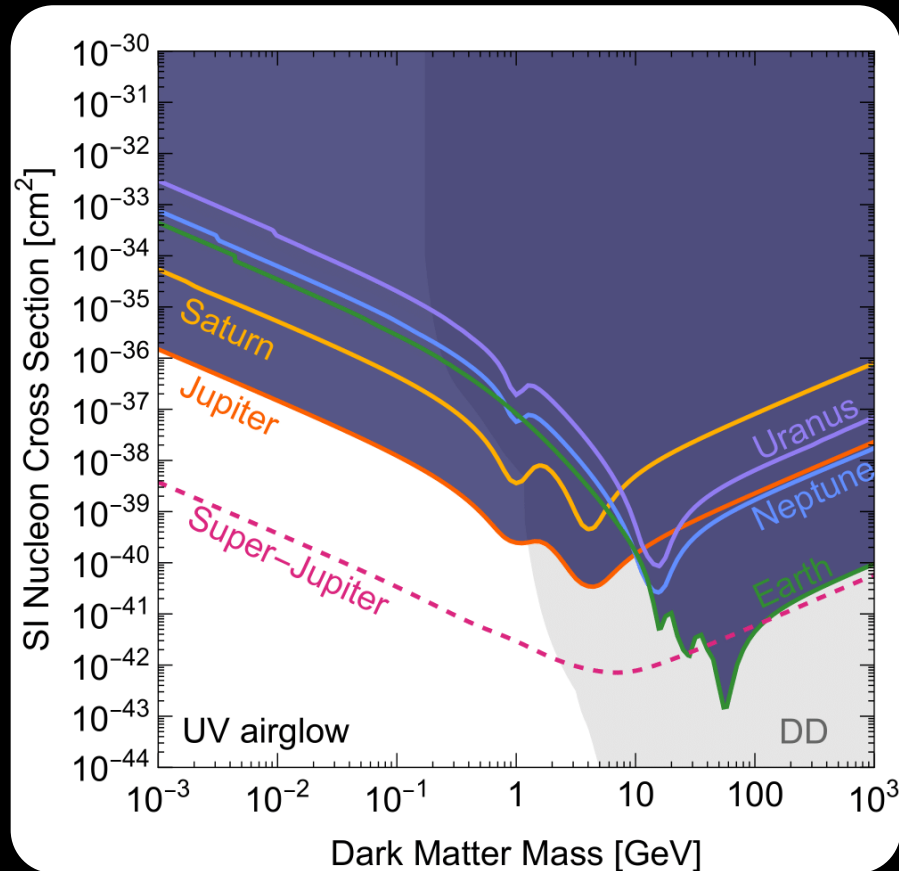
annihilation through  
a **light** mediator



$$L \approx \tau m_\phi / m_\chi$$

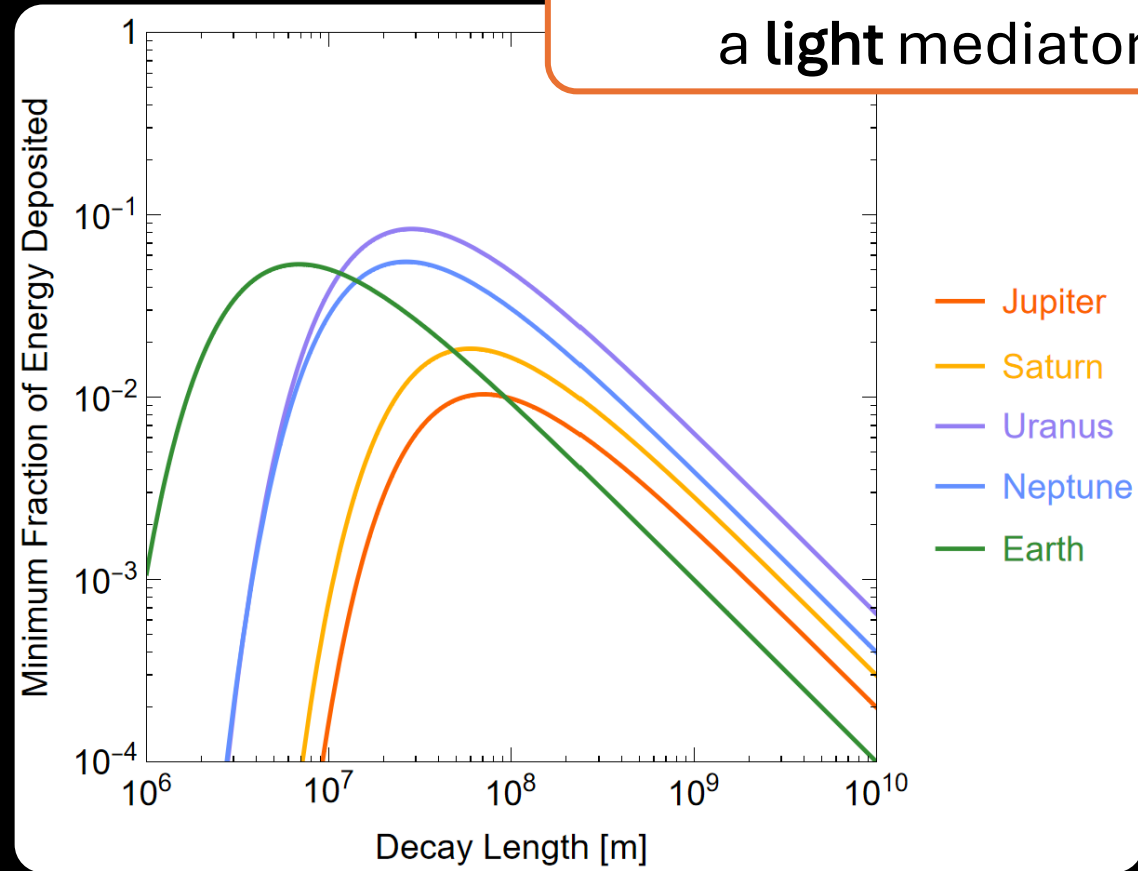
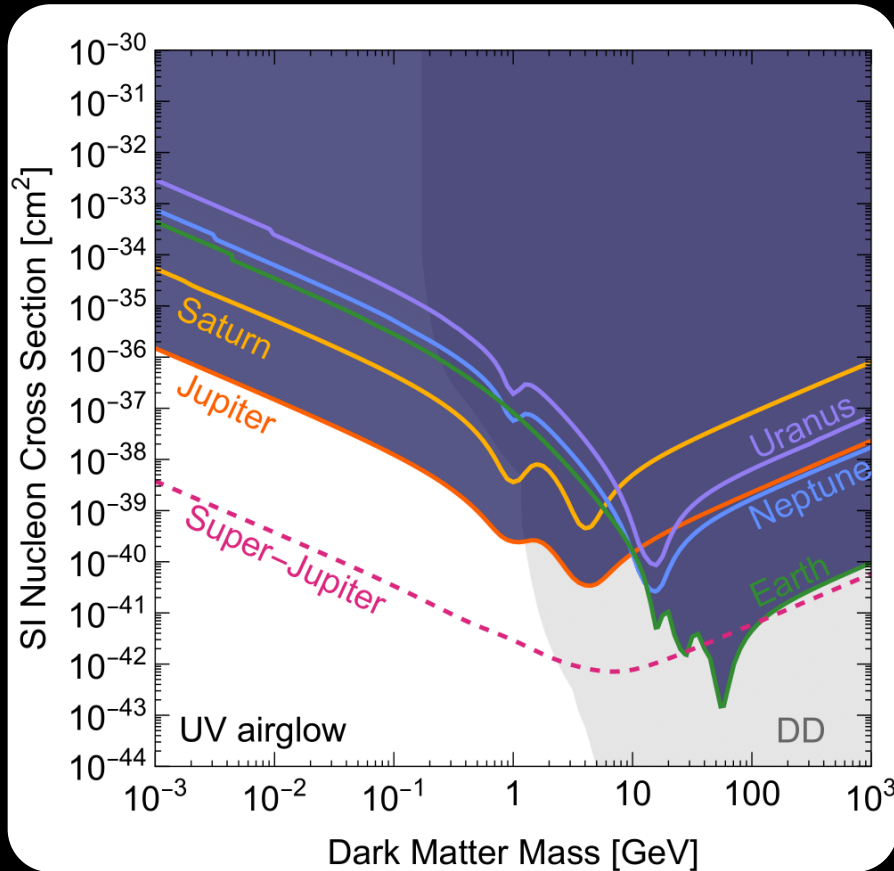
# Why consider multiple planets?

## Why not just Jupiter?



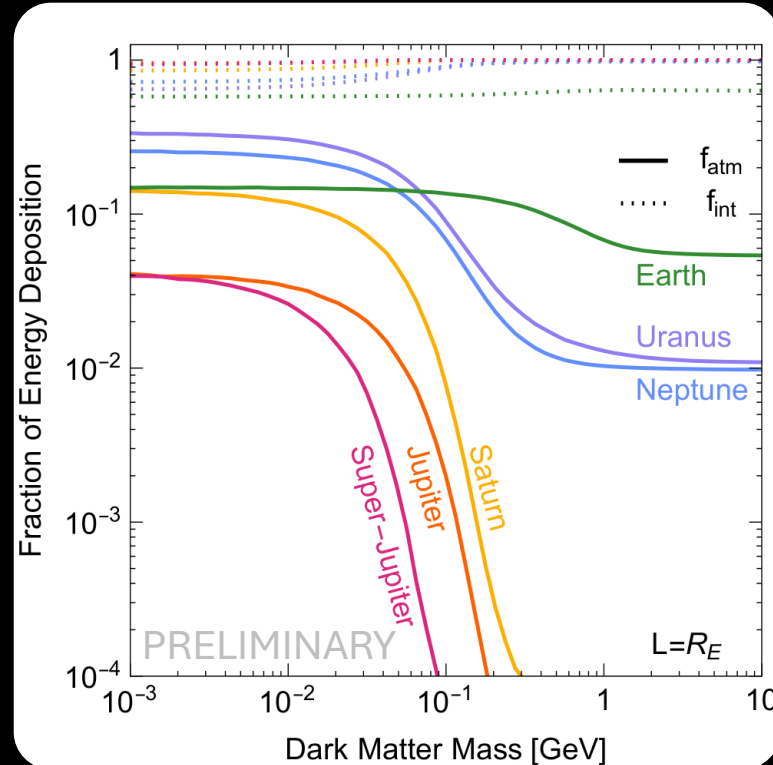
# Why consider multiple planets?

## Why not just Jupiter?



# without assuming annihilation in the core

annihilation through  
a **light** mediator



# Where does dark matter settle in a planet?

## Light dark matter

- Uniformly distributed in the interior and atmosphere

## Heavy dark matter

- Almost exclusively in the core



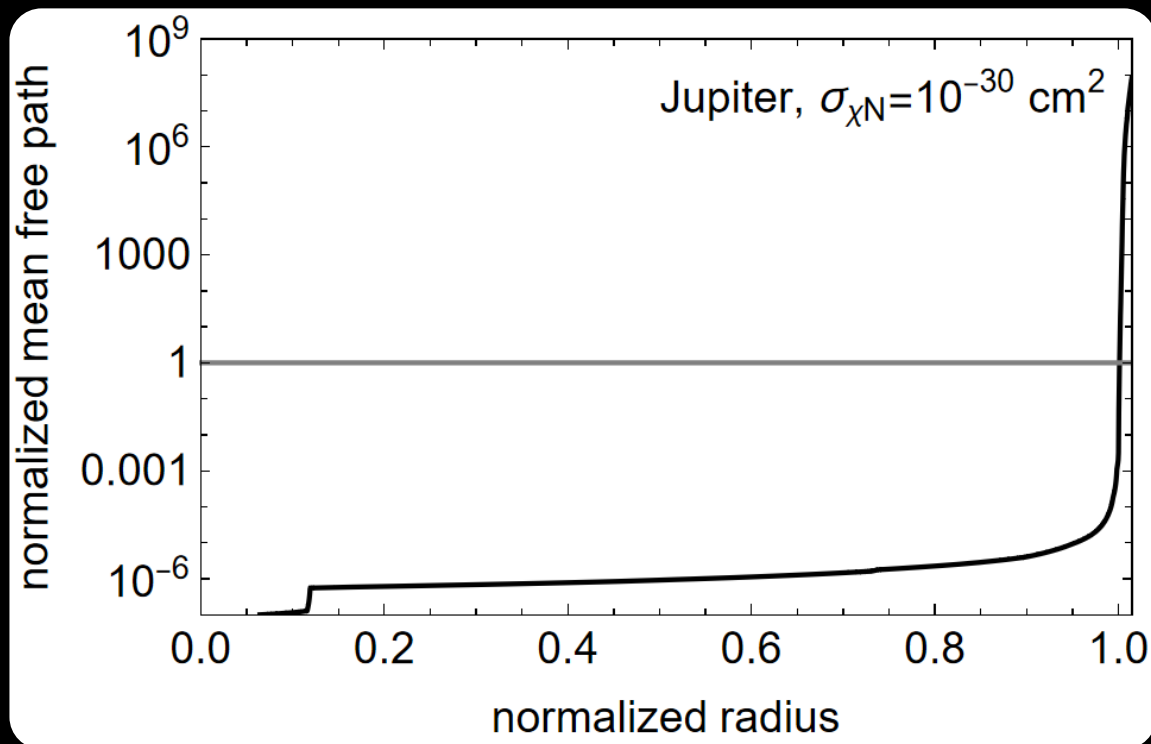
Does it make sense?

# (Loss of) local thermal equilibrium

- Dark matter particles scatter often and share a local temperature with Standard Model particles

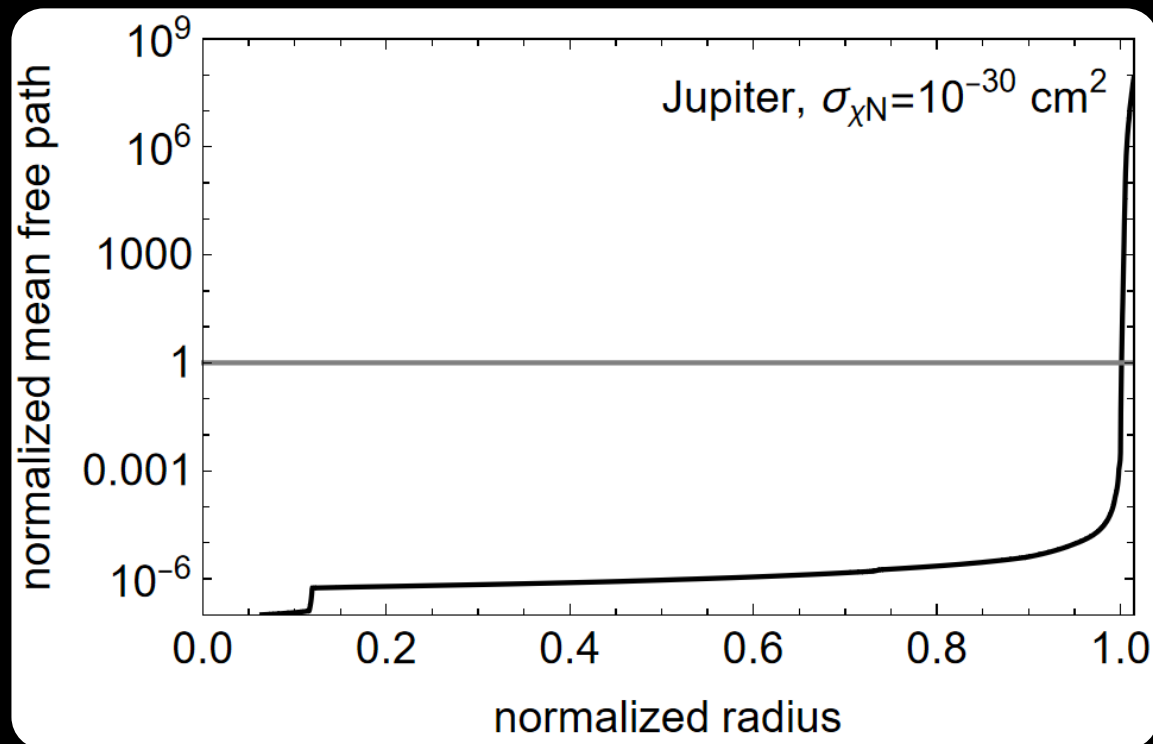
# (Loss of) local thermal equilibrium

- Dark matter particles scatter often and share a local temperature with Standard Model particles



# (Loss of) local thermal equilibrium

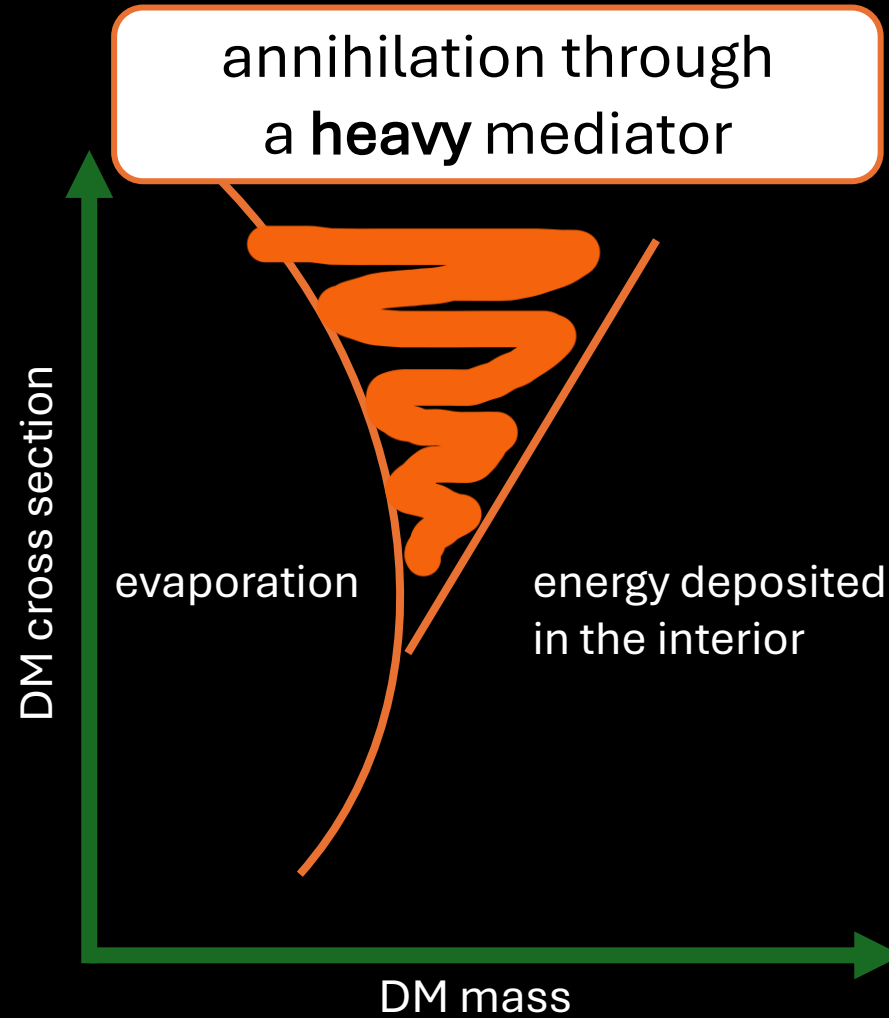
- Dark matter particles scatter often and share a local temperature with Standard Model particles



- Particles can be located outside of the planet while remaining accumulated
- Particles located outside cannot be in local thermal equilibrium

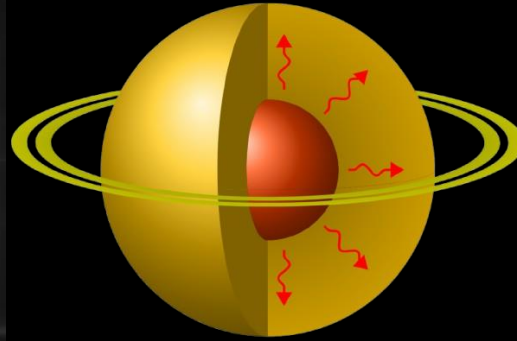
These constraints assume *no* evaporation

# So what's left?



# Summary

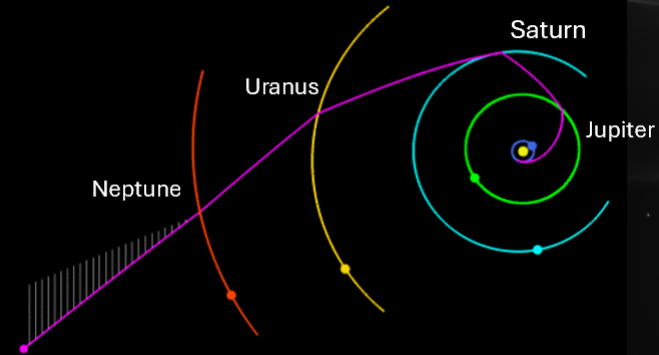
## Signals



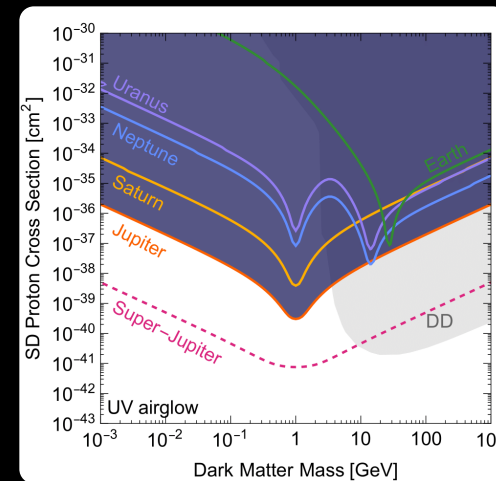
## Data

1997-01-22

Voyager 2



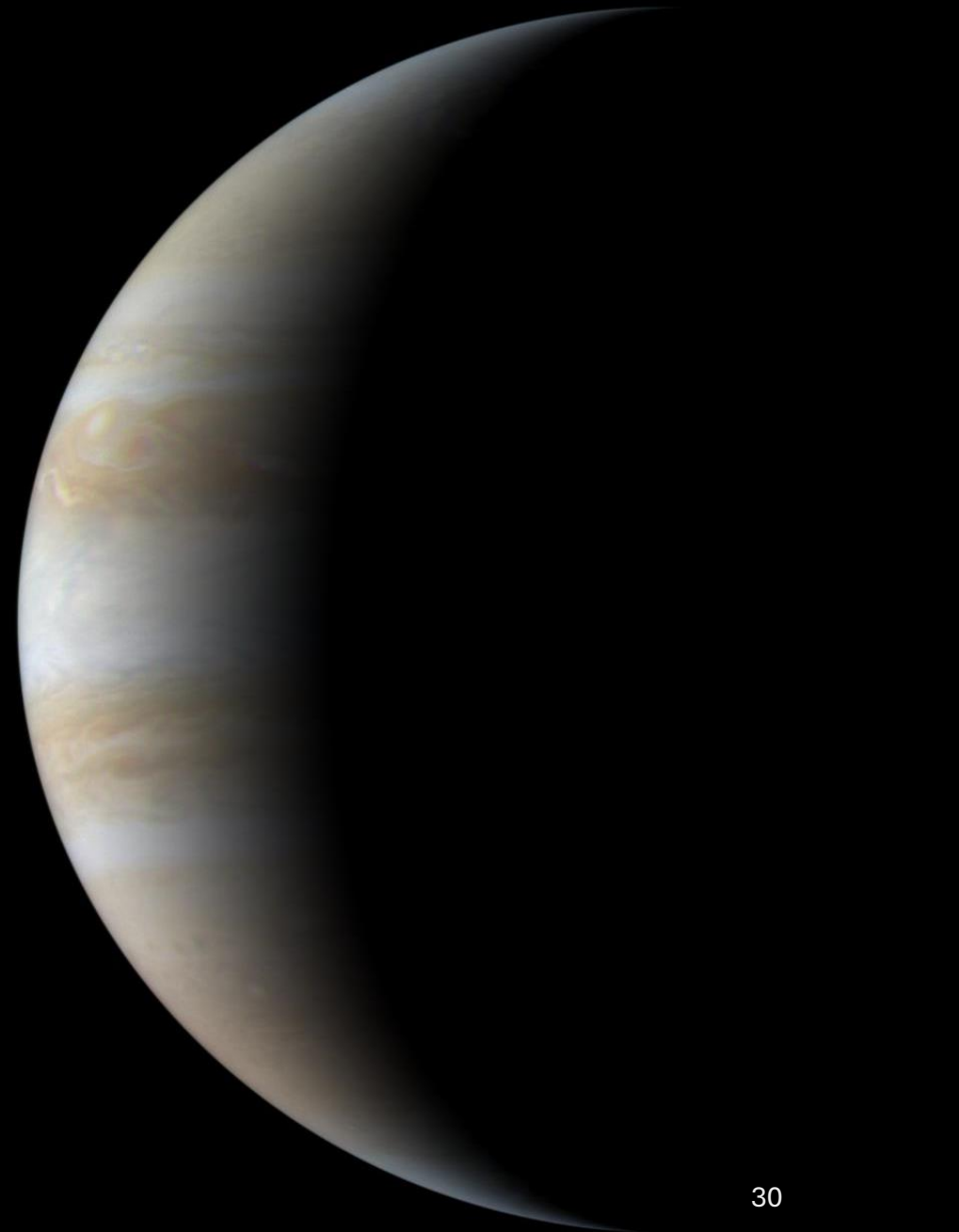
## Our constraints



Marianne Moore (MIT)

# Summary

Planetary spectroscopy is a promising avenue to search for dark matter



Backup slides

# UV airglow values

Planet	$P_{\text{observed}}^{\text{airglow}}$ ( $\mu\text{W}/\text{m}^2$ )	Space probe
Jupiter	$0.31^{+0.19}_{-0.15}$	New Horizons
Saturn	<1	Voyager 1
Uranus	4.6	Voyager 2
Neptune	$1.9 \pm 0.3$	Voyager 2
Earth	0.05	AMS, CubeSats

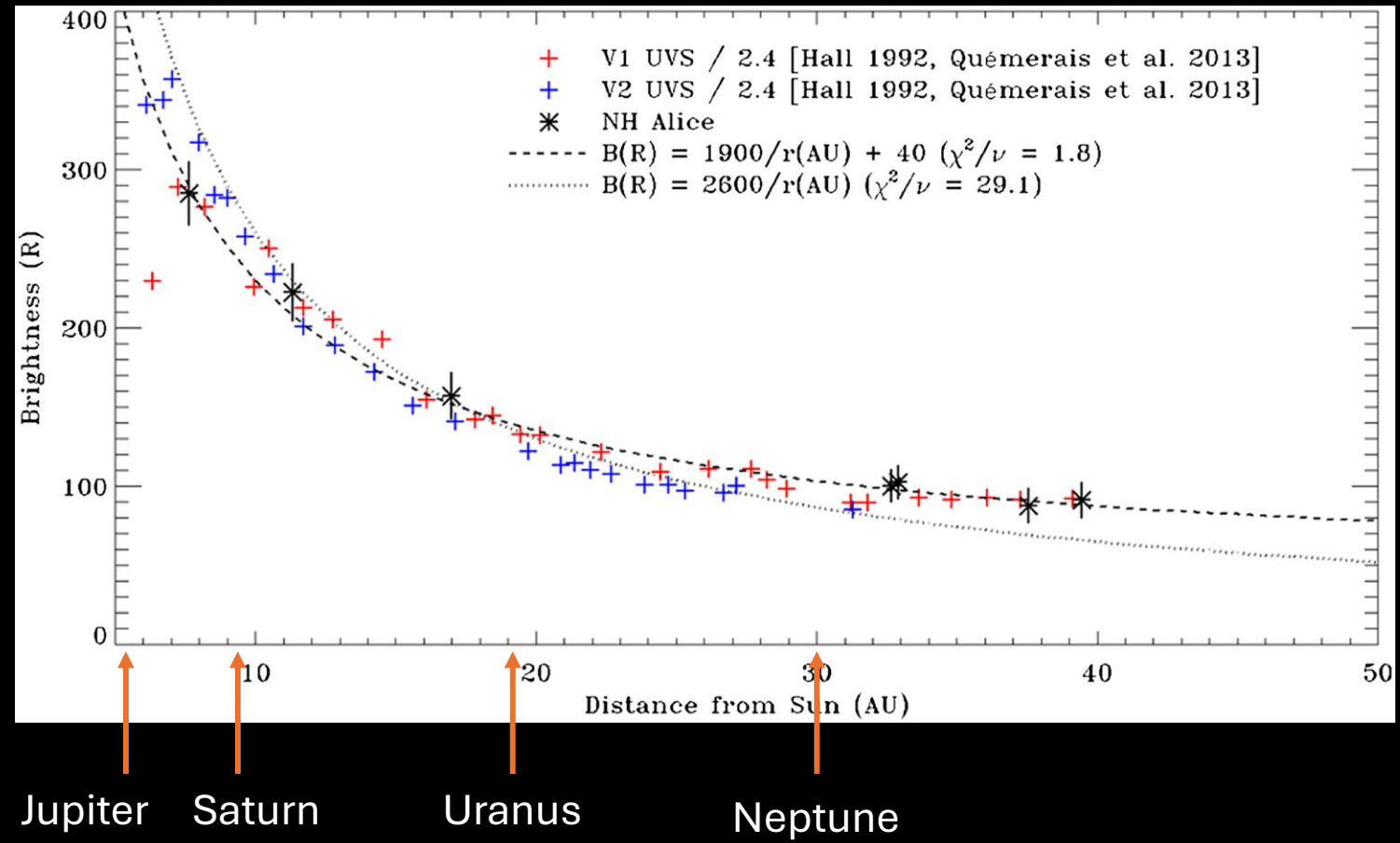
Planet	$P_{\text{observed}}^{\text{heating}}$ ( $\text{W}/\text{m}^2$ )	Space probe
Jupiter	7	Cassini
Saturn	3	Cassini
Uranus	0.04	Voyager 2
Neptune	0.4	Voyager 2
Earth	0.09	boreholes

# heating values

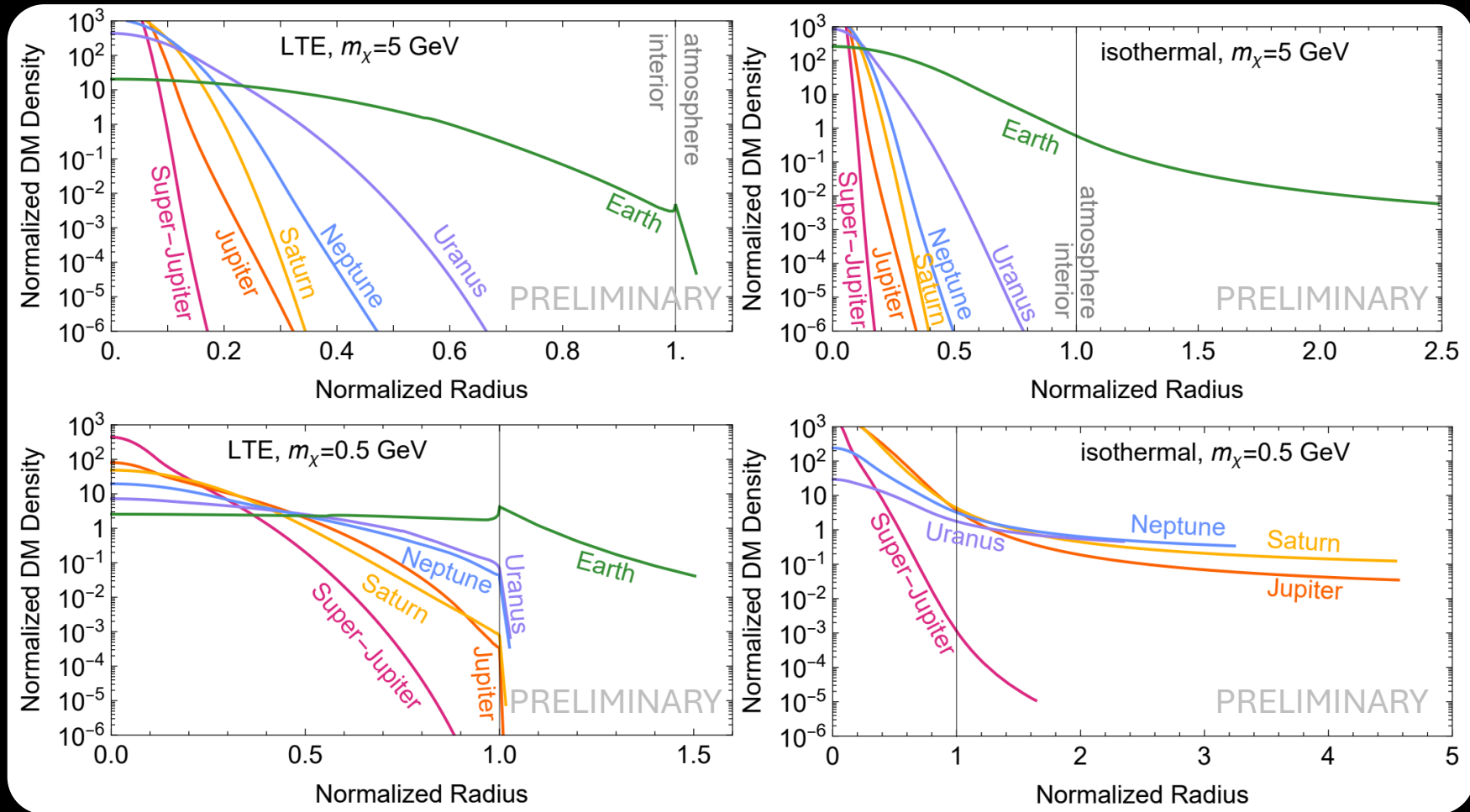
# Why not Lyman-alpha?

Gladstone *et al.*, GRL 2018

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



# Dark matter radial profile



# Evaporation boundary

