

# 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

June 6, 2025



Fonds  
de recherche

Québec



# Outline

A person is silhouetted against a vibrant, multi-colored aurora borealis in a dark, starry night sky. The aurora displays a spectrum of colors including purple, pink, orange, and green, with a dense field of stars visible in the background.

Dark matter accumulation

Ultraviolet airglow

Dark matter-induced airglow

Results

Internal heat flow

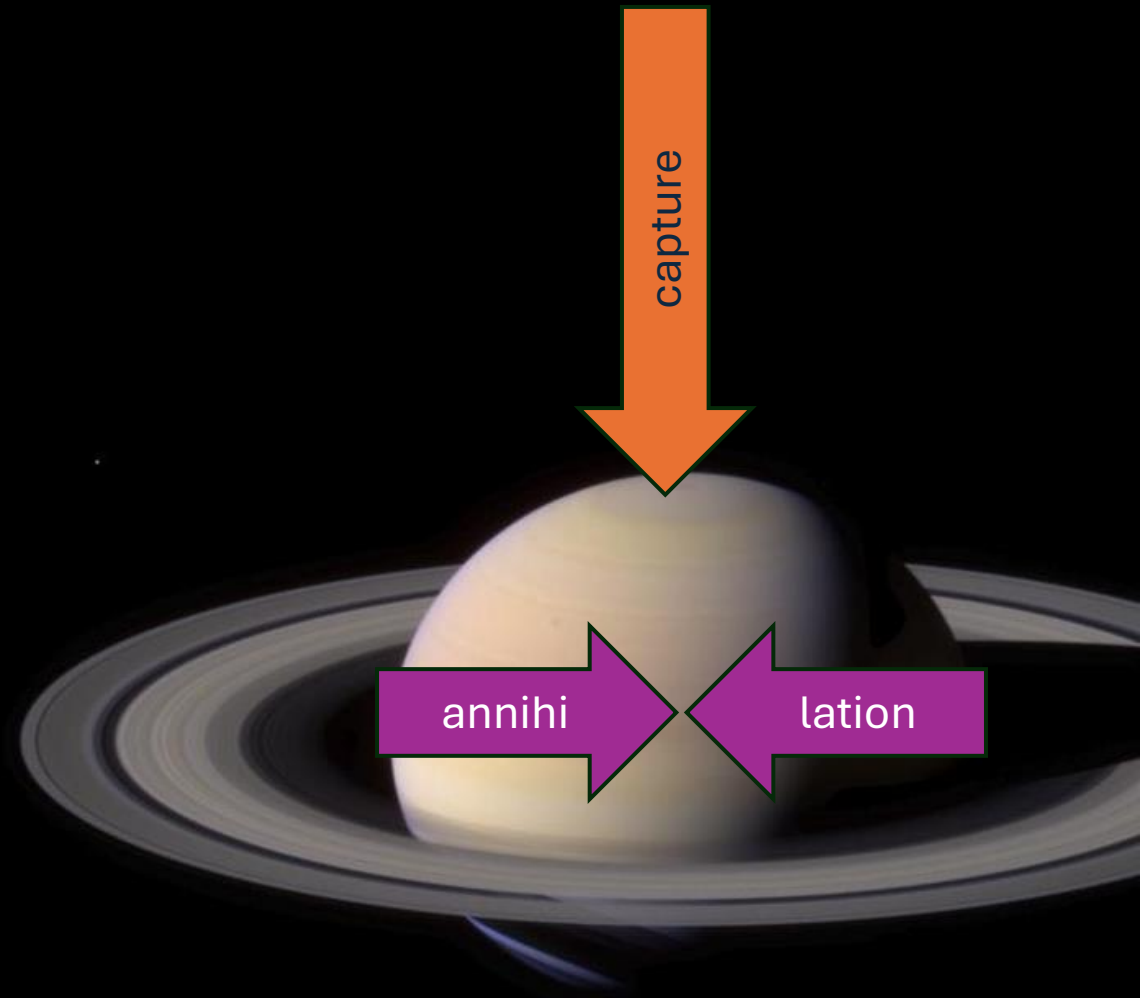
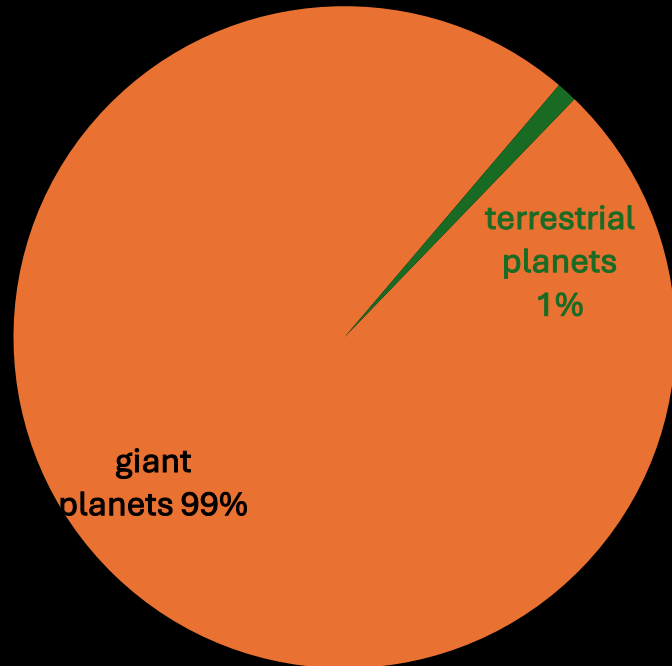
Fraction of annihilation energy

Summary

# Dark matter accumulation in planets

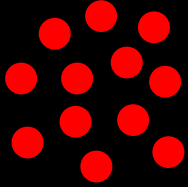
$$\frac{dN_\chi}{dt} = \Gamma_{\text{capture}} - N_\chi^2 \Gamma_{\text{annihilation}}$$

## Mass fraction of Solar System planets



# Signatures of accumulated dark matter

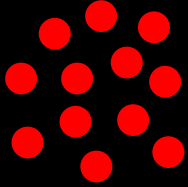
## Asymmetric (scattering)



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

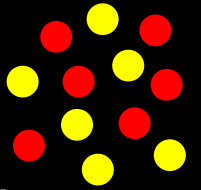
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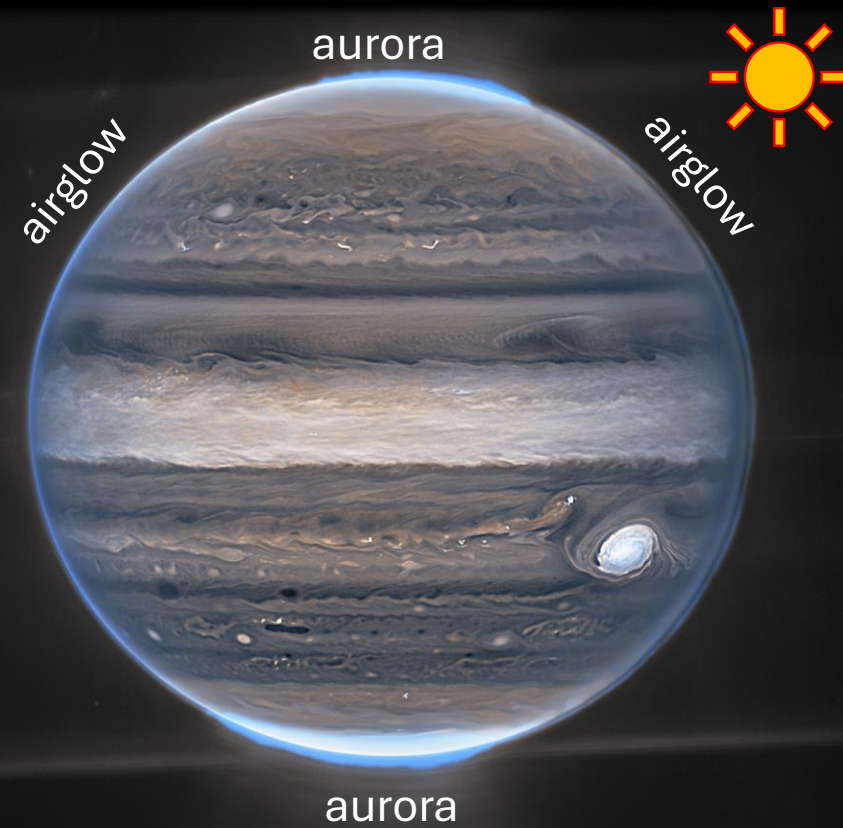
## Symmetric (annihilation)



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

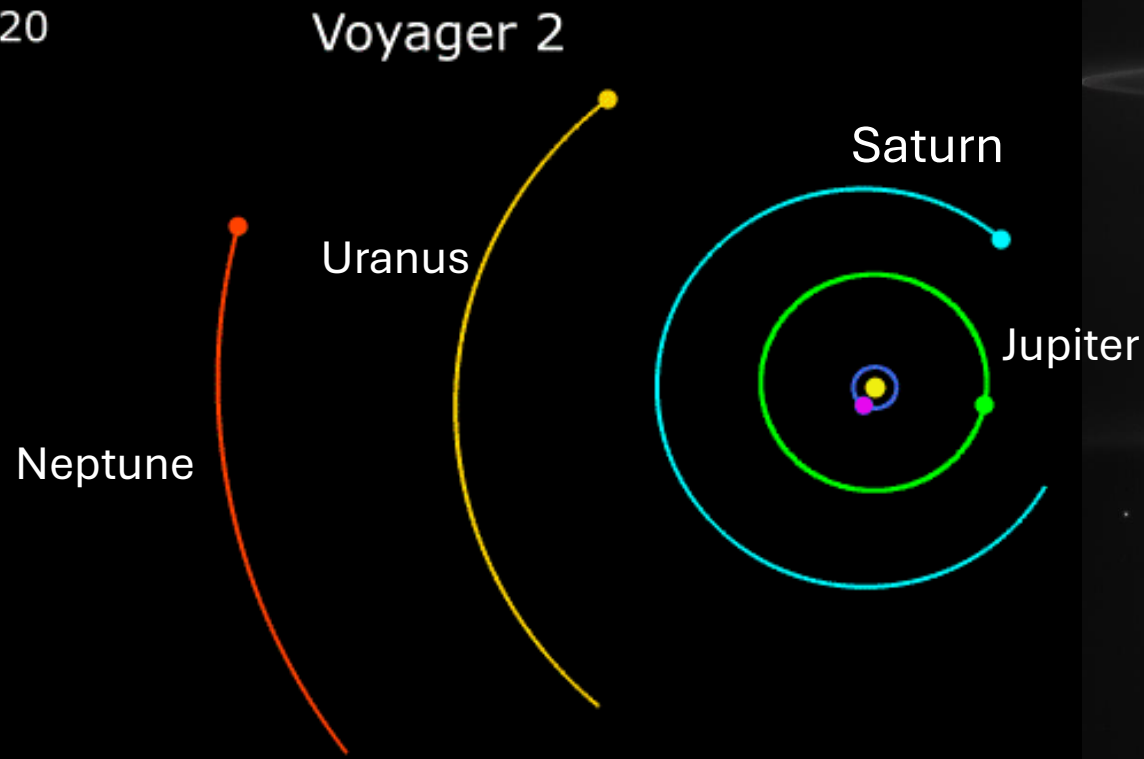
# Ultraviolet airglow

- 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

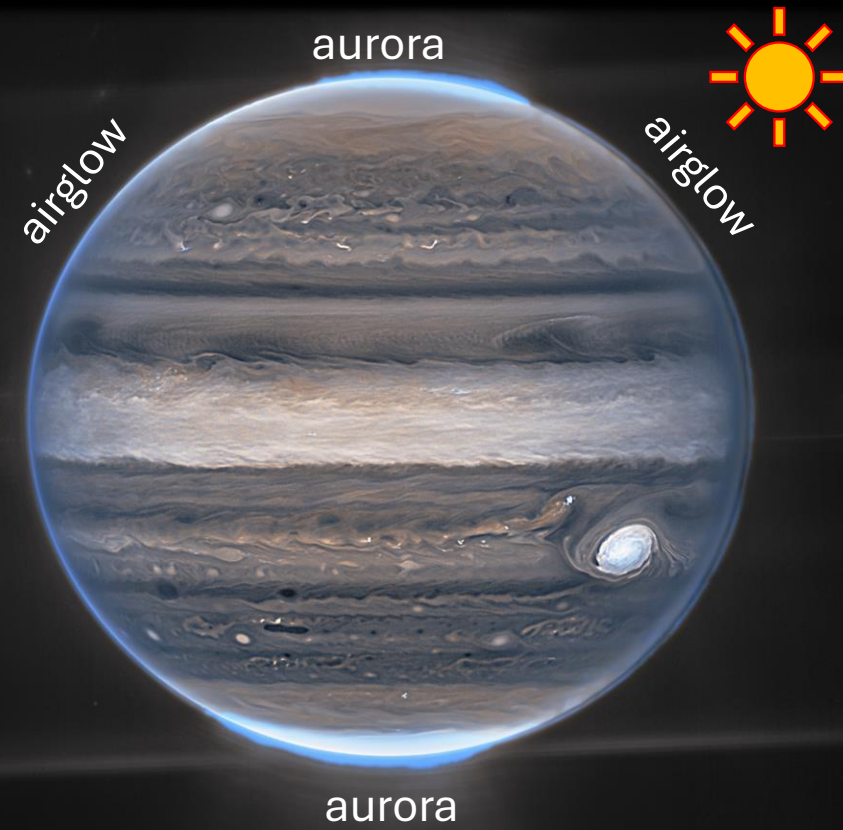
1977-08-20



0.0km/s

4,487,373,409km

Wikipedia



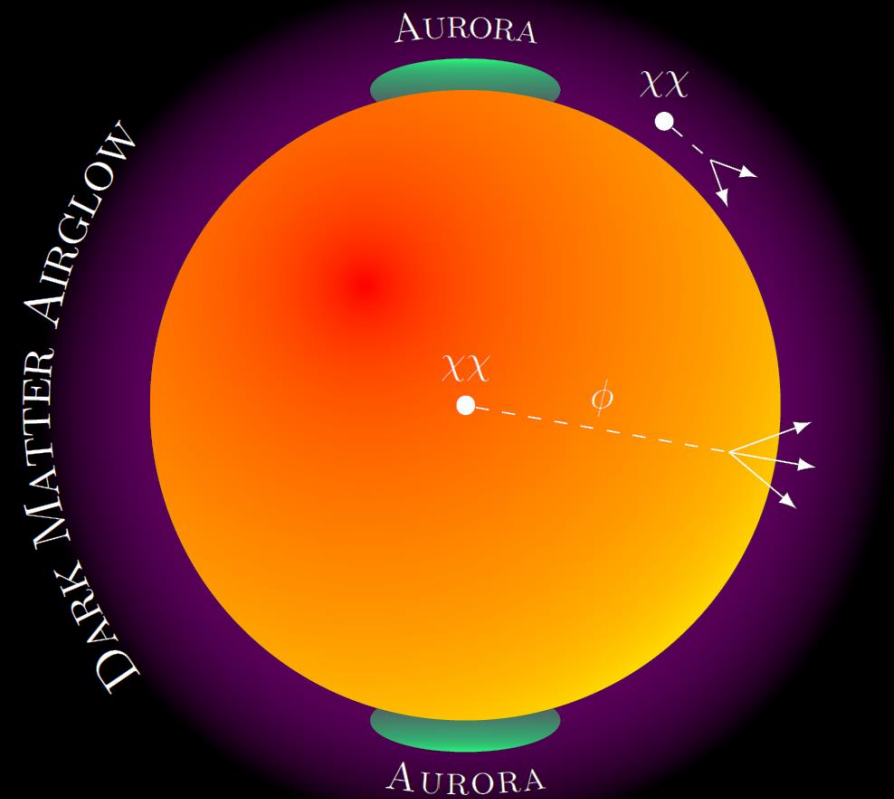
# Dark matter-induced airglow

Assuming

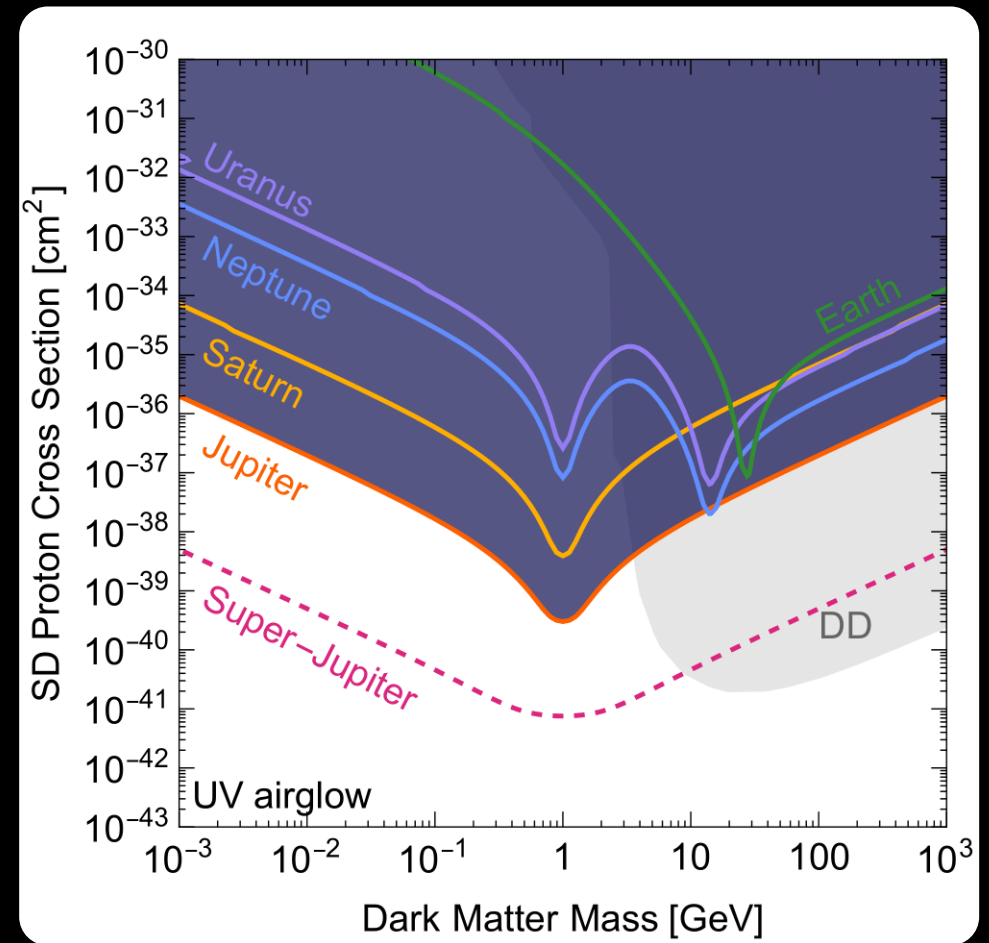
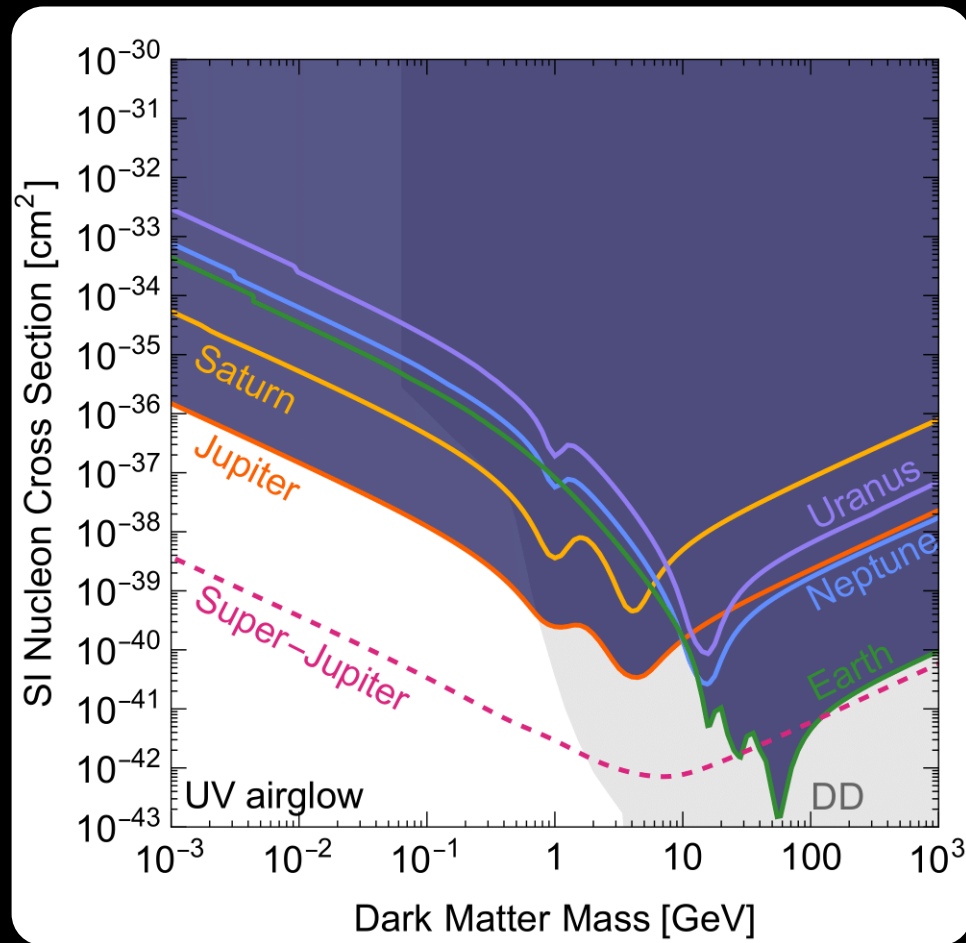
- dark matter annihilates to electrons

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

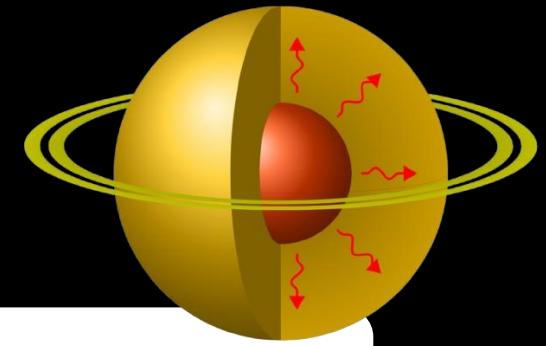
- dark matter annihilates to other final states
  - The limit is reduced by a factor of a few



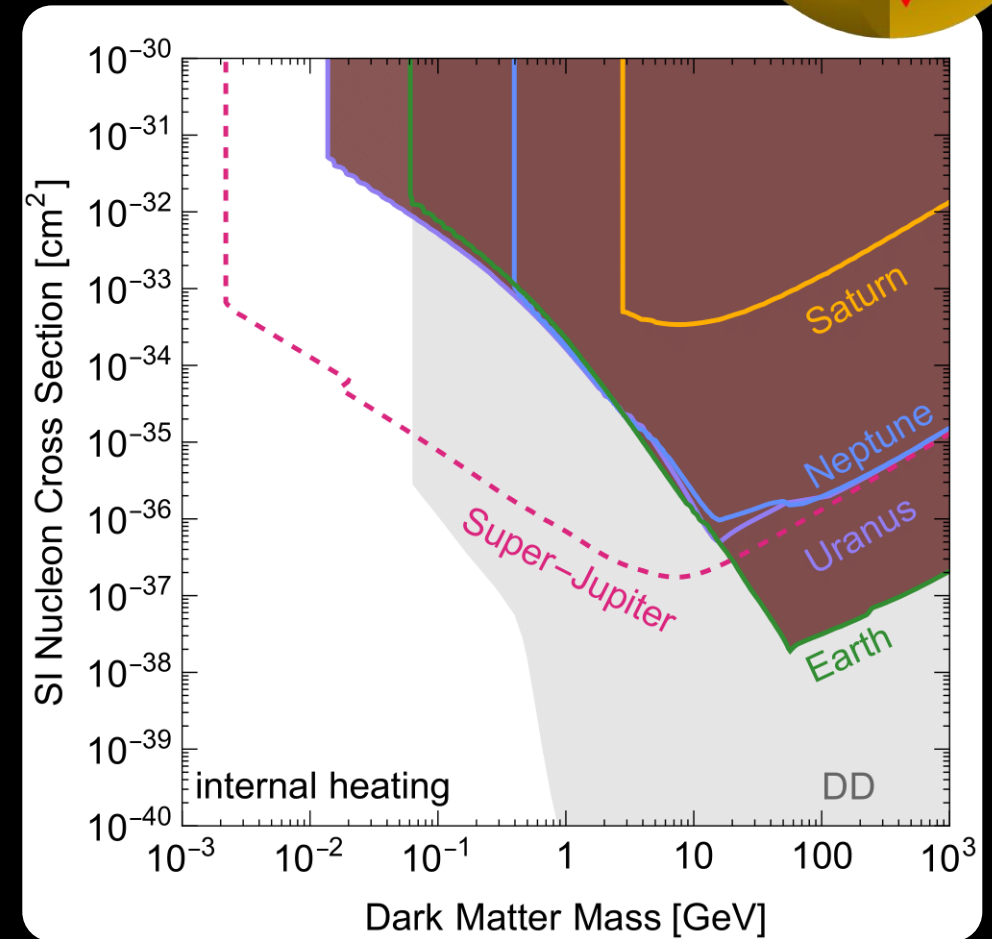
# Results



# Comparing with other accumulation constraints



- Anomalous heating: power is  $\sim 1000$  larger but annihilation volume is much larger
- see e.g. [0705.4298](#), [0808.2823](#), [1909.11683](#), [2210.01812](#)

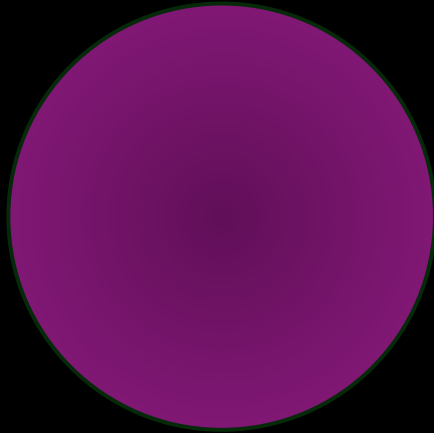


but these constraints assumed *all* annihilation energy goes into the spectroscopic signature

# Where does dark matter settle in a planet?

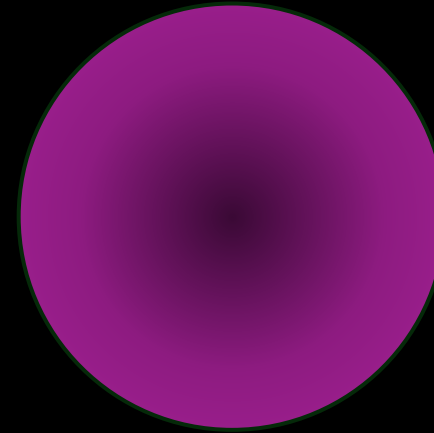
## Light dark matter

- Uniformly distributed in the interior and atmosphere



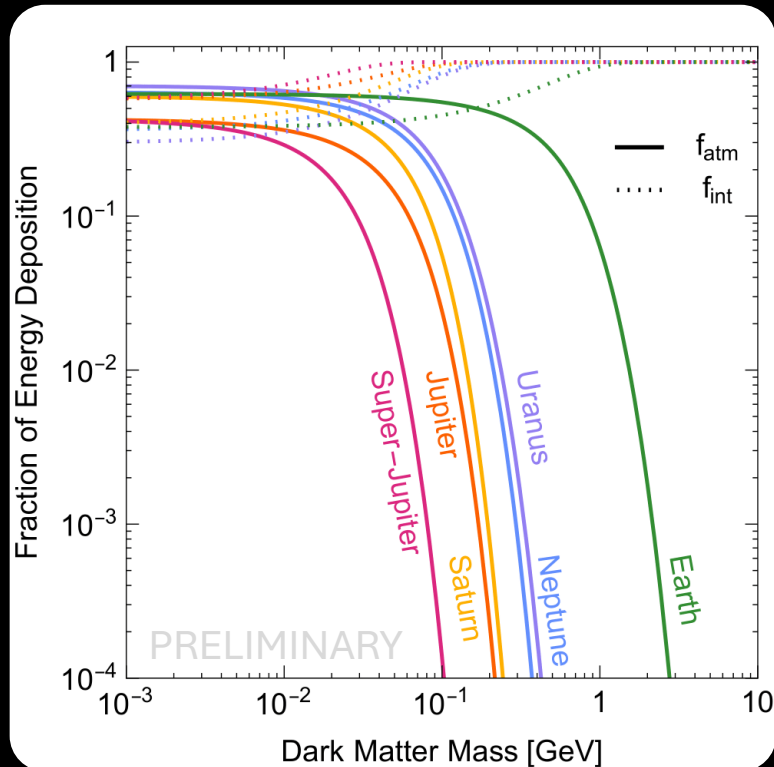
## Heavy dark matter

- Almost exclusively in the core

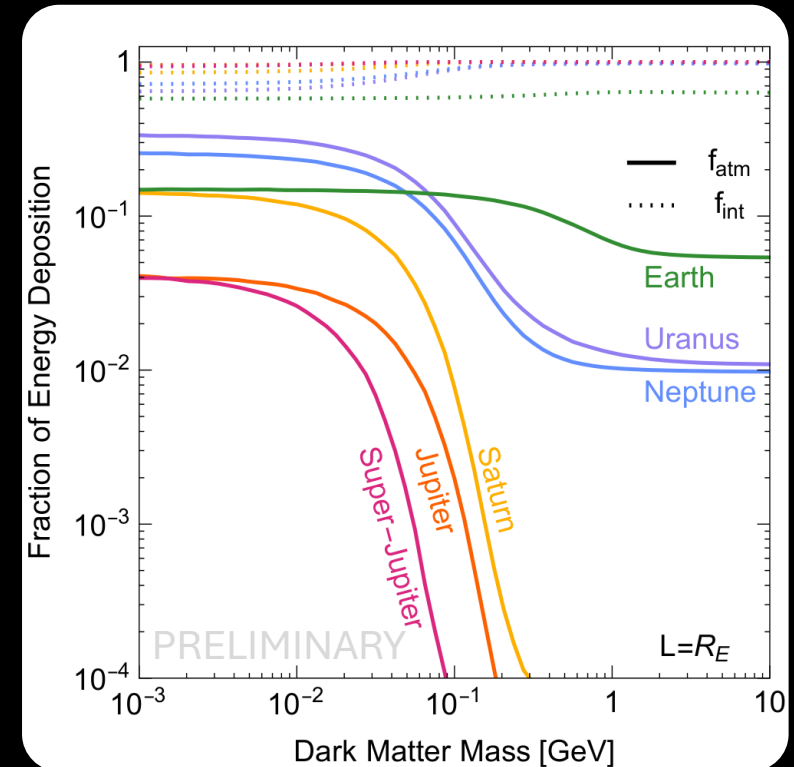


# ... and inject annihilation energy in a planet?

annihilation through  
a *heavy* mediator

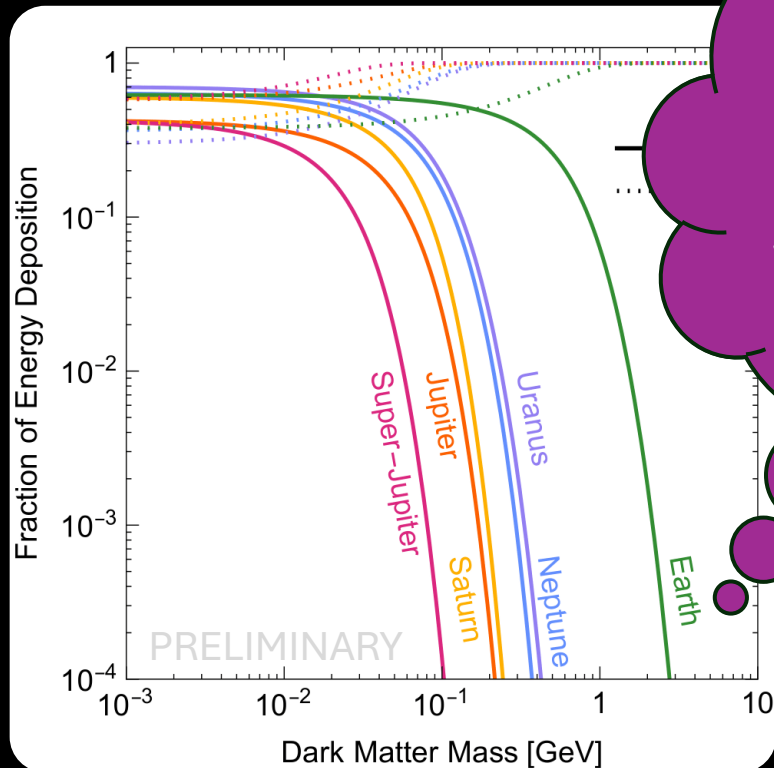


annihilation through  
a *light* mediator



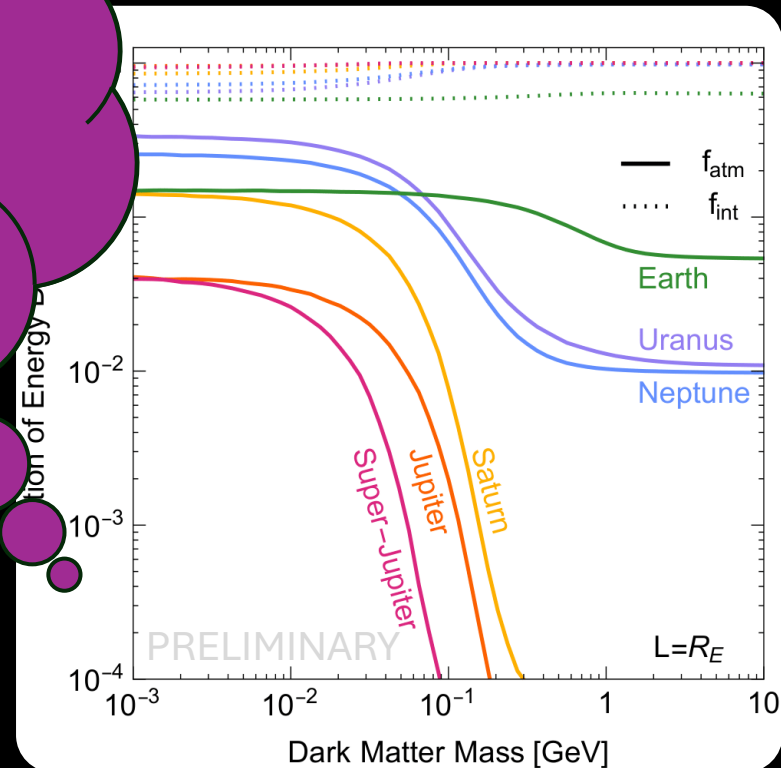
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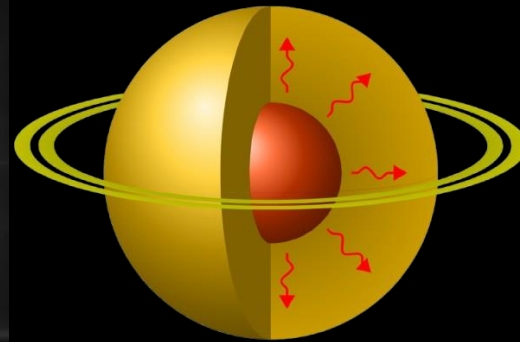
non-negligible  
even if the  
atmosphere is  
small compared  
to the planet!

annihilation through  
a *light* mediator



# Summary

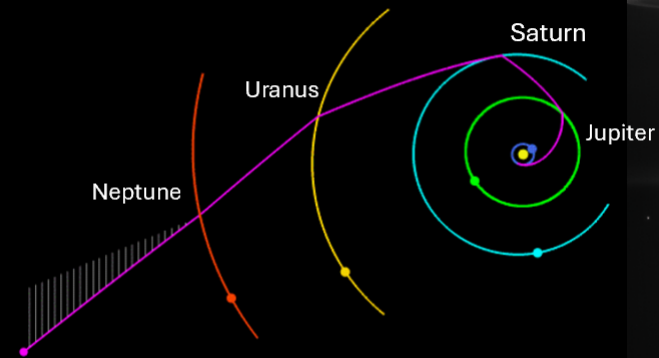
## Signals



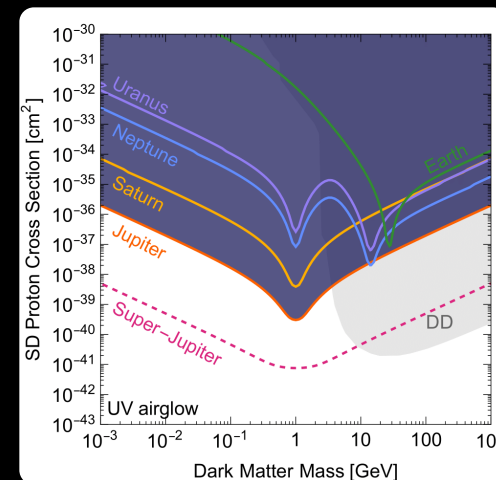
## Data

1997-01-22

Voyager 2



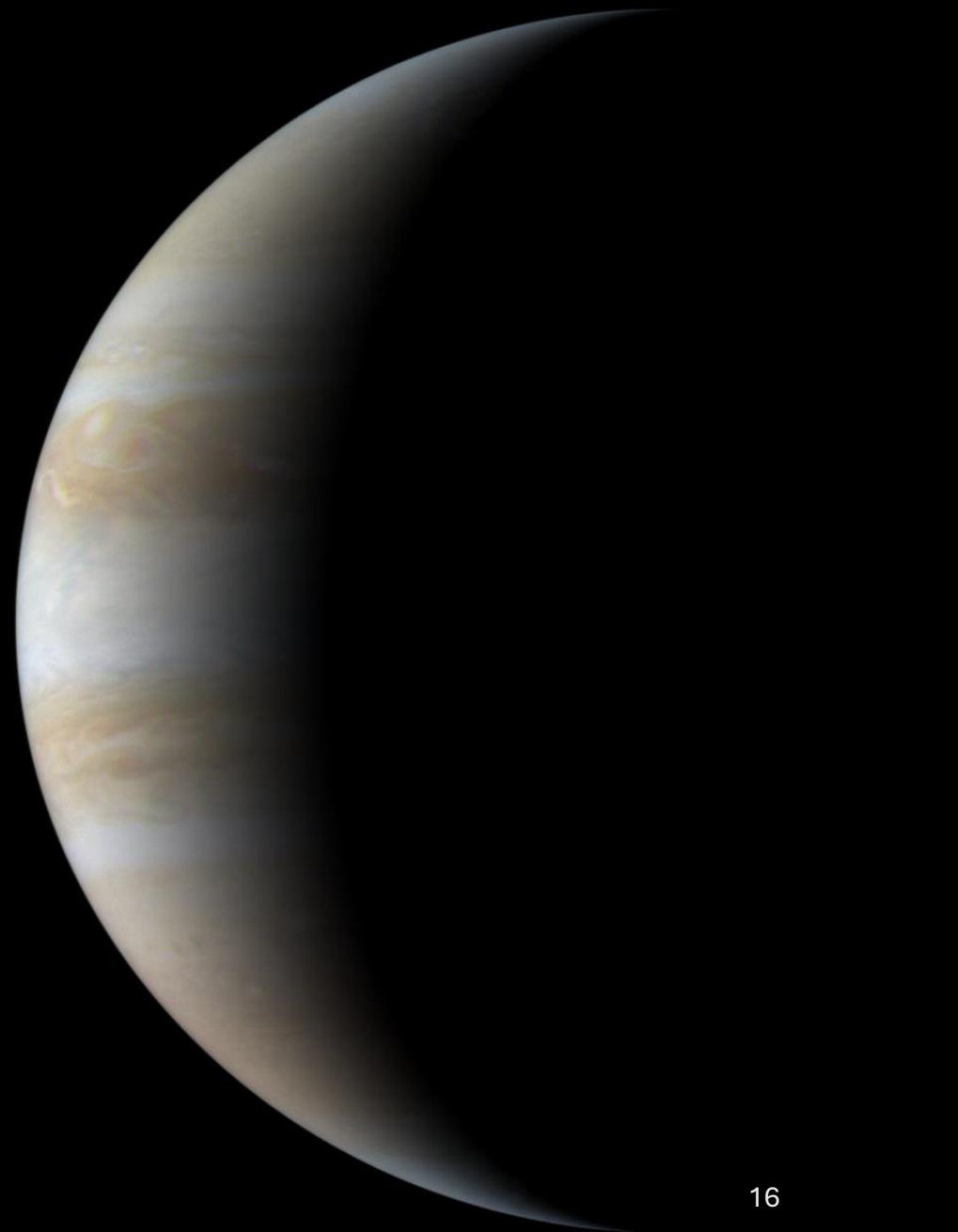
## Our constraints



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

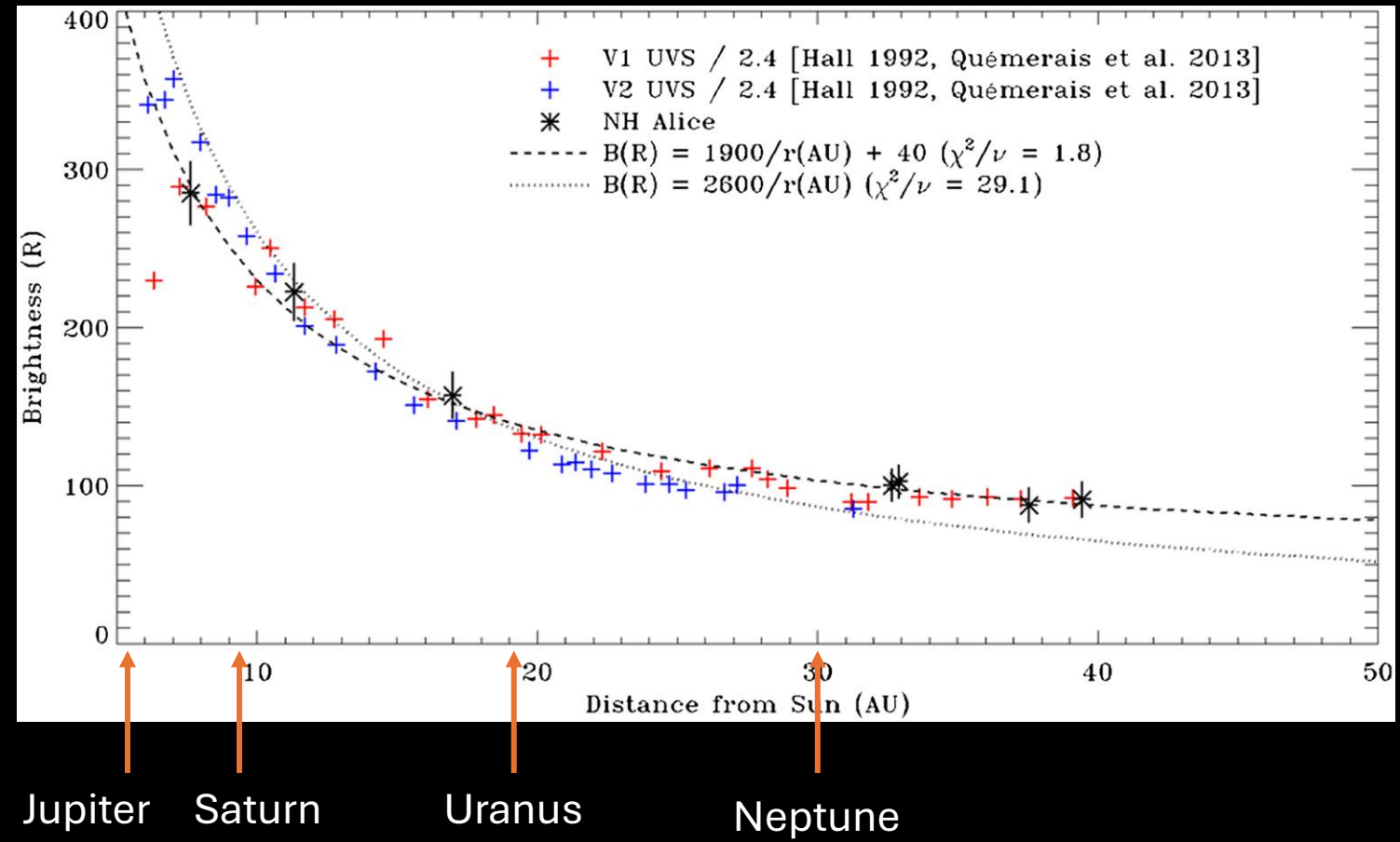
Planet	$P_{\text{observed}}^{\text{heating}}$ ( $\text{W}/\text{m}^2$ )	Space probe
Jupiter	7	Cassini
Saturn	3	Cassini
Uranus	0.04	Voyager 2
Neptune	0.4	Voyager 2
Earth	0.09	boreholes

# heating values

# Why not Lyman-alpha?

Gladstone *et al.*, GRL 2018

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



Equilibration time  
compared to our  
optimal limits

