Gamma-Ray Searches for Dark Matter in Celestial Bodies

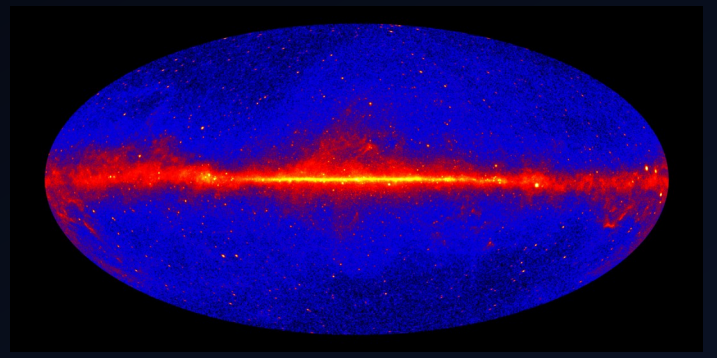
REBECCA LEANE
SLAC National Accelerator Laboratory

PANIC2021
SEPTEMBER 5TH 2021

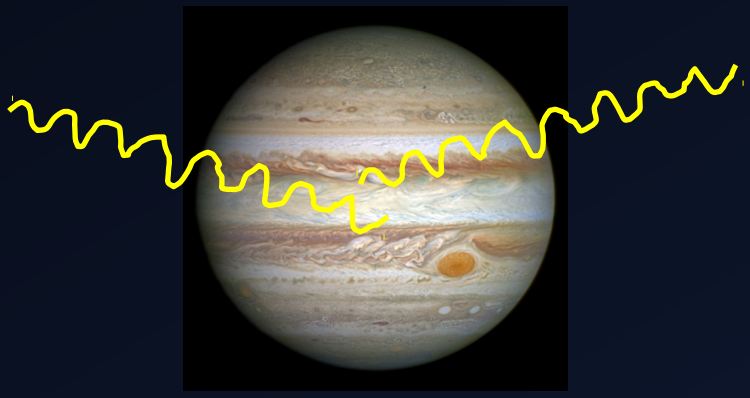
BASED ON 2101.12213 + 2104.02068
W/ TIM LINDEN, PAYEL MUKHOPADHYAY, NATALIA TORO

New Gamma-Ray Searches

- Traditional indirect detection:
  - Look for annihilation products in DM halos

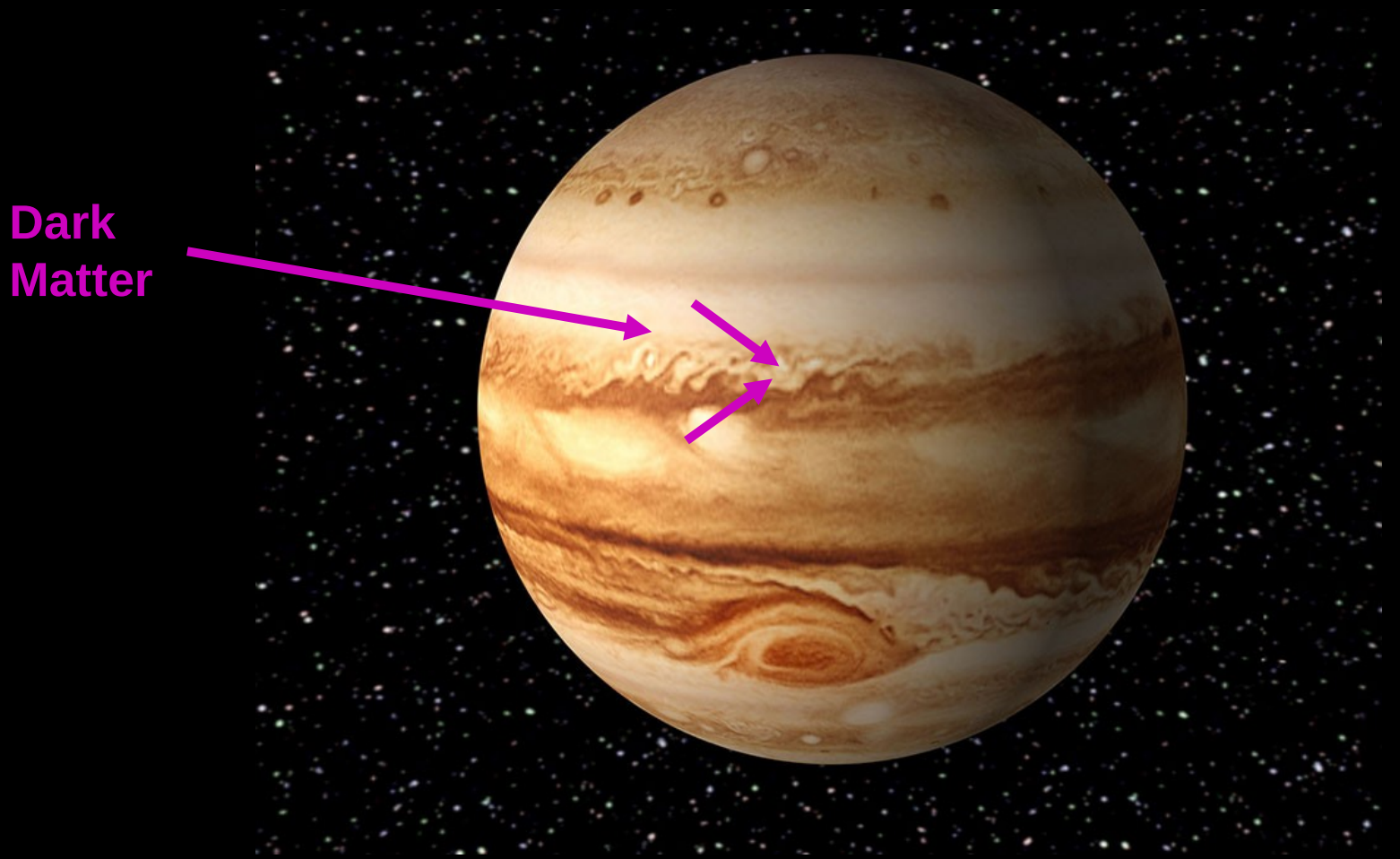


- Alternate signal:
  - Gamma rays from celestial objects!

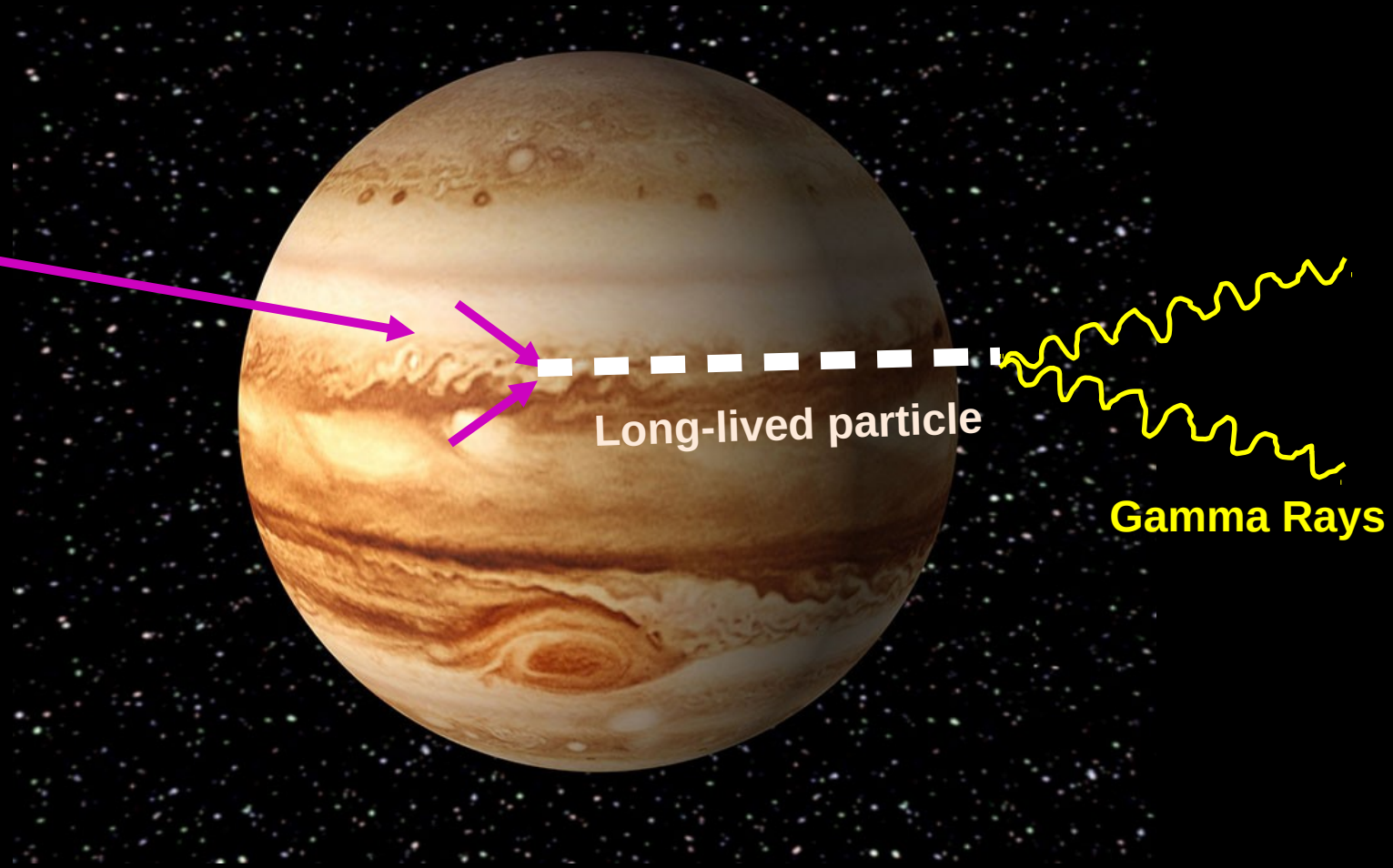


Fermi-LAT, HAWC, HESS gamma-ray data available

DM-sourced gamma rays



DM-sourced gamma rays



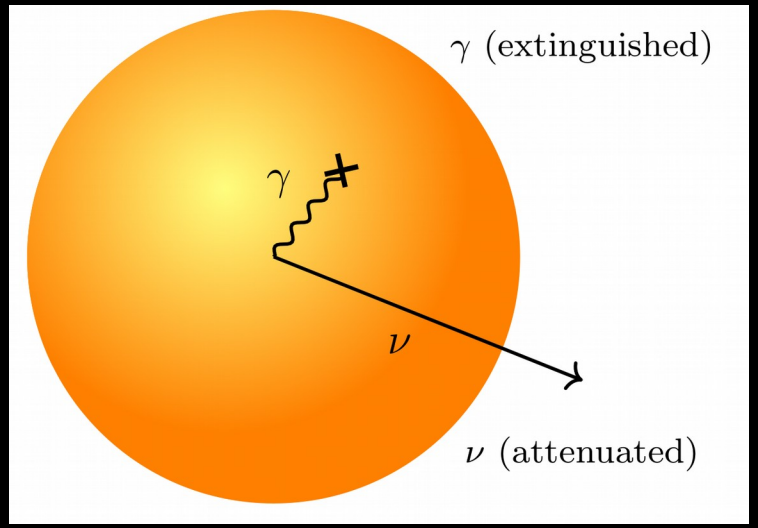
Assumption:

$$\gamma c\tau > R_{\oplus}$$

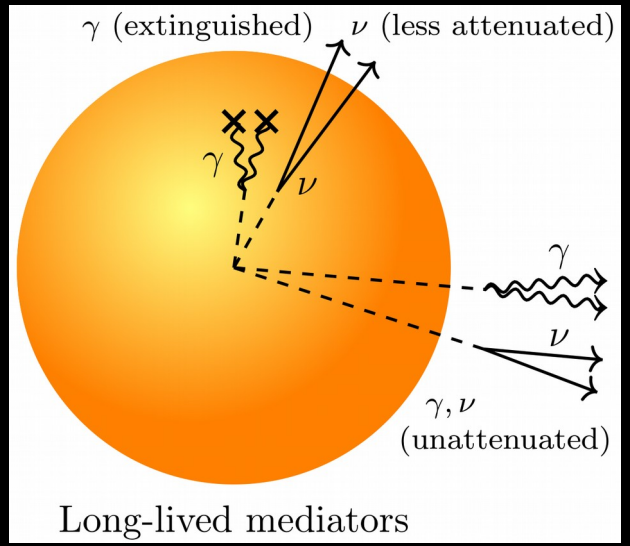
Complementary Searches

Two regimes:

- 1. DM annihilates to short-lived mediators → heats objects



2. DM annihilates to long-lived mediators → *escapes* objects!



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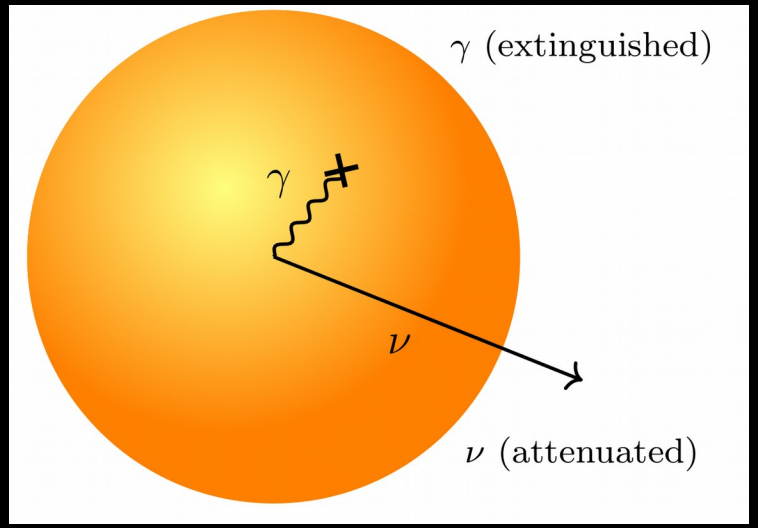

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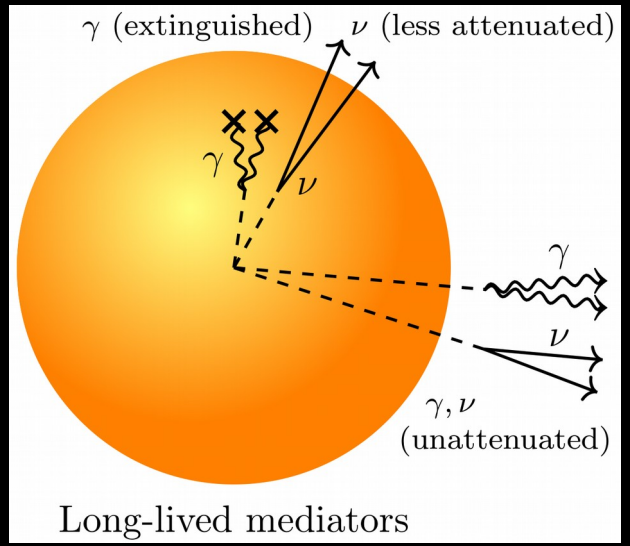
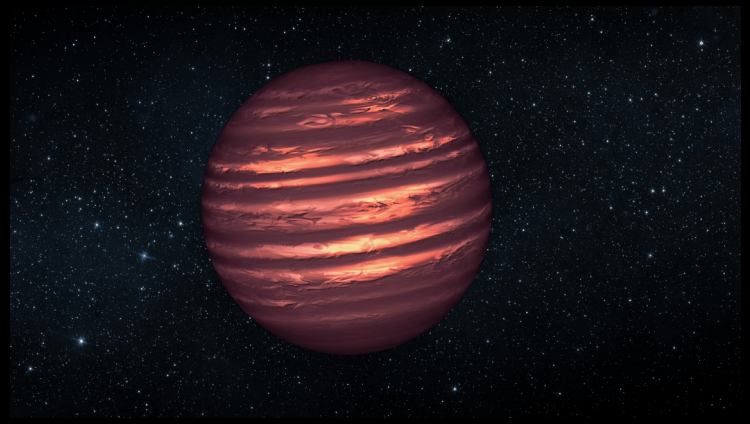
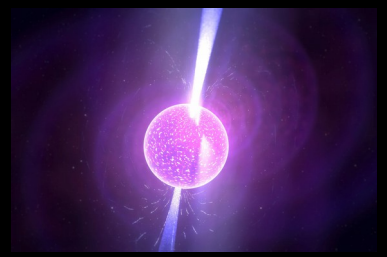
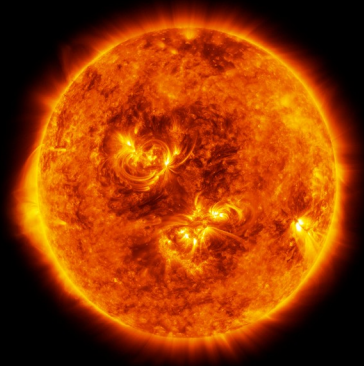


Optimal Celestial Target?

- Radius: Larger amount of DM captured, larger annihilation signal
- Core Temperature: Gives kinetic energy to DM, if high, more evaporation
- Density: Lower cross section sensitivities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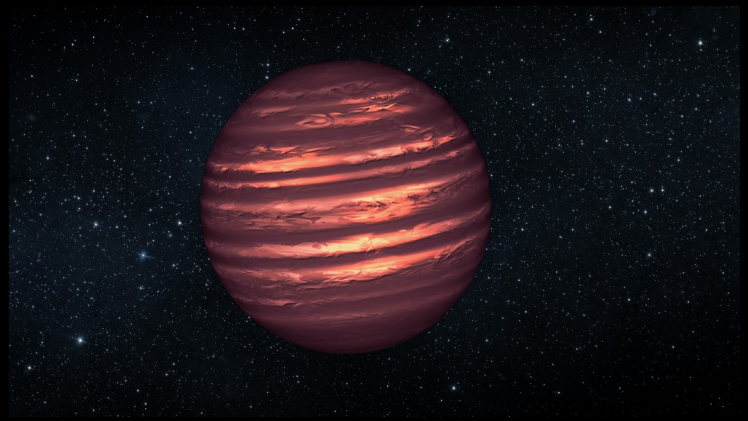
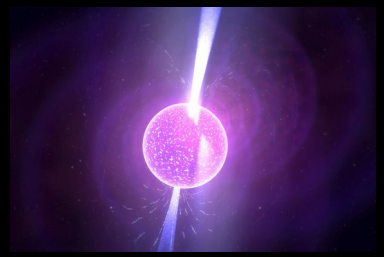


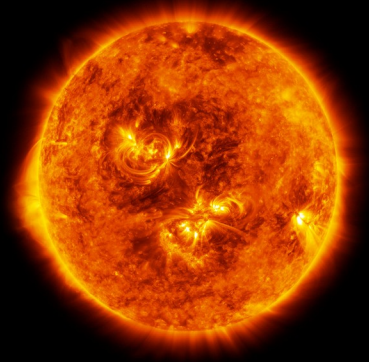
Brown Dwarf

BIG
Cold
Dense



Neutron Star

Small
Cold
Ultra-dense



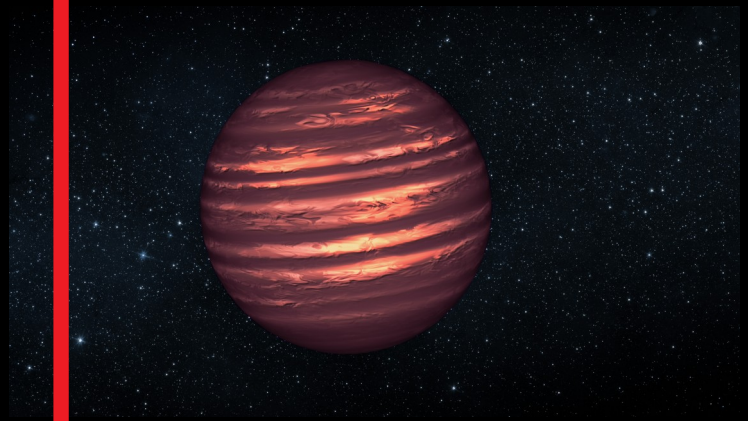
Sun

BIG
Hot

Jupiter

BIG
Cold

Optimal Celestial Target?



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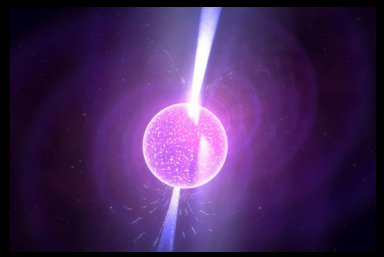

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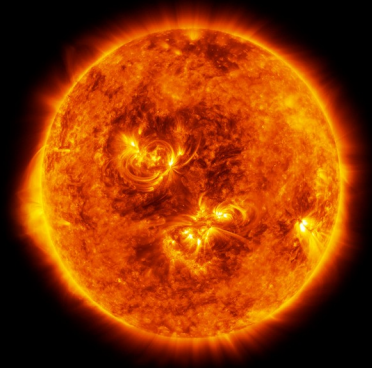

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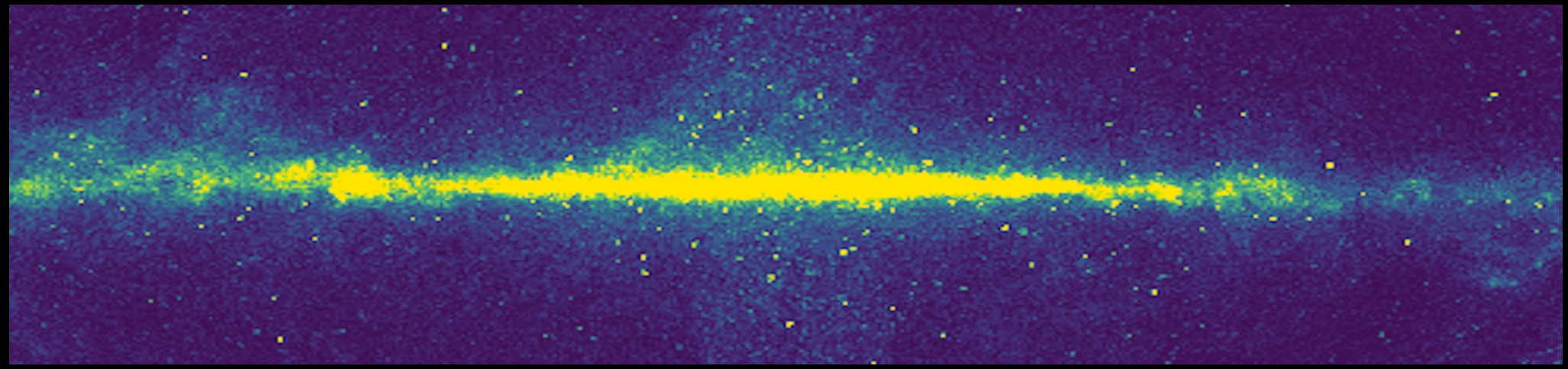
Galactic Center Population Signal

- Galactic Center benefits:
  - High DM density
  - Lower DM velocity
  - Lots of neutron stars and brown dwarfs present



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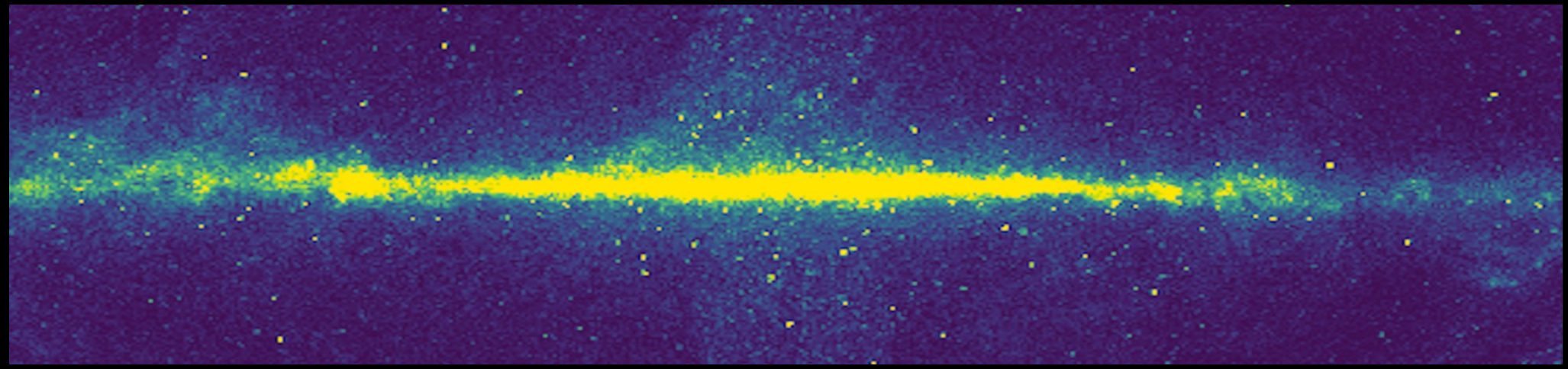
Galactic Center Population Signal

- Use all the neutron stars, all the brown dwarfs
  - Indirect detection flux with celestial objects!

- Our new signal follows matter density: DM density * stellar density
  - In comparison, DM Halo annihilation scales with DM density squared



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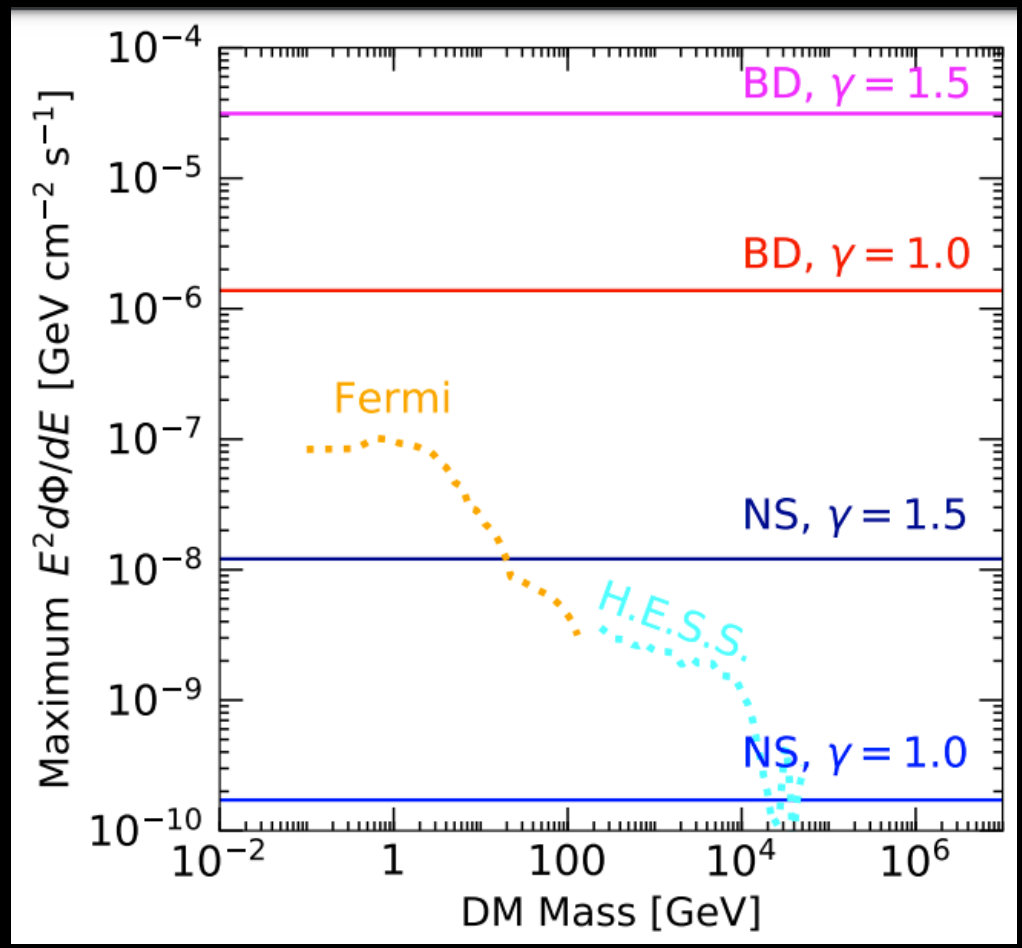
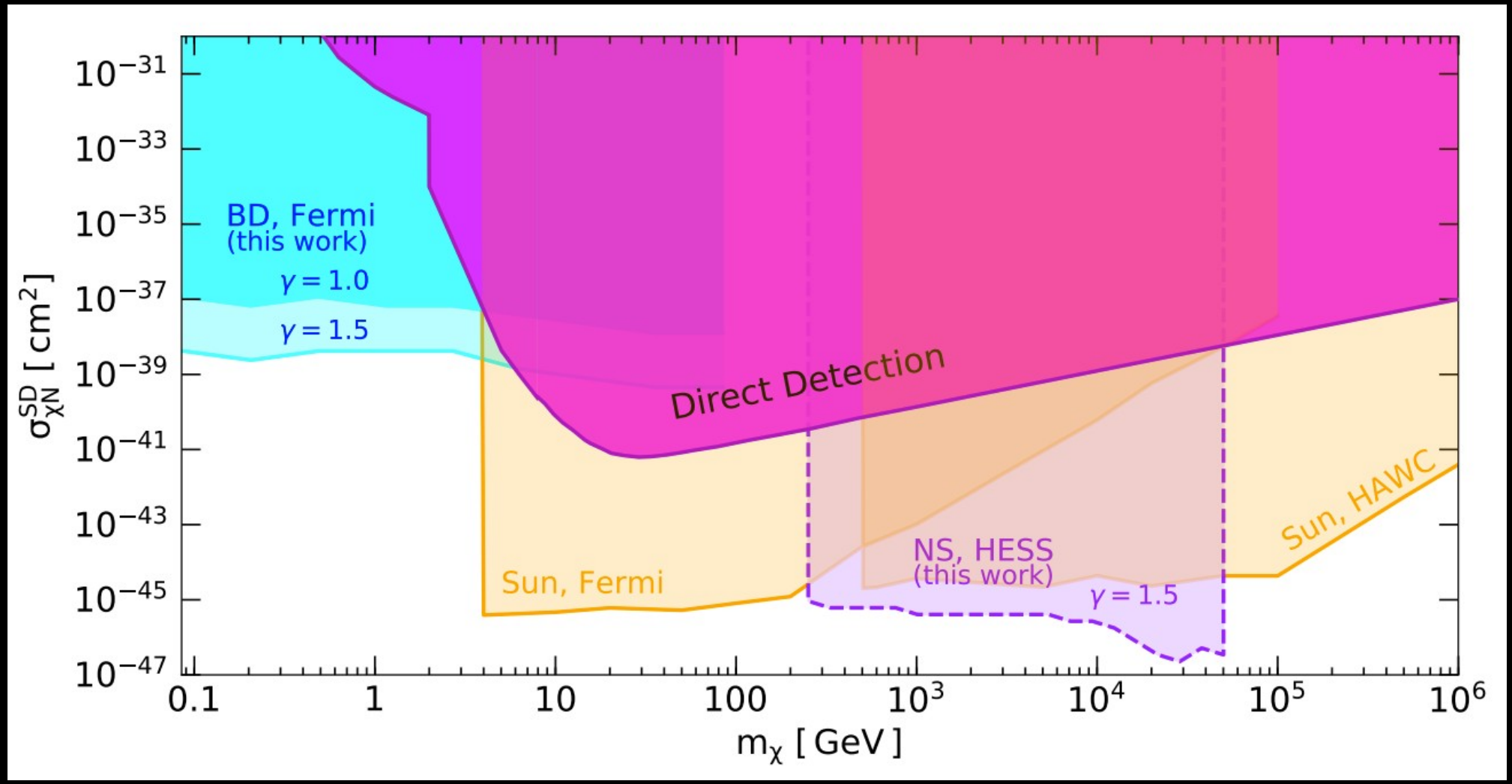
Galactic Center Population Signal

- Detectability: compare with known gamma-ray data
  - Use Fermi and H.E.S.S. data for Galactic Center
  - No model assumptions on mediator, other than must escape
  - Brown dwarfs very large signal!



RKL, Linden, Mukhopadyay, Toro, 2021

New Limits w/ Brown Dwarfs and Neutron Stars



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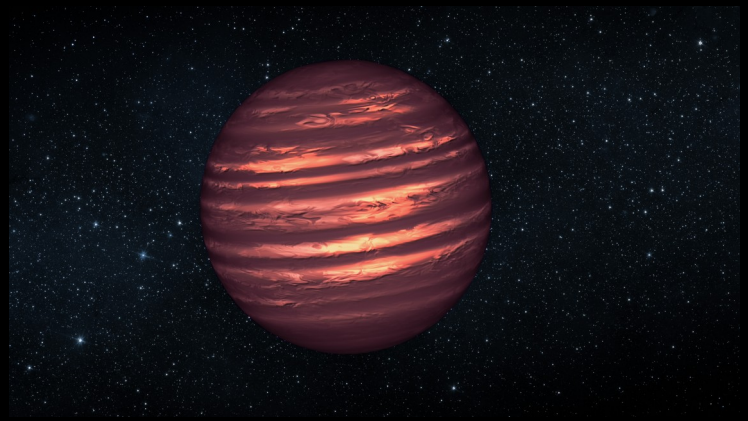

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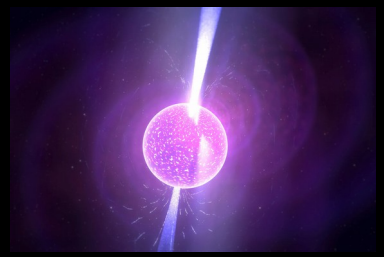

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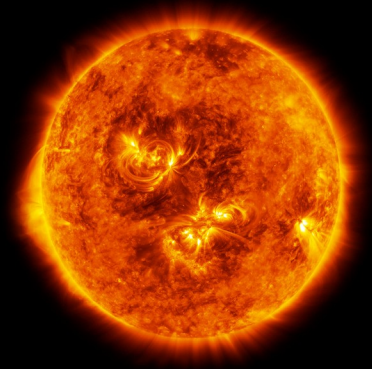

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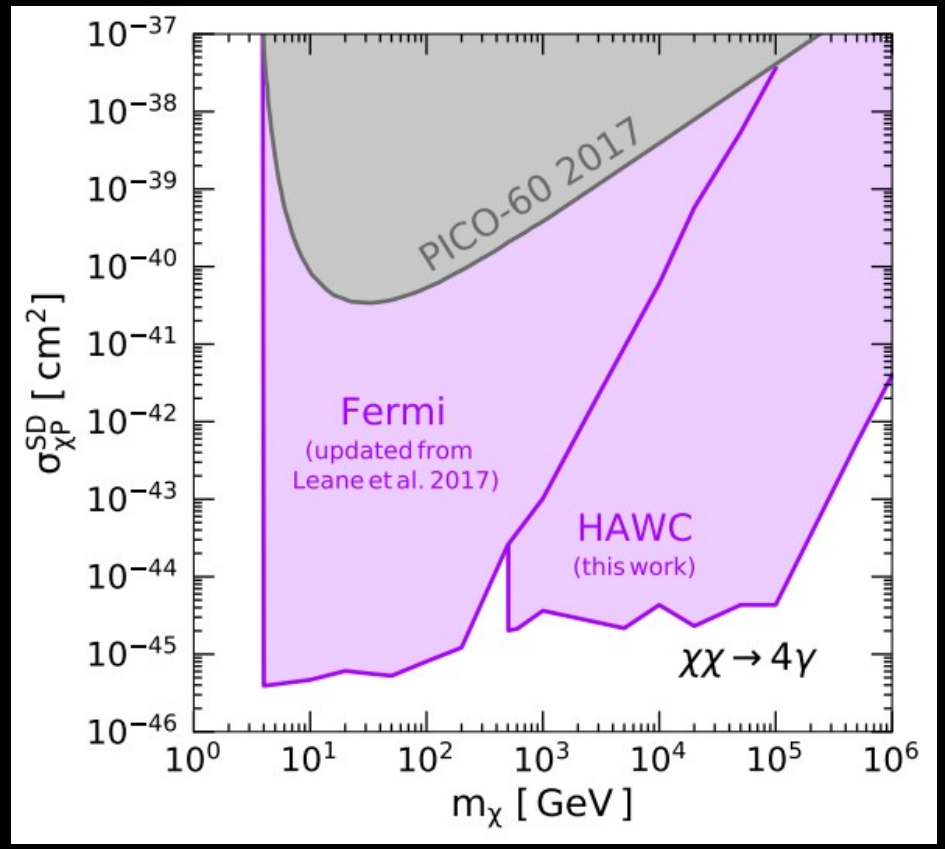
Hot

Jupiter

BIG
Cold

Solar System Objects



Sun

Long-Lived Mediator Limits

RKL, Ng, Beacom (PRD ‘17)

RKL + HAWC Collaboration (PRD ‘18)

What about Jupiter?

Cooler than the Sun:
MeV-DM mass sensitivity!

Jupiter in Gamma Rays

What does Jupiter look like in gamma rays?
No one has ever really checked!

+ Use Fermi Gamma-Ray Space Telescope

+ Analyze 12 years of Fermi data,
  10 MeV – 10 GeV

Jupiter in Gamma Rays

What does Jupiter look like in gamma rays?
No one has ever really checked!

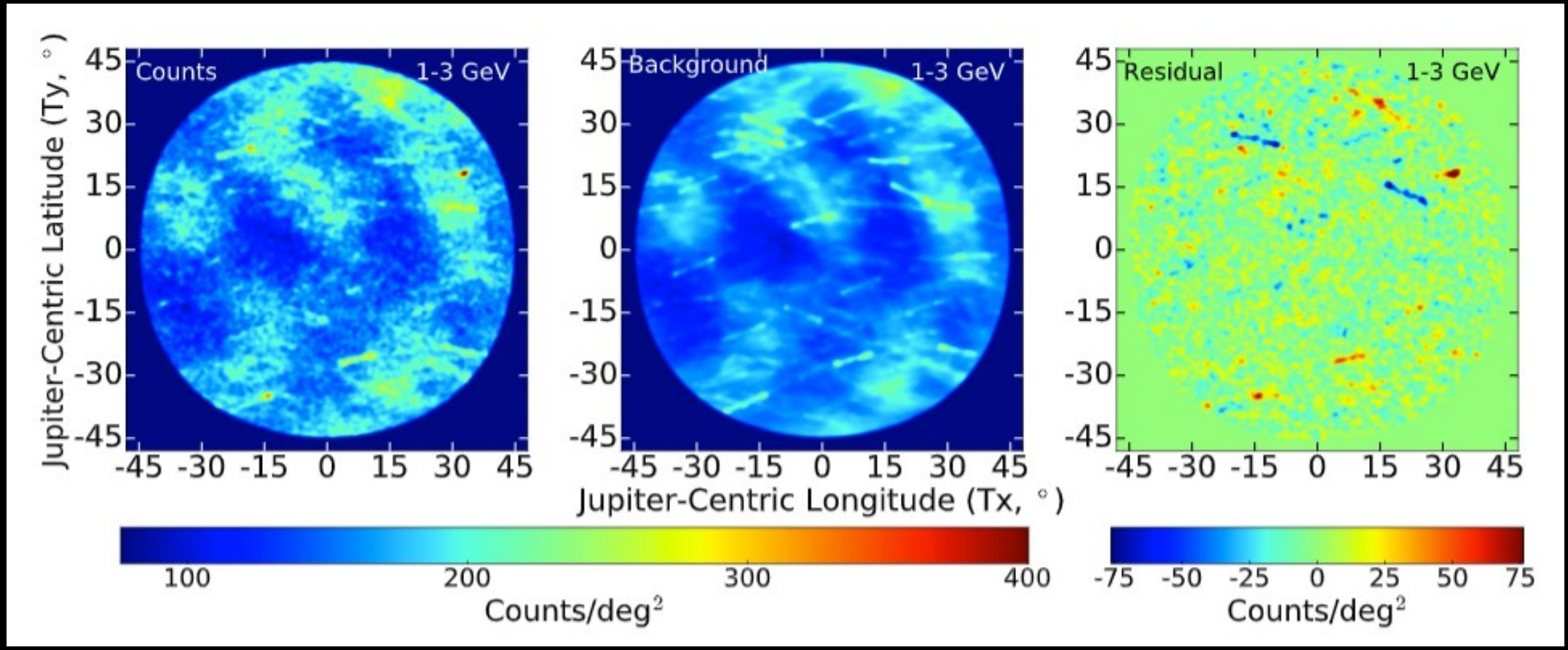
If we find gammas, they could be from:

+ acceleration of cosmic rays in Jovian magnetic fields

+ interaction of cosmic rays with Jupiter's atmosphere

...or something exotic (dark matter)!

Jupiter in Gamma Rays



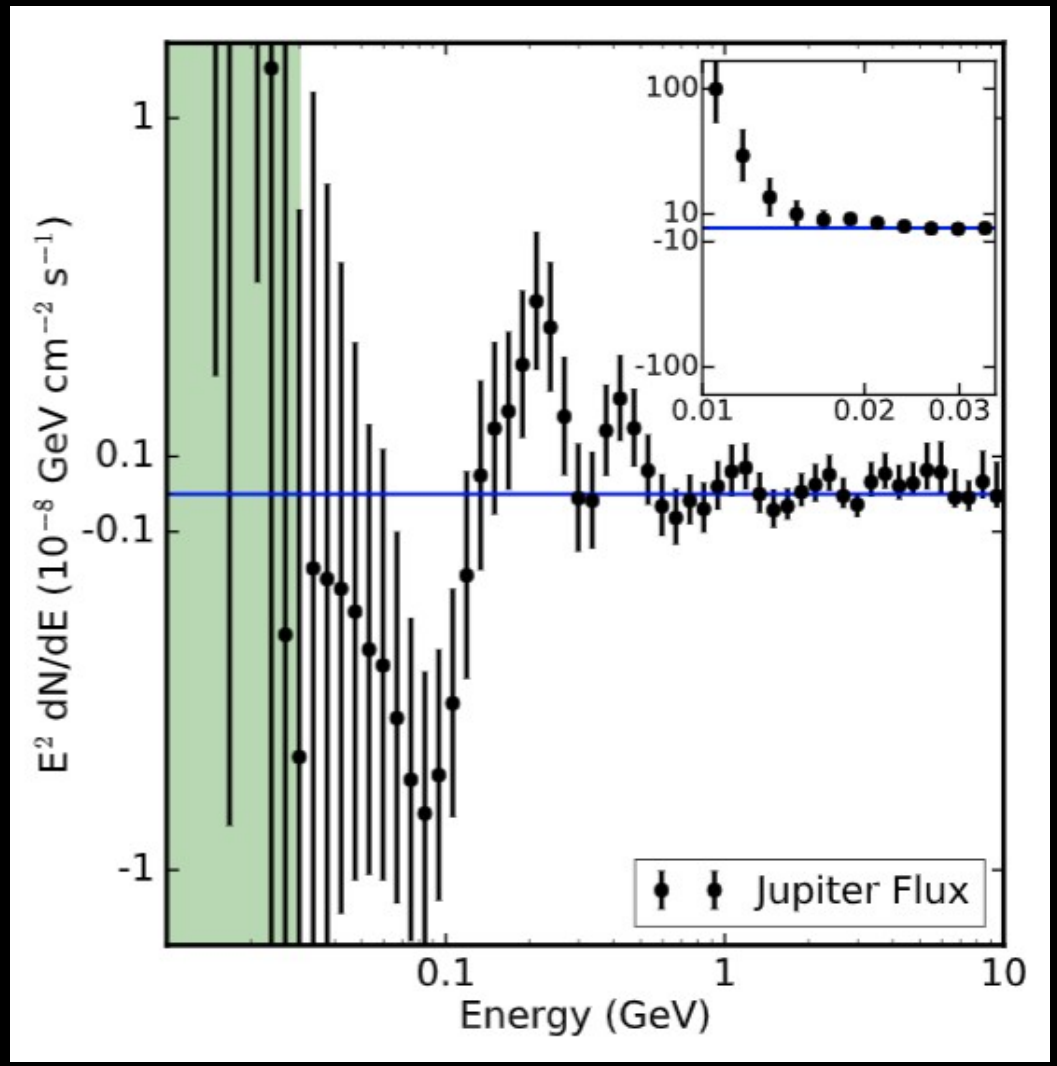
Leane + Linden ‘21

Jupiter Flux Limits

+ For range of power-law spectra, statistical sig of Jupiter emission never exceeds ~1.5σ

+ In low energy bins, “5σ” excess, but important systematics not there

+ Motivates follow-up with MeV telescopes: AMEGO, e-ASTROGAM



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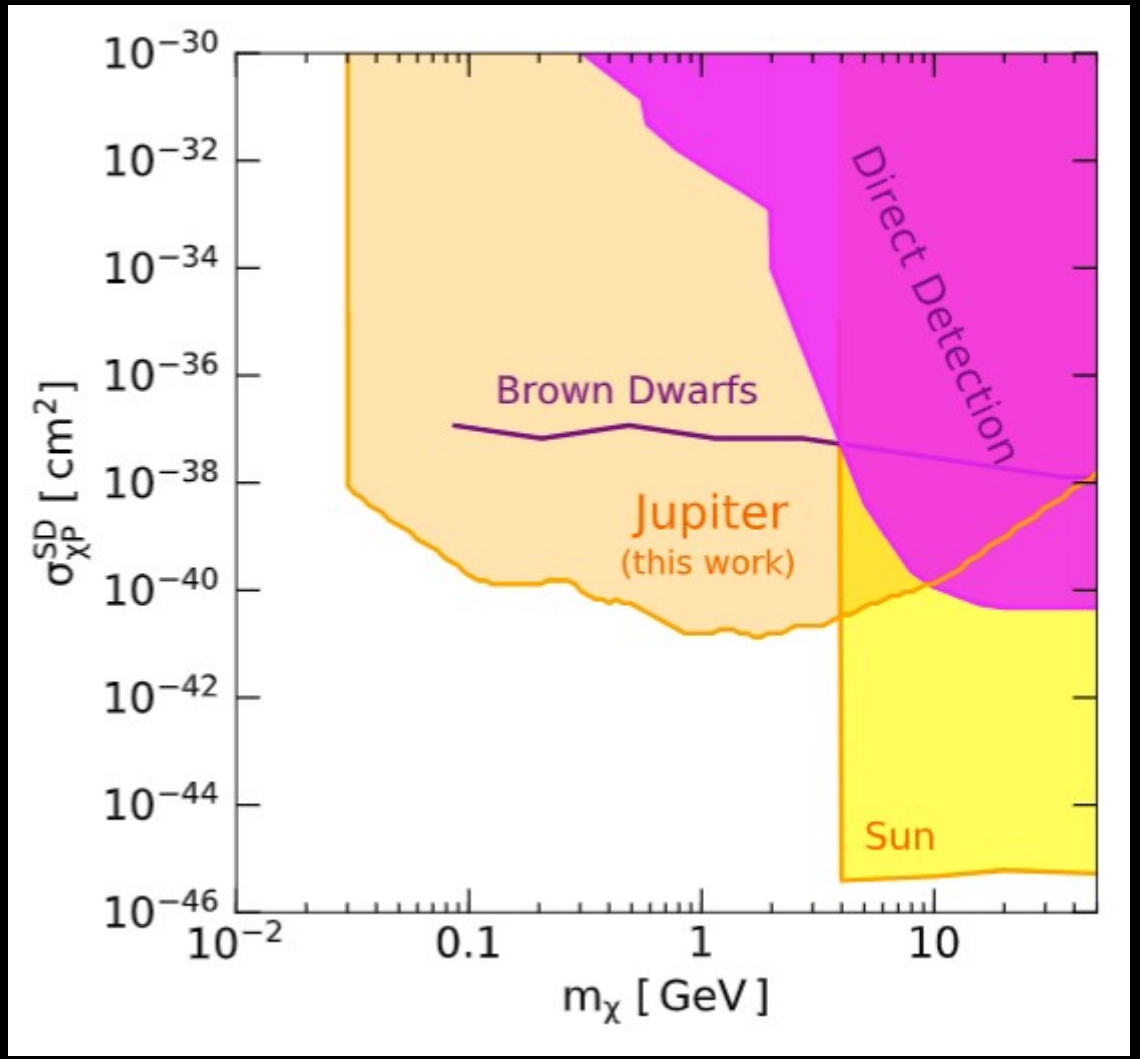
New dark matter limits

- Total flux:

$$E^2 \frac{d\Phi}{dE} = \frac{\Gamma_{\rm ann}}{4\pi D_\oplus^2} \times E_\gamma^2 \frac{dN_\gamma}{dE_\gamma} \times {\rm BR}({\rm X} \to {\rm SM}) \times P_{\rm surv}$$

- Assume direct decay to gammas, but other final states possible
- Assume mediator decay length > Jupiter radius
- Assume equilibrium, though this will be model dependent



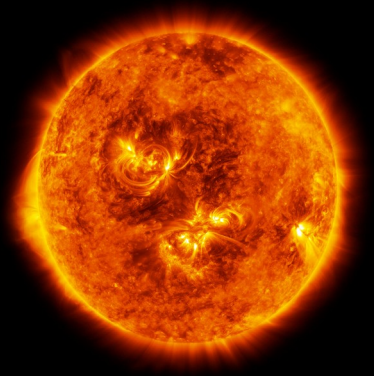
Leane + Linden ‘21

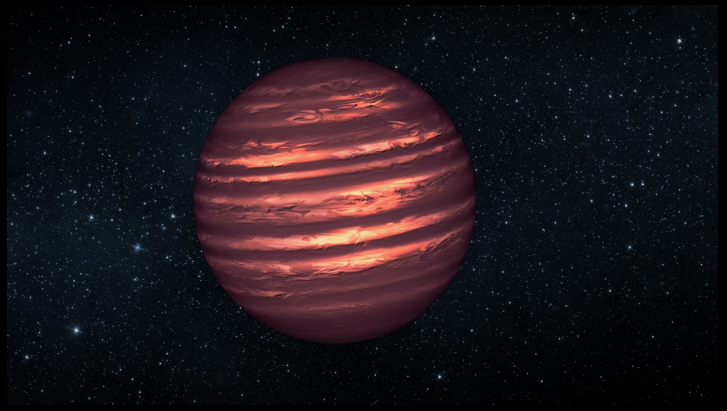
Summary

- New gamma-ray searches for sub-GeV DM in celestial bodies:

  + Search for gamma rays, powered by Galactic Center population of brown dwarfs or neutron stars, new sub-GeV limits

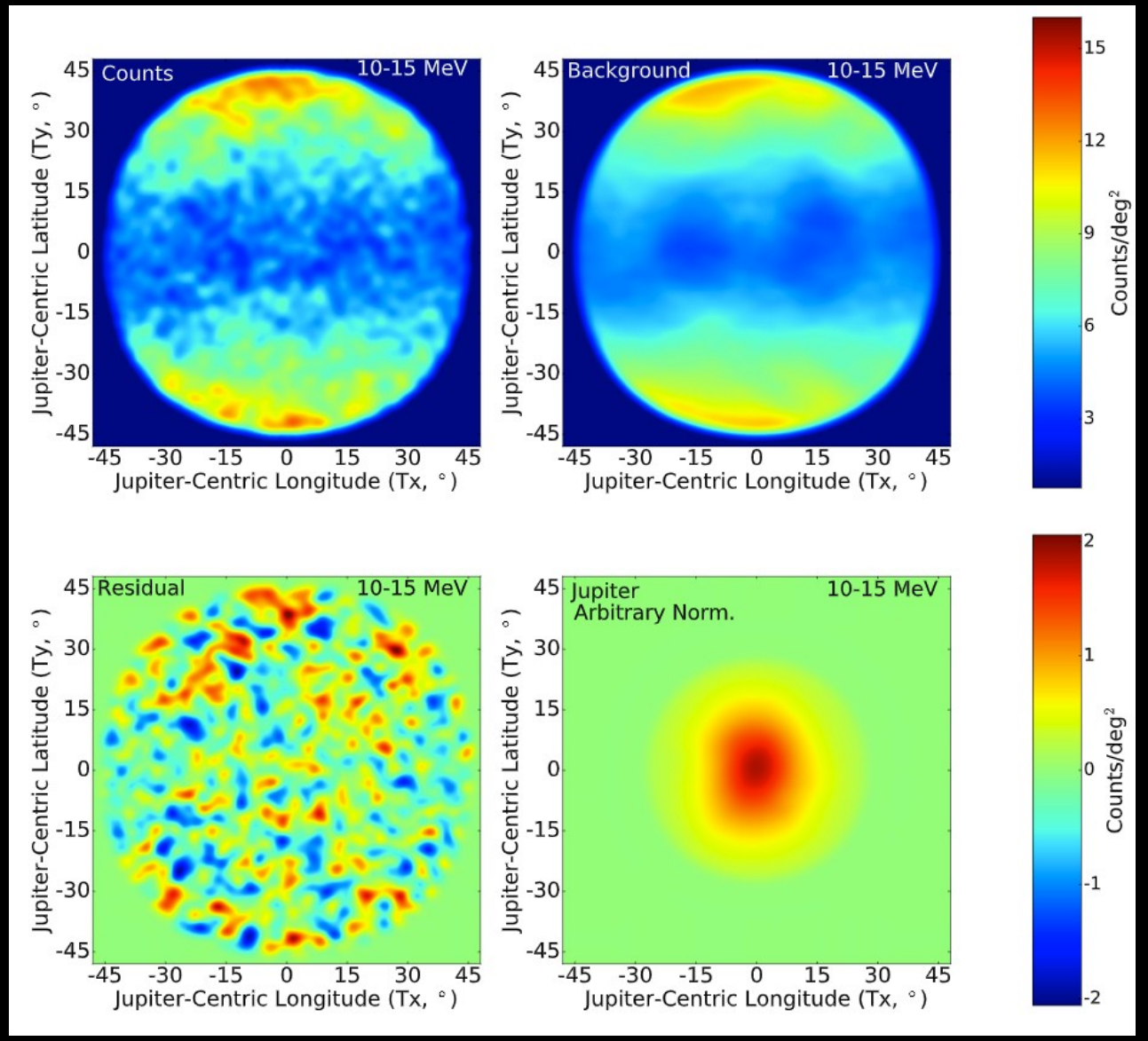
  + Search for gamma rays from Jupiter, new sub-GeV limits, motivates follow up with MeV gamma-ray telescopes





EXTRA SLIDES

Jupiter in Gamma Rays



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