# Dark Matter and Neutron Stars

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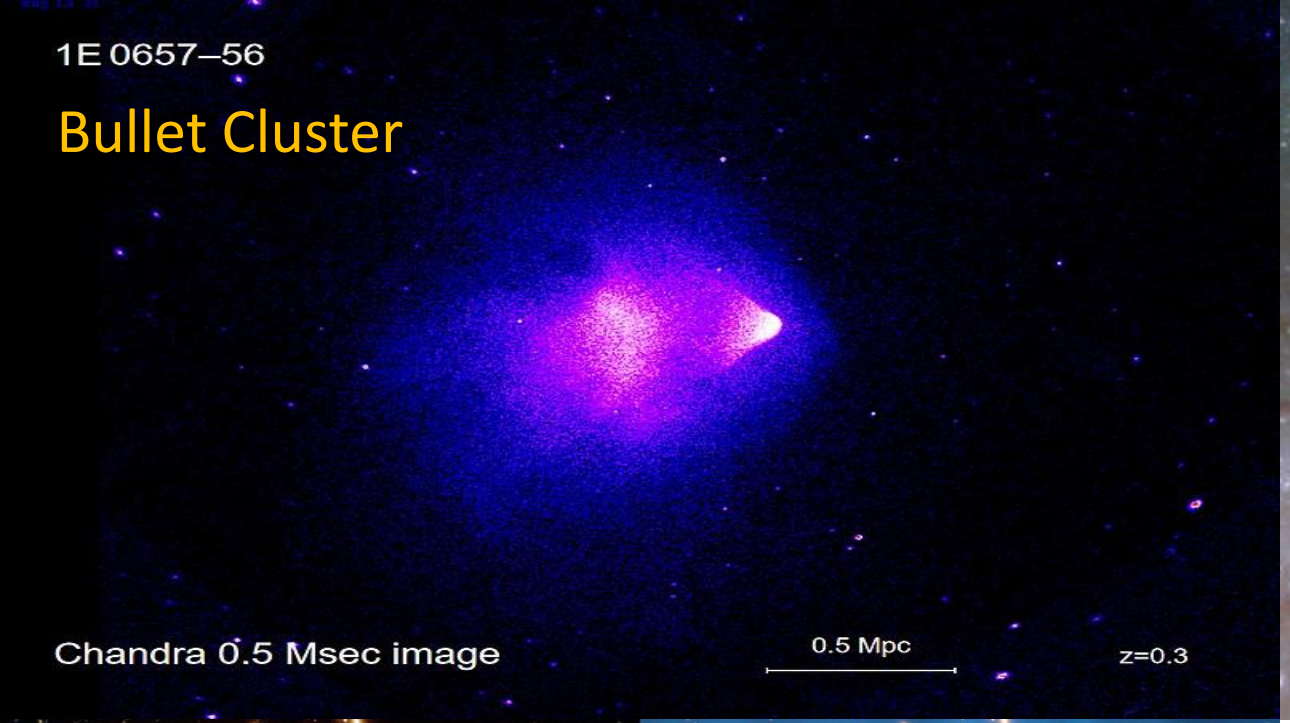
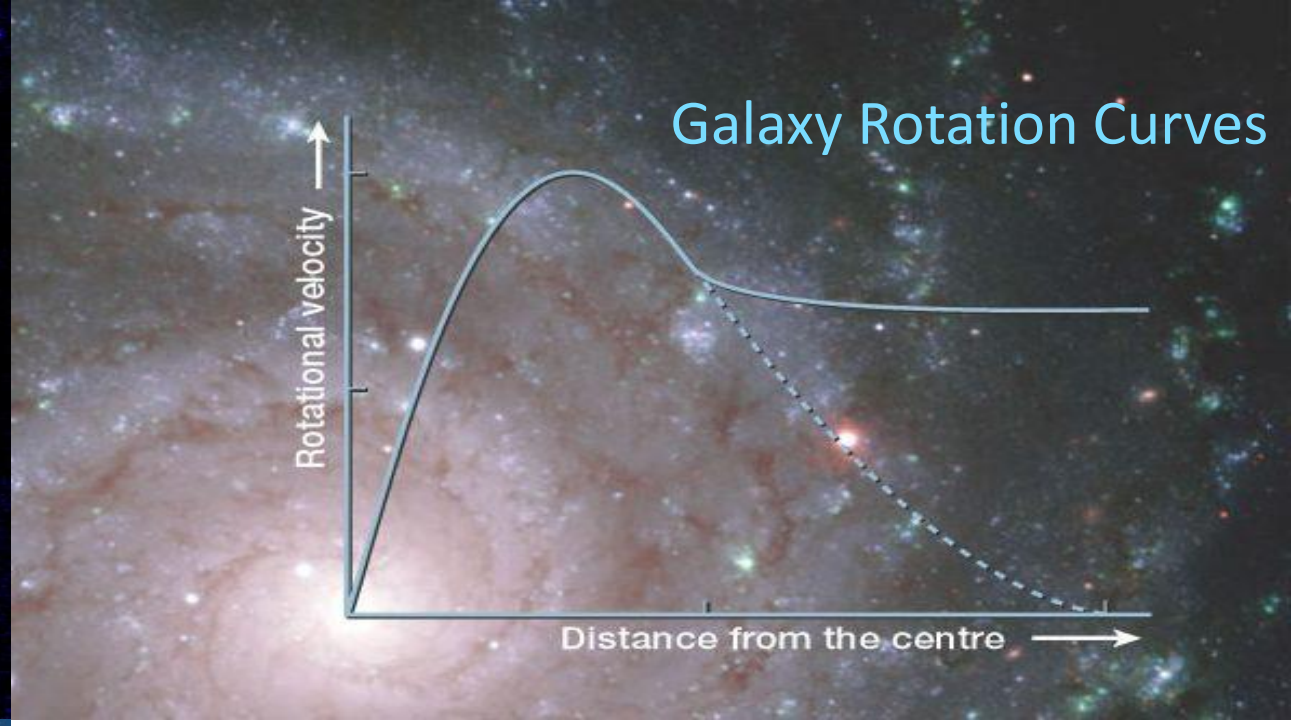
Assemblée Générale Enigmass2, Annecy

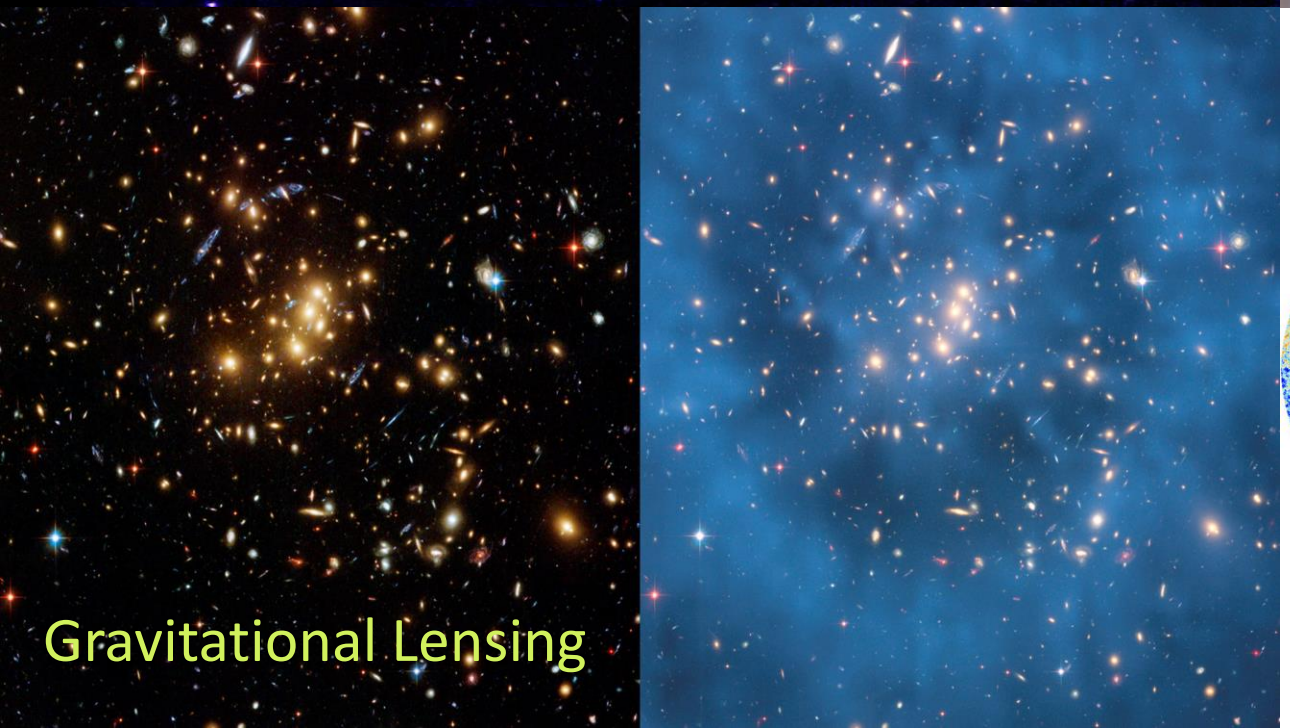
28 October 2021

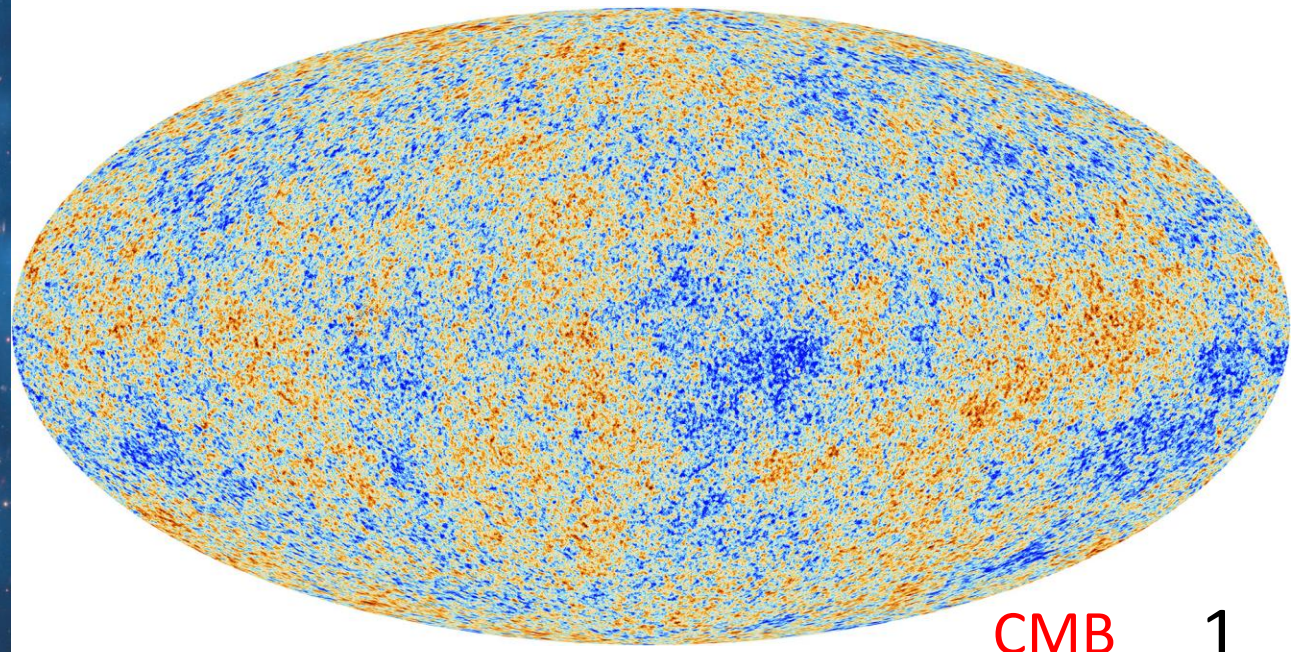

Bullet Cluster




Galaxy Rotation Curves

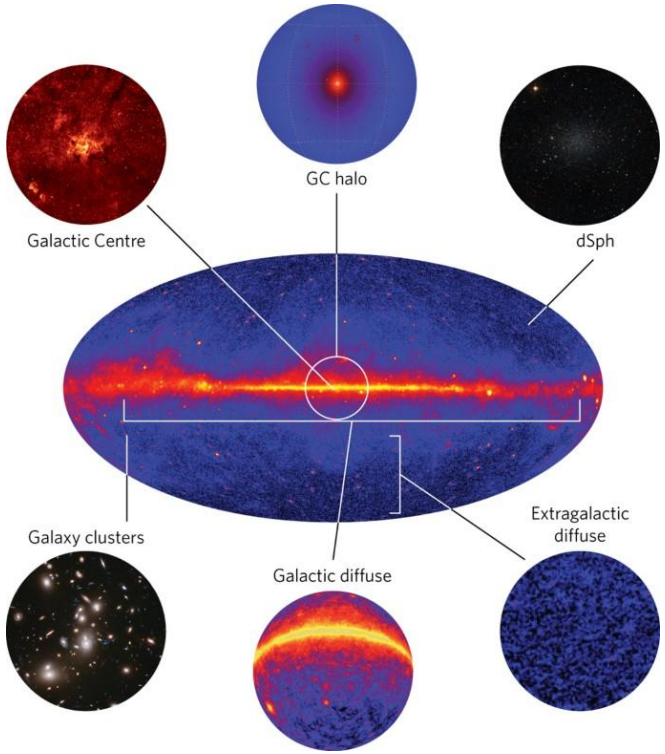


Gravitational Lensing

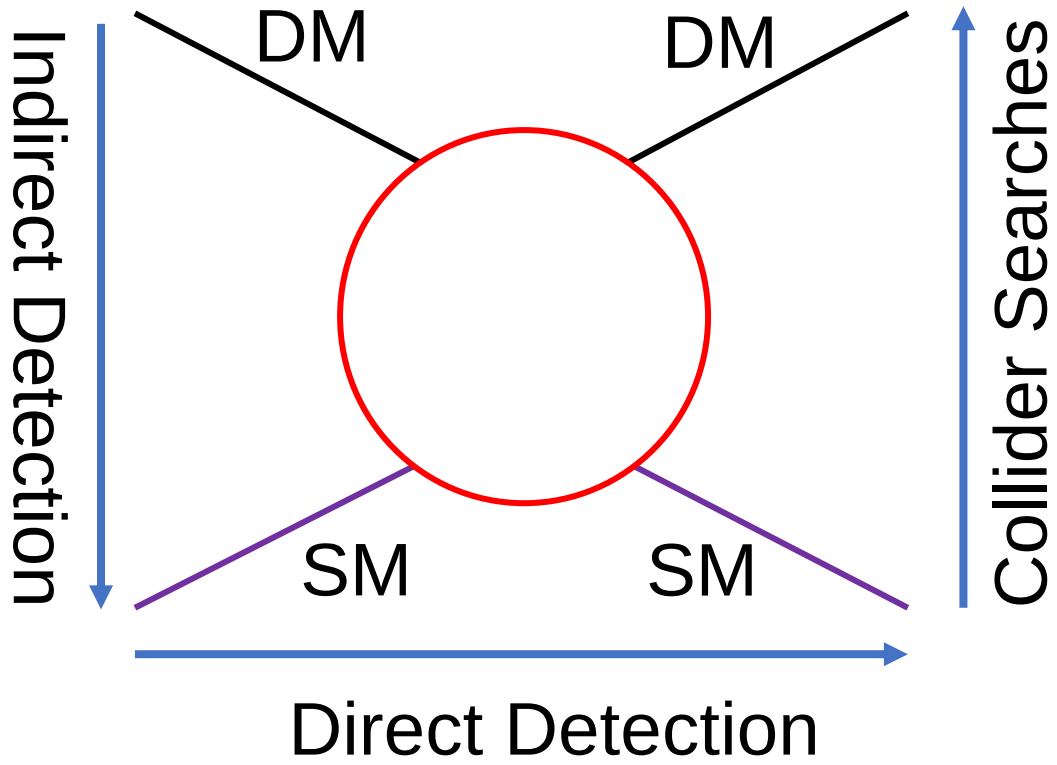


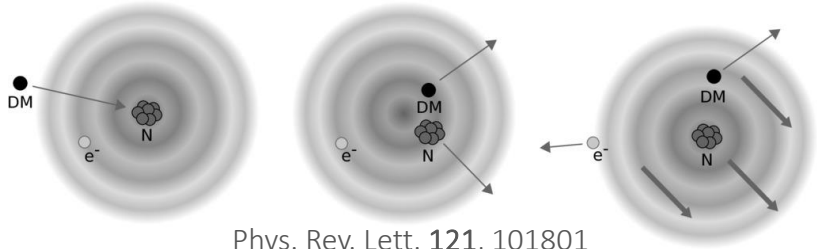
CMB

# How to Probe the Nature of Dark Matter?

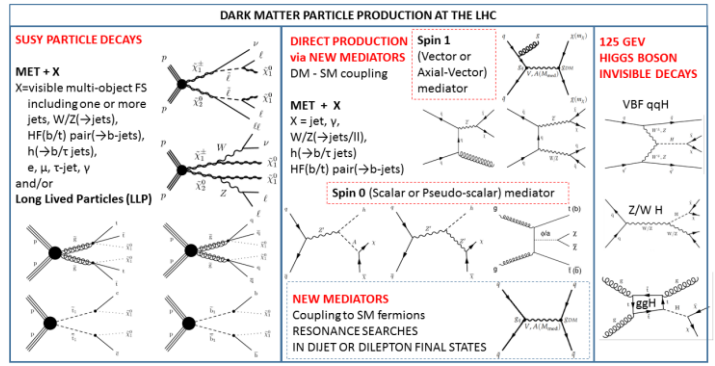



*Nature Physics* volume 13, pages224–231 (2017)




Phys. Rev. Lett. **121**, 101801

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# Direct Detection of Dark Matter

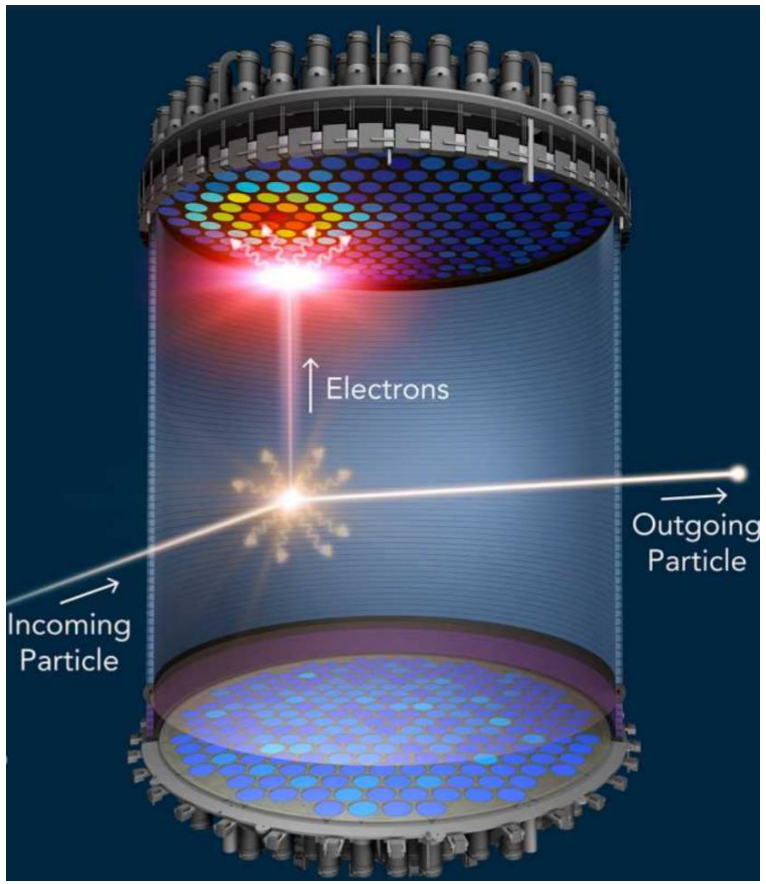



Image: Lux-LZ

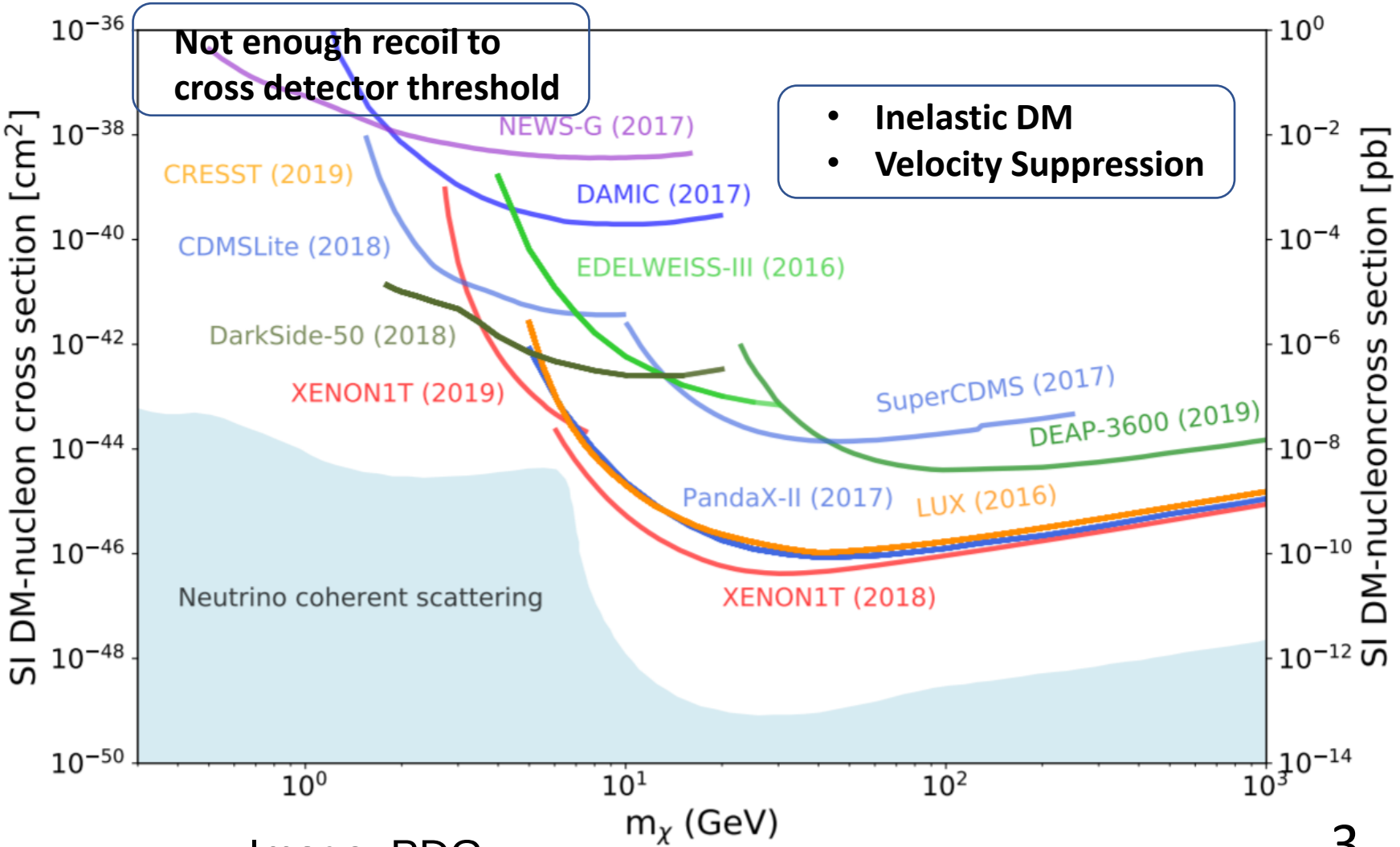



Image: PDG

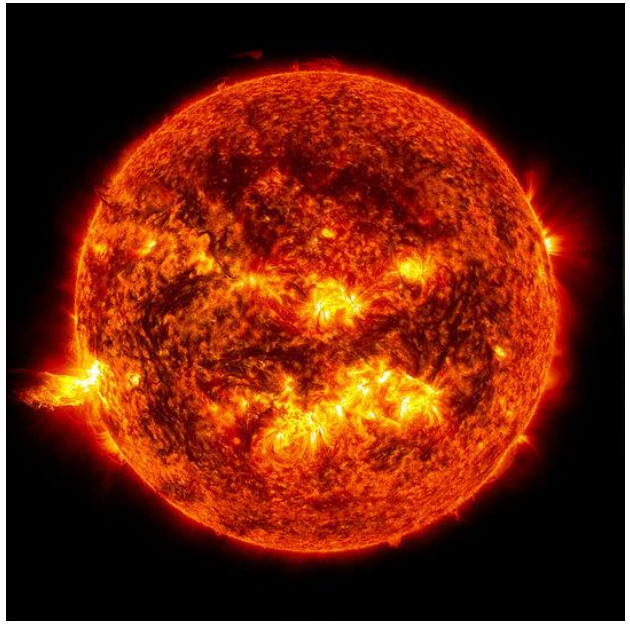
# What Celestial Bodies Can Probe Lower $\sigma_{\chi T}$ ?

## White Dwarfs

Density less by factor $10^8$ compared to NS

Neutron Stars $\sim 10^{-45}\,\mathrm{cm}^2$

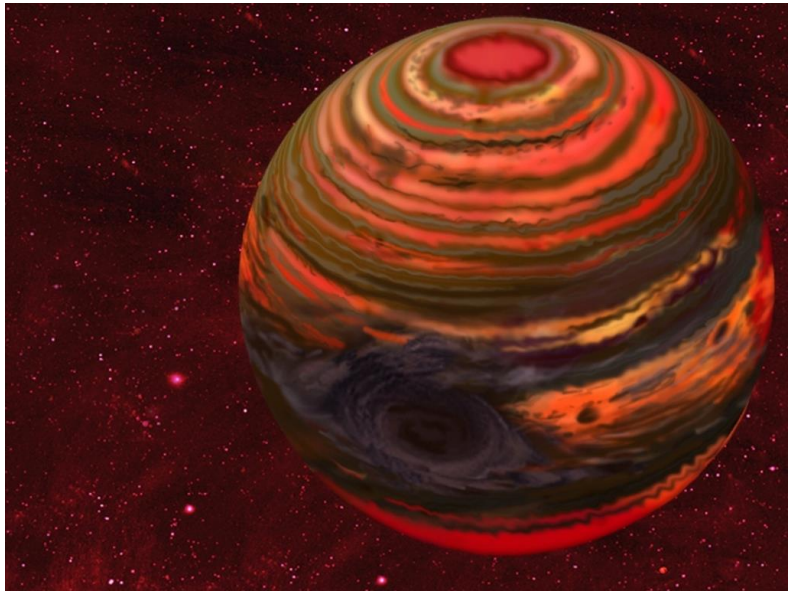
## Sun-like Stars



by factor $10^{14}$

Capture $\propto$ Density

## Brown Dwarfs



by factor $10^{11}$ - $10^{13}$

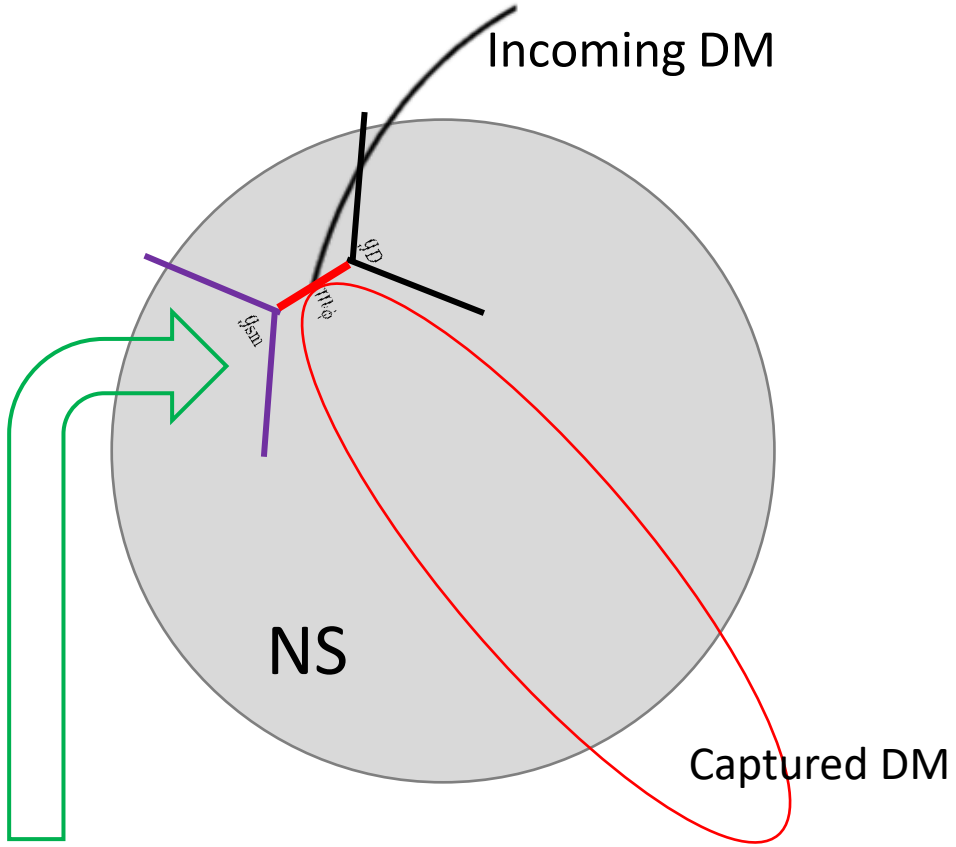
Other stuff $\sim 10^{-35}\,\mathrm{cm}^2$

Much larger cross-section $\sigma_{\chi T}$ needed to gather enough DM to generate signals in bodies other than NS

$10^{-35}\,\mathrm{cm}^2$ mostly excluded already! But not $10^{-45}\,\mathrm{cm}^2$

# How Does the Capture Work?

Continuous dark matter flux incident on the NS




$$M_\star = 1.5\, M_\odot$$
$$R_\star = 12.6\,\mathrm{km}$$

$\sim 5 \times 10^{57}$ Targets

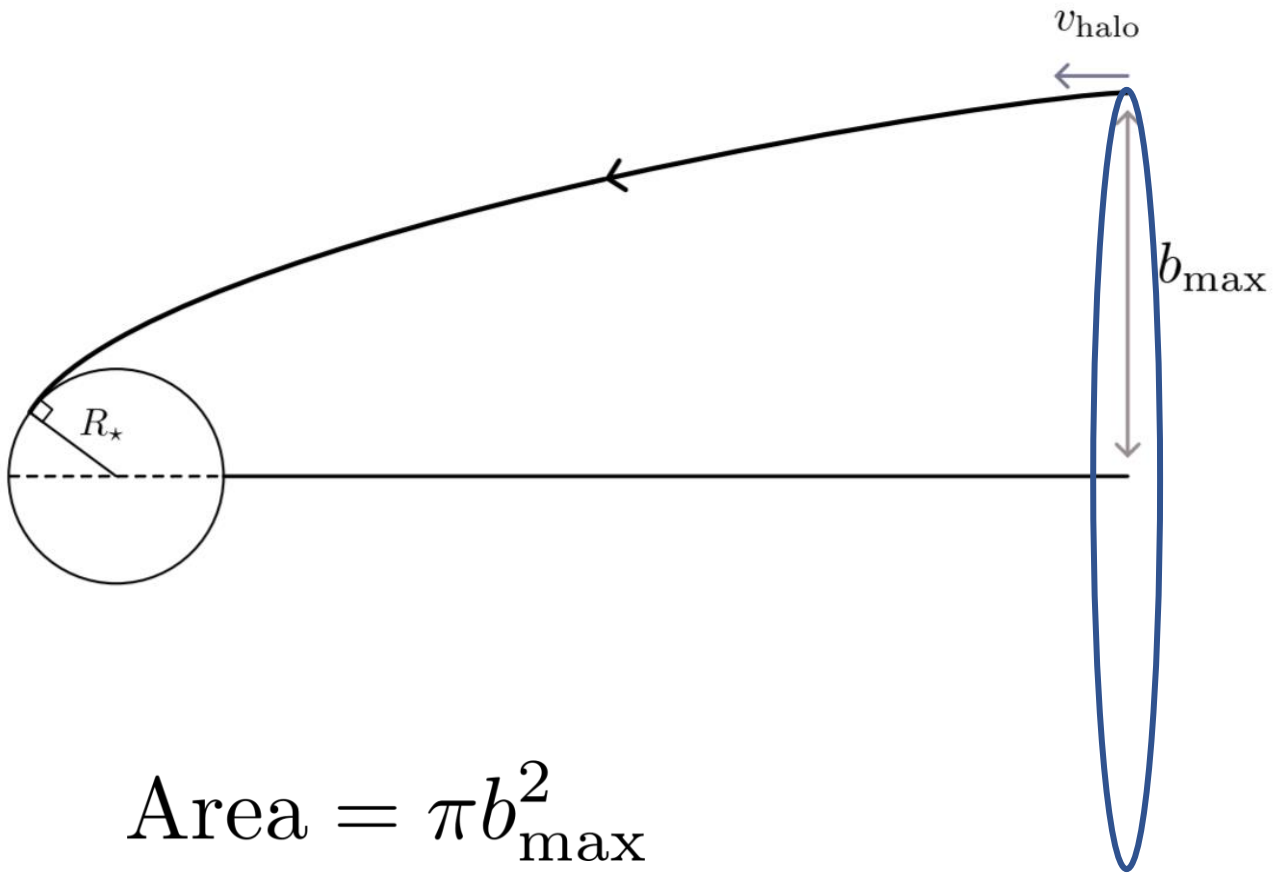
Densely Packed

Accelerates DM to $v \sim 0.6\, c$

Interaction where DM loses more energy than its Halo KE

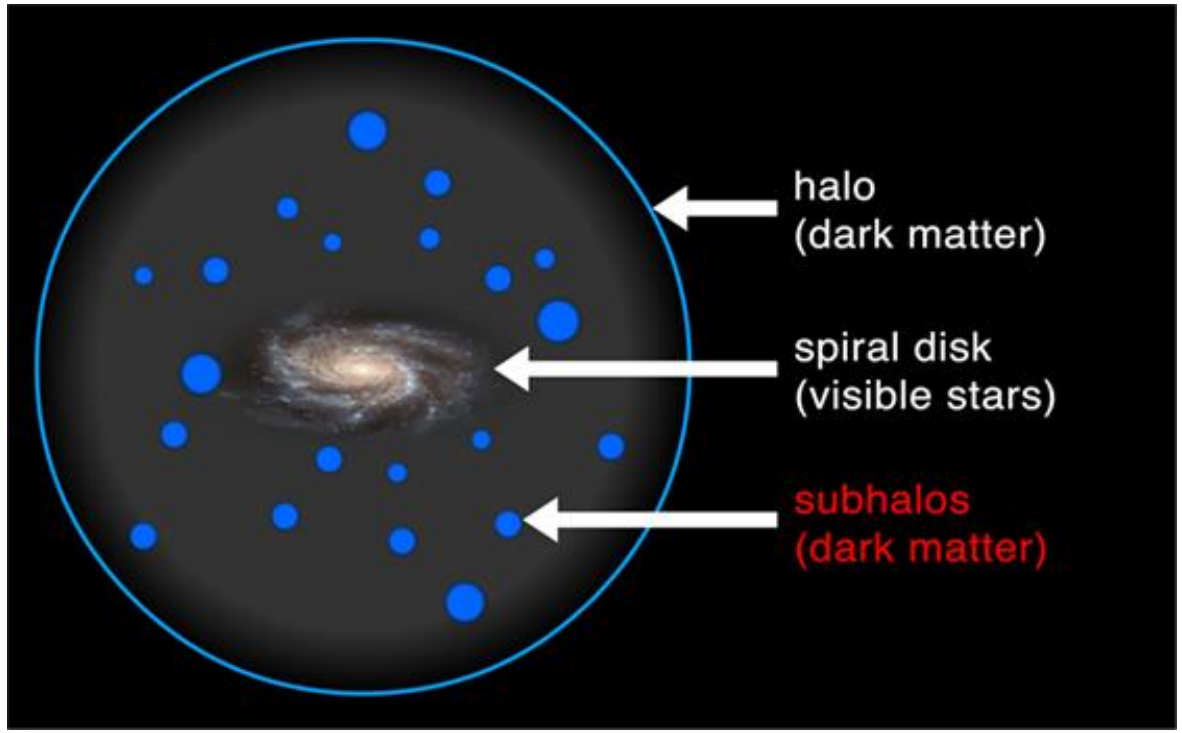
# Flux

Continuous dark matter flux incident on the NS




$$\text{Area} = \pi b_{\rm max}^2$$

DM being fed to NS with velocity $v_{\rm halo}$

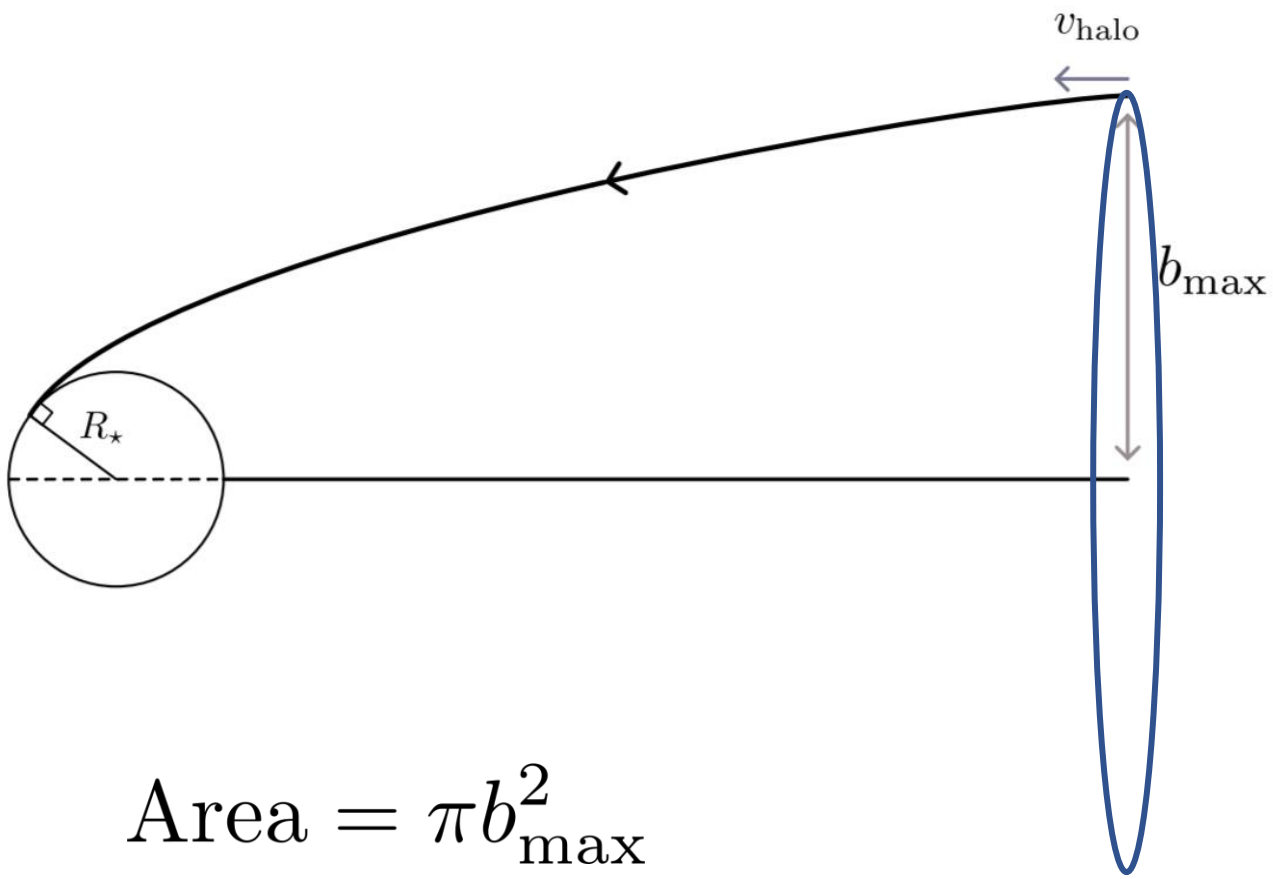



$$v_{\rm halo} = 8 \times 10^{-4},\ \rho_\chi = 0.3\ \text{GeV/cc}$$

$$M_\star = 1.5\, M_\odot,\ R_\star = 12.6\,\text{km}$$

# Flux

Continuous dark matter flux incident on the NS




$$\text{Area} = \pi b_{\rm max}^2$$

DM Flux is : $\pi b_{\rm max}^2 \rho_\chi v_{\rm halo}$

We take:

$$v_{\rm halo} = 8 \times 10^{-4},\ \rho_\chi = 0.3\ \text{GeV/cc}$$

$$M_\star = 1.5\, M_\odot,\ R_\star = 12.6\,\text{km}$$

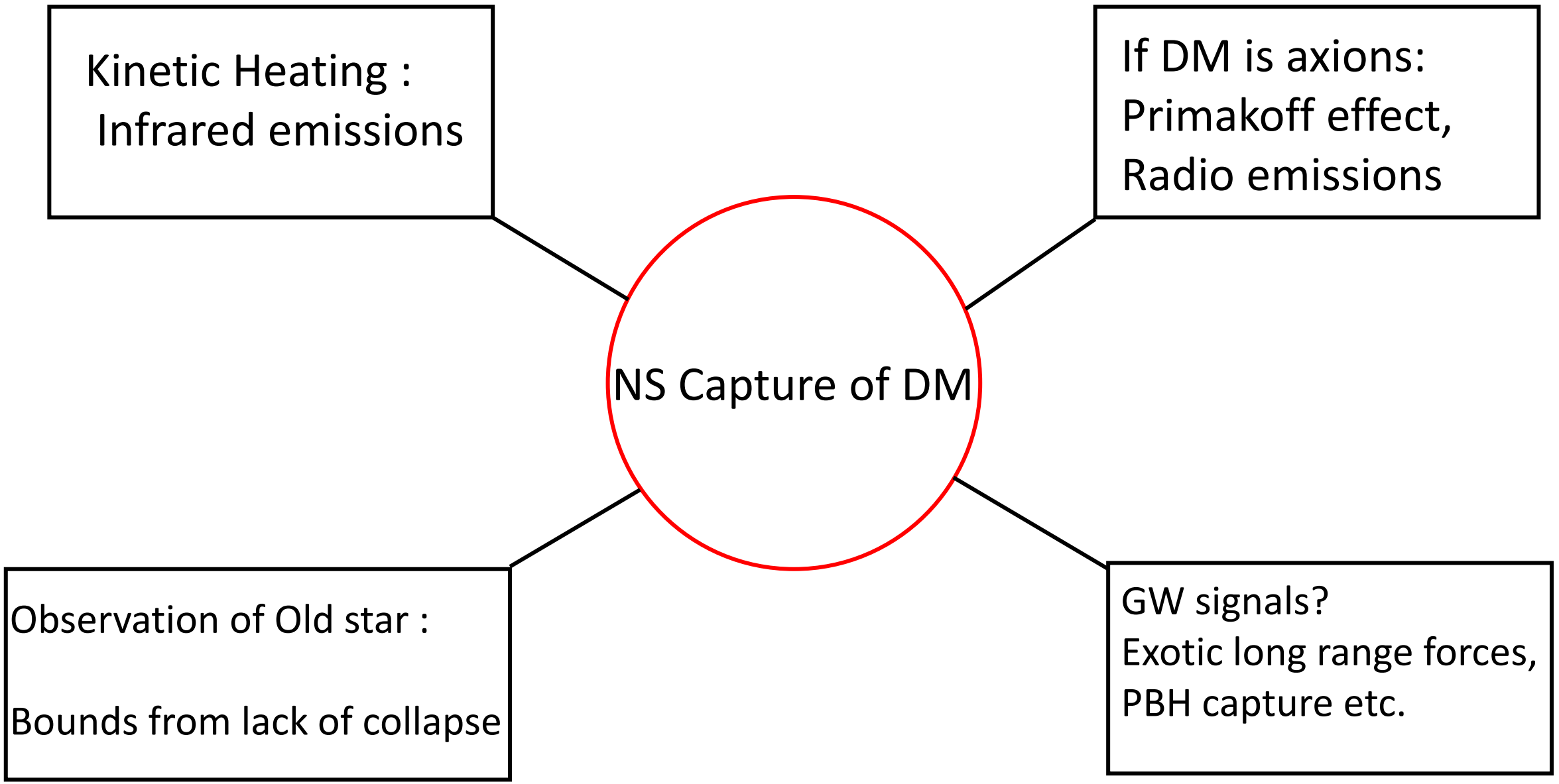
This means :

$$b_{\rm max} = \frac{R_\star}{v_{\rm halo}} \sqrt{\frac{2GM}{R}} \left(1 - \frac{2GM}{R}\right)^{-1/2}$$

$$\frac{2GM_\star}{R_\star} \sim 0.35 \qquad b_{\rm max} \sim 10^3\, R_\star$$

Large compared to $R_\star$!

# Types of Signals



# Dark Kinetic Heating

# NS Kinetic Heating : Dark Fires

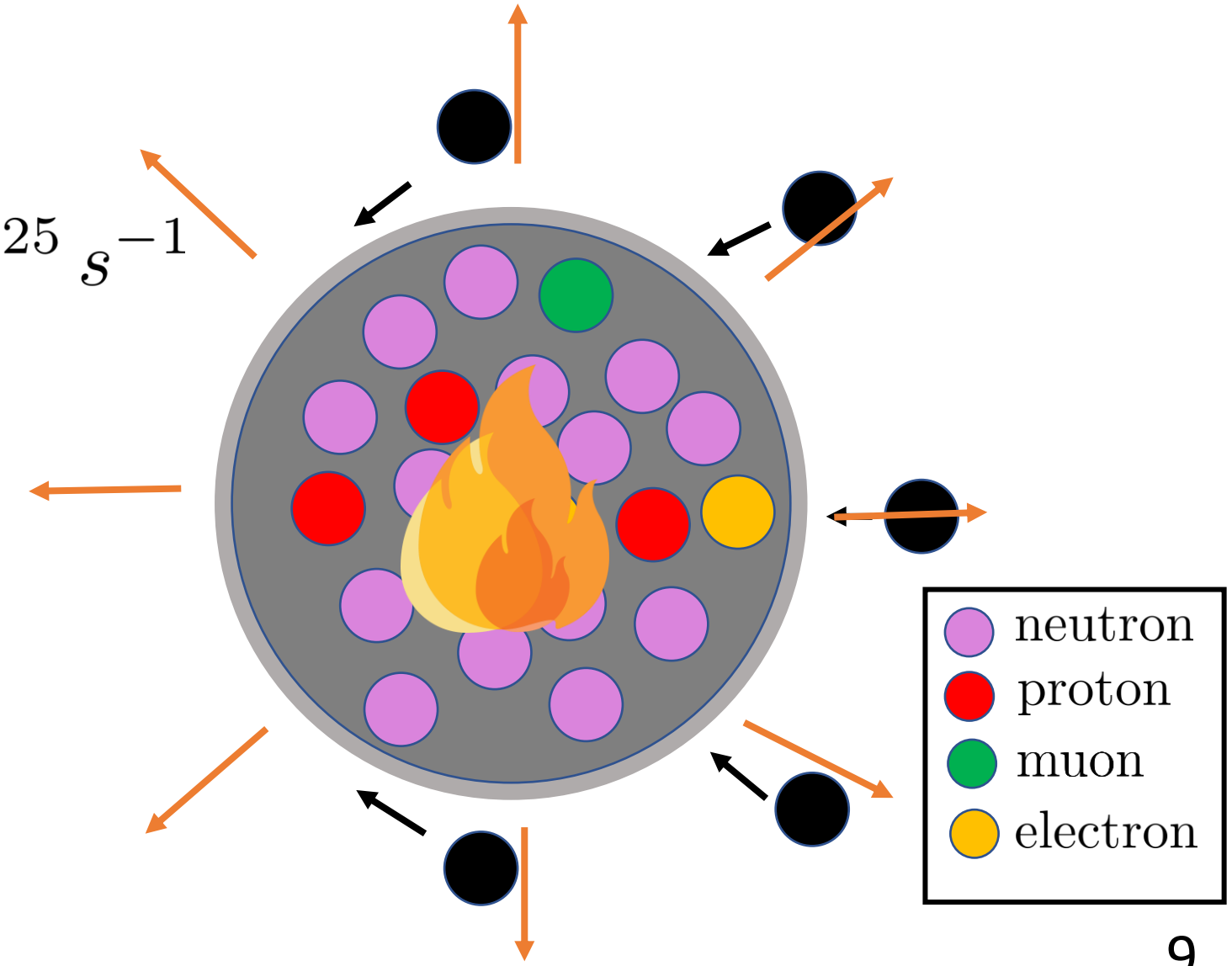
$$\gamma_{\rm esc} \sim 1.35$$

$$\dot{E} = f \times (\gamma_{\rm esc} - 1) \times 4 \times 10^{25}\, s^{-1}$$

**Stephan-Boltzmann Law**

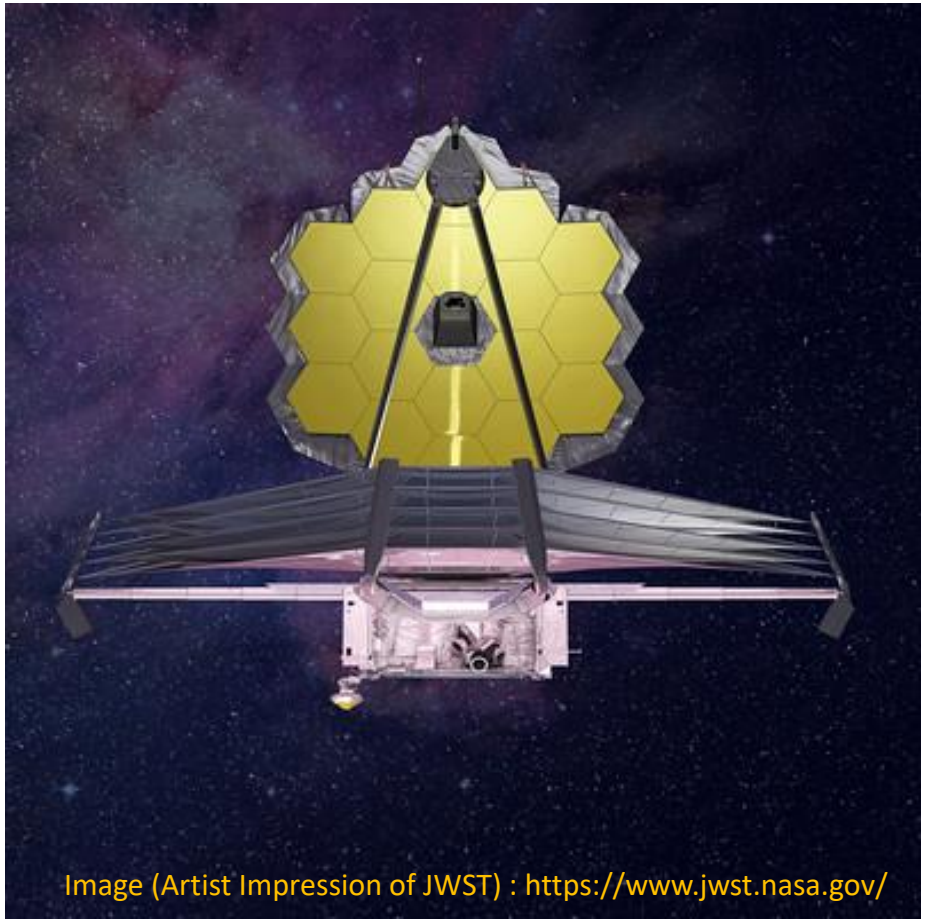
$$\dot{E} = 4\pi R_\star^2 \sigma_{\rm SB} T^4$$

$$T \sim 1600 f^{1/4}\, K$$

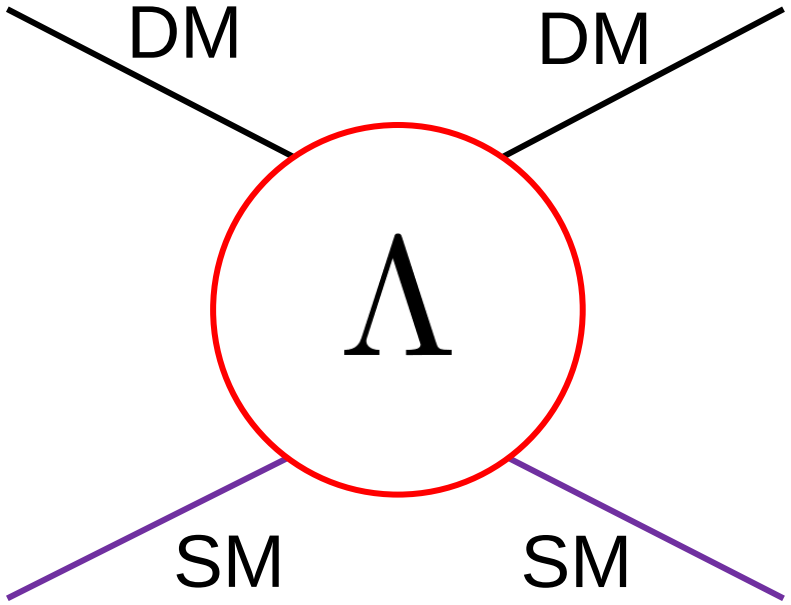


# How to Detect Excess Heating?

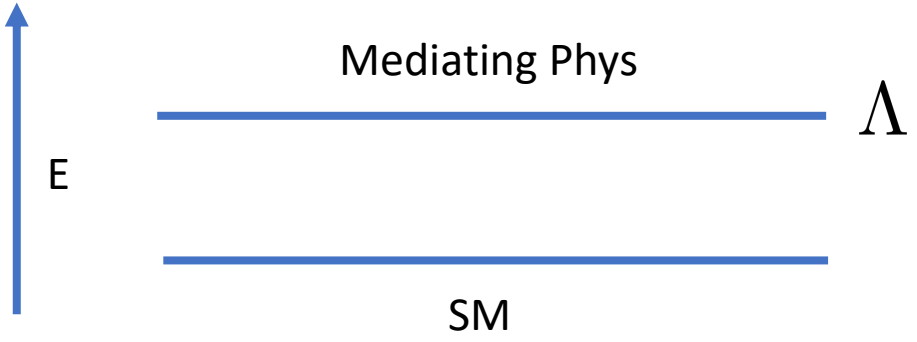
Find an old “nearby” NS with radio telescope with expected temp $\mathcal{O}(10-100)\,\mathrm{K}$

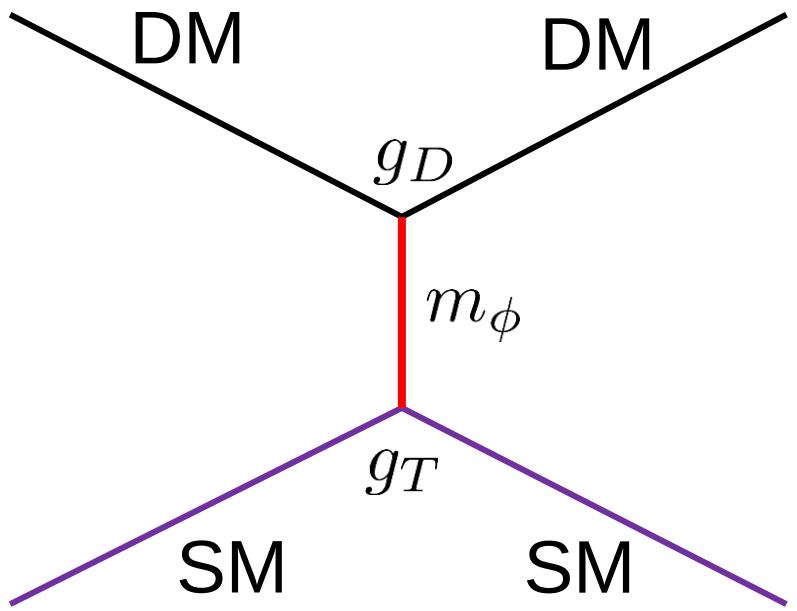




Point JWST towards it to see if it has infrared temperatures of $\mathcal{O}(1000)\,\mathrm{K}$




$\Lambda >>$ momentum transfer

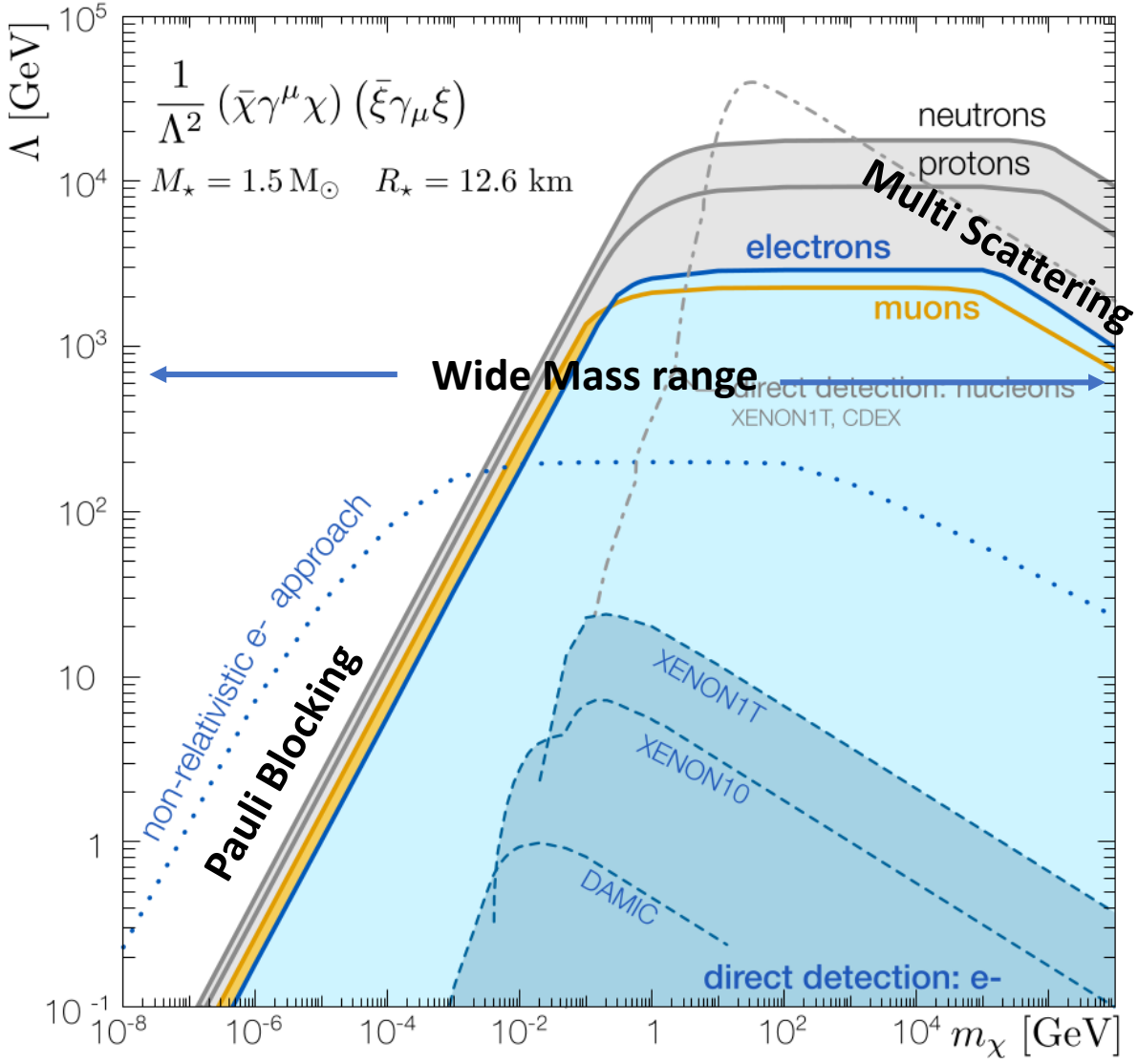


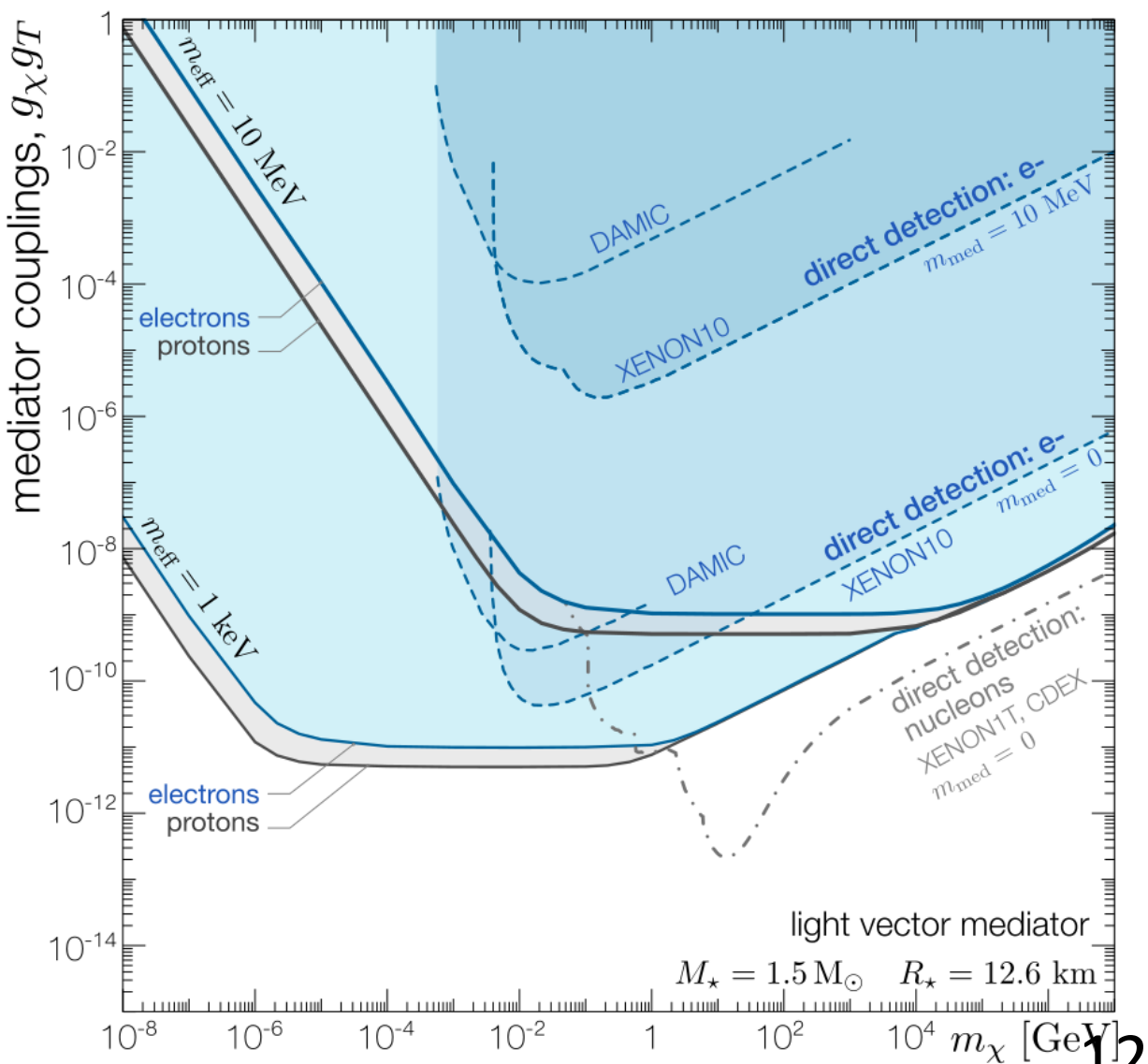




Light mediator

$m_\phi <$ momentum transfer

# Reach



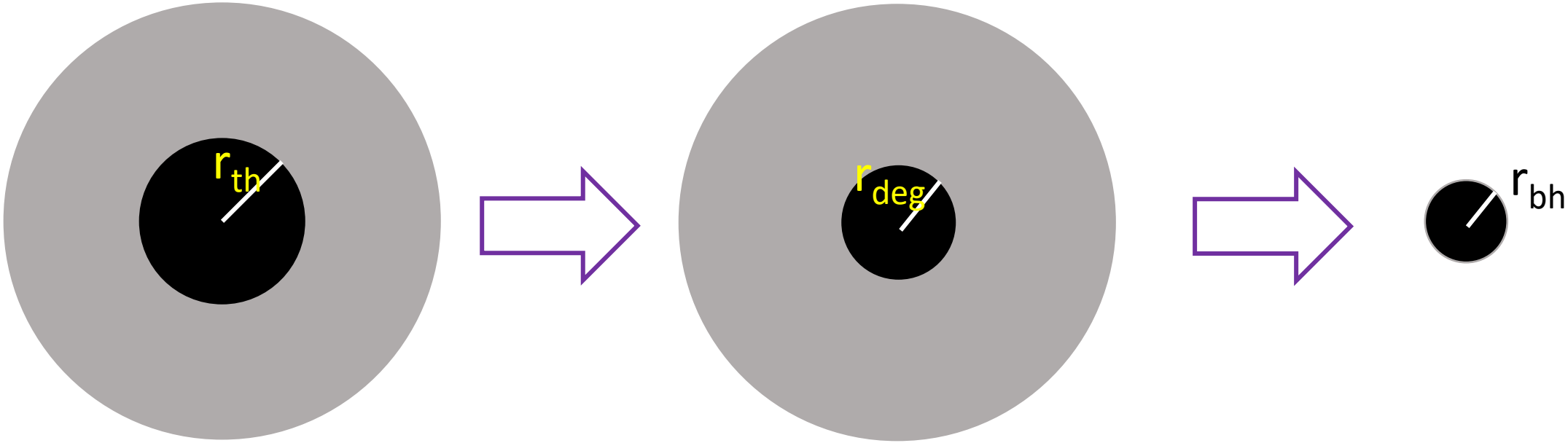




Joglekar, Raj, Tanedo, Yu *Phys.Lett.* B (2020) 135767, *Phys.Rev.D* 102 (2020) 12, 123002

# Collapse to Black Hole

## Probing ‘invisible’ forces in the dark sector

# Dark Cores




Thermal radius :
Virial balance between temperature & gravity

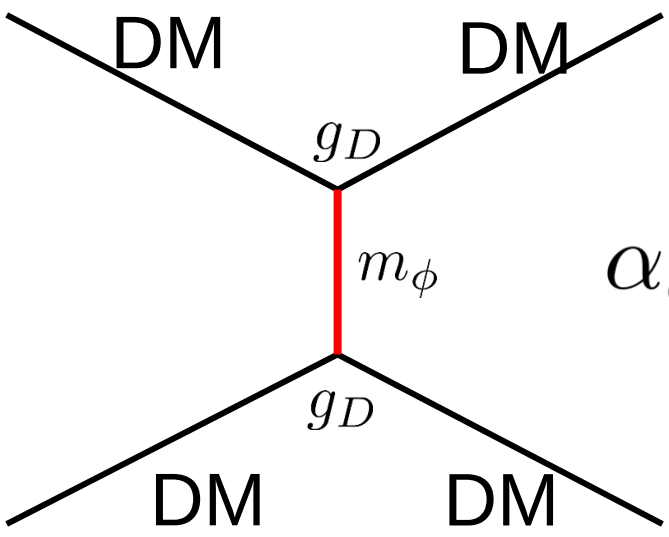
Nudge due to an additional attractive force can trigger collapse

Resultant BH can eat up the star

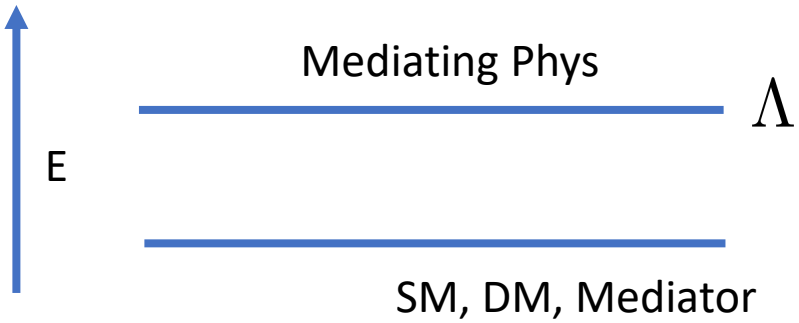
$$r_{th} \sim \left(\frac{T}{T_\odot}\right)^{1/2} \left(\frac{1\,\mathrm{GeV}}{m_\chi}\right)^{1/2} \mathrm{m}$$

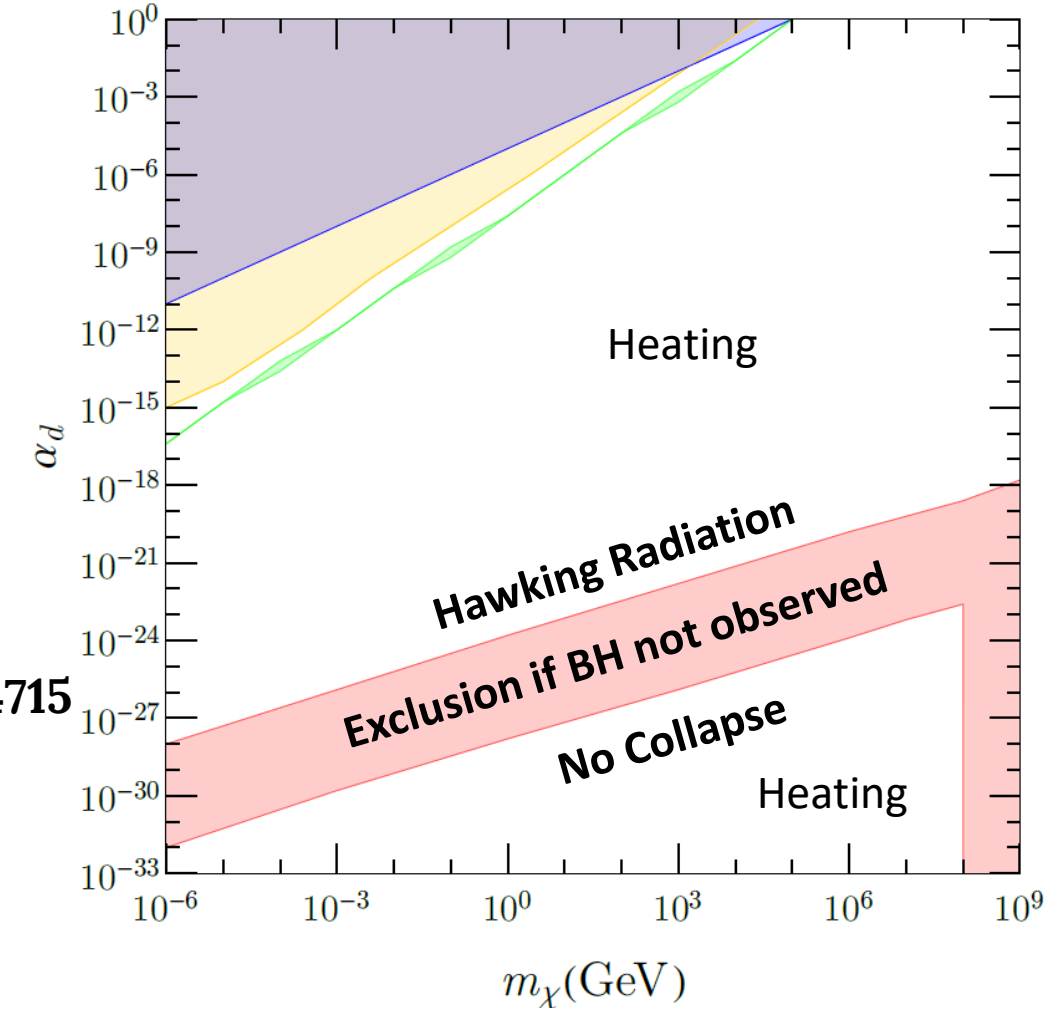
Old star observation ⇨ Constraint on attraction strength

# Exclusion Bounds from Non-observation of Collapse




$$\alpha_d = \frac{g_D^2}{4\pi}$$




Remarkable that huge parameter space prev. ignored, very tiny couplings for self-interactions can be probed

AJ, Serpico 2112.xxxx

# Summary

- Neutron stars are great for learning more about the nature of DM
- Can complement or exceed terrestrial searches
- Collapse or its non-observation can put strong bounds on dark sector parameters
- Thermal emission of old NS is an intriguing frontier. JWST launches very soon, so may be more data soon …

Thank You!