Multi-scatter Capture of Intermediate Mass Dark Matter by Population III Stars

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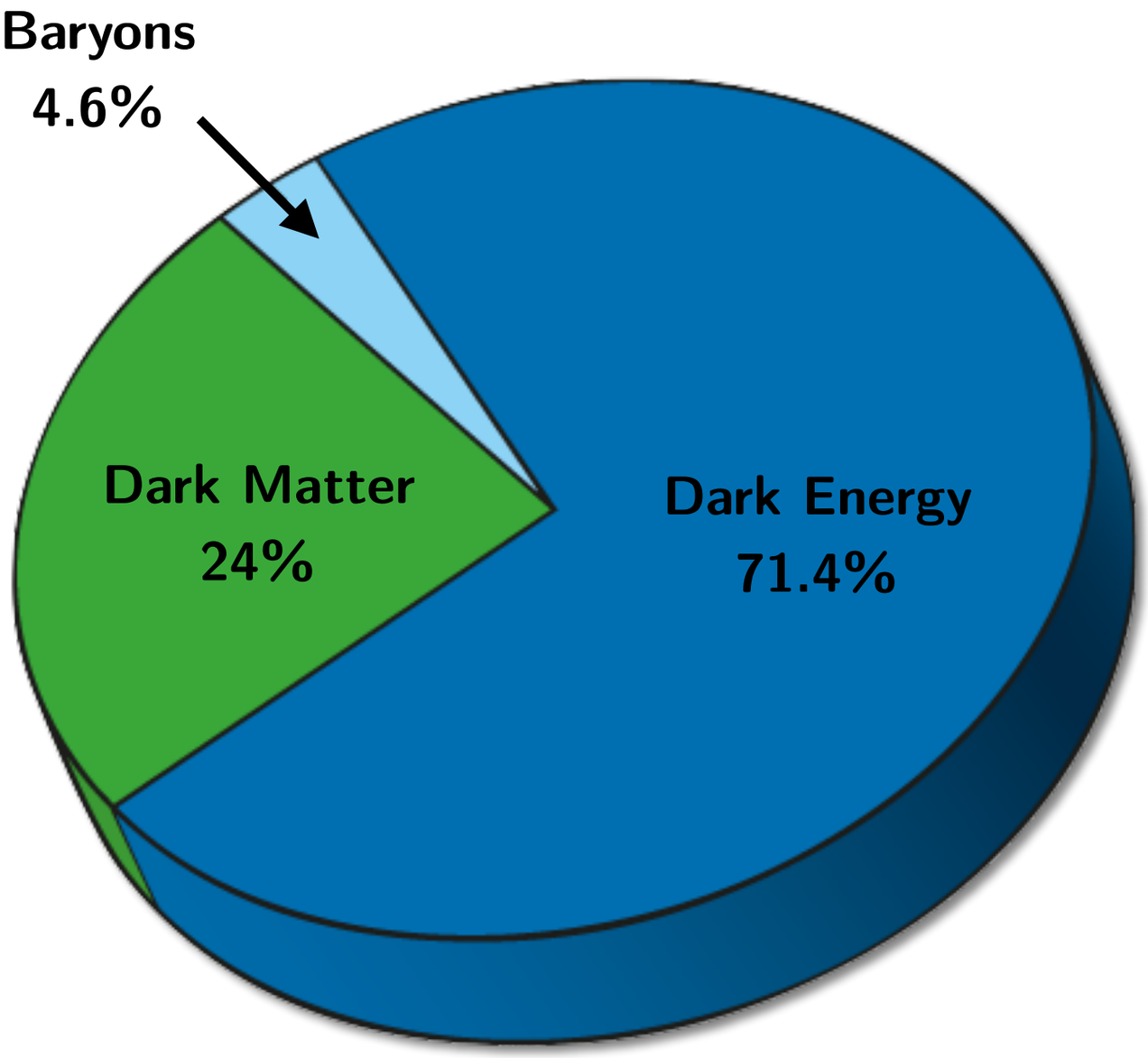
Physics 410
Prof. Cosmin Ilie

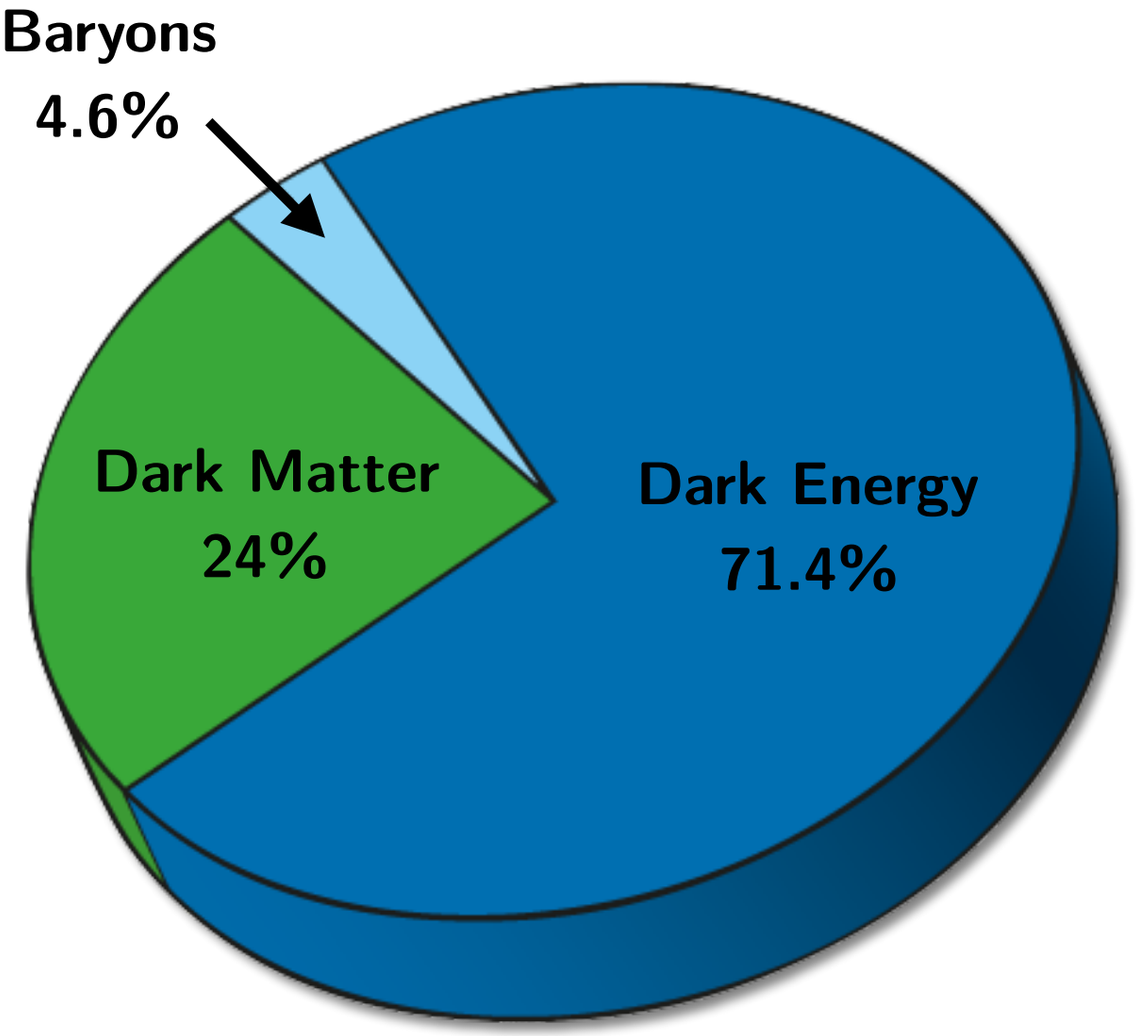
Introduction
Capture Rates
Stellar Luminosity
Upper Mass Limits
Dark Matter
Population III Stars

Ingredients of the Universe

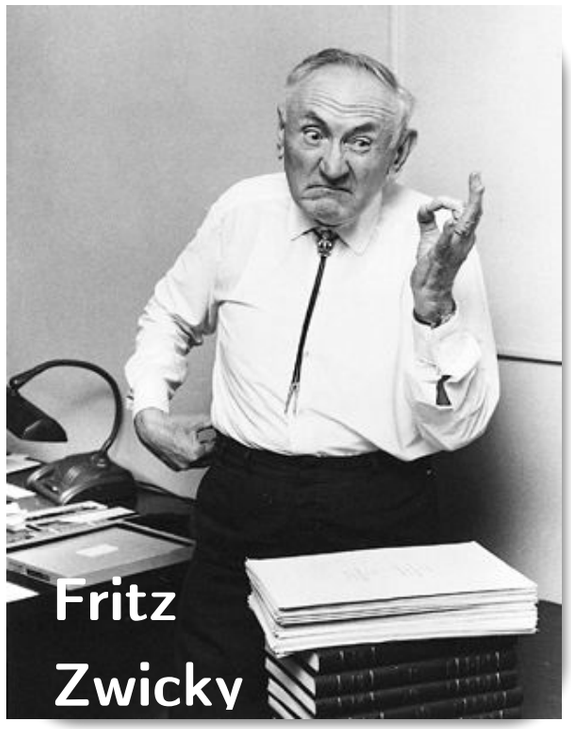


Ingredients of the Universe

- Baryons: Galaxies, Stars, Planets
- Dark Energy: Accelerates expansion of the Universe
- Dark Matter: Aptly named.



Dark Matter Evidence


Fritz Zwicky


Coma Cluster


Vera Rubin


Andromeda Galaxy

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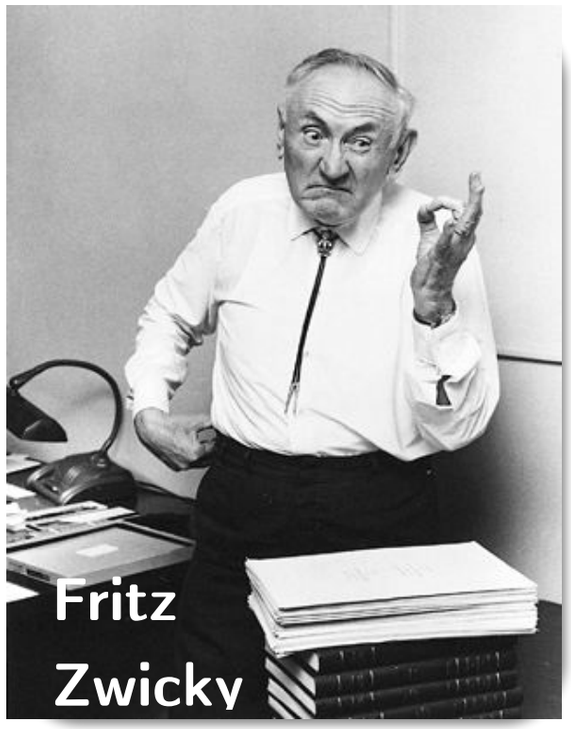
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1937: *On the Masses of Nebulae and of Clusters of Nebulae*


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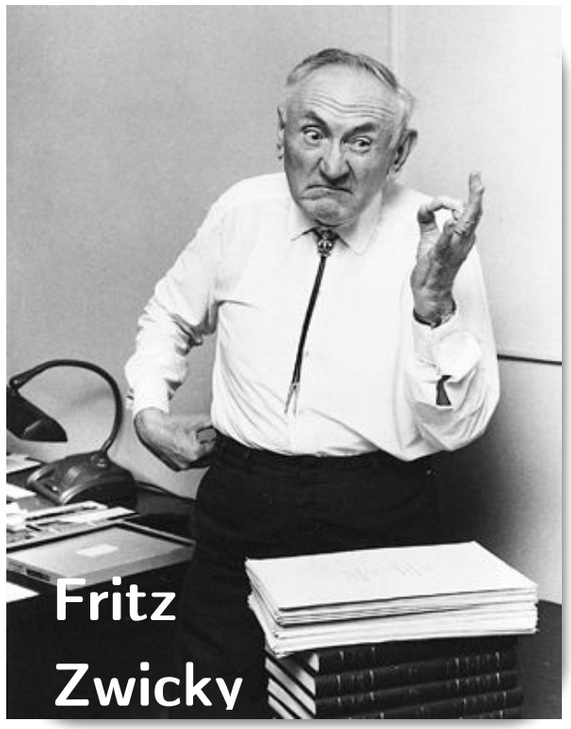

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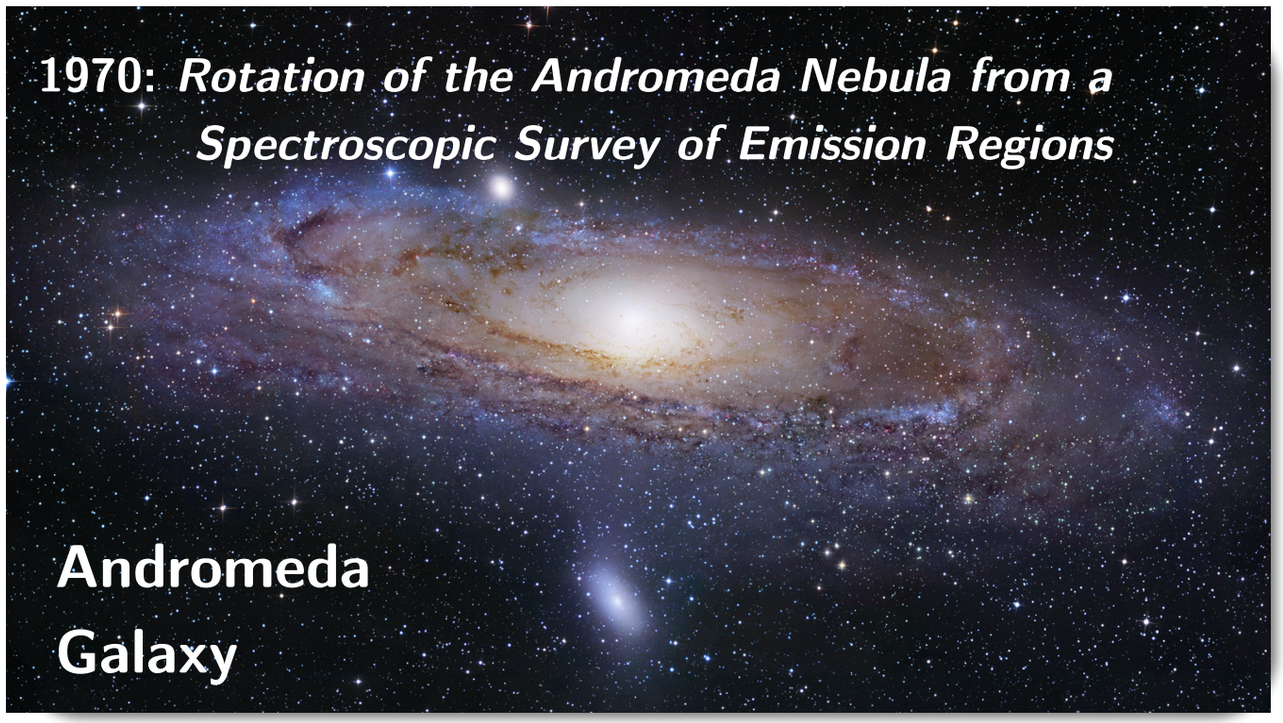
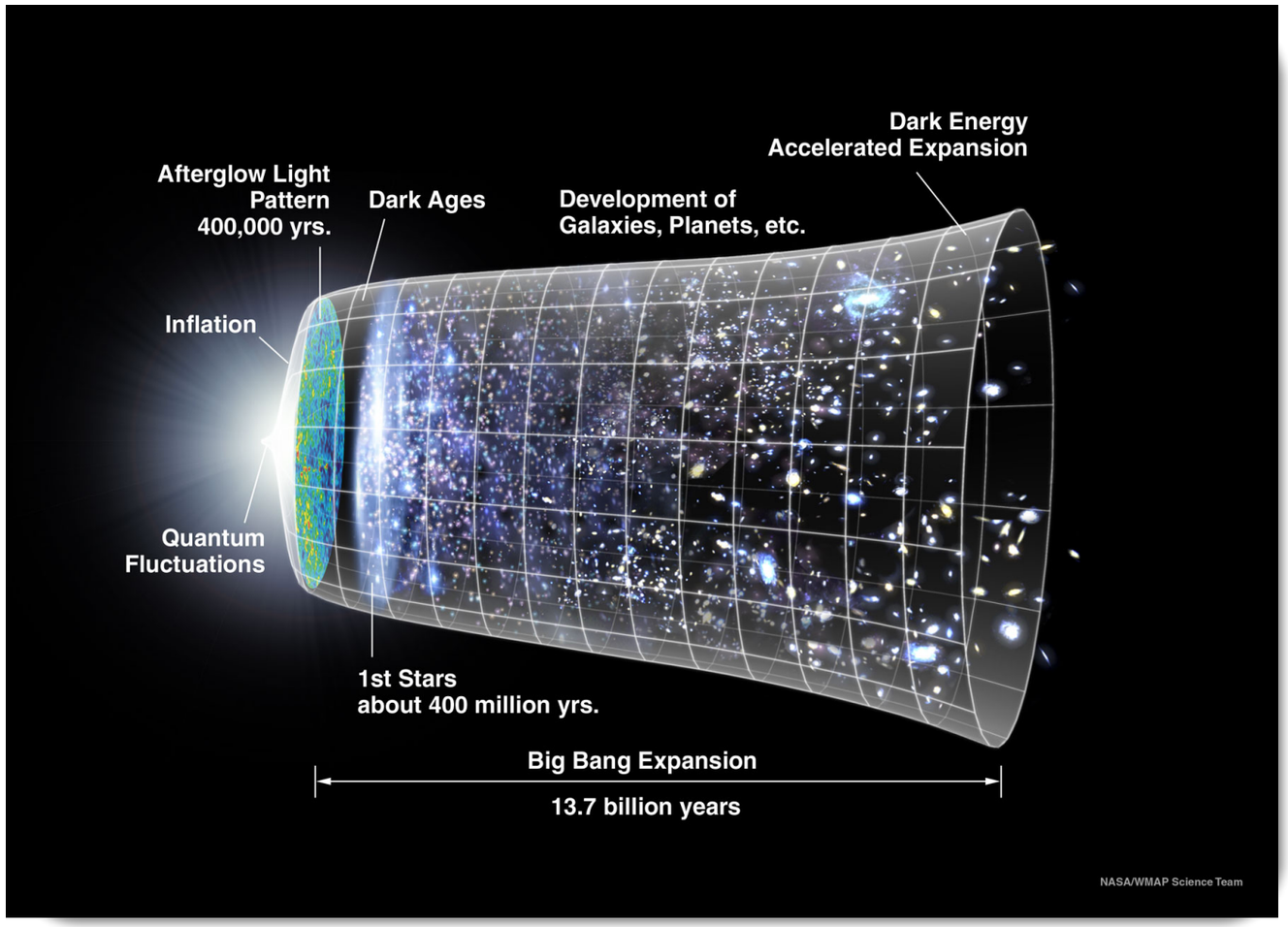


Andromeda Galaxy

The First Stars in the Universe

- $z \sim 10 - 50$



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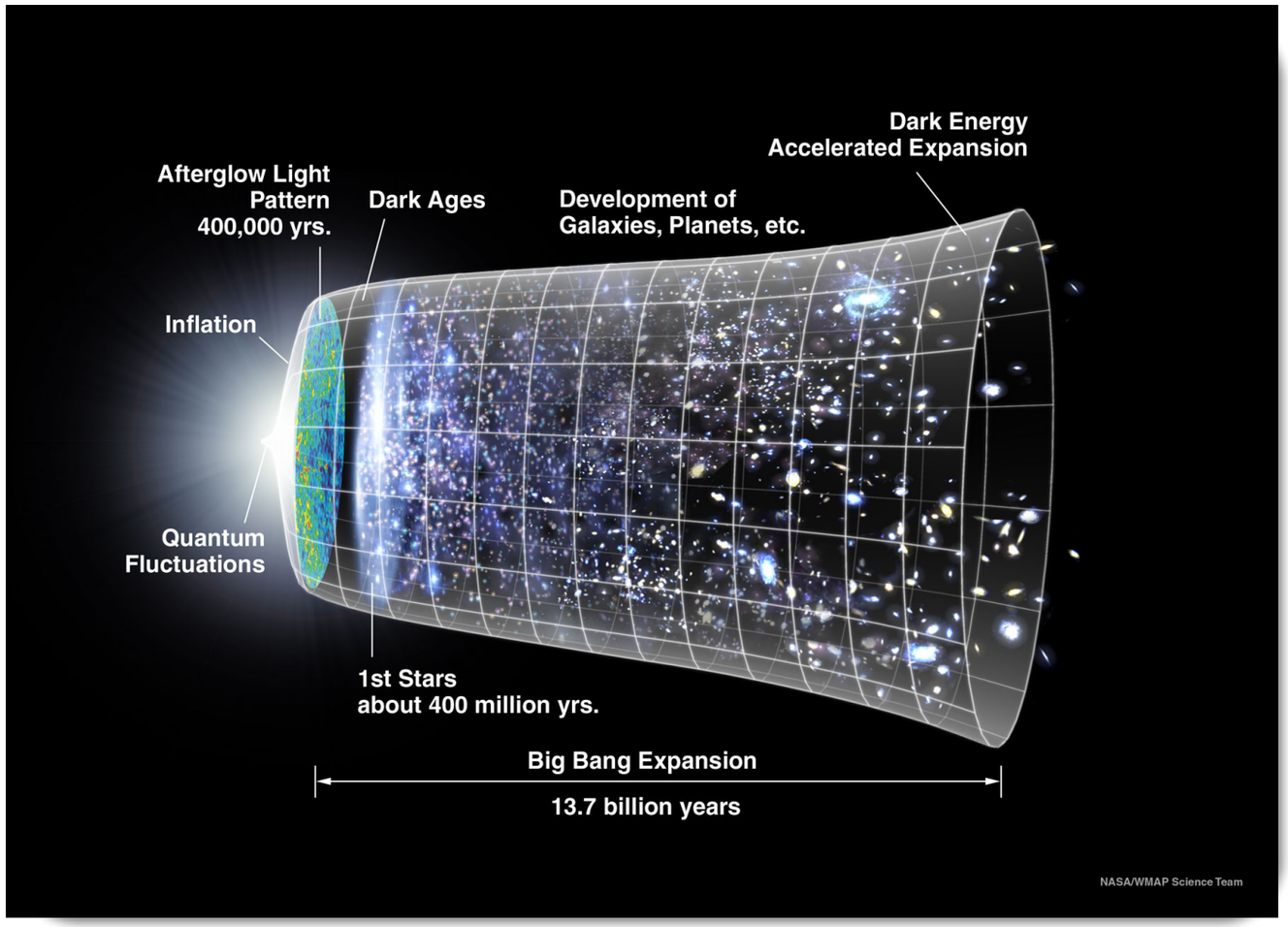

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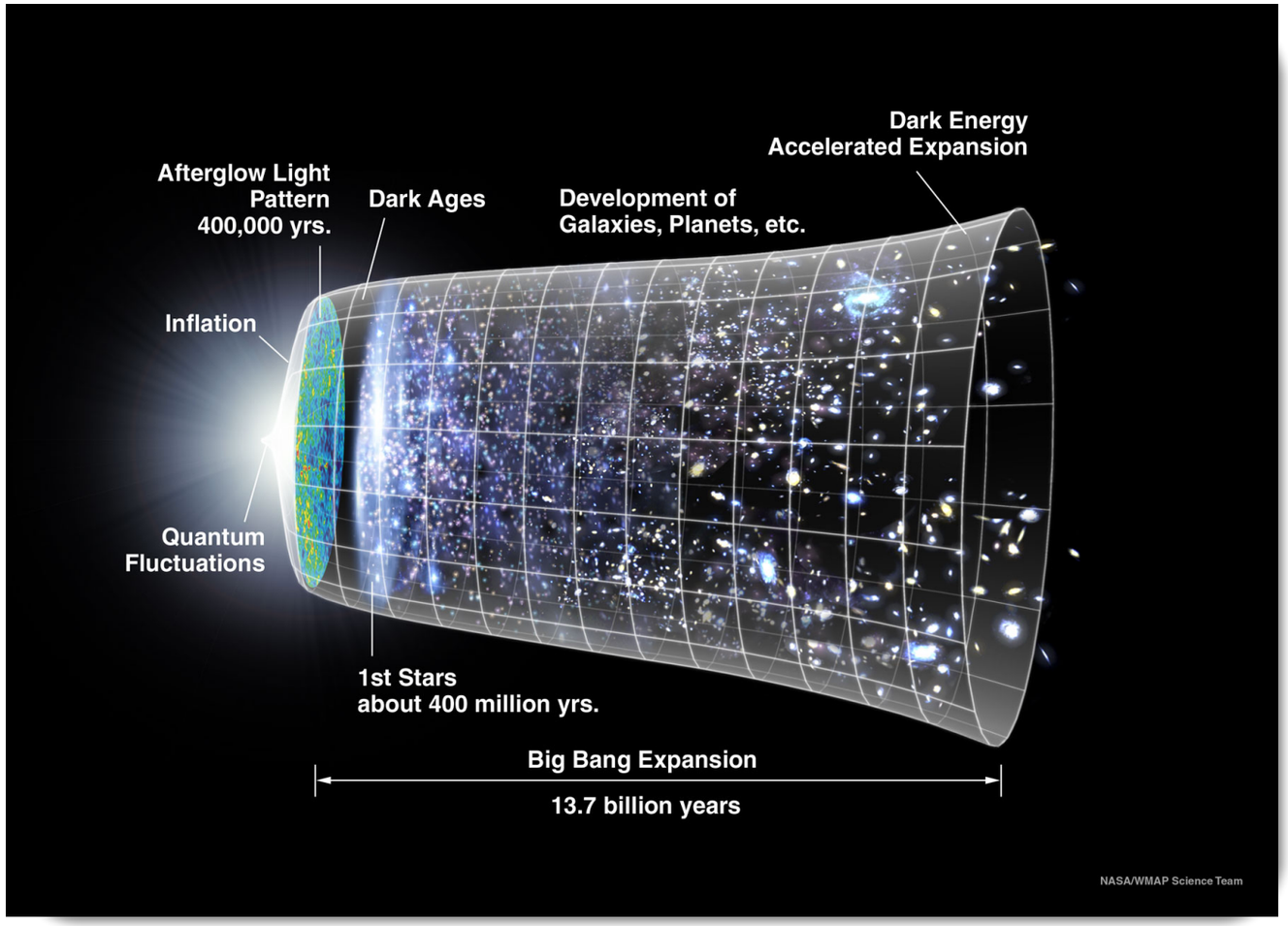

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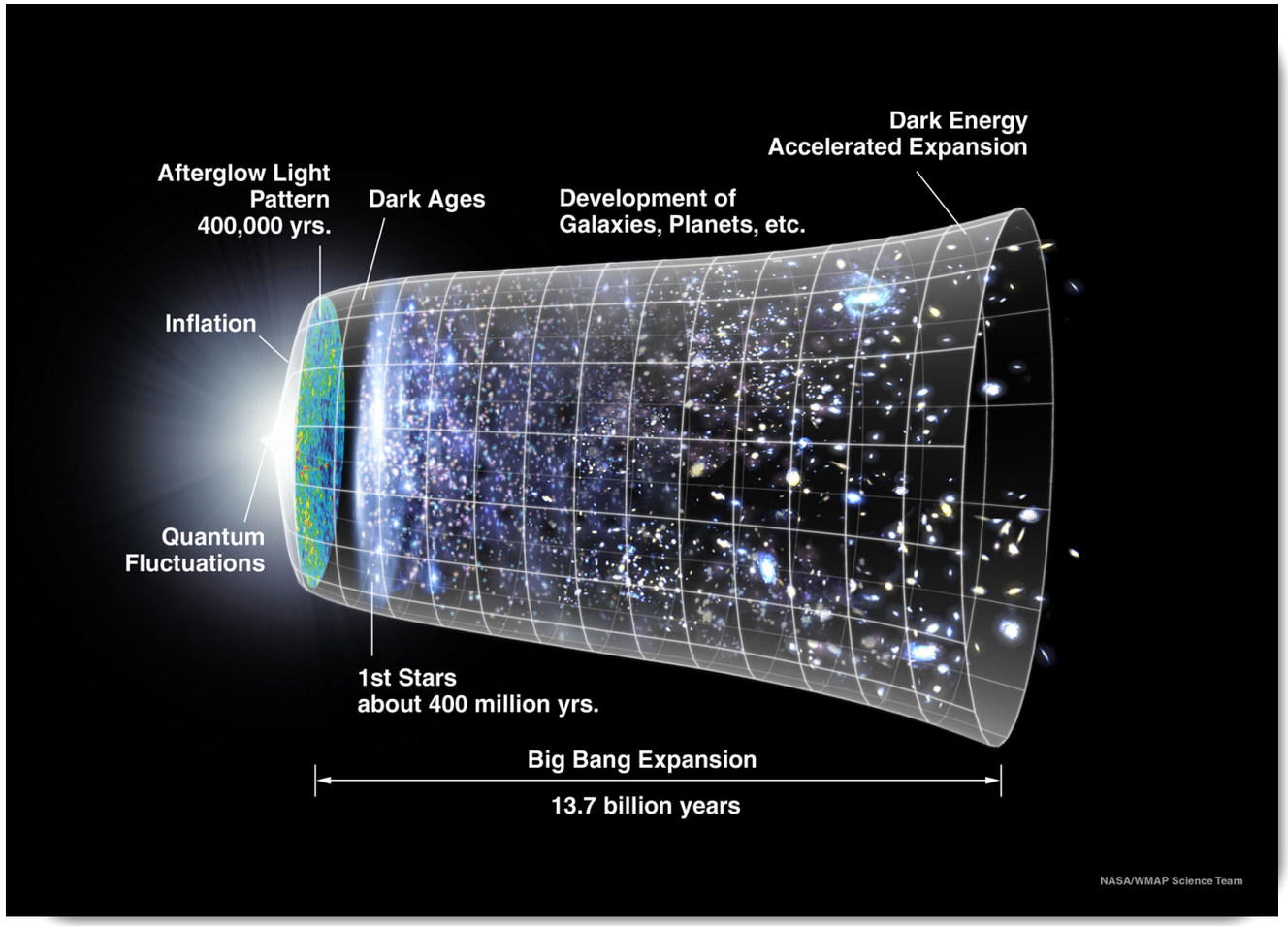

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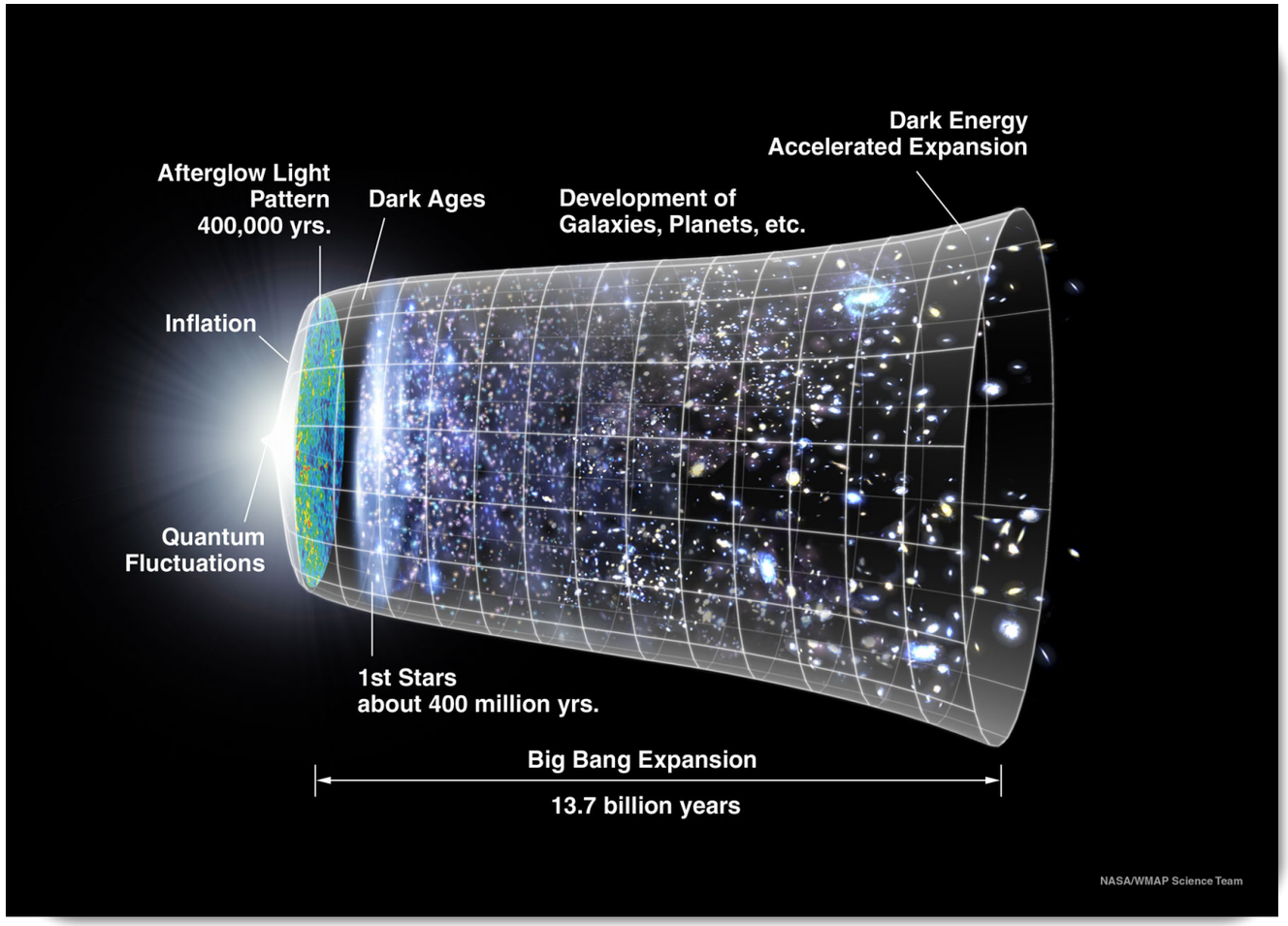

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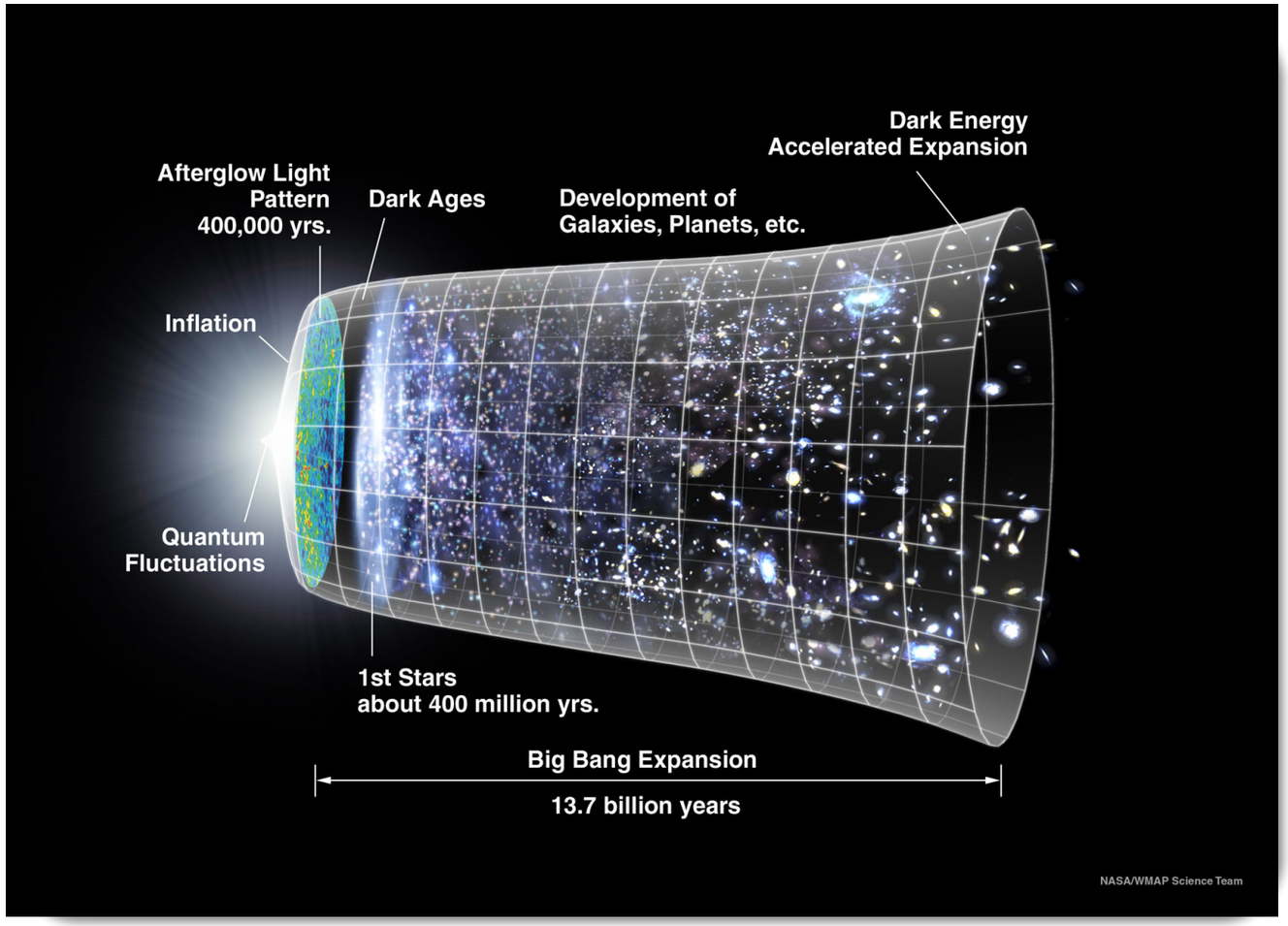

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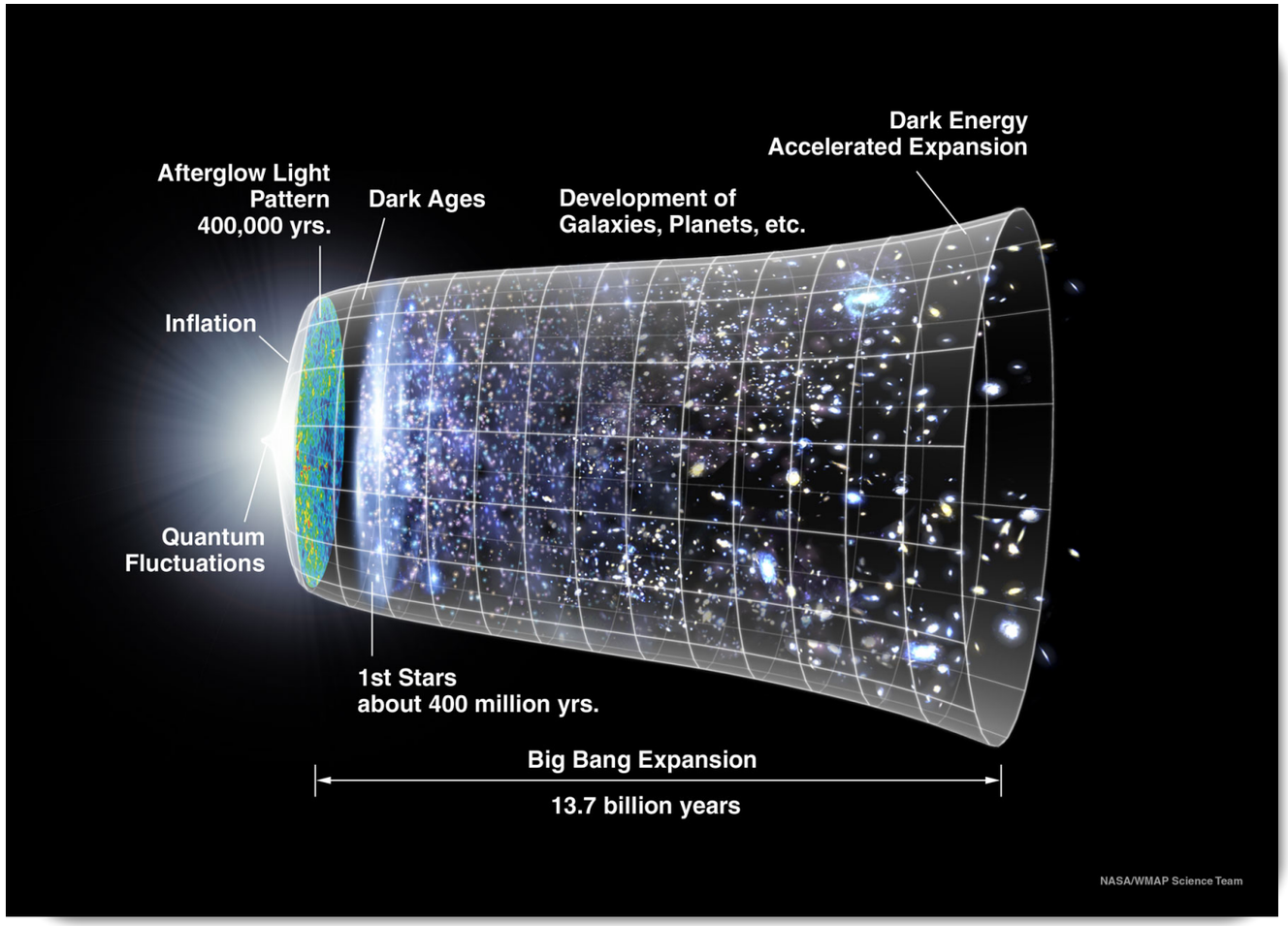
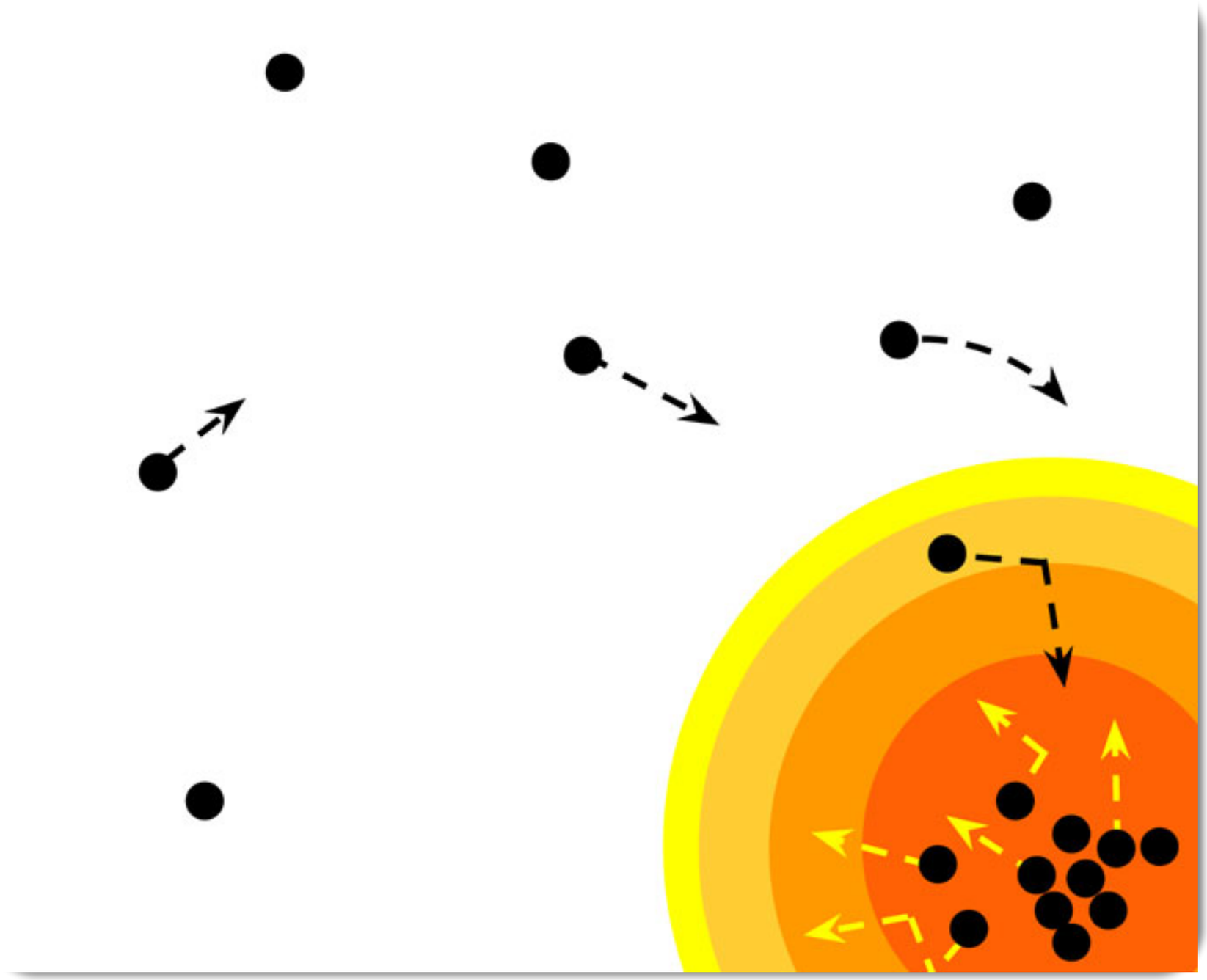


- **Zero metallicity, simple laboratories for stellar evolution.**

We need only consider the chemistry of H & He, gravity, and dark matter.

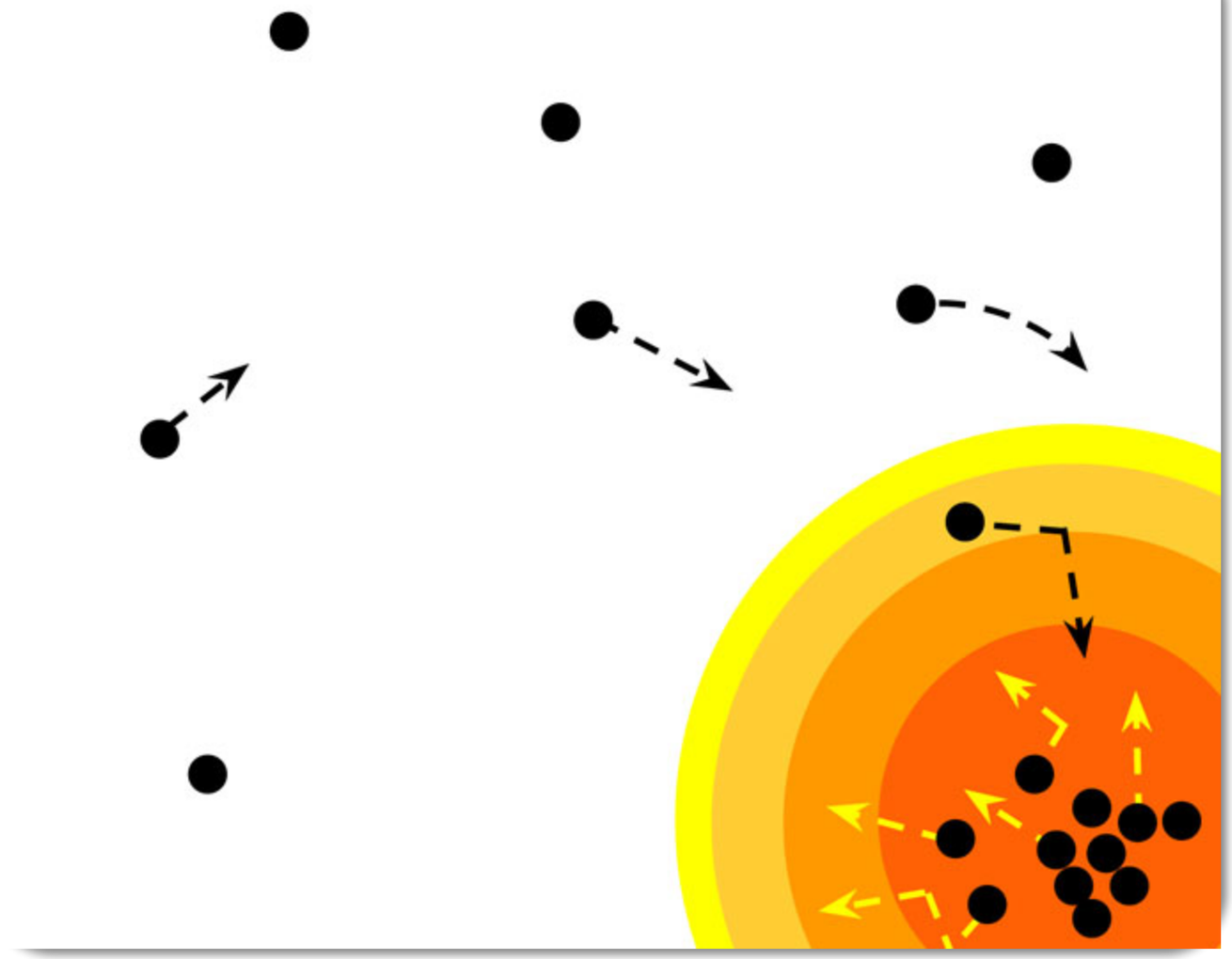
Capture via Scattering

Putting it together...



Capture via Scattering

- **Light dark matter:** $N \approx 1$
    - **Freese (2008)**



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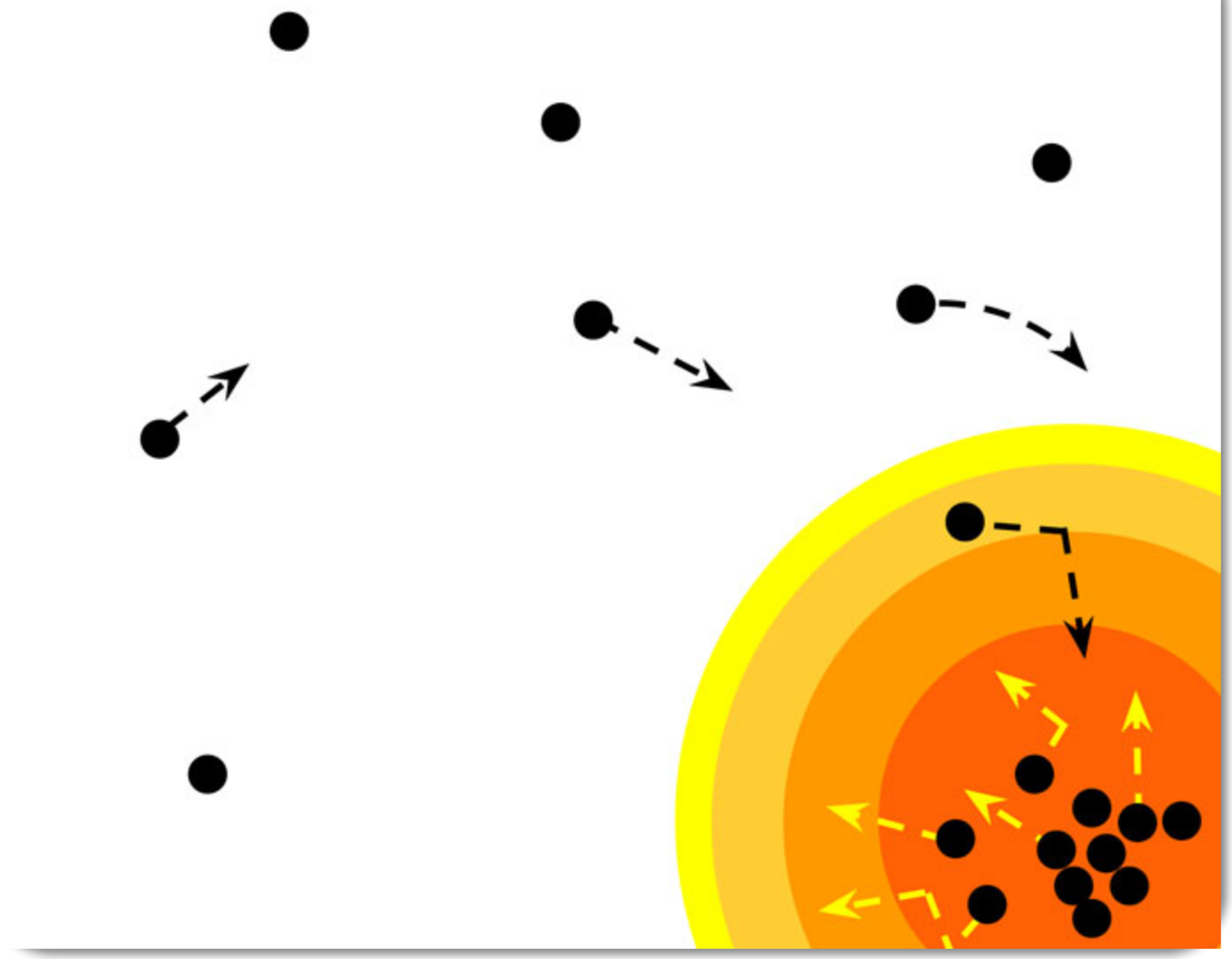

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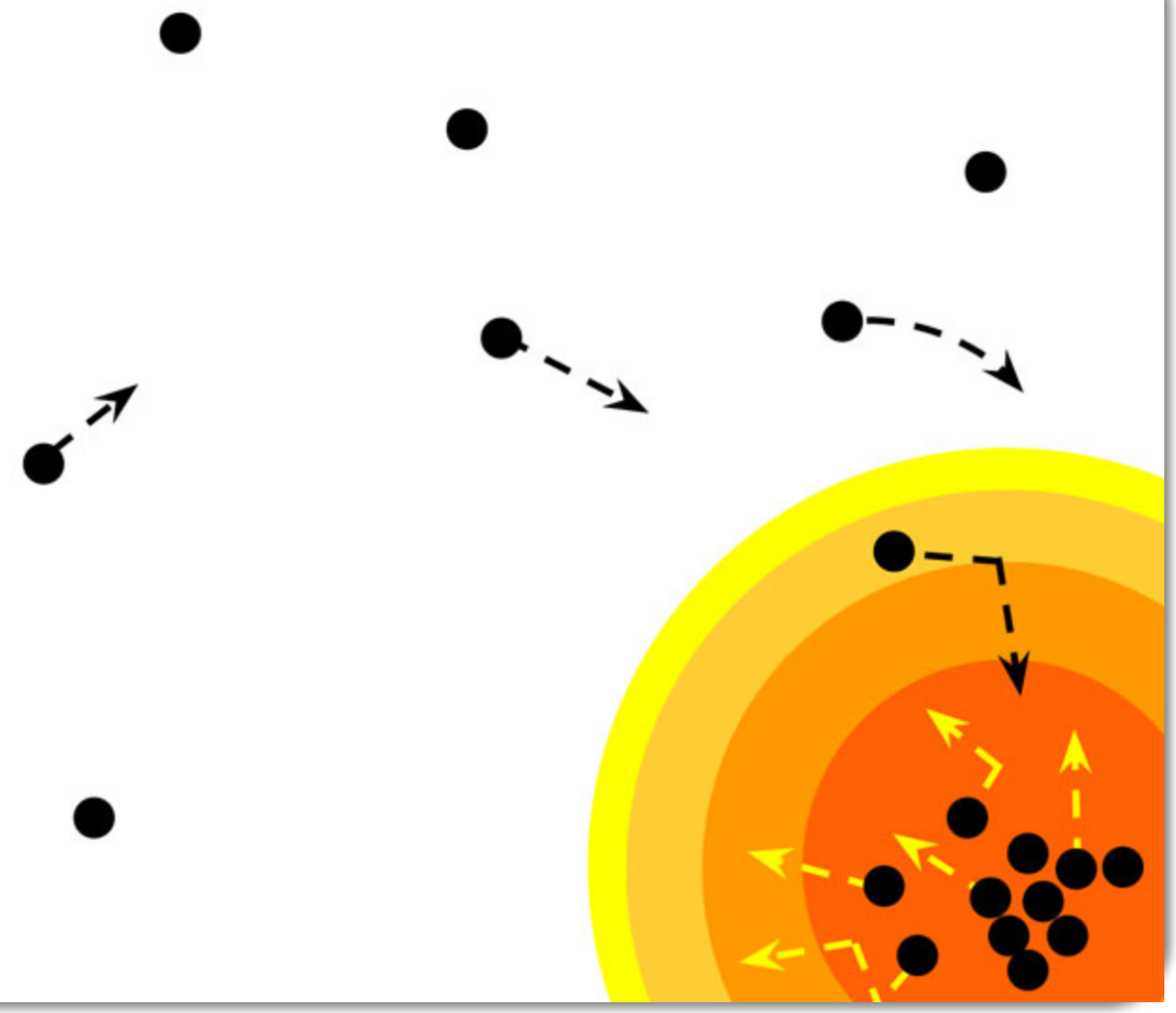

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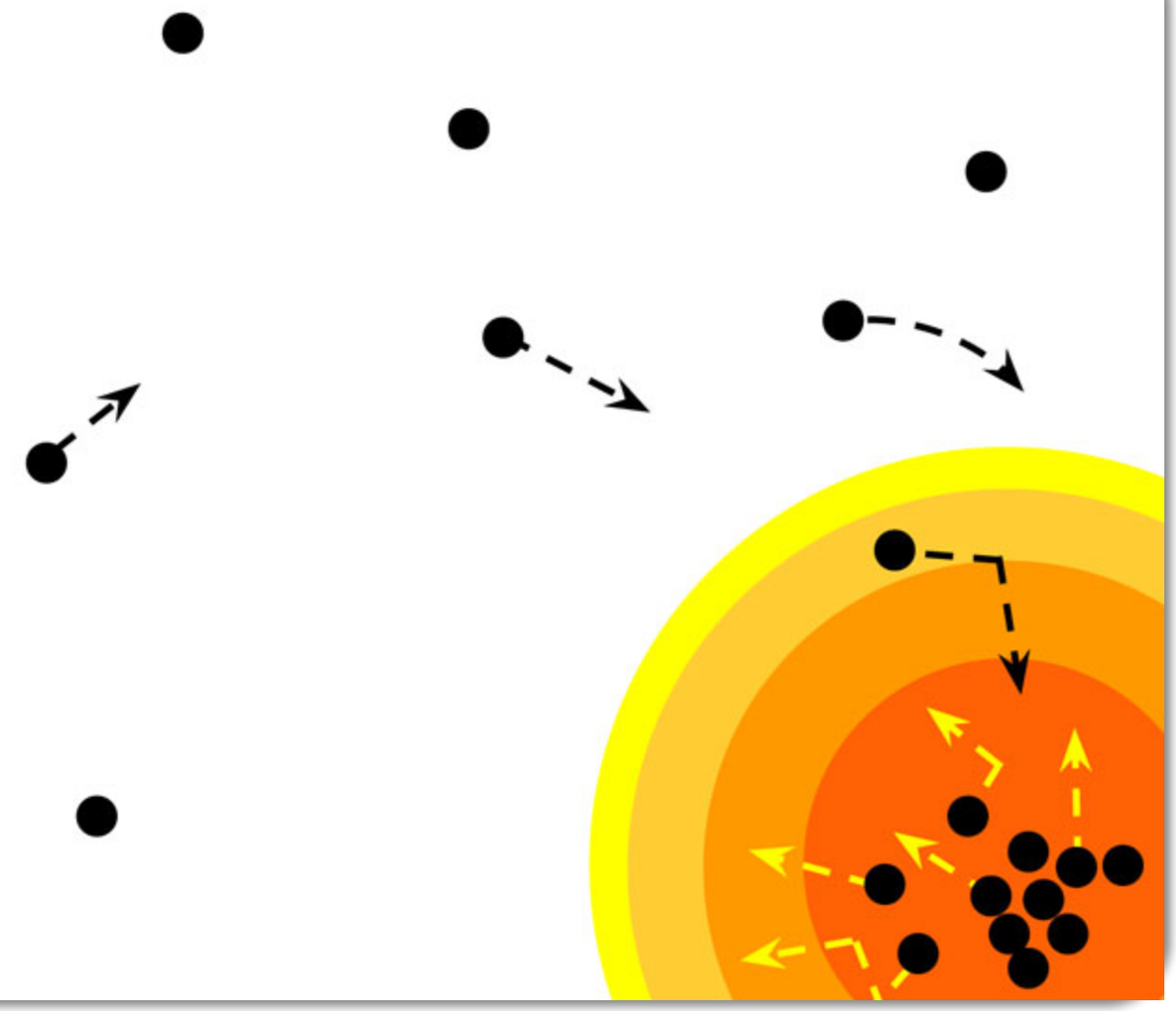
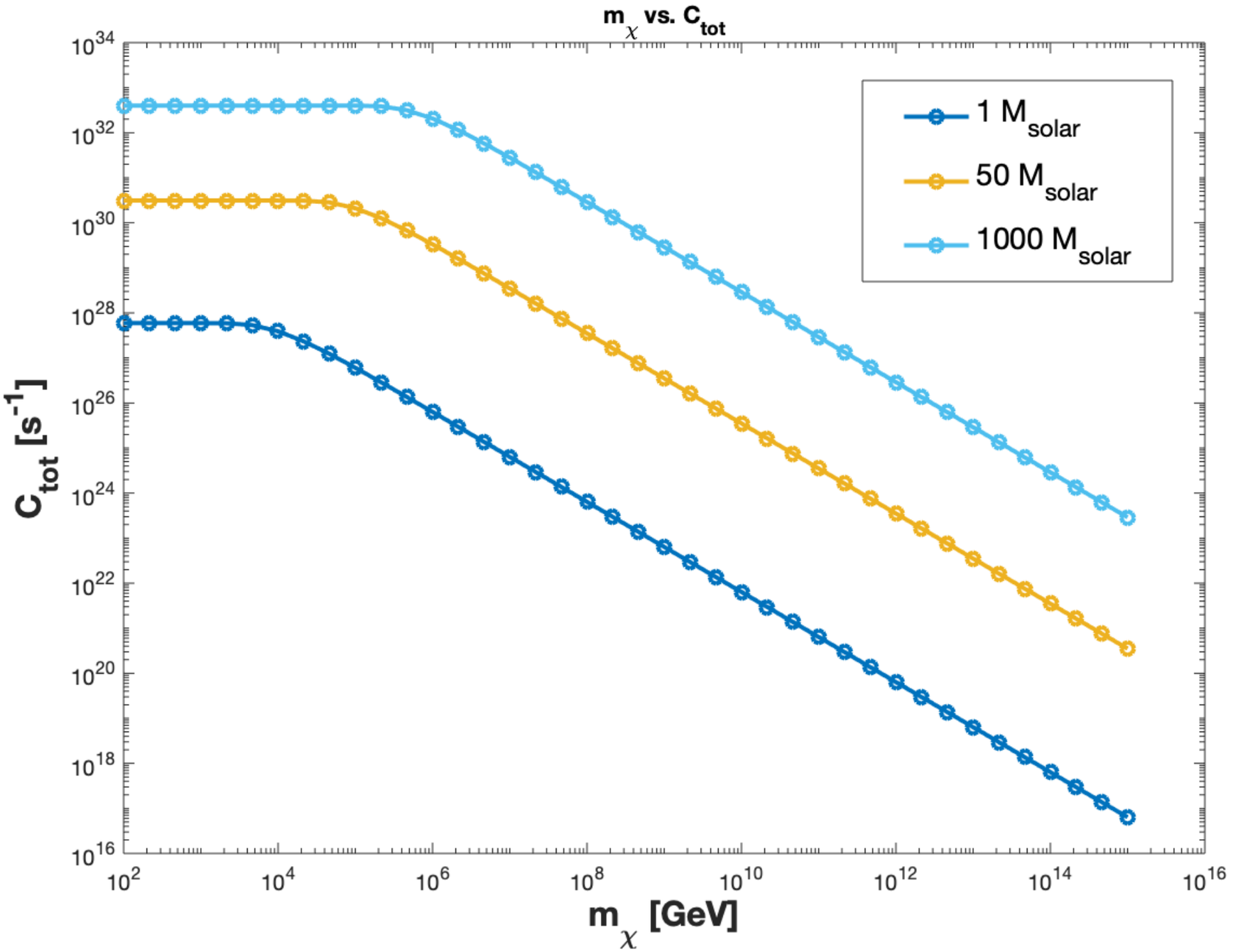


$$C_N = \sqrt{24\pi} p_N(\tau) G \frac{\rho_\chi}{m_\chi} M R \frac{1}{\bar{v}} \left(1 - \left(1 + \frac{2A_N^2 \bar{v}^2}{3v_{esc}^2}\right) e^{-A_N^2}\right)$$

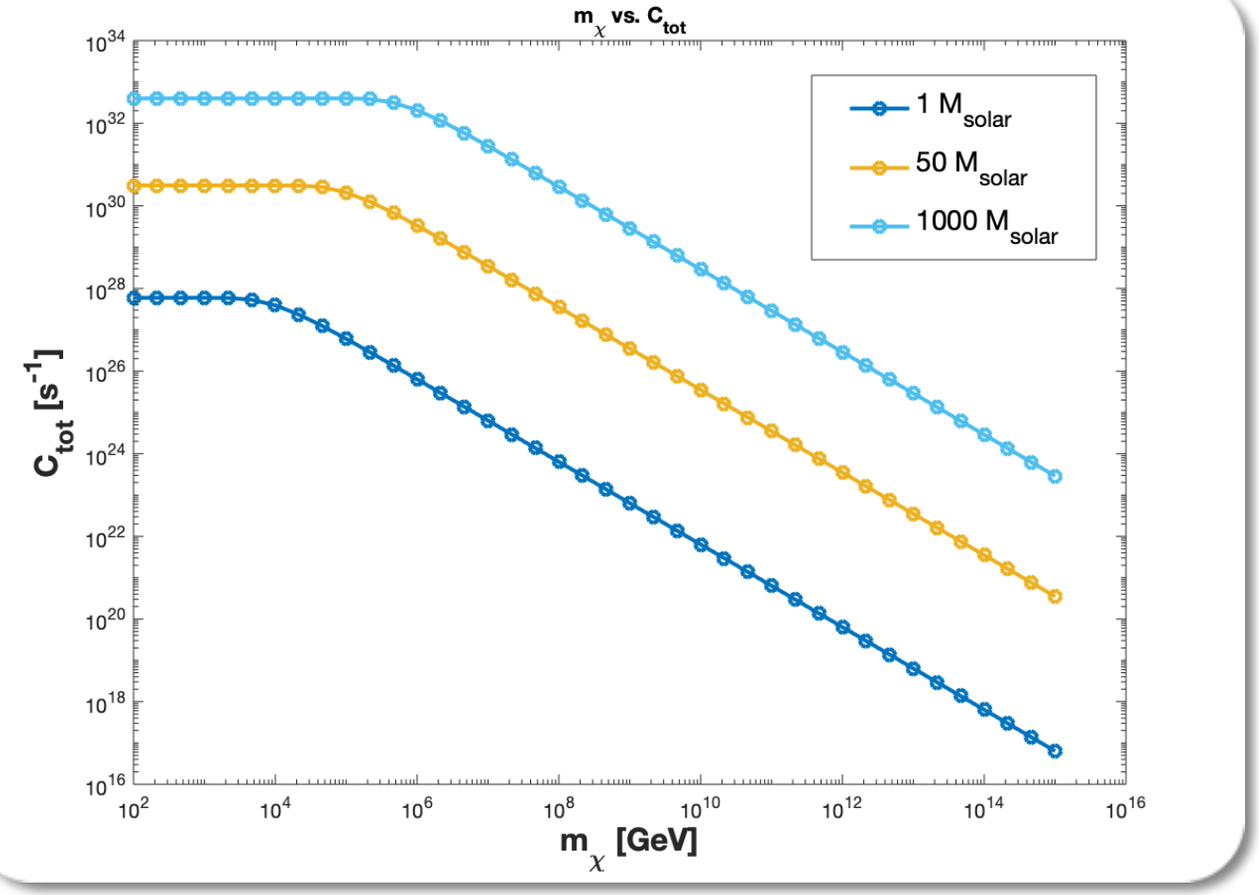
And the calculations for our mass range:

Capture via Scattering



Capture via Scattering

- **Total capture rate has two distinct shapes.**



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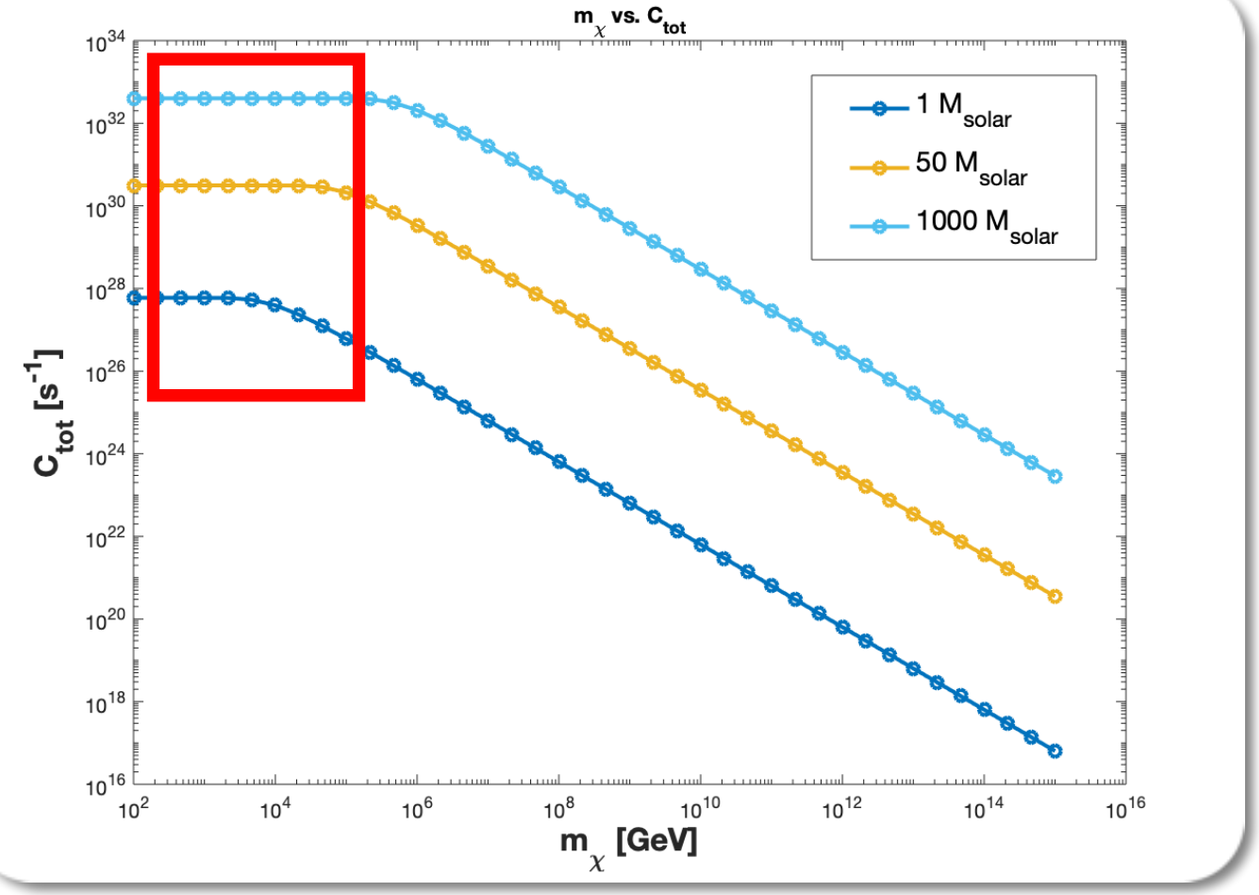

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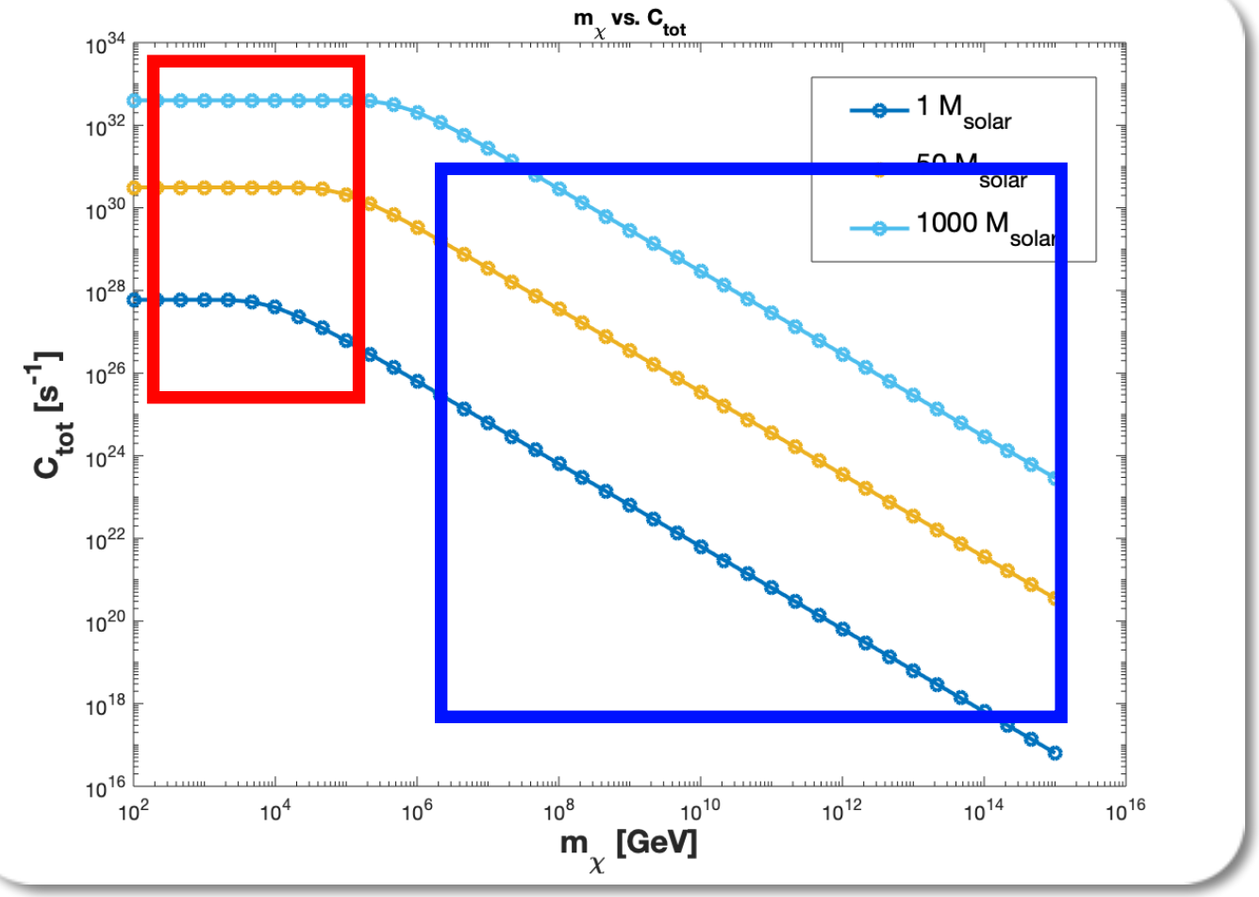

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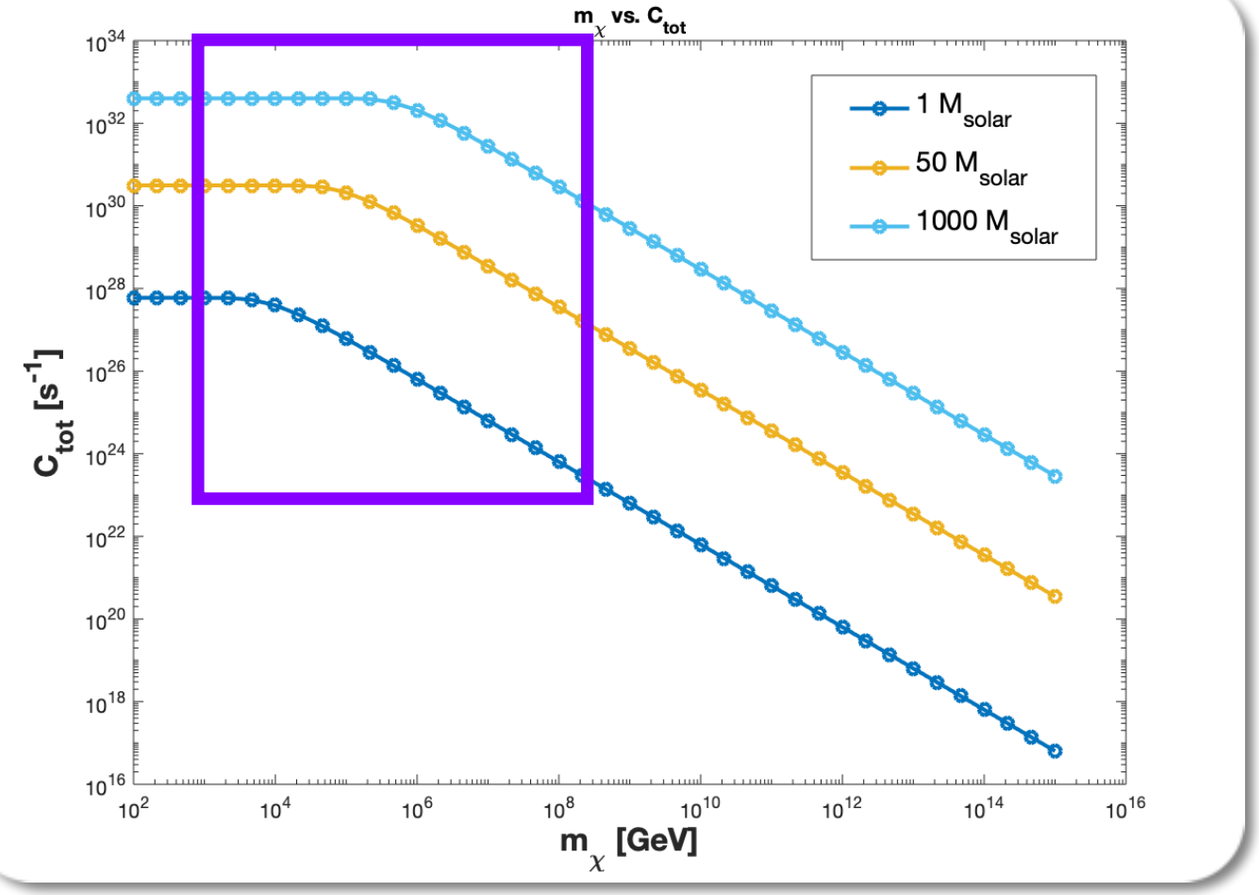

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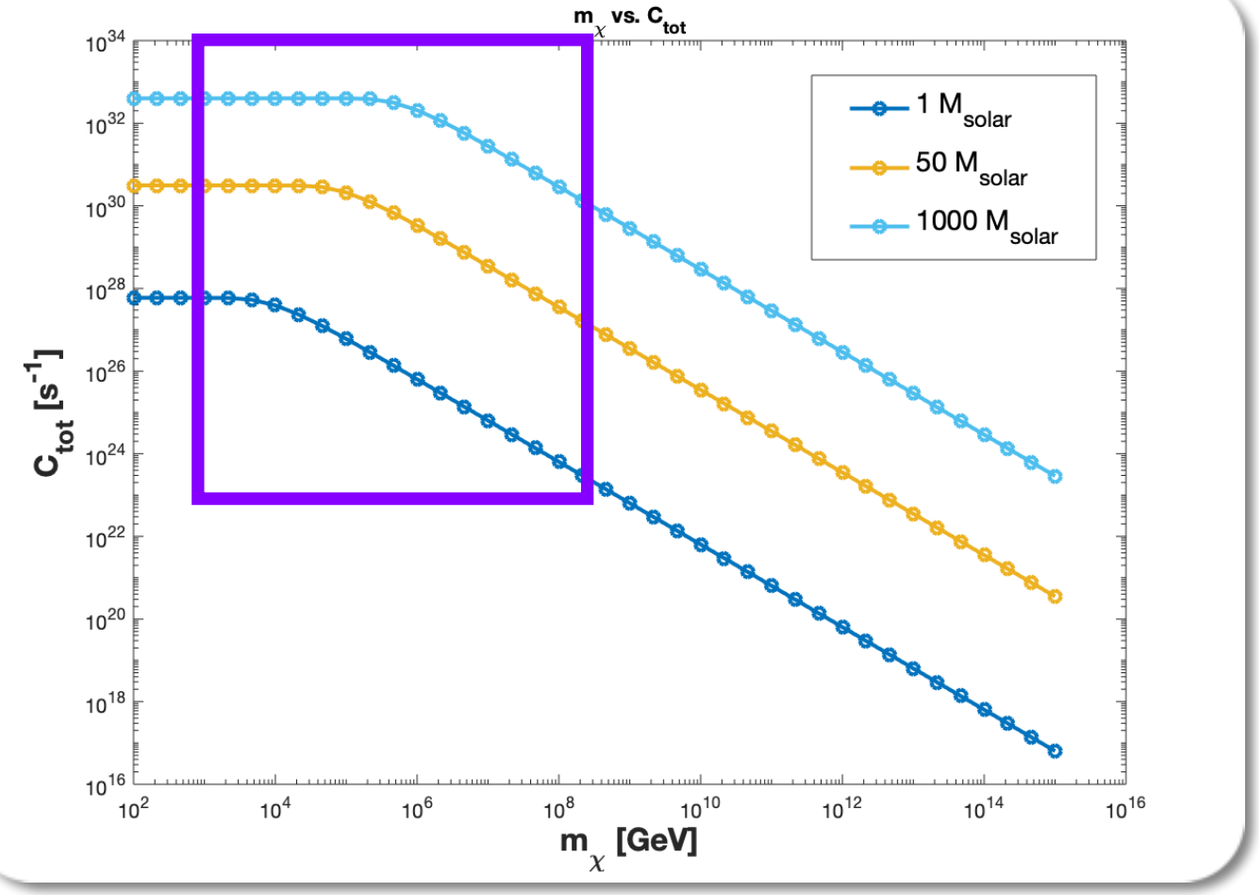
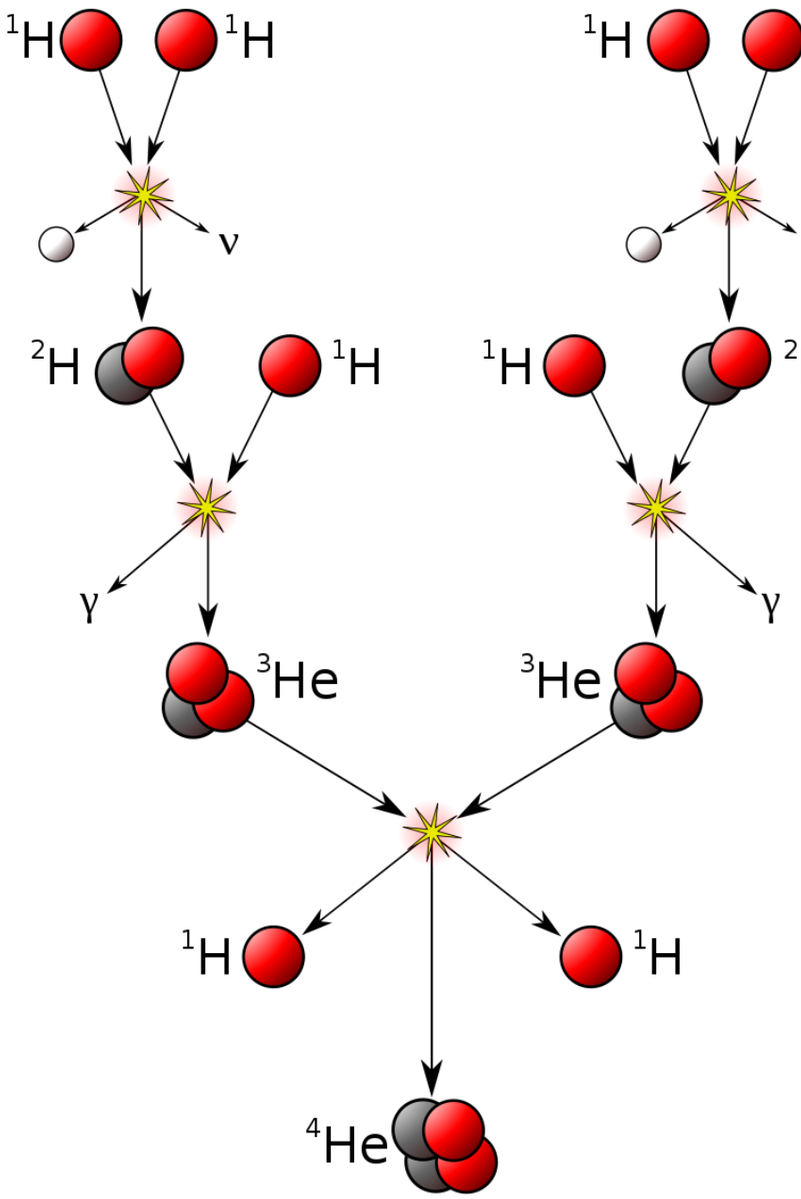


- **More complicated, but why?**
  - **Non-linear dependence on mass.**
  - **Non-linear dependence on stellar parameters.**

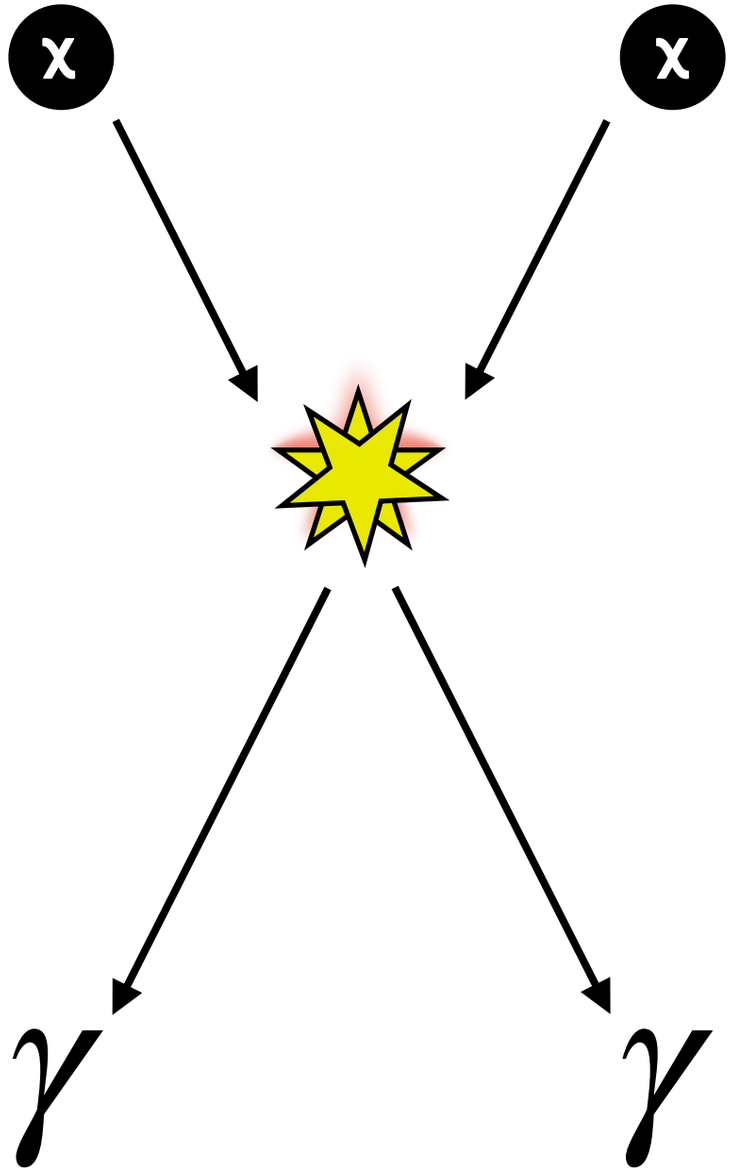
So what effect does this have for stellar evolution?

Capture via Scattering



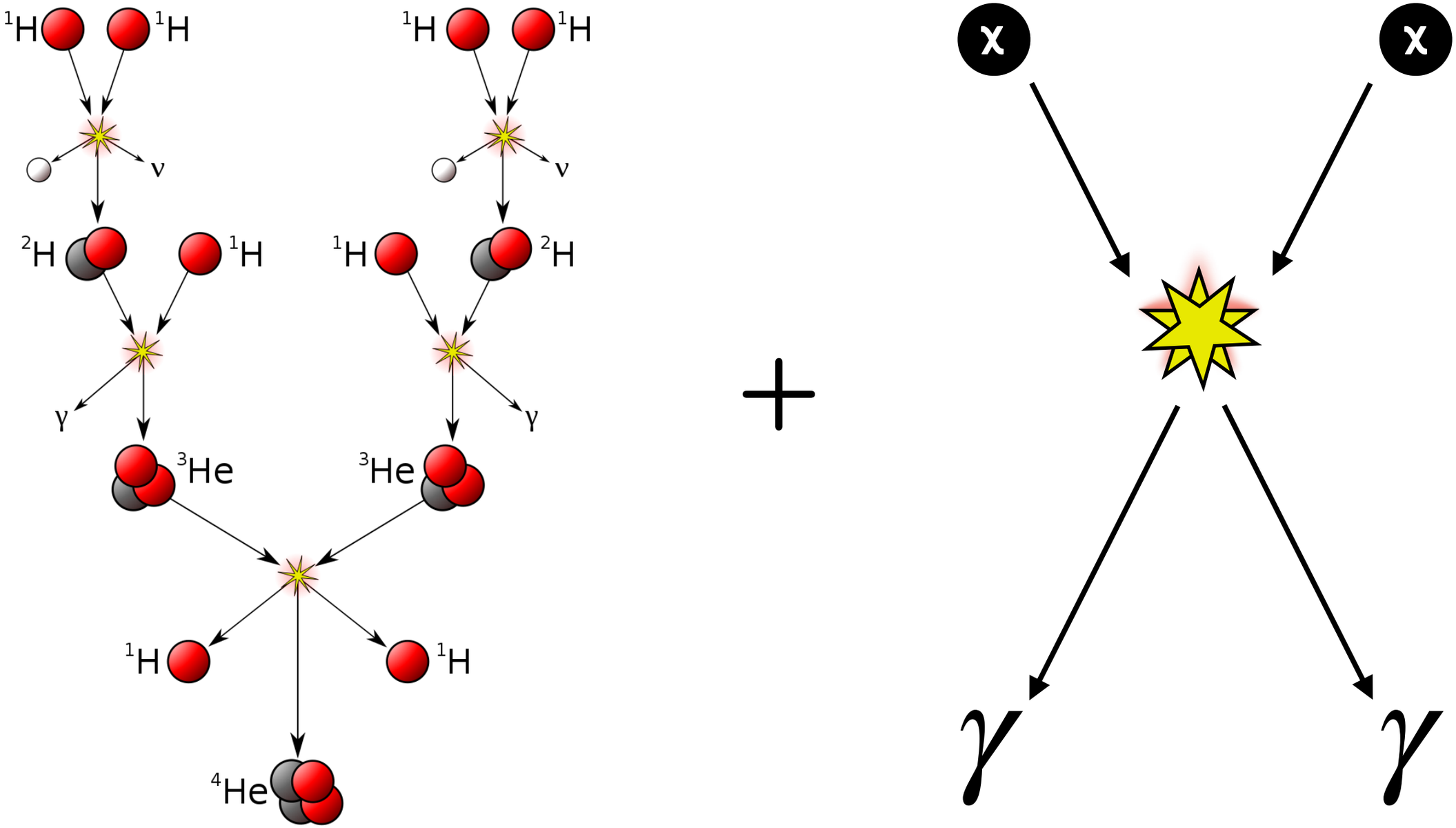
Nuclear Fusion

+



DM Self Annihilation

Capture via Scattering



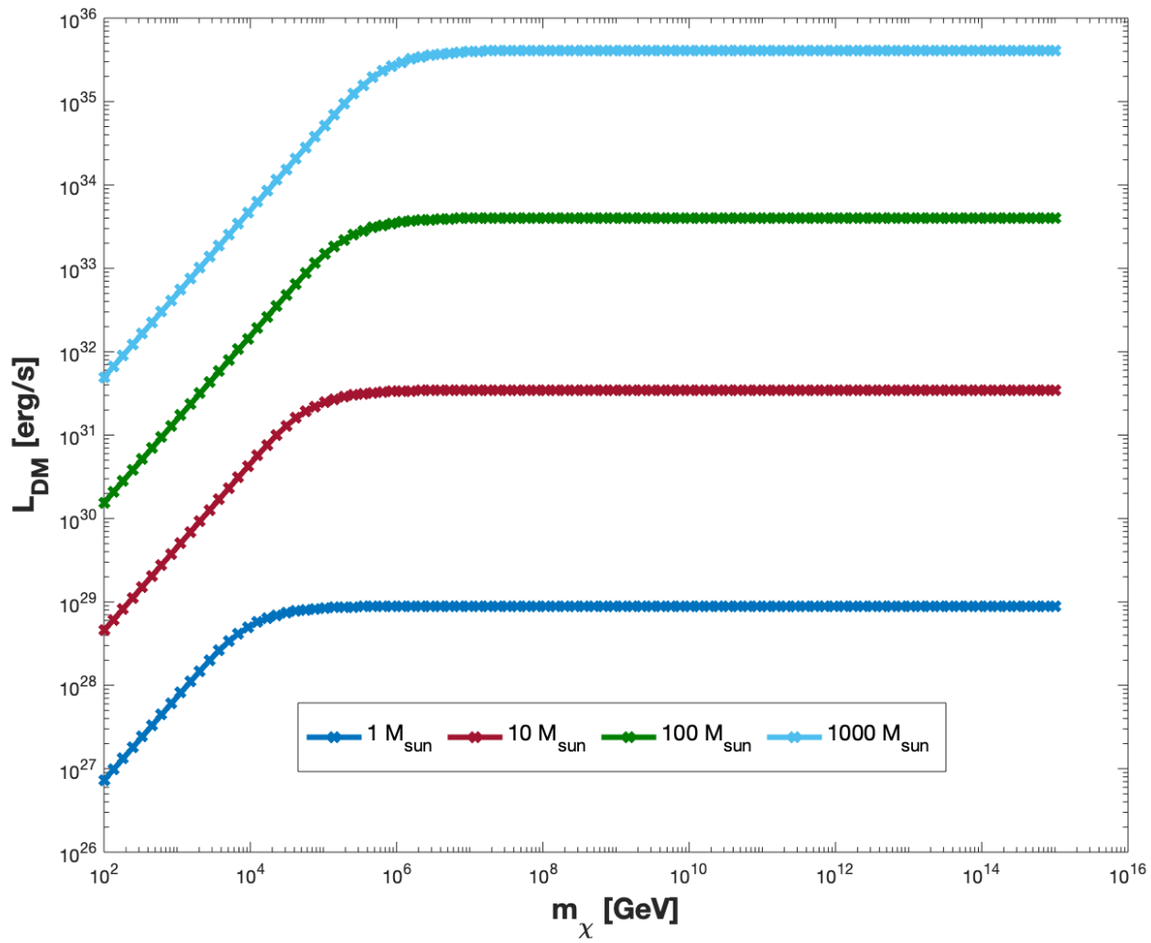
Nuclear Fusion

DM Self Annihilation

Additional Heating = Additional Luminosity

Effects on Stellar Evolution

$$L_{DM} = \frac{2}{3} C_{tot} m_\chi$$



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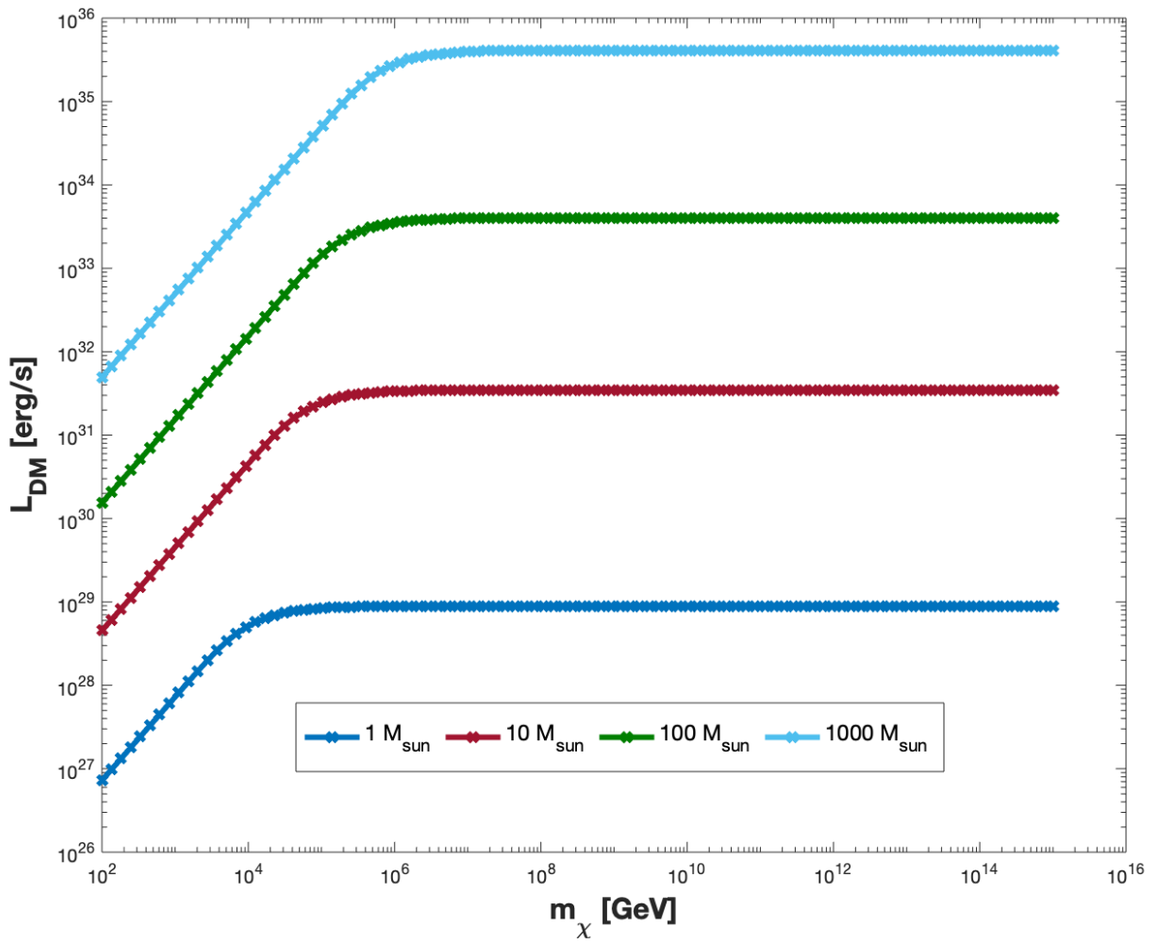
- **Compare!**



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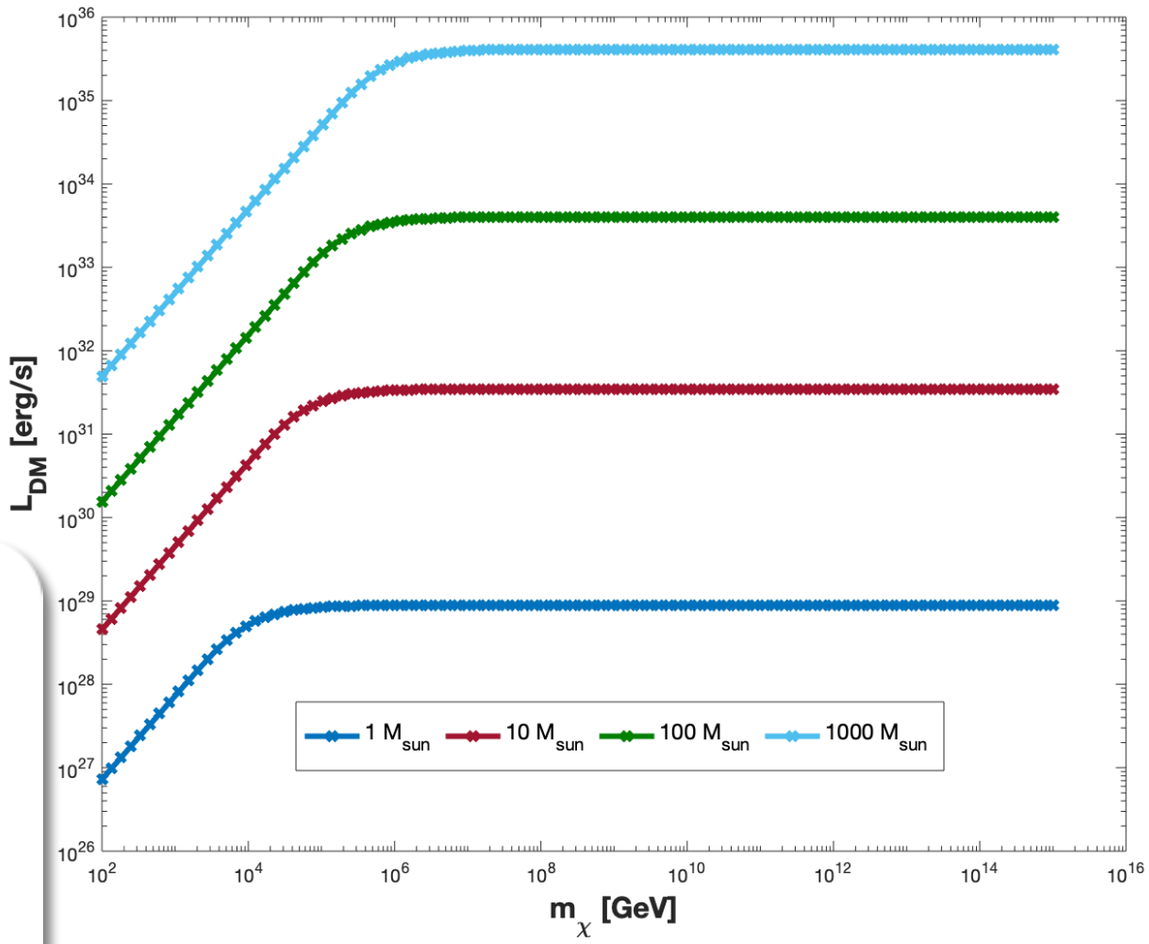

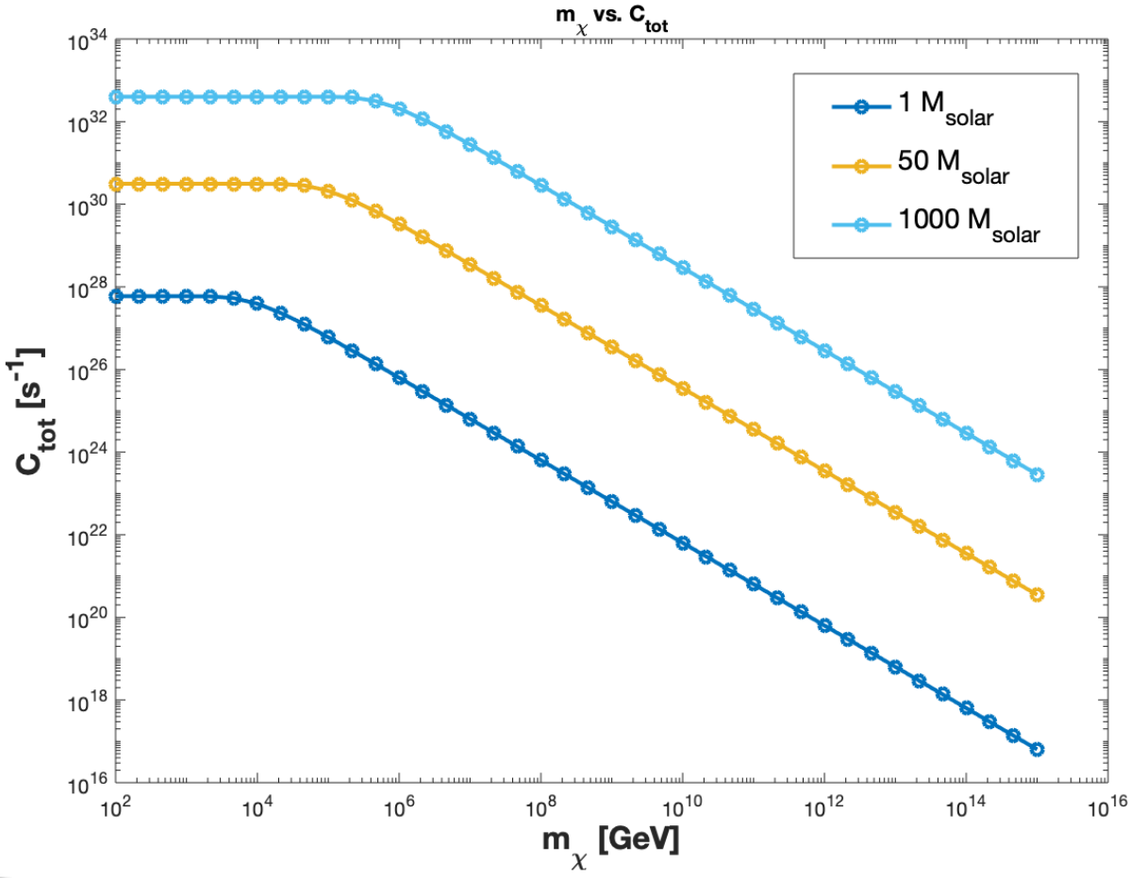

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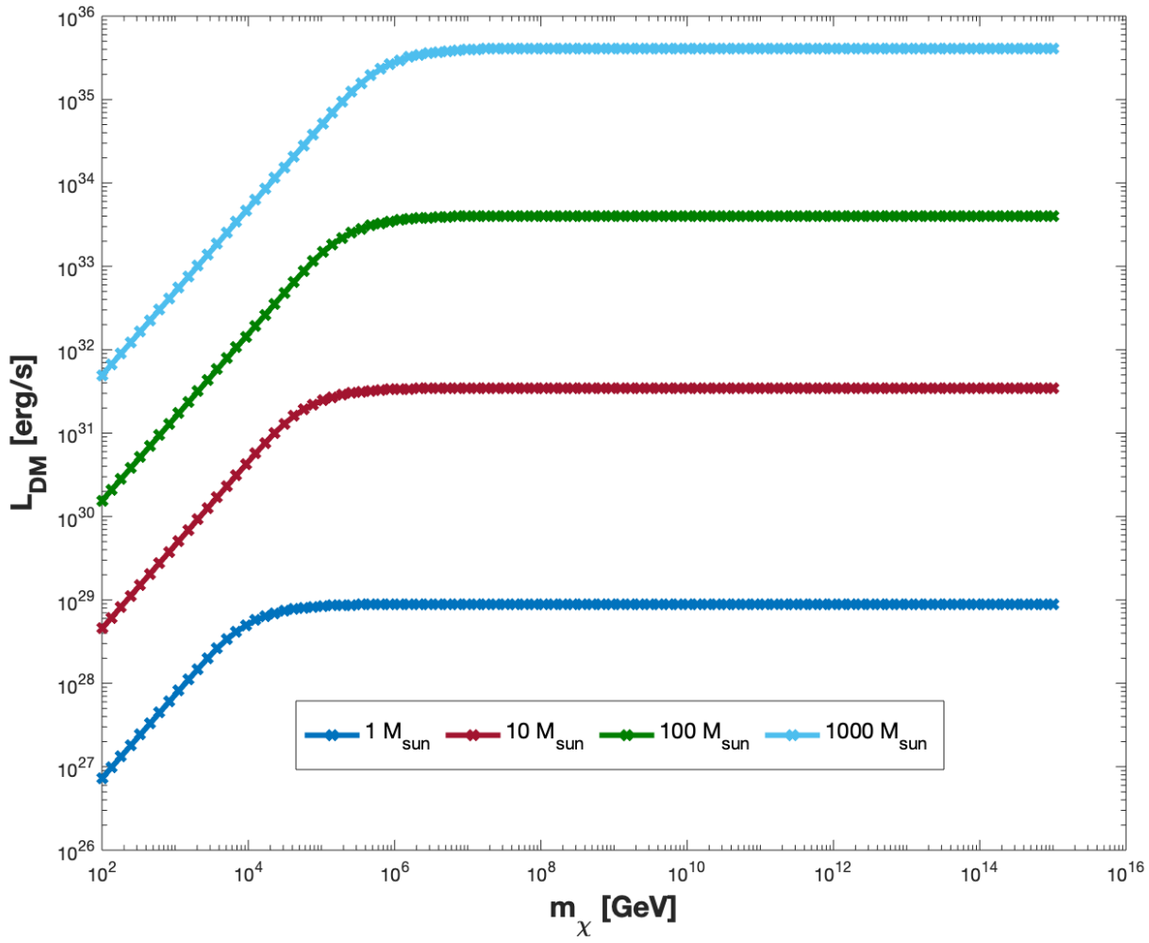
- **This additional luminosity source allows us to calculate upper mass bounds for Pop. III stars using the "Eddington luminosity."**



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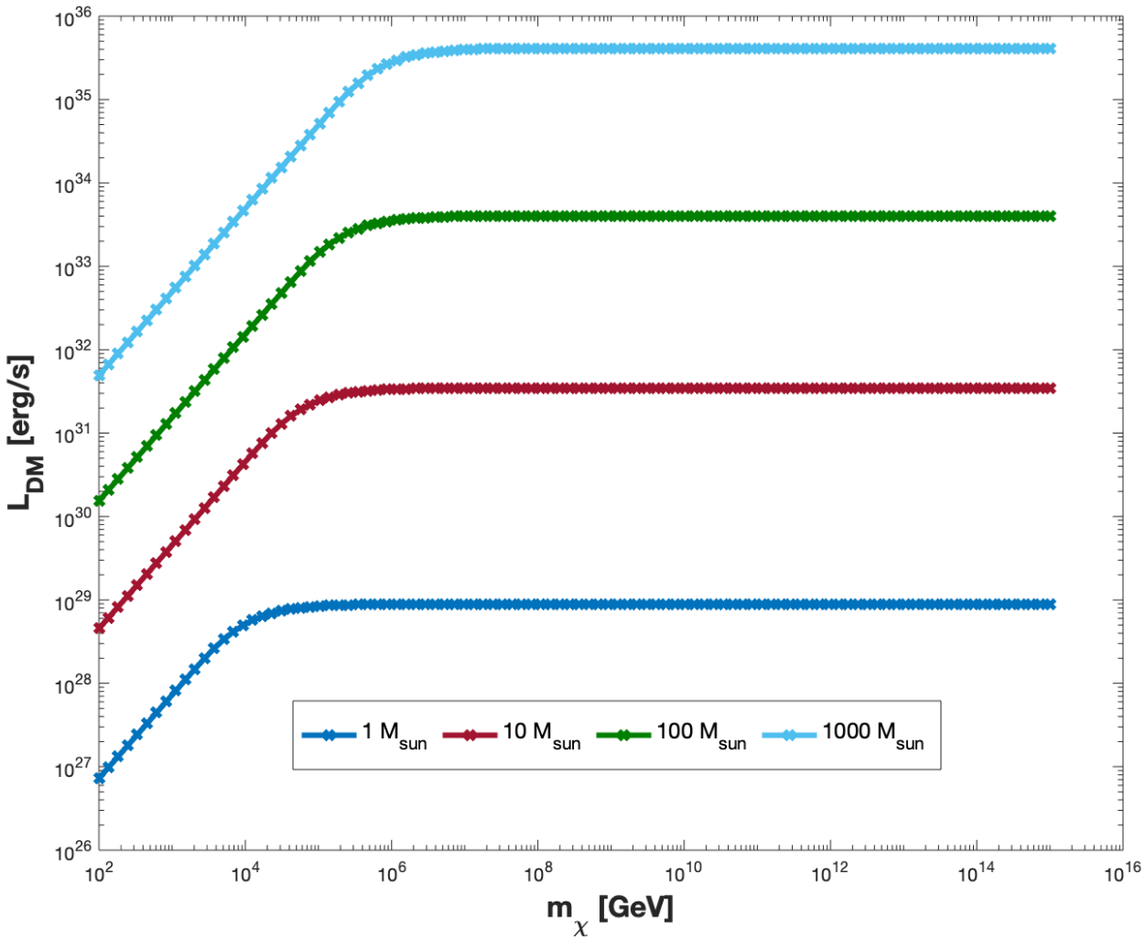
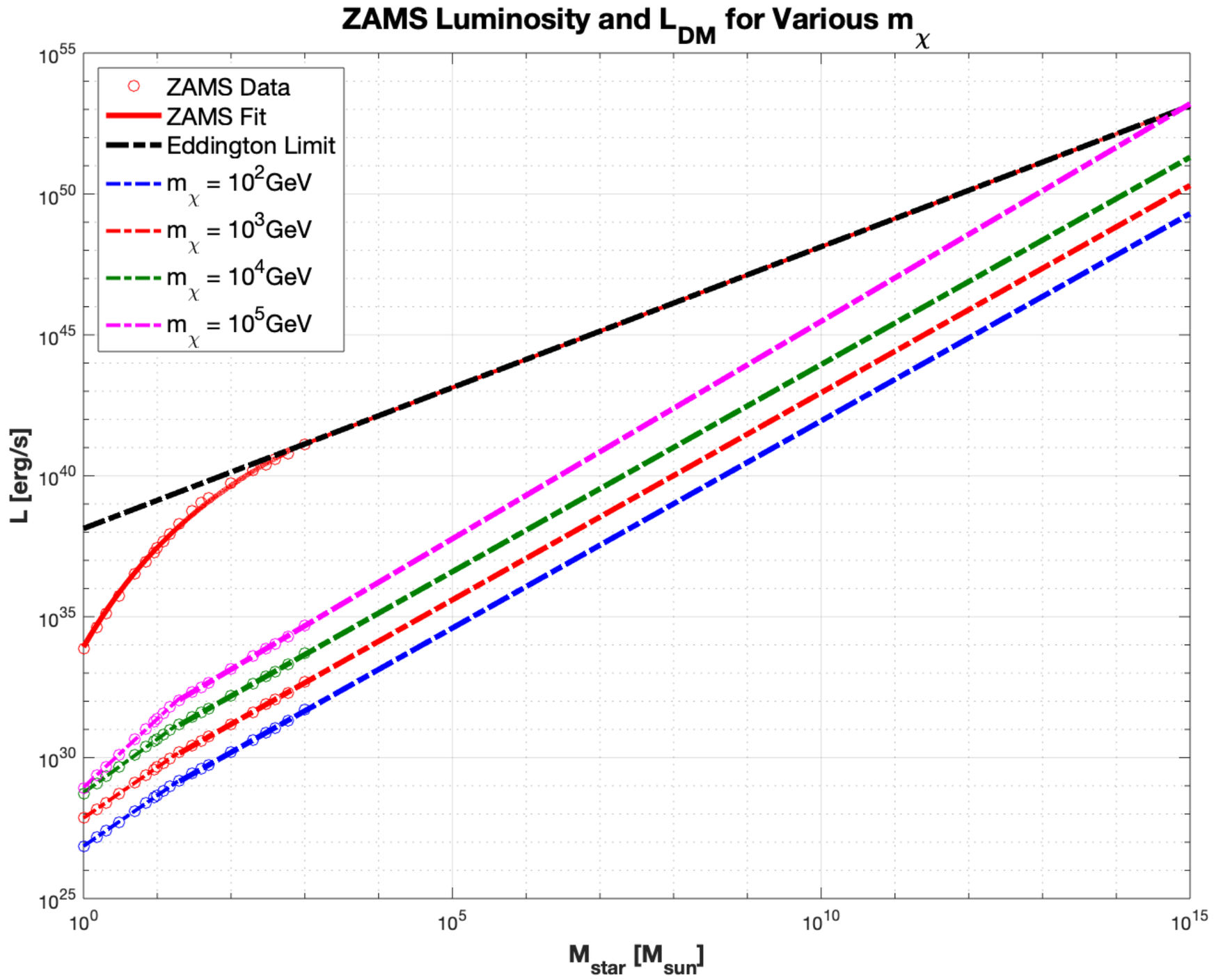
The Eddington Luminosity is the maximum luminosity allowed while preserving hydrostatic equilibrium.



$$L_{Edd} = 3.5 \times 10^4 \left(\frac{M_\star}{M_{sun}} \right) L_{sun}$$

Effects on Stellar Evolution



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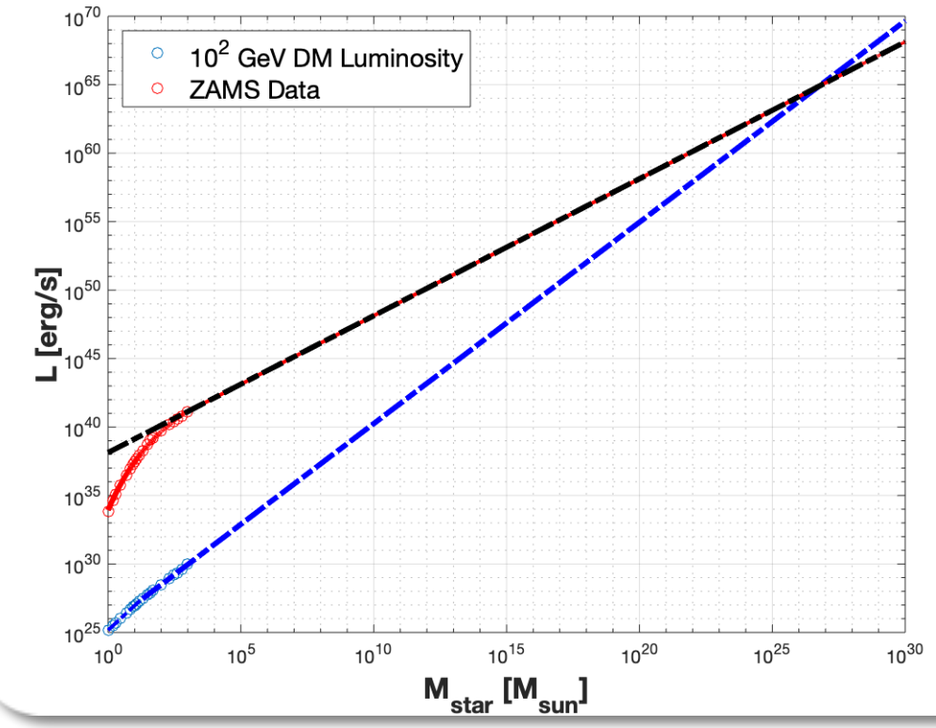

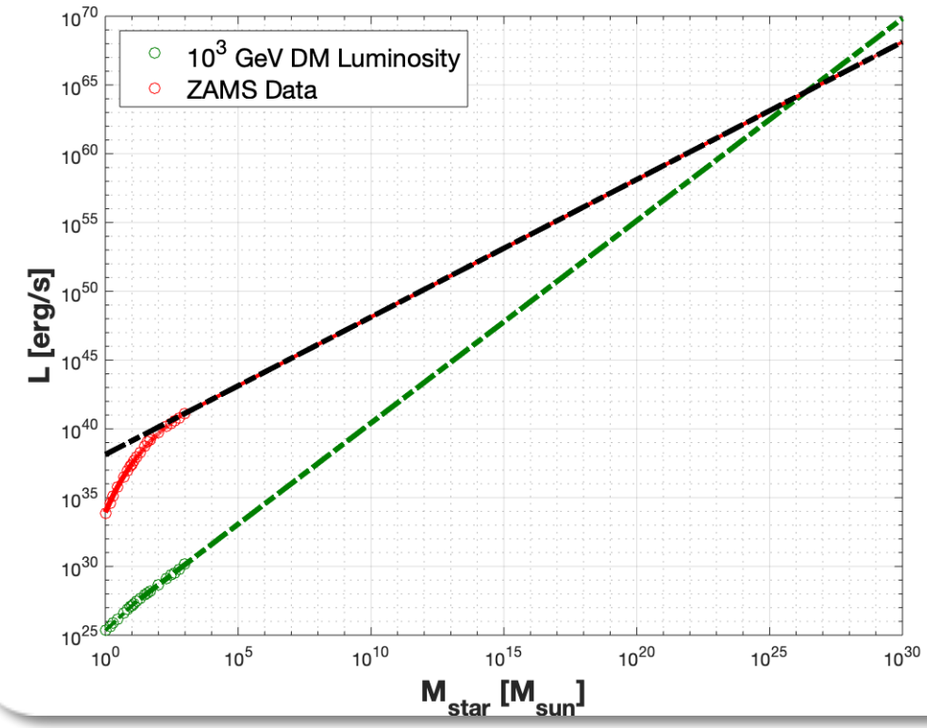

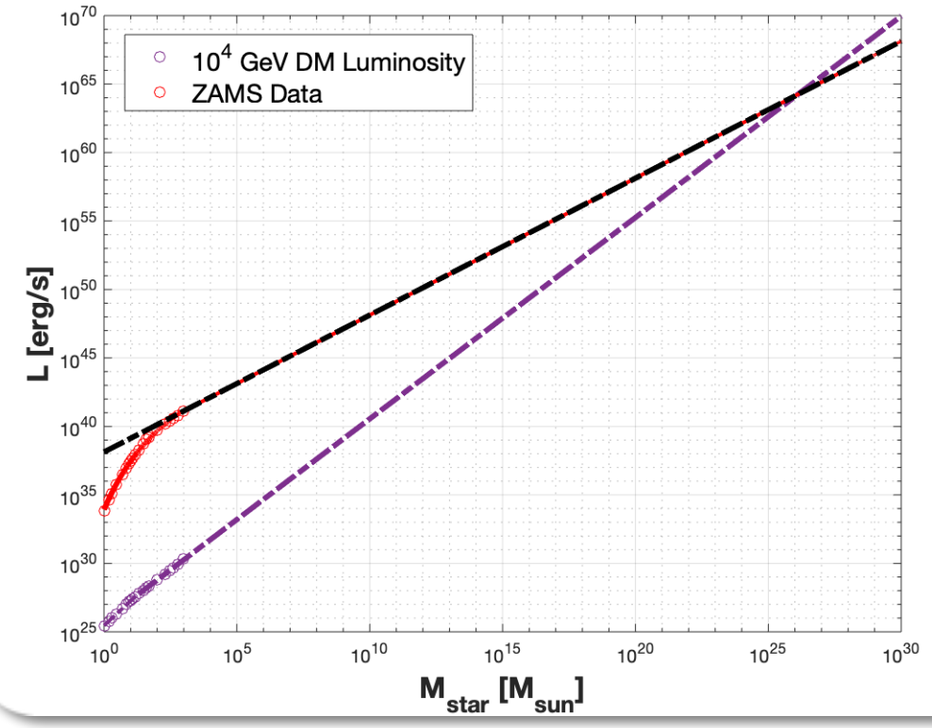

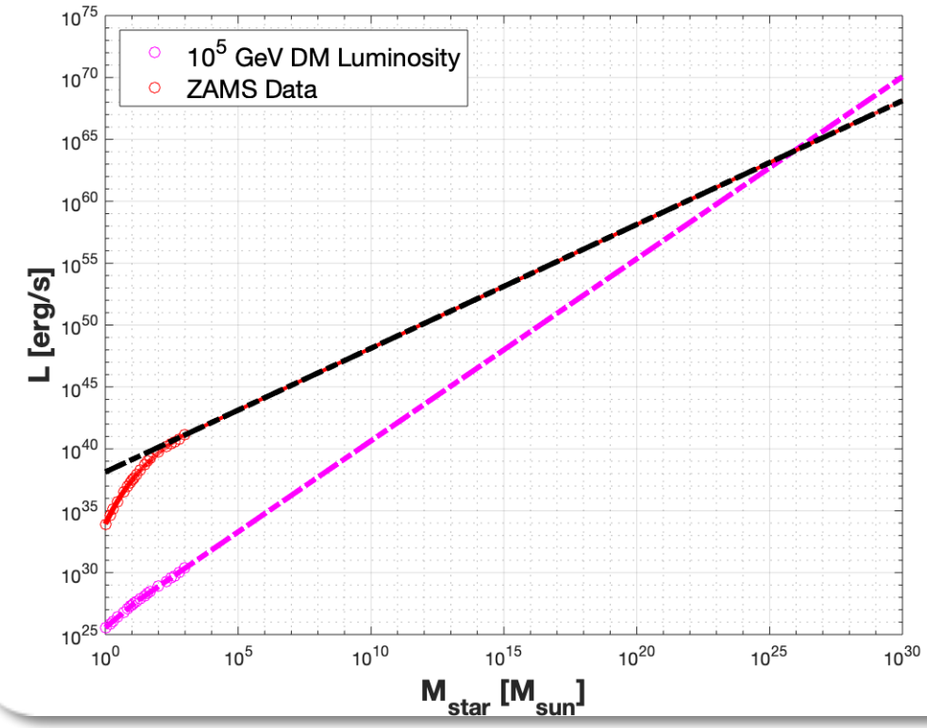

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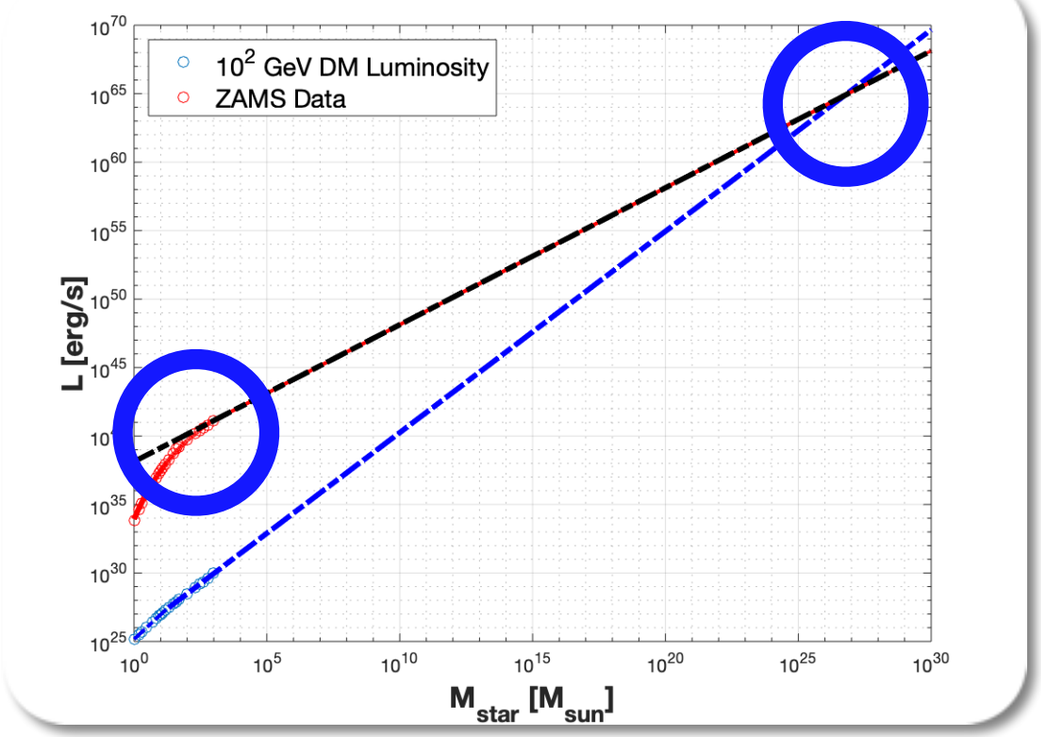

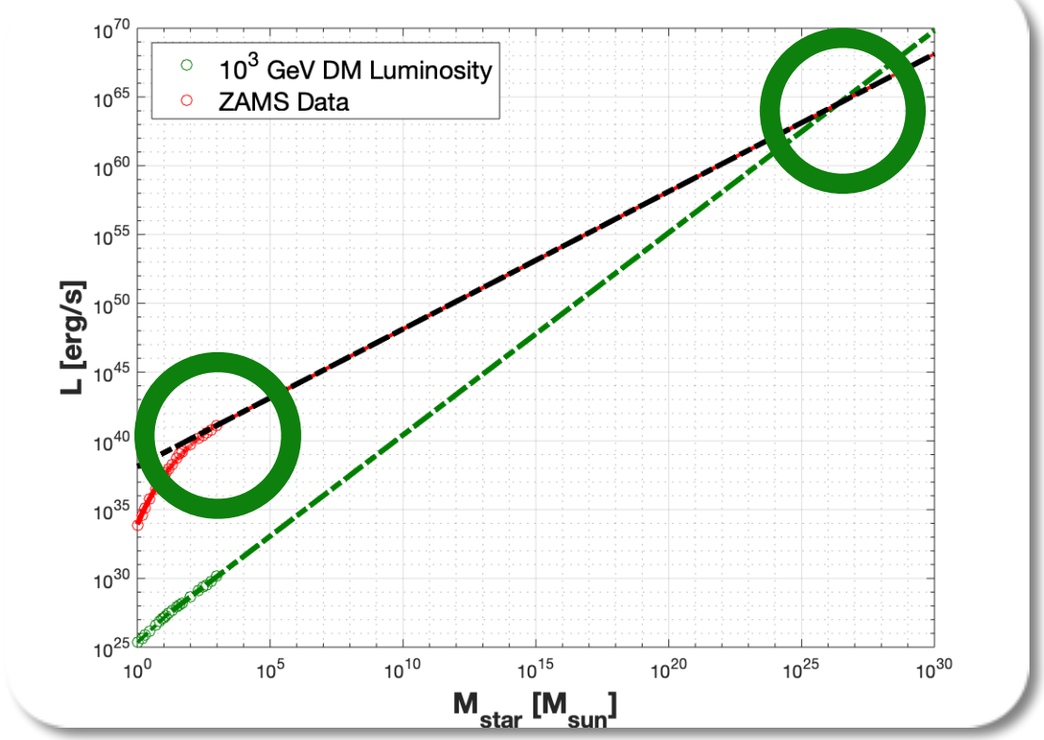

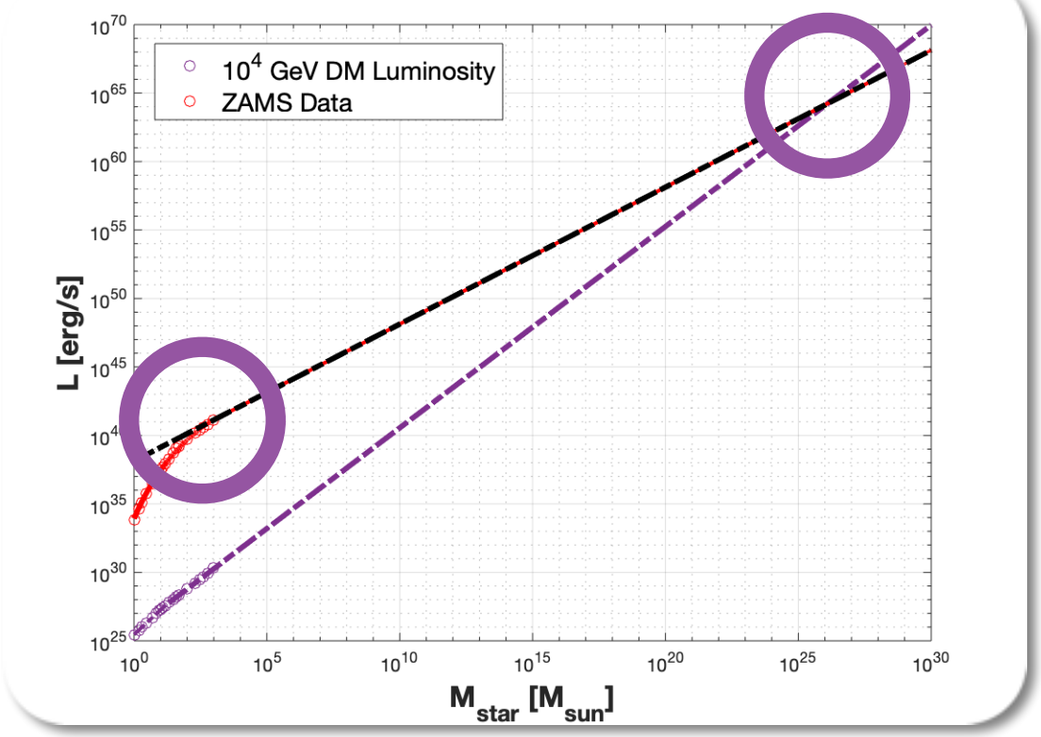

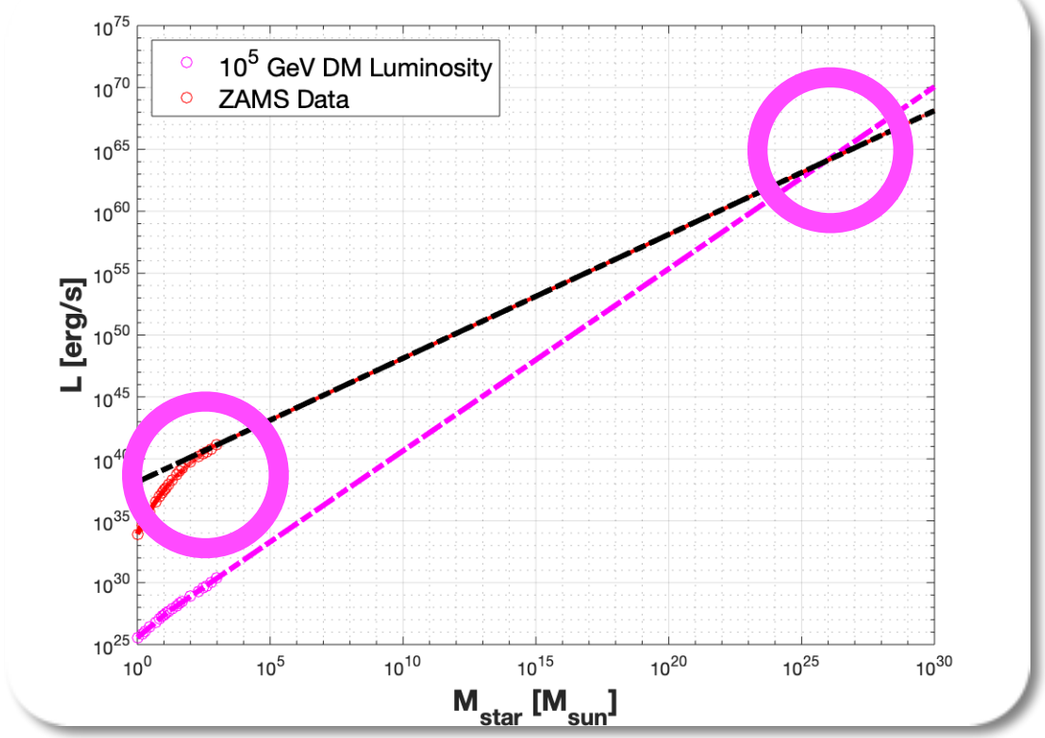

Effects on Stellar Evolution

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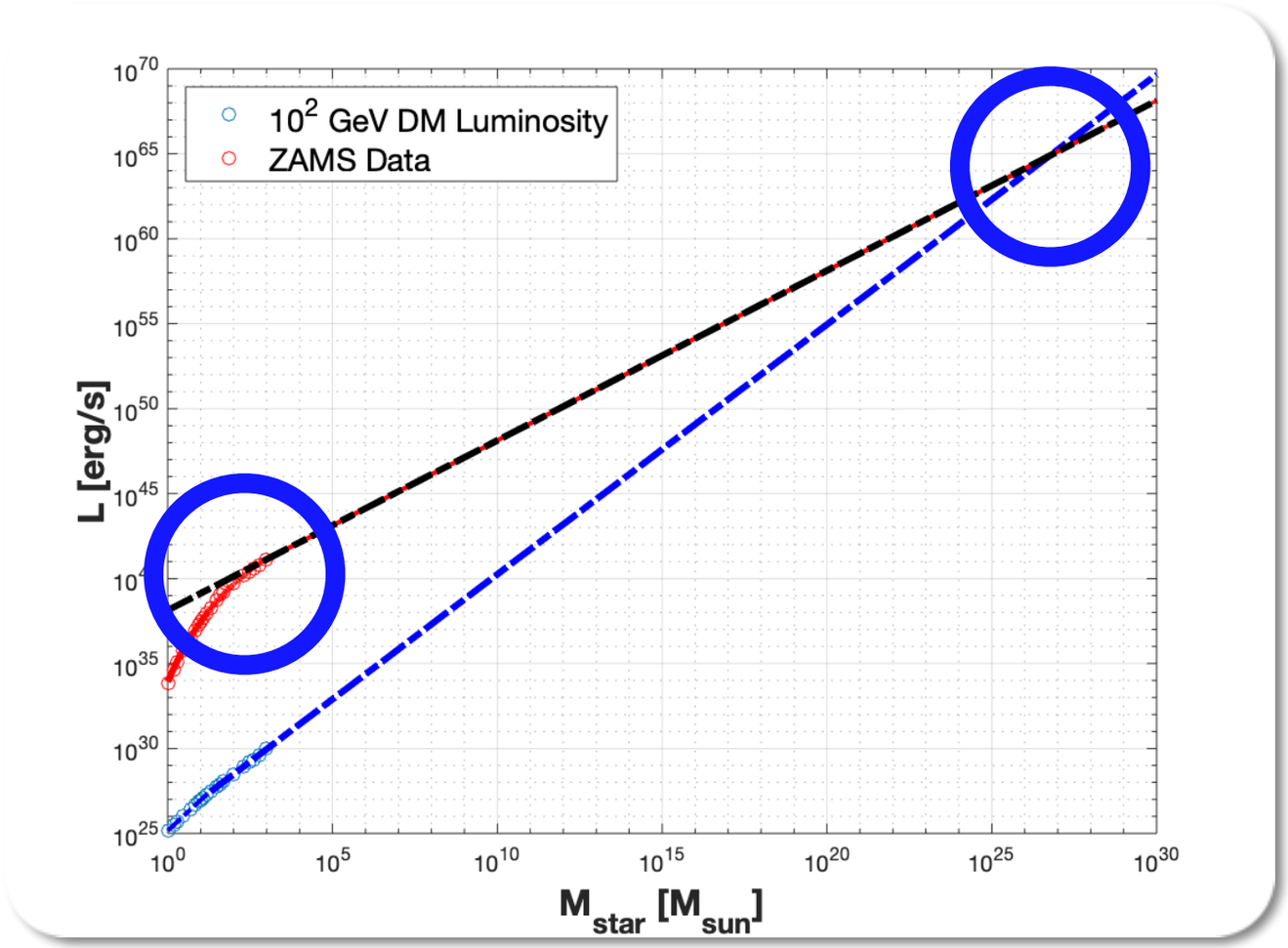
  - Note: These depend on the mass of the dark matter and the ambient DM density.



Effects on Stellar Evolution

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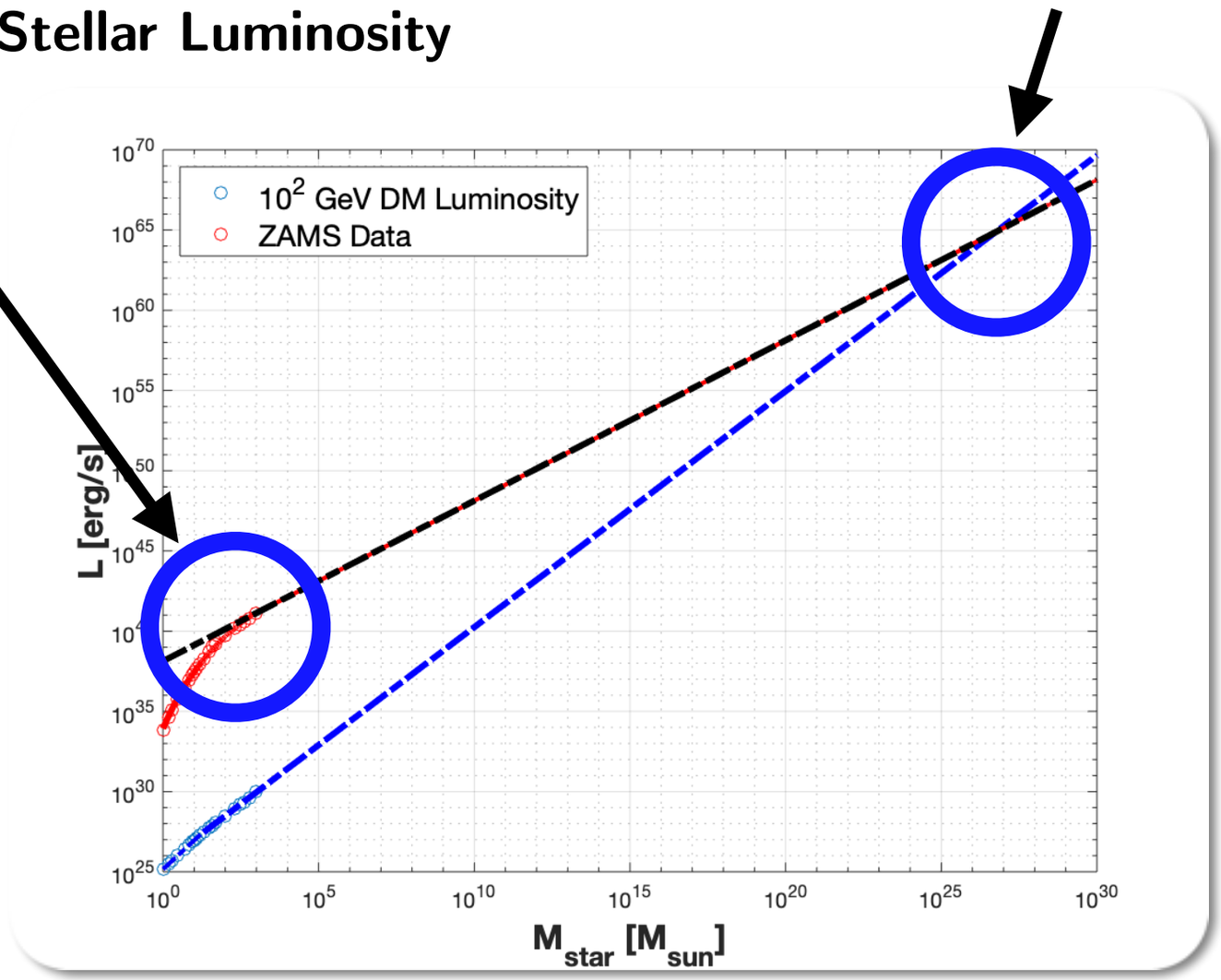
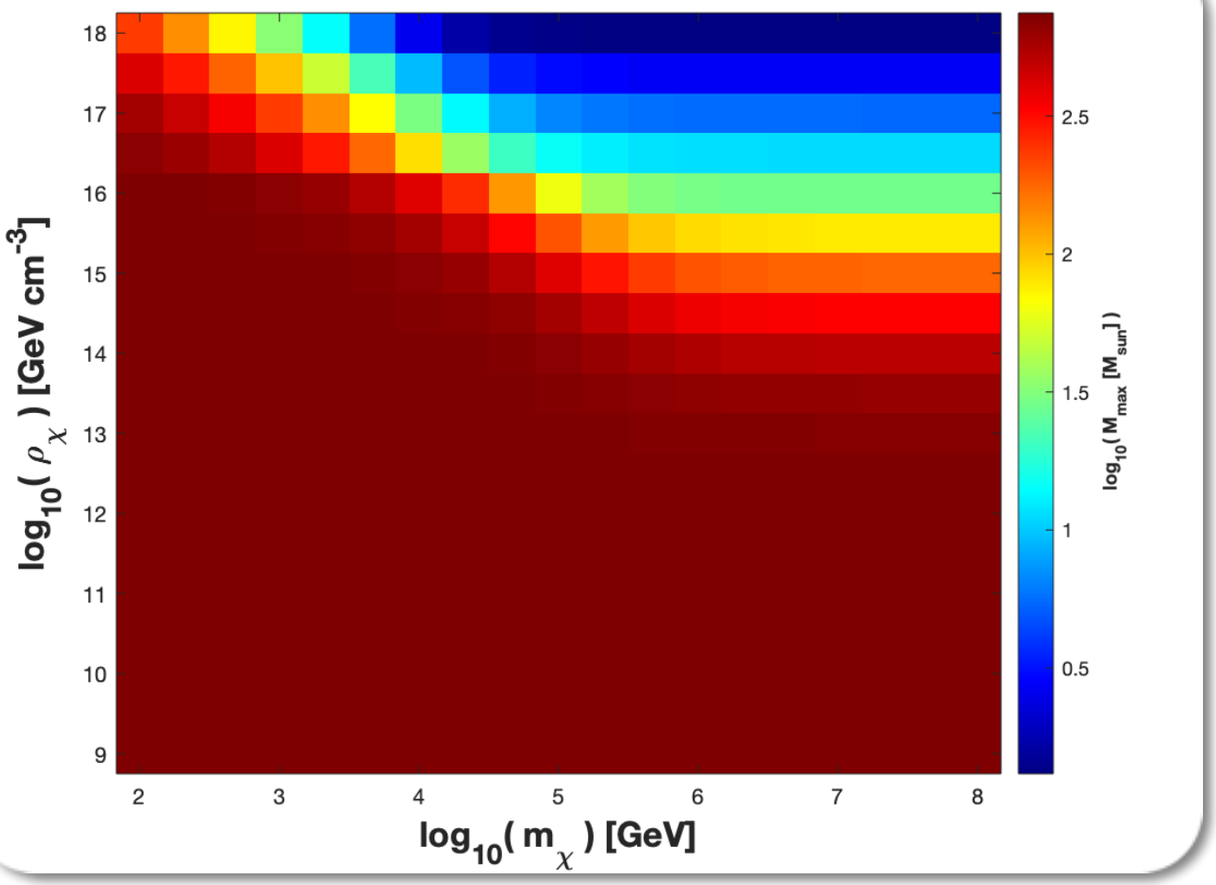
- Strong Limit: Dark Matter + Stellar Luminosity

- Weak Limit: Dark Matter Only

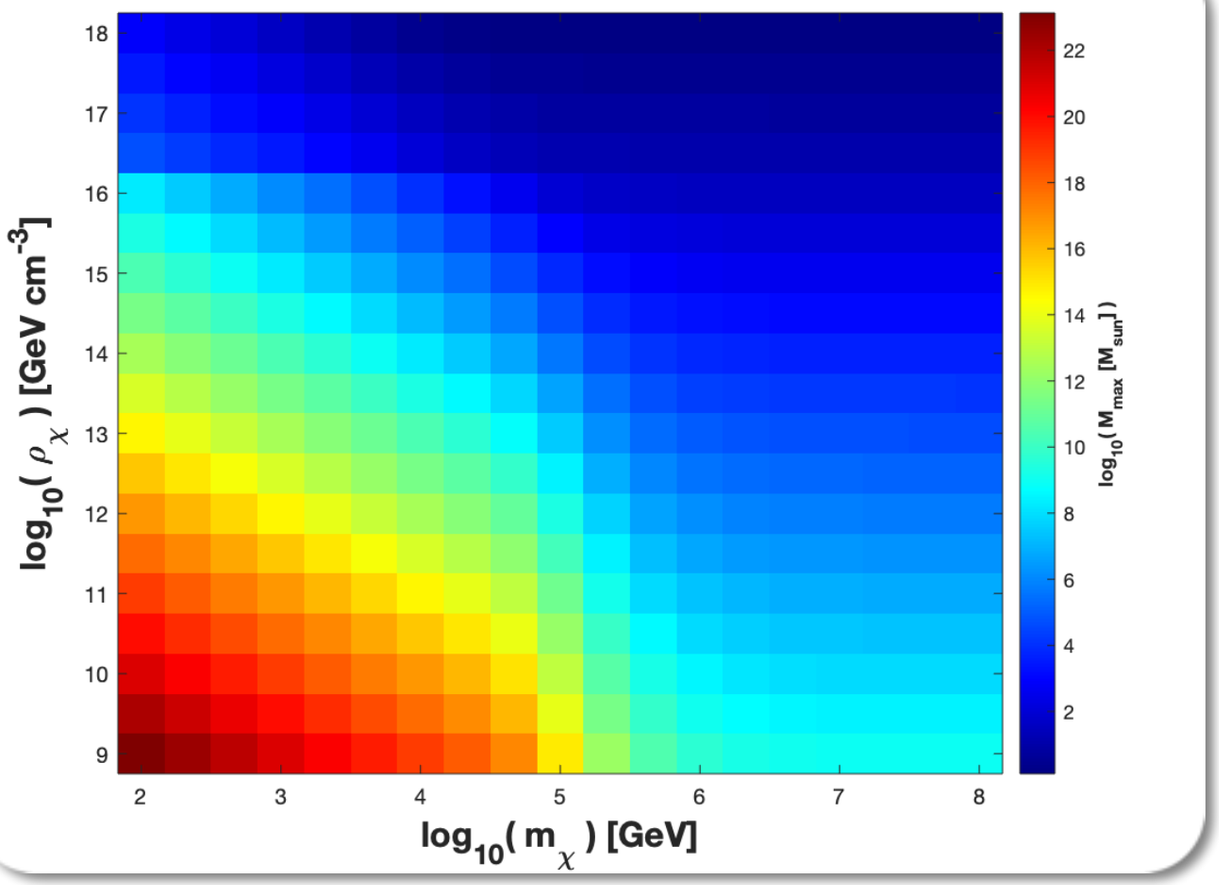


High Mass Limits

Dark Matter + Nuclear Fusion

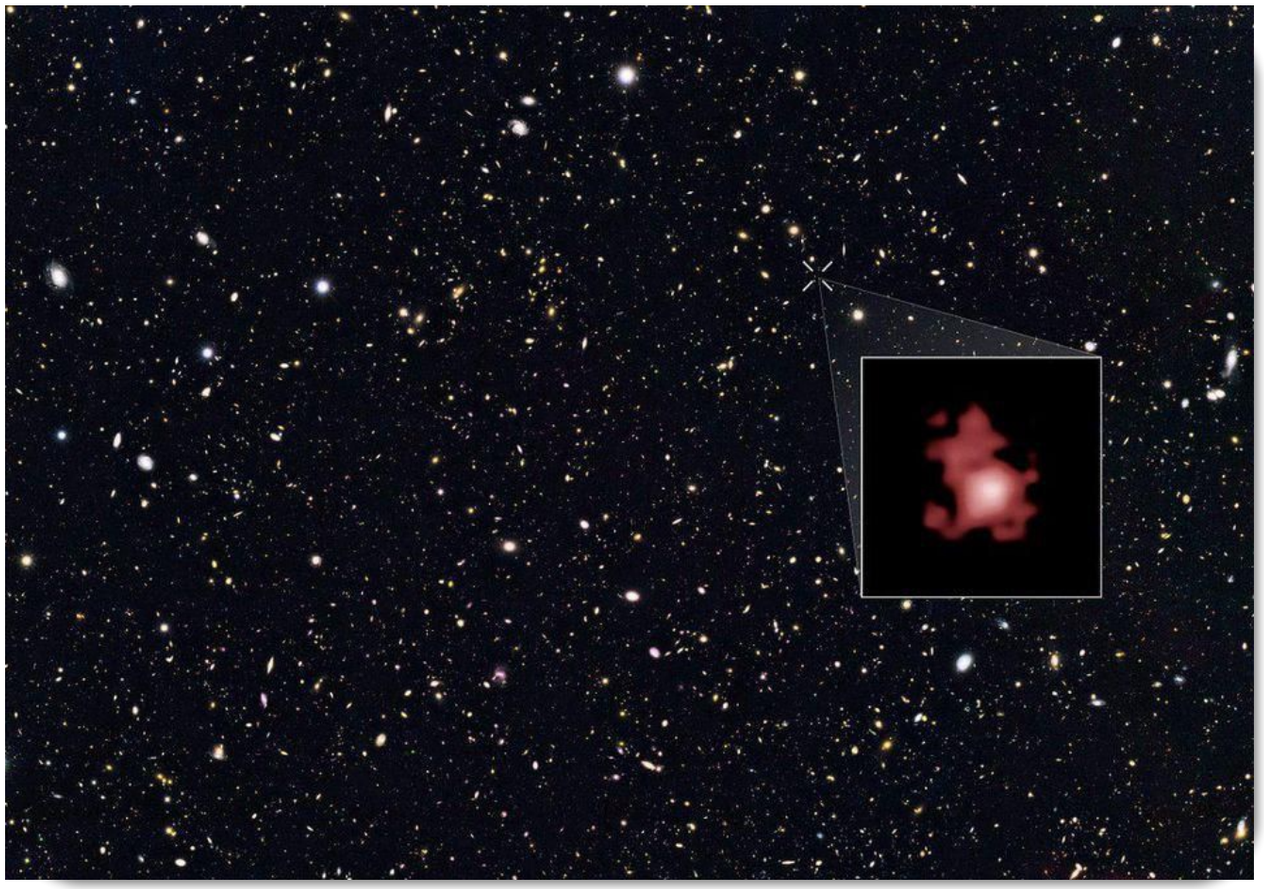


Dark Matter Only



So why do we care?

How did these objects form so quickly?



GN-z11: 1 Billion Solar Masses

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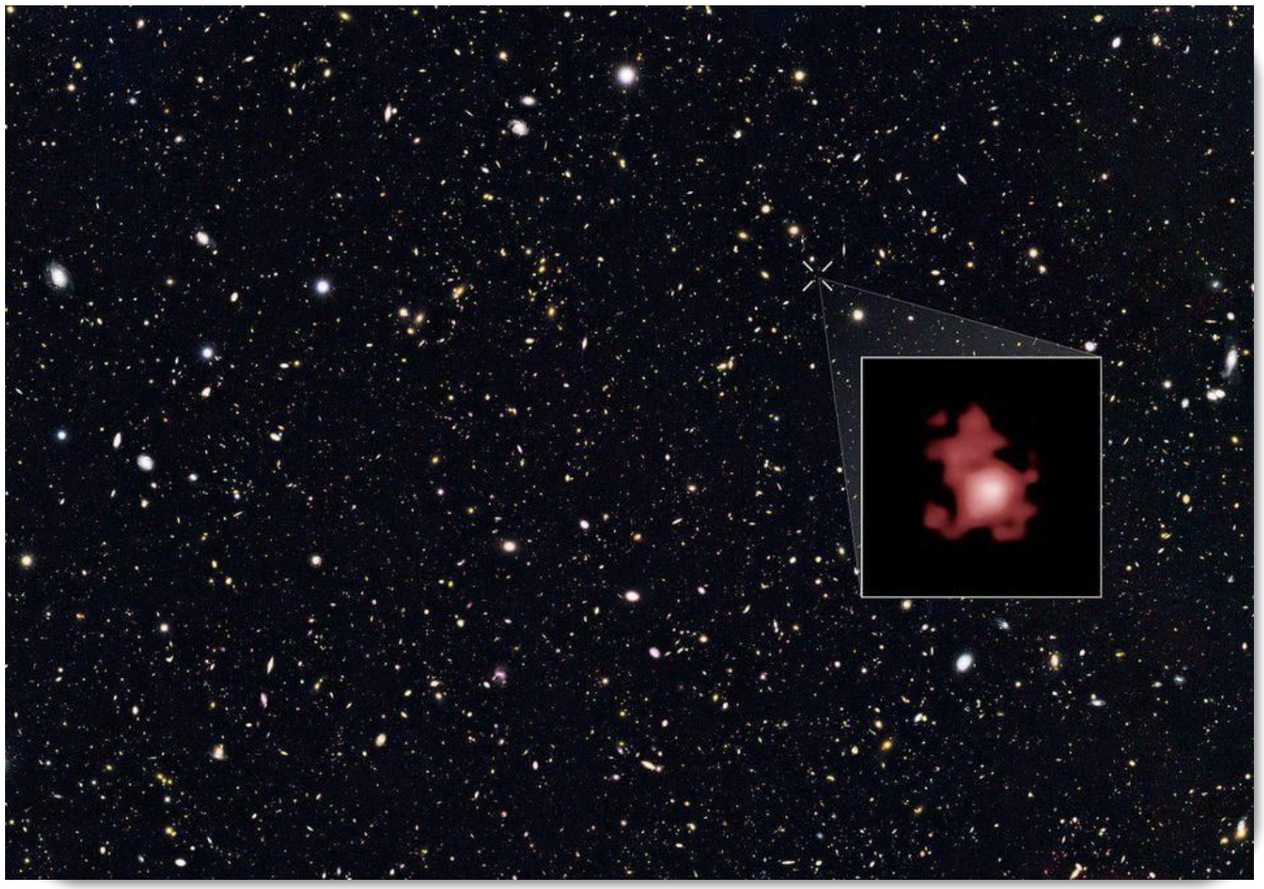
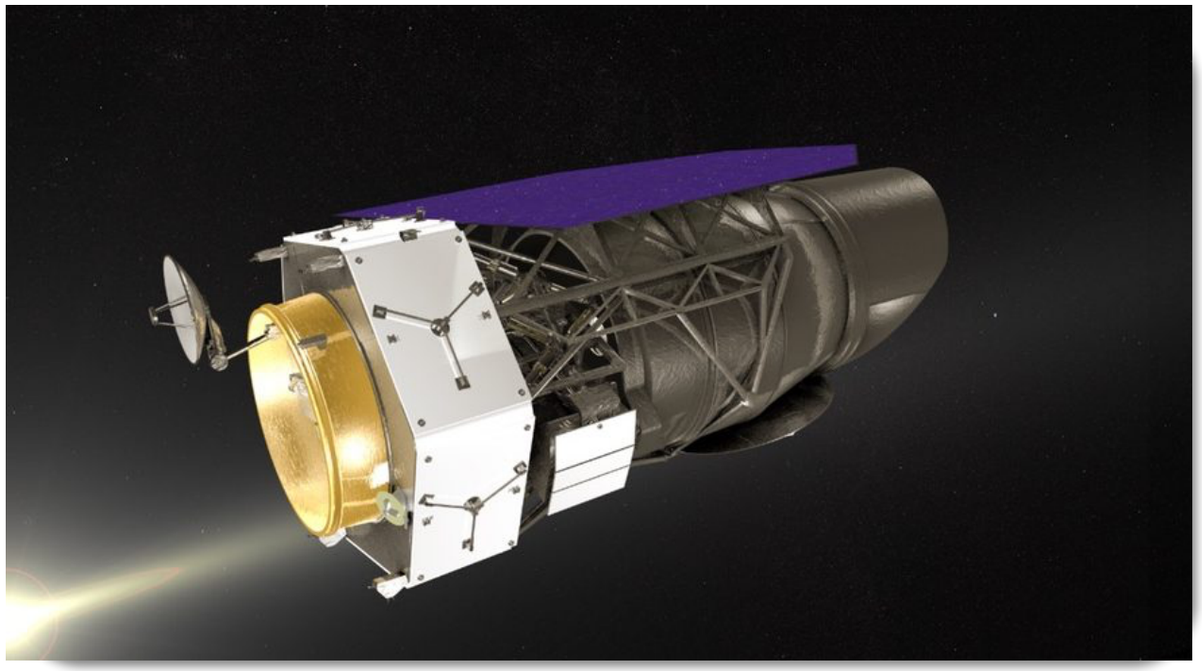
M87 SMBH: 7 Billion Solar Masses



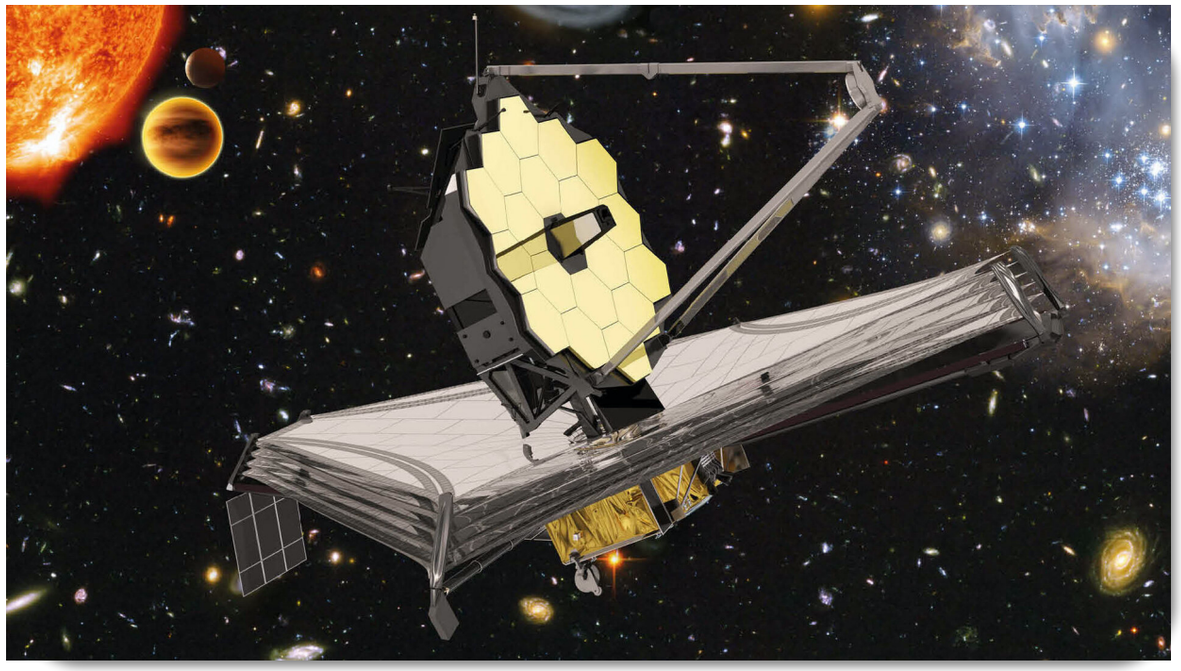
GN-z11: 1 Billion Solar Masses

So why do we care?

Next Generation Telescopes



WFIRST



James Webb Space Telescope

Thank you!

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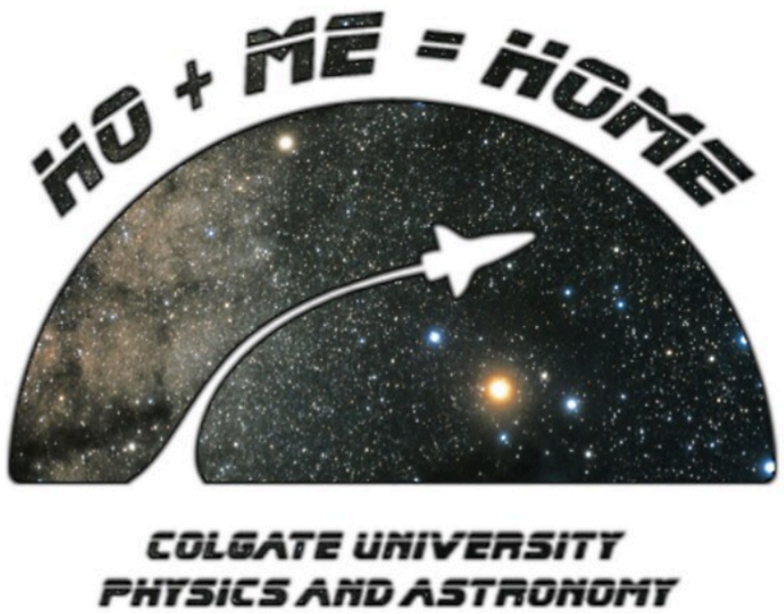

Additional Slides

Homology Relations (ZAMS)