Dark Kinetic Heating of Exoplanets and Brown Dwarfs

Aidan Reilly

arxiv.org/2405.02393 with J. Acevedo & R. Leane

U.S. DEPARTMENT OF ENERGY
Office of Science

SLAC NATIONAL ACCELERATOR LABORATORY

Outline

- Background / Set up
- Particle Physics Model
- Capture and Heating Calculations
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Dark Matter Heating of Celestial Bodies

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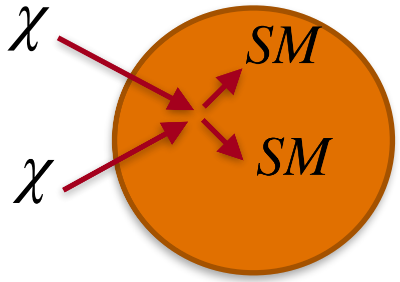
Annihilation Heating



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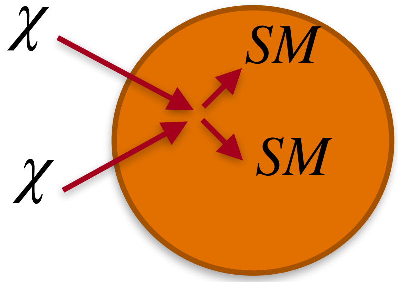

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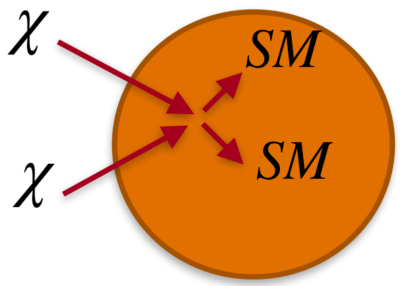

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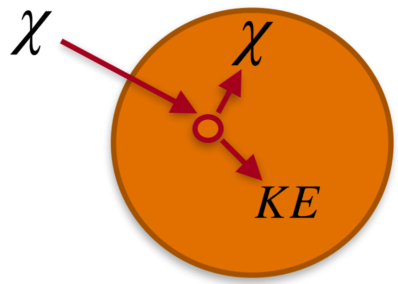

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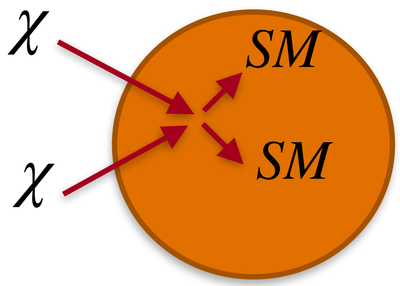

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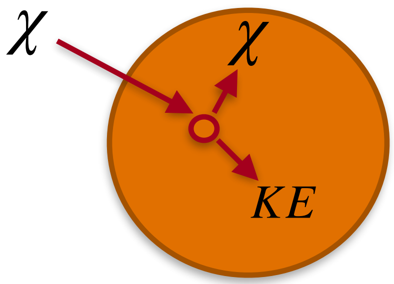

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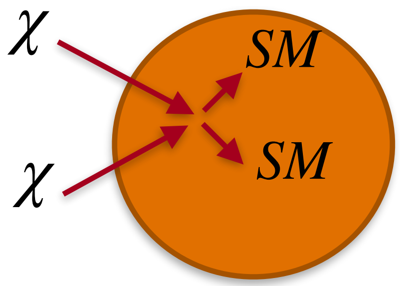

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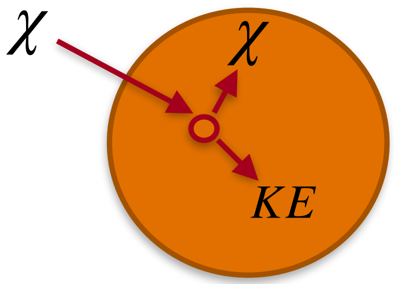

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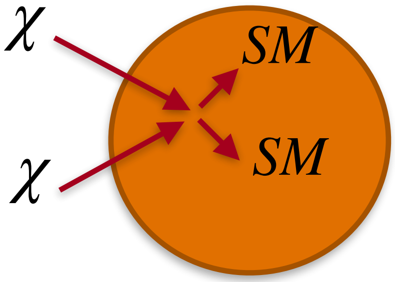

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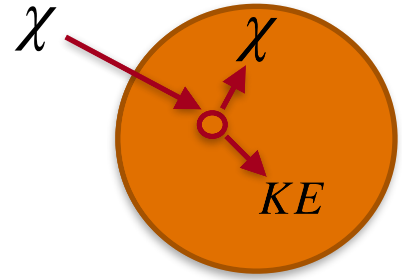

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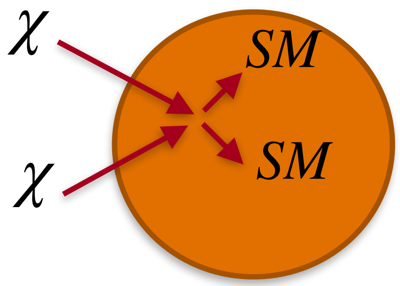

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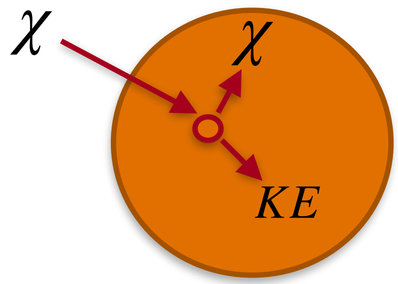

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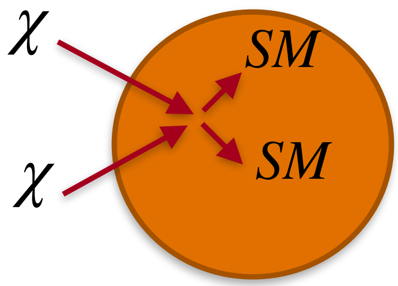

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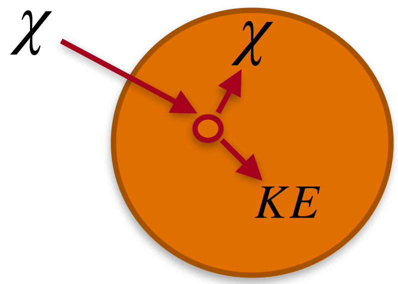

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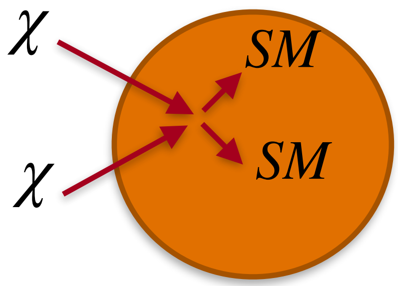

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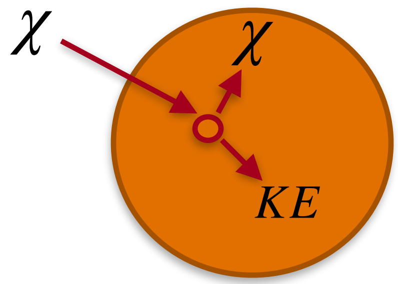

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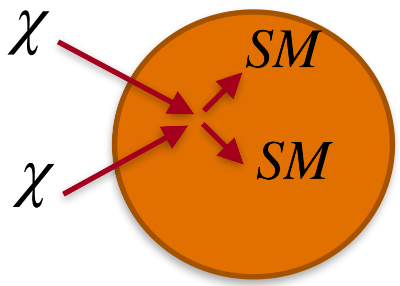

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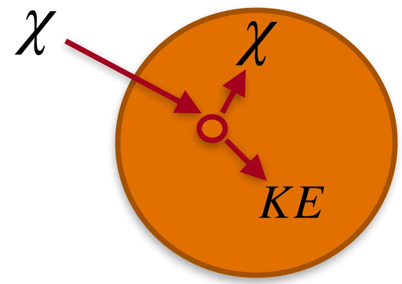

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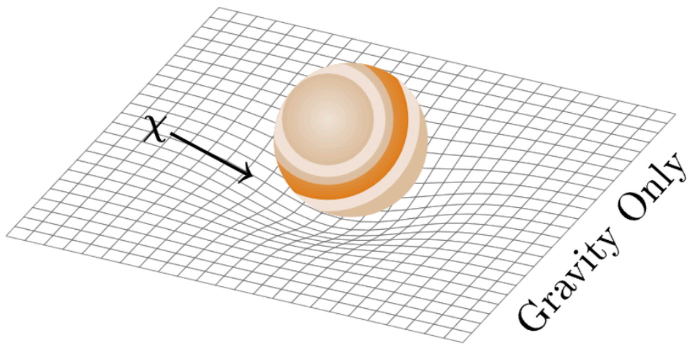

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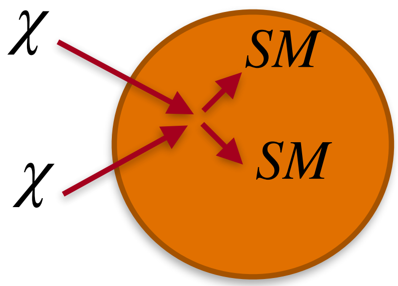

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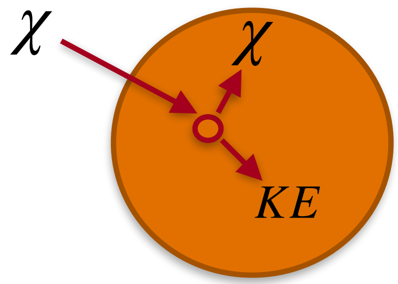

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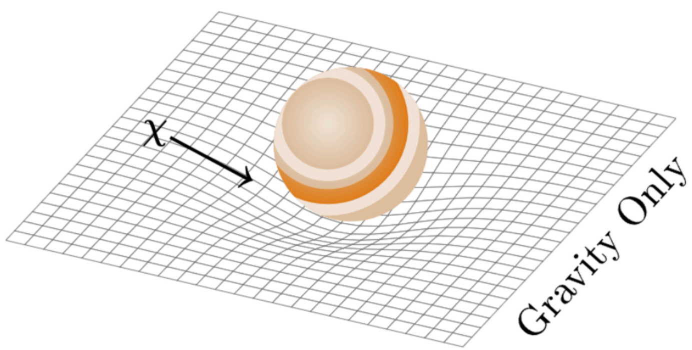

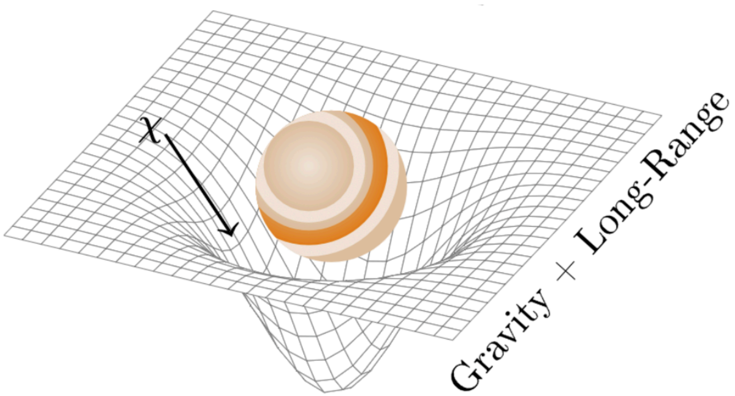

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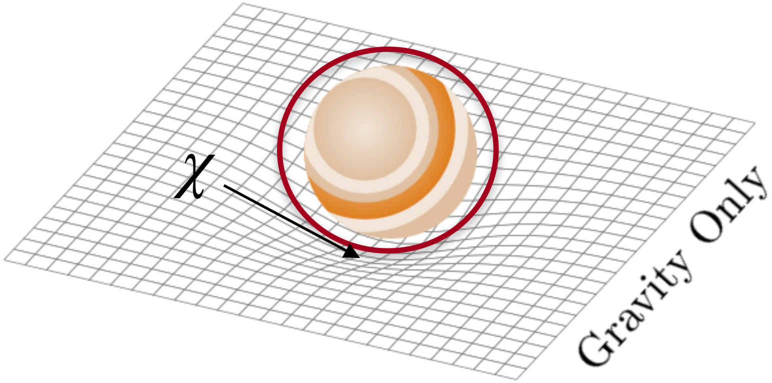

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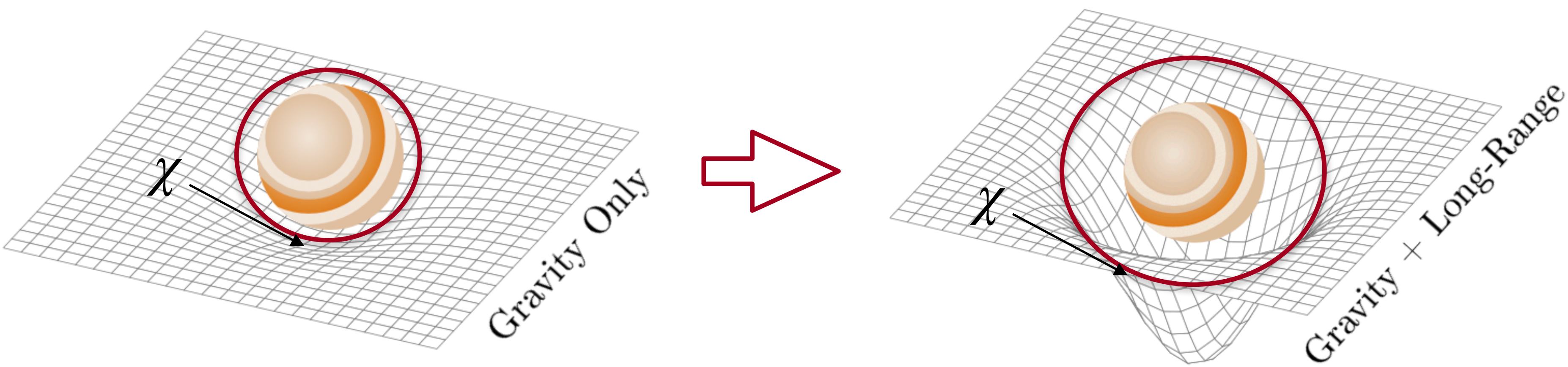

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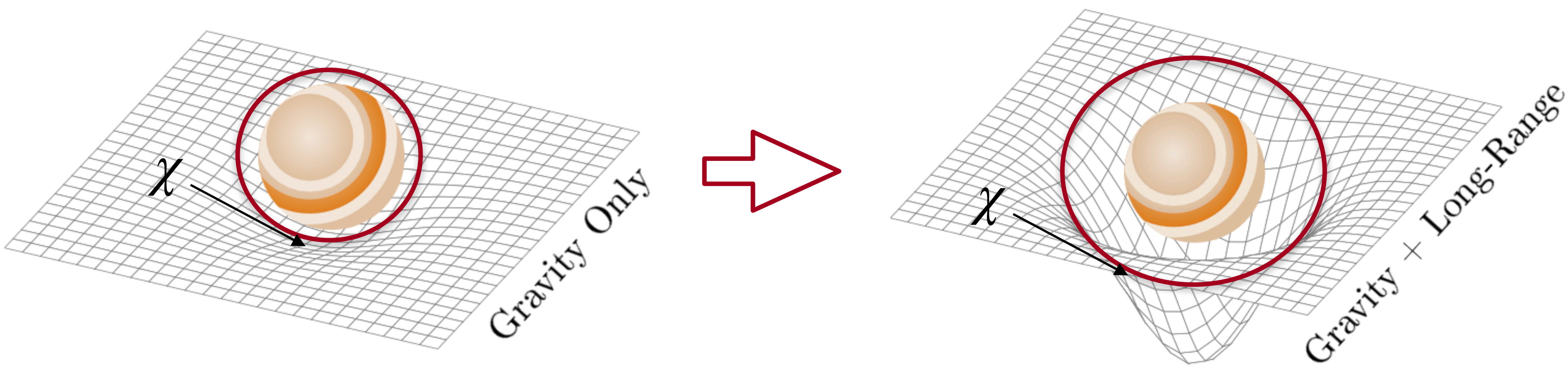
Relativistic boost at surface



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$$\dot{N}_\chi = \frac{\rho_\chi}{m_\chi}\pi\langle b^2_{\rm max} v_\chi P_{\rm cap}\rangle \propto\!\!\!\!\sim N_\chi \quad \Rightarrow \quad \Phi(t) \propto\!\!\!\!\sim e^{\kappa t}$$

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$$M = 55\ M_{\text{Jupiter}}$$

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$$M = 55\ M_{\text{Jupiter}} \qquad R = R_{\text{Jupiter}} \qquad \text{Age} = 10\ \text{Gyr}$$

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99% capture   Local DM density

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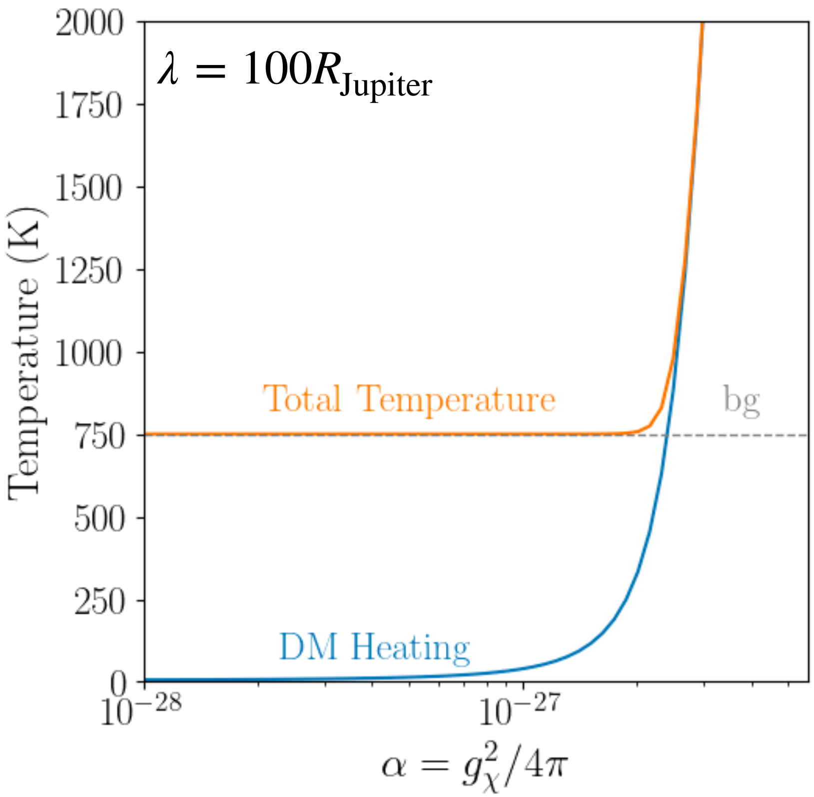

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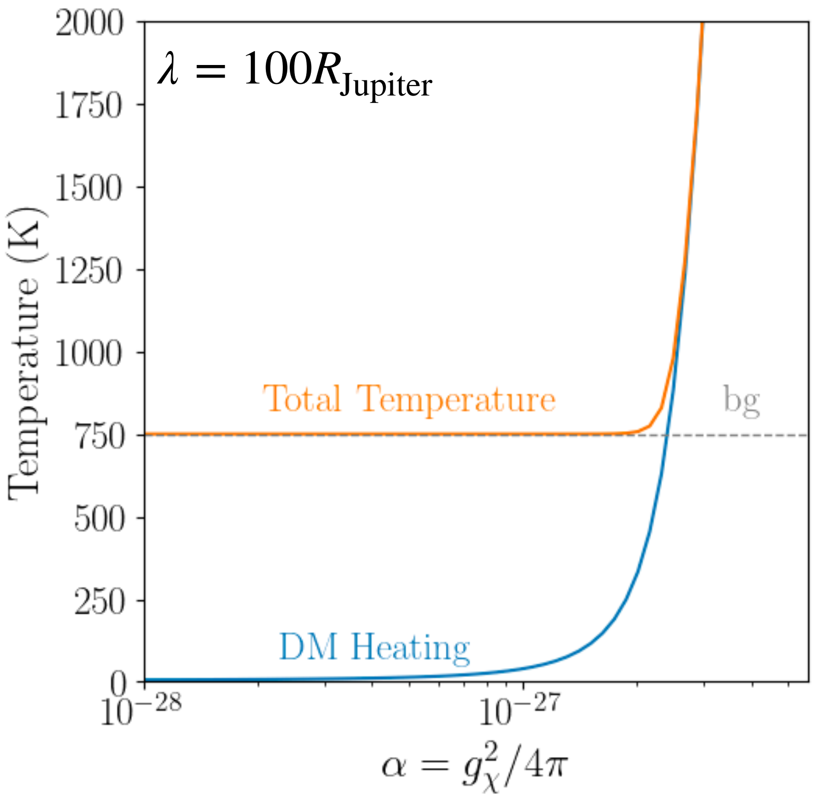
Exponential dependence on coupling strength



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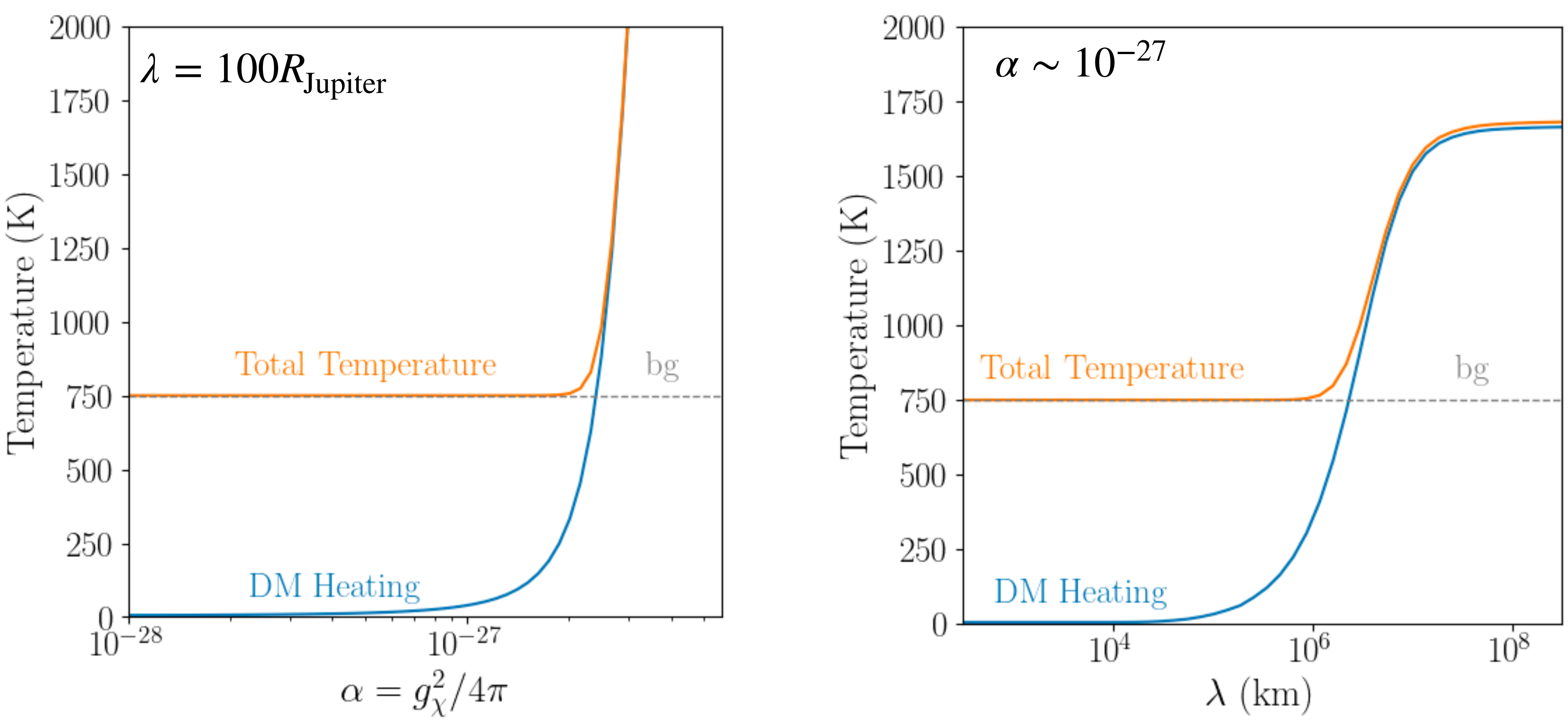

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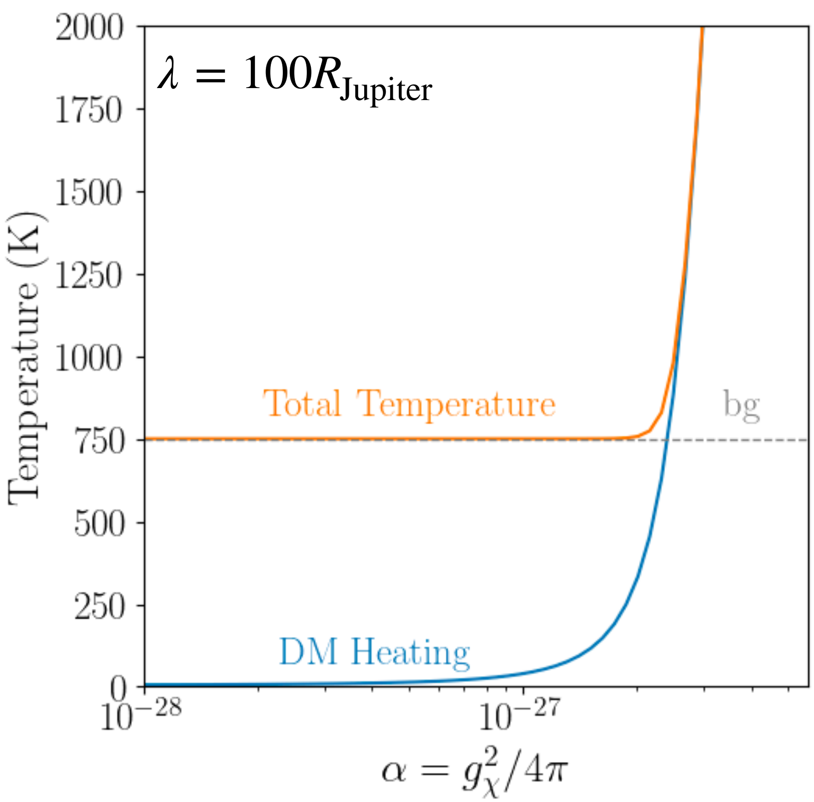

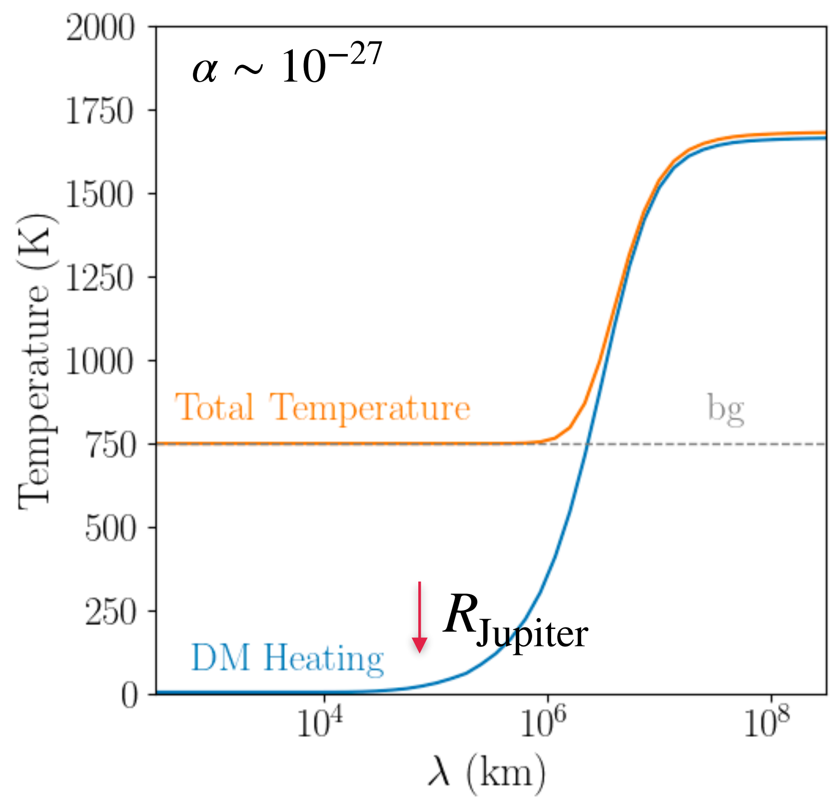

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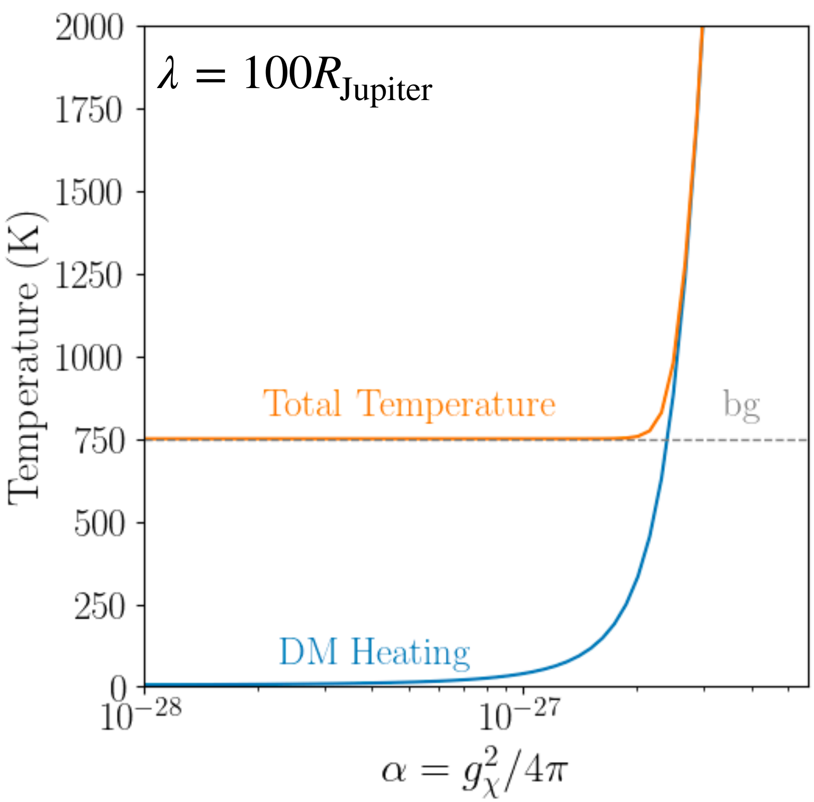
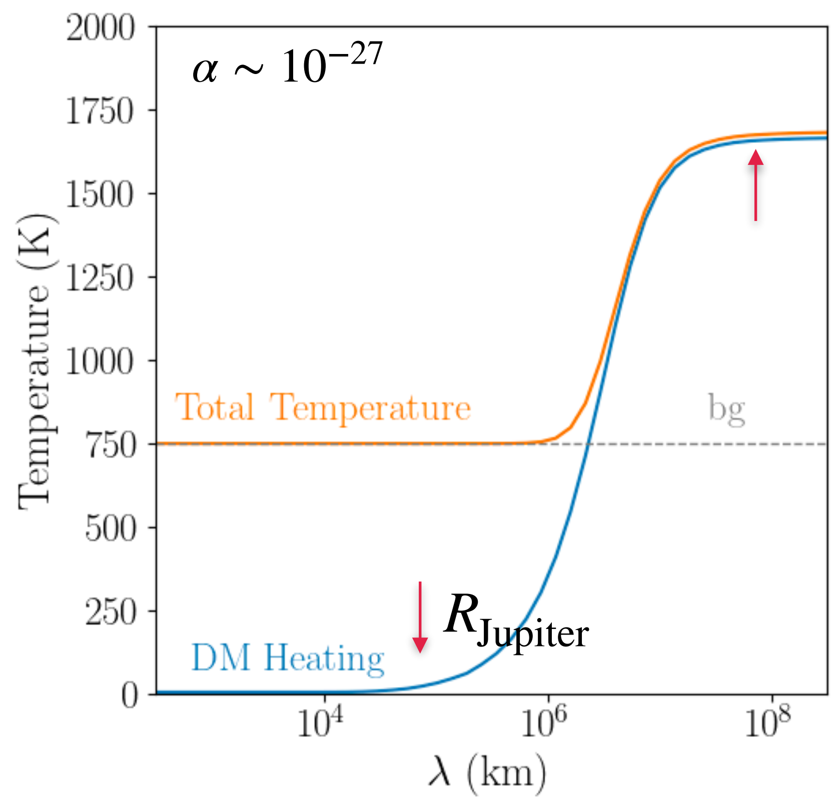
Upper limit on changing force range





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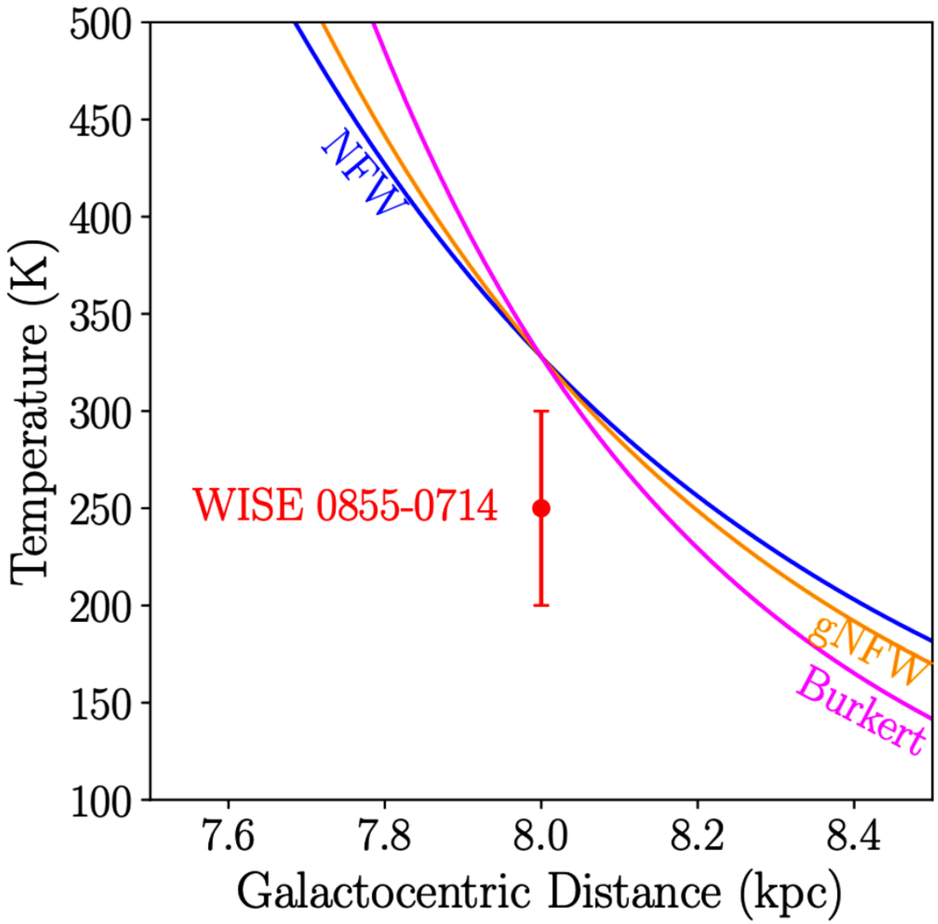

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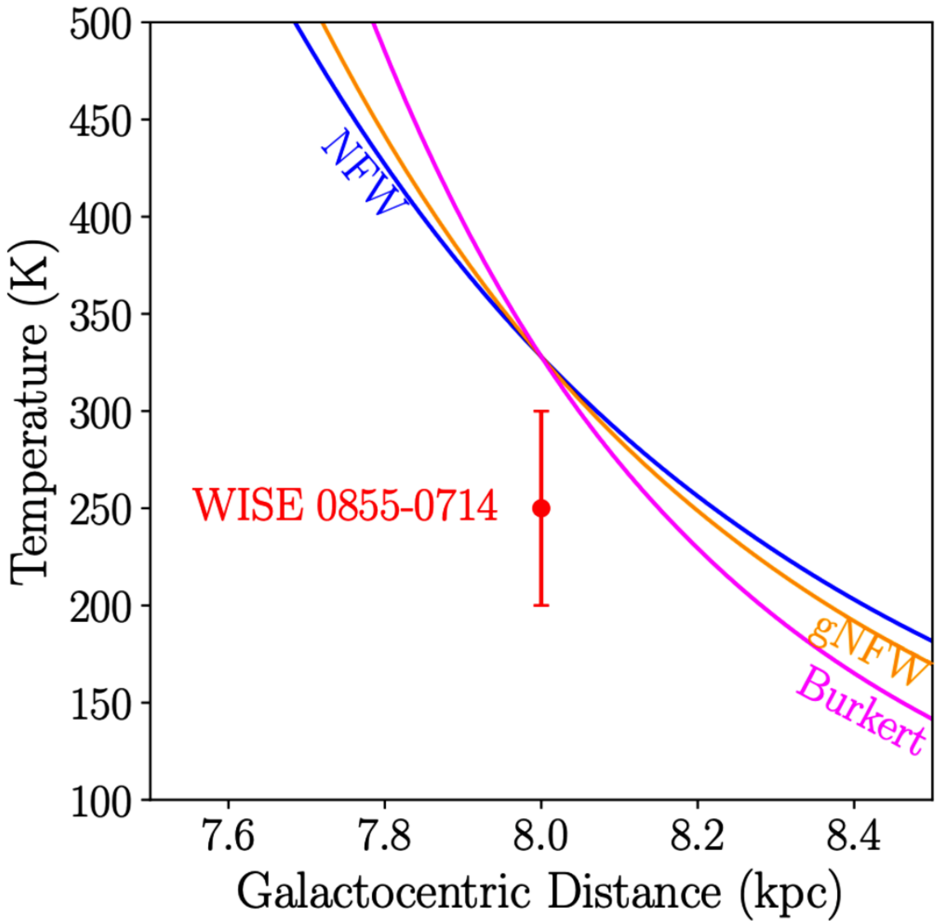

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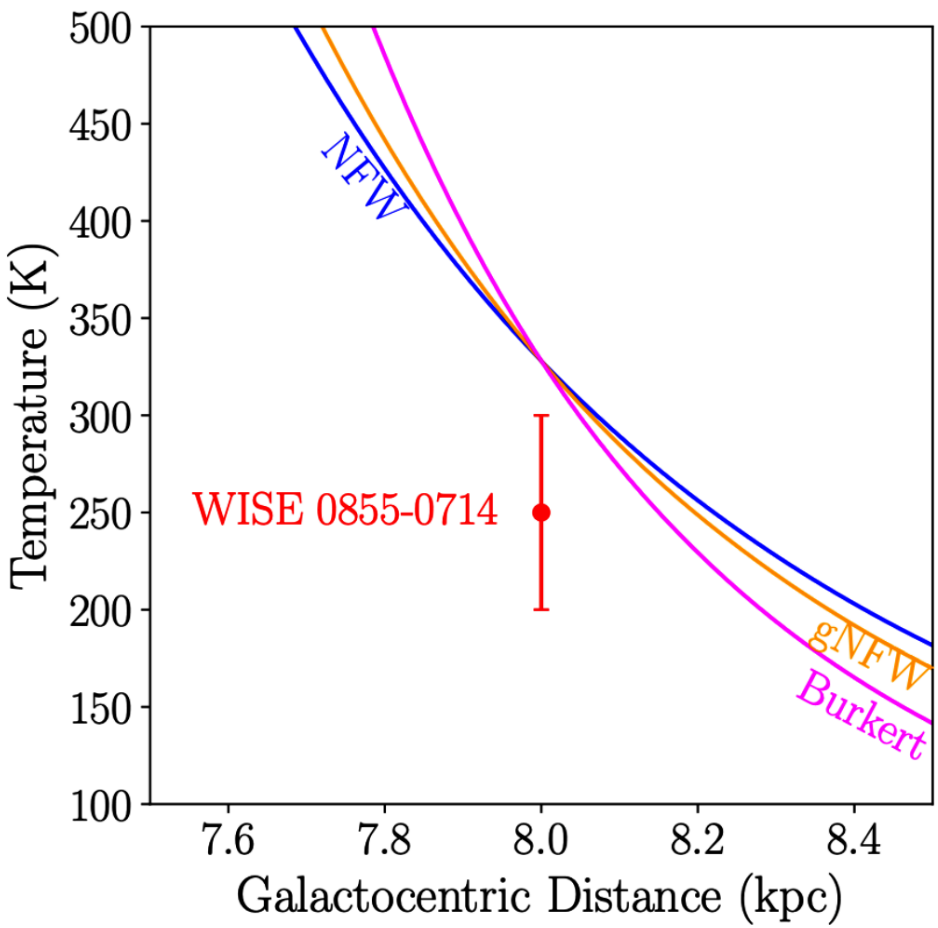

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If older than expected, could also be modeled as a positive signal

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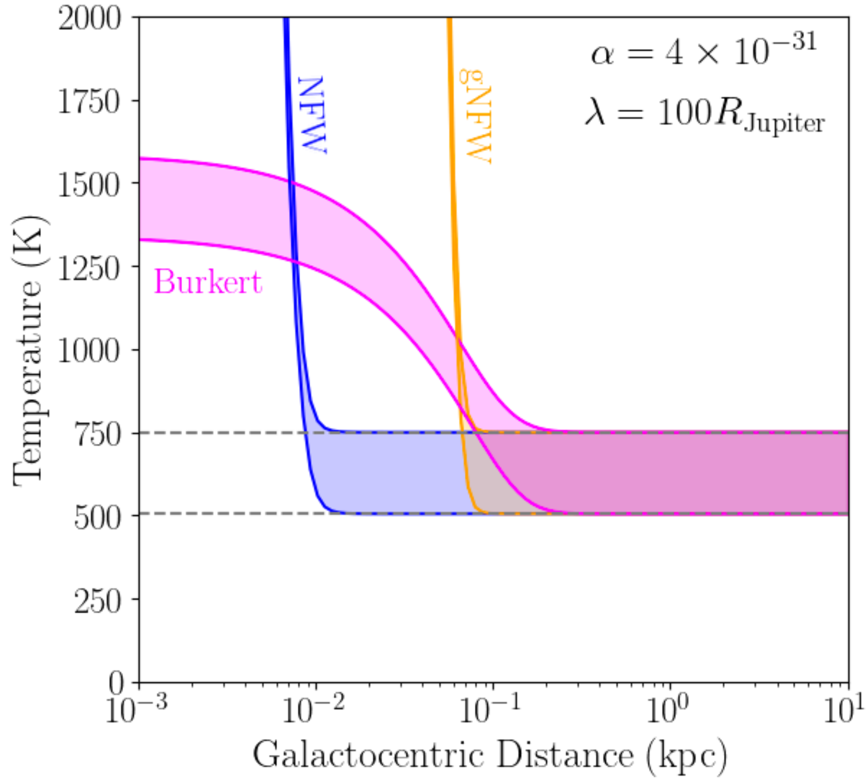

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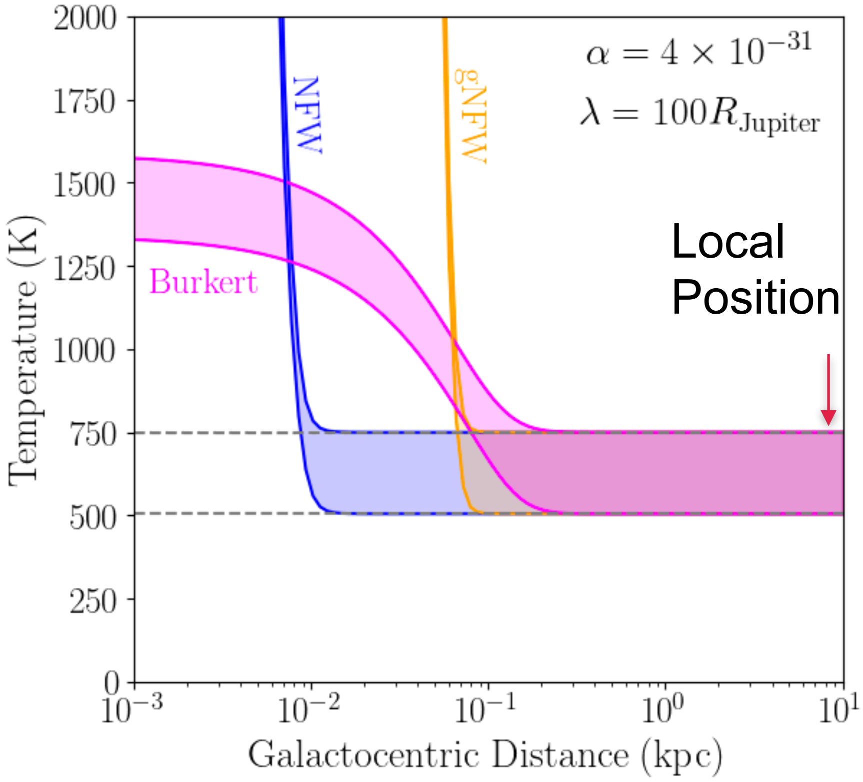
Heating Traces DM Density

Higher density probes weaker couplings



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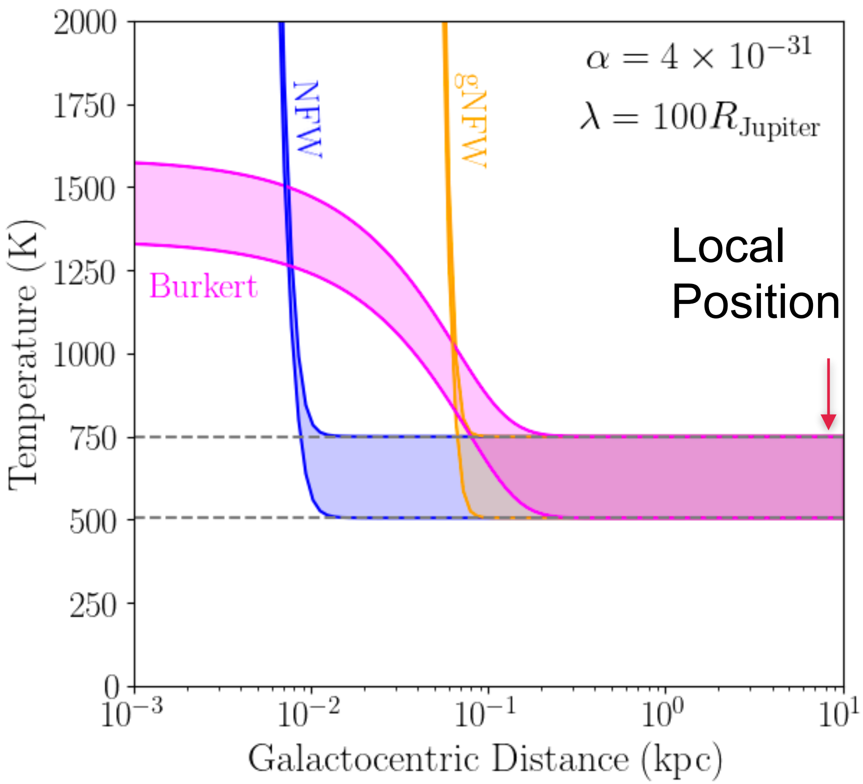
Can give insight into DM density profile



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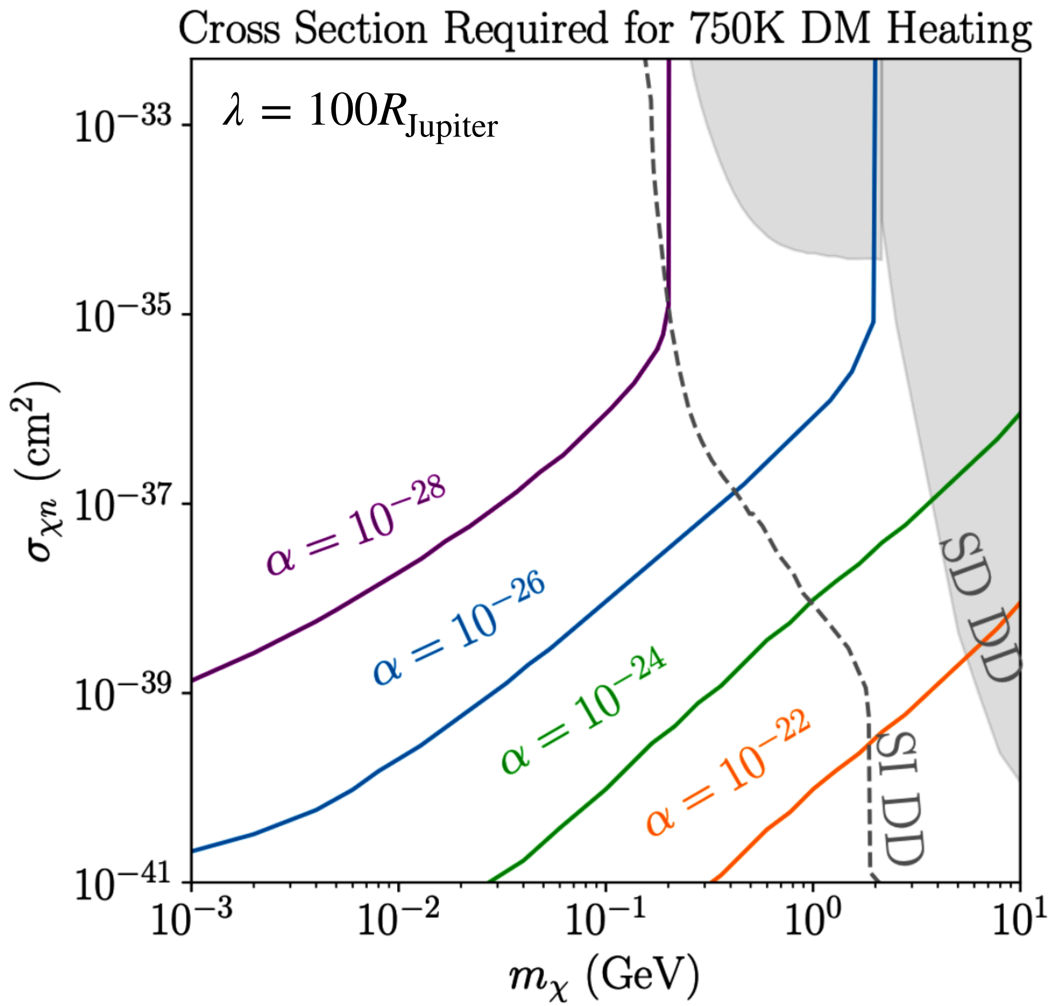

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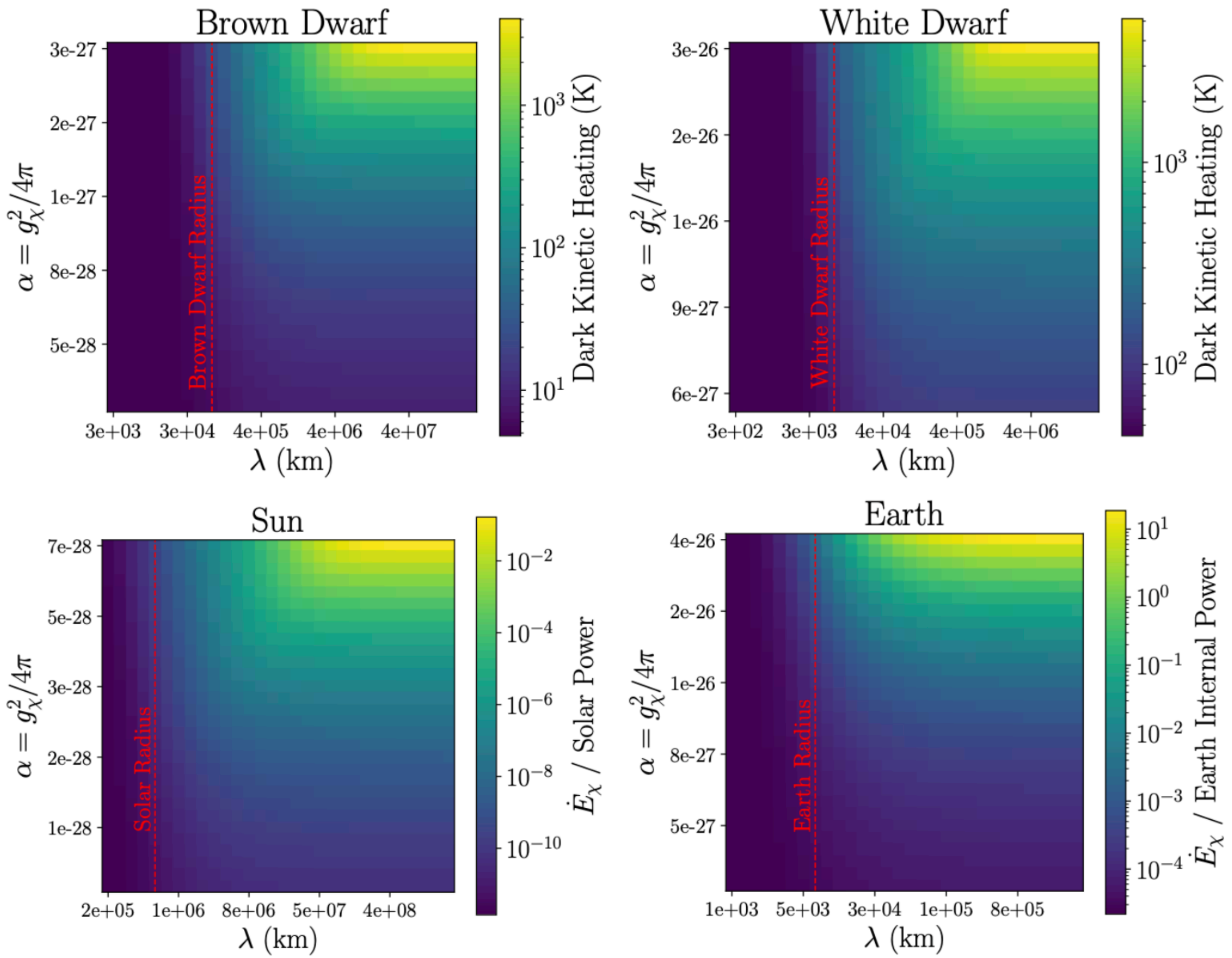

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DM capture is extremely efficient

- Probe of very small DM-SM cross sections

In the presence of a long rang force in the dark sector…

Striking and easily detectable Dark kinetic heating signals

- Can already make exclusions

Sharp probe of the galactic DM distribution

DM capture is extremely efficient

- Probe of very small DM-SM cross sections

Various objects can be used to observe complementary regions of parameter space

Thermalization Time Scale

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We estimate the heating timescale based on the heat capacity of the target material

Thermalization Time Scale

SLAC

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$$C_v \frac{dT}{dt} = \dot{E}_\chi - \dot{E}_{\rm cool}$$

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$$C_v = \frac{N_{SM}}{\Gamma - 1} \qquad \Gamma = 7/5$$

Assuming fixed energy injection rates, we find that heating is effectively instantaneous

Thermalization Timescales

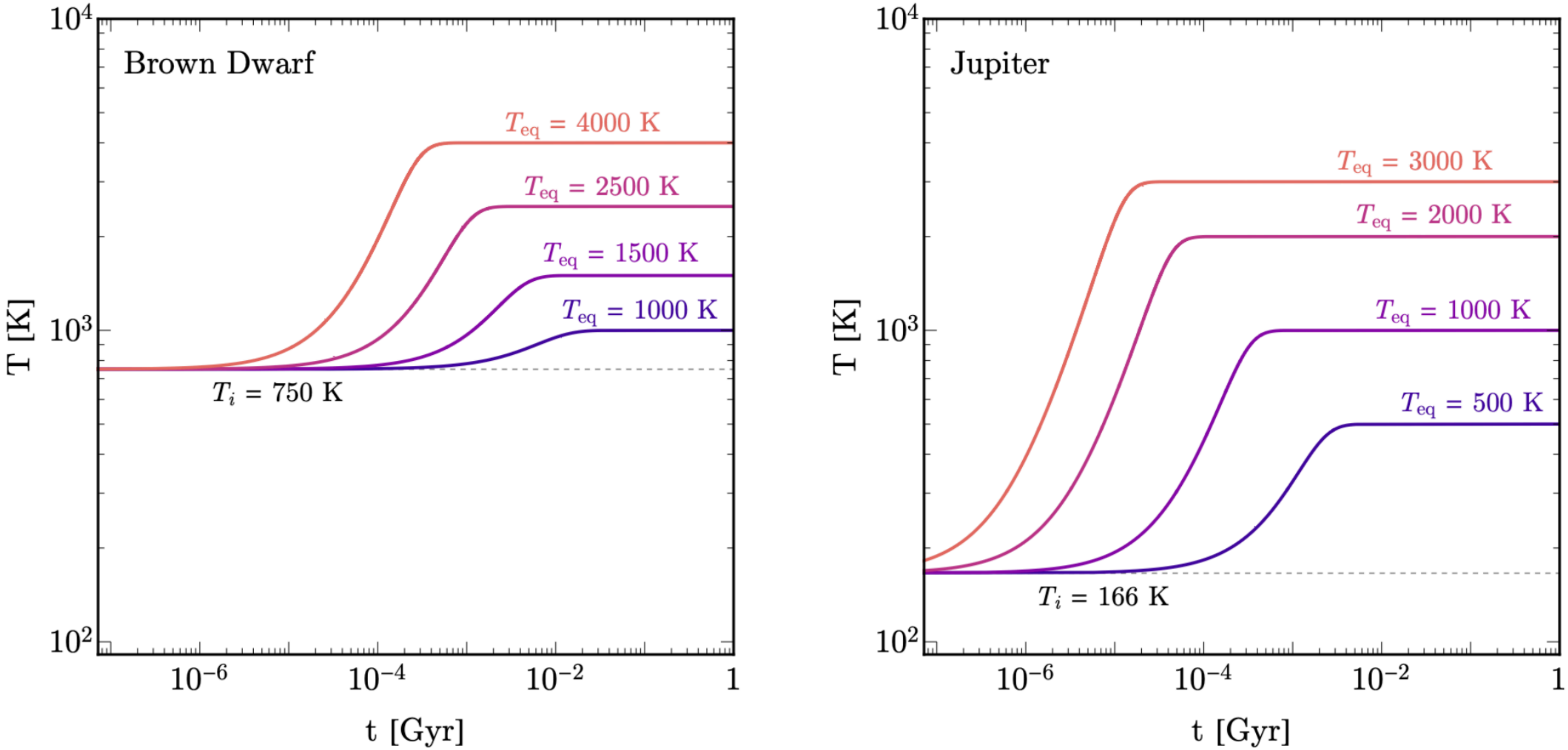

FIG. 5. Temperature evolution for a benchmark 55 Jupiter-mass brown dwarf and Jupiter, assuming fixed energy injection rates. The dashed line indicates the initial temperature assumed. Each colored label shows the final equilibrium temperature reached for the given line.