Thermalization of inelastic dark matter in the Sun

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Introduction

Two states χ and χ^* that satisfy

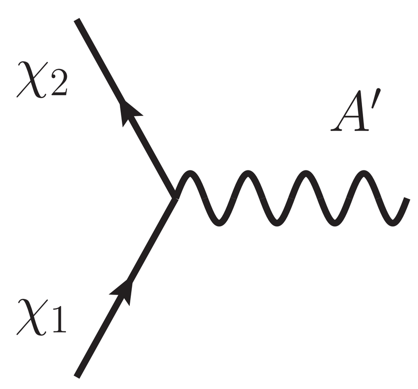
$$m_{\chi^*} - m_\chi = \delta, \qquad m_\chi \gg |\delta|.$$

Primary scattering:

$$\chi + X \longleftrightarrow \chi^* + X.$$

Inelastic since energy is absorbed or released when scattering.

Relevant scattering vertex:



Possibly captured by the Sun, annihilate, and give rise to high-energy neutrinos. The annihilation rate depends on the DM number density.

However, Large velocities required for $\chi \rightarrow \chi^*$ scattering to be kinematically allowed.

- **Does inelastic DM thermalize?**
- **If not, how is the annihilation rate affected?**
- **Does $\chi^* \rightarrow \chi$ scattering increase evaporation rates?**

Simulation setup

A particle in orbit characterized by reduced angular momentum $L = |\vec{r} \times \vec{v}|$ and energy

$$E = \frac{1}{2}\dot{r}^2 + \frac{L^2}{2r^2} + \phi(r)\,.$$

Particles are distributed into states f_α, orbits with discretized values of E and L, f_α. The distribution evolves according to

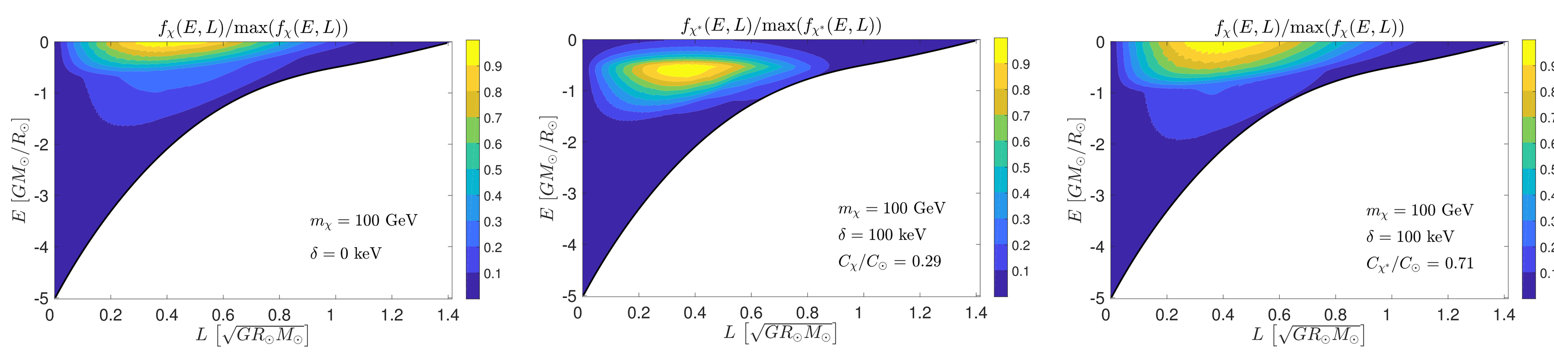
$$\dot{f}_\alpha = C_\alpha + \sum_\beta \Sigma_{\beta\to\alpha} f_\beta - f_\alpha \sum_\beta \Gamma_{\alpha\beta} f_\beta\,.$$

- C_α: Capture rate into state α
- $\Sigma_{\beta\to\alpha}$: Scattering rate from state β to α
- $\Gamma_{\alpha\beta}$: Annihilation rate for a particle in state α and another in β.

Capture rates

Capture rates calculated numerically where particles are sorted into the corresponding states.

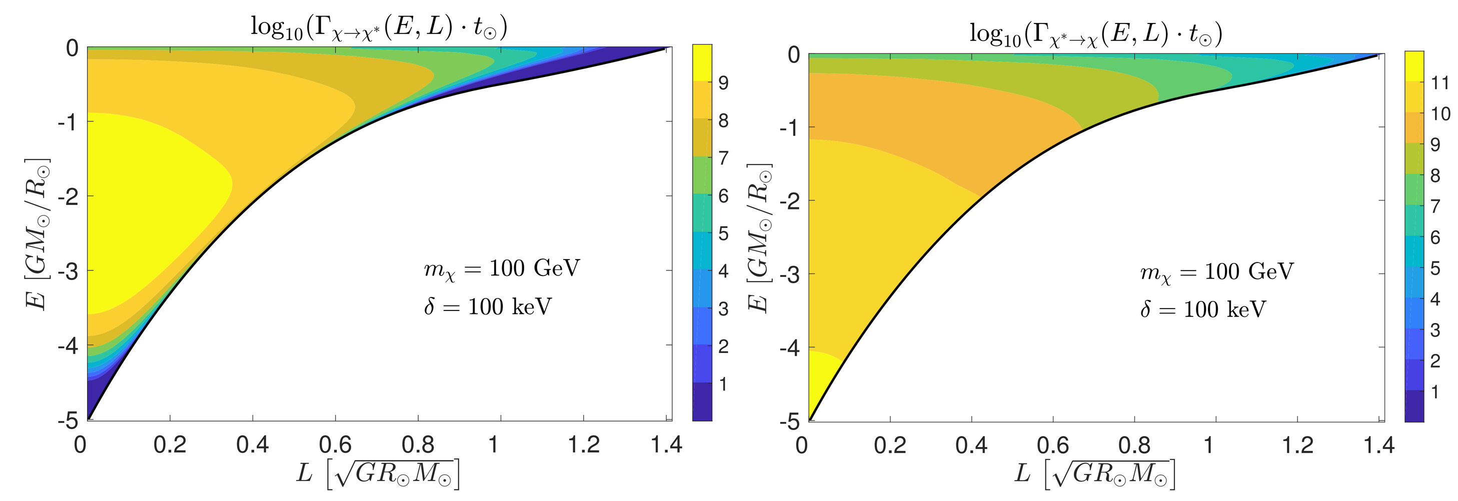
Elastic capture: χ capture: χ^* capture:



- Capture of χ leaves particles more strongly bound.
- Elastic and exothermic scattering very similar.

Scattering rates

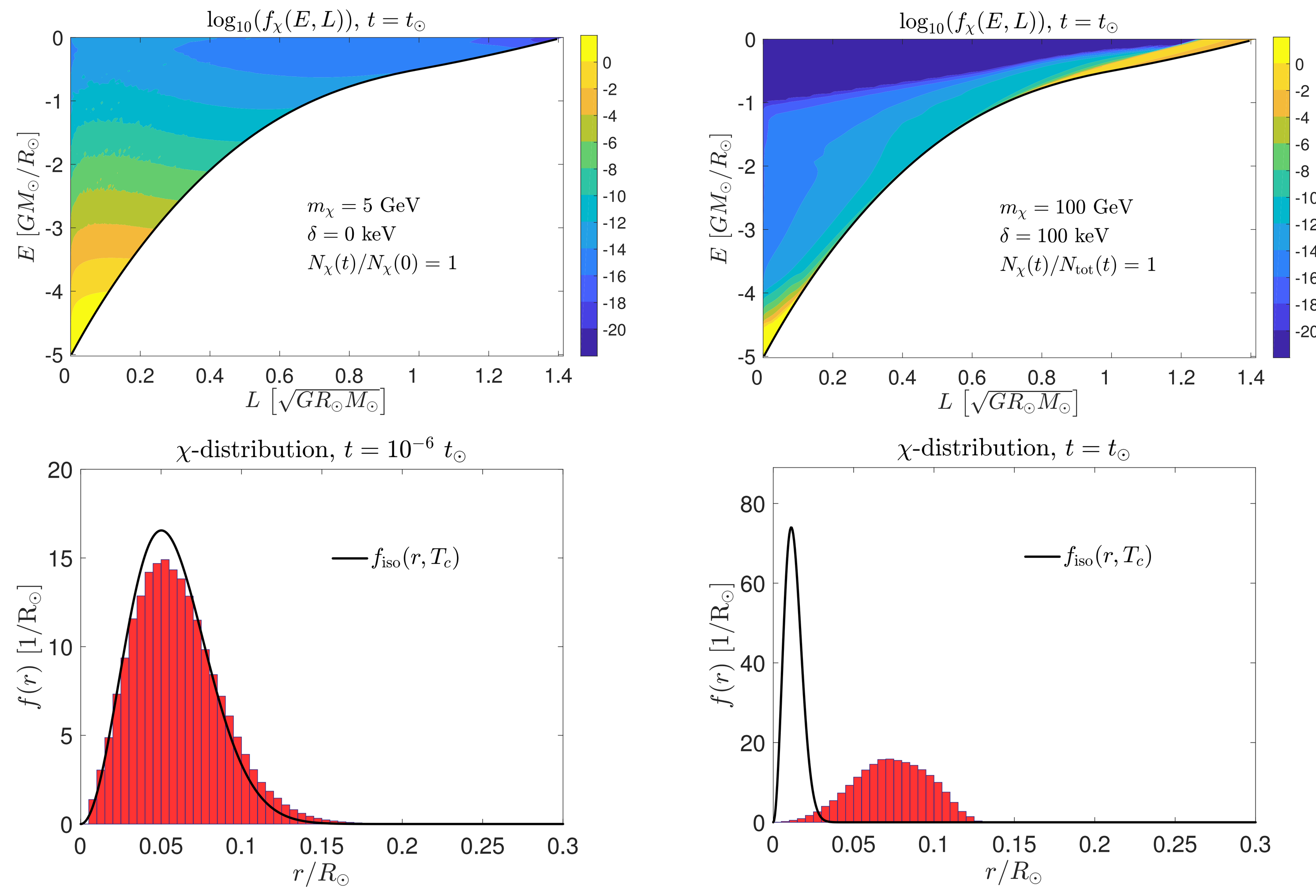
MC methods are employed to calculate $\Sigma_{\beta\to\alpha}$.



- Elastic scattering is identical in behaviour to exothermic scattering.
- Inelastic scattering is kinematically forbidden in some regions.

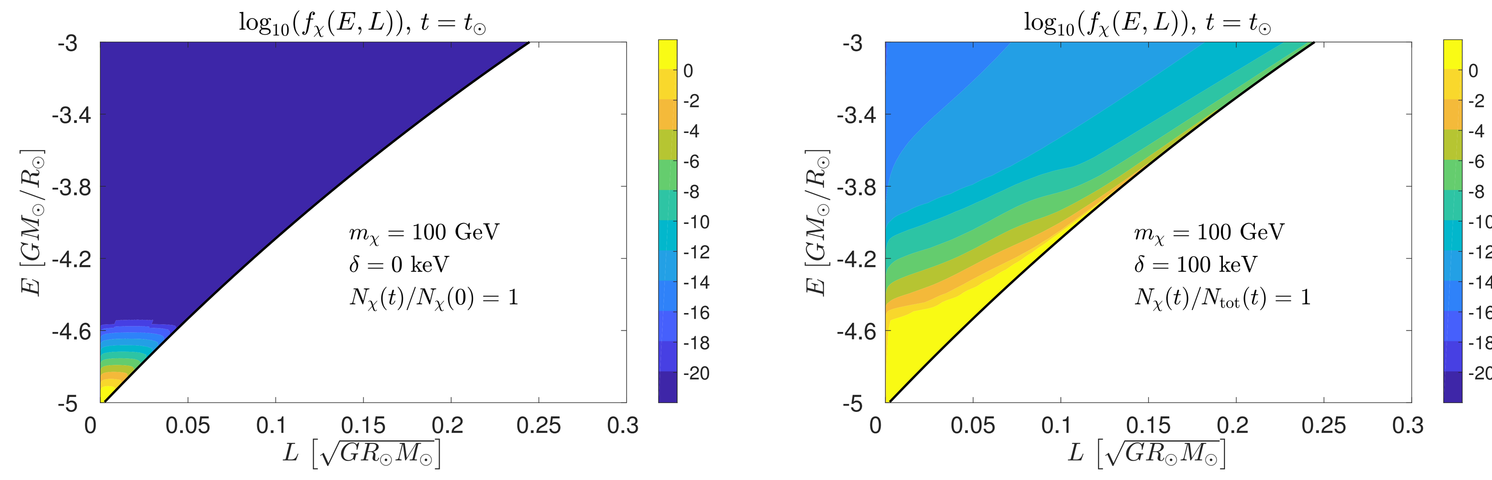
Evolved distributions

We evolve distributions neglecting additional capture and annihilation for a full solar lifetime.



- Elastic DM thermalizes.
- Negligible number of χ^* remaining at $t = t_\odot$ is zero.
- A thermal Boltzmann distribution is generally a bad fit.

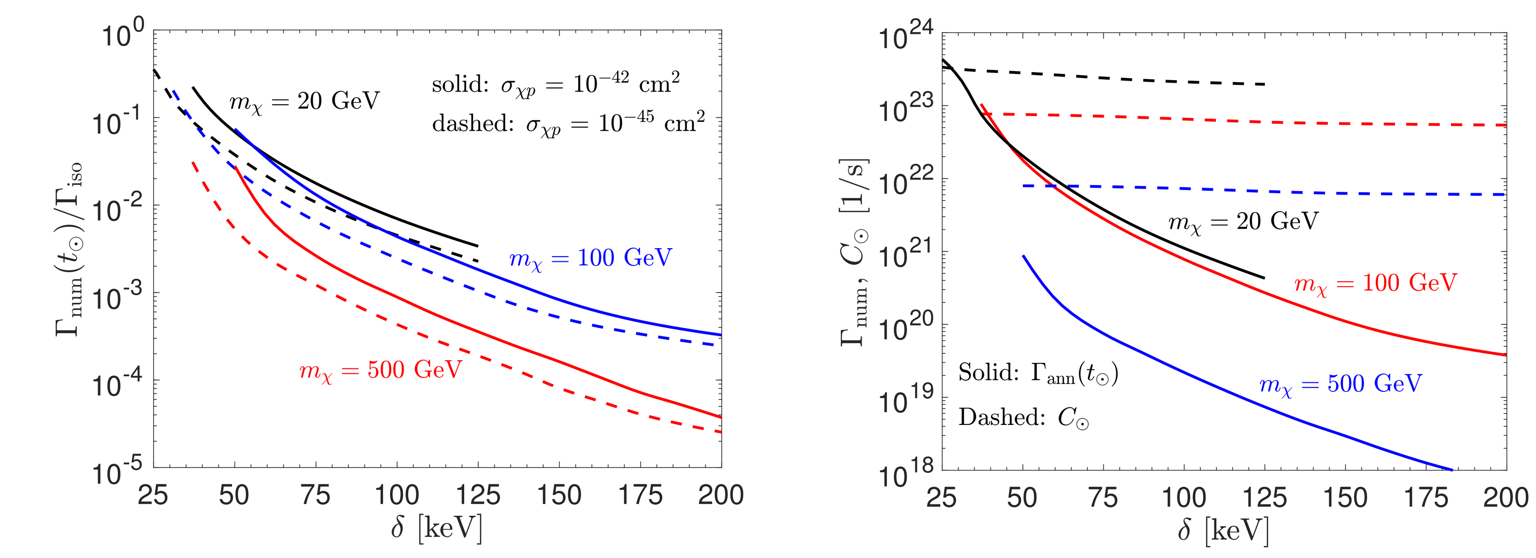
Comparing distributions with $m_\chi = 100$ GeV.



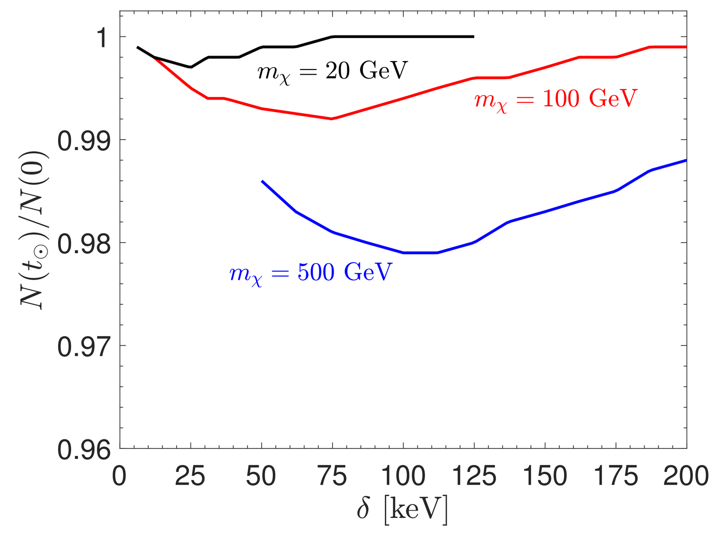
- Much wider distribution for the inelastic case.

Annihilation and evaporation

An upper bound on the annihilation rate can be calculated from distributions calculated taking continuous capture into account.



- Annihilation rate severely hampered for large δ.
- Equilibrium between capture and annihilation does not occur.
- Evaporation due to kinetic boosts when χ^* scatters is not an issue.



Conclusions

- Inelastic DM does not thermalize in the Sun.
- No equilibrium between capture and annihilation in these models.
- No significant evaporation from χ^* scattering.

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