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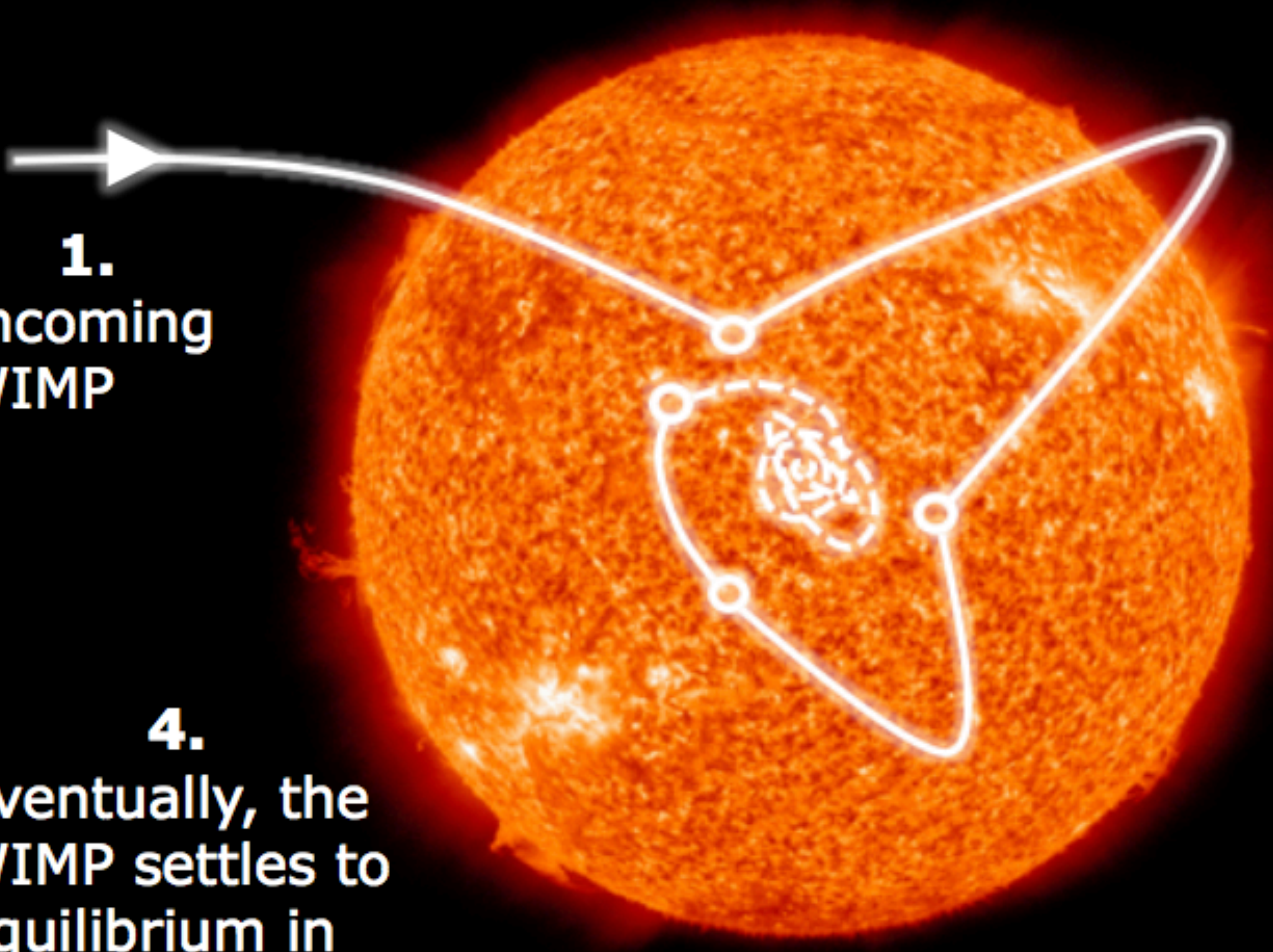
THERMALIZATION TIME SCALES FOR WIMP CAPTURE BY THE SUN

OUTLINE

- Background on WIMP capture by the Sun
- Thermalization time scales – **arXiv:1703:06878**
- WIMP self-interaction – **arXiv:1609:04825**
- Outlook, possible future work

WIMP capture and thermalization



1.
Incoming WIMP

2.
A scattering event binds the WIMP in orbit

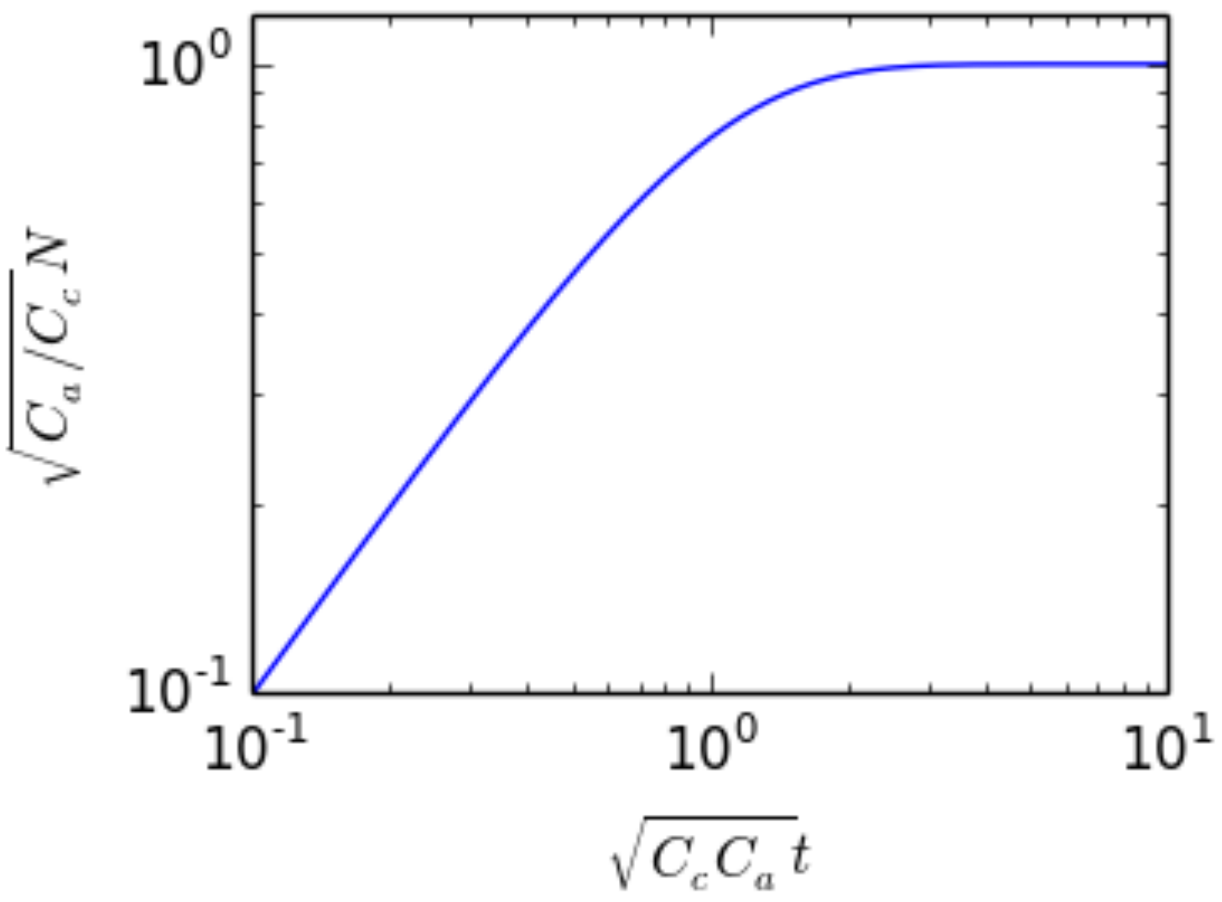
3.
With each collision, the WIMP loses more of its energy

4.
Eventually, the WIMP settles to equilibrium in the Sun's core

WIMP CAPTURE DIFFERENTIAL EQUATION

$$\frac{\mathrm{d}N}{\mathrm{d}t} = C_c - C_a N^2$$

$$N(t) = \sqrt{\frac{C_c}{C_a}} \tanh\left(\sqrt{C_c C_a} t\right)$$



COMMONLY MADE ASSUMPTIONS

- Instantaneous thermalization
- Thermal profile

$$\epsilon(r) \propto \exp\left(-\frac{m_\chi \phi(r)}{k_B T_c}\right)$$

- (Constant capture rate)

SIMULATING WIMP TRAJECTORIES

- Effective field theory

$$\hat{\mathcal{O}}_1 = \mathbb{1}_{\chi N}$$

$$\hat{\mathcal{O}}_3 = i\hat{\mathbf{S}}_N \cdot \left(\frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^\perp\right)$$

$$\hat{\mathcal{O}}_4 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{S}}_N$$

$$\hat{\mathcal{O}}_5 = i\hat{\mathbf{S}}_\chi \cdot \left(\frac{\hat{\mathbf{q}}}{m_N} \times \hat{\mathbf{v}}^\perp\right)$$

$$\hat{\mathcal{O}}_6 = \left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left(\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)$$

$$\hat{\mathcal{O}}_7 = \hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^\perp$$

$$\hat{\mathcal{O}}_8 = \hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^\perp$$

$$\hat{\mathcal{O}}_9 = i\hat{\mathbf{S}}_\chi \cdot \left(\hat{\mathbf{S}}_N \times \frac{\hat{\mathbf{q}}}{m_N}\right)$$

$$\hat{\mathcal{O}}_{10} = i\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}$$

$$\hat{\mathcal{O}}_{11} = i\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}$$

$$\hat{\mathcal{O}}_{12} = \hat{\mathbf{S}}_\chi \cdot \left(\hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^\perp\right)$$

$$\hat{\mathcal{O}}_{13} = i\left(\hat{\mathbf{S}}_\chi \cdot \hat{\mathbf{v}}^\perp\right)\left(\hat{\mathbf{S}}_N \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)$$

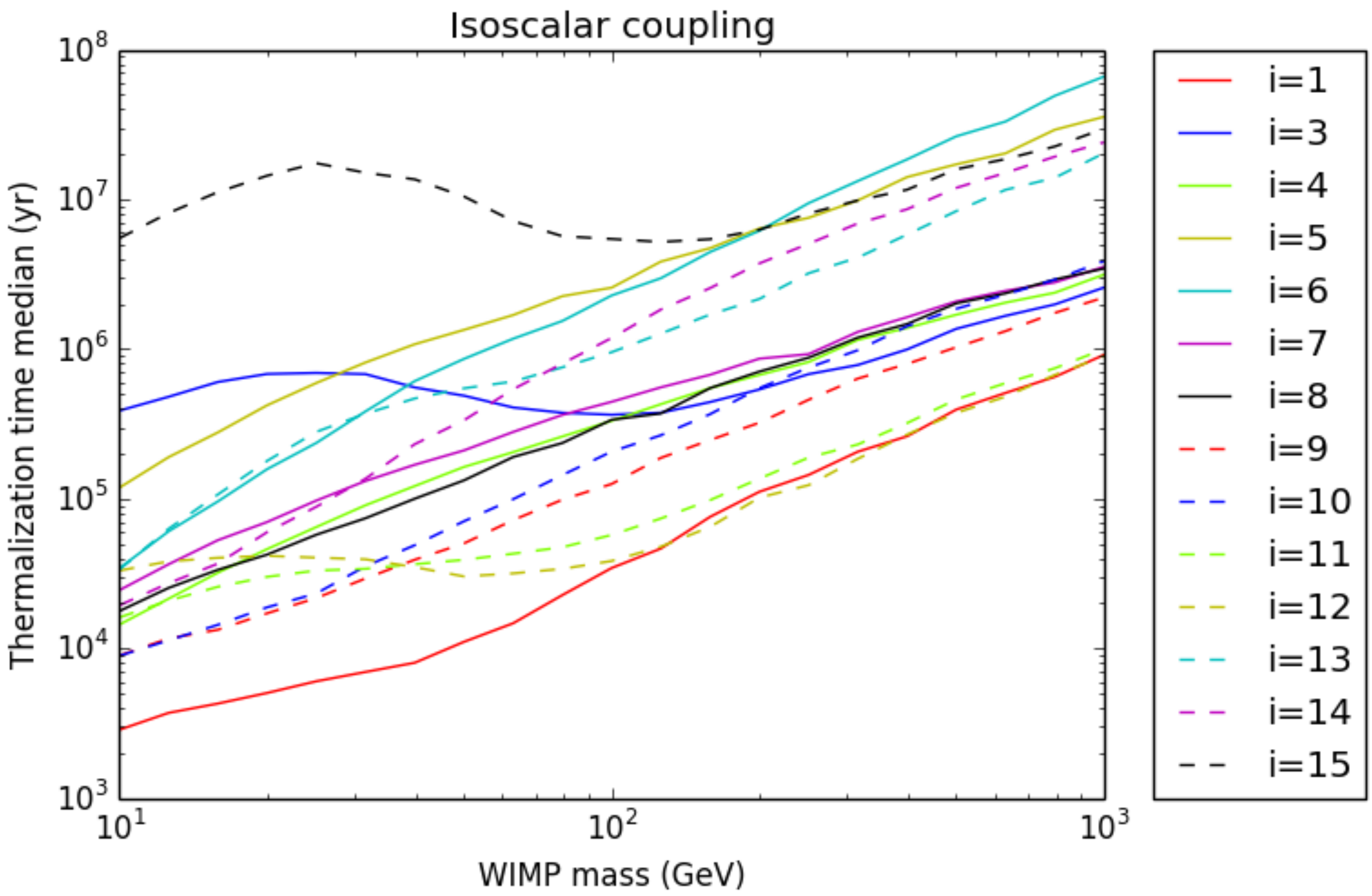
$$\hat{\mathcal{O}}_{14} = i\left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left(\hat{\mathbf{S}}_N \cdot \hat{\mathbf{v}}^\perp\right)$$

$$\hat{\mathcal{O}}_{15} = -\left(\hat{\mathbf{S}}_\chi \cdot \frac{\hat{\mathbf{q}}}{m_N}\right)\left[\left(\hat{\mathbf{S}}_N \times \hat{\mathbf{v}}^\perp\right) \cdot \frac{\hat{\mathbf{q}}}{m_N}\right]$$

- Randomize scattering events and trajectories
- 3-d kinematics, local thermal motion of solar nuclei

THERMALIZATION TIME SCALES

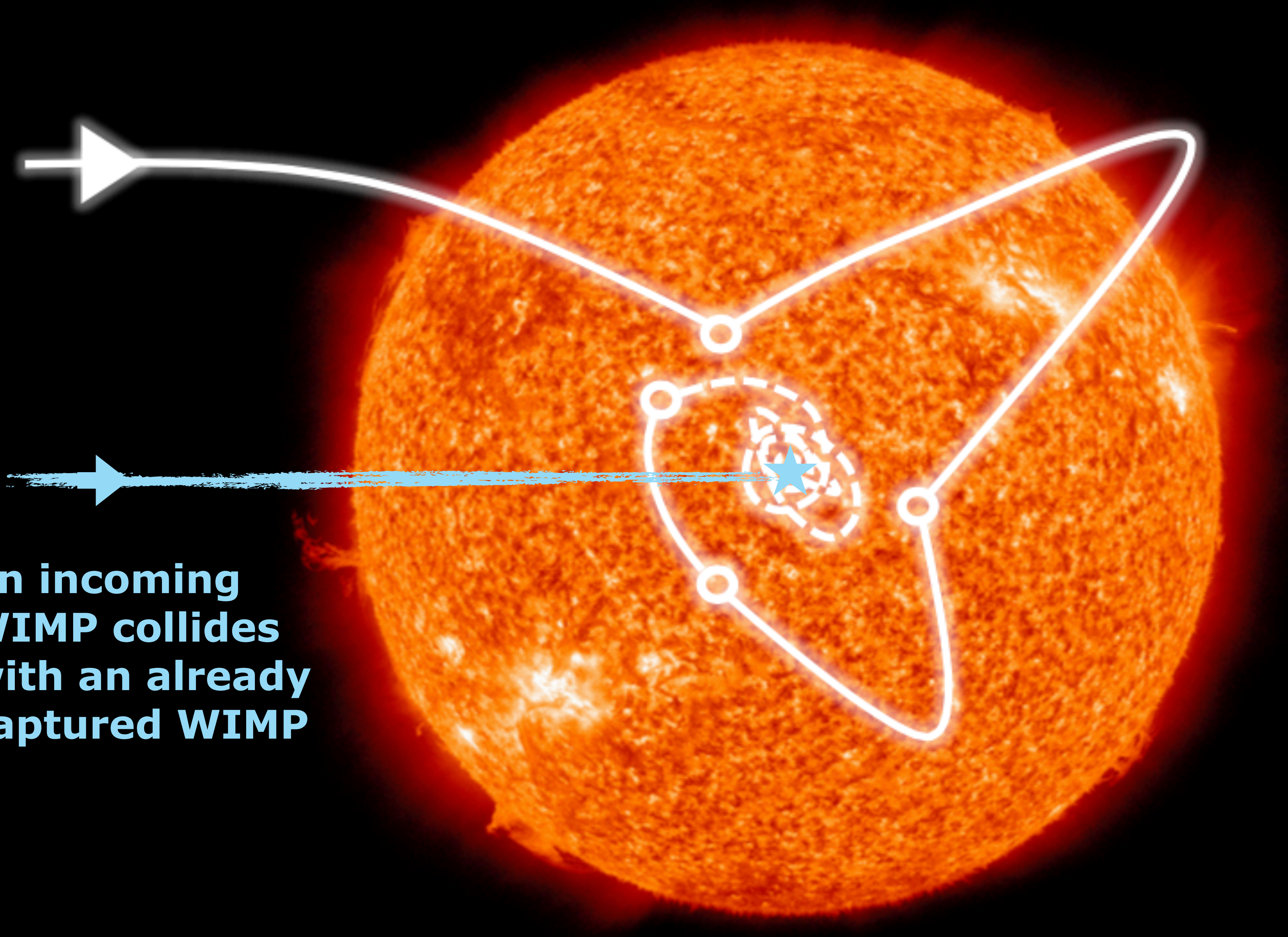
- Coupling normalized to a fixed capture rate



CONCLUSIONS ON THE THERMALIZATION PROCESS

- The assumption of instantaneous thermalization is valid in most cases of interest
- For most operators, a majority of the thermalization time is spent in the solar interior – especially true for operators with a dependence on transferred momentum
- The canonical assumption of a thermal profile is valid (for WIMP masses >10 GeV)

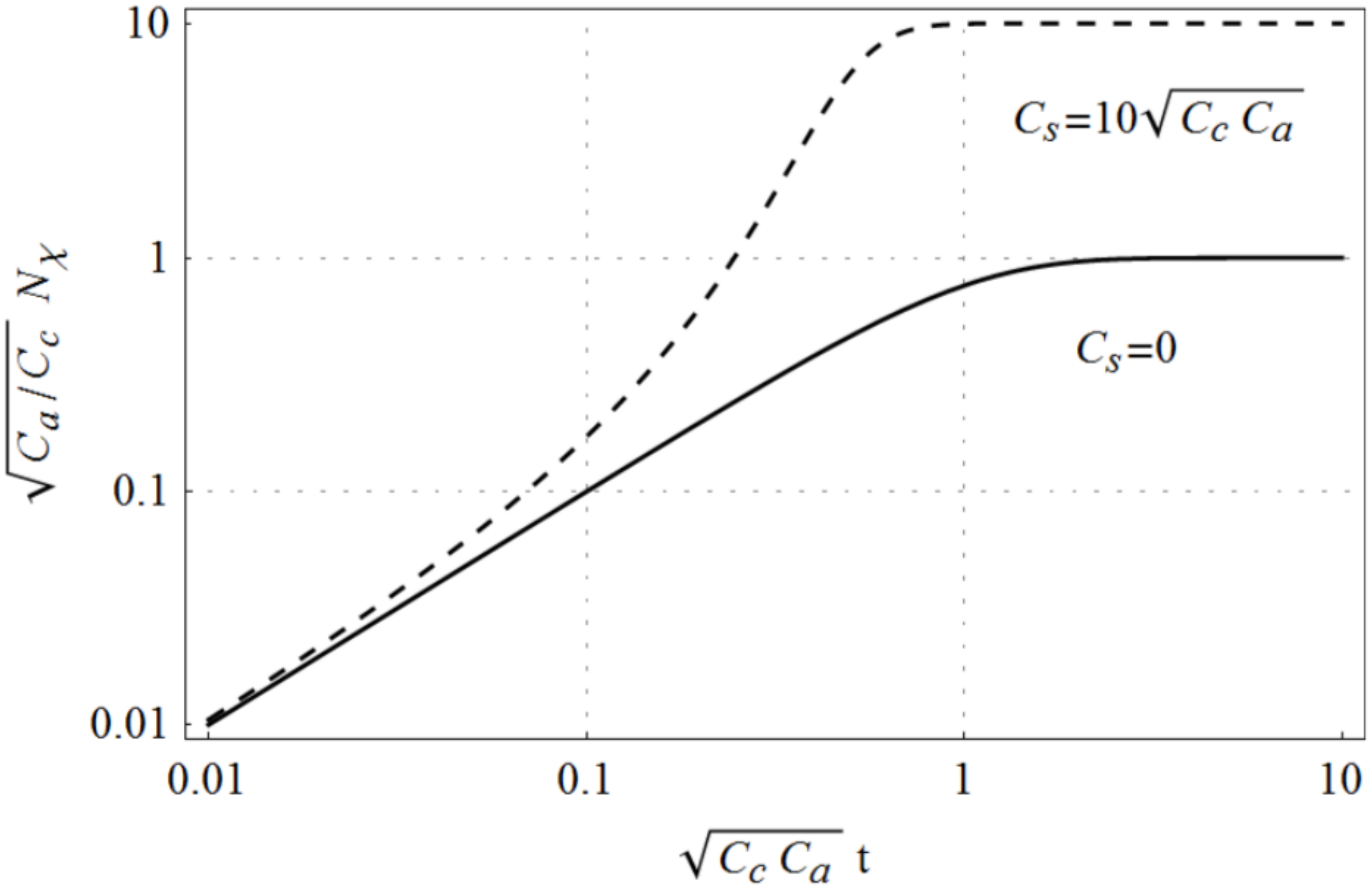
Capture by WIMP self-interaction



An incoming WIMP collides with an already captured WIMP

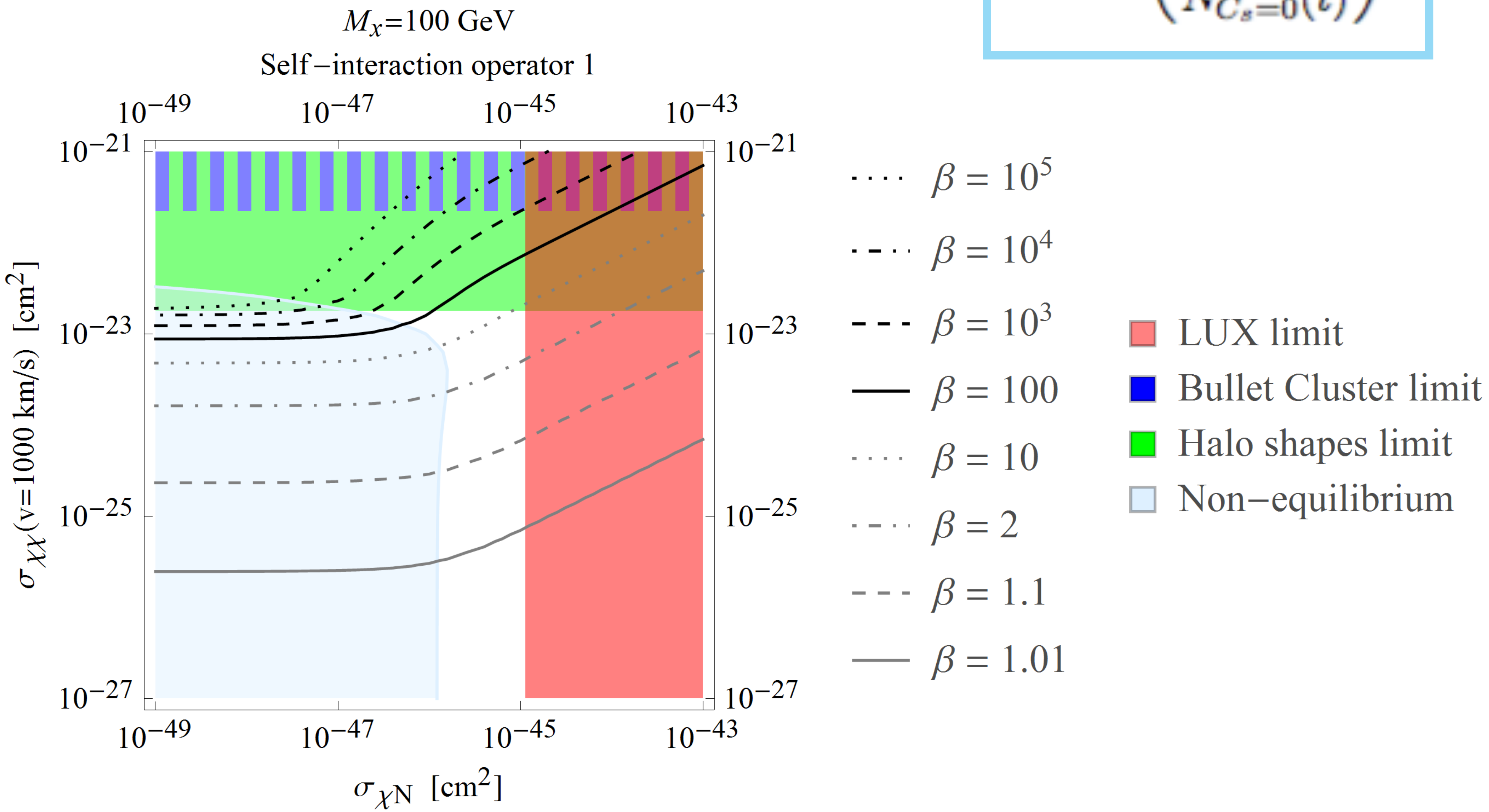
WIMP CAPTURE DIFFERENTIAL EQUATION

$$\frac{\mathrm{d}N_\chi}{\mathrm{d}t} = C_c + C_s N_\chi - C_a N_\chi^2$$



WIMP SELF-INTERACTION CAN BOOST THE NEUTRINO SIGNAL BY SEVERAL ORDERS OF MAGNITUDE

$$\beta(t) \equiv \left(\frac{N_{C_s \neq 0}(t)}{N_{C_s = 0}(t)} \right)^2$$



OUTLOOK

- Halo substructure
- A time-varying capture rate could translate into a time-varying neutrino signal
- Thermalization time dependence?
- WIMP self-capture dependence?