The WIMP capture process for dark stars
including scattering

Studies DM component only,
fixed stellar evolution by Spolyar, Bodenheimer, Freese & Gondolo

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Overview

- Initial NFW halo
- Star form at the center, accretes mass and contracts
- Pulls in DM towards center
- Halo WIMPs passing through the star can scatter and loose energy, boosting central density further
- Monte Carlo following individual WIMPs and their response to changing gravitational potential

Initial NFW halo

- Start with an initial NFW halo

$$\rho(r) = \frac{\rho_c}{r/r_s(1 + r/r_s)^2}$$

- Initial distribution found through Eddington's formula (spherically symmetric and isotropic)

$$f(\mathcal{E}) = \frac{1}{\sqrt{8}\pi^2} \int_{r_\mathcal{E}}^{\infty} g(r) \frac{1}{\sqrt{\mathcal{E} - \Psi(r)}} \mathrm{d}r$$

$$g(r) = \frac{r(r_s - 3r + 6\xi)}{4G\pi(r_s + r)^3(r - \xi)^2}$$

$$\xi = (r_s + r) \ln\left(1 + \frac{r}{r_s}\right)$$

- Monte Carlo picks individual WIMPs from this distribution, isotropic

Adiabatic contraction

- Conserves:

$$\mathcal{J} \quad \text{and} \quad \mathcal{J}_r = 2\int_{r_{\min}}^{r_{\max}} \sqrt{2(\Psi(r) - \mathcal{E}) - \mathcal{J}^2/r^2}\,\mathrm{d}r$$

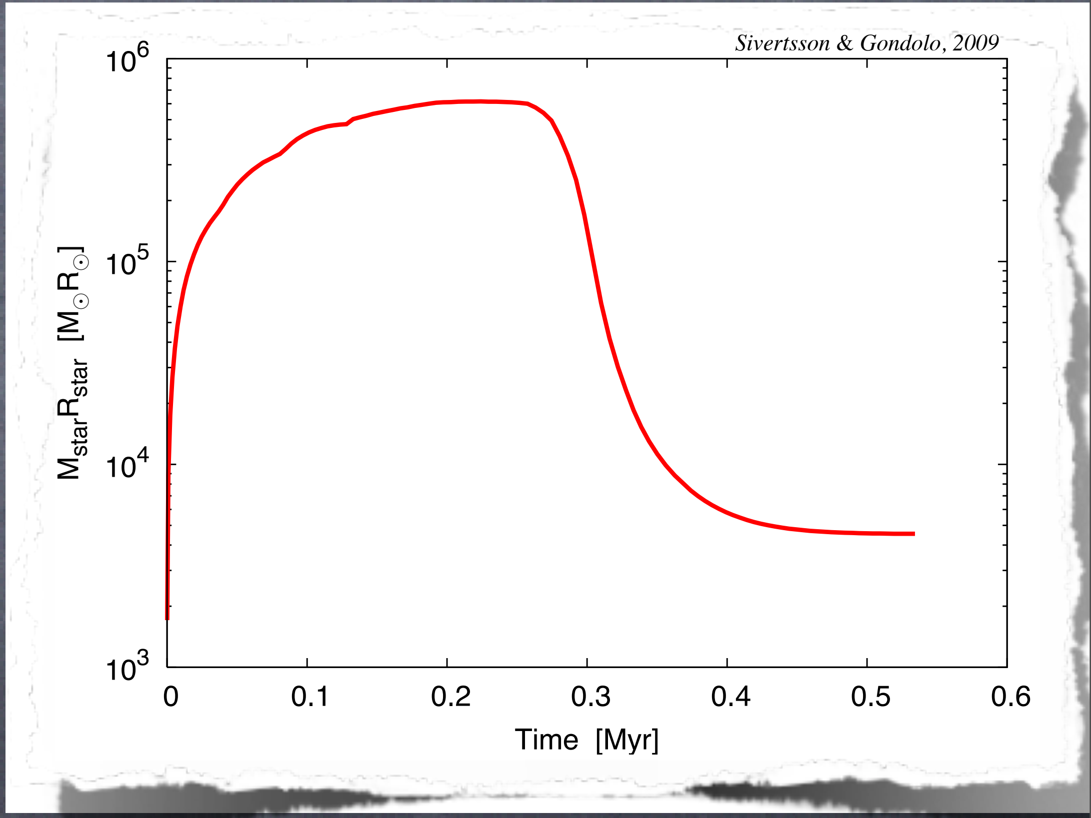
- WIMP energy found as star evolves (numerically, not elliptical orbit inside star)
- Spherical symmetry -> orbit specified
- WIMPs are followed by the Monte Carlo and are allowed to scatter and annihilate

How attractive the star is to WIMPs

- Only WIMPs on orbits crossing the star are interesting
- Stellar mass increases -> DM halo contracts more

$$r_{\min} = \frac{(\mathcal{J}_r + 2\pi\mathcal{J})^2}{4\pi^2 G M_\star}\left(1 - \sqrt{1 - \frac{4\pi^2\mathcal{J}^2}{(\mathcal{J}_r + 2\pi\mathcal{J})^2}}\right)$$

- Also star contracts
- $\sim M_\star R_\star$

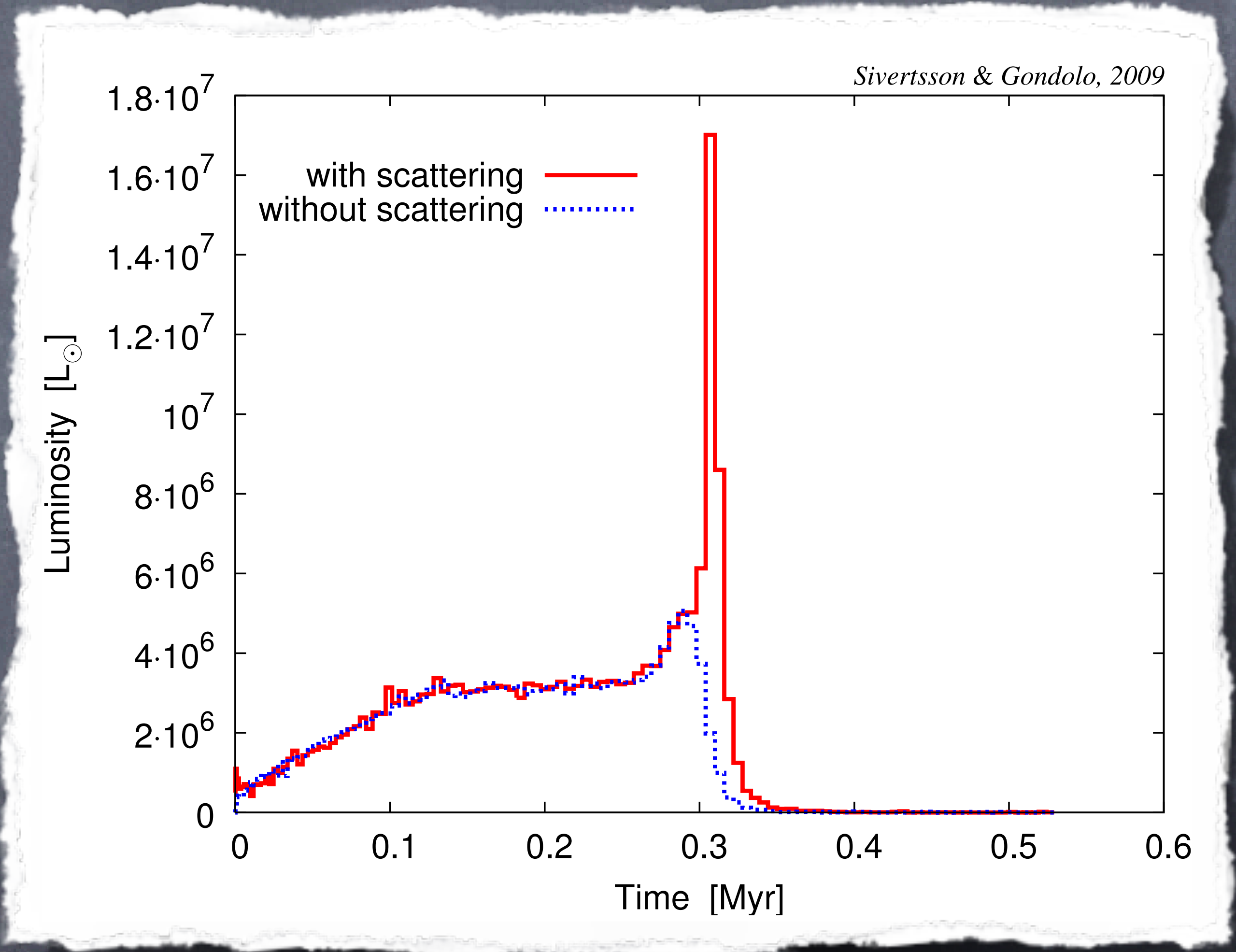


The role of scattering

- WIMPs can scatter and loose energy
- WIMPs scattering again and again, sinks to the core and annihilate
- Early star undense -> scattering not important

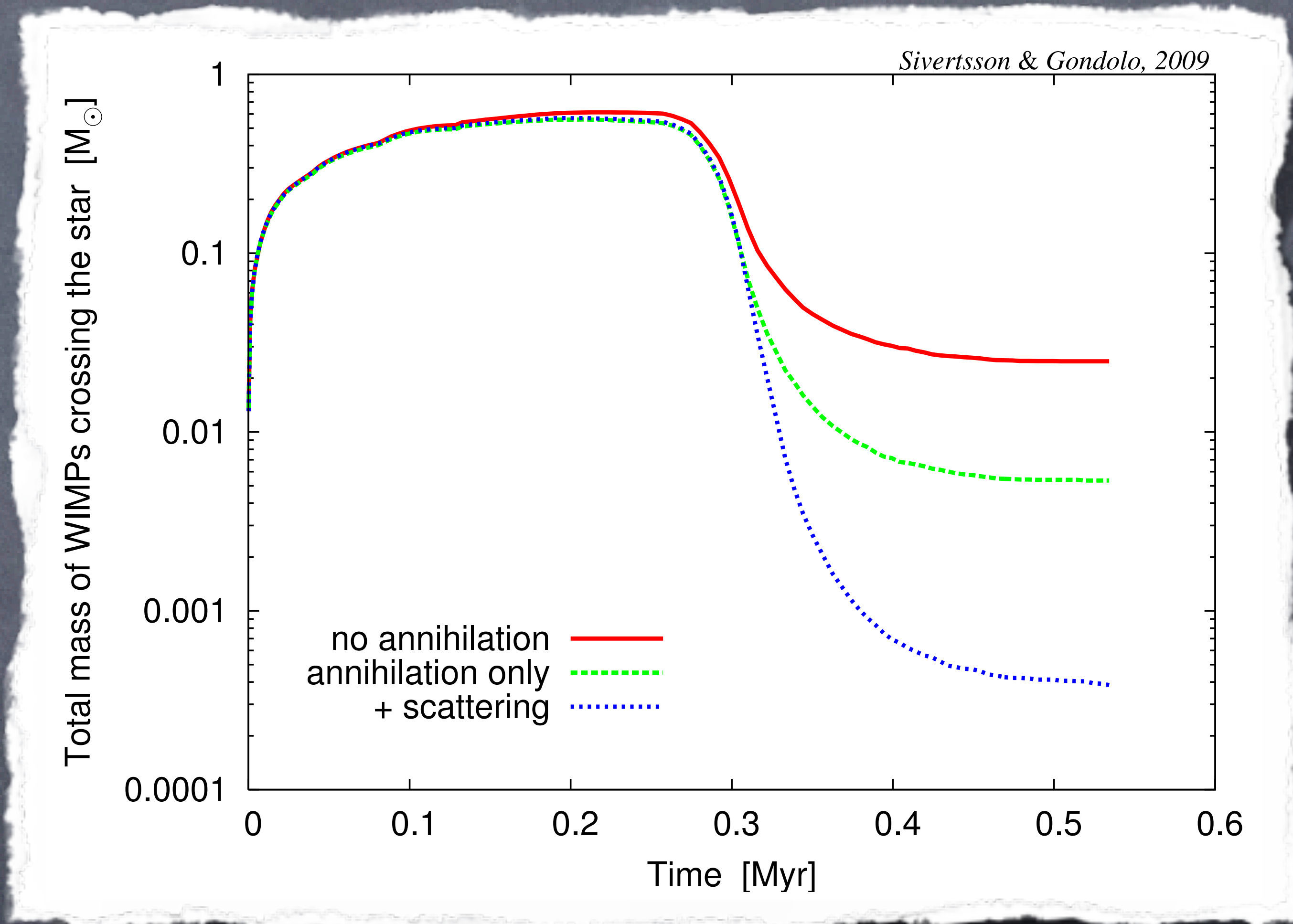
Dark luminosity

- Energy injected by WIMP annihilations with and without scattering
- Scattering important when star becomes dense enough
- Scatterable WIMPs deplete fast
- With scattering the star eats 0.13 solar masses of DM
- Star contracts too much



WIMPs available to the star

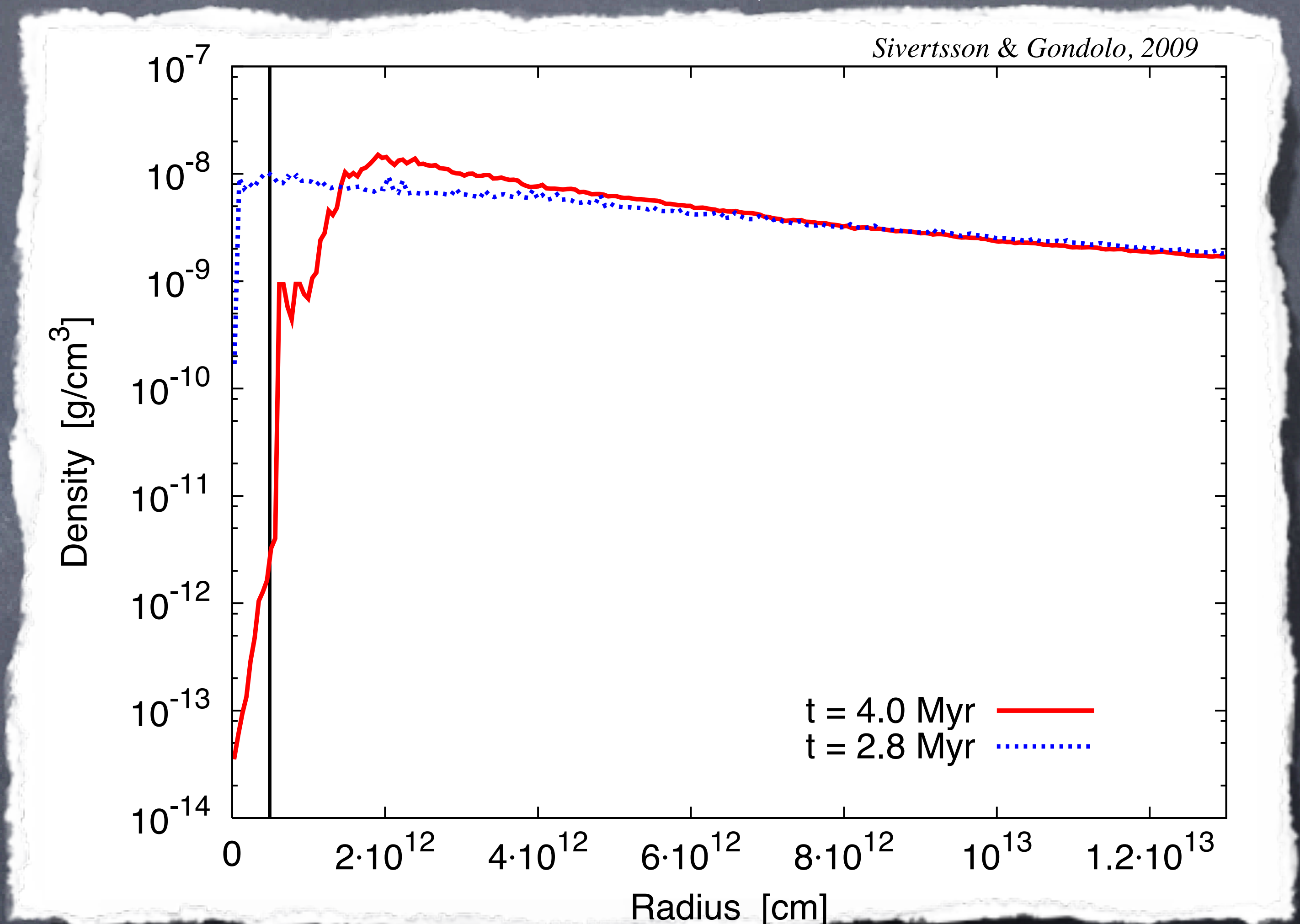
- Total mass of WIMPs on orbits crossing the star
- High depletion for ZAMS star
- Low angular momentum WIMPs are depleted fast, others cannot be reached



Final WIMP density

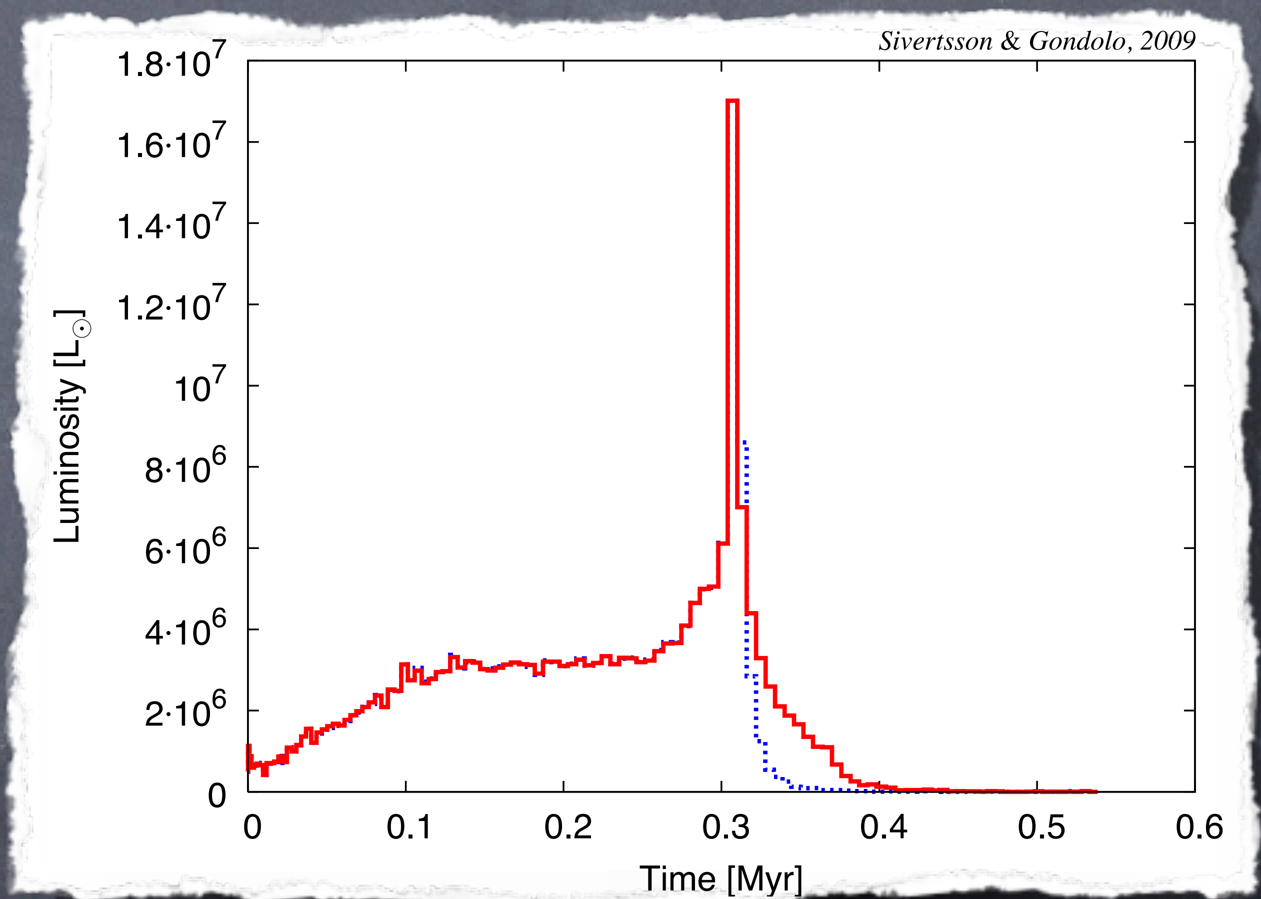
- WIMP density profile after WIMP capture ended
- Annihilation outside star not included

$\times 5.6 \times 10^{23} \rightarrow \mathrm{GeV/cm^3}$



Stellar evolution dependence

- Extra DM injected slows stellar contraction
- Keeps the star a better DM target for longer
- Slight increase, but still depletion



Angular momentum loss needed

- Substructure in halo (gas and DM) could perturb orbiting WIMPs slightly
- Very high perturbation needed as star is very hungry
- For the formed star to be supported by DM for 1 million years the DM needed (0.8 solar masses) corresponds to all the dark matter inside 1000 stellar radii (orbit of Jupiter is at 1000 solar radii) (WIMP dens at 1000 stellar radii is 6e11 GeV/cm3)
- 1 billion years -> 6 million stellar radii (=0.01 r_s), outer density of 3000 GeV/cm3