WIMP capture for dark stars in the early universe

Sivertsson & Gondolo: arXiv:1006.0025

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Overview

- Dark star: "Burn" WIMPs instead of nuclei
- How much dark matter fuel does the star get?
- Looking at scenario of 800 solar mass final star
  (As in: Spolyar, Bodenhaimer, Freese, Gondolo. arXiv: 0903.3070)
- First stars form in the centers of dark matter haloes
- The forming star pulls in dark matter via adiabatic contraction
- Halo WIMPs passing through the star can scatter and loose energy, contributing to the central density

The surrounding WIMP halo

- Dividing the halo into two parts:
  - Central part: sensitive to adiabatic contraction, becomes bound to the star. Limited amount.
  - Outer part: not so affected by the forming star. Not bound to the star
- First investigating the more central region (1% virial radius)
- Need to know how the halo responds to the star formation

NASA

Setup

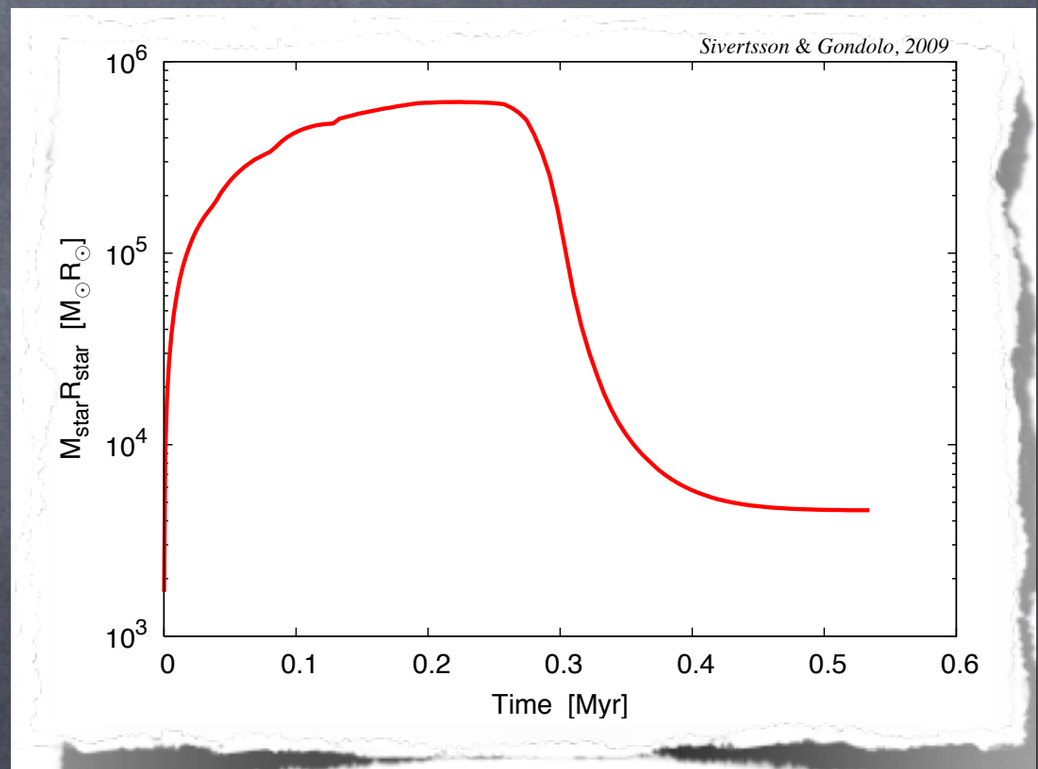
- Monte Carlo picks WIMPs in the original NFW halo
- Forming star gives adiabatic contraction, conserves:

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

- Allows to follow the WIMPs and their orbits in and around the forming star
- Boosts central density
- Boosts number of WIMPs on star crossing orbits, i.e. the ones avaliable for scatter

How attractive the star is to WIMPs

- The forming star fast dominates the gravitationl potential in the central halo region
- Only very low angular momentum orbits will cross the star
- WIMP willingness to cross the star $\sim M_\star R_\star$
- Star increasing in mass contracts the WIMP halo but the star also contracts, making it a small target

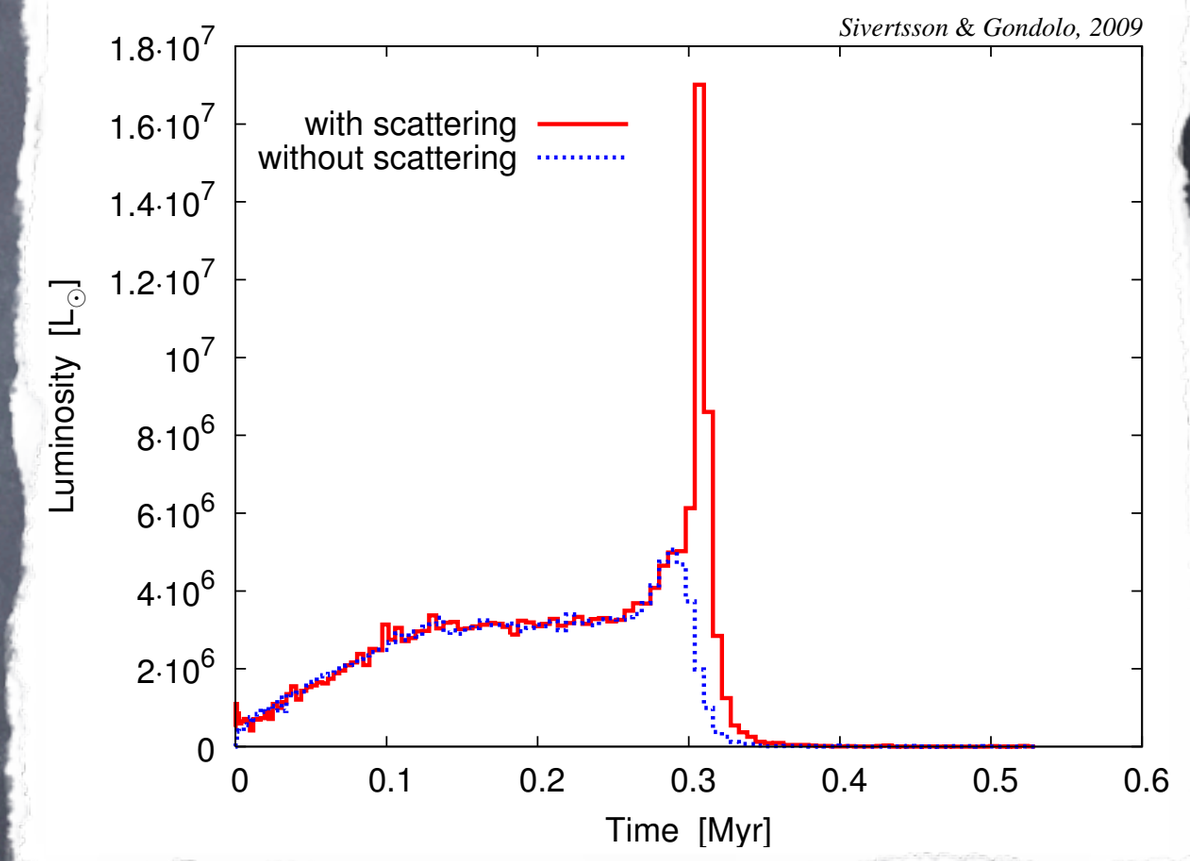


The role of scattering

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

Dark luminosity

- Energy injected by WIMP annihilations with and without scattering
- Adiabatic contraction important initially
- Scattering important when star becomes dense enough
- Easily scatterable WIMPs deplete fast
- With scattering the star eats 0.13 solar masses of DM

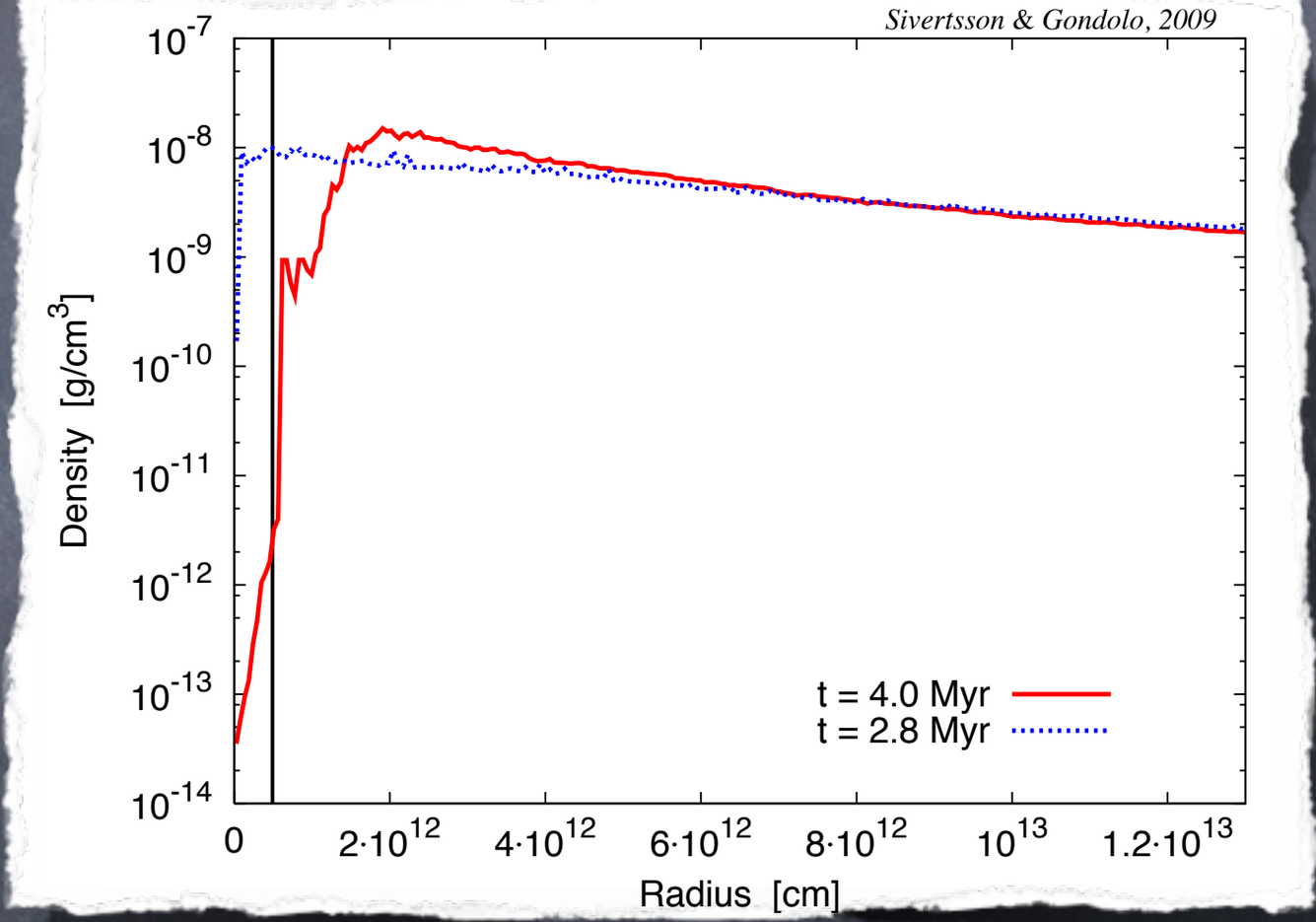


$$\sigma_{\rm scatt} = 10^{-39}\ {\rm cm}^2$$

Final WIMP density

- WIMP density profile close to the star after efficient WIMP capture ended
- Not sensitive to the outside halo structure
- Very high perturbation needed to continue feeding the star

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



- WIMP annihilation outside the star not included

What about the far away WIMPs?

- Bound to the surrounding halo but not to the star
- Not very affected by the formation of the central star (i.e. almost no adiabatic contraction)
- WIMPs from outer halo could pass through the star, scatter and be captured
- Possibly complicated halo structure, angular momentum conservation not useful
- Big halo so feeds the star for a very long time

Capture rate of far away WIMPs

- Assuming isotropy at the star's radius of influence one can calculate the inflow of WIMPs towards the star
  (Gould and Press & Spergel method for solar WIMP capture rate)

- Even if all the WIMPs passing through the star are captured the rate is too low by a factor $\sim 10^5$ (800 $M_\odot$ star)

- Only a small fraction of WIMPs passing the star will scatter

- Would need the orbits to be extremely centerophilic

Summary

- Star fast eats out the low energy and angular momentum WIMPs
- Perturbations in the surrounding WIMP enevelope?
- More and more perturbations needed
- Capture rate from far away halo too low to matter
- Short initial dark star phase, very difficult to sustain the high capture rate for long lived dark star