
# The WIMP capture process, including scattering, for dark stars in the early universe.

Sofia Sivertsson

Paolo Gondolo

Joakim Edsjö

Pat Scott

*TeVPA 2009, SLAC*

# Dark stars in the early universe

- The first stars form in dark matter halos, here NFW.
- Single star forms in the center of the halo.
- As the star increases in mass the dark matter gets adiabatically contracted towards the central region.
- Giving very high DM densities.
- WIMP annihilations heat the proto star, giving a dark star phase.
- This delays the star's contraction, giving a longer accretion phase, making the star more massive.

# Dark stars in the early universe

- The dark matter gravitationally pulled into the star eventually annihilates away.
- How would scattering alter this picture?
- If scattering is included, the star can access more dark matter.
- Could also the main sequence star benefit from the high dark matter densities?
- This has previously been discussed by Freese, Iocco and others.

# Method

- This was approached using a Monte Carlo picking individual WIMPs from the initial NFW DM halo, using Eddington's formula.
- Followed the response of the WIMPs to the change in gravitational potential as the star forms.
- Used the evolution of the proto star as calculated by Spolyar, Bodenheimer, Freese and Gondolo [arXiv:0903.3070]
- The WIMPs and their orbits were followed during the stellar evolution and allowed to annihilate and scatter in the star as they pass through.

# Adiabatic contraction

- The WIMP's response to the change in gravitational can be found using the adiabatic invariants:

$$J \qquad J_r = 2\int_{r_{\min}}^{r_{\max}} \sqrt{2m\left[E - V(r)\right] - (J/r)^2}\,\mathrm{d}r$$

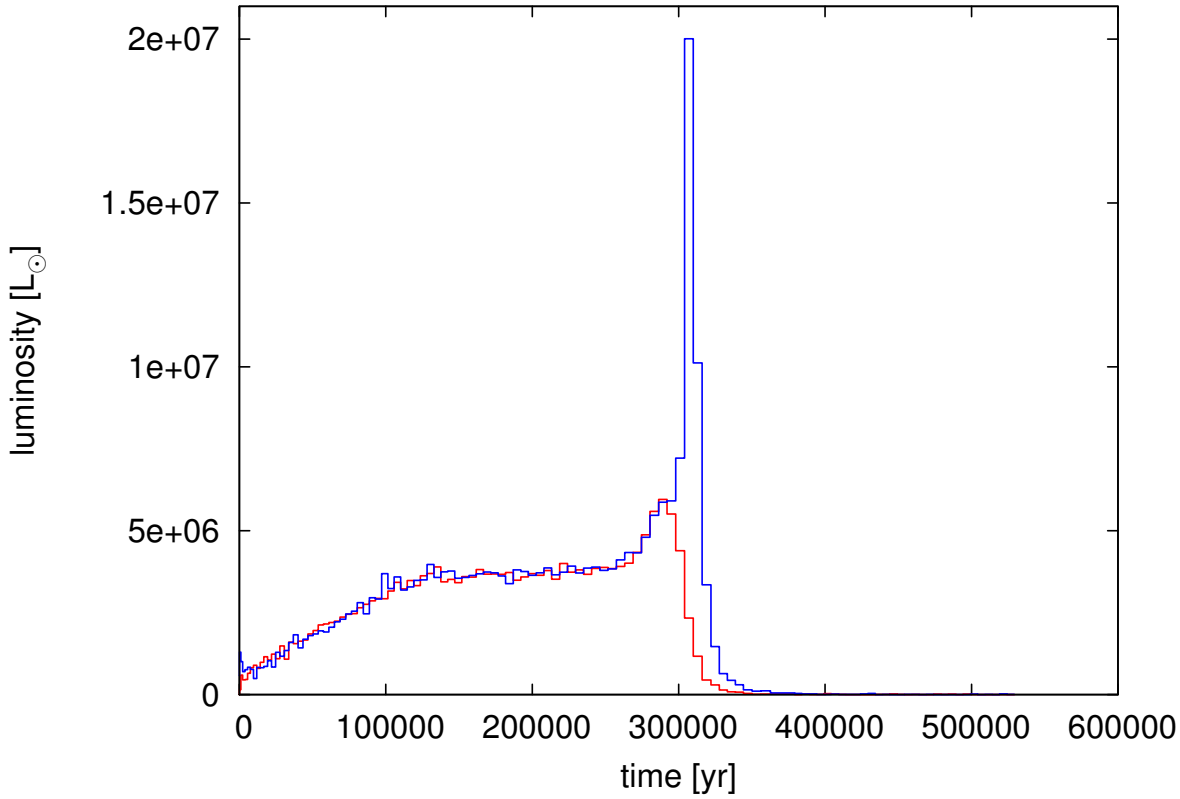
- Knowing the potential, the energy of the WIMP can be found numerically.
- Knowing energy and angular momentum the WIMP's orbit is fully specified (assuming spherical symmetry).
- Can then determine scatter and annihilation probabilities as the WIMP pass through the star.

# Results

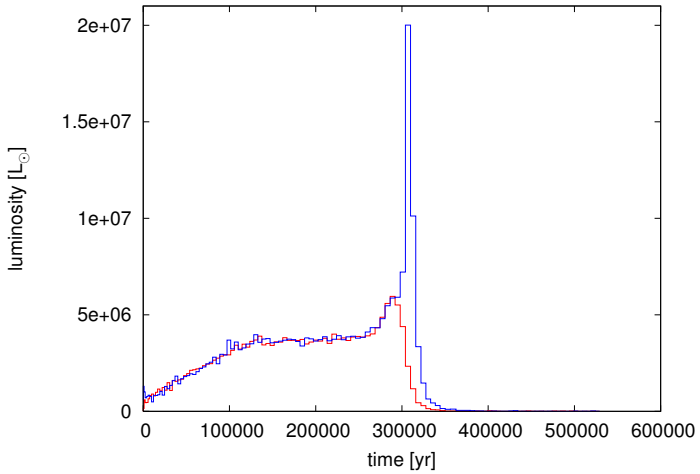
- Energy injected in the star for (blue curve) $m_\chi = 100$ GeV

  $\langle \sigma v \rangle = 3 \times 10^{-26}\,\mathrm{cm^3 s^{-1}}$ $\sigma_{sc} = 10^{-39}\,\mathrm{cm^2}$

- Red curve: without scatter
- Change in stellar evolution from WIMP captured via scattering is not included.



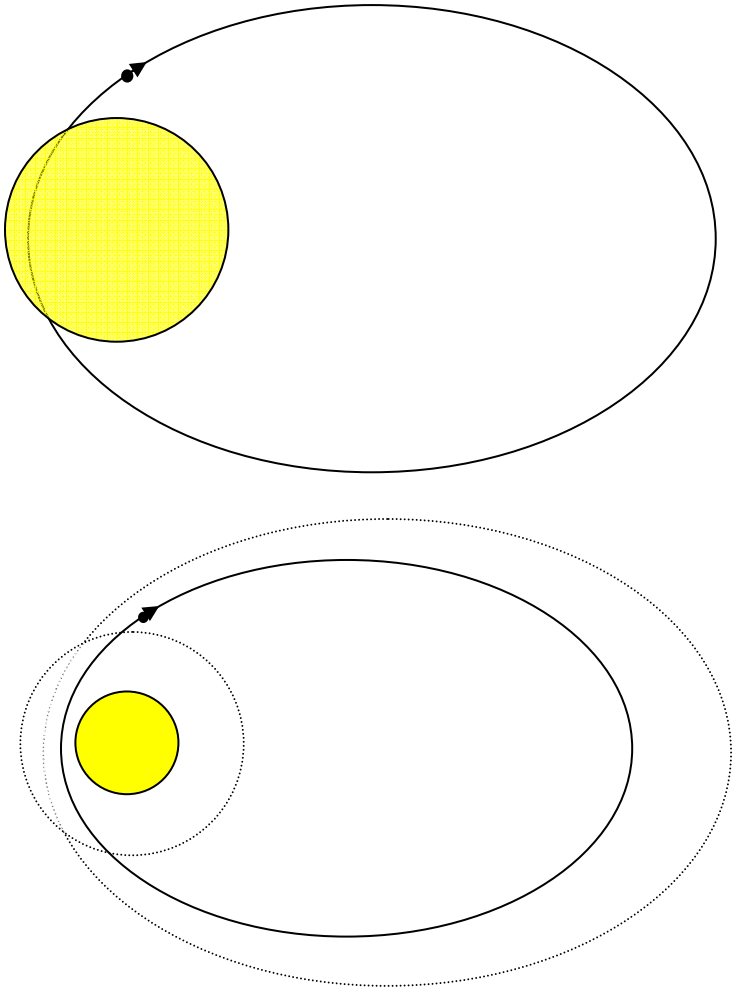
# Results




- WIMP scattering has no effect in the very early stages since the baryon densities are too low.
- Scattering suddenly becomes very important as the star becomes dense enough.
- As the star contracts further it shrinks into a region already depleted of its dark matter.
- As long as this single star system is not disturbed, the high DM densities are out of reach of the main sequence star.

# Analysis

- As the forming star approaches the main sequence it increases slightly in mass but contracts rapidly.
- Orbits that would intersect the star at the later stages pass central, dense, regions earlier on.
- This depletes the phase space of WIMPs that would have been accessible to main sequence star.
- For long term dark matter heating this setting needs to be disturbed.



# Conclusions

- Without long term energy injection from dark matter, stars this massive are very short lived.
- These stars then typically die before the local dark matter halo is disturbed my merging events.
- WIMPs far out in the halo at star formation have orbiting time scales greater than the star's lifetime.
- The star is small so even though the DM densities are high the total mass of WIMPs on orbits passing through the star is not necessarily that high, even without depletion effects.
- WIMPs available via scattering could further prolong contraction of the proto star, could increase the star's mass further.
- This work assumes single star and does not take into account inhomogeneities in the dark matter halo.
- Dark matter densities are high but hard to reach over time.