How do stars affect ψDM

[arXiv:1712.01947]

James Chan
EPFL-LASTRO/NTU

Collaborators:
Hsi-Yu Schive, Tak-pong Woo, Tzihong Chiueh, Sherry Suyu

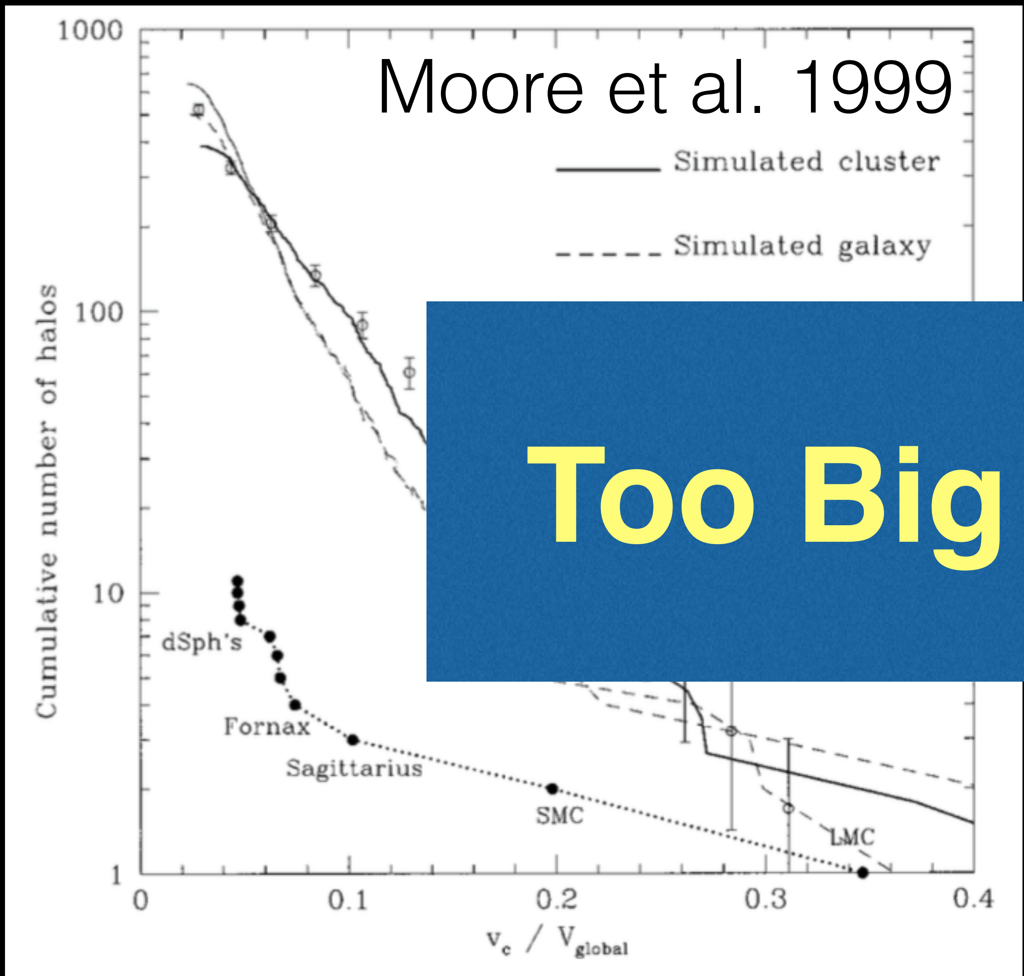
Outline

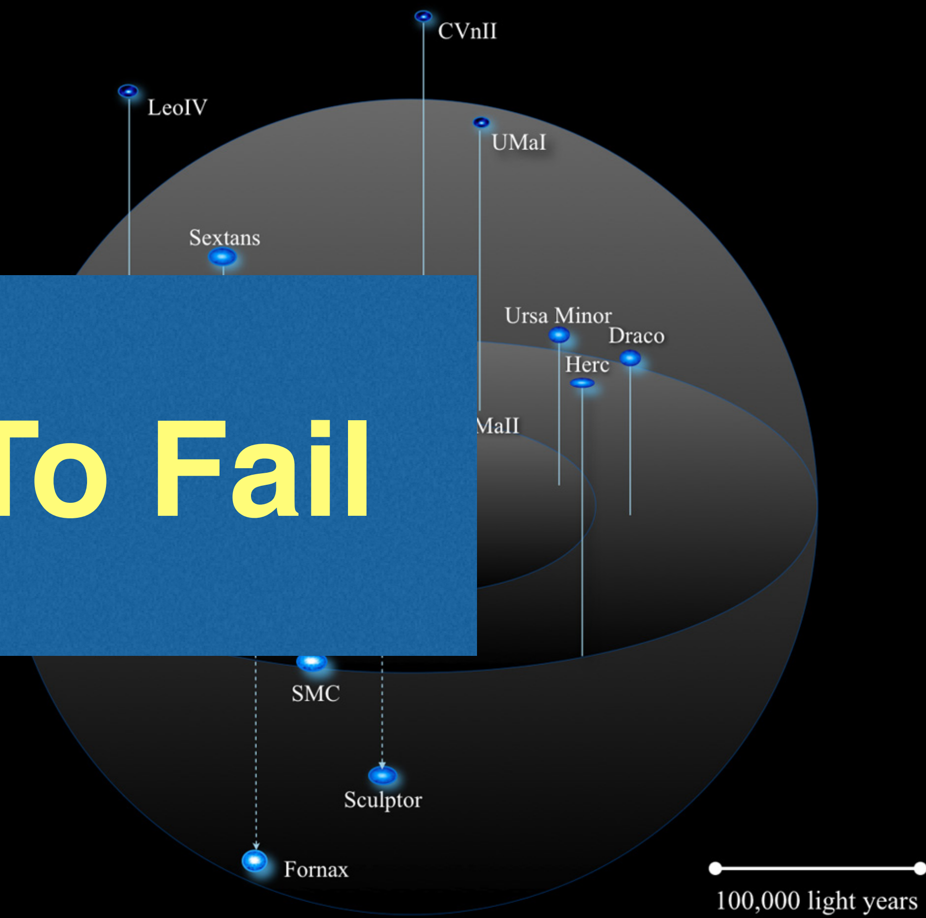
- Motivation
- Wave Dark Matter (ψDM)
- Addition of stars
- Results/Future prospects

ΛCDM is awesome!

The missing satellite problem

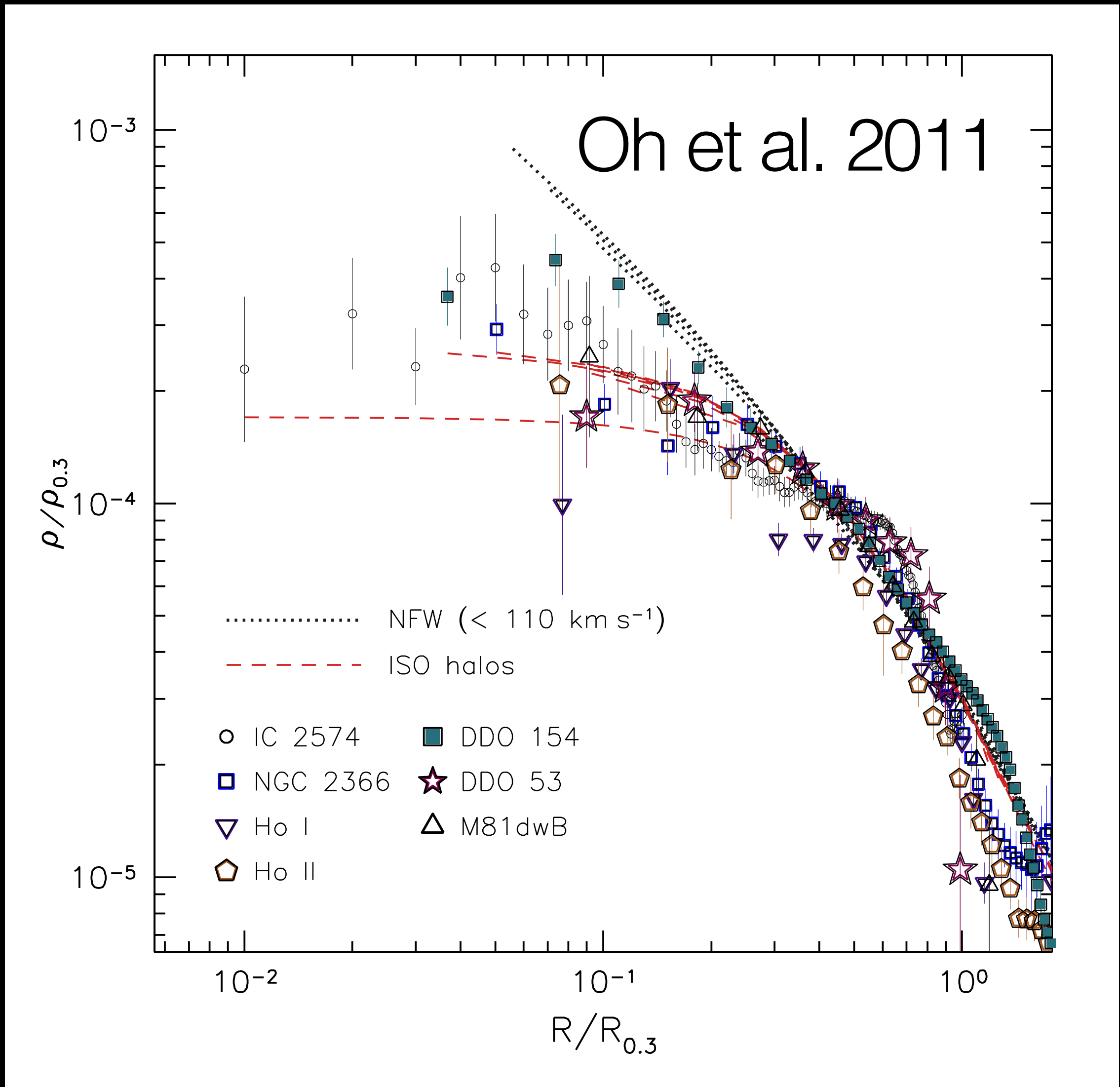
Klypin et al. 1999, Moore et al. 1999





Too Big To Fail

The cusp-core problem



$$\rho_{\mathrm{NFW}}(r) = \frac{\rho_s}{\frac{r}{r_s}\left(1+\frac{r}{r_s}\right)^2}$$

http://wwwmpa.mpa-garching.mpg.de/~swhite/pictures/Tormen_NFW_Col.jpg

ΛCDM is awesome!

in large scale. But there is a "small scale crisis".

Wave Dark Matter
(ψDM)

ψDM: Wave Dark Matter

- Scale Field Dark Matter without self-interaction (fuzzy dark matter)
- consists of extremely light bosons ($\sim 10^{-22}$ eV)
- The corresponding Compton wavelength becomes galactic scale (~kpc)
- $T < T_c$, dark matter particles must be condensed into the Bose-Einstein state and described by a coherent wave function.

Equation

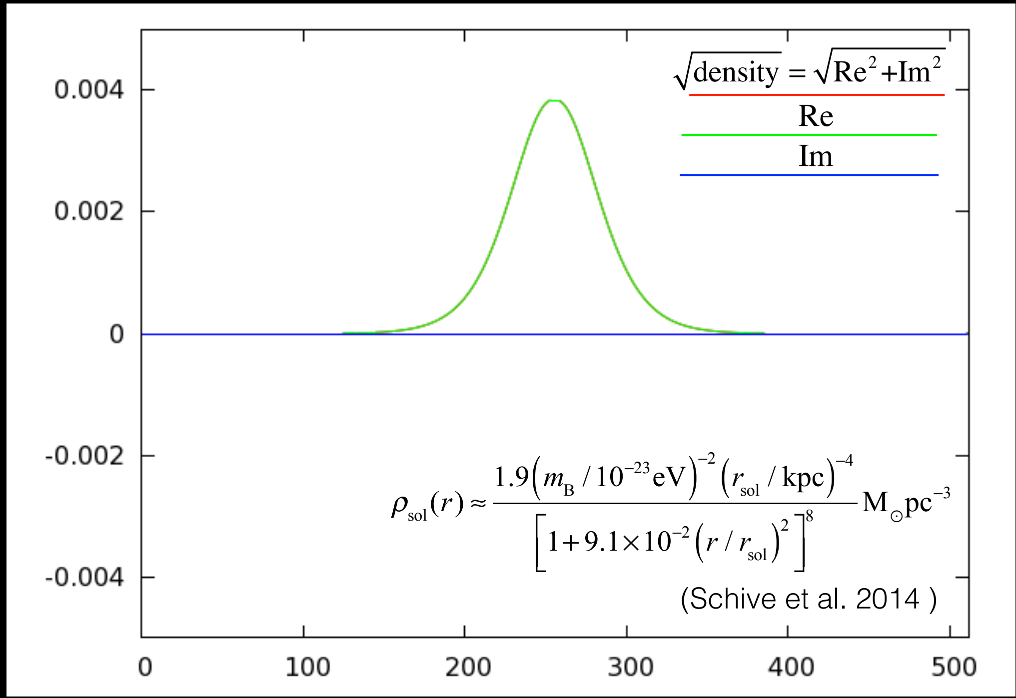
- Schrödinger equation

$$i\hbar\frac{\partial\psi}{\partial t} = -\frac{\hbar^2}{2m_B}\nabla^2\psi + m_B\Phi\psi$$

- Poisson equation

$$\nabla^2\Phi = 4\pi G\rho$$

$$\rho = m_B|\psi|^2$$



ψ = wave function
m_B= particle mass ~ 10^{-22} eV
Φ = self-gravitational potential
ρ = the mass density

- Uncertainty principle counters gravity:

  1. compressing small scale structures

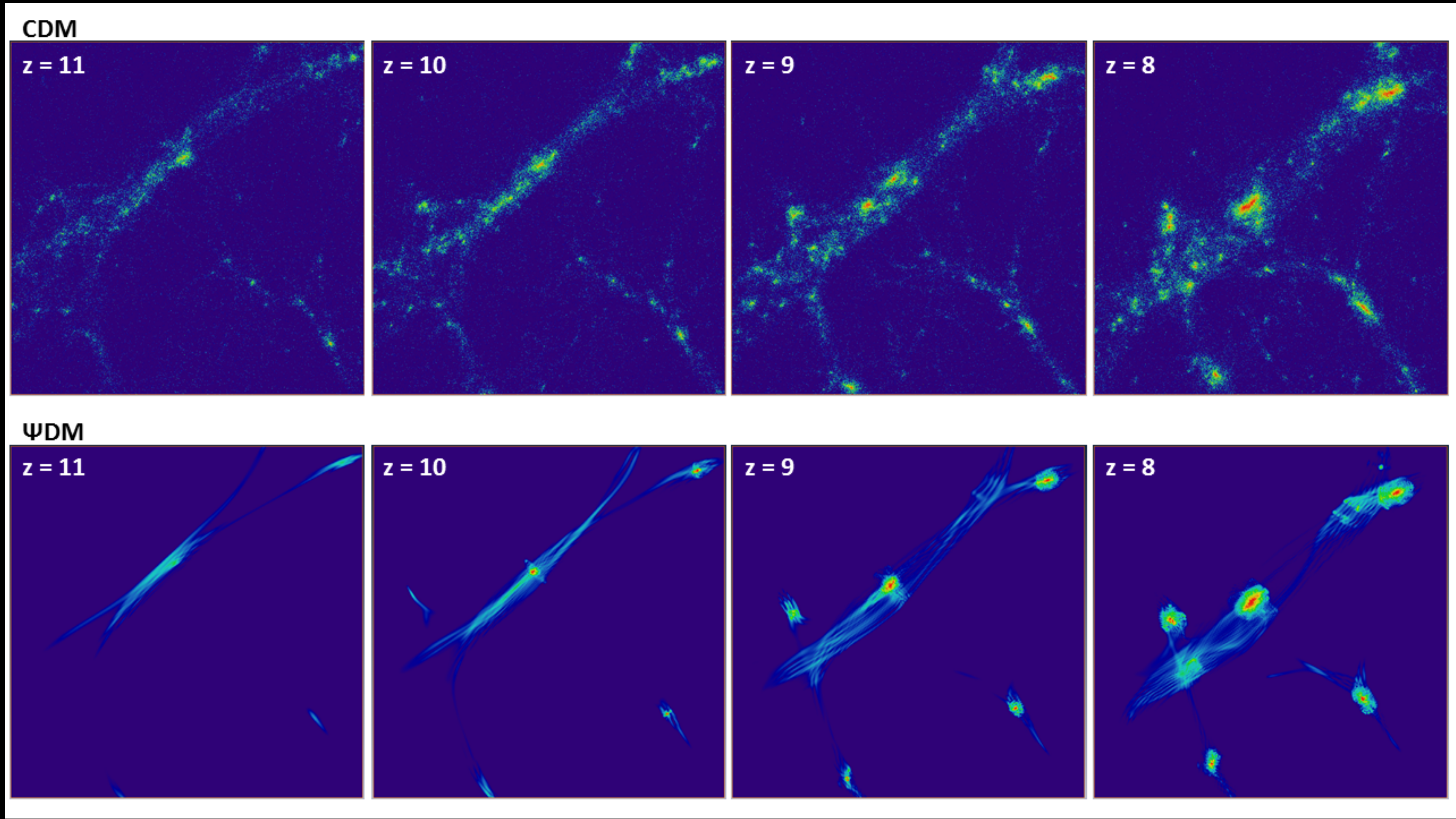
  2. flattening a central core

- Simulation is very expensive.

  → GAMER (Schive et al. 2009)

High-z mass fluctuation

GAMER ΛψDM simulation (Schive et al. 2015)

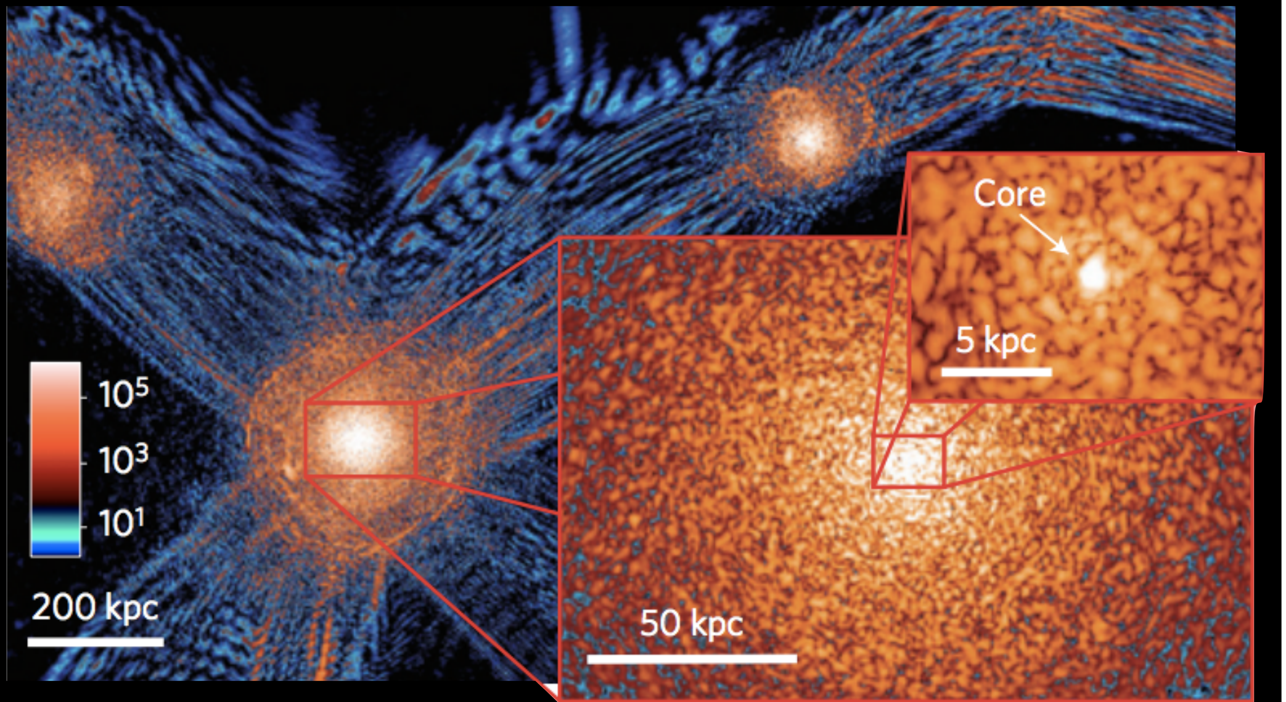


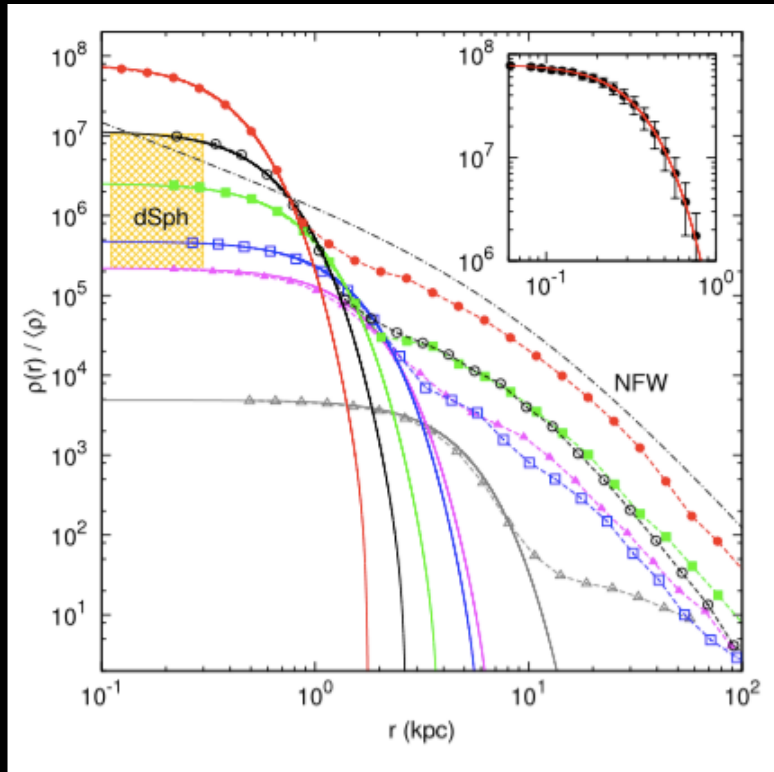
Potential solution to:

the missing satellites problem

Density Field

GAMER ΛψDM simulation (Schive et al. 2014)





Potential solution to:

the cusp/core problem

ΛψDM predicts

$$M_{\rm sol} \cdot r_{\rm sol} = {\rm const.}$$

$$M_{\rm sol} \propto M_{\rm halo}^{1/3}$$

granule's size ~ soliton's size

what if there are baryons?

DM + stars

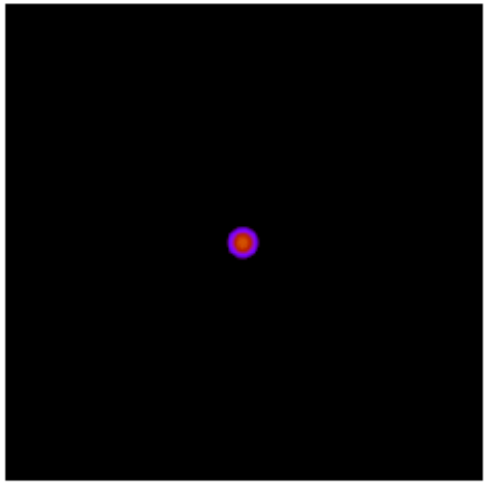
- ψDM halos (grid-base) evolve with stars (particle-base), using GPU

[pix = 0.17 kpc/h, boxsize = 87.5 kpc/h]

- ψDM halos are from ΛψDM cosmological simulations (GAMER).

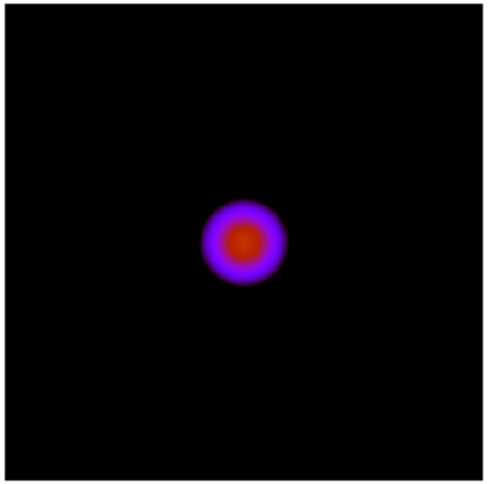
- Stars are formed cold in a star burst in the inner halo. Gases are a negligible component. (particle mass ~40 $M_\odot$)

DM

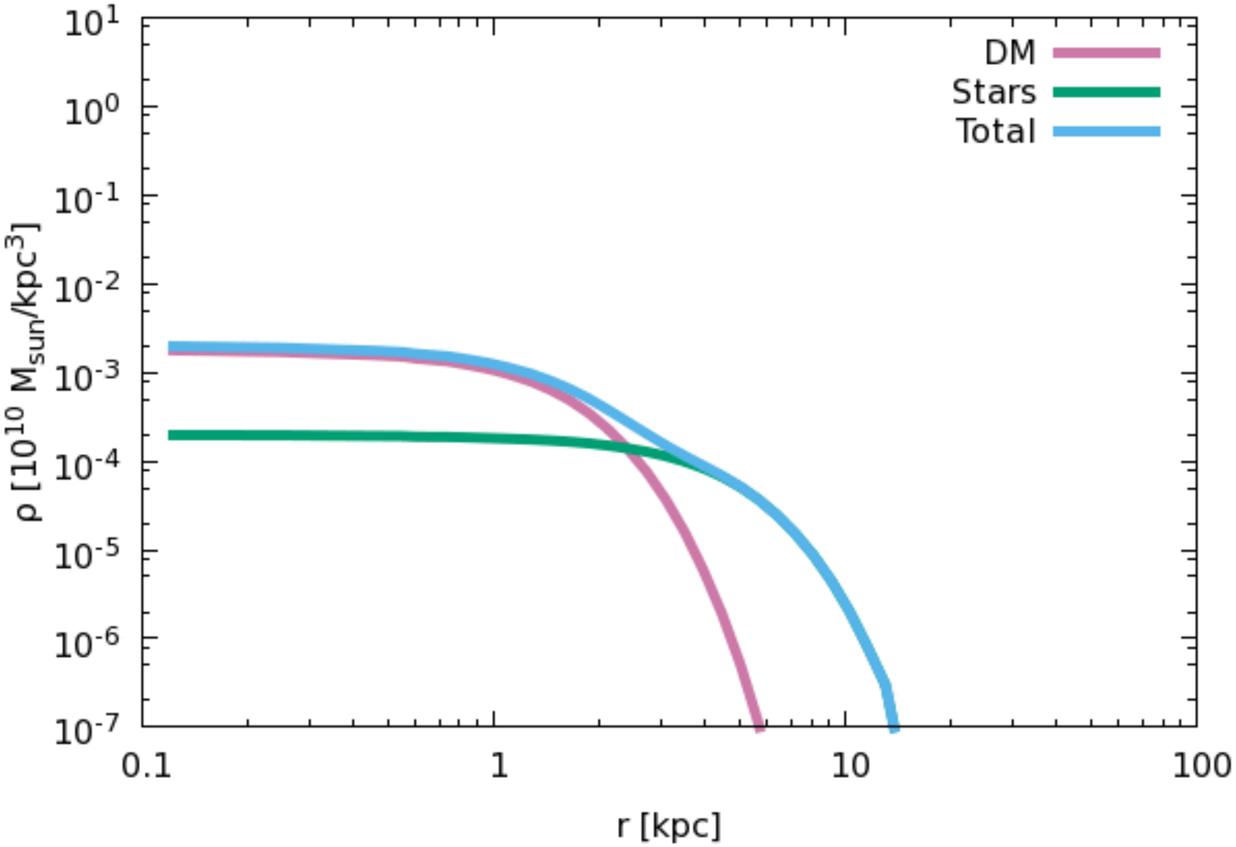


$M_{\mathrm{DM}} = 3.3 \times 10^8 M_{\odot}$

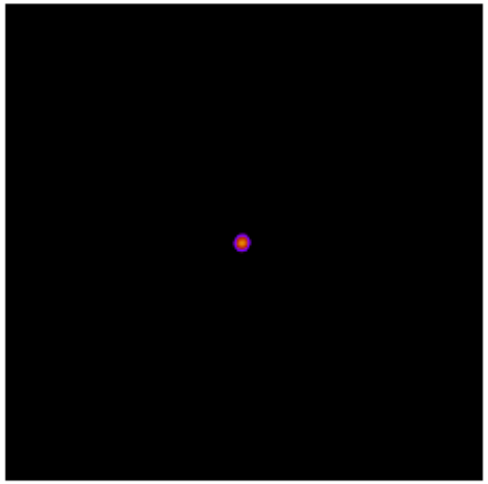
Stars



$M_{\mathrm{Stars}} = 10^9 M_{\odot}$

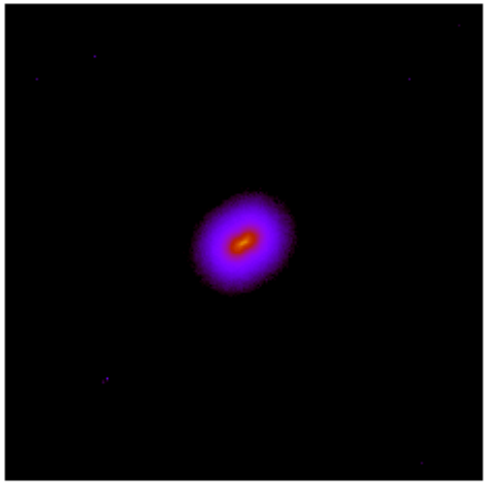


DM

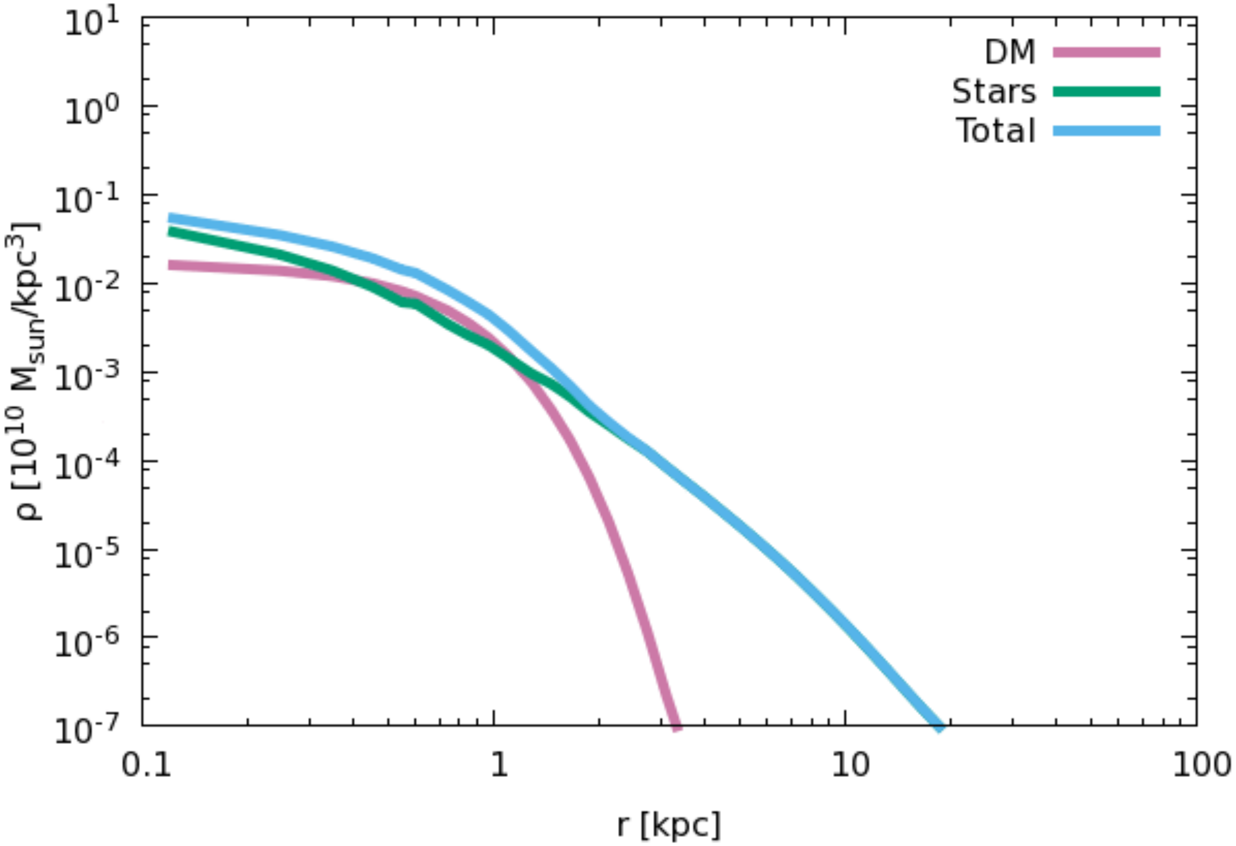


$M_{\rm DM} = 3.3 \times 10^8 M_\odot$

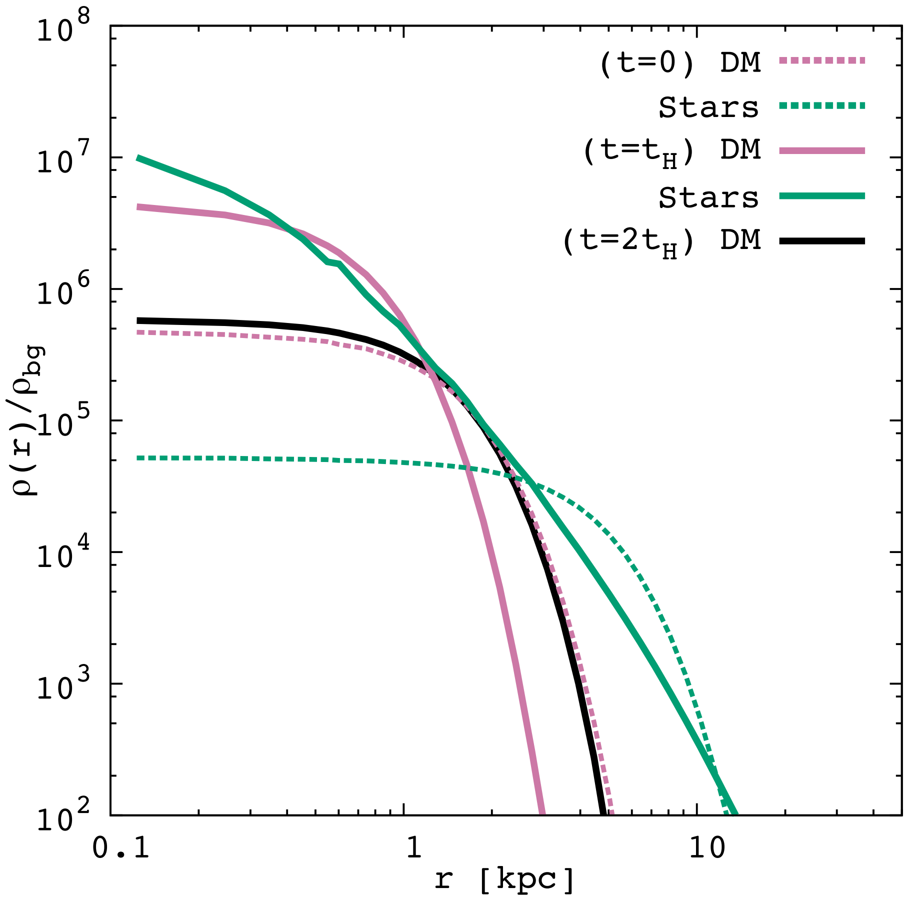
Stars



$M_{\rm Stars} = 10^9 M_\odot$



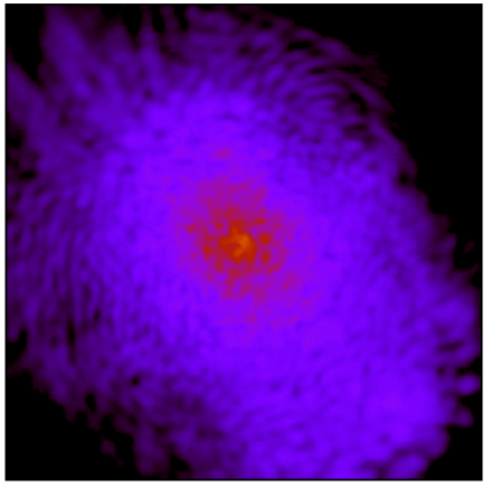
Soliton+Stars



$t_H \rightarrow 2t_H$:
remove stars

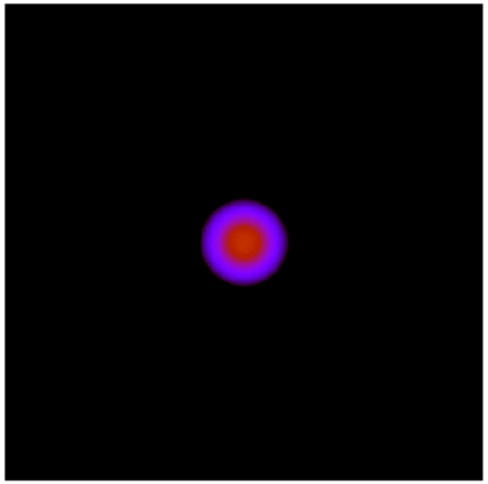
- the soliton responds to the environmental gravity by adjusting its size and shape.
- but the soliton is no longer satisfied with the universal profile ($M_{sol} \cdot r_{sol}$ = const.)
- the soliton responds to environmental changes time-reversibly

DM

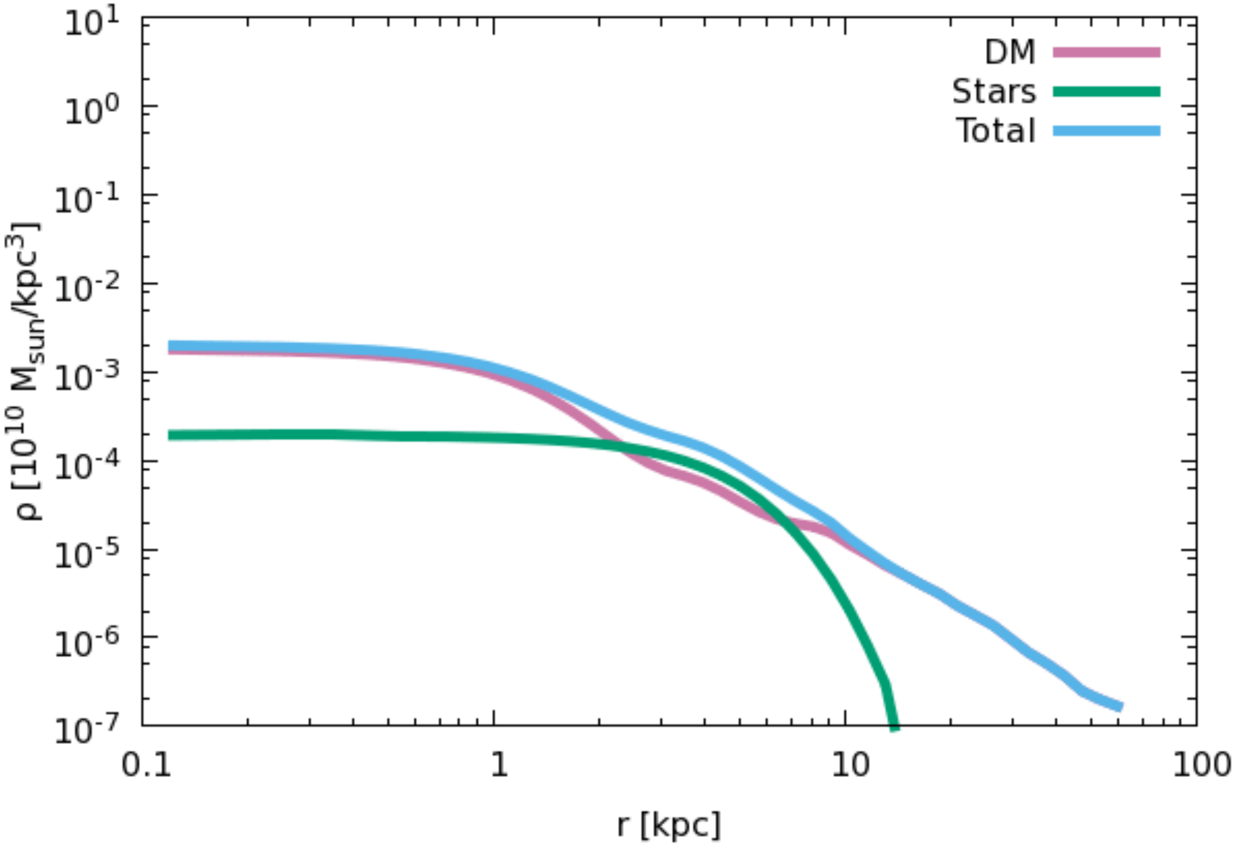


$M_{\mathrm{DM}} = 5.0 \times 10^9 M_\odot$

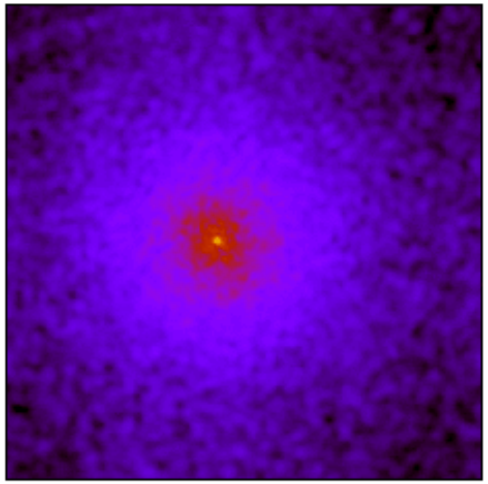
Stars



$M_{\mathrm{Stars}} = 10^9 M_\odot$

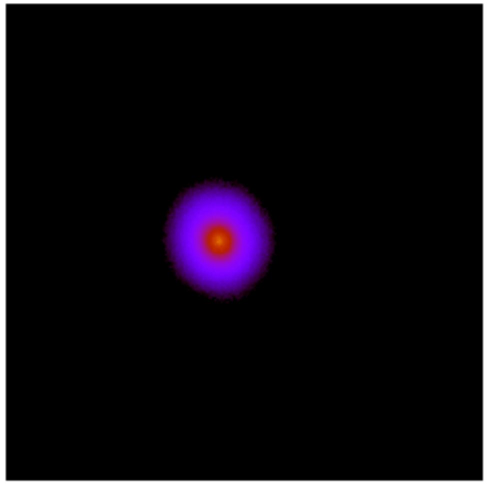


DM

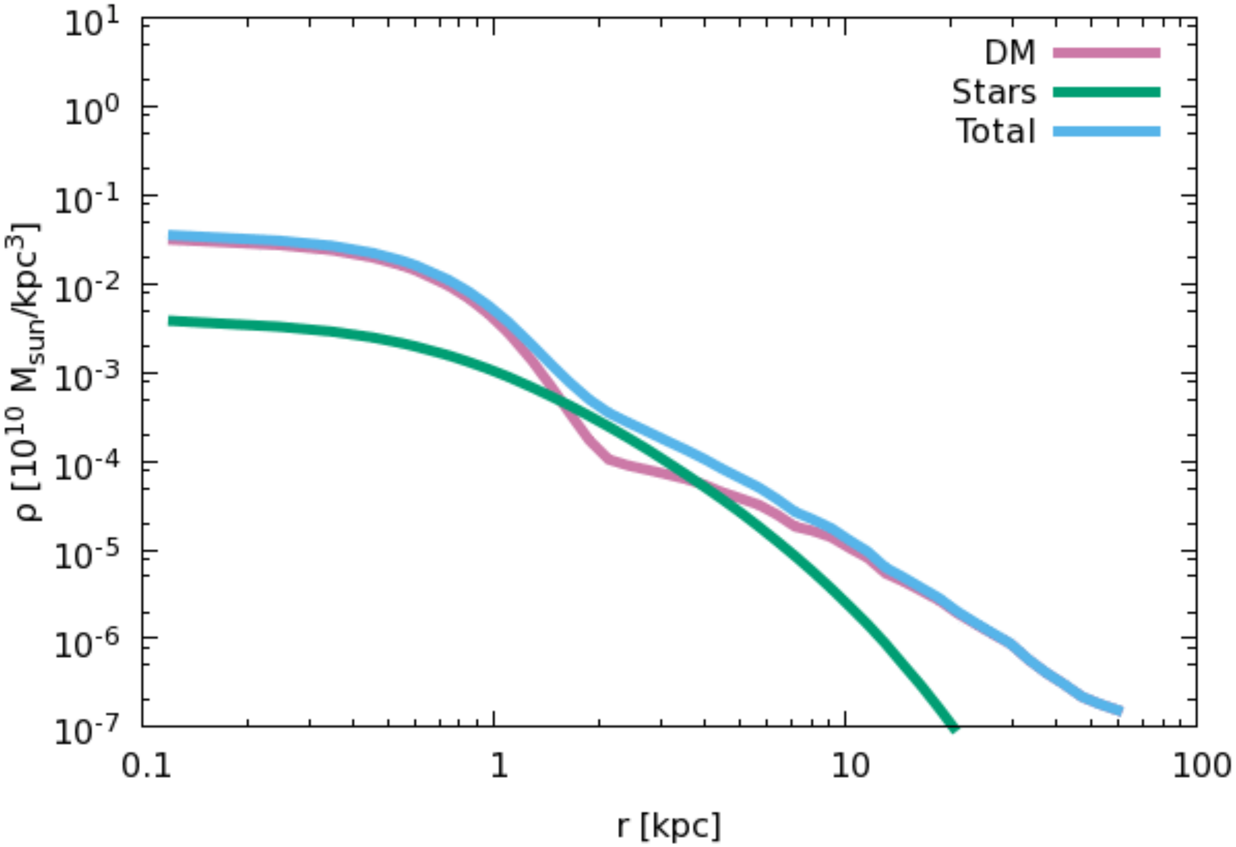


$M_{\rm DM} = 5.0 \times 10^9 M_\odot$

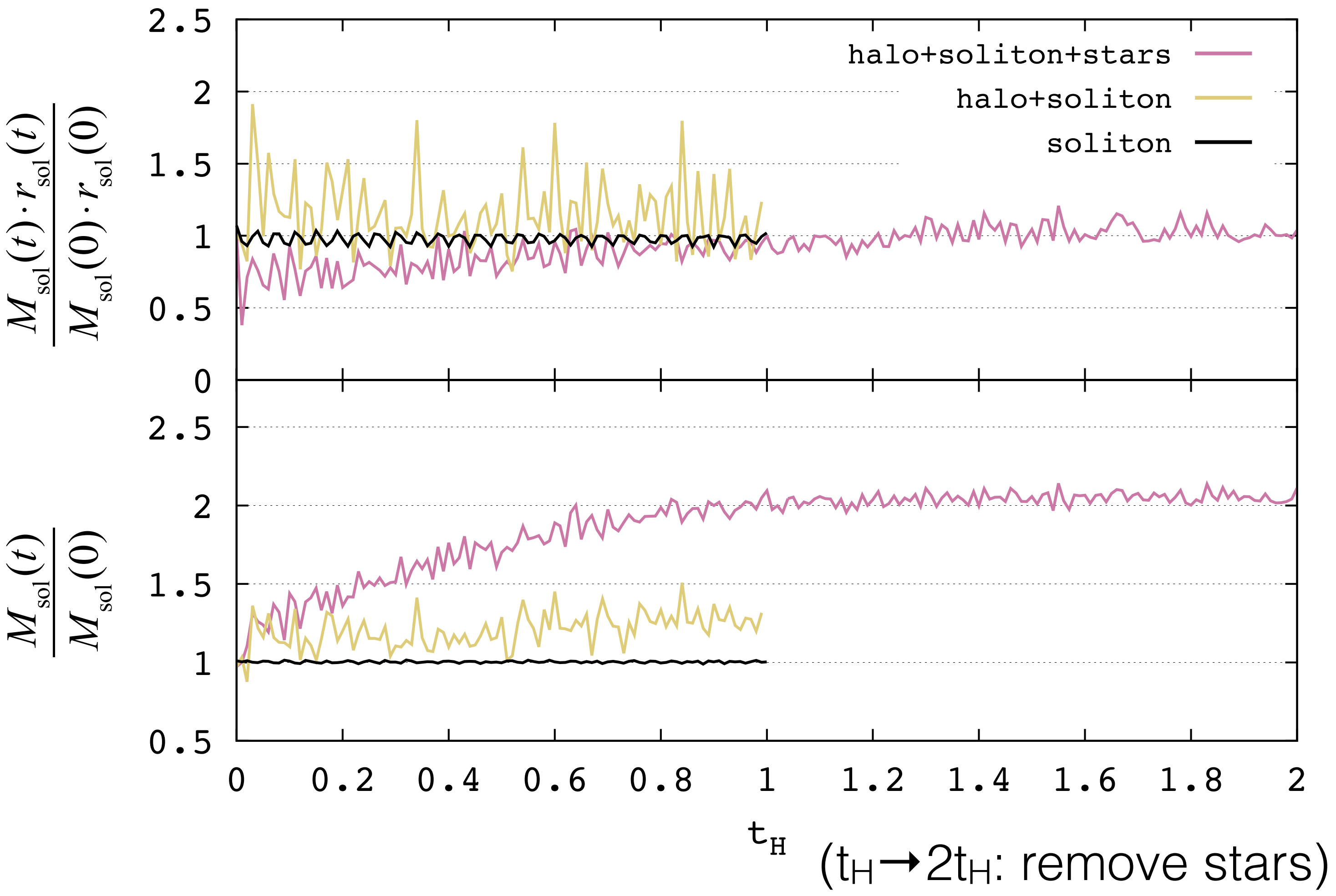
Stars



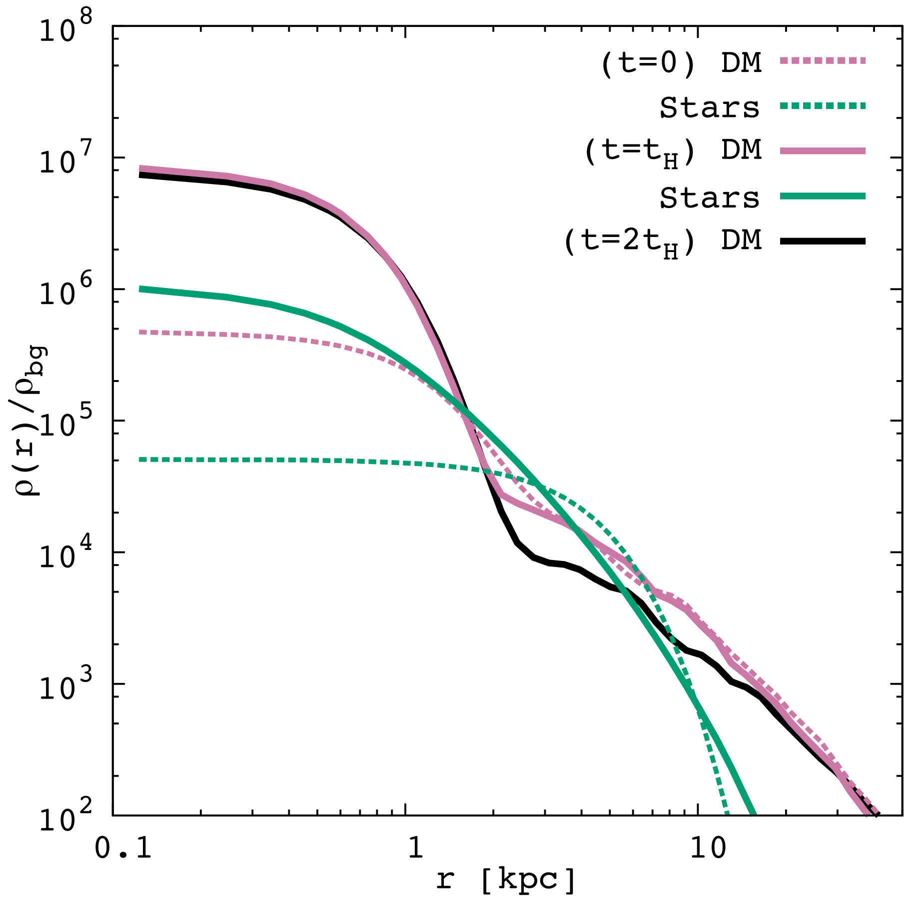
$M_{\rm Stars} = 10^9 M_\odot$



$M_{sol} \cdot r_{sol} = \text{const.?}$



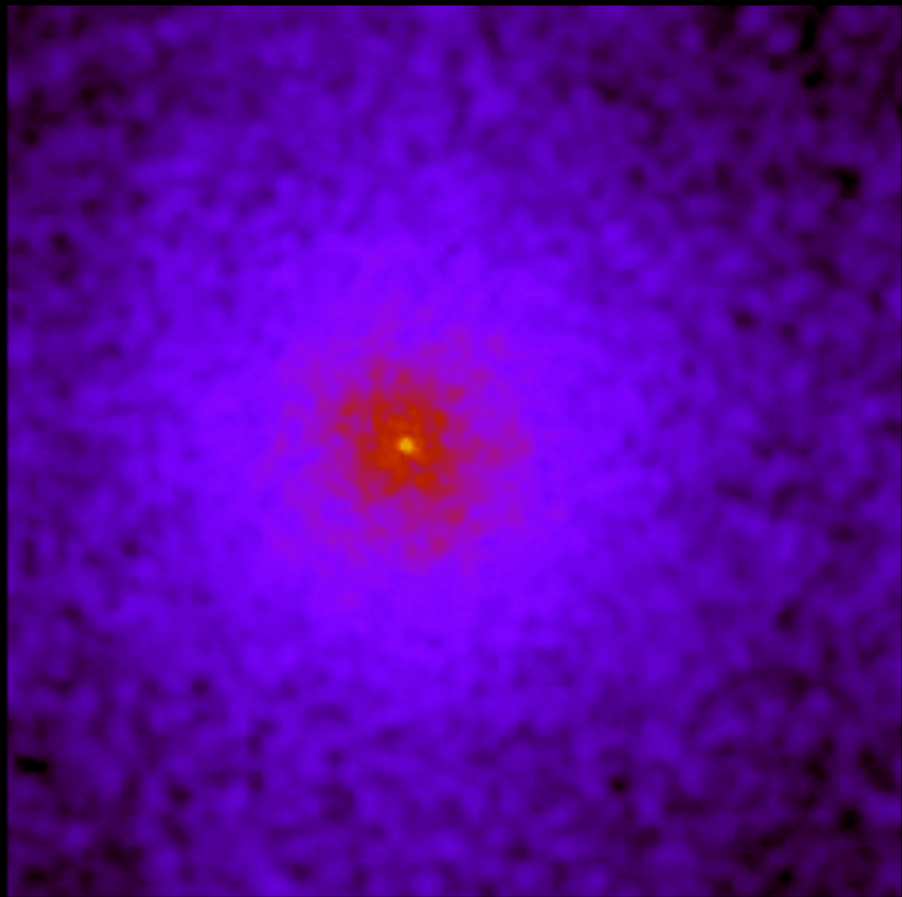
Halo+Soliton+Stars



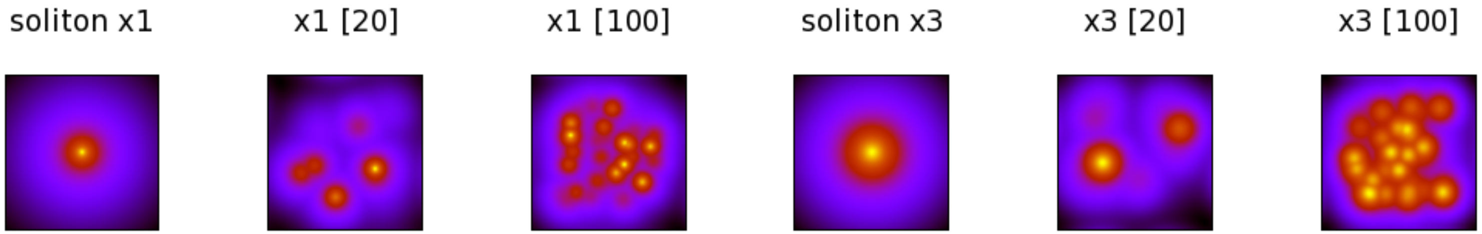
$t_H \rightarrow 2t_H$:
remove stars

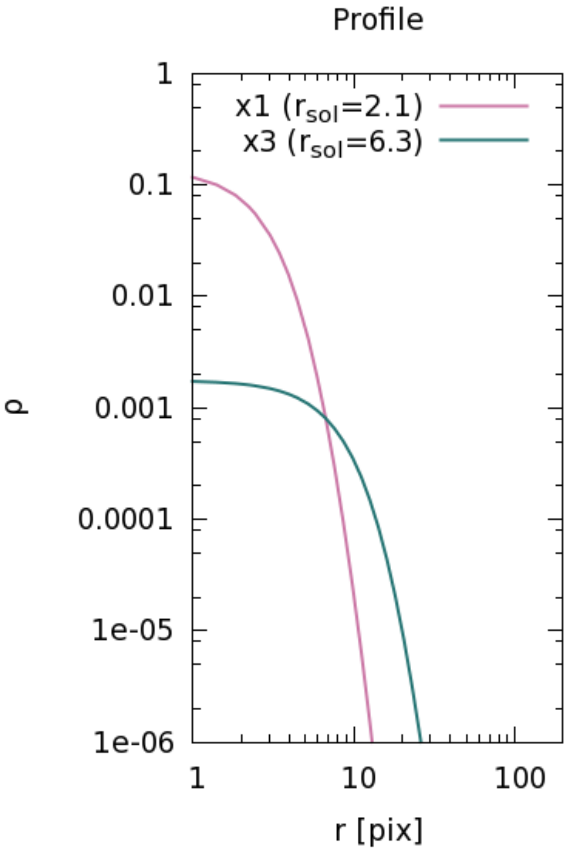
- The peak of solitonic core increases around an order of magnitude.
- Unlike the previous single soliton test, the soliton manages to preserve the scaling relation, by absorbing the mass from halo.

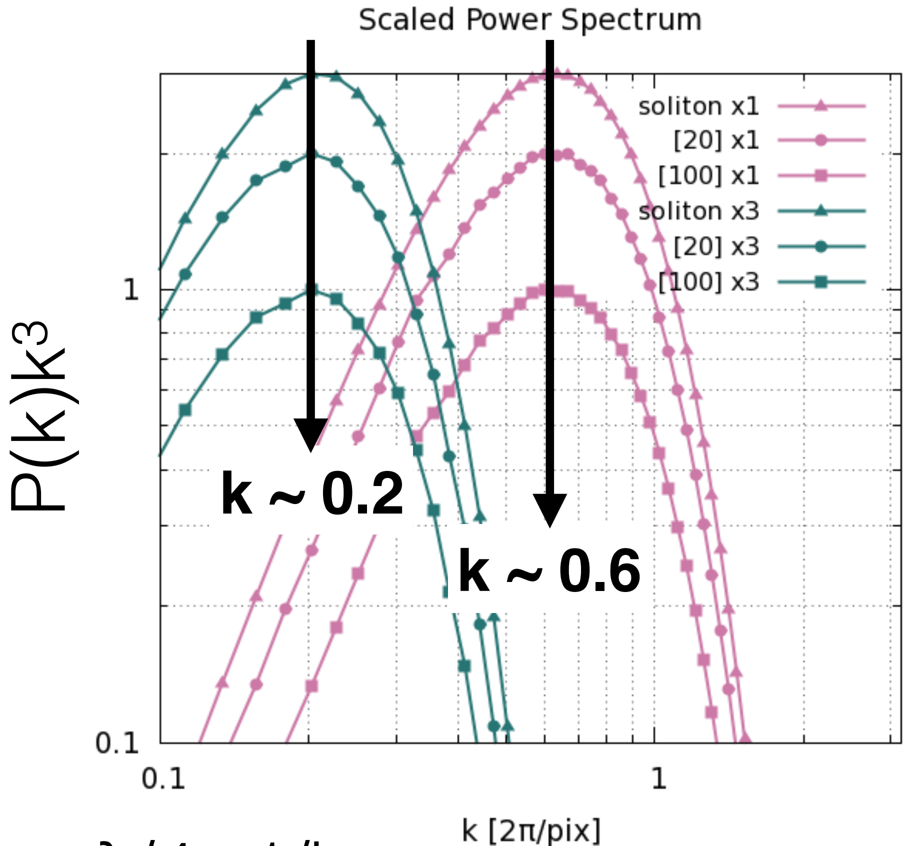
Granules



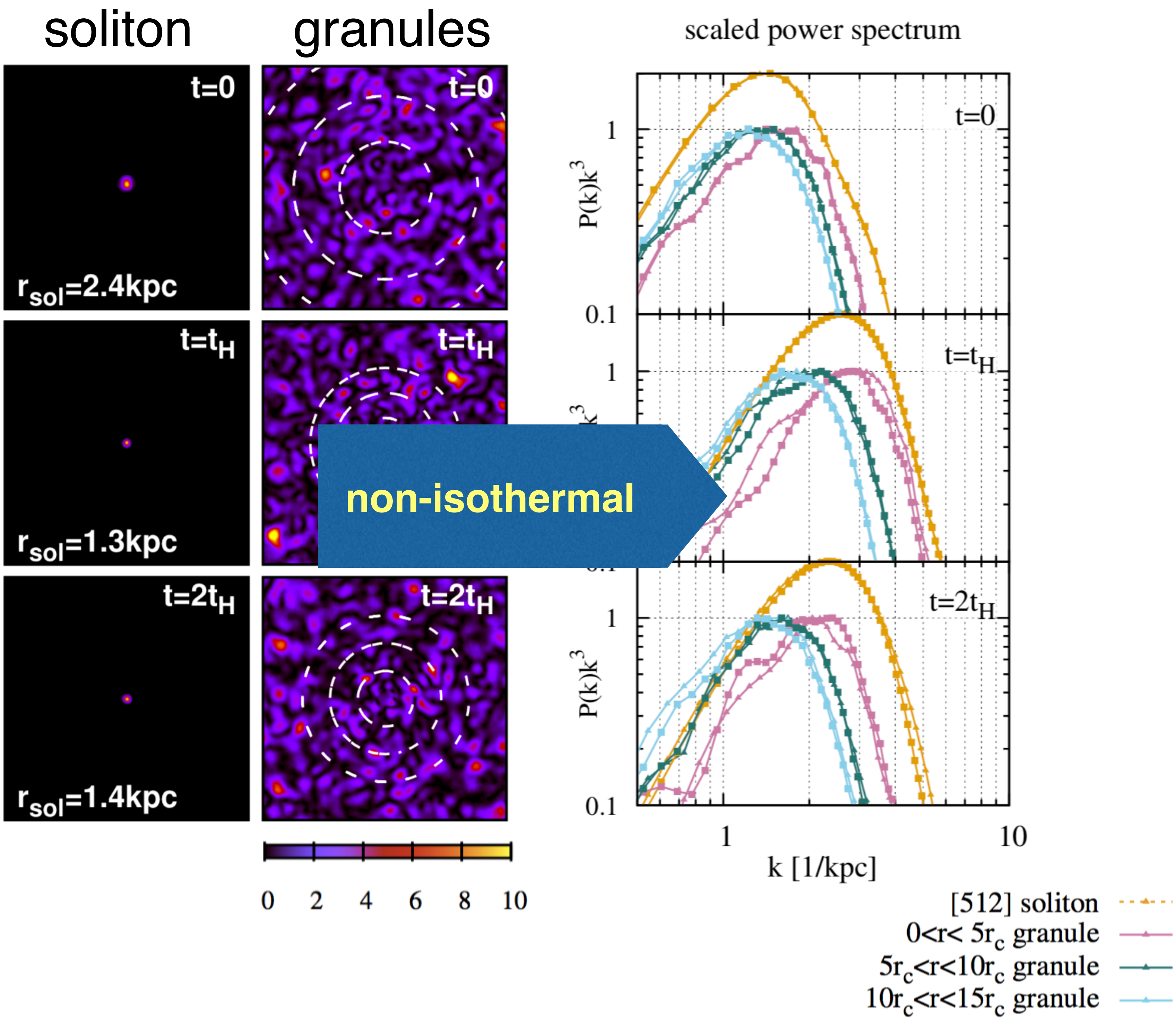
Granules' size







$$r_{sol} \propto \lambda/4 \propto 1/k$$



soliton
granules
scaled power spectrum
t=0
r_{sol}=2.4kpc
t=t_H
r_{sol}=1.3kpc
t=2t_H
r_{sol}=1.4kpc
non-isothermal
$P(k)k^3$
k [1/kpc]
0 2 4 6 8 10
[512] soliton
0<r< 5r_c granule
5r_c<r<10r_c granule
10r_c<r<15r_c granule

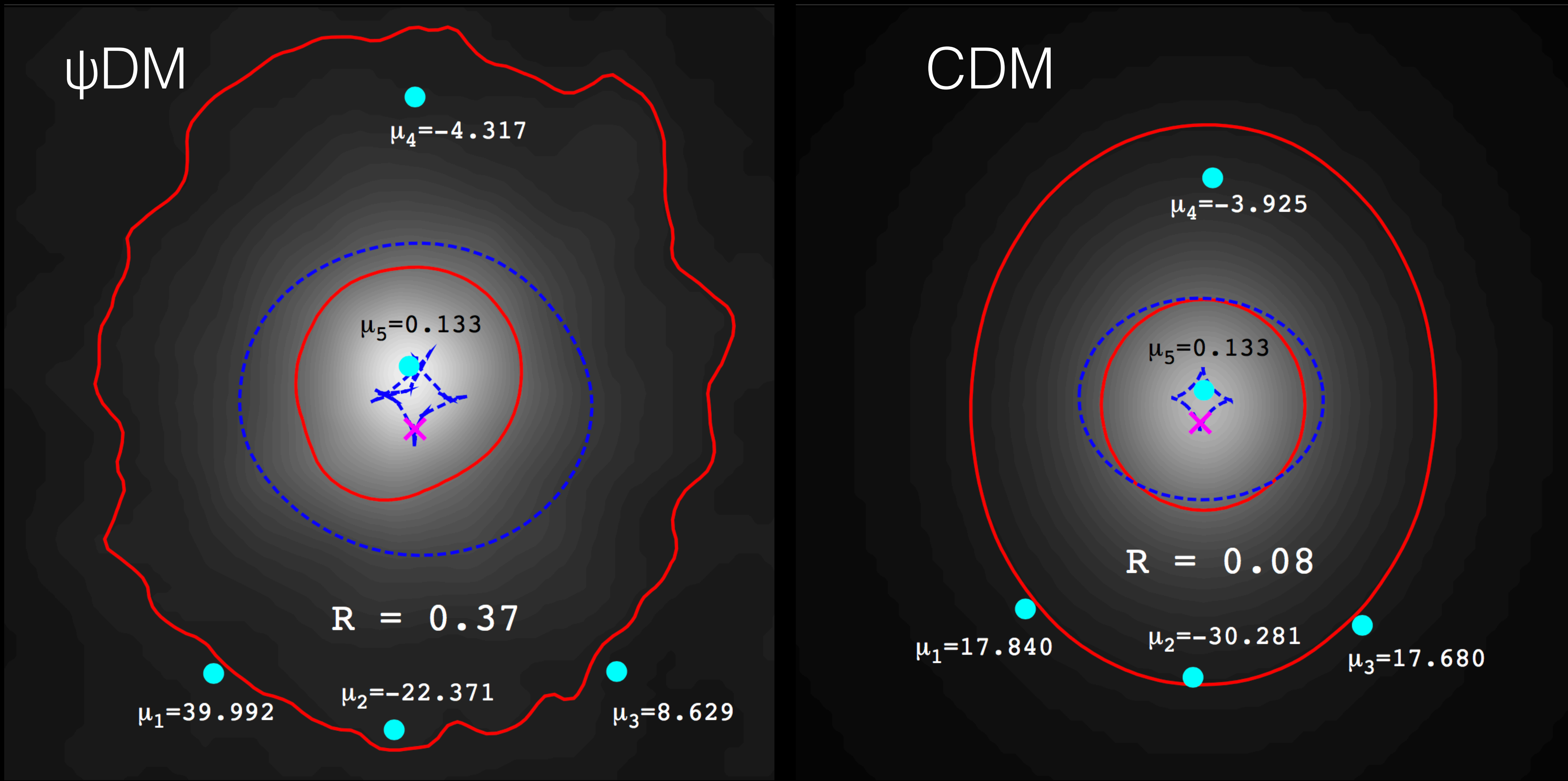
Result of “addition of stars”

- The solitonic core becomes more massive.
- Dark matter halos become non-isothermal.

arXiv:1712.01947

Connect to real world:

Flux Anomalies
in Gravitationally Lensed Quasars



Future Prospect

- Galaxy-scale halos
- Other baryonic effects
- Black hole in soliton
- Application to strong gravitational lensing, such as flux anomalies or lensed arc reconstruction.