Gamma-rays from Earth-Size dark-matter halos

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Presentation by: JM

Bottom line

- **Microhalos (mass $\sim$ earth mass) do survive to the present time.**
- **Their contribution dominates the annihilation γ-ray flux.**
- **Nearest halos might be observed as pointlike sources with extremely large proper motions**
- **Pulsar timing might also detect these halos.**

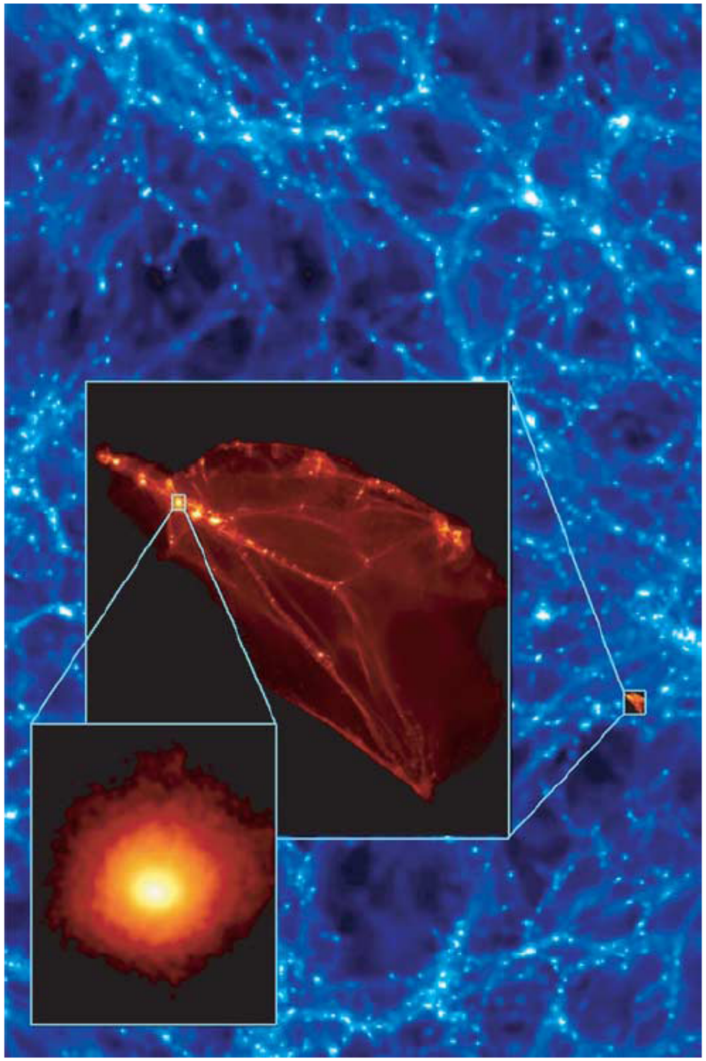
Structure of the talk

- Why microhalos?
- Previous works and their problems
- Our experiment
- Structure of microhalos
- Disruption by tidal fields
- γ-ray all-sky map
- Detectability by Pulsar timing
- Summary

Why microhalos?

- **First structures in the Universe**
  - **mass** $\sim 10^{-6} M_\odot$
  - **radius** $\sim$ **100 AU**
- **Might have survived**
- **If survived, main sources for the annihilation** γ**-ray**

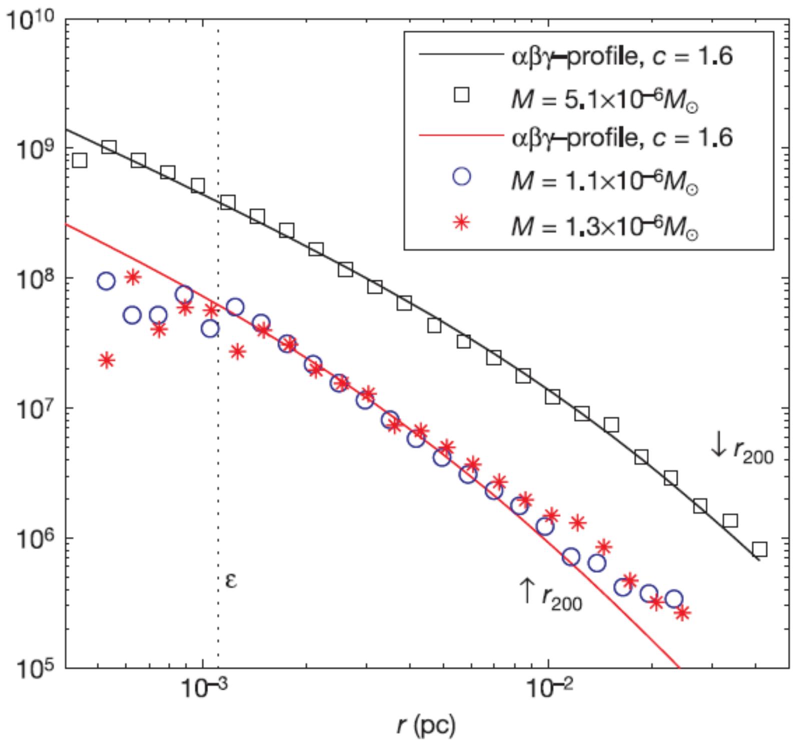
Previous works and their problems



Diemand et al. 2005,
Nature 433, 389

- cosmological N-body simulation
- Express earth-mass halos with 10^4 particles

Density profile



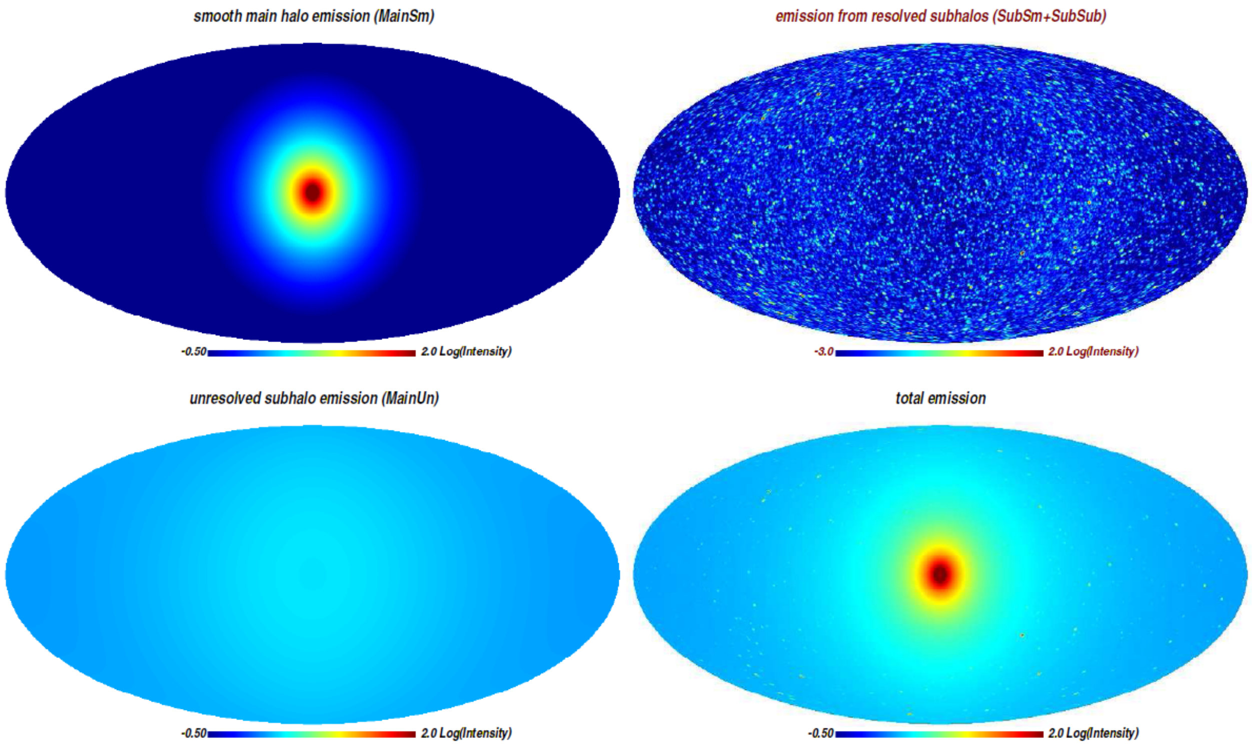
- Quite similar to so-called NFW profile
- Claim: slope ~ -1.2
- Very low resolution
- Probably completely wrong

Controversy

- **If survived to the present, microhalos are primary sources for annihilation γ-ray**
- **However, they might have been disrupted by**
  - **merging with similar or somewhat larger halos**
  - **tidal field of parent halo (or subhalo)**
  - **encounters with stars**

Both the parent halo and stars are very effective, if the density profile of Diemand et al is correct.

Springel et al 2008



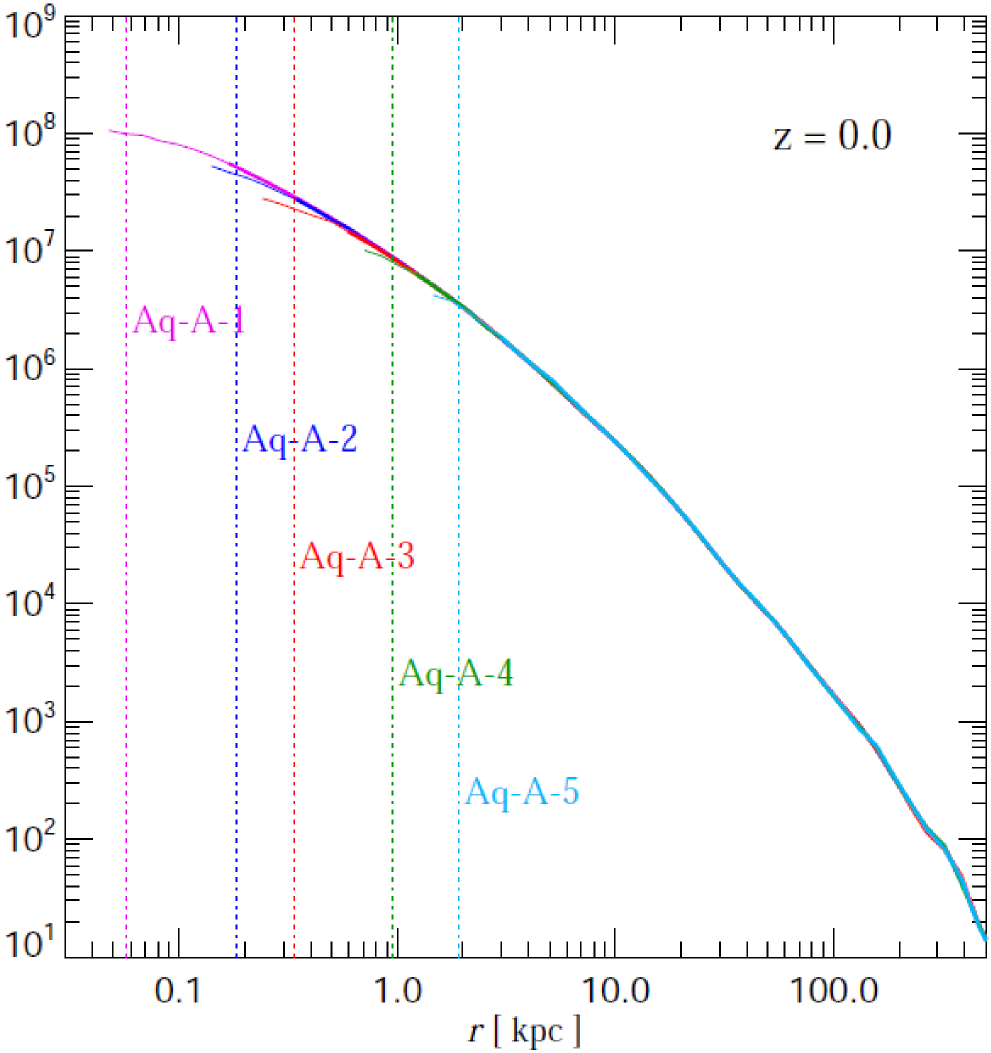
You cannot see individual microhals
Subhalos are unimportant

Problem with low resolution

- **Two-body relaxation: Heat up the central region, resulting in a flat core**
- **Gravitational softening: resolution limited by softening**

Typically, to obtain reliable structure at radius r, one need $\sim 10^4$ particles inside r (of course depends on the crossing time)

Highest-resolution DM simulation

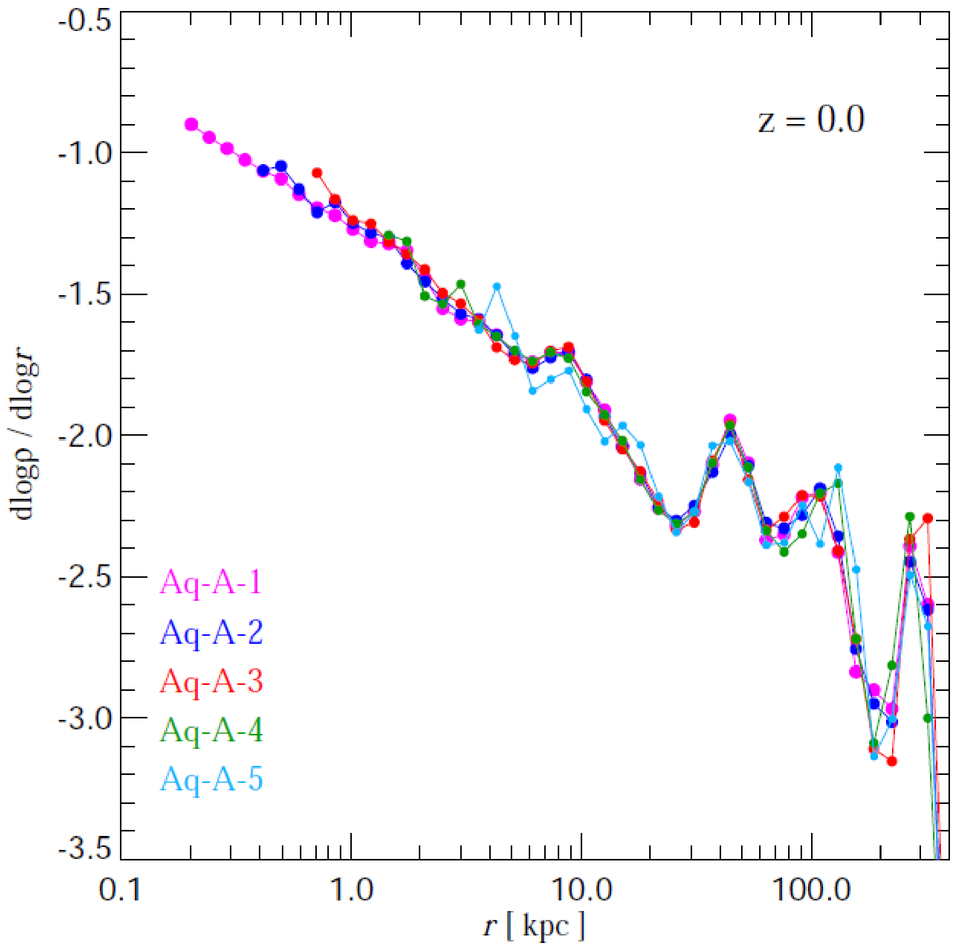


Current best calculation, Springel et al (2008)

Change *N* by three orders of magnitude

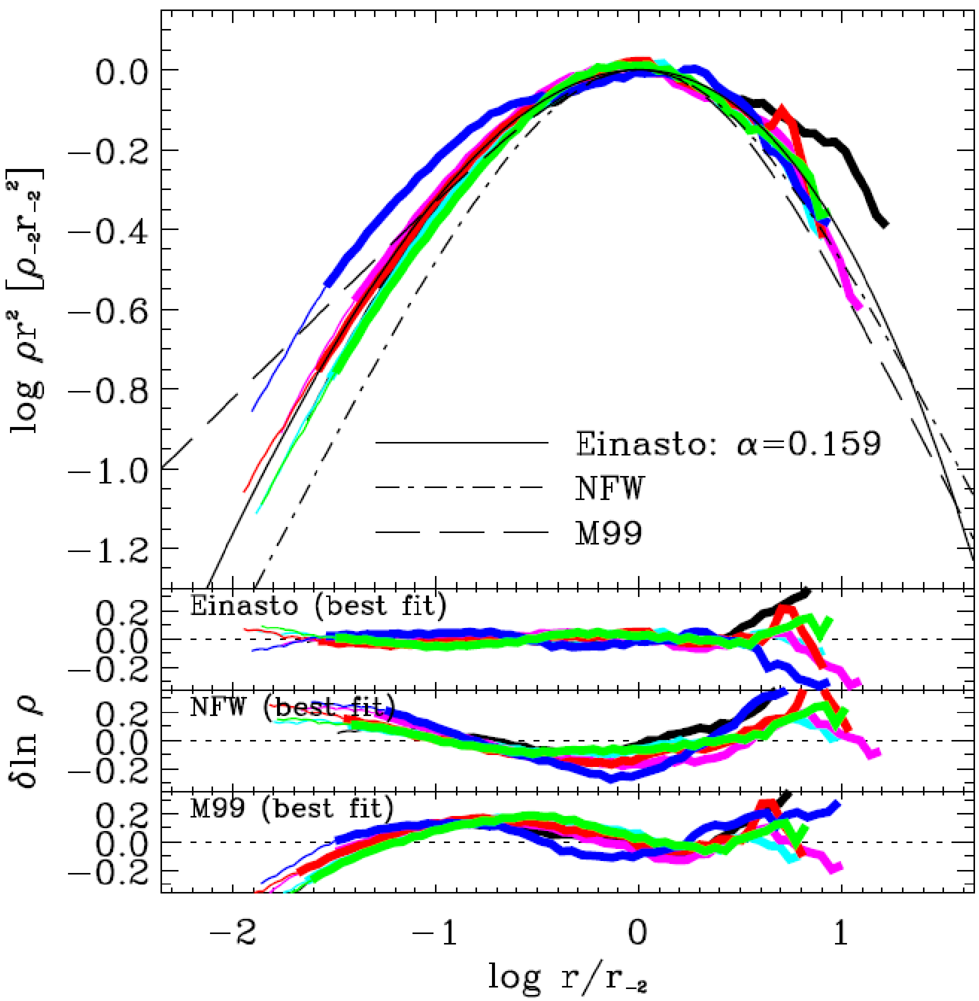
Shows convergence?

Power index of the density slope



No single power...

Comparison with NFW profile etc



Navarro et al. 2008 (not accepted yet?)

NFW: $\dfrac{1}{r(1+r)^2}$

Moore99: $\dfrac{1}{r^{1.5}(1+r^{1.5})}$

Einasto: $\exp[(-2/\alpha)(r^{\alpha}-1)]$

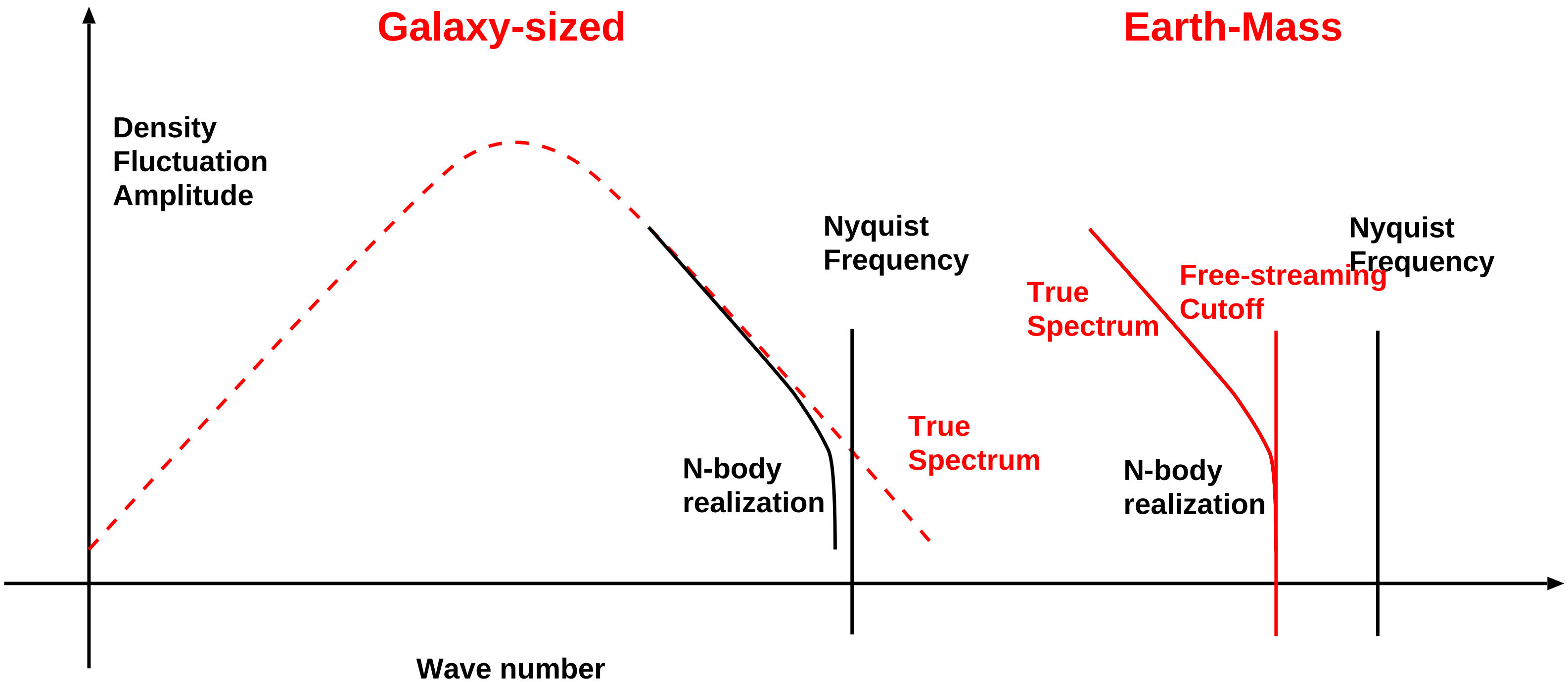
Current status of the DM halo simulation

- For galaxy-size or cluster-size halos, numerical results show central slope decreasing inward.
- no theoretical understanding yet.
- For earth-mass halos, no high-resolution simulation yet.

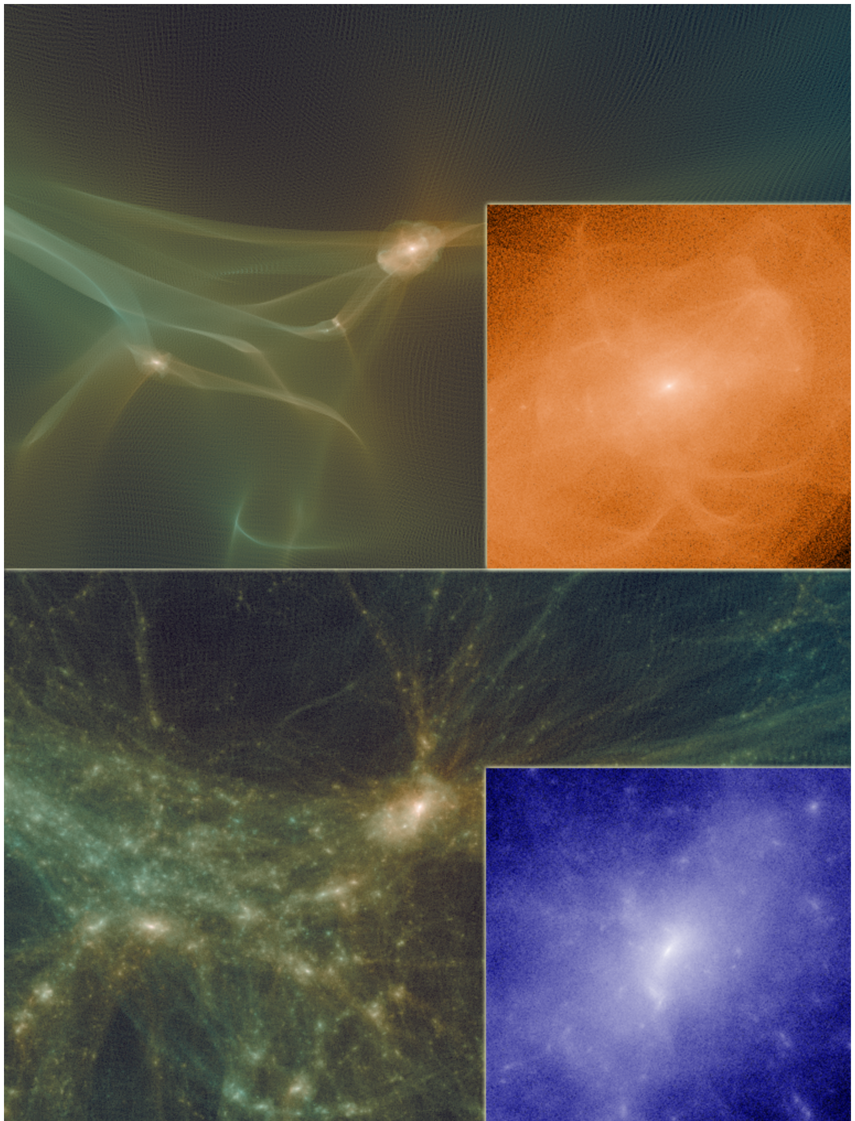
Difference between earth-mass and galaxy-mass halos

- **CDM: Galaxy-sized halos contain many substructures**
- **Free-streaming cutoff: No substructures**

Initial condition



Structure formed



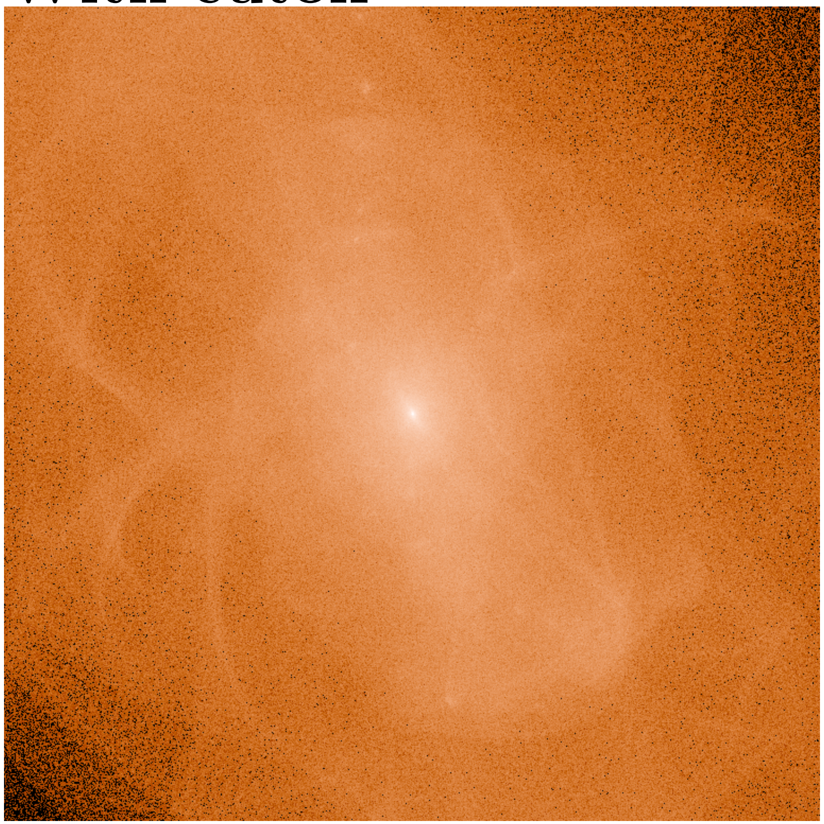
Ishiyama et al., in preparation.

100 times more particles than Diemand et al.

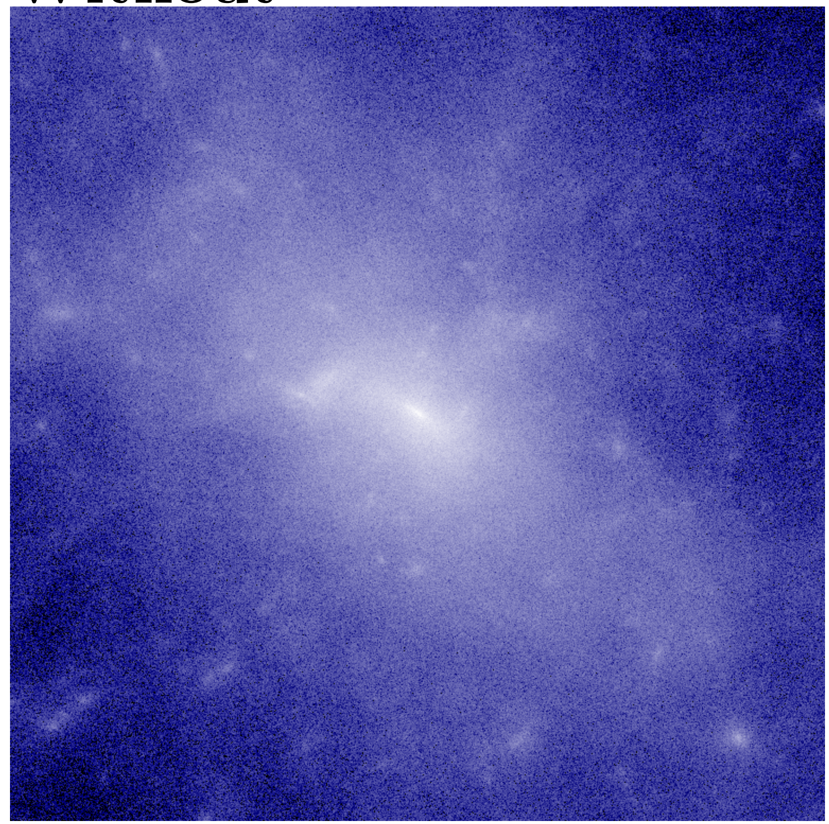
- Top: with free-streaming cutoff
- Bottom: without cutoff

Halos

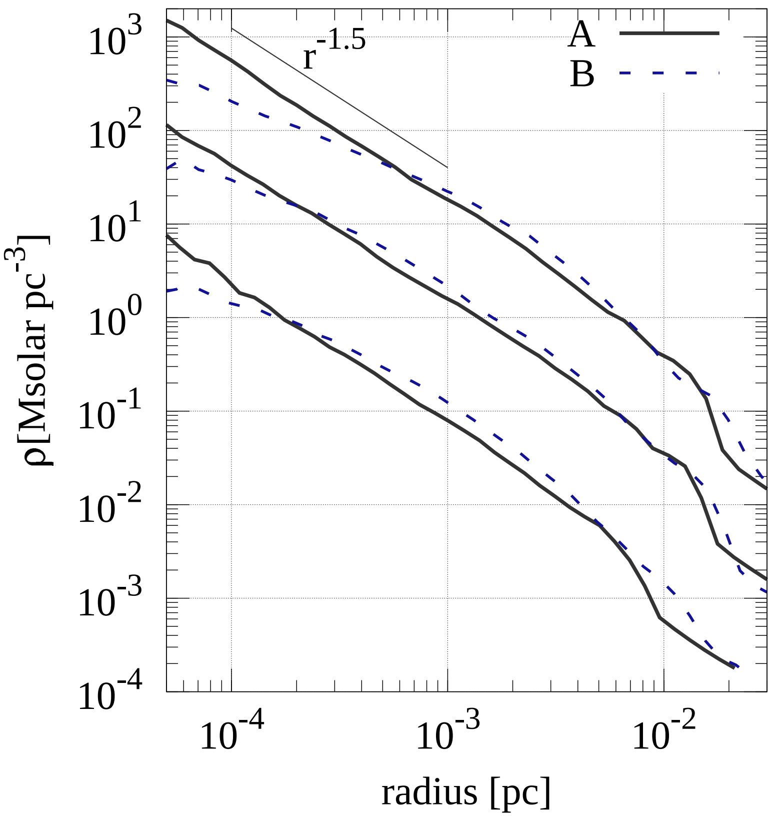
With cutoff



Without



Structure of microhalos



Solid: with cutoff. quite clear single power

Dashed: without cutoff. Similar to galaxy-sized halos.

Earth-mass microhalos have steep, $\rho \propto r^{-1.5}$ cusp

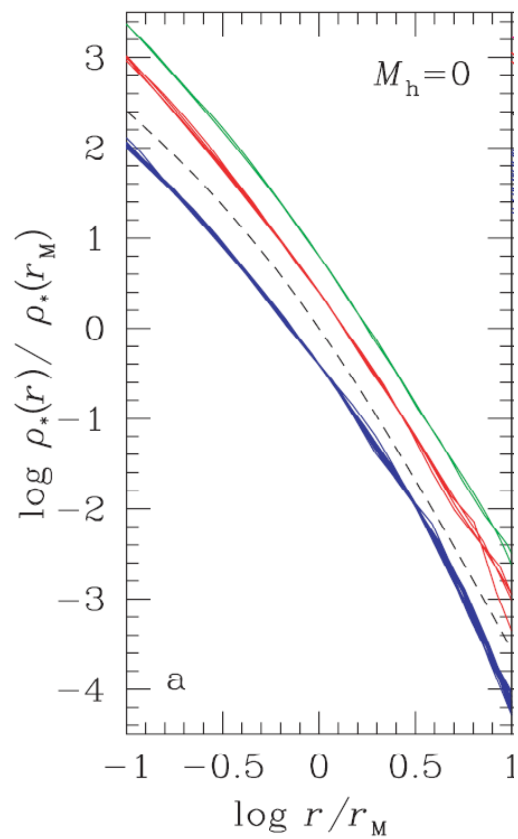
Meaning of -1.5

Annihilation γ-ray flux diverges as $r \to 0$.
Two questions:

1. **Why -1.5?**
2. **Is there any limit radius?**

Why −1.5?

No real clue yet...
Resent cold-collapse simulations show the same −1.5 slope. (Nipoti et al 2006)



Single power is sort of natural

- **"Cold" initial condition: no limit in the central density**
- **No characteristic scale: result should be a power law?**

Is there any limit radius?

- **“Cold” dark matter still have finite temperature.**
- **Leuville’s theorem — maximum phase space density is conserved (or does not increase): $\sim 10^{15} \mathrm{M}_\odot \mathrm{pc}^{-3} (\mathrm{km/s})^{-3}$.**

$$\downarrow$$

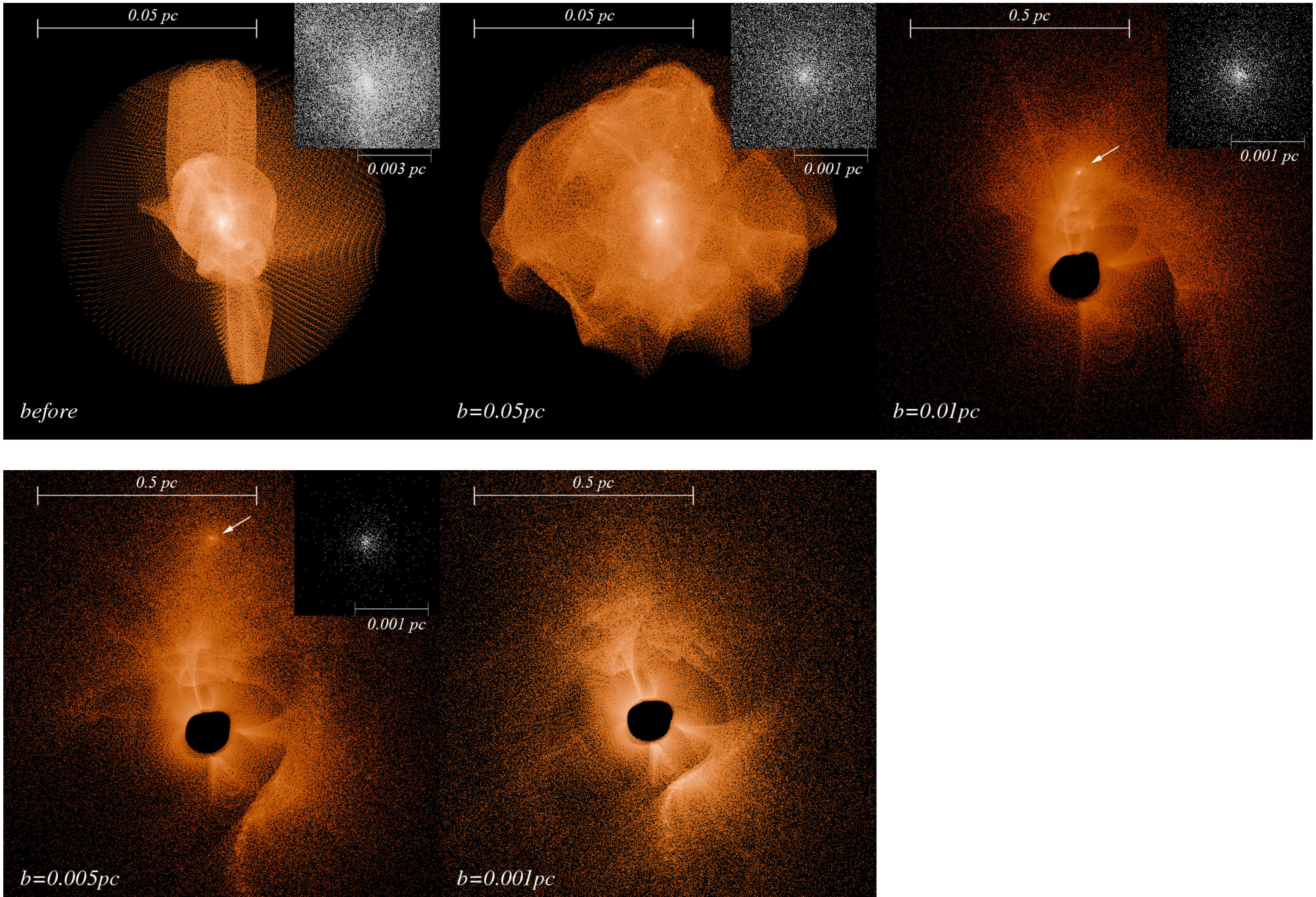
- **Core radius: $r_{\mathrm{c}} \sim 10^{-5}\mathrm{pc}$**
- **Core density: $\rho_{\mathrm{c}} \sim 2 \times 10^{4} \mathrm{M}_\odot \mathrm{pc}^{-3}$.**

Disruption by tidal fields

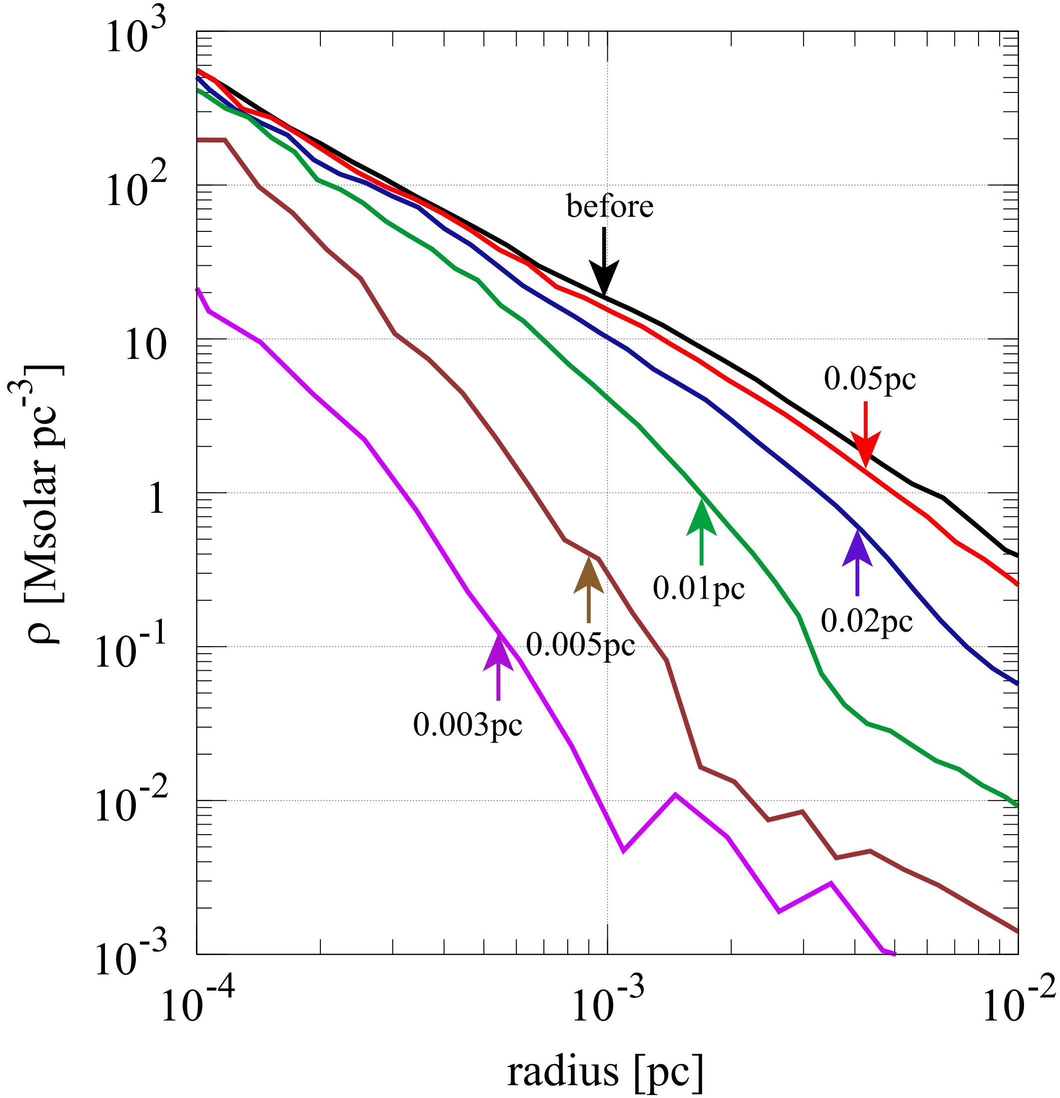
In previous studies, microhalos were assumed have shallow central slope (~ -1.2).
Our high-resolution simulation:

- **Central density is very high — difficult to disrupt**
- **γ-ray flux distribution logarithmic in radius — heavily stripped halos still retain most of luminocity**

Encounters with stars



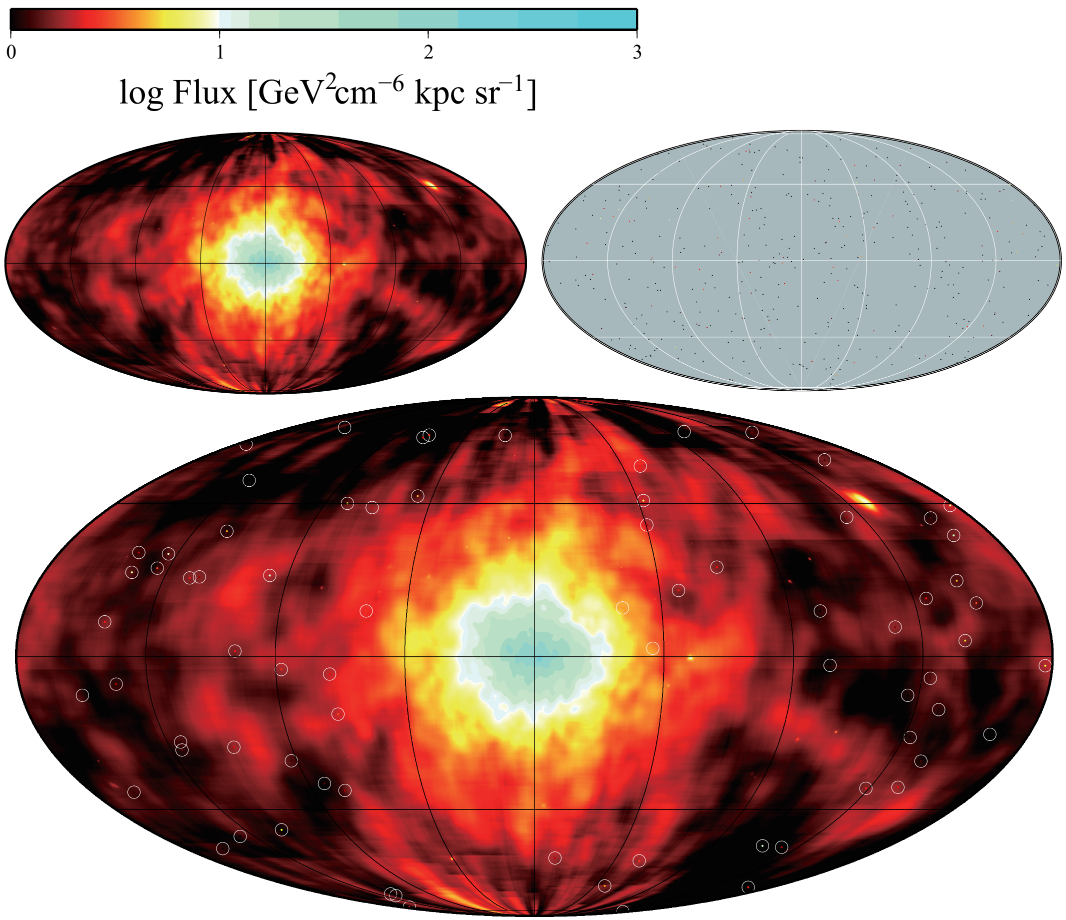
Structure after encounters



Central parts of Halos do survive very close encounters with stars.

Complete disruption requires impact parameter $b = 5 \times 10^{-5}$pc.

γ-ray all-sky map



Top left: Smooth component due to microhalos
Top right: resolvable flux from microhals (within 1pc)

Theoretically, $r_{\text{tidal}} \propto b^{8/11}$.

Nearby microhalos

- distance $\sim$ 0.2pc, core size $\sim 1AU$ $\longrightarrow$ image size $\sim$ 1 arcmin
- Proper motion: 300km/s, 0.2 pc $\longrightarrow$ $\sim$0.2deg/y
- total flux: $\sim 10^{6}$ of the total galactic flux
- 10-100 times blighter than average background

Detectability by Pulsar timing

Encounter with Pulsars causes variation in the time of arrival.

$$\Delta T = 40\left(\frac{R}{5000\mathrm{AU}}\right)^{-2}\left(\frac{M}{10^{-6}M_\odot}\right)\left(\frac{t}{10\mathrm{yr}}\right)^{2}\mathrm{ns}.$$

Change in the relative position should show up as the residual of TOA.
Current PPTA timing accuracy: 100ns
Many MSPs are in the direction of GC: High DM density.
PPTA might find microhalo in 10 years.

Summary

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