The gamma-ray signature of an early matter-dominated era

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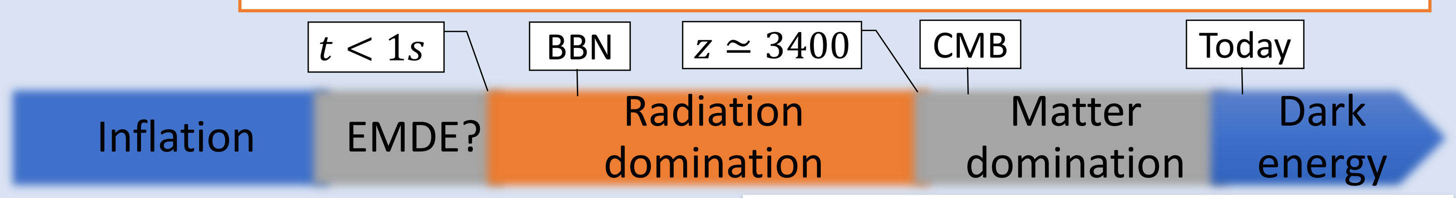
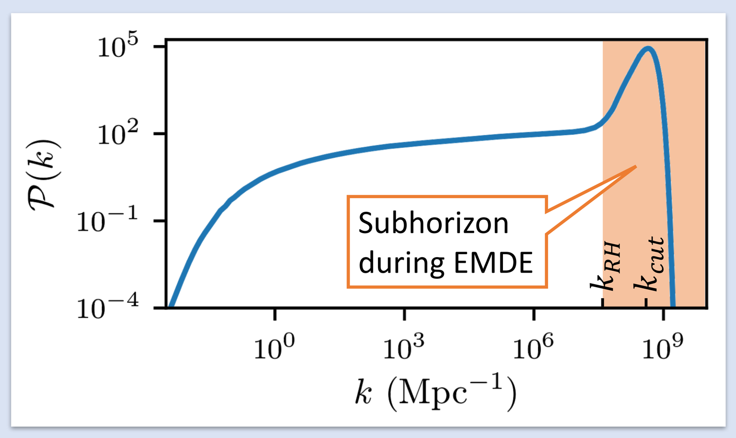
An early matter-dominated era (EMDE)

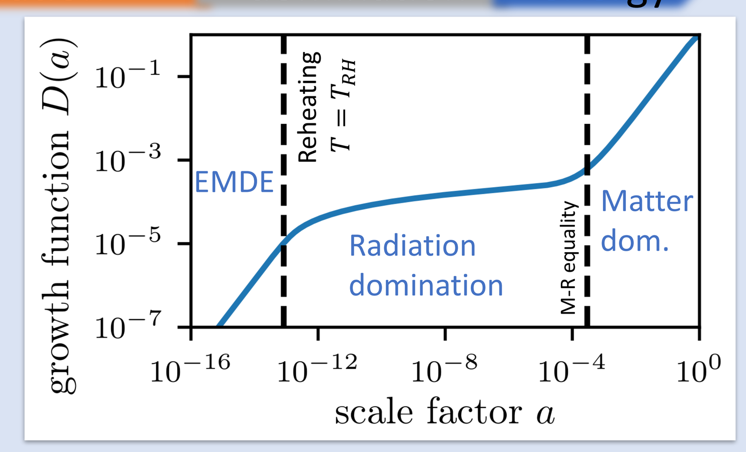
The Universe may have been dominated by a pressureless fluid during the first second after inflation.

Example
- Unstable heavy relics
- Gravitationally coupled heavy moduli fields
- Inflaton oscillating about the bottom of its potential



Subhorizon matter density fluctuations grow rapidly when pressureless fluids dominate.



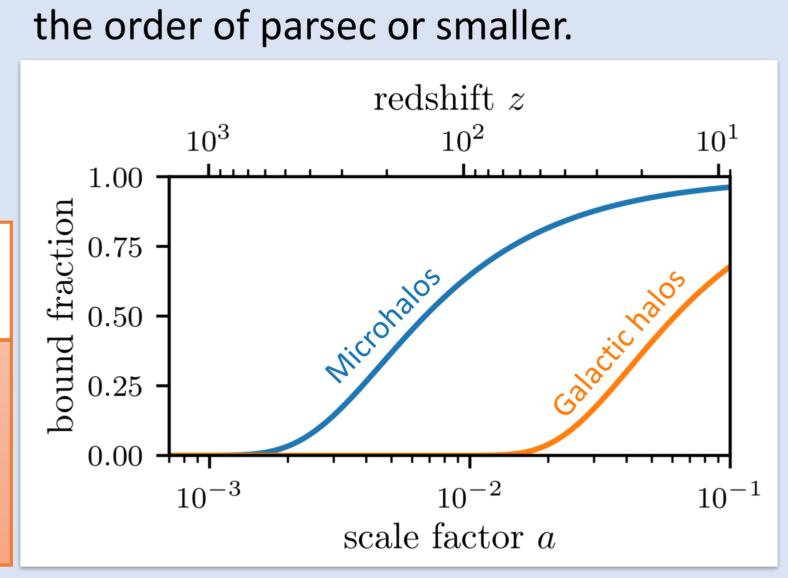


An EMDE thus enhances these fluctuations, whose wavelengths are on the order of parsec or smaller.

The enhanced fluctuations collapse into dark matter microhalos.

By $z \sim 100$, most dark matter is in superdense sub-earth-mass microhalos.

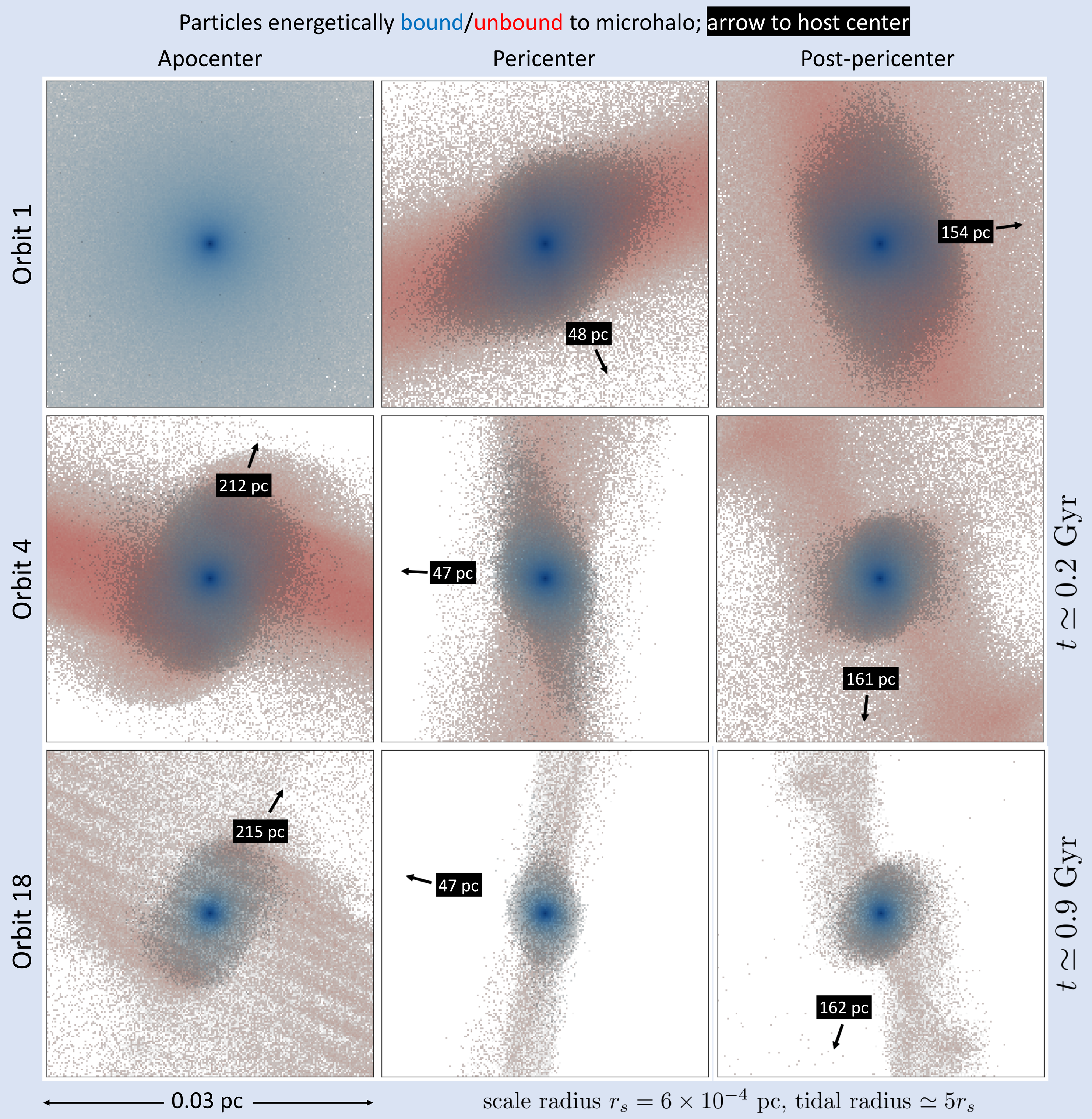
These microhalos greatly boost the gamma-ray signal from dark matter annihilation. But can they survive within galactic halos?



Simulating microhalo survival

- We use the GADGET-2 N-body simulation code, modified to apply the tidal force from a host galaxy.
- Microhalos are prepared using an isotropic distribution function.
- We simulate these microhalos on a variety of orbits.

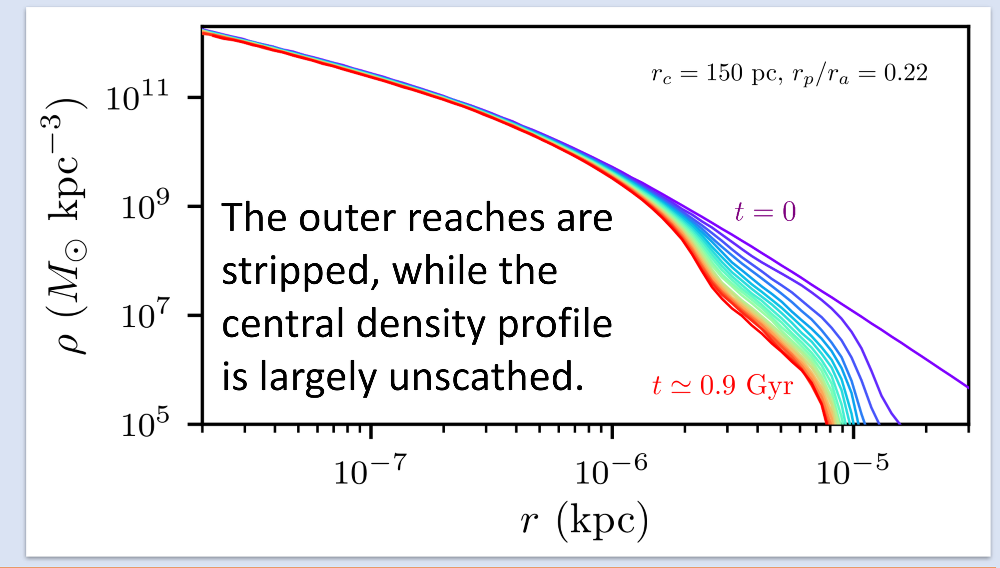
Particles energetically bound/unbound to microhalo; arrow to host center



The impact of tidal stripping

Microhalos survive, but they are diminished over time.

We study the impact of tidal stripping as a function of orbit.



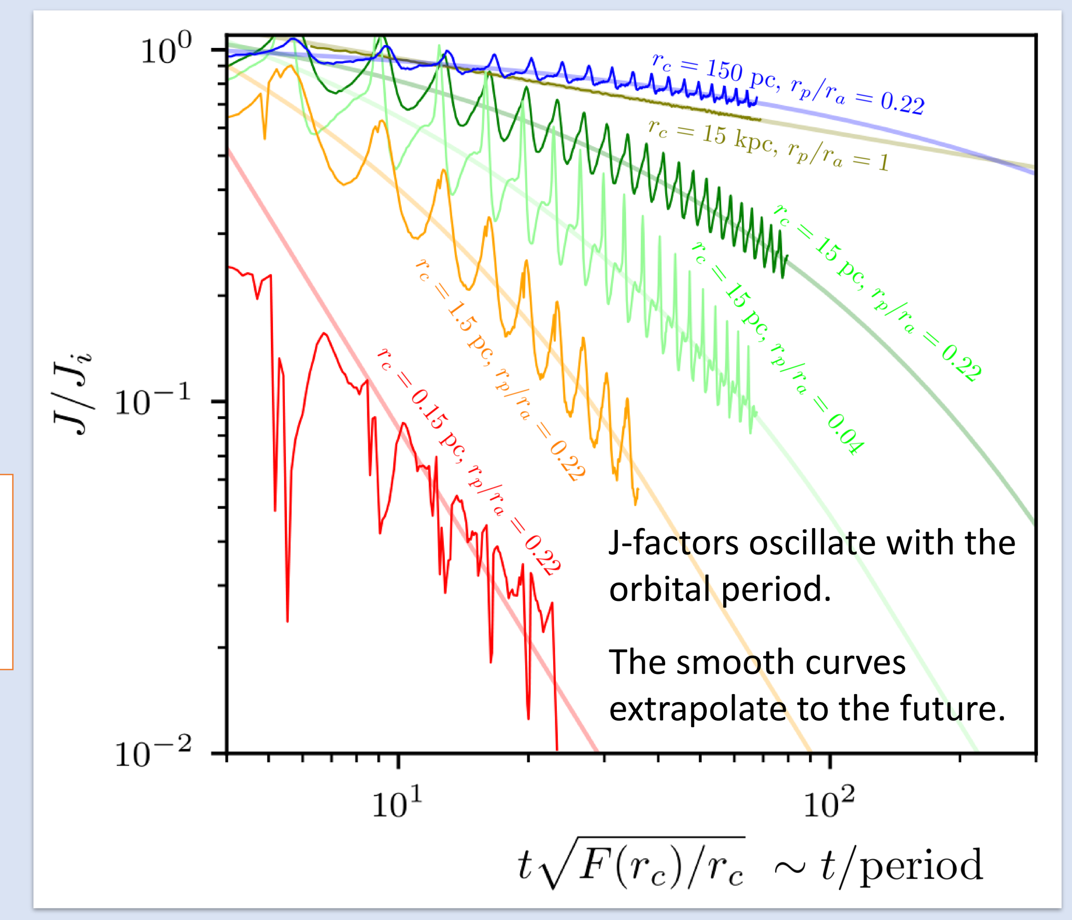
Orbit parametrization:

1. A scale parameter. We use the circular orbit radius r_c, the radius of a circular orbit with the same energy. (This is roughly the time-averaged radius.)
2. A shape parameter, such as the pericenter-apocenter ratio r_p/r_a.

The dark matter annihilation rate is proportional to the J-factor:

$$J \equiv \int \rho^2 dV$$

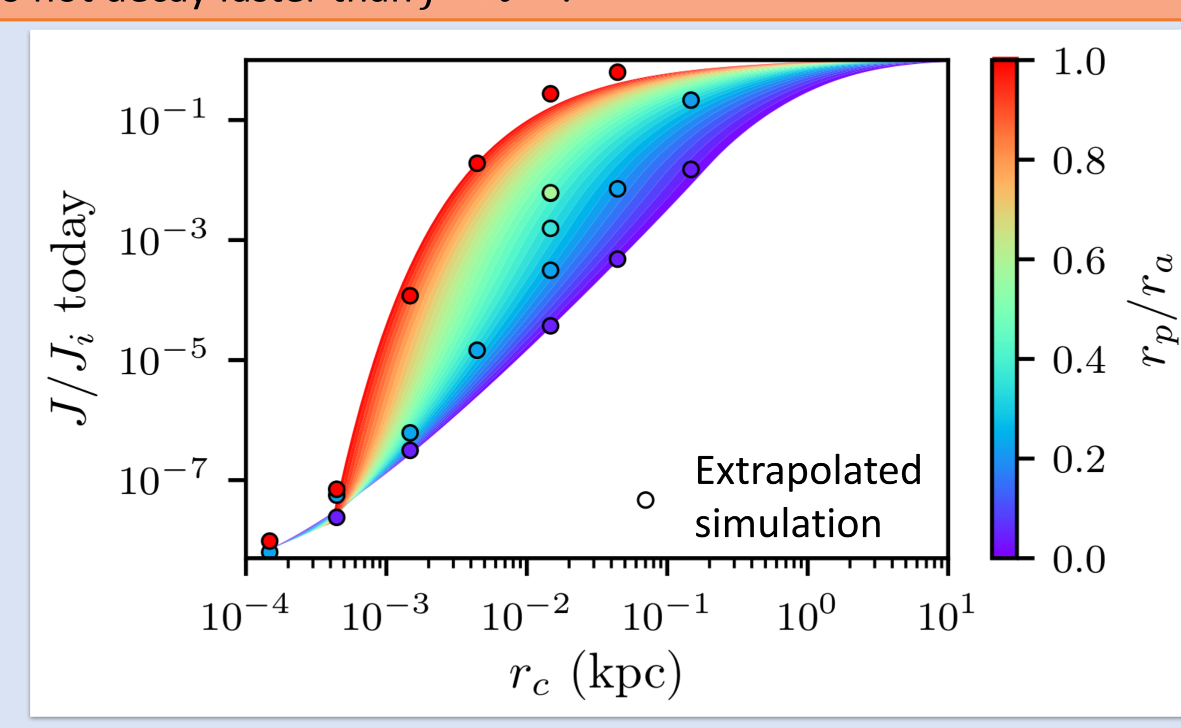
How does the J-factor decay in time?



We find:

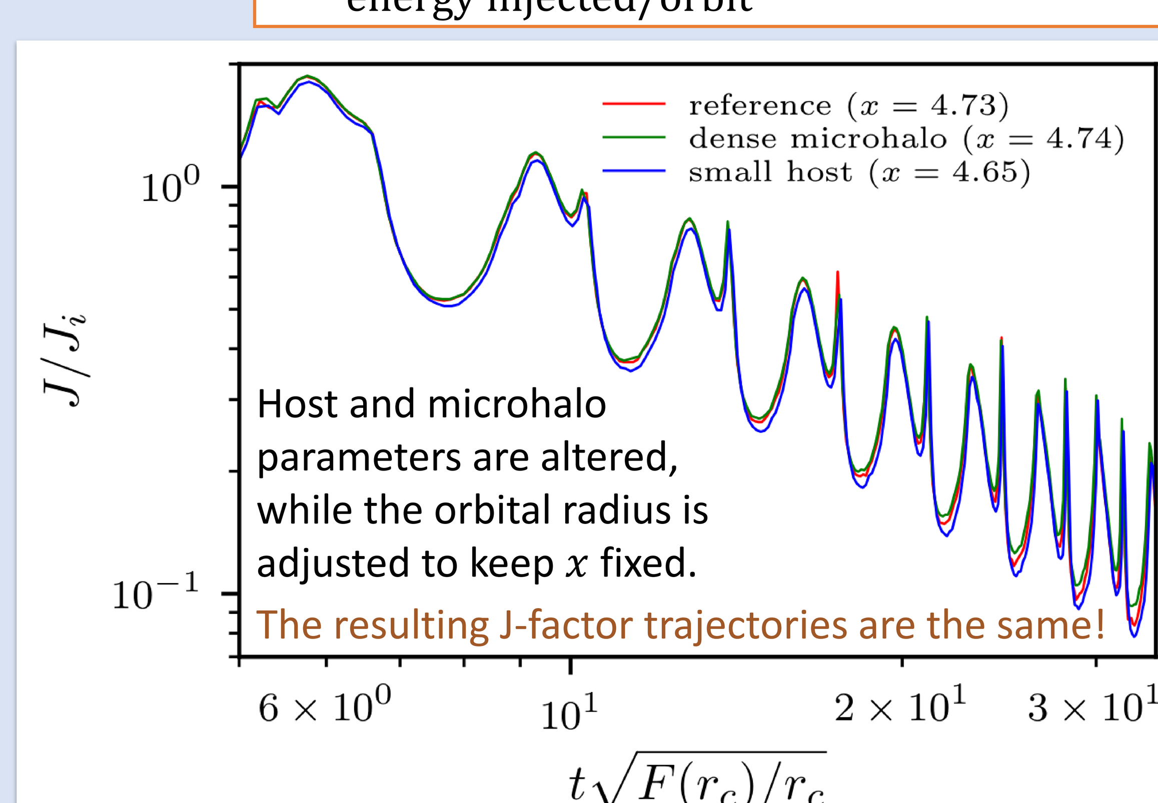
- The initial power-law index of $J \propto t^{-\alpha}$ is connected to the orbital radius.
- The running of the power-law index is connected to the orbital shape. Circular orbits follow single power laws.
- J-factors do not decay faster than $J \propto t^{-2}$.

Using these rules, we obtain a model:



To generalize to any microhalo or host galaxy, consider the "reduced orbital radius" x:

$$x \sim \frac{\text{binding energy}}{\text{energy injected/orbit}} \text{ at microhalo (initial) scale radius}$$



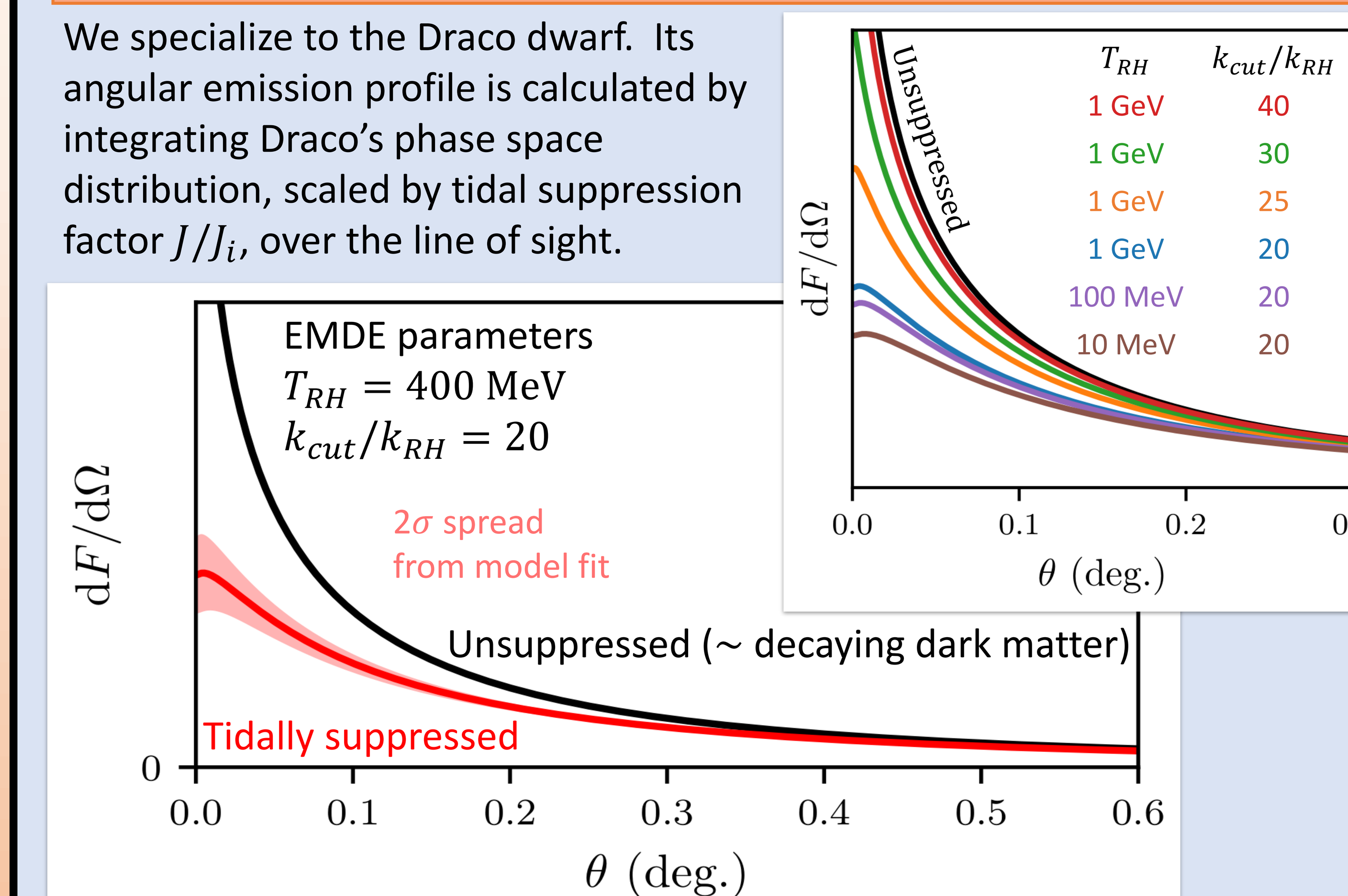
$x \propto r_c$ when r_c is small, so the model can be reframed in terms of x.

We now have a general model for the impact of tidal stripping!

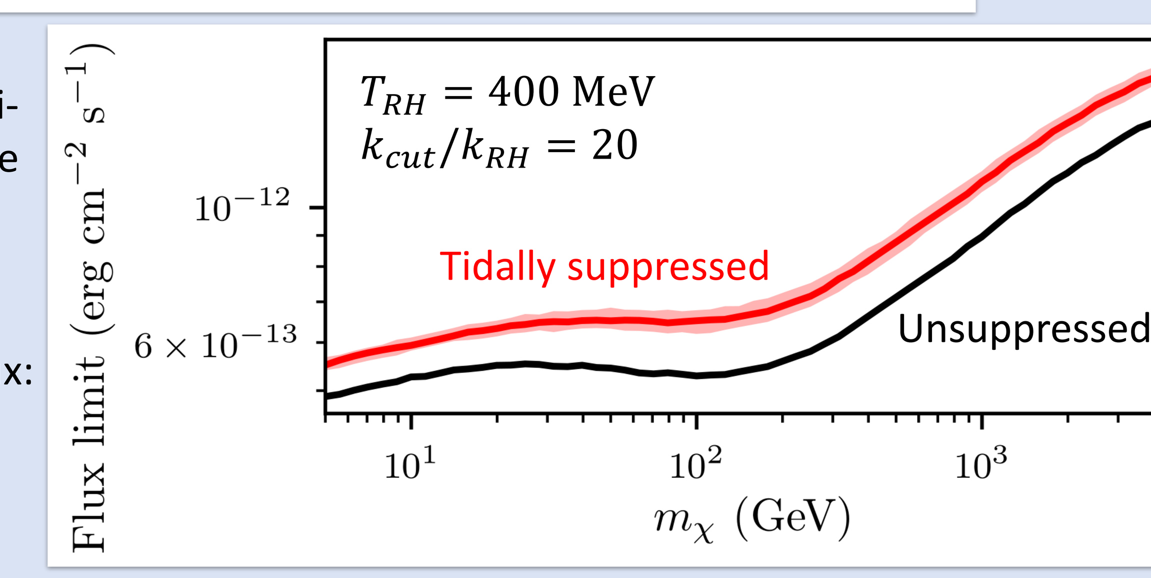
The gamma-ray emission signature

We want to constrain EMDE scenarios using Fermi-LAT limits on gamma rays from dwarf spheroidal galaxies. With our model of tidal stripping, we can predict these systems' emissions.

We specialize to the Draco dwarf. Its angular emission profile is calculated by integrating Draco's phase space distribution, scaled by tidal suppression factor J/J_i, over the line of sight.



Using Fermi-LAT data, we now obtain 2σ upper bounds on the total flux:

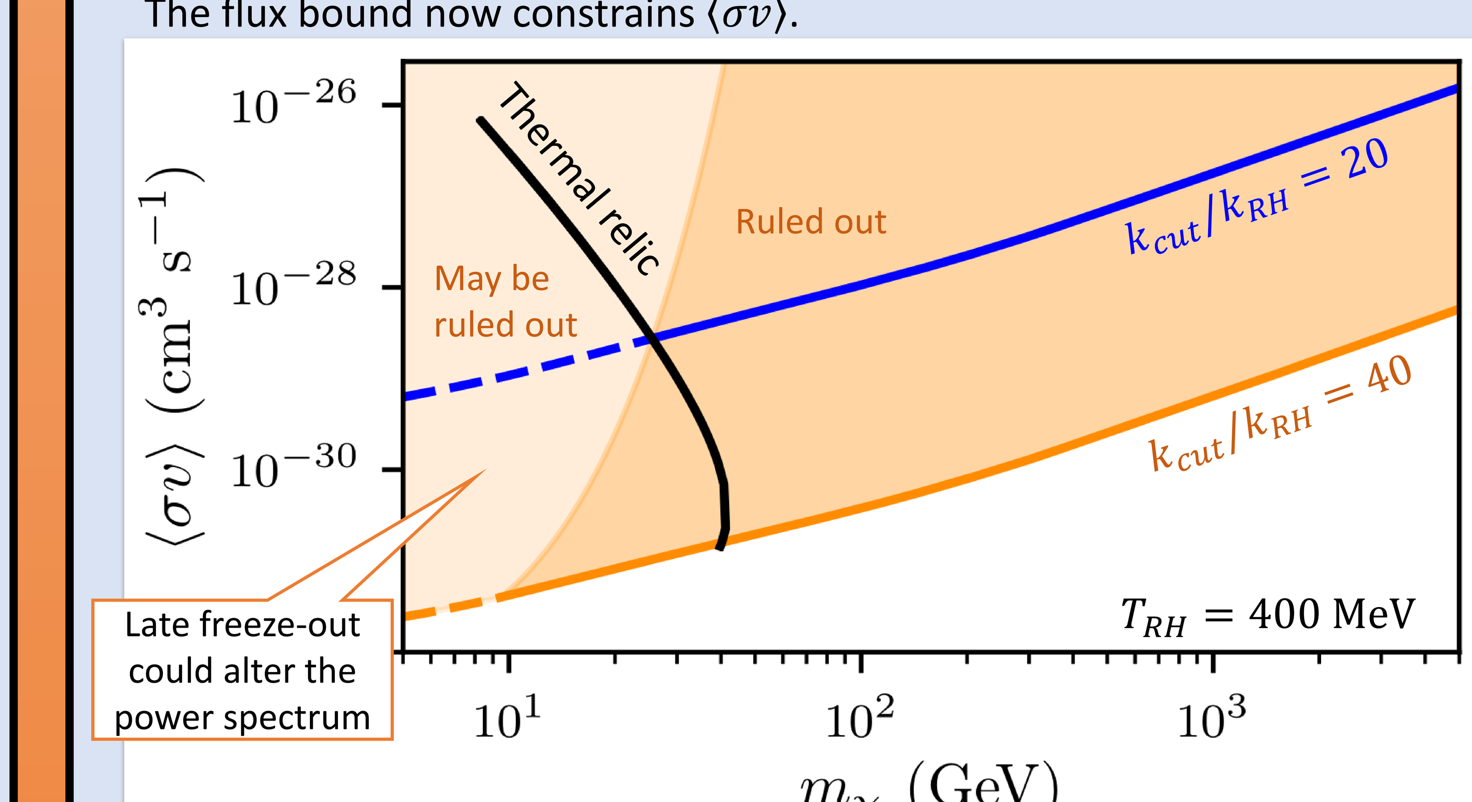


Constraining EMDEs

To constrain physics, we need to predict the total flux.

- The microhalo population is obtained from the statistics of the primordial density field. This population, scaled by Draco's density and a tidal suppression factor, sets Draco's annihilation rate.
- We assume dark matter annihilates into $b\bar{b}$.

The flux bound now constrains $\langle\sigma v\rangle$.



Next steps

- Constrain the tidal stripping model at large r_c.
- Include the effect of late freeze-out on the power spectrum.
- Consider other dSphs. However, Draco is likely to supply the strongest constraints.
- Explore the full range of EMDE parameters.
- Investigate the EMDE signature from the Galactic center. Stellar encounters, which are subdominant in Draco, are likely the dominant disruptive process in the Galactic center.