The first WIMPy halos

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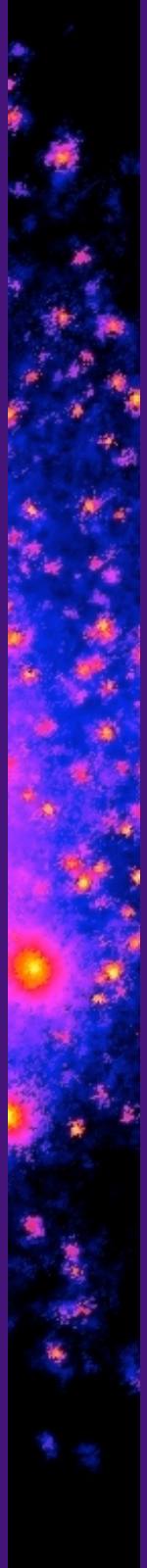
building on earlier work by Hofmann, Schwarz & Stöcker

- Why?
- WIMP micro-physics
- First halos



Why?

In CDM cosmologies structure forms hierarchically (small halos form first, larger halos are then formed via mergers and accretion).

How small are the first WIMP halos?
How many survive to the present day?

WIMP direct detection: probes the dark matter distribution on sub-milli-pc scales.

WIMP indirect detection: event rates proportional to ρ^2, enhanced by small scale sub-structure.

WIMP micro-physics

[Schmid, Schwarz & Widerin; Boehm, Fayet & Schaeffer; Chen, Kamionkowski & Zhang; Hofmann, Schwarz & Stocker; Schwarz, Hofmann & Stöcker; Berezinsky, Dokuchaev & Eroshenko; Green, Hofmann & Schwarz x2; Loeb & Zaldarriaga]

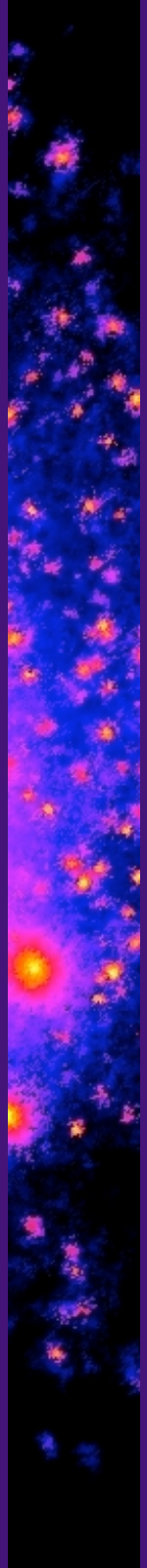
After freeze-out (chemical decoupling) WIMPS carry on interacting kinetically with radiation.

$$\chi + \chi \not\Leftrightarrow X + X \qquad \chi + X \Rightarrow \chi + X$$

Eventually elastic scattering ceases and WIMPs kinetically decouple.

[n.b. energy transfer per collision is small
$\therefore$ relaxation time-scale >> collision time-scale]

Chemical decoupling temperature: O(1-10 GeV)
Kinetic decoupling temperature: O(1-10 MeV)



Prior to kinetic decoupling energy transfer between radiation and CDM fluids (due to bulk and shear viscosity) erases very small scale density perturbations (collisional damping).

After kinetic decoupling WIMPs free-stream, erasing perturbations on slightly larger scales.

Net effect: perturbations on (comoving) scales smaller than ~1pc are erased.

Loeb & Zaldarriaga numerical treatment:

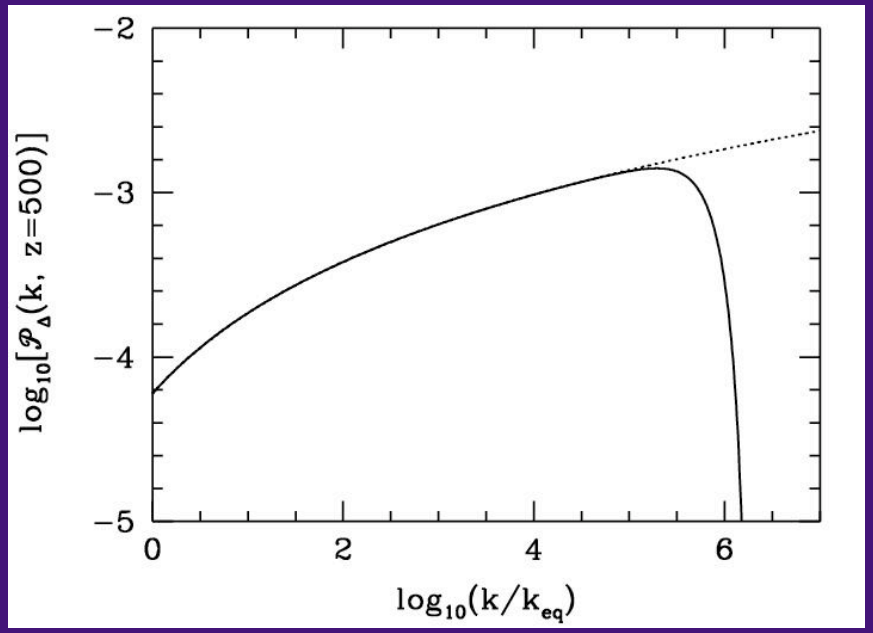
Memory of coupling to radiation fluid leads to accoustic oscillations of CDM fluid and additional damping.

Agree (at 10% level) with our calculation of cut-off scale (when same value of kinetic decoupling temperature is used).

Other ingredients:

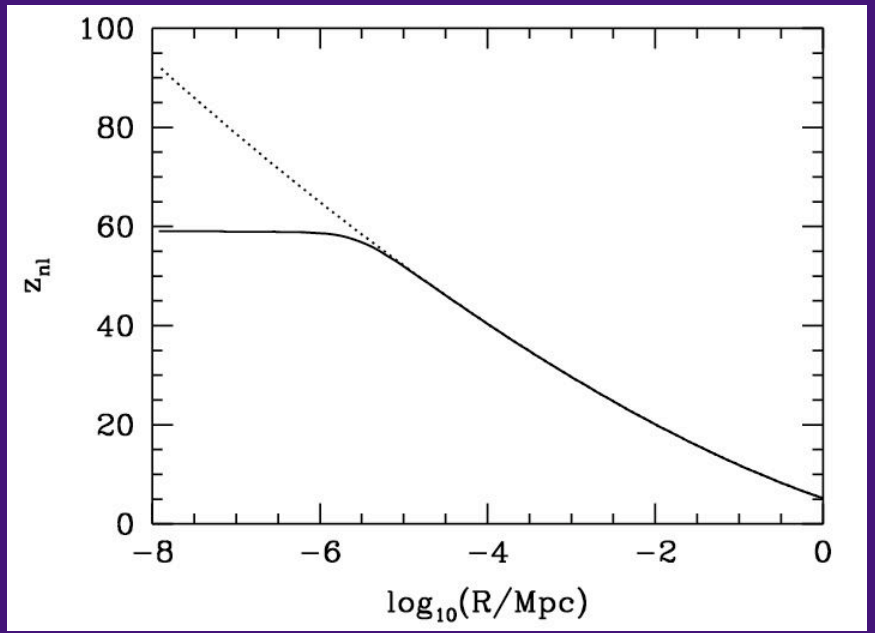
- Primordial power spectrum
- Gravitational growth of perturbations

For a 100 GeV bino-like WIMP and a scale invariant, WMAP normalised, primordial power spectrum:



Power spectrum at z=500

$$\mathcal{P}_\Delta = \frac{k^3}{2\pi^2}\langle|\Delta^2|\rangle \qquad \Delta \equiv \frac{\delta\rho}{\rho}$$



Red-shift at which 1-sigma fluctuations go non-linear

First Halos

Typical one-sigma fluctuations collapse at z_{nl}~60. (N-sigma fluctuations collapse at z_{nl}~60N)

Estimates of properties using spherical collapse model:

$$M \sim 10^{-6} M_{sun}$$

$$r \sim (0.02/N) \text{ pc}$$

present day density contrast: $\Delta \sim 10^6 N^3$

[c.f. Milky Way disc ~ 10^5 halo (in solar neighbourhood) ~ 10^6]

Effect of:

changing WIMP properties:

free streaming scale k_{fs} varies by up to a factor of 10

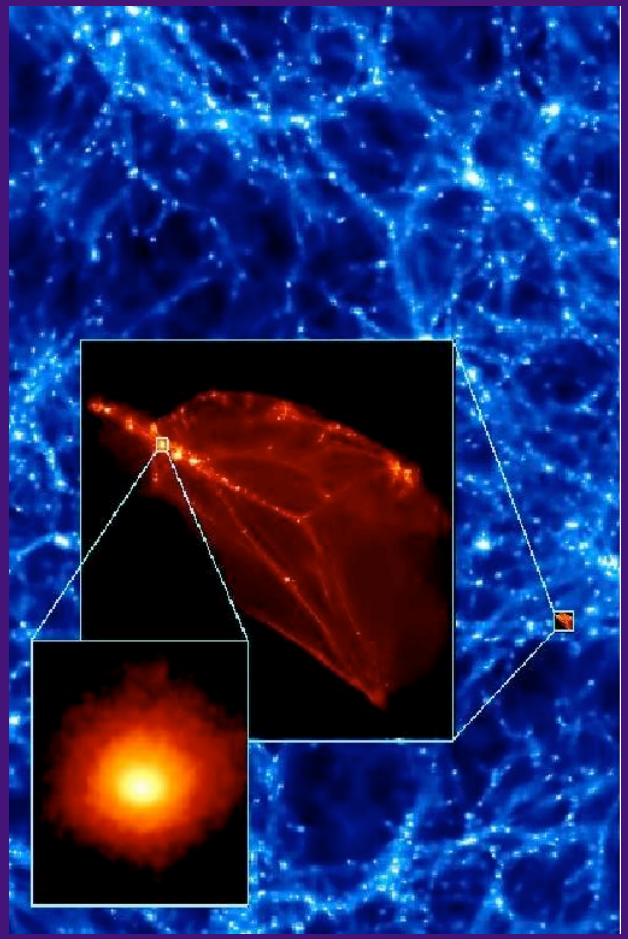
scale dependent primordial power spectrum:

z_{nl} can change by ±20

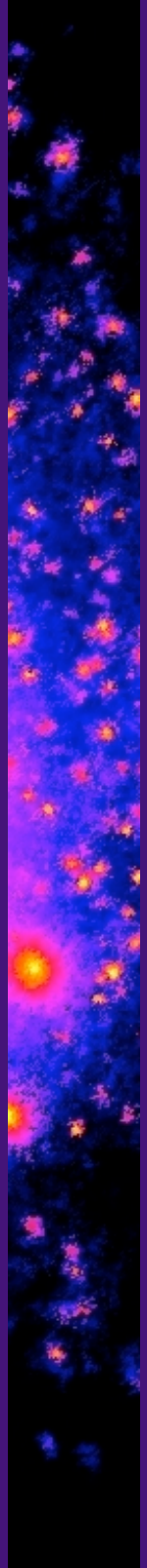
Simulations

[Diemand, Moore & Stadel]

Re-simulated a small region starting at z=350 (when the fluctuations are still linear) up until z=26 (when the high resolution region begins to merge with surrounding low resolution regions).



Initial box size $(3\ \mathrm{kpc})^3$
both zooms are x100.



Do they survive to the present day?

Tidal stripping:

Matter stripped from outer parts of mini-halos if gravitational force from parent halo greater than that from sub-halo.

'Back of the envelope calculations' by Diemand et al. indicate that first halos should not be tidally destroyed outside the inner few pc of the Milky Way.

Encounters with stars:

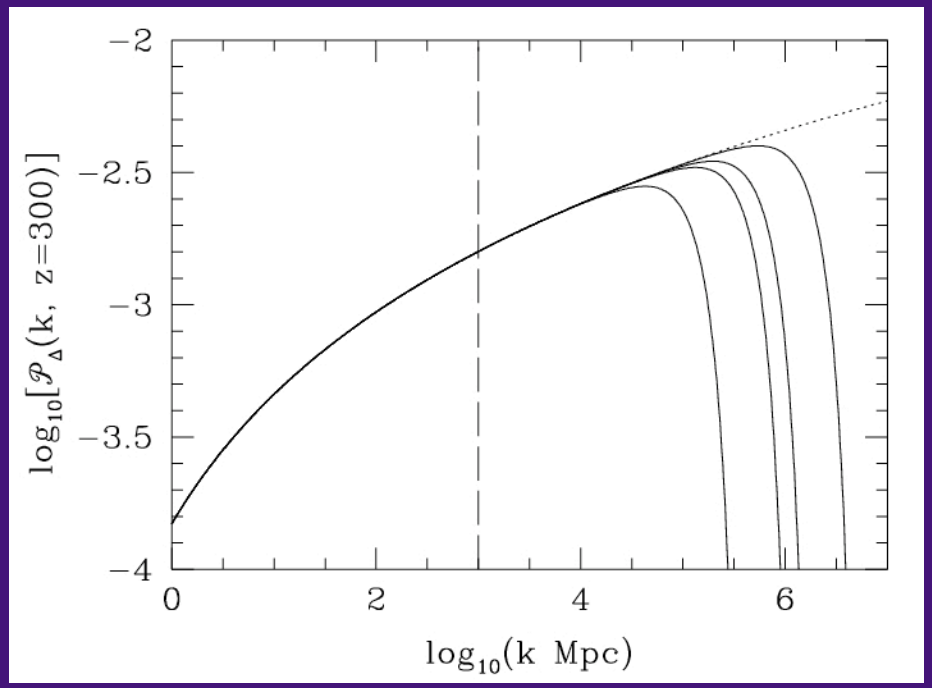
Zhao, Taylor, Silk & Hooper: tidal heating due to repeated encounters with stars may destroy mini-halos.

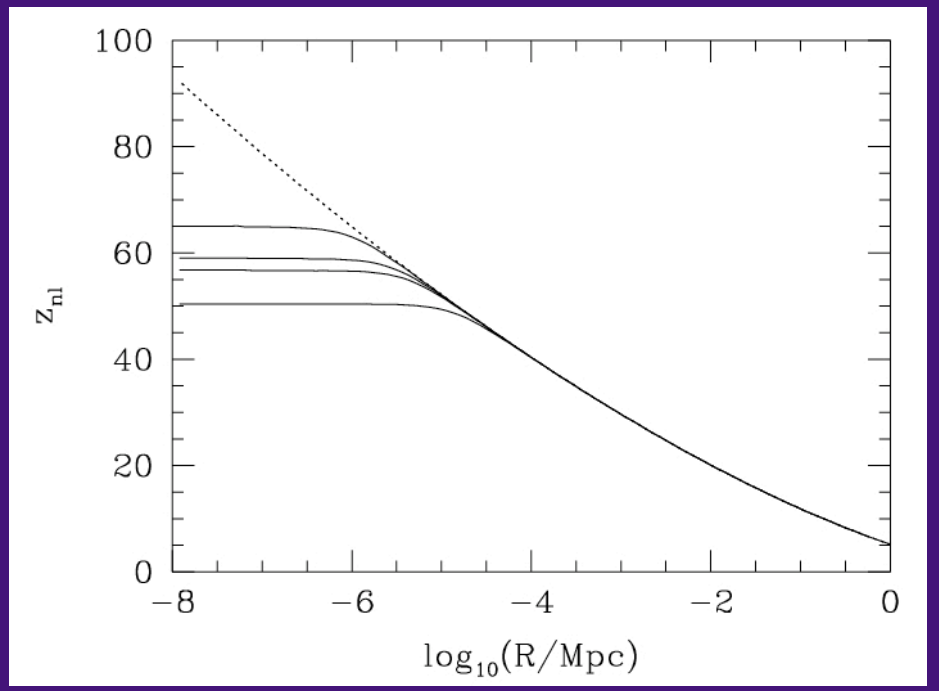
In the Milky Way mass loss rate depends strongly on orbital parameters (i.e. the number of time a mini-halo passes through the disk or bulge).

Summary

- WIMP direct and indirect detection probe the dark matter distribution on small scales.
- Collisional damping and free-streaming erase density perturbations on small scales and set the scale of the first halos to form.
- Do (a significant fraction of) these halos survive to the present day??

Effect of varying: WIMP properties



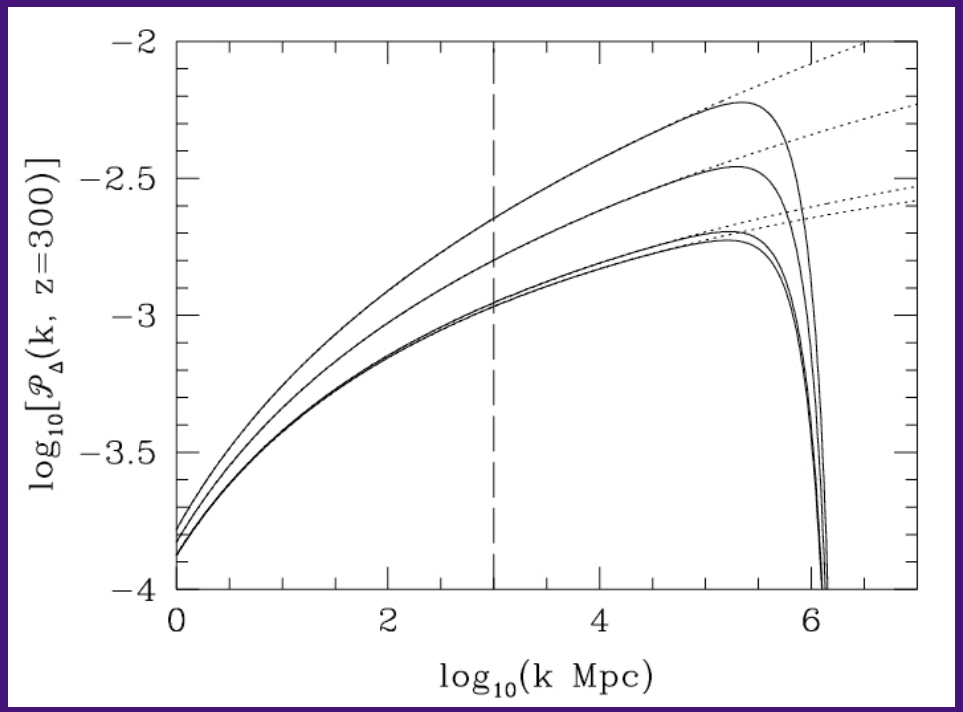


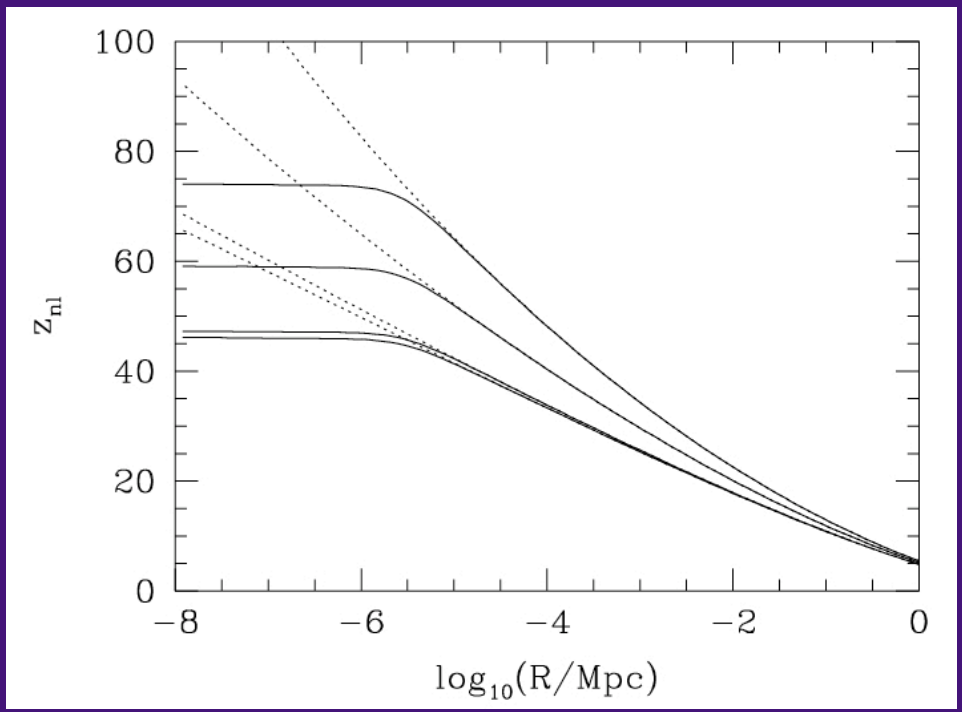
left to right/bottom to top:

Dirac (elastic scattering mediated by Z_0 exchange) m = 100 GeV

Majorana (Z_0 exchange supressed) m = 50, 100, 500 GeV

primordial power spectrum





top to bottom:

false vacuum dominated hybrid inflation	n=1.036, α =0
scale invariant	n=1.000, α =0
power law inflation	n=0.964, α =0
$m^2 \phi^2$ chaotic inflation	n=0.964, α =-0.0006