Constraints on Decaying Dark Matter Models from Simulations of Isolated Halos

Annika Peter, Caltech

Christopher Moody, UCSC

Marc Kamionkowski, Caltech

AHGP, Phys. Rev. D 81, 083511 (2010)

AHGP, CEM, MK, Phys. Rev. D 81, 103501 (2010)

Decay Model

$$X \to Y + \zeta$$

ζ is a massless particle.

$$\epsilon \equiv \frac{M_X - M_Y}{M_X} \ll 1$$

For $\epsilon \ll 1$, $\dfrac{v_k}{c} = \epsilon$.

Parameters of the model:

M_X (take to be WIMP-like)

v_k (kick speed, non-relativistic)

τ (decay time)

Decay Model

$$X \to Y + \zeta$$

ζ is a massless particle.

$$\epsilon \equiv \frac{M_X - M_Y}{M_X} \ll 1$$

For $\epsilon \ll 1$, $\frac{v_k}{c} = \epsilon$.

Parameters of the model:

M_X (take to be WIMP-like)

v_k (kick speed, non-relativistic)

τ (decay time)

- Consequences: if the decay time is long (> Gyr), change the structure of virialized halos:
  - Kinetic energy injection (reduces central density).
  - Mass loss.

Decay Model

$$X \rightarrow Y + \zeta$$

ζ is a massless particle.

$$\epsilon \equiv \frac{M_X - M_Y}{M_X} \ll 1$$

$$\text{For } \epsilon \ll 1, \ \frac{v_k}{c} = \epsilon.$$

Parameters of the model:

M_X (take to be WIMP-like)

v_k (kick speed, non-relativistic)

τ (decay time)

- See Bell, Galea & Petraki 2010 for constraints if $\zeta=\gamma$, $\zeta \rightarrow e^+e^-$, or $\zeta \rightarrow \nu\bar{\nu}$.

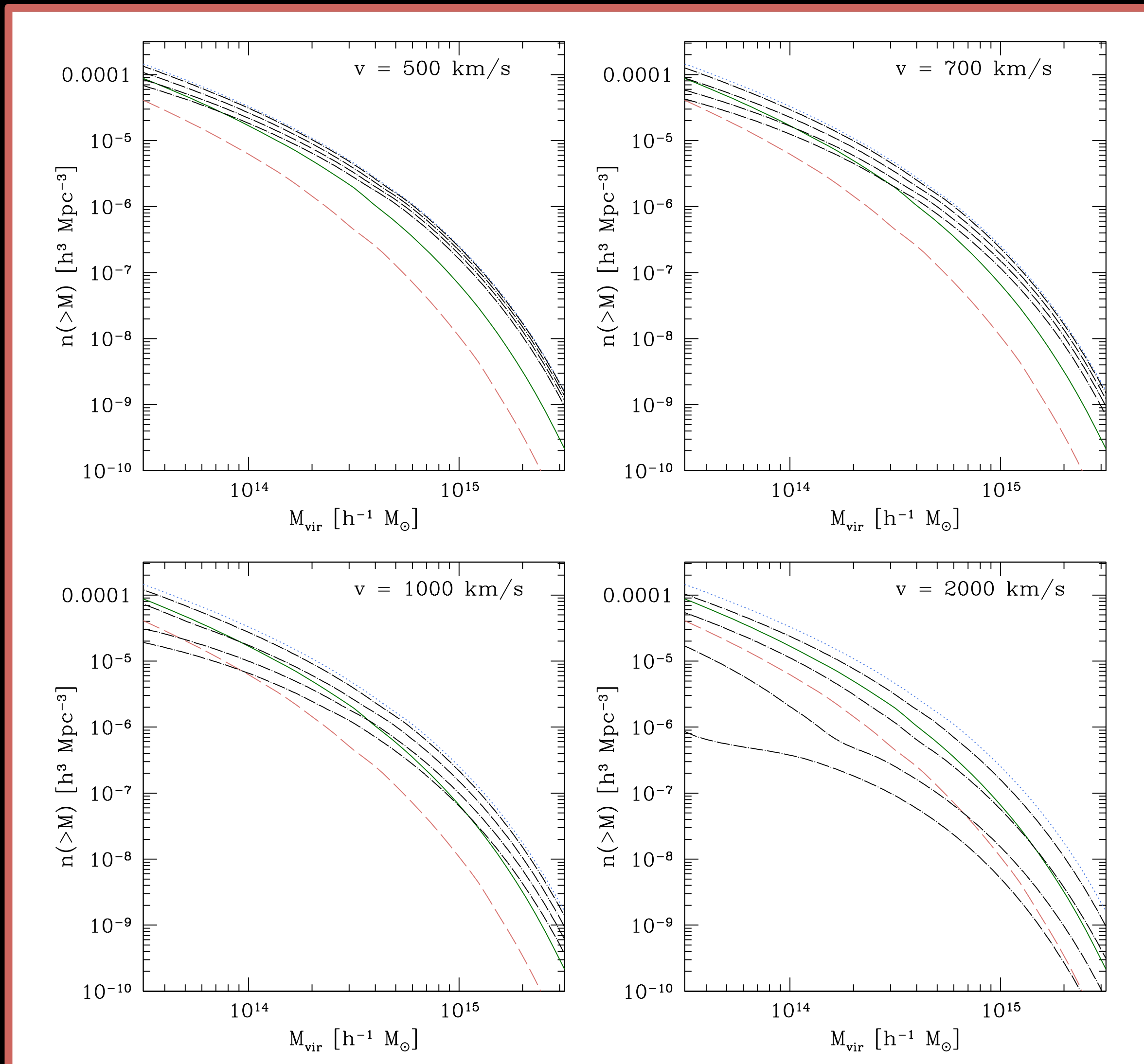
Constraints on the Model from Halos

- Method:
  - For late decays, starting with CDM initial conditions is OK.
  - Simulations of equilibrium dark-matter halos (originally CDM: Navarro-Frenk-White) using GADGET-2 (Springel 2005), varying:
    - concentrations (c=5,10)
    - different v_k/v_{vir}
    - τ/t_{dyn}.
  - Compare simulations and observations for:
    - The cluster mass function (see Vikhlinin et al. 2009 for observation).
    - The mass-concentration relation (see, e.g., Bullock et al. 2001 for theory, Mandelbaum et al. 2008 for observations).

Z=0 Cluster mass function

Use highest σ_8 consistent w/ CMB for initial conditions for initial relations/ functions, make sure z=0 observables consistent.

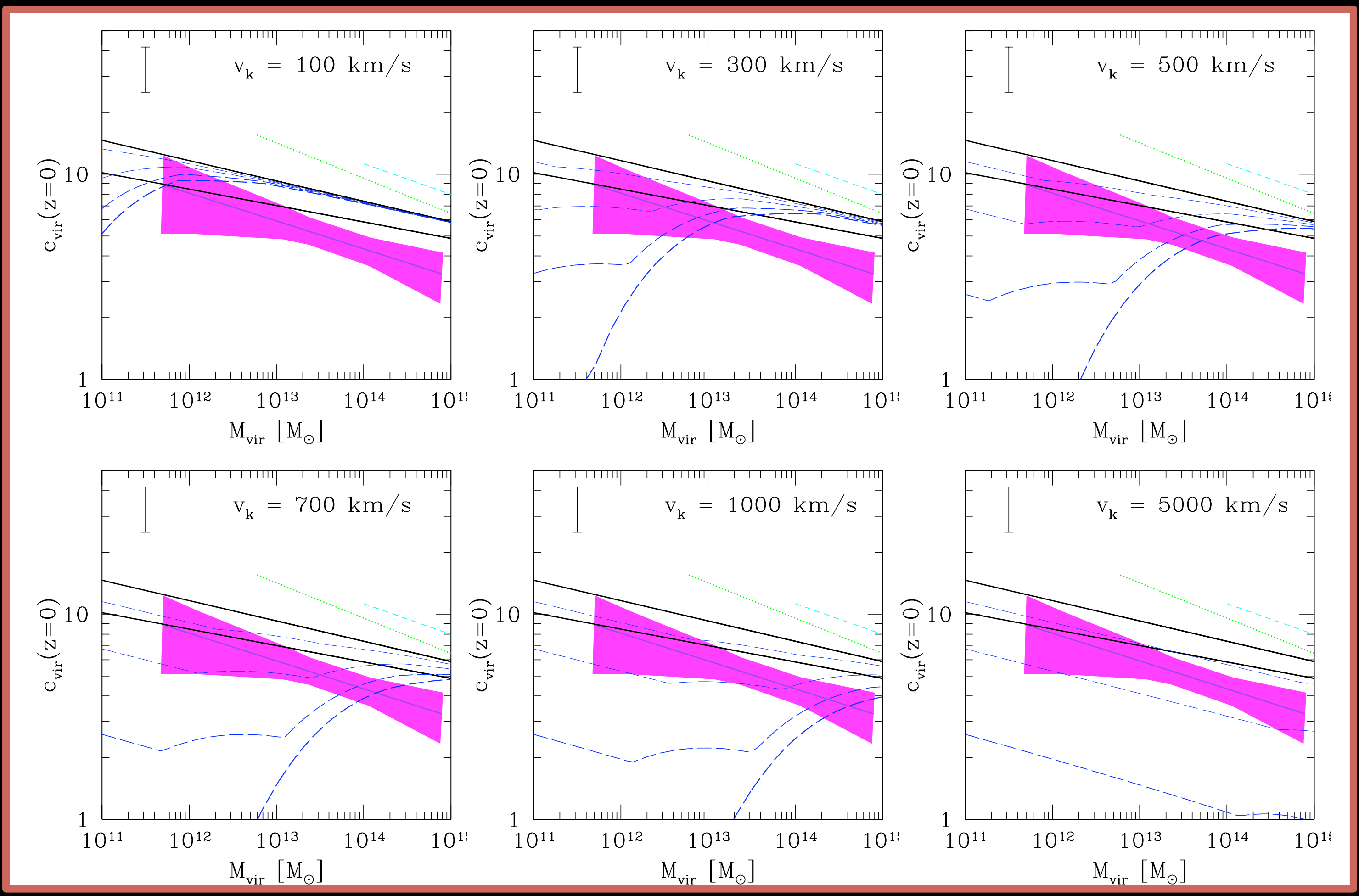
Not sensitive to baryons (Rudd et al. 2008).



Dashed lines:
τ = 100
40
20
5 Gyr

Z=0 Mass-concentration relation

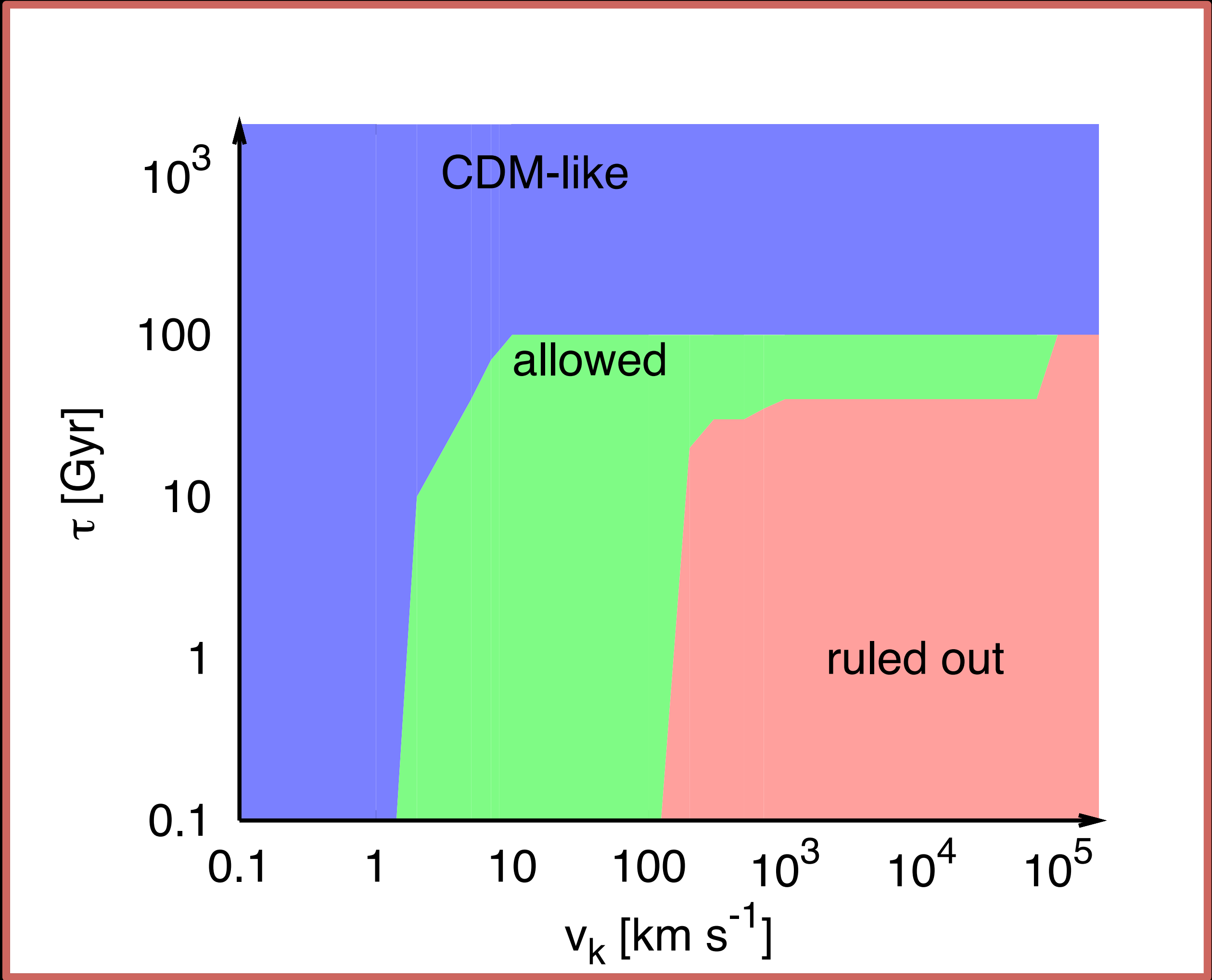
Fitted value for NFW concentration (even if poor fit)



Dashed lines:
τ = 100
40
20
5 Gyr

Mass

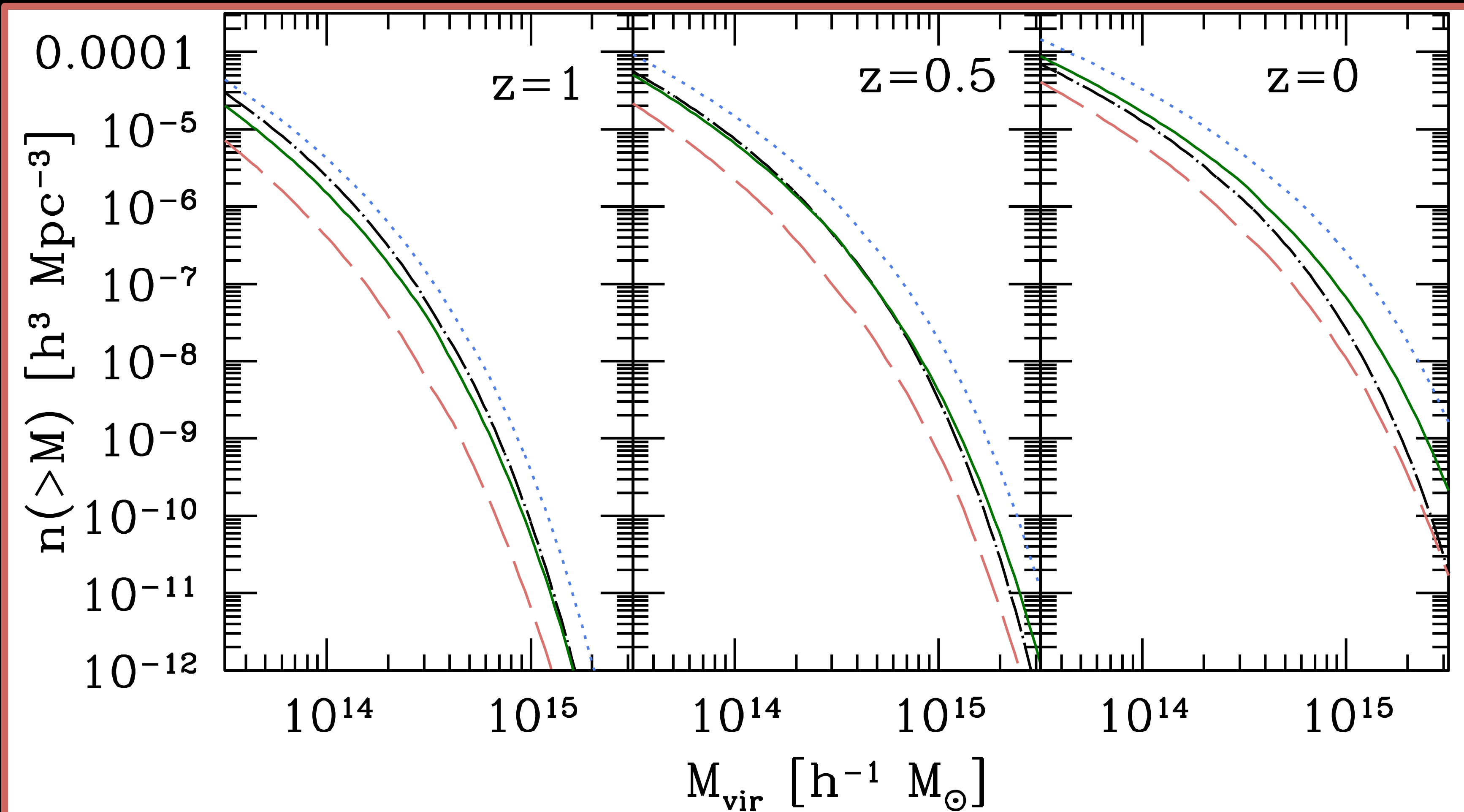
Results


CDM-like
allowed
ruled out
τ [Gyr]
10^3
100
10
1
0.1
0.1
1
10
100
10^3
10^4
10^5
v_k [km s^{-1}]

Other possible constraints

- Decays serve to artificially reduce σ_8 as a function of time
  - Track redshift-dependent changes to the cluster mass function or M-c.

Z-dependent cluster mass function



$$v_k >> v_{vir}, \tau = 50 \text{ Gyr}$$

Other possible constraints

- Decays serve to artificially reduce σ_8 as a function of time
  - Track redshift-dependent changes to the cluster mass function or M-c.
  - Need good control over errors, though, and may be degenerate with dark energy.
- Milky Way satellites (Peter & Benson, in prep.)

Milky Way satellites—a sketch

- The mismatch btw. # observed satellites and # subhalos in simulations originally dubbed "missing satellites problem", and spurred great creativity among model builders.
- However, in order to see satellites, they must have stars, and galaxy evolution esp. on small scales is poorly understood!!! (cf. Benson 2010)
- Goal: highlight properties of these satellites that are robust to the messy baryonic physics.

Milky Way satellites—a sketch

- Plan (Peter & Benson, in prep.):
  - Merge simulations of decay in isolated halos w/ CDM merger trees.
  - Provides the most conservative set of subhalo/ satellite population properties (any dynamical friction/tidal effects will bring population further from the fiducial).
  - Major properties we are concerned with:
    - V_{max}
    - M300

M300

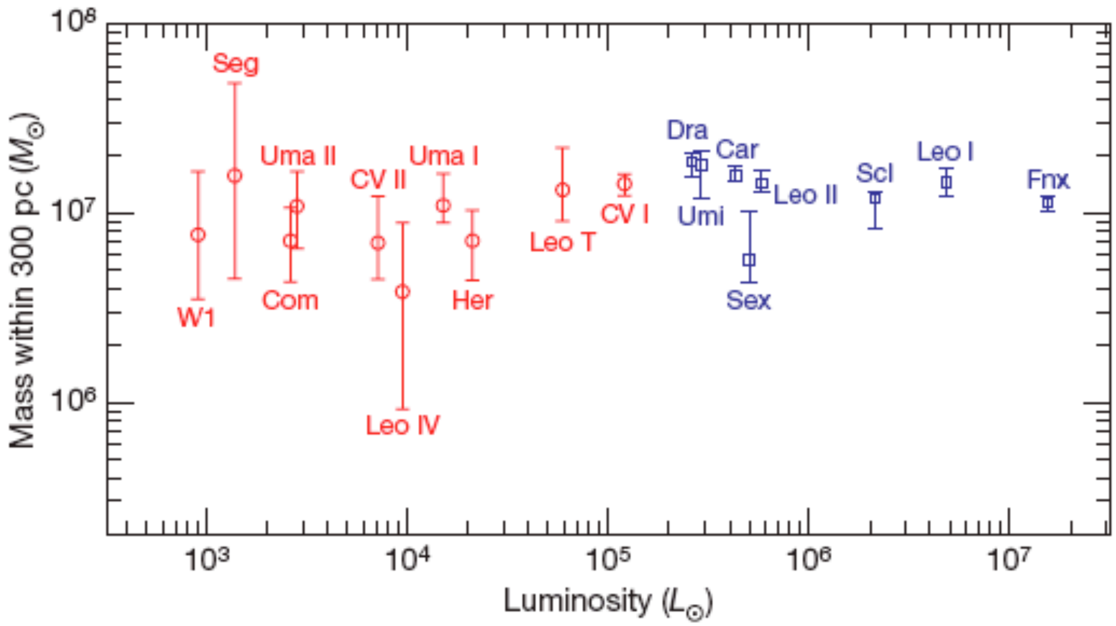
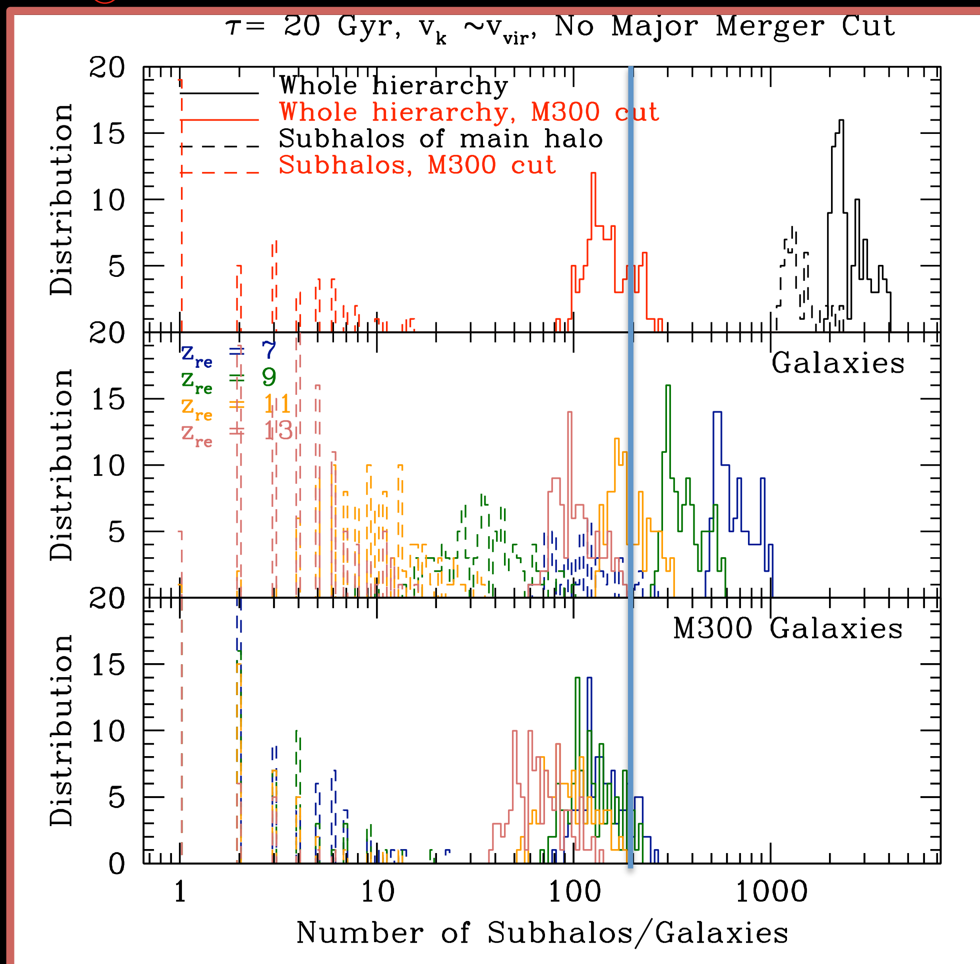


Figure 1 | The integrated mass of the Milky Way dwarf satellites, in units of solar masses, within their inner 0.3 kpc as a function of their total luminosity, in units of solar luminosities. The circle (red) points on the left refer to the newly discovered SDSS satellites, whereas the square (blue) points refer to the classical dwarf satellites discovered pre-SDSS. The error bars reflect the points where the likelihood function falls off to 60.6% of its peak value.

Strigari et al. 2008, Nature

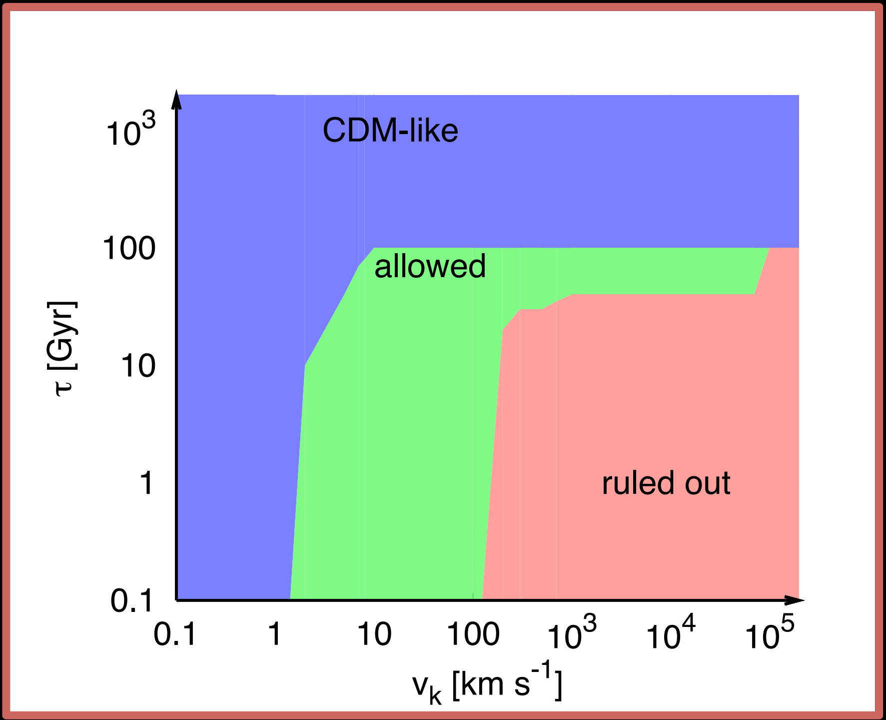
Example of possible constraints

$M300 > 5 \times 10^6 M_\odot$



Min. satellites for MW (extrapolated from Tollerud et al. 2008)

Conclusion

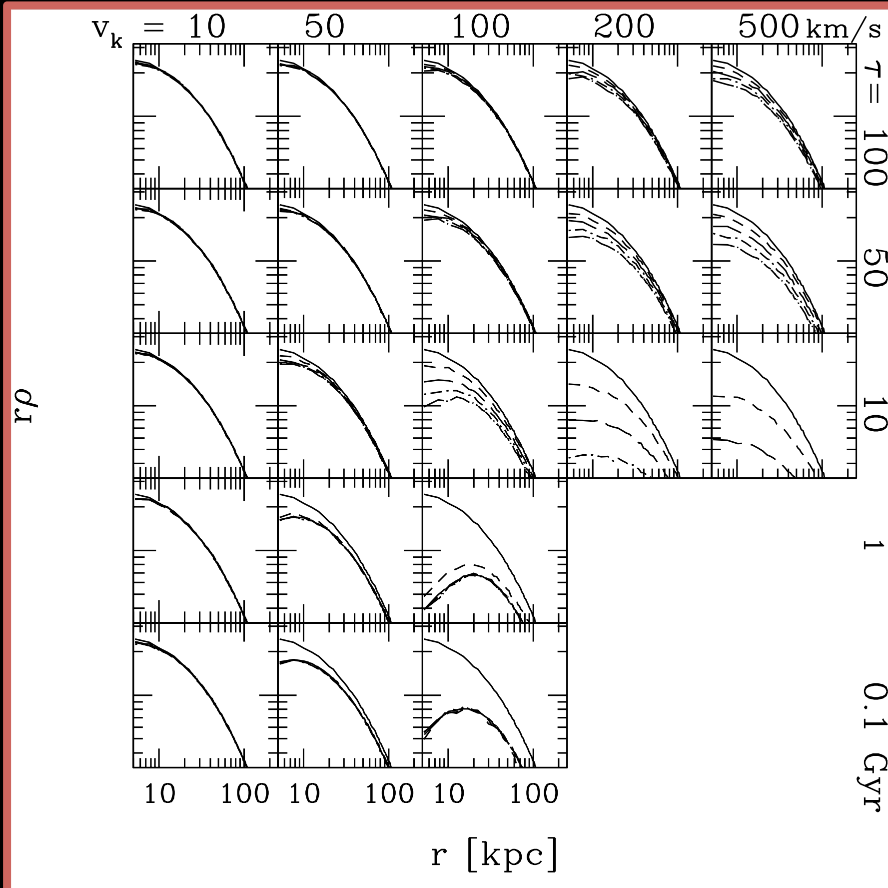


- Decaying dark-matter models can be robustly constrained using properties of halos that can be robustly inferred from observations (M-c, cluster MF).
- Tighter constraints forthcoming
  – MW satellites are PARTICULARLY intriguing, but need to be careful how to use them!

Bench warmers

Results

- Density profiles deviate from NFW:



$M_{vir,\,i} = 10^{12} M_{\odot}$

Velocity dispersion profiles