I Workshop Challenges of New Physics in Space

Clumps and Cusps:
how small scale structure may challenge current dark matter paradigm

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Summary

- Clumps and dwarf galaxies:
  - Number of satellite galaxies
  - Common mass scale
  - Distribution of satellite galaxies
  - Tentative explanations to the MSP
- Cusps:
  - Density profiles in simulated halos
  - Observed density profiles
- Final remarks

Number of satellite galaxies

The "missing satellites problem"

- Total number of subhalos of mass $M \sim 10^7 M_\odot$ predicted by N-body simulations:

  $N \sim 10^3$ (Diemand *et al.* 2007)

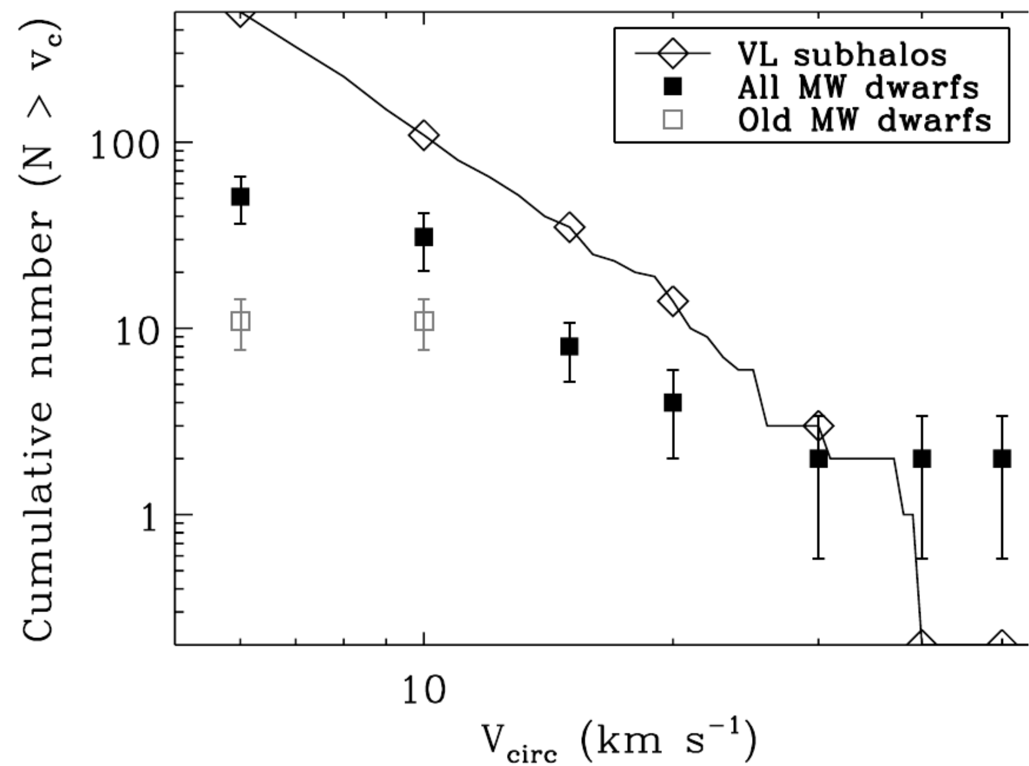
- Number of observed satellites:

  N= 8 ("classical") + 12 (SDSS)

  (Simon & Geha 2007, Geha *et al.* 2008)

- Estimated total number of satellites (taking incompleteness of SDSS into account):

  N~80 (Koposov *et al.* 2008)

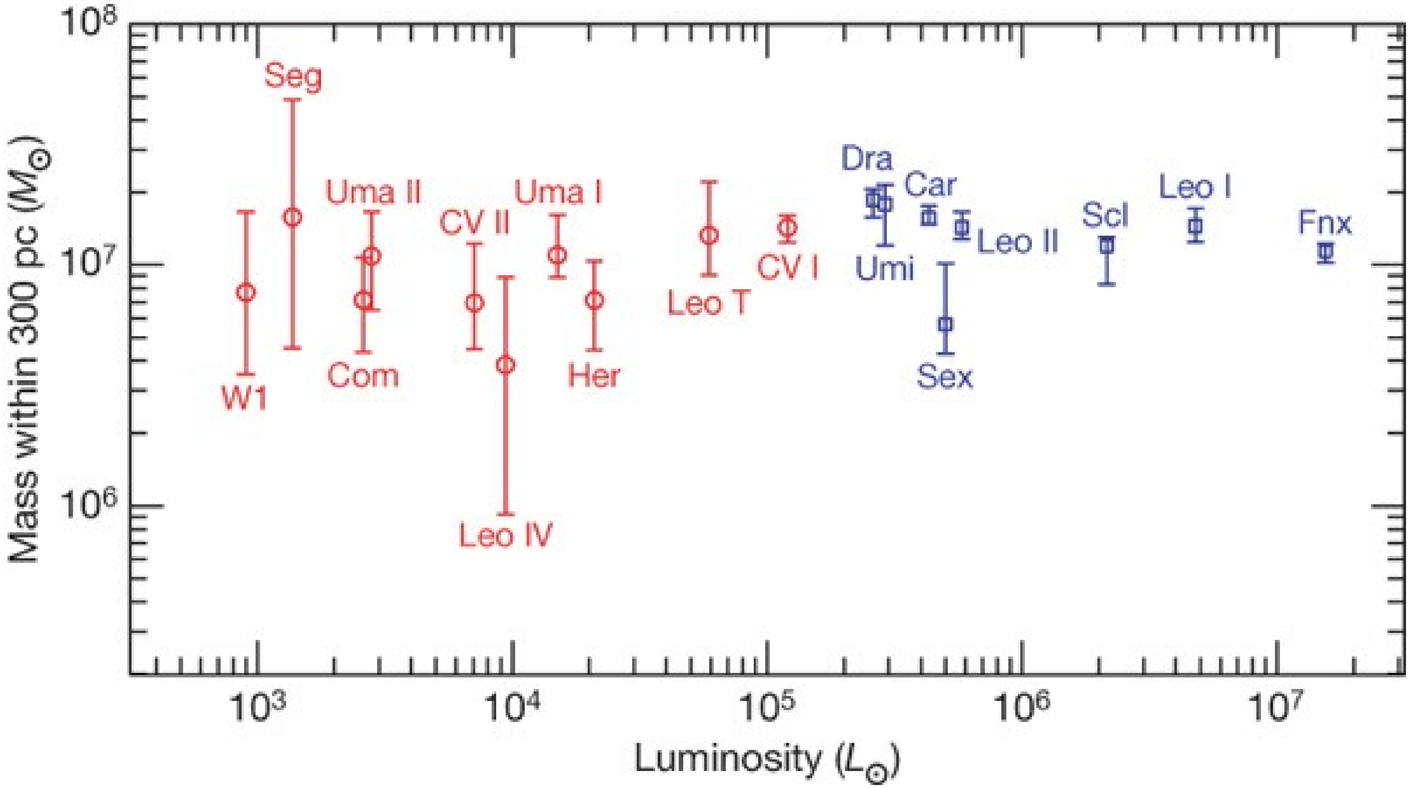


Comparison of the the number of subhalos in Via Lactea simulation (radius-limited) and the number of observed satellites (SDSS's dwarfs multiplied by 5). (Simon & Geha 2007)

Observed Common Mass Scale

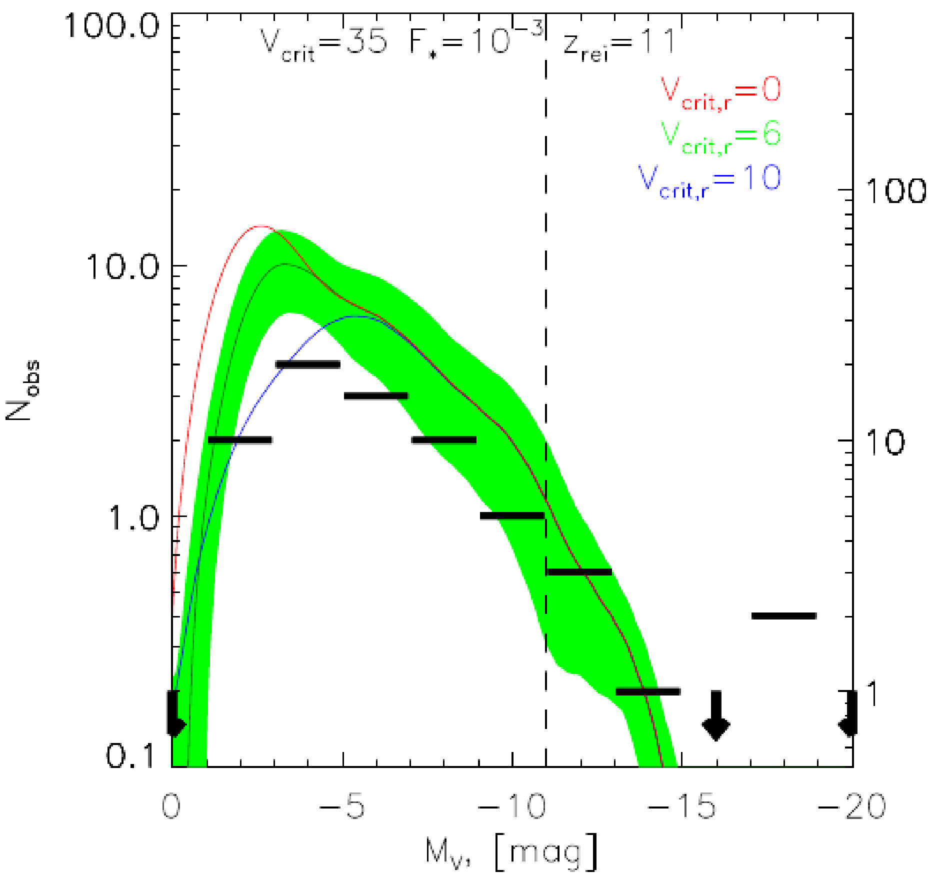
The mass within 300 pc of Milky Way satellites is always $M \sim 10^7 M_\odot$ independent of their luminosity

(Strigari *et al.* 2008)



Possible explanation: Star formation suppression during reionization

- "Suppression due to reionization" picture:
  - During reionization, the gas content of dark matter halos is heated
  - This leads to a suppression in the gas accretion and an interruption of star formation in small mass halos
  - Most small mass halos remain dark, solving the "missing satellites problem".

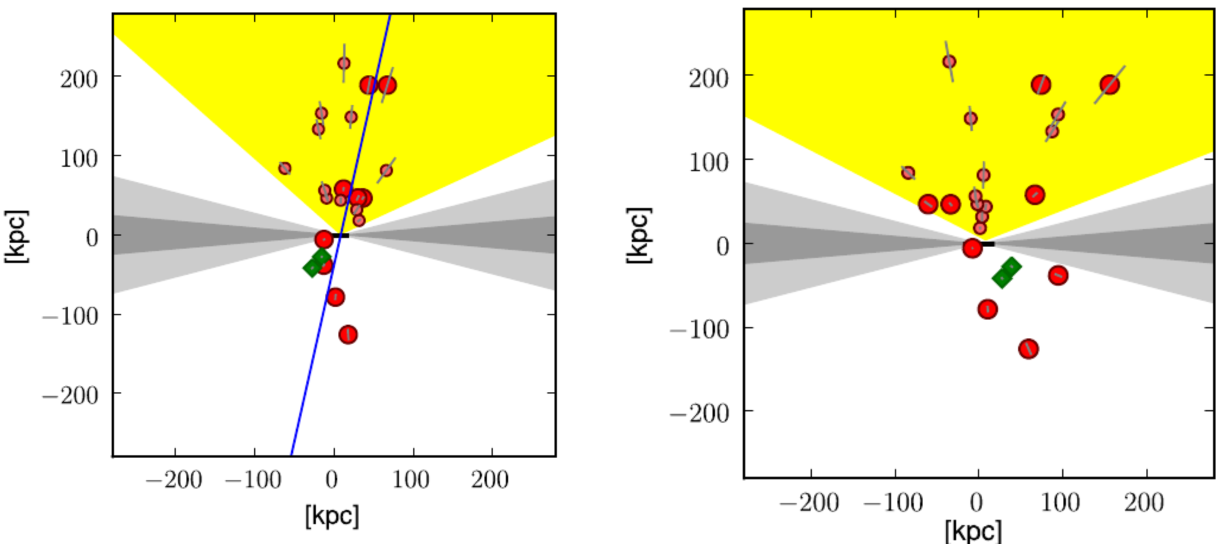


  - Several semi-analytic models have been made to test this "suppression due to reionization" picture (Macciò *et al.* 2008, Busha *et al.* 2009, Koposov *et al.* 2009).
  - These were able to obtain:
    - Apropriate mass function of observable satellites
    - A common inner mass consistent with previous slide's observations

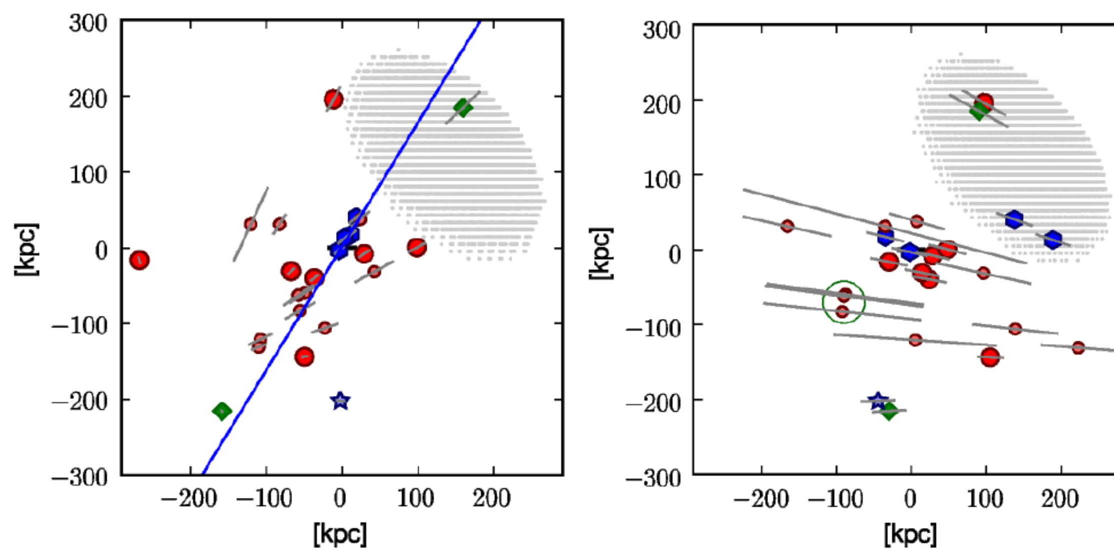
Coloured curves: number of predicted observable satellites
Black stripes: Observed number of satellites.
Koposov *et al.* 2009.

Distribution of Local Group satellites

- Both Milky Way's and Andromeda's satellites are roughly distributed on a disk (Metz *et al.* 2009)



Milky Way's disk of satellites: egde-on (left) and face-on (right)



Andromeda's disk of satellites: egde-on (left) and face-on (right)

Difficulties with current models of dwarf galaxies number supression

- A solution to the missing satellites problem through star formation supression during reionization have the following possible weaknesses:
  - depends strongly on early star formation modelling, a subject is not completely understood
  - have a big number of free parameters
  - predicts an isotropic distribution of dwarf galaxies
  - relies strongly on a cuspy density profile assumption (generally a NFW profile)

Alternative explanations: changes in the perturbation power spectrum

- A smaller amplitude in small-scale dark matter perturbations power spectrum could inhibit the dark matter structures on those scales. (Zentner & Bullock 2003)
- There are two ways to achieve this small-scale power suppression
  - Damping of small perturbations with free-streaming due to a WDM particle.
  - A non-scale-invariant primordial power spectrum, consequence of a specific inflaton potential form.
- But
  - Data from the Lyman-α forest does not seem to allow for a small scale power spectrum cutoff.

The density profiles of simulated halos

- N-body simulations predict that dark matter halos are well described by a (cuspy) NFW profile (Navarro, Frenk & White, 1997)

$$\rho_{nfw}(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left[1 + \frac{r}{r_s}\right]^2}$$

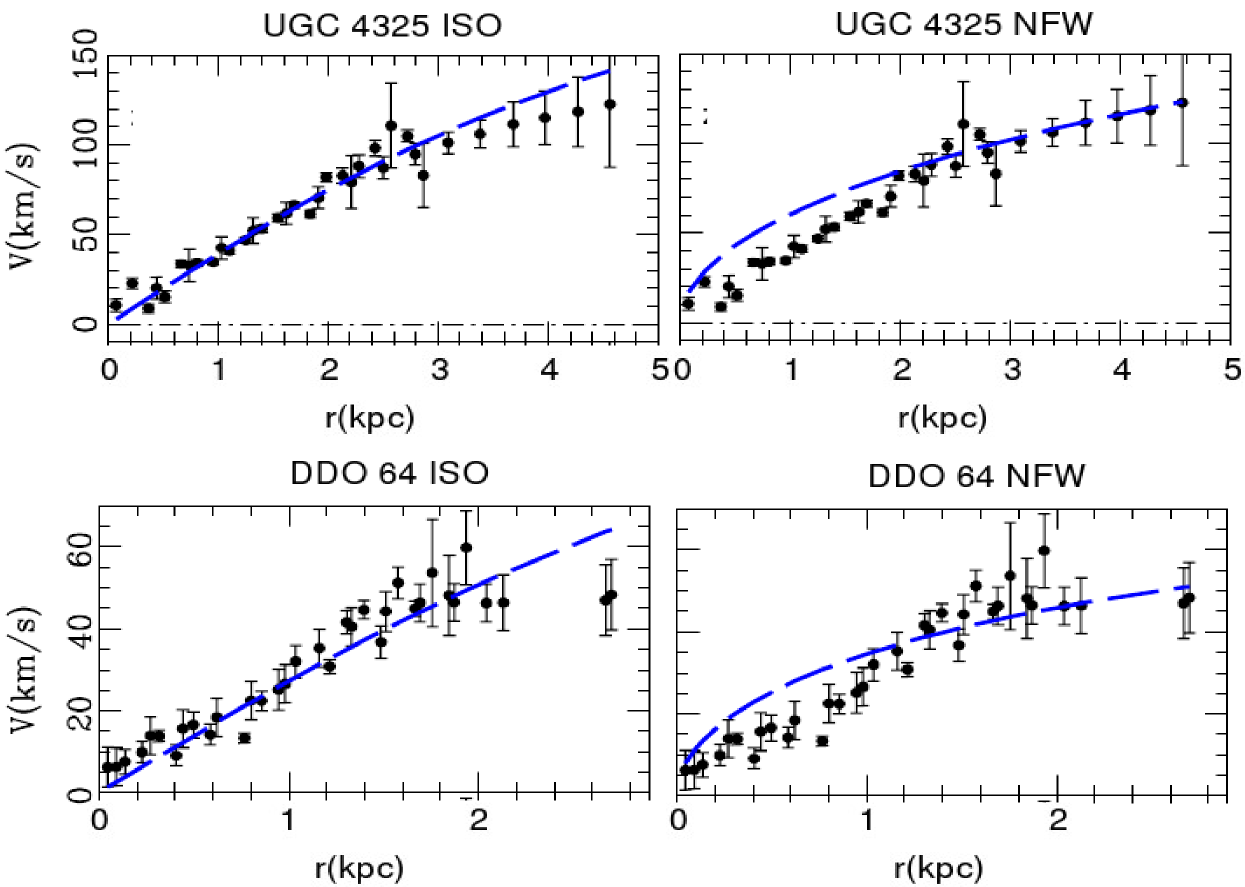
- This behaviour occurs for halos of any mass.
- This can be characterized by a single concentration parameter c

$$r_s = \frac{R}{c} \qquad \text{and} \qquad \rho_s = \frac{\rho_v}{3} \frac{c^3}{\ln(1+c) - \frac{c}{1+c}}$$

- The concentration of an individual halo depends on its mass, on its redshift and on its specific mass accretion history. (Zhao *et al.* 2008)

The observed density profiles

- Cored profiles provide a better fit to rotation curves of LSB galaxies than NFW. (Kuzio de Naray *et al.* 2008, Oh *et al.* 2008, Martins 2008)
  - Rotation curves measurements favor Burkert and Pseudo-Isothermal profiles.



$$\rho_{iso}(r) = \frac{\rho_0}{1 + \frac{r^2}{r_c^2}}$$

$$\rho_{bur}(r) = \frac{\rho_0}{\left(1 + \frac{r}{r_0}\right)\left(1 + \frac{r^2}{r_0^2}\right)}$$

$$\rho_{nfw}(r) = \frac{\rho_s}{\left(\frac{r}{r_s}\right)\left[1 + \frac{r}{r_s}\right]^2}$$

Examples of fits of NFW and pseudo-isothermal models to observed velocity rotation curves of LSB galaxies.

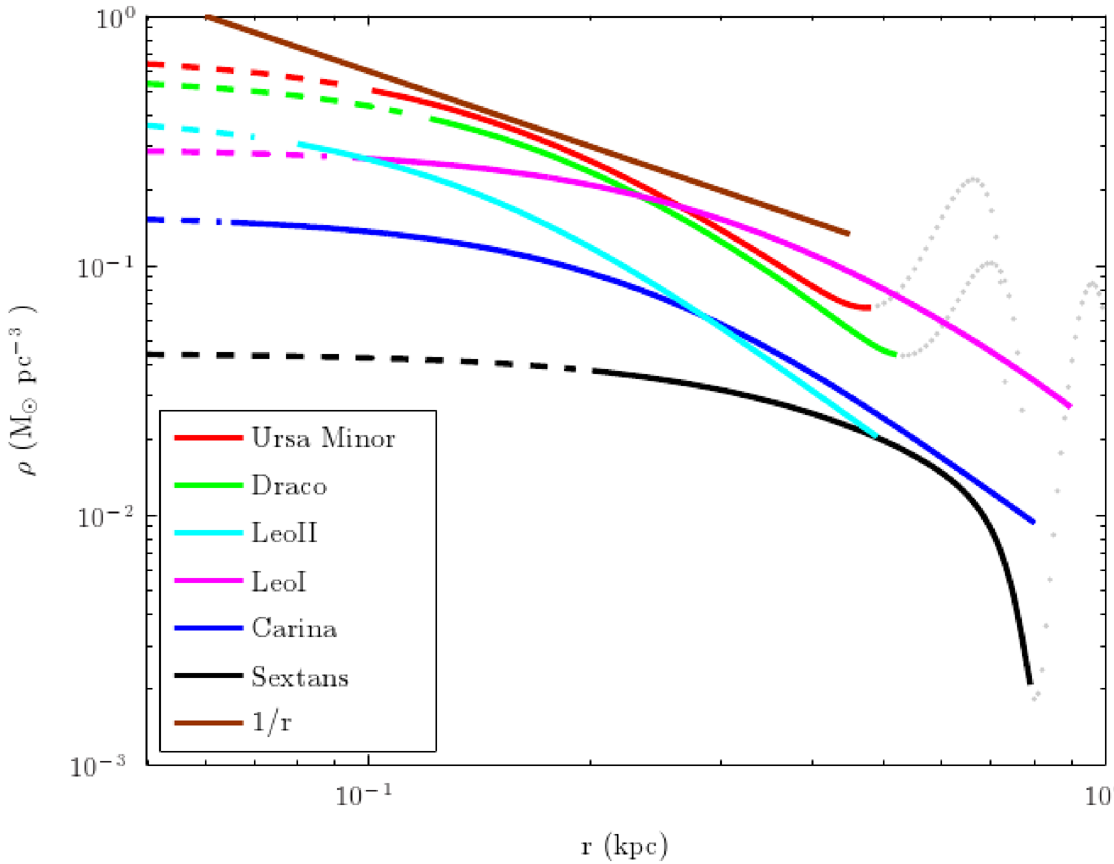
(Kuzio de Naray *et al.* 2008)

Final Remarks

- Despite recent theoretical advances and observations, the missing satellites problem is still open and challenges our physical understanding of the universe.
- There is still tension between the simulated and observed density profiles.

Extra slide: Density profiles of dSph

- Measurements of velocity dispersion profiles of dSph also lead to cored density profiles.
- But
  - The inner slope of the profile is degenerate with anisotropy of the velocity dispersion



Derived density profiles for dSph galaxies. Assuming a spherical symmetrical density profile and isotropic velocity dispersions.

(Gilmore *et al.* 2007)