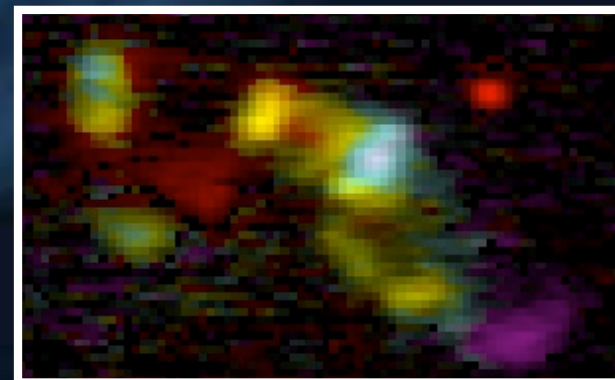
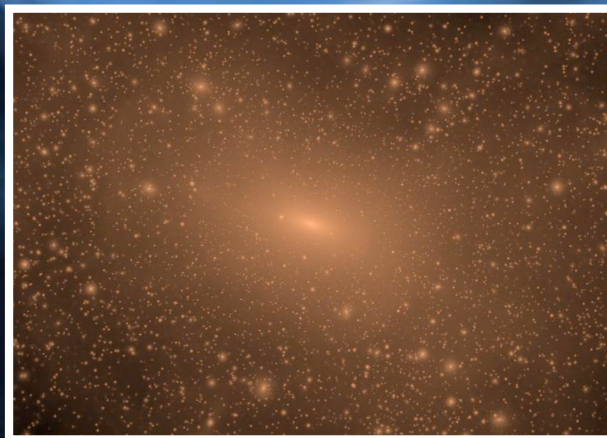


Are There Dark Galaxies in the Local Group?

Josh Simon
Caltech

Marla Geha (HIA)
Tim Robishaw (Berkeley)
Leo Blitz (Berkeley)



DARK GALAXY

Dark Galaxy is a massively multiplayer browser based strategy game.

Welcome to Dark Galaxy

In Dark Galaxy you control planets and fleets in games lasting for 3 months at a time. [Read more..](#)

[Click here to join the game!](#)

[Jupiter Login \(game open\)](#)

[Visit our forums](#) | [Game manual](#)



Outline

- I. The missing satellite problem
- II. Can the new SDSS dwarfs be the missing satellites?

Keck/DEIMOS kinematics of 8 SDSS dSphs

- III. Are HVCs the missing satellites?

Arecibo H I maps of 12 HVCs

CDM and the Missing Satellites



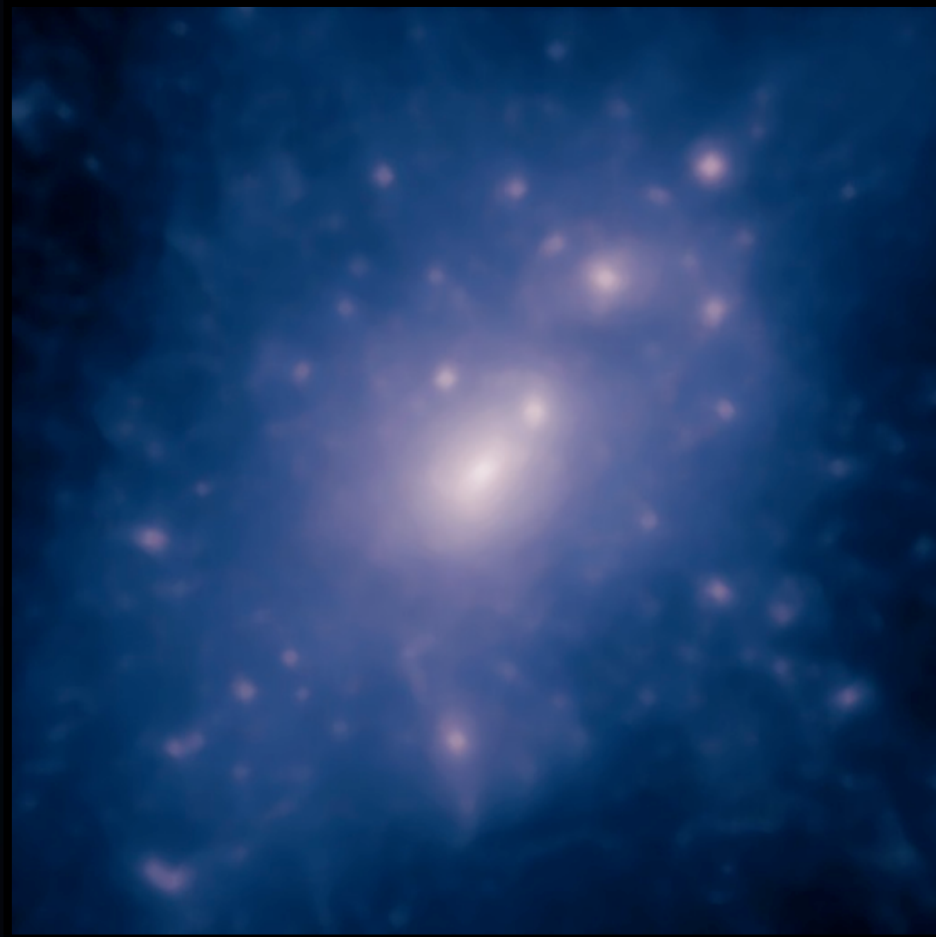
Springel et al. 2001

CDM predicts large numbers of subhalos (~100-1000 for a Milky Way-sized galaxy)

Milky Way only has 23 known satellites

What happened to the rest of them?

CDM and the Missing Satellites



Springel et al. 2001

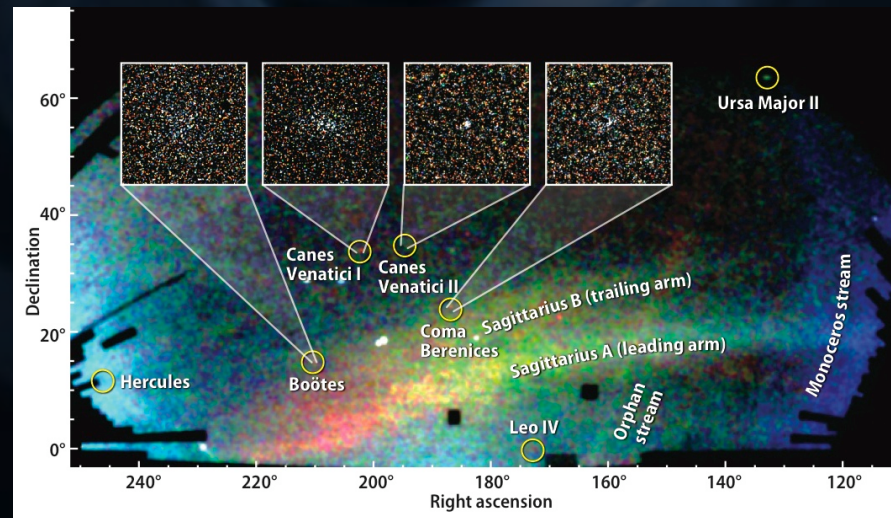
CDM predicts large numbers of subhalos (~100-1000 for a Milky Way-sized galaxy)

Milky Way only has 23 known satellites

What happened to the rest of them?

New SDSS Dwarfs

- Only 11 Milky Way dwarfs known through 2004
- Since 2005, SDSS has discovered:
 - 8 new dSphs Willman et al. (2005), Zucker et al. (2006a,b), Belokurov et al. (2006,2007)
 - 1 dlrr Irwin et al. (2007)
 - 3 ??? dSph/GCs? Willman et al. (2005), Belokurov et al. (2007), Walsh et al. (2007)



Belokurov et al. (2006)

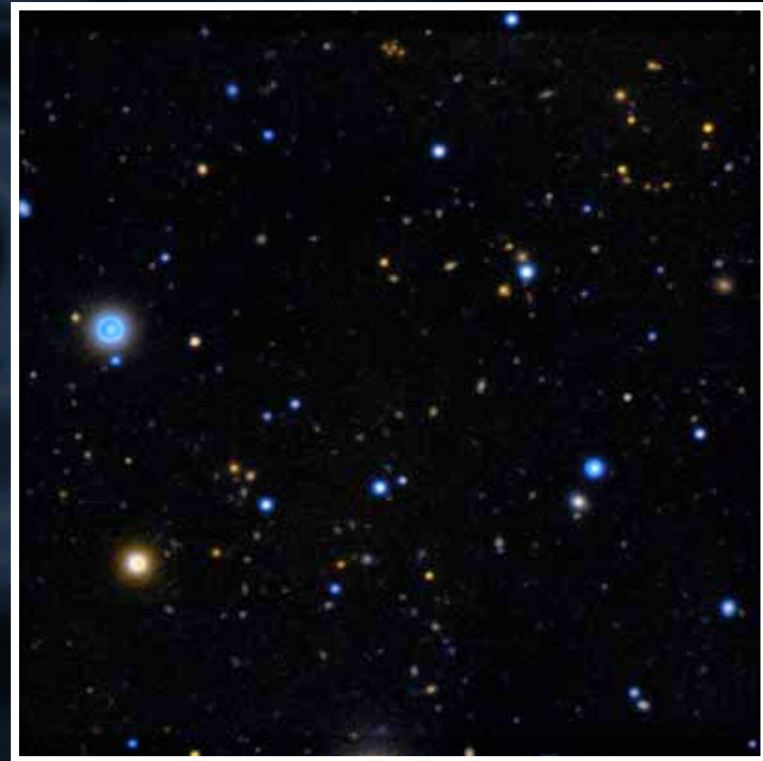
New SDSS Dwarfs

Old dwarfs (Leo II)



Palomar Sky Survey

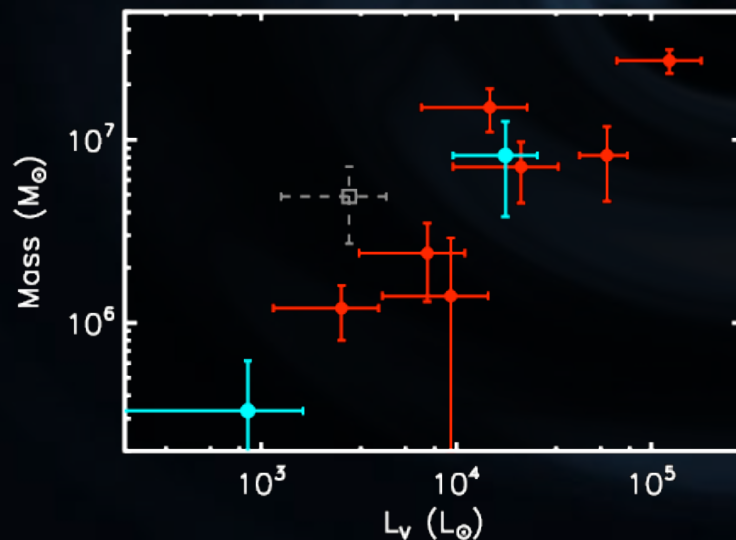
New dwarfs (Ursa Major I)



Willman et al. (2005)

Keck Spectroscopic Survey of SDSS Dwarfs

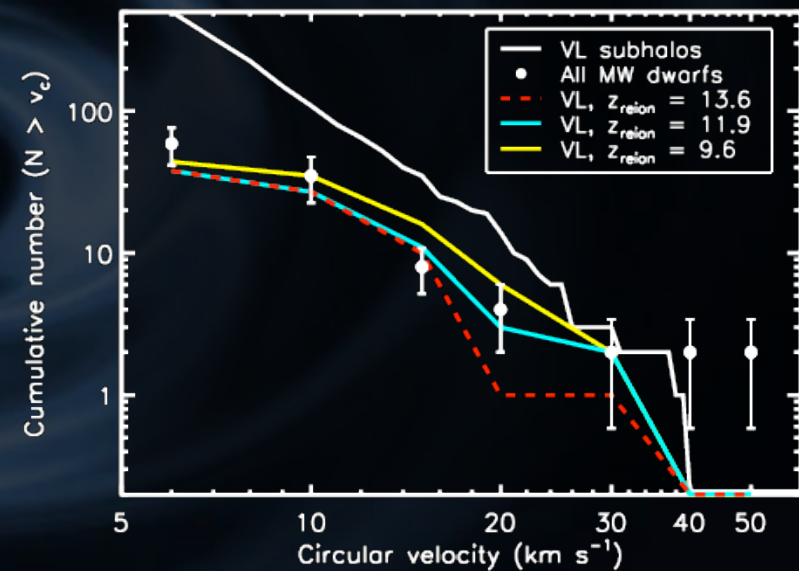
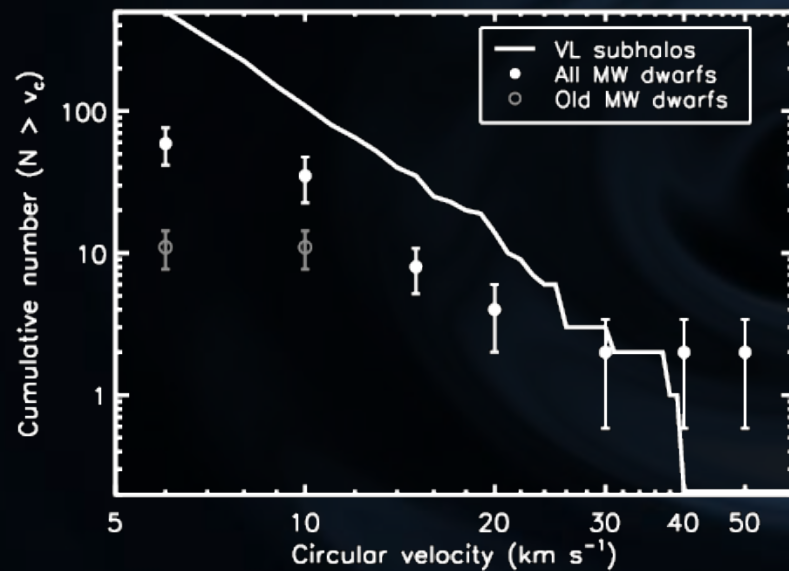
- Medium-resolution spectra of 841 stars (424 members) across 8 dwarfs
(CVn I, CVn II, Coma Berenices, Hercules, Leo IV, Leo T, UMa I, UMa II)
- Measured stellar velocities + metallicities



- Simon & Geha (2007)
- UMa II (tidally disrupting; SG07)
- Martin et al. (2007)

Are There Still Satellites Missing?

Comparison to Via Lactea N-body simulation (Diemand et al. 2007)



Simon & Geha (2007)

What About HVCs?

Major HVC models:

Extra/circumgalactic	Hot halo	Tidal debris
(Oort 1966, Blitz et al. 1999)	(Maller & Bullock 2004)	(no formal model)
- $d = 50 - 250$ kpc	- $d \sim 150$ kpc	- $d = 10 - 50$ kpc
- $m = 10^5 - 10^7 M_{\odot}$	- $m = 10^5 - 10^7 M_{\odot}$	- $m = 10^3 - 10^5? M_{\odot}$
- dark matter halos	- no dark matter	- no dark matter
- gravitationally bound	- pressure-confined	- not bound

Crucial questions about the bulk of the HVC population:

- Are they gravitationally bound?
- Do they have dark matter halos?

Are HVCs Bound?

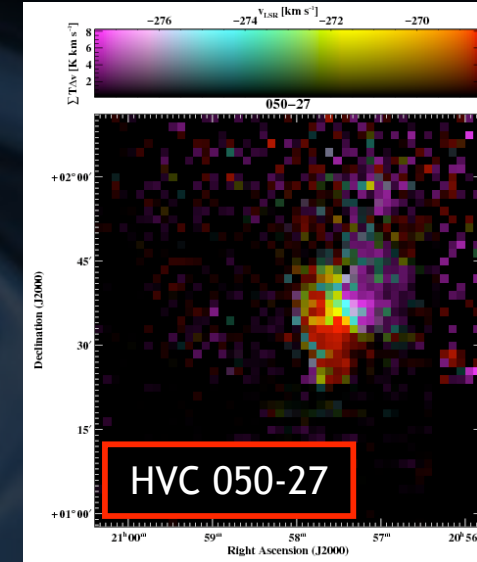
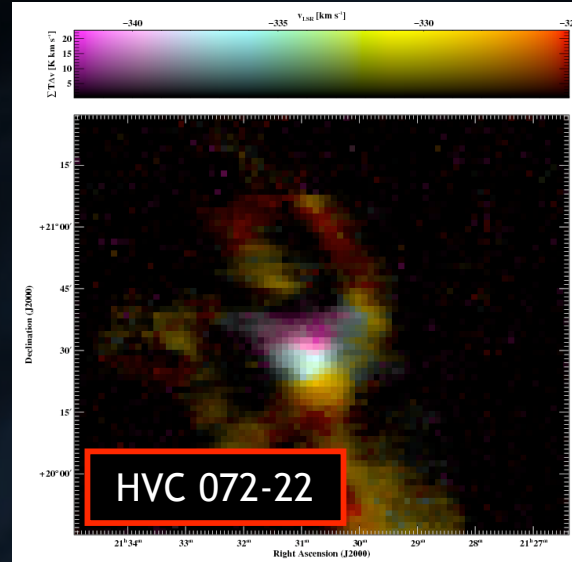
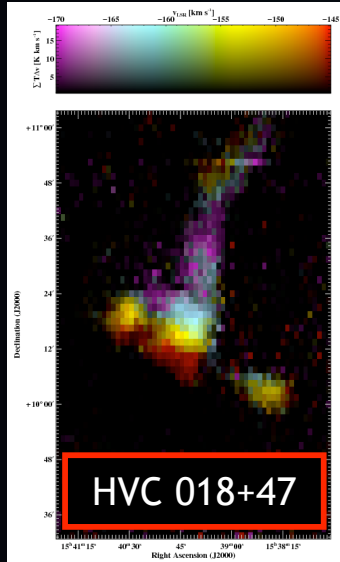
- If not, calculate expansion timescale

$$\Delta t \approx \frac{2r}{\Delta v} \left(\frac{d}{100 \text{ kpc}} \right)$$

- $5.3 \times 10^7 \text{ yr} < \Delta t < 2.5 \times 10^8 \text{ yr}$
- Not stable for very long
- What about dynamical masses?
 - Assuming virialization:
 $300 (d/100 \text{ kpc})^{-1} < M_{\text{vir}}/M_{\text{HI}} < 2100 (d/100 \text{ kpc})^{-1}$

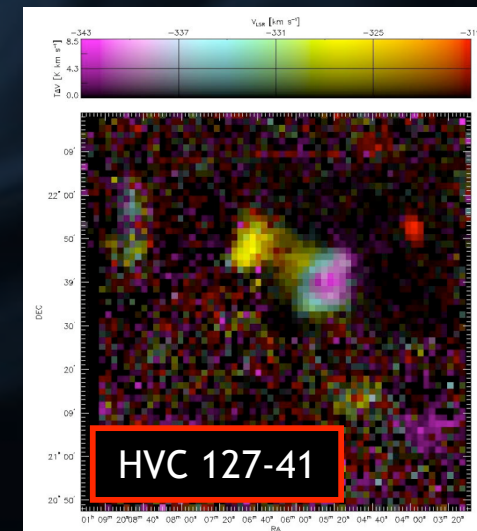
Must have dark matter to be bound!

Four Rotating HVCs?



Simon et al.
(in prep)

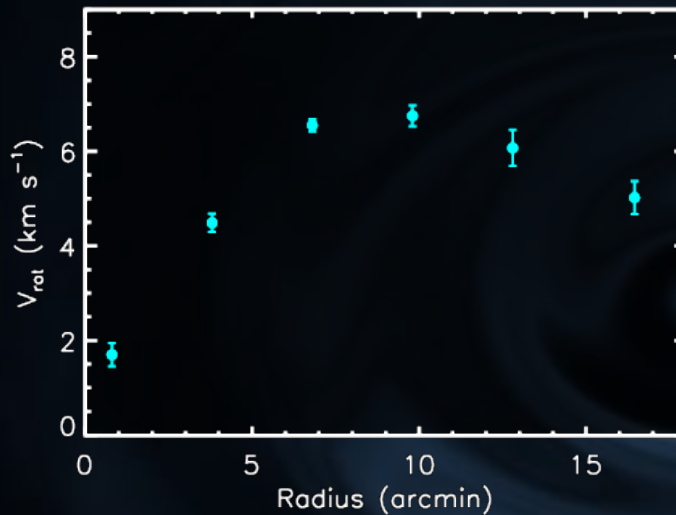
4/12 HVCs have major axis
velocity gradients with
apparent rotation velocities
of 4 - 14 km/s . . .



Robishaw,
Simon &
Blitz (2002)

HVC Rotation Curves

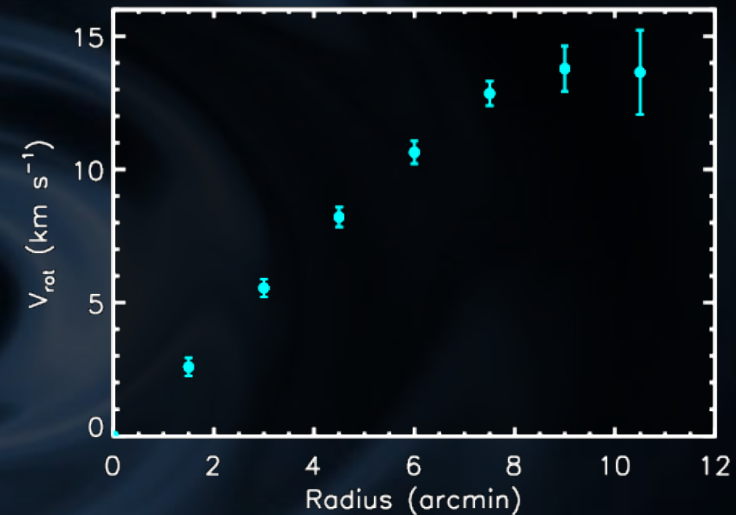
HVC 127-41



$$V_{\text{rot}} = 7 \text{ km s}^{-1}$$

$$M_{\text{dyn}}/M_{\text{HI}} = 7 (d/700 \text{ kpc})^{-1}$$

HVC 018+47



$$V_{\text{rot}} = 14 \text{ km s}^{-1}$$

$$M_{\text{dyn}}/M_{\text{HI}} = 78 (d/100 \text{ kpc})^{-1}$$

Summary

1) Ultra-faint dwarfs are extremely dark matter-dominated

- Masses of $10^6 - 10^7 M_{\odot}$, $M/L = 100 - 1000 M_{\odot}/L_{\odot}$
- Ultra-faint dwarfs alleviate but don't remove the substructure problem . . .
- *UNLESS* dwarf galaxy formation was strongly suppressed by reionization at $z \approx 12$ (Simon & Geha 2007)

2) HVC kinematics show that they are either dark matter-dominated or unbound

- Some HVCs appear to be plausible dark galaxies

Solution to missing satellite problem now in reach . . .