The Milky Way and Near-Field Cosmology

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Annette Ferguson
(Edinburgh)Eric Bell (MPIA -
Heidelberg)

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- diffuse collection of stars surrounding the Milky Way
- ~1% of the total luminosity

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And what can it possibly tell us about on cosmological scales?

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And what can it possibly tell us about on cosmological scales?

Answer: think about hierarchical structure formation in the Local Group

Why is this interesting?

field dwarfs
(mostly irregulars, gas rich)

↓ accreted, stripped of gas, morphologically transformed (e.g. Mayer et al 2002, 2007, Kravtsov, Gnedin & Klypin 2004, Knebe et al 2006)

satellites
(mostly spheroidals, gas poor)

↓ tidally disrupted (e.g. Johnston, Hernquist & Bolte 1995)

star streams

↓ phase-mixed (e.g. Johnston 1998, Helmi & White 1999, Knebe et al 2005, Penarrubia et al 2006)

stellar halo

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field dwarfs = next victims
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satellites = current survivors
(mostly spheroidals, gas poor)

↓ tidally disrupted (e.g. Johnston, Hernquist & Bolte 1995)

star streams = recently casualties

↓ phase-mixed (e.g. Johnston 1998, Helmi & White 1999, Knebe et al 2005, Penarrubia et al 2006)

stellar halo = long-dead relatives

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star streams

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stellar halo

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=> stellar halo consists of stars formed in objects prior to accretion => stellar populations tell us about building blocks of galaxies

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SDSS

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- Prior to SDSS: Ibata et al discovery of Sagittarius; Majewski's giant star survey; Morrison (et al's) "Spaghetti" survey....

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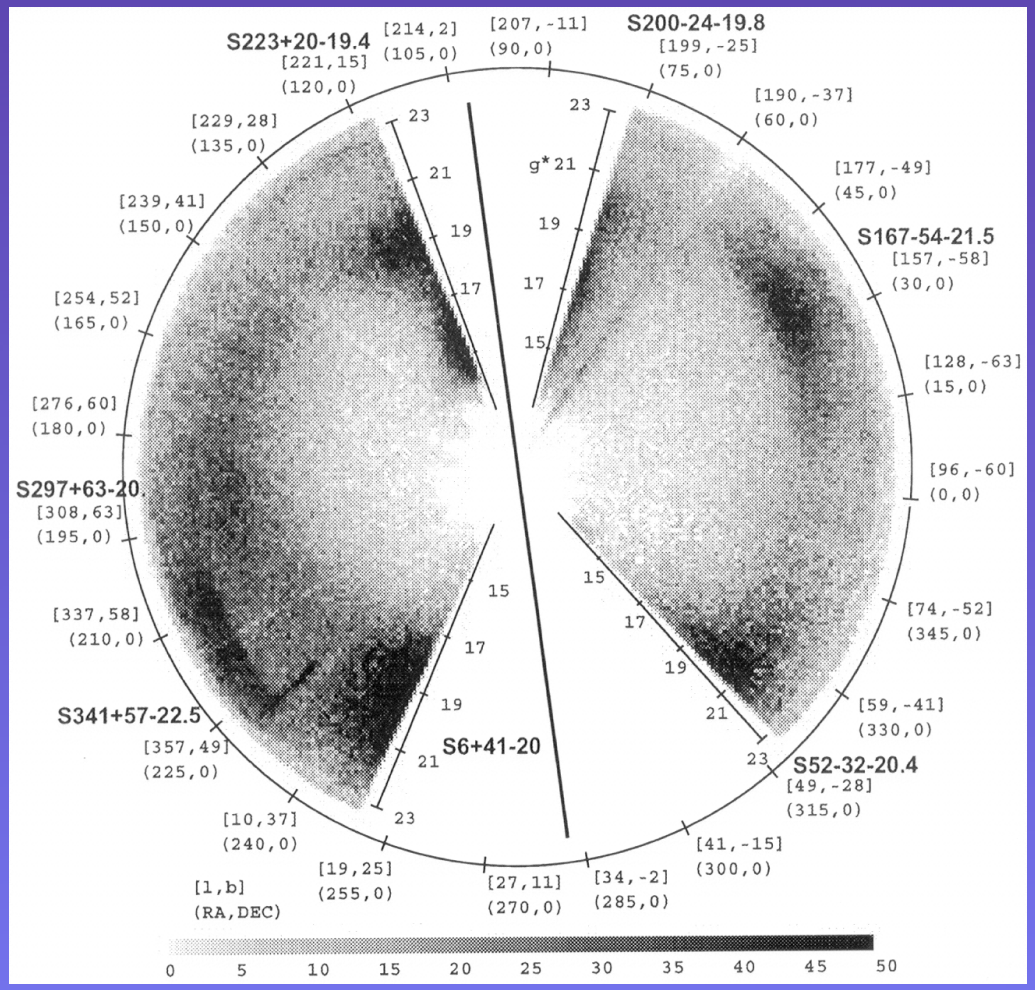
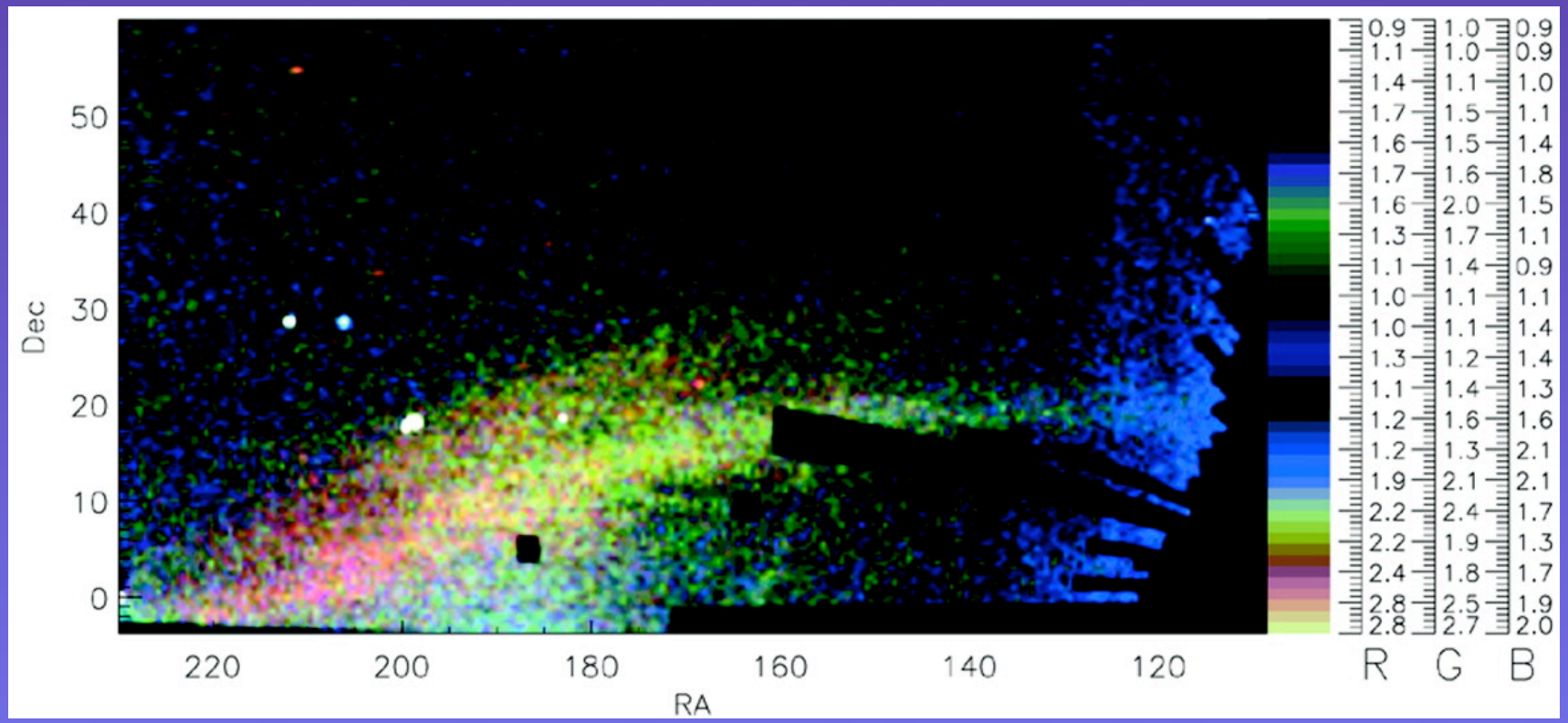
- First SDSS results



Newberg et al 2002 - blue-colored turnoff stars along celestial equator, g*=19.4~11kpc g*=22.5~45kpc

Substructure in the stellar halo



"Field of Streams" in SDSS - Belokurov et al, 2006

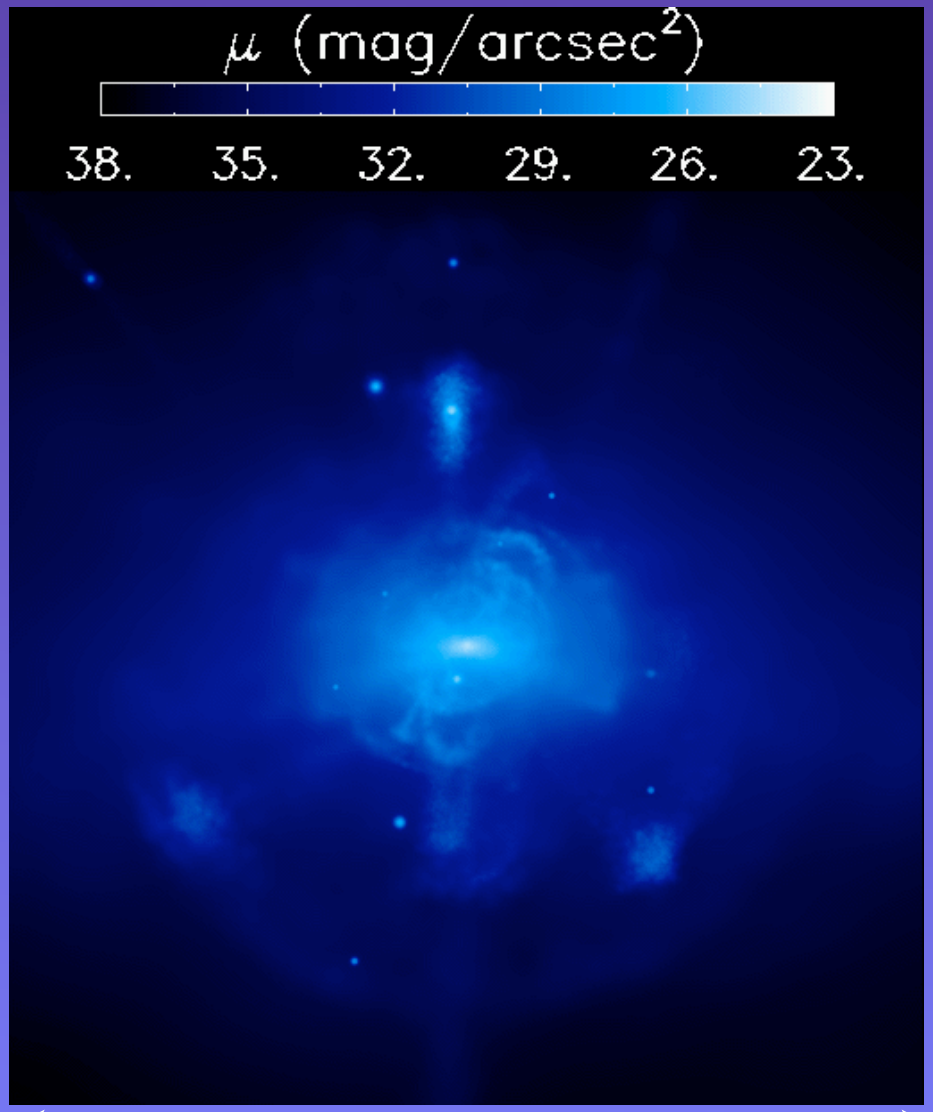
Substructure and galaxy formation

? Do the numbers add up? ie given our expectation (from cosmology) for the numbers of recent accretions, do the number of field dwarfs/ satellites/star streams make sense?

? What are the numbers telling us about recent accretion history?

Stellar halo models within LCDM

- N-body simulations for dark matter evolution
  - mass function, accretion times and orbit times drawn from cosmological accretion history
- Semi-analytic models to paint on stars
  - normalized to match number and structure of Local Group dwarfs
- N.B. NO DISK/BULGE COMPONENTS



300kpc

Bullock & Johnston, 2005

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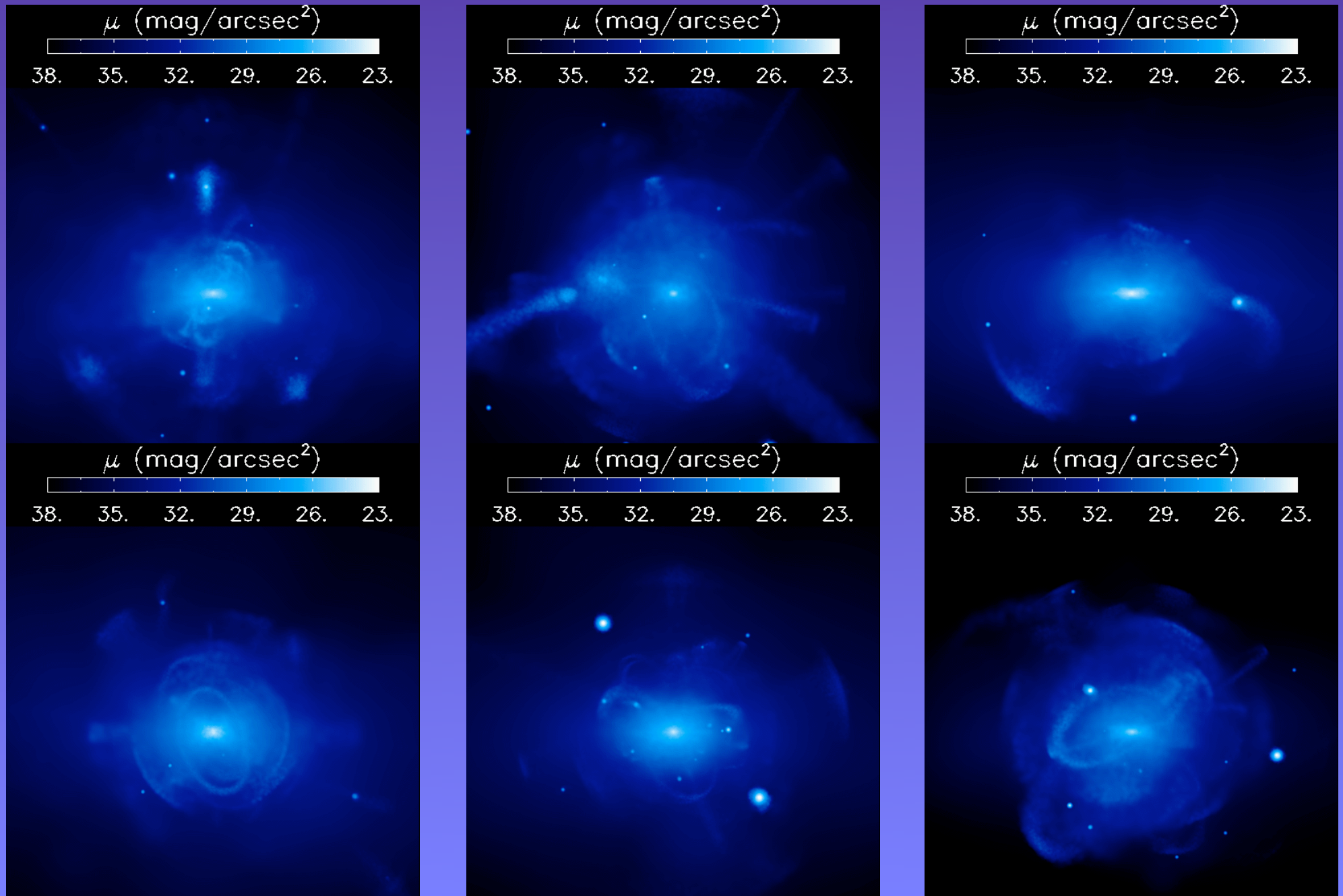
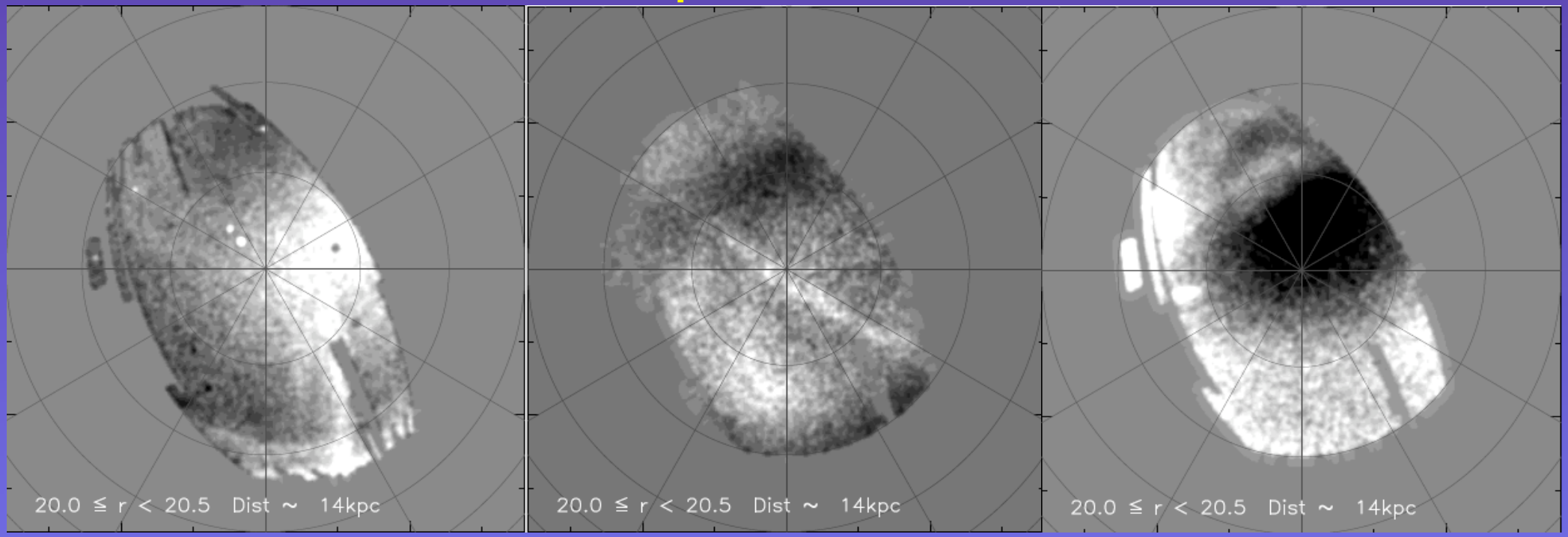


The Milky Way's Stellar Halo

Do the numbers add up? .....YES!.... well, sometimes



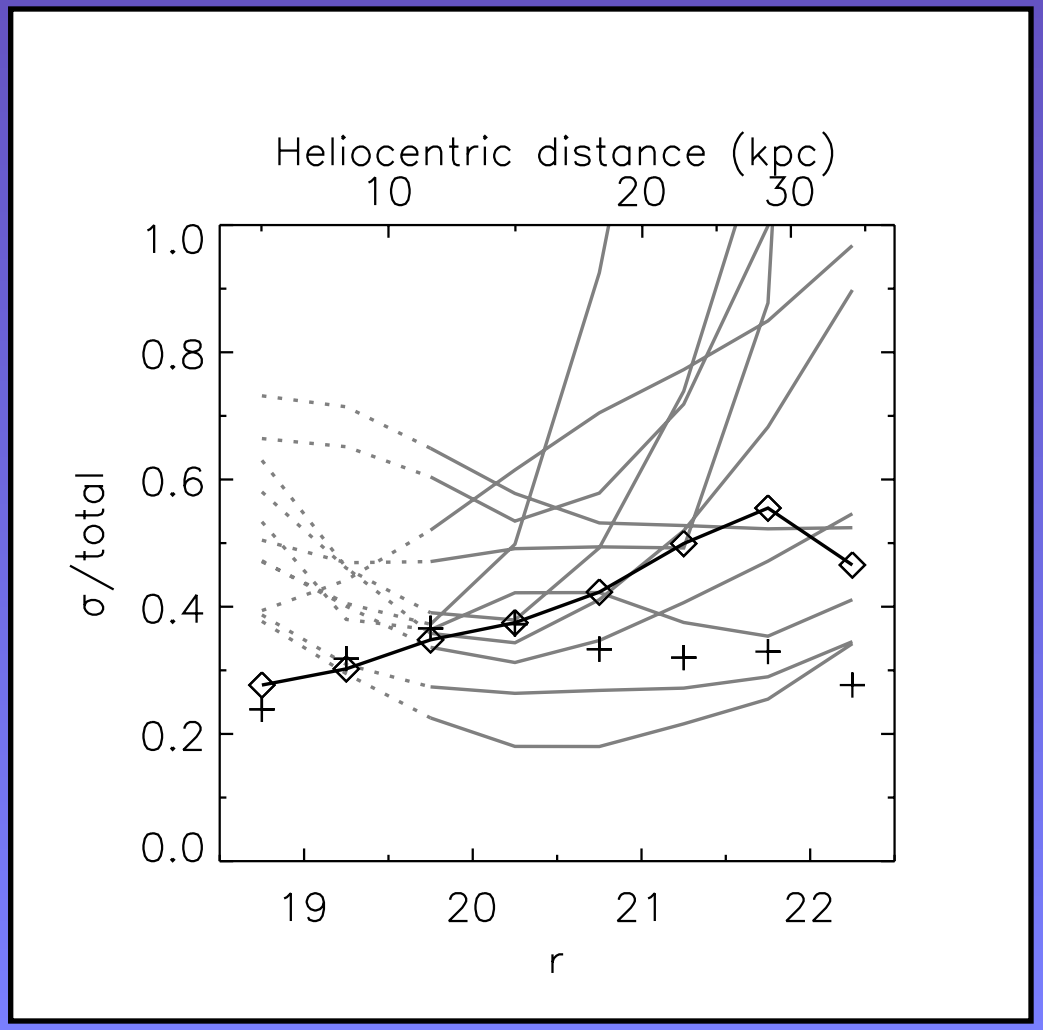
e.g. Bell et al (2007)

- analysis of faint turnoff stars in SDSS DR5
- plots show fluctuations around a smooth model density for shell ~14 kpc from the Sun
- data *vs* 2 models

The Milky Way's Stellar Halo

Bell et al (2007)

- dispersion in fluctuations as function of distance for all 11 models (thin lines) and data (diamonds)



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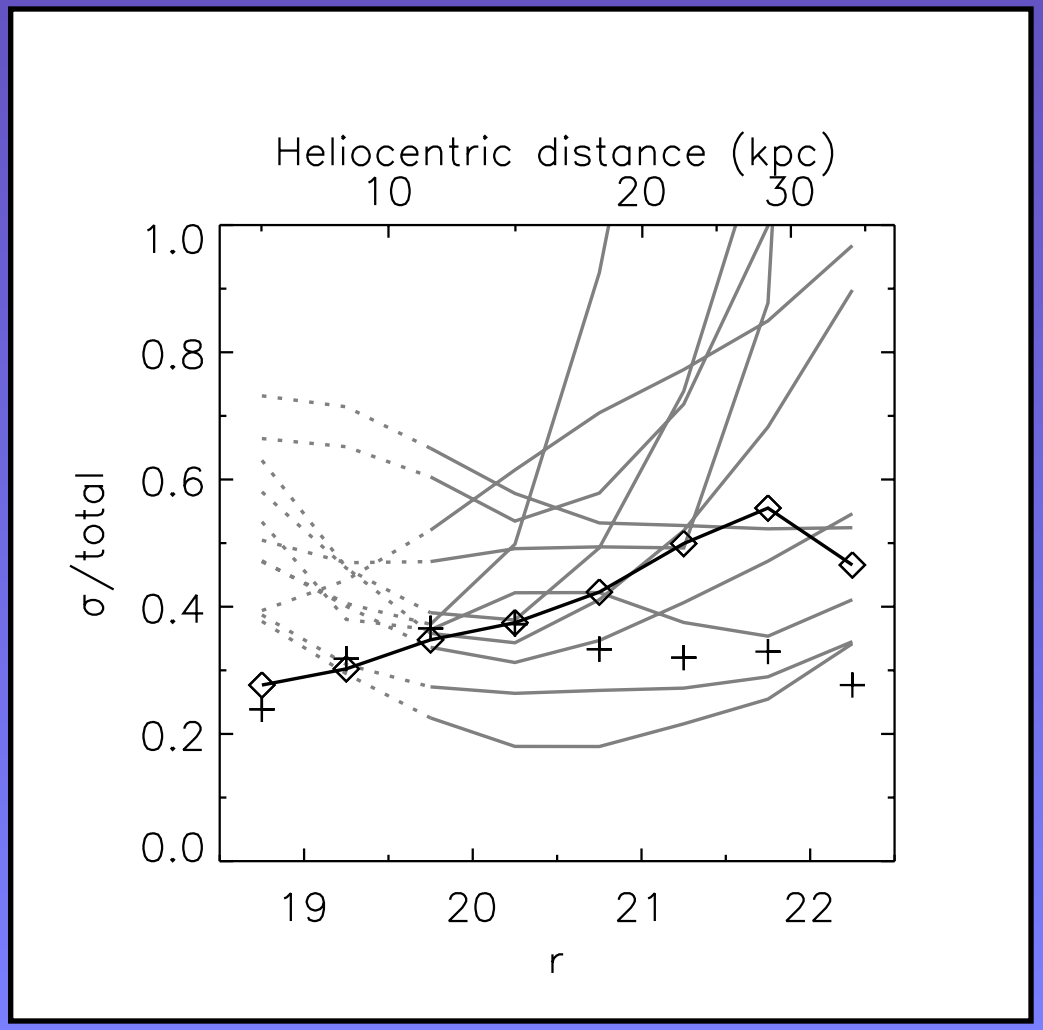

Conclusion: broad consistency between level of fluctuations in density in Milky Way's halo and models stellar halos

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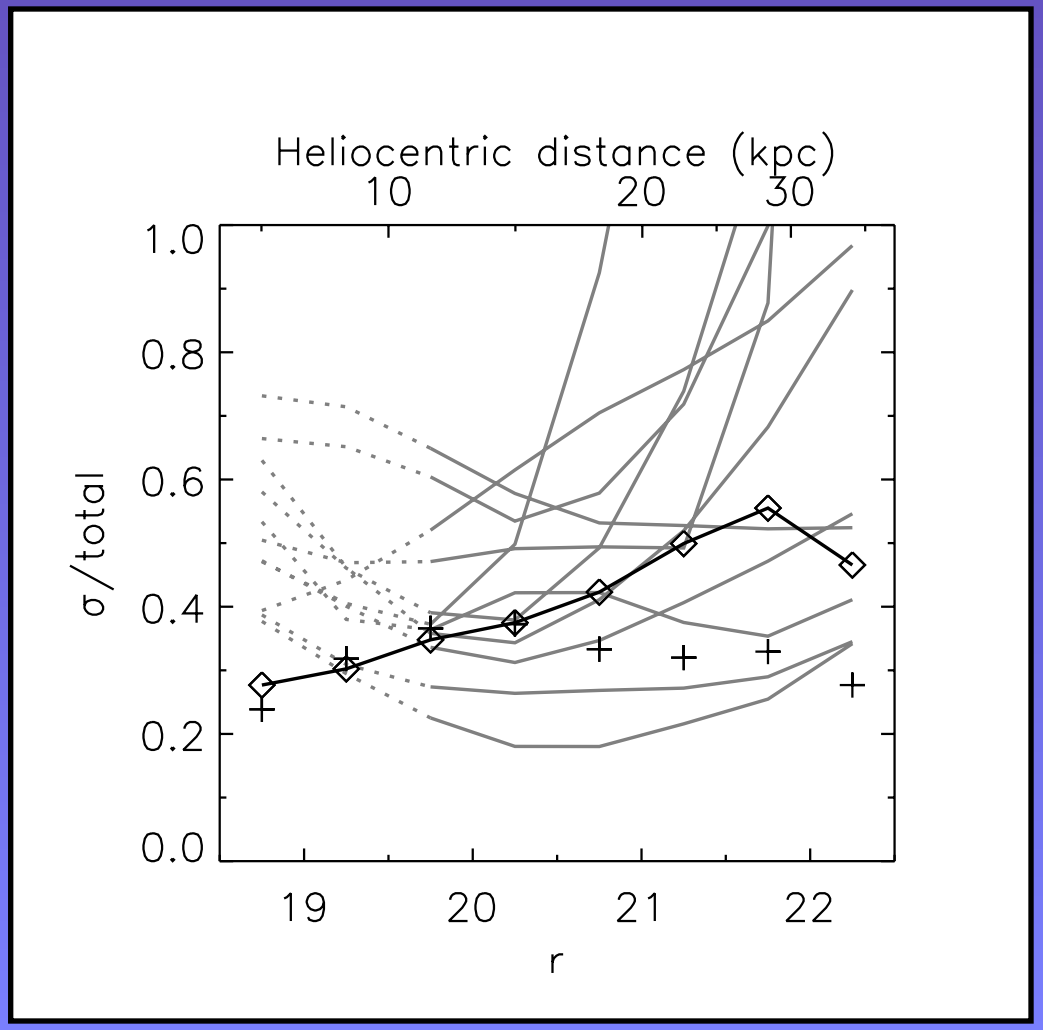

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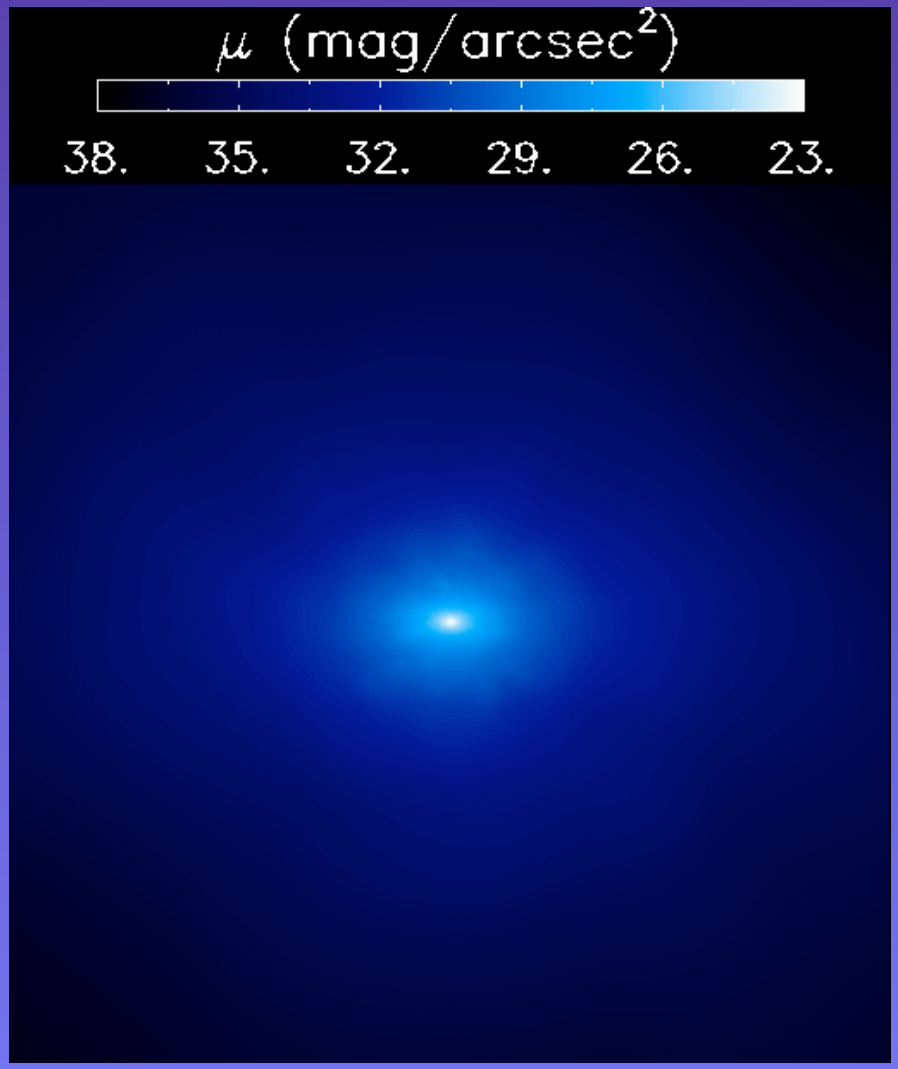
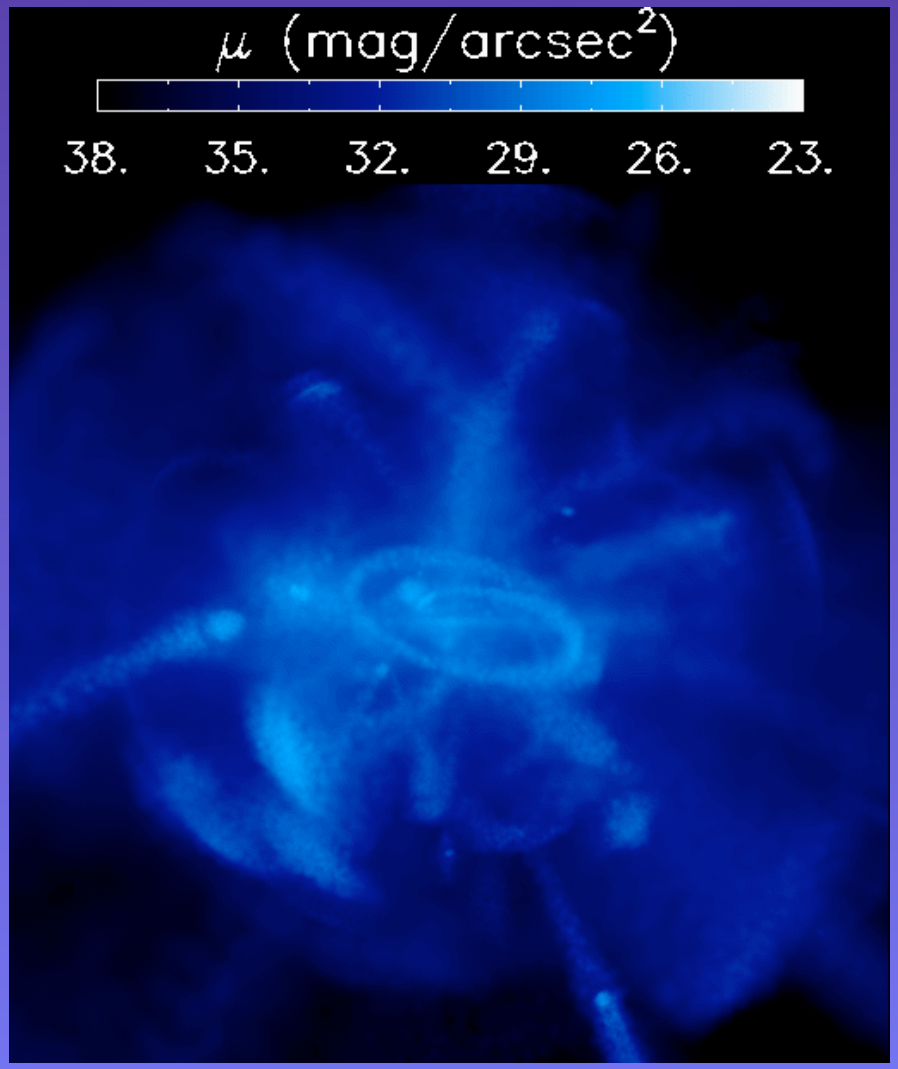
How can we say more?

Stellar halo models ignoring LCDM



Early
vs
Late
events

(Johnston et al, astro-ph: 0807.3911)



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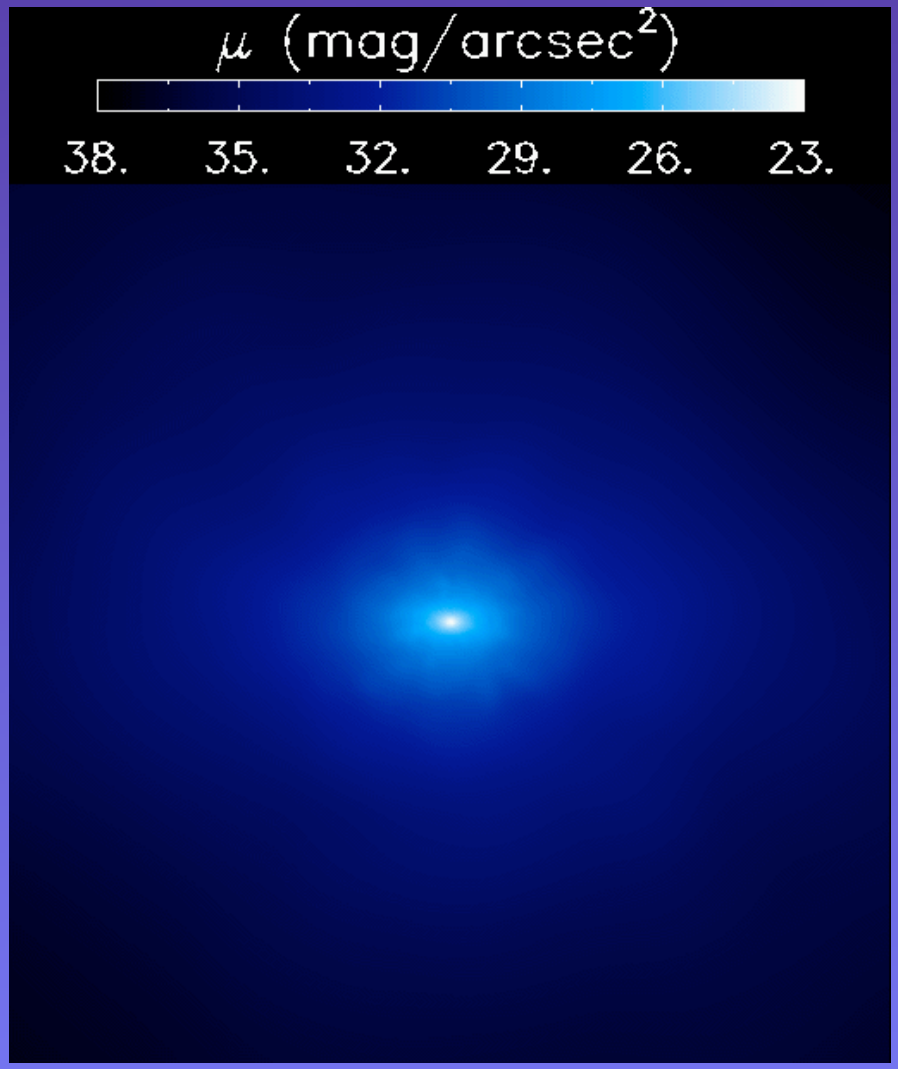

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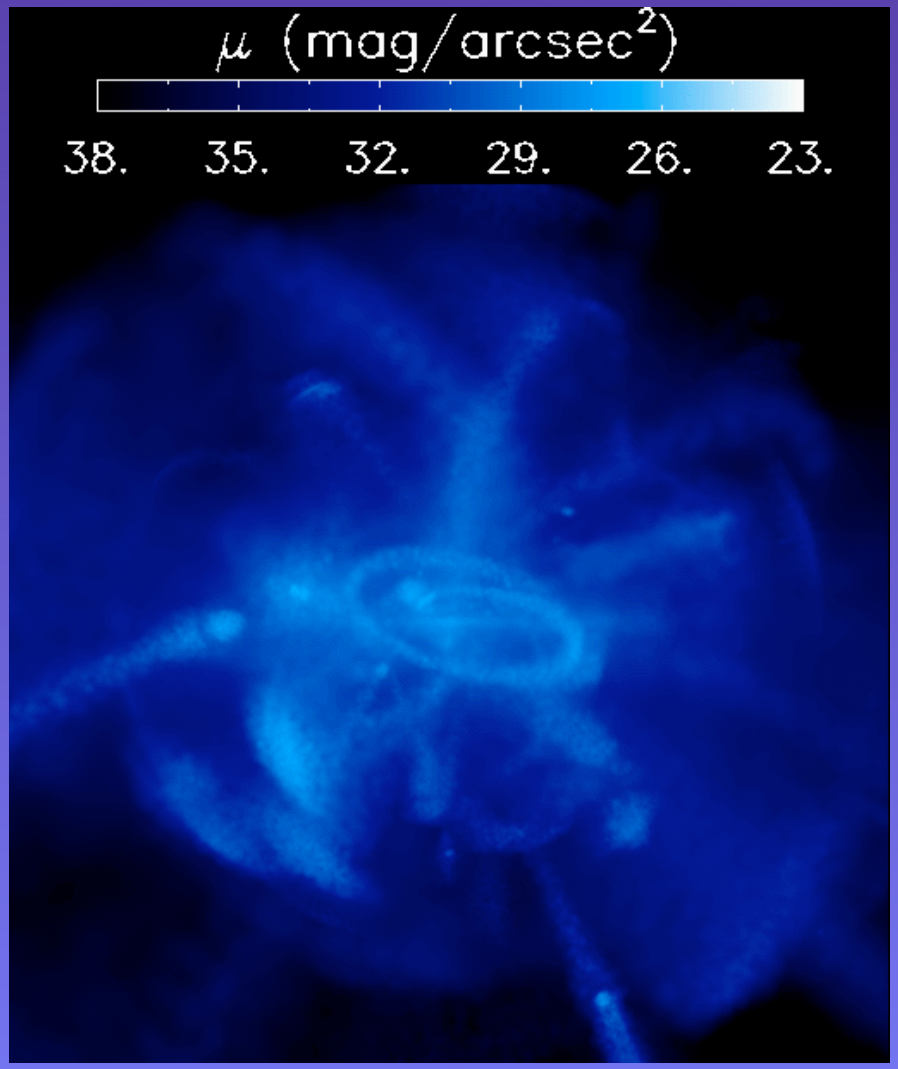
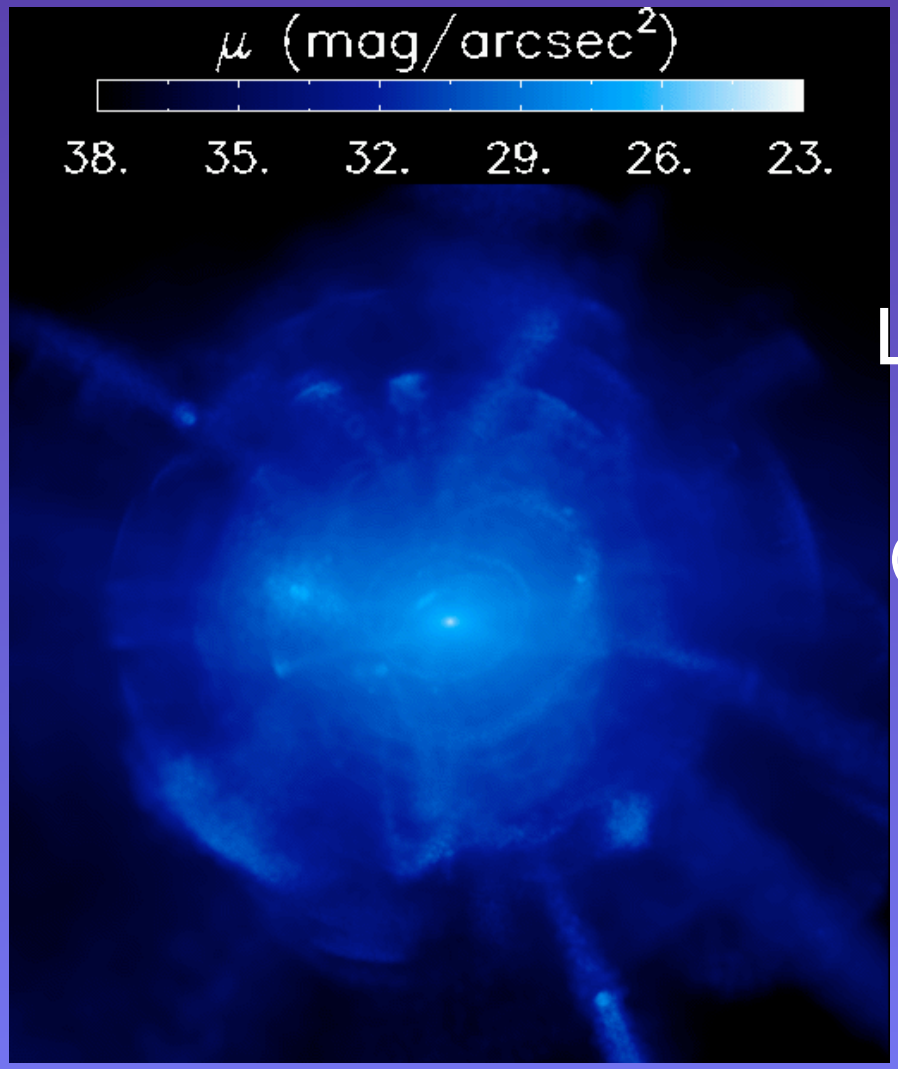


- Fraction of halo in substructure

➡ importance of recent accretion

Stellar halo models ignoring LCDM



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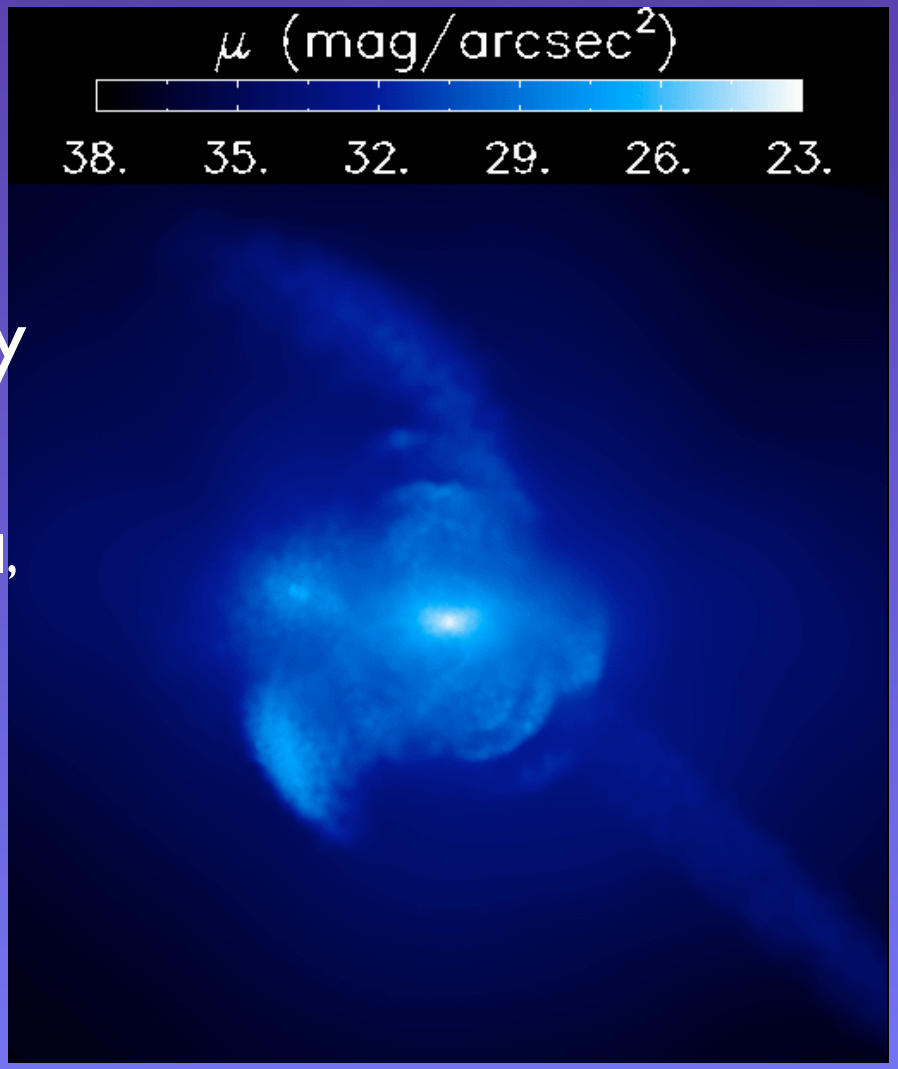

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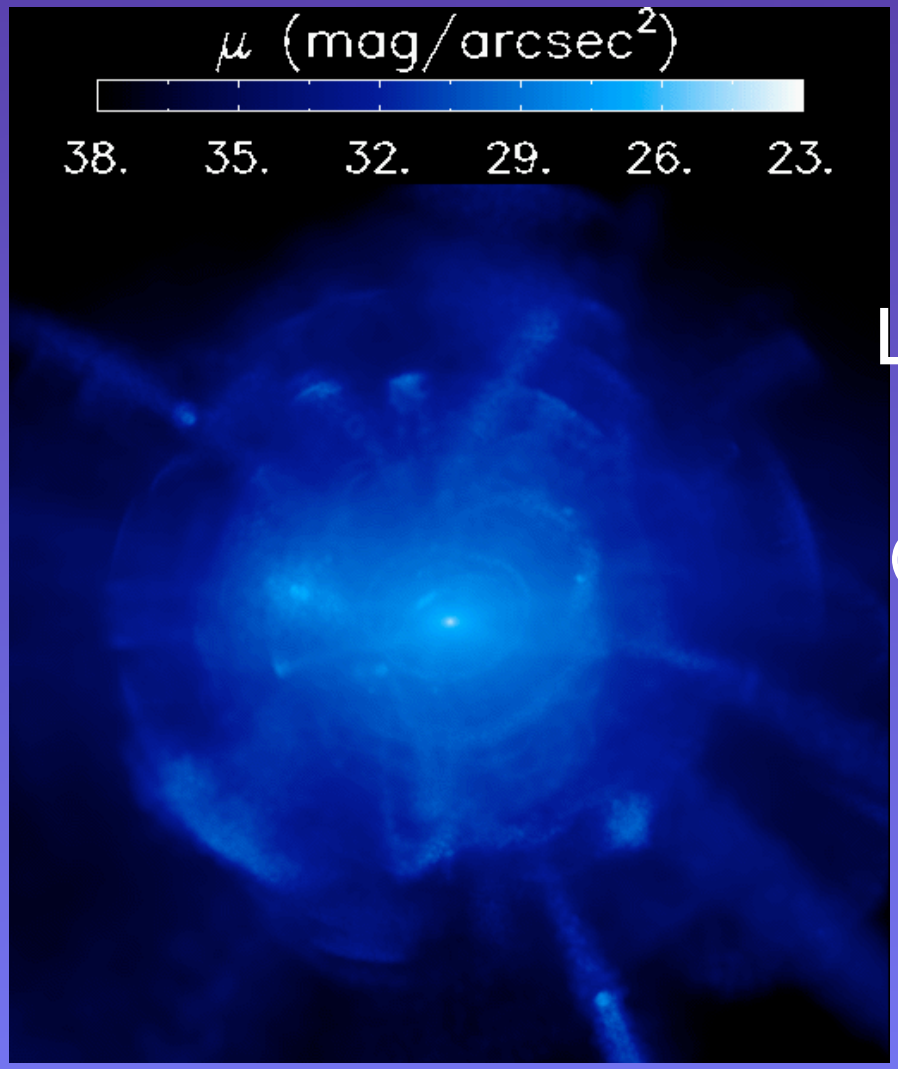

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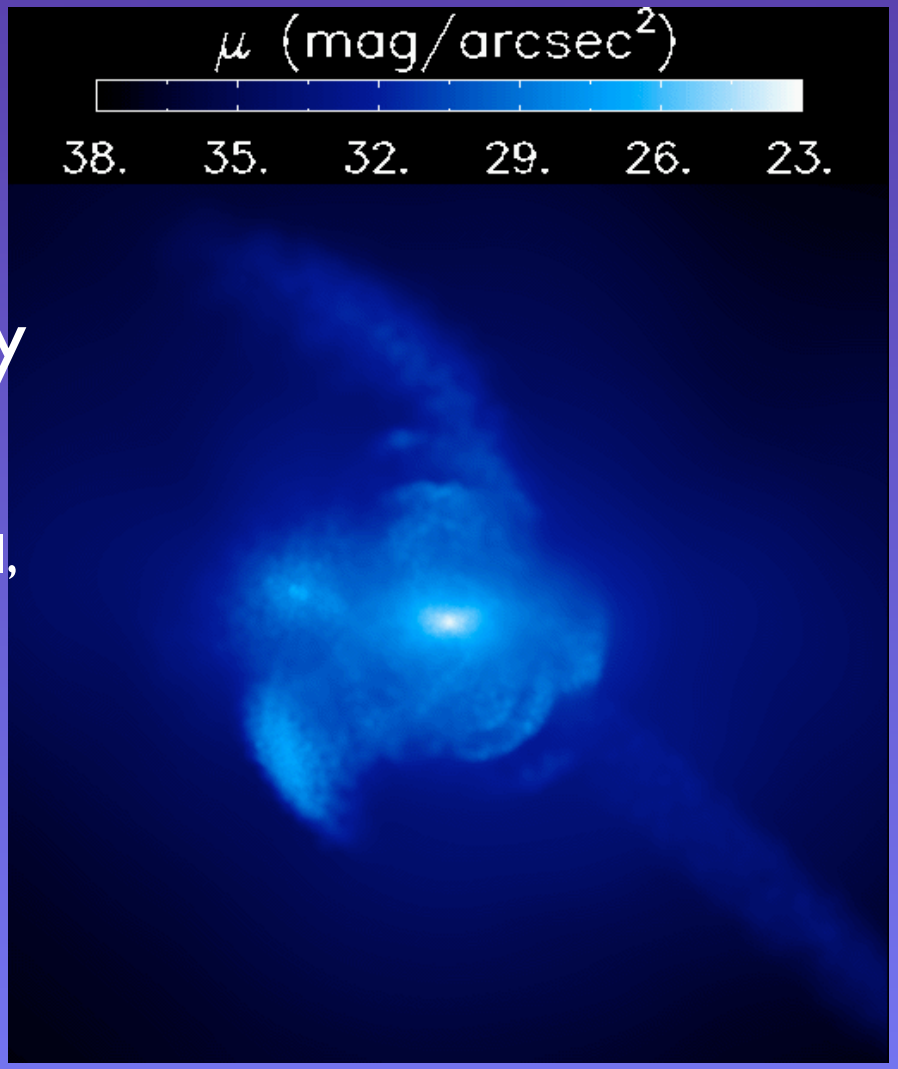

- Spatial scales of substructure

➡ luminosity function of recent accretors

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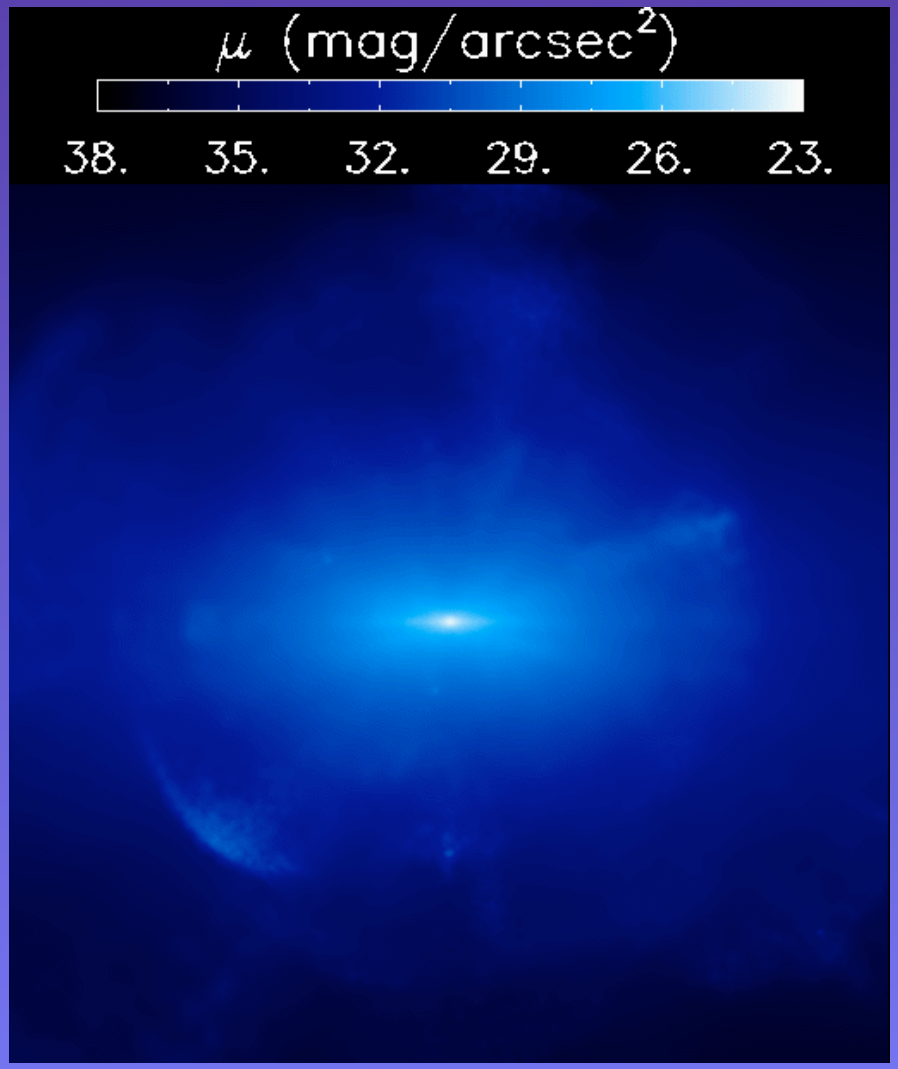

Radial *vs* Circular Orbit events

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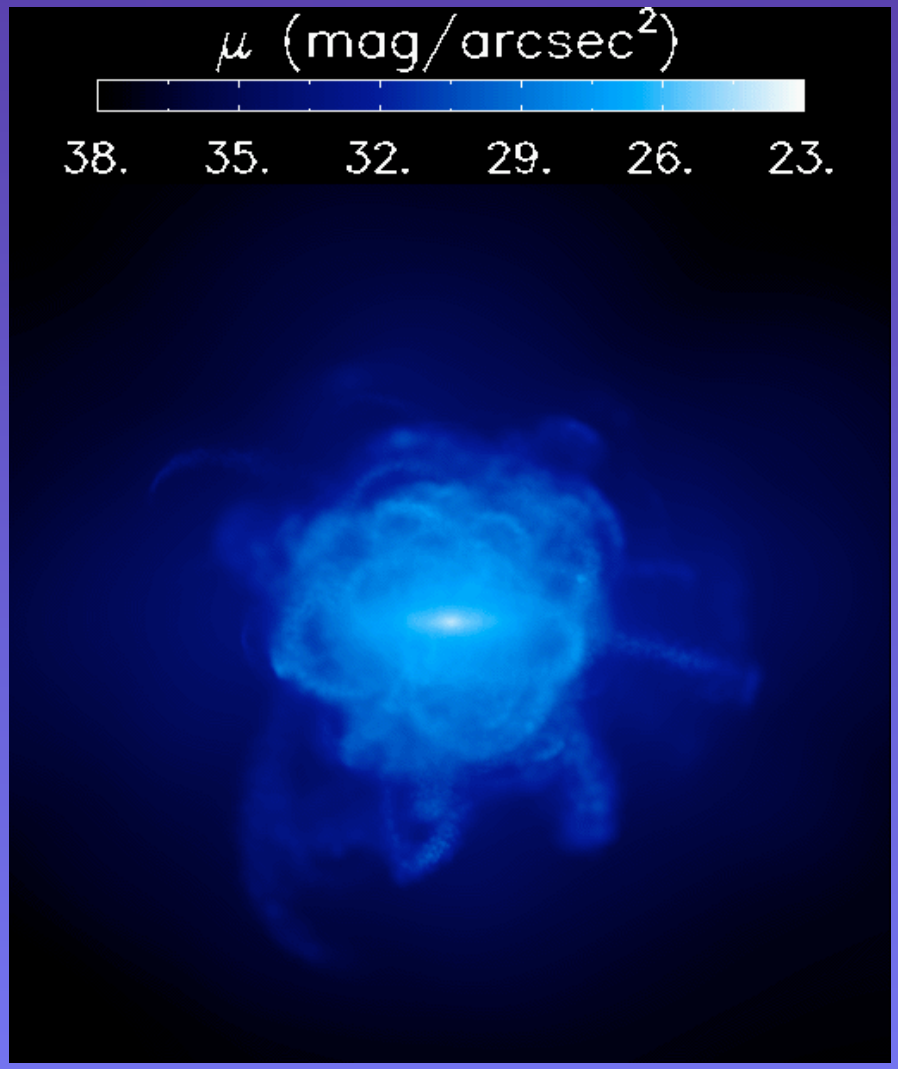

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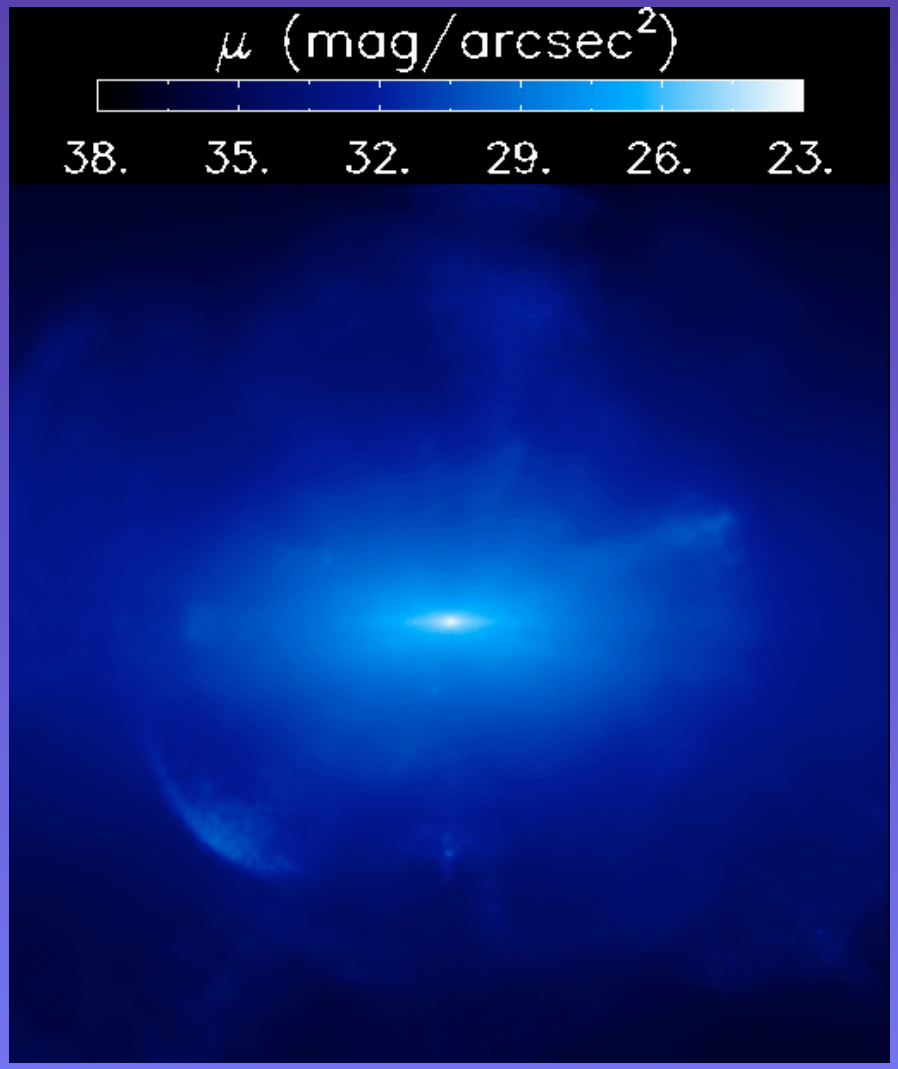

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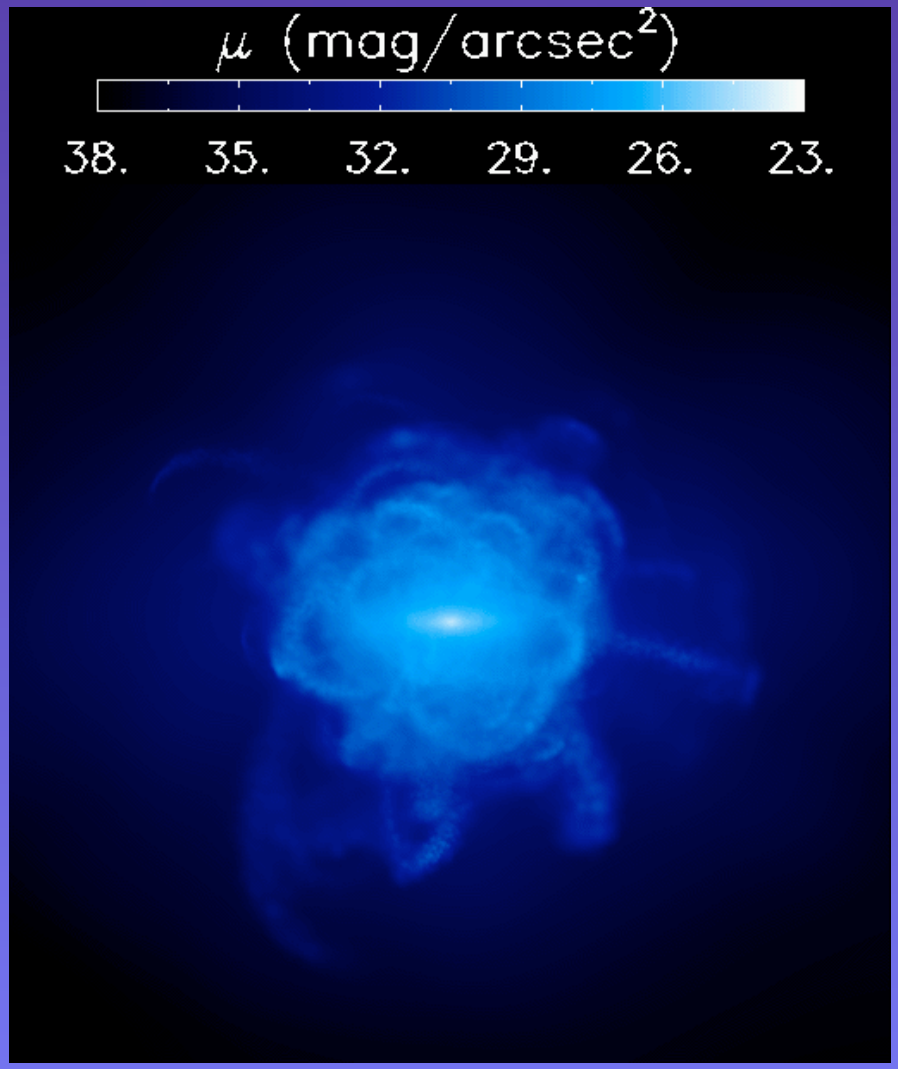

- Morphology of substructure

➡ orbit distribution of recent accretors

“Saying more” with the stellar halo...

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Analysis approaches:

- Statistics

“Saying more” with the stellar halo...

Analysis approaches:

- Statistics
- A group finder that can work

  - in arbitrary number dimensions

  - with dimensions of different types (e.g. apparent magnitude, angular position and radial velocity) and with varying error scales

  - with highly anisotropic structures (e.g. tails) of many different scales and orientations

  -with large numbers of points

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My solution?????

Hire a postdoc!

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Sanjib Sharma

Group finding

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Sharma & Johnston, in prep

General problem: finding and characterizing substructure in large data sets

Method:

1. Find density field *and local metric* in *N*-dimensions of observables (Sharma & Steinmetz, 2006)

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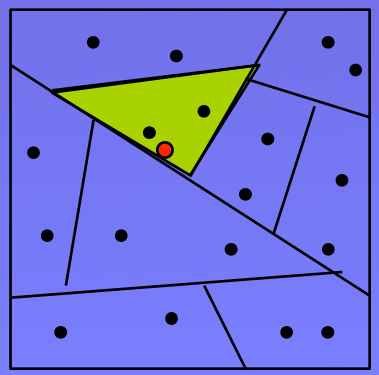
   - orientation of splitting planes defined by data itself



E.g. M-giants in the 2MASS data set
(from Majewski sample)

“radius” refers to magnitude difference from M-giants at Sun

Group finding

2. Groups in *N*-dimensions identified from density field using a nearest-neighbor algorithm (HOP or SUBFIND-style)
   - metric defines the distance between points
   - no need to make *a-priori* assumption of scales or orientations of structures in data
   - gives hierarchy of groups within 'tree' structure

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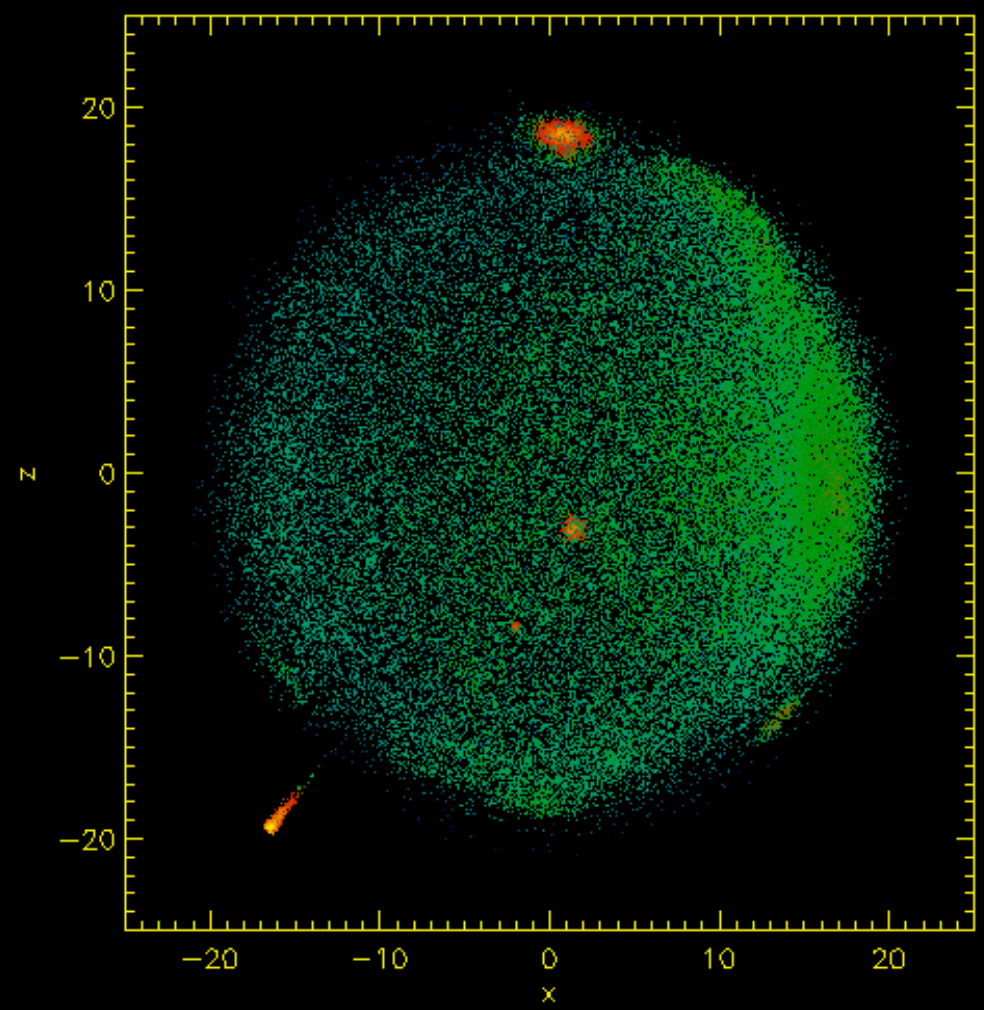
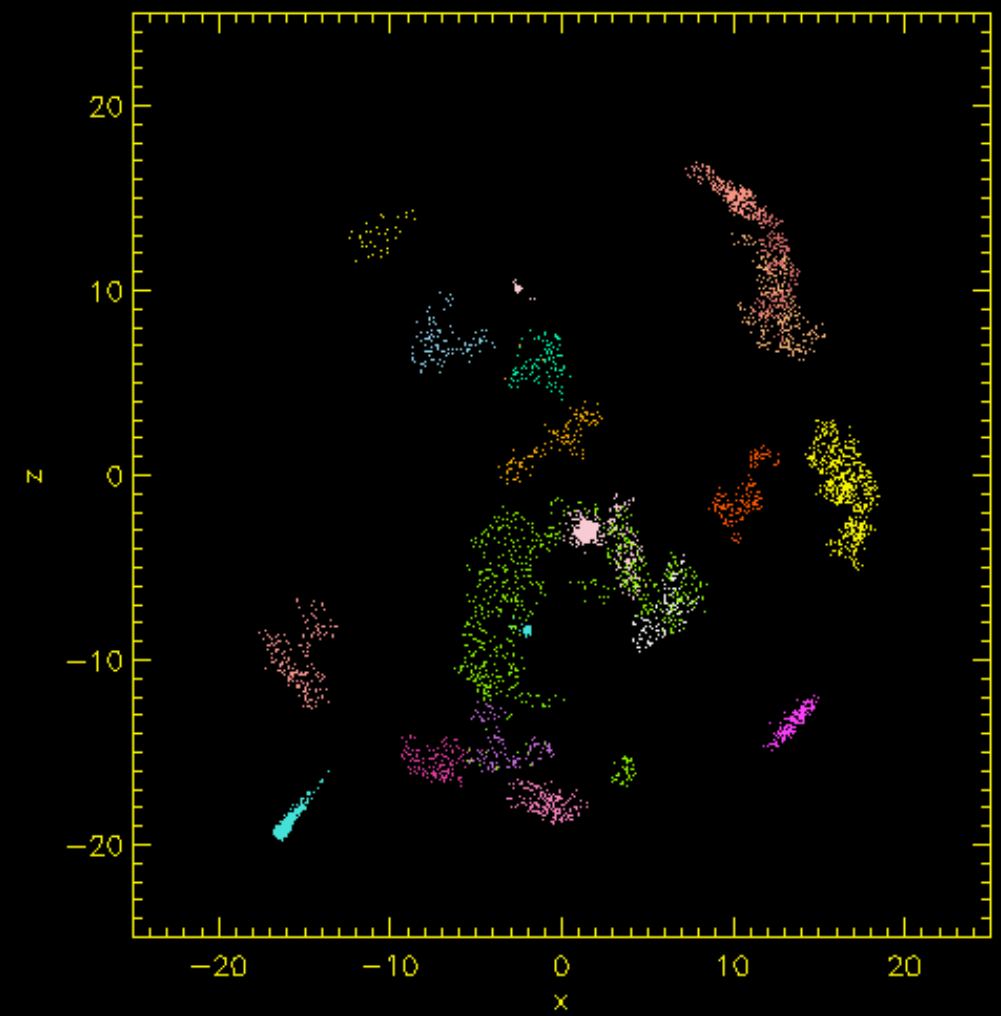
recovered groups in the data set

Group finding

- Application to a (LCDM) model stellar halo - recovered groups reminiscent of 2MASS





Group finding

How can we estimate which groups have physical meaning?

recovered groups in 2MASS M-giants when the angles are scrambled

Group finding

How can we estimate which groups have physical meaning?

Define their *significance* from the group finder as:

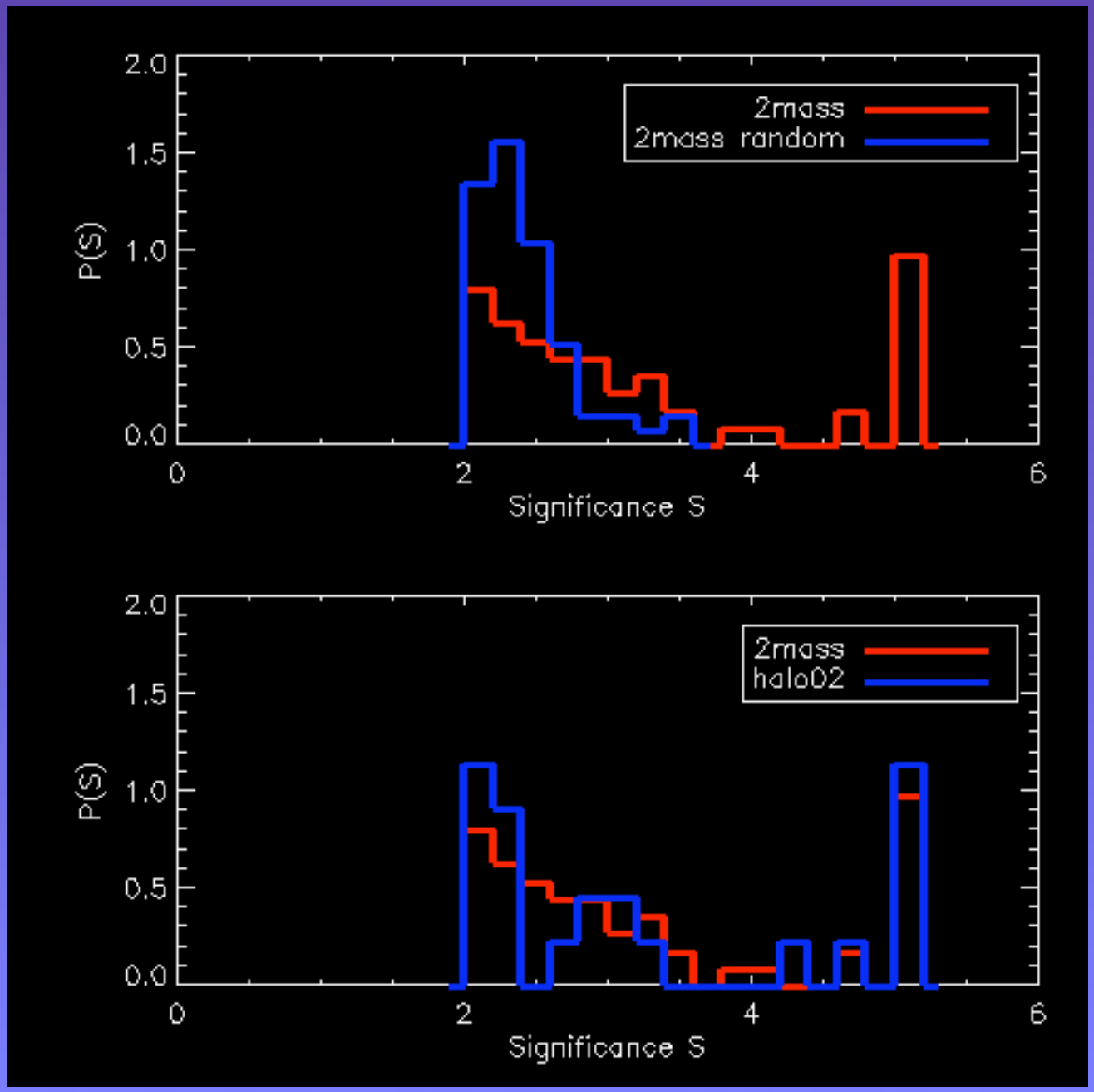
$$S = \frac{\log \rho_{\max} - \log \rho_{\min}}{\sigma_{\log \rho}}$$

minimum density of group member

maximum density of group member

expected Poisson noise

Group finding

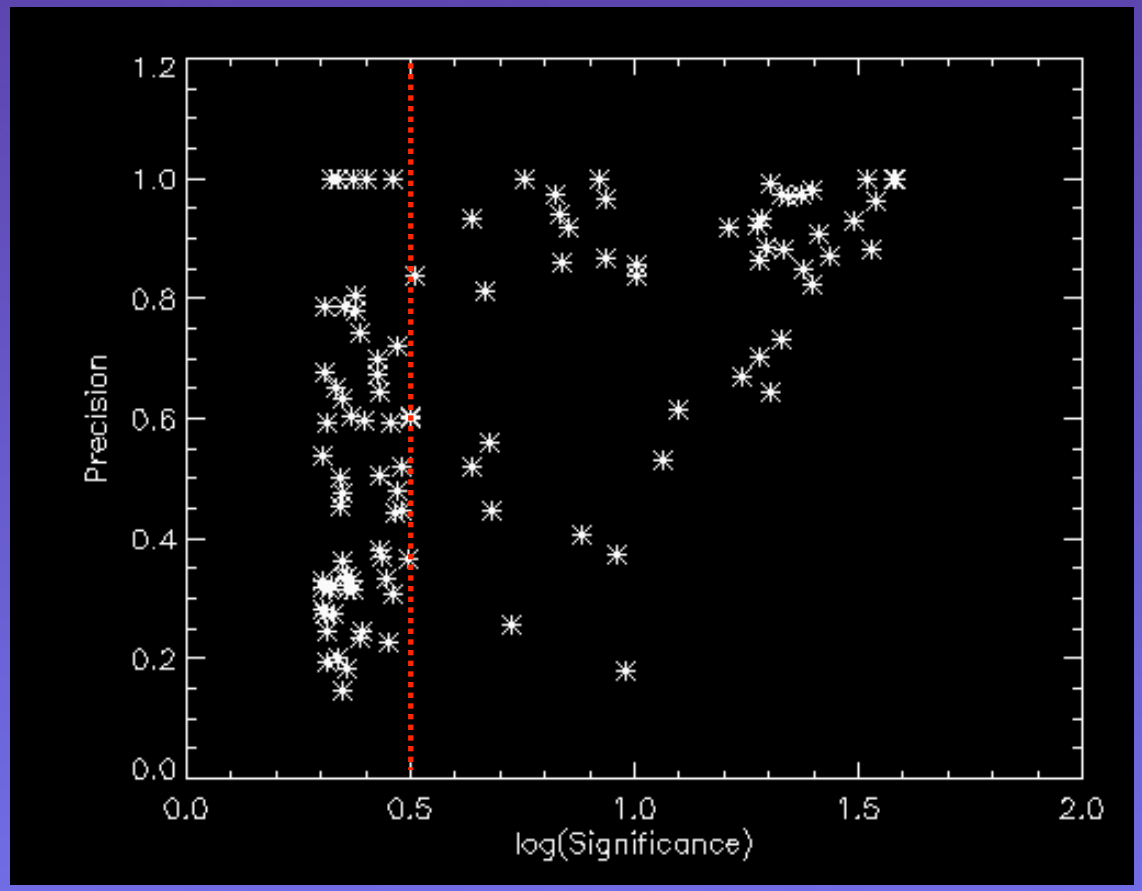


Plotting only the high-S tails of the distribution...

- higher fraction of high-sigma groups in 2MASS than randomized halo
- similar fraction in 2MASS and model LCDM halos

Group finding

"Precision" = % of a group originating from a single satellite



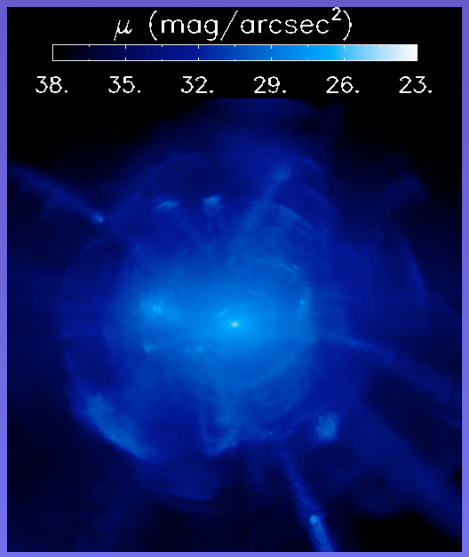
Significance

- 80% of groups in our LCDM model halos with $S > 3$ are dominated by debris from single satellite (i.e. "precision">0.5)

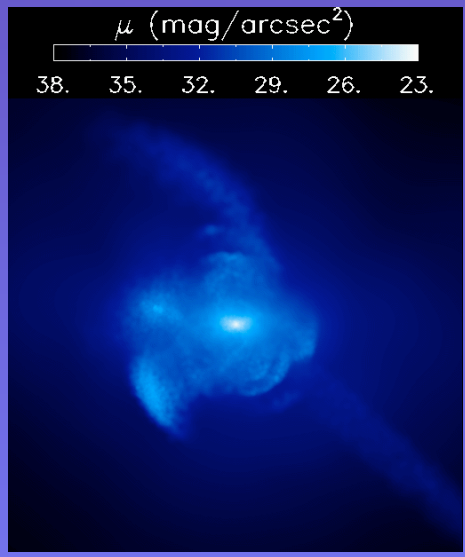
- Also true for 50% of groups with $2 < S < 3$

Group finding

A preliminary analysis: could looking only at S>2 groups could reflect luminosity function of accretions?



groups found in halo built from many low-L events



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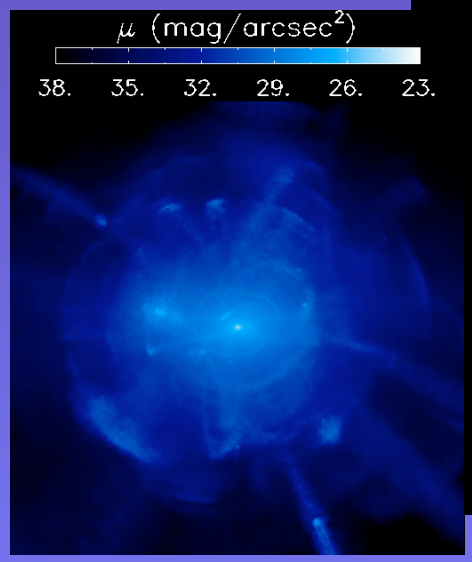

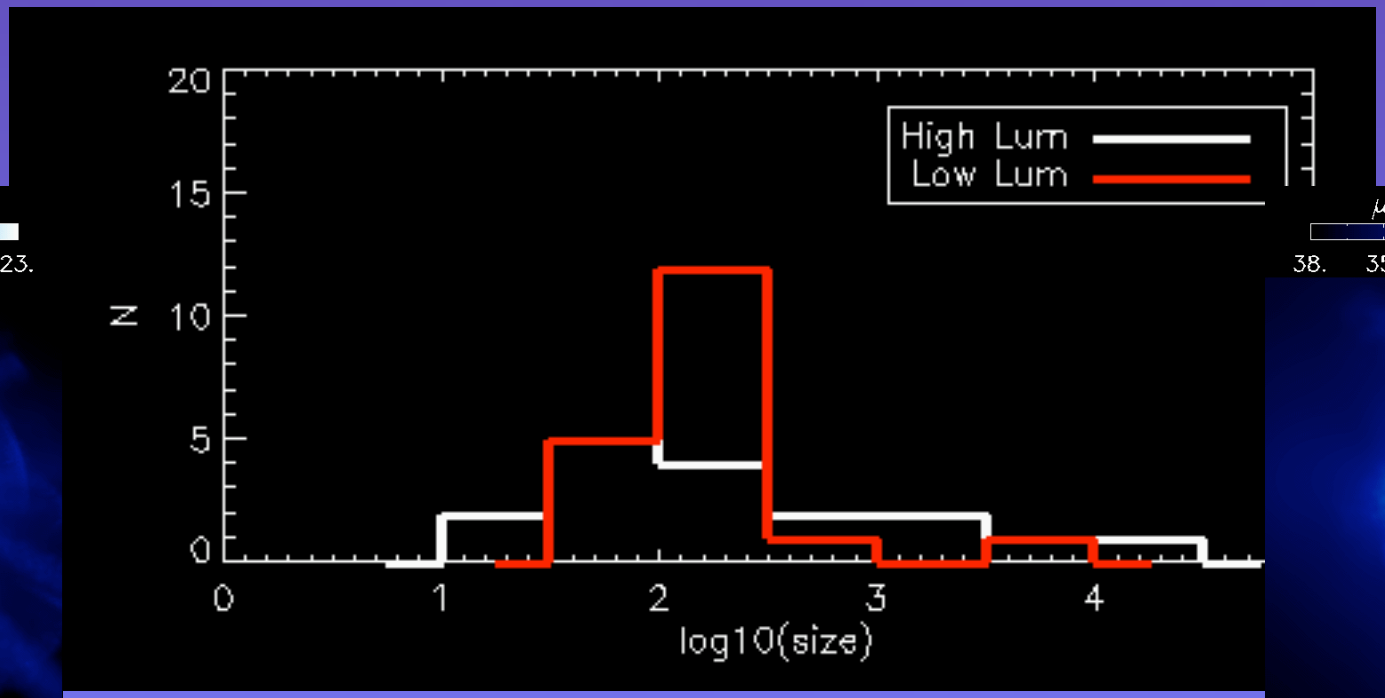

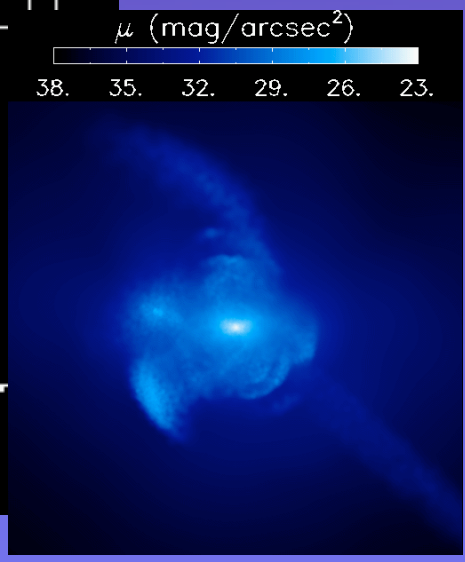

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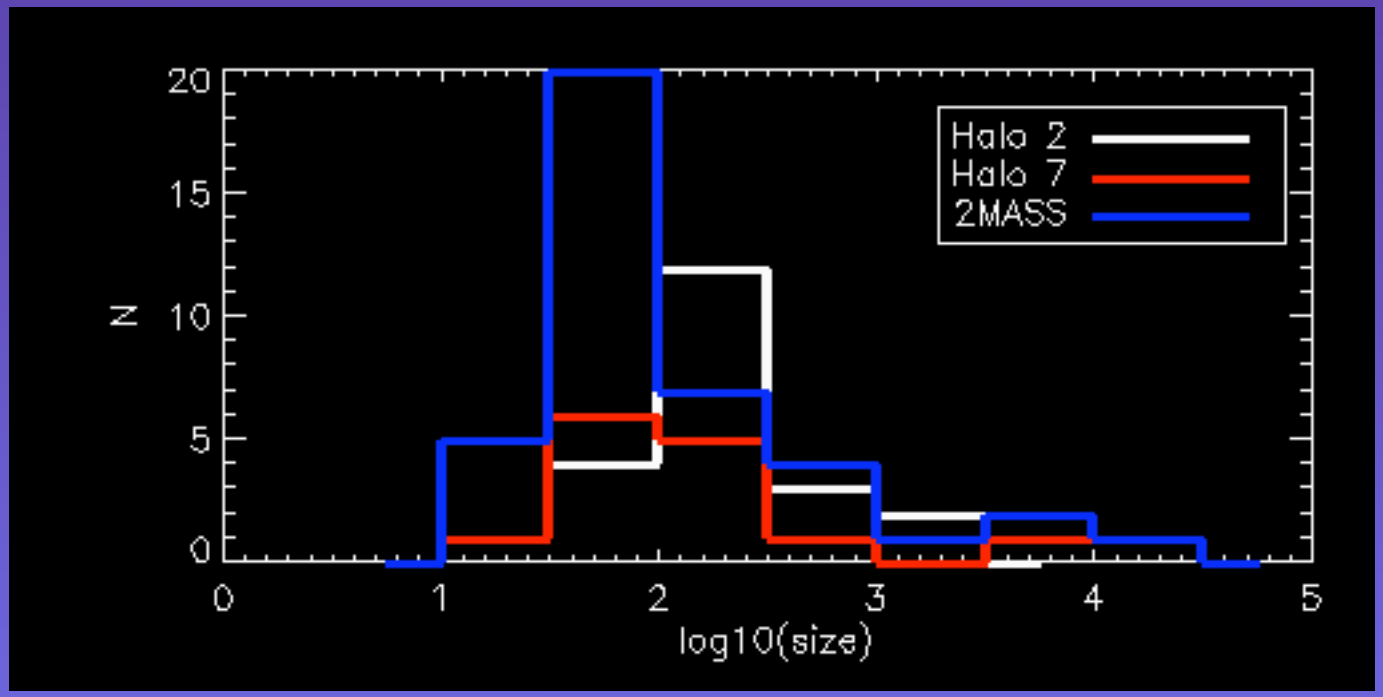
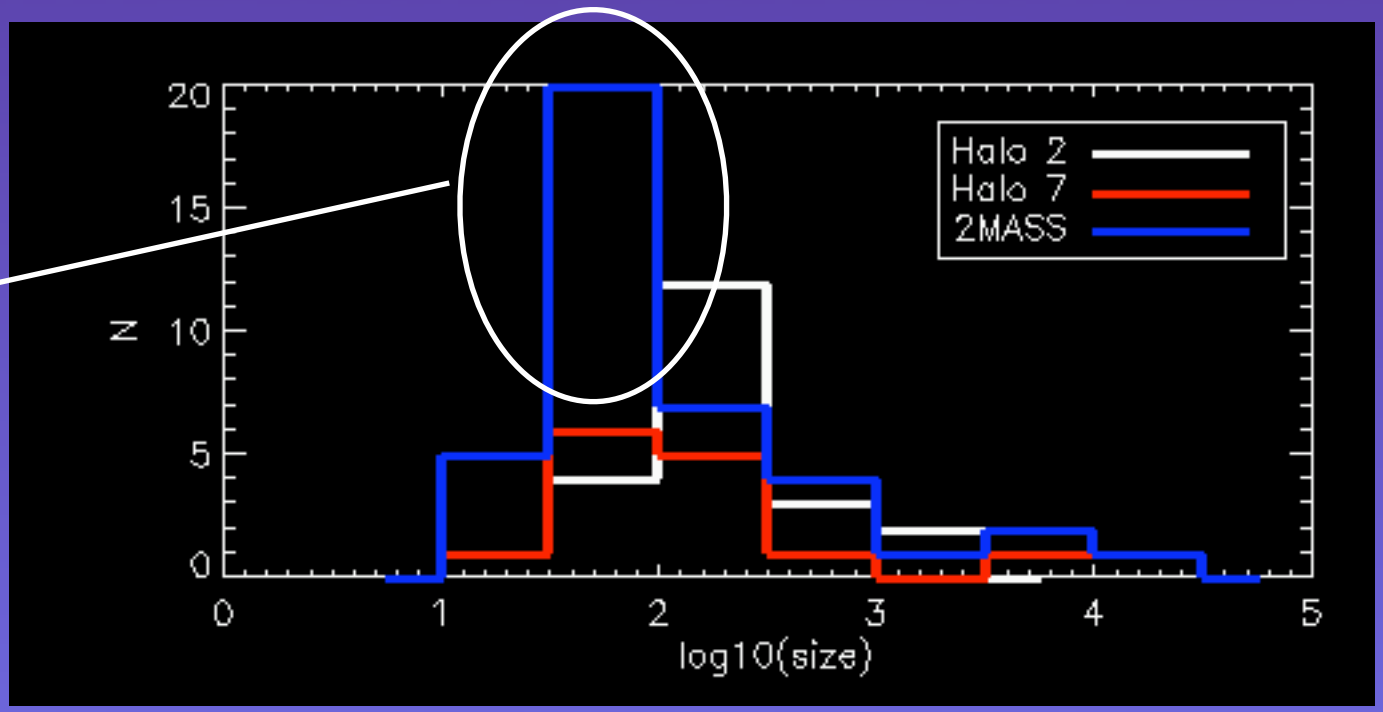


Group finding

?*!



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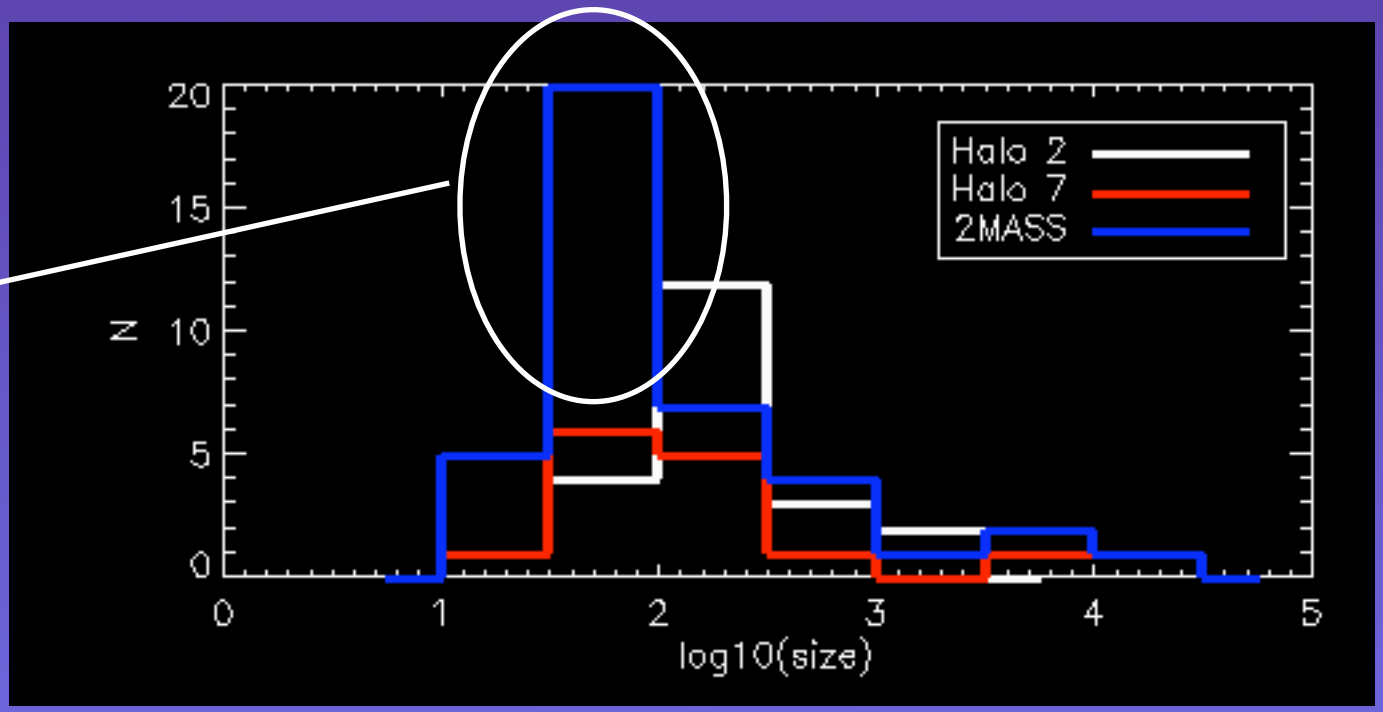


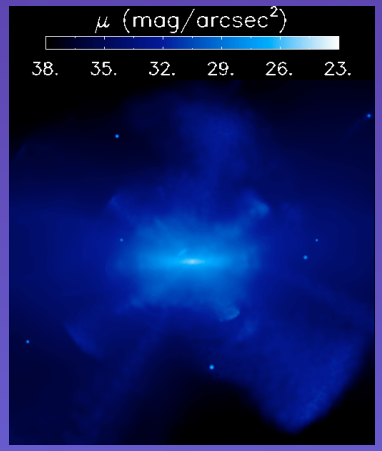
More low luminosity groups in 2MASS because ...

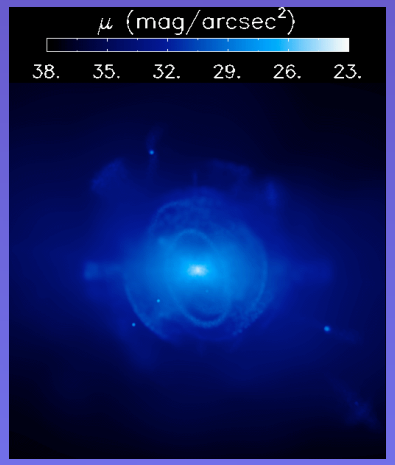
? of a fundamental flaw in our understanding of luminosity functions?

? our models did not include lowest luminosity dwarfs?

? our models did not include structures kicked out from the disk?

Summary

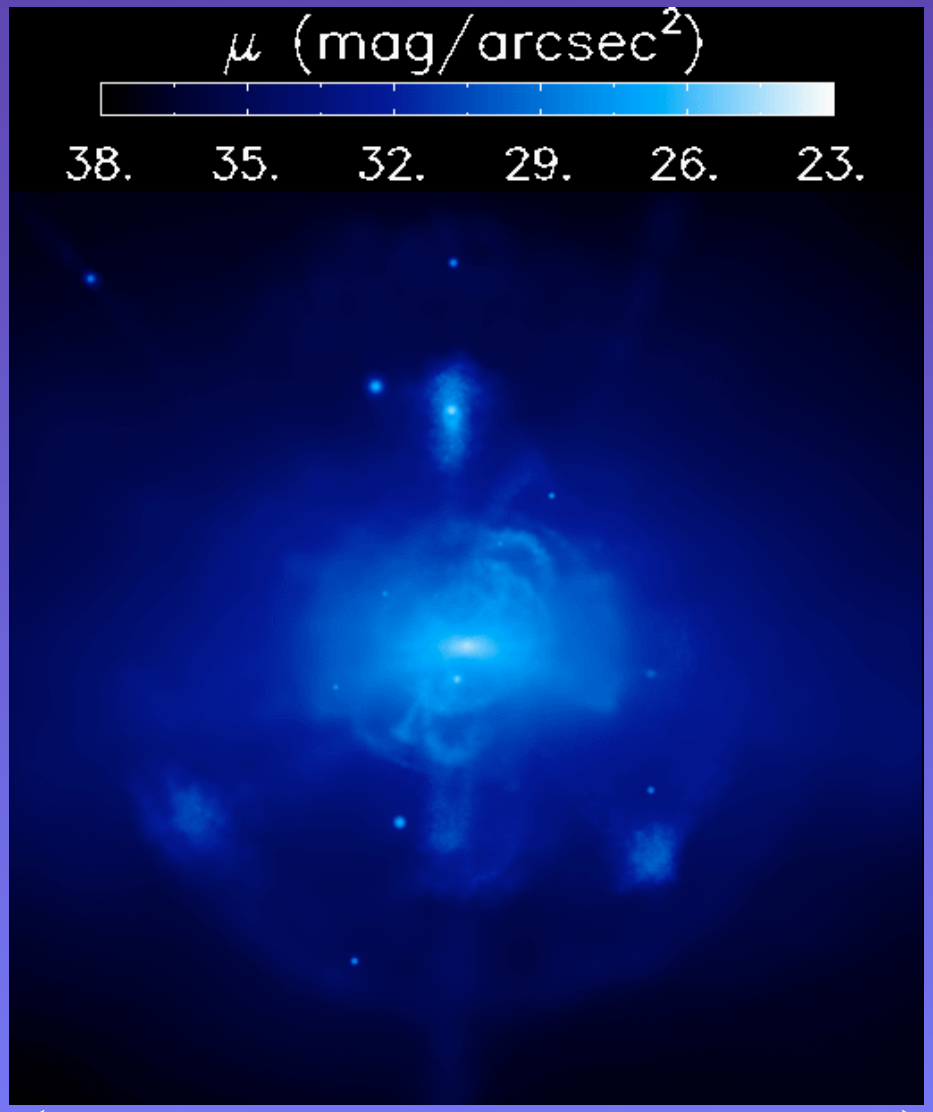




- Current SDSS maps of stellar halo are broadly consistent with hierarchical structure formation
- Current maps contain further formation signatures in substructure
- Great potential for upcoming SDSS data sets - larger and more dimensions!
- Characterizing this substructure objectively will require group-finder working in large numbers of dimensions of different types.

Stellar halo models within LCDM

- Epoch of merging/ accretion: > 8Gyrs ago
- Dominant size of contributors by luminosity/mass fraction: >10^7 Lsun
- Orbit type of contributors: mixture of radial and circular



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Dark matter <-> LCDM

- modeled via merger tree.

- 100,000-particle N-body model run for each luminous satellite accreted.

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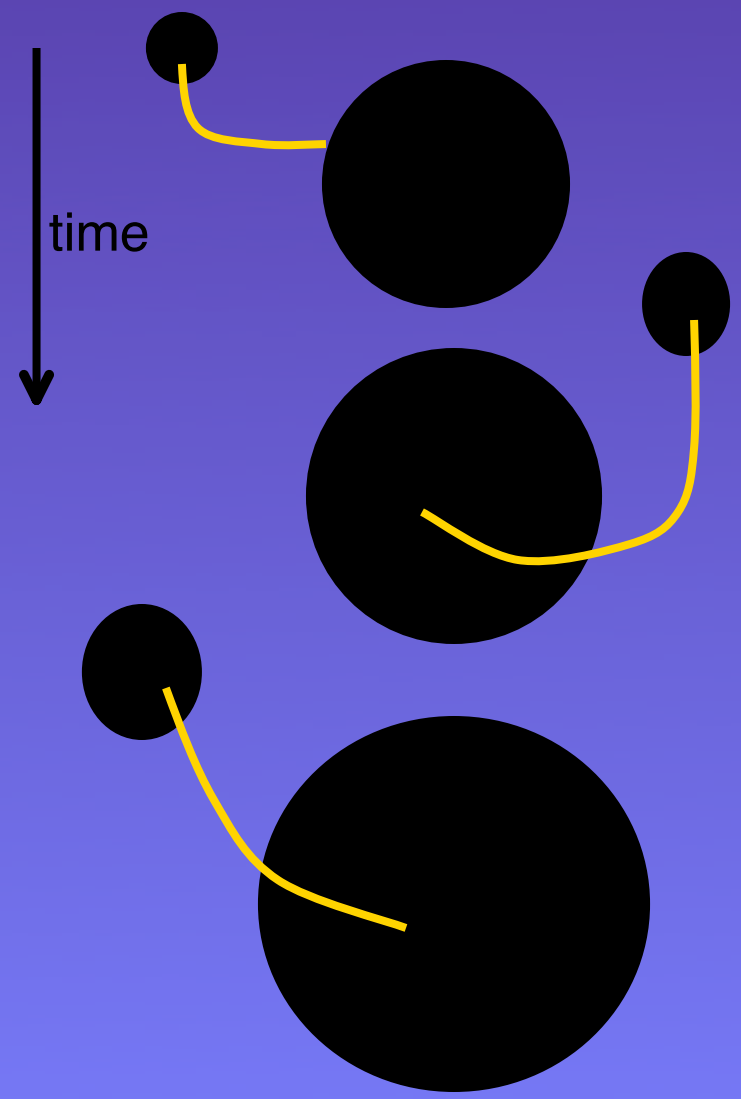

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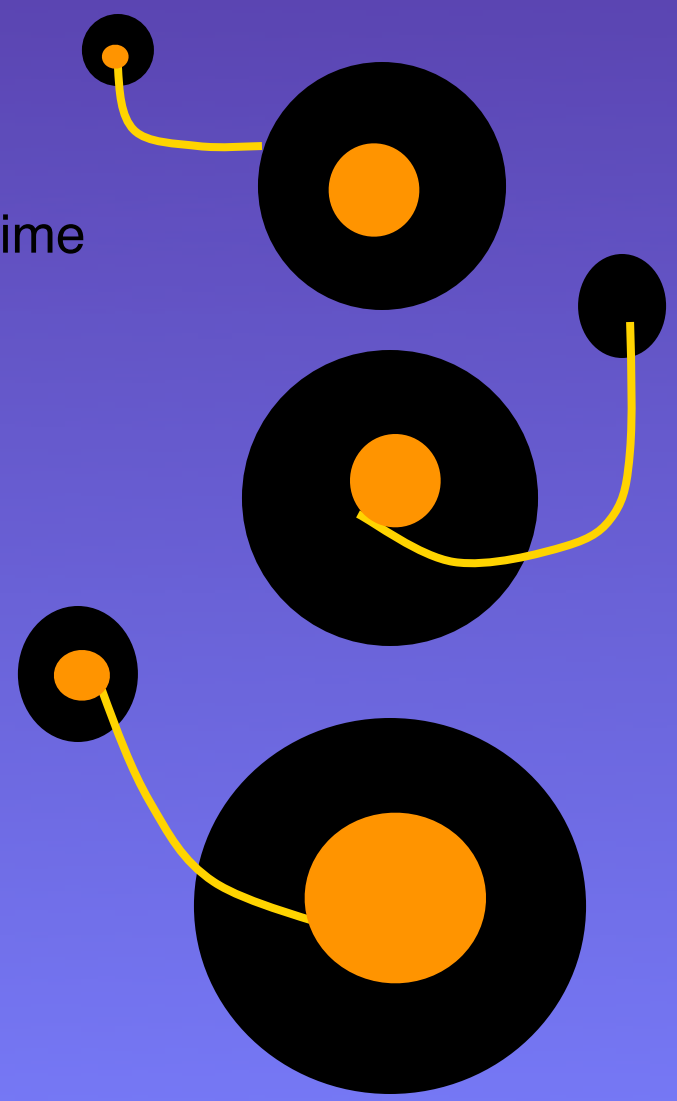
- 100,000-particle N-body model run for each luminous satellite accreted.

- masses, orbits, accretion times and growth of parent dictated by cosmology.



Light matter <-> Local Group observations

- stars painted on after simulations to match

  * number of satellites

  * gas content of field dwarfs (requires long SF time)

  * structural properties of field dwarfs