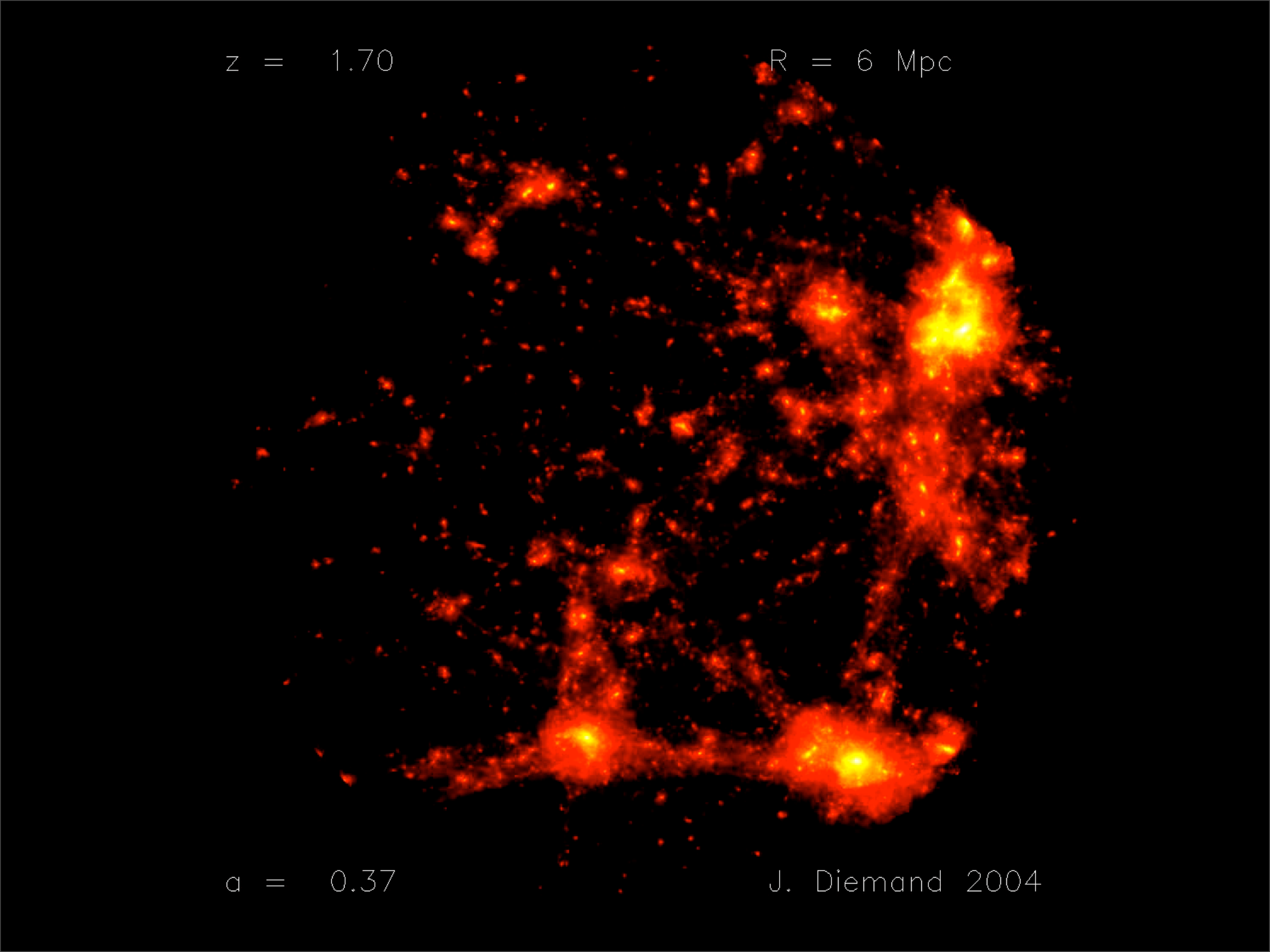
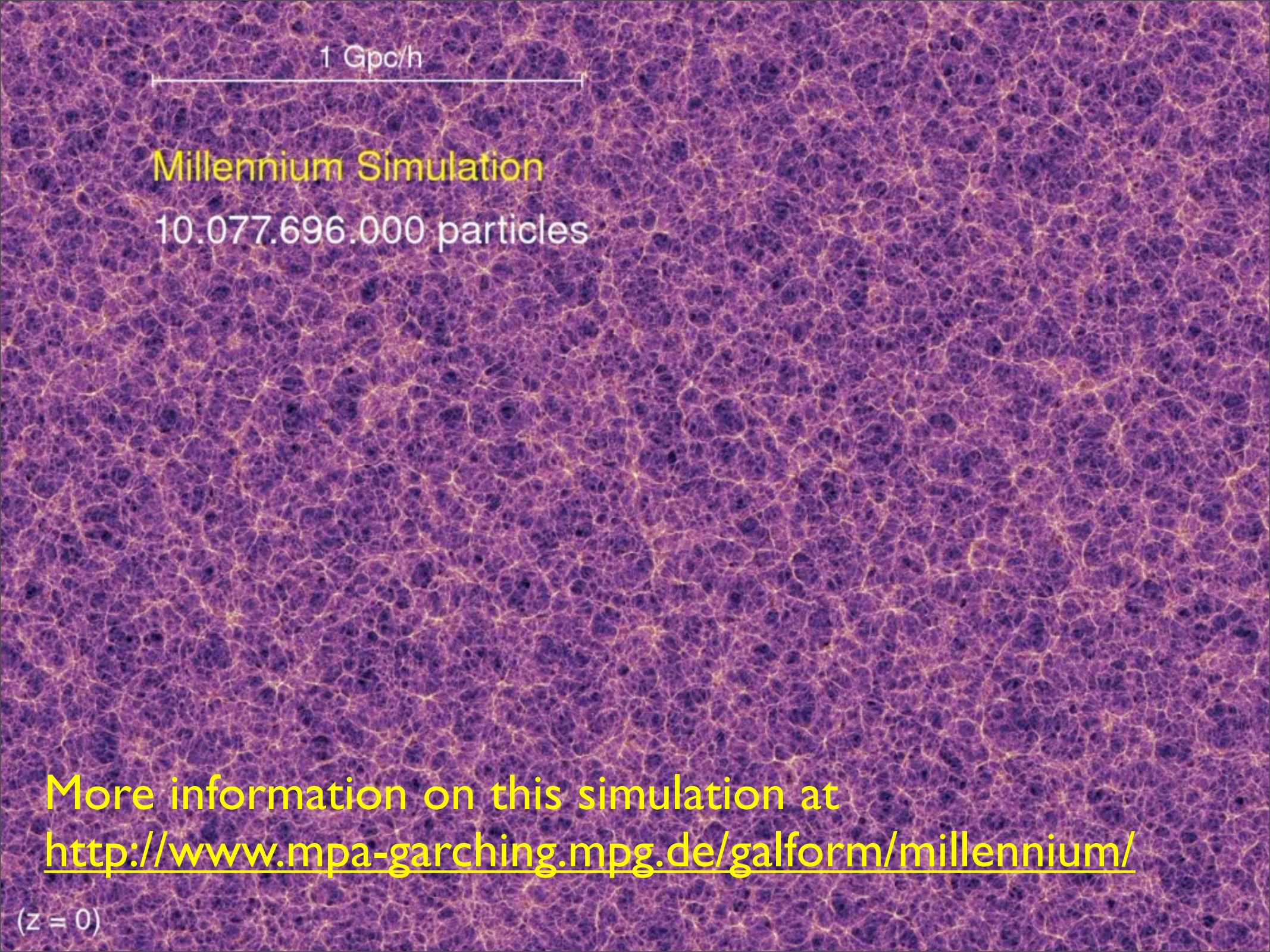
On the shoulders of dwarfs

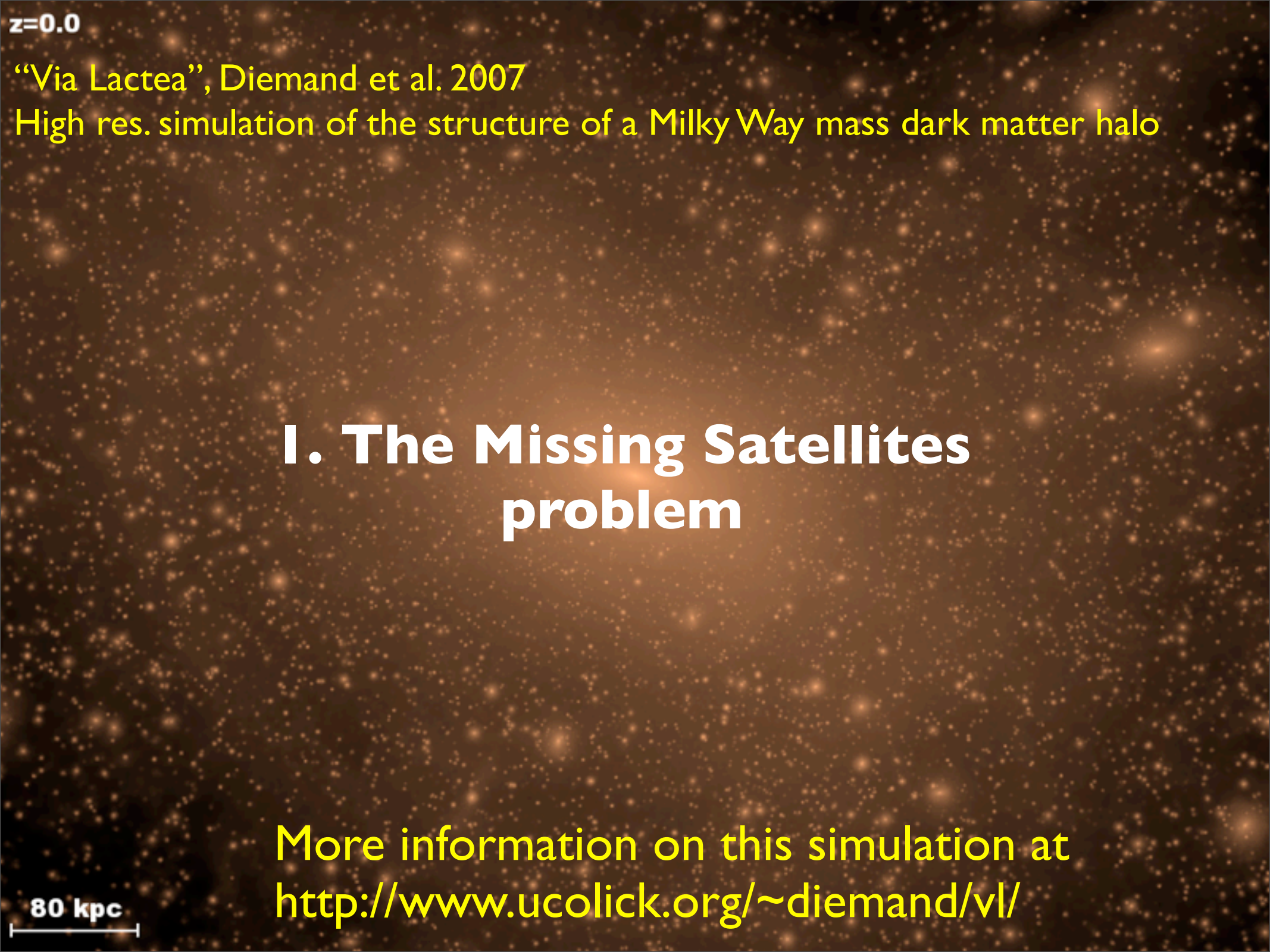
Galaxy formation and the smallest galaxies in the Universe

- Alan McConnachie (UVic)


z = 1.70
R = 6 Mpc
a = 0.37
J. Diemand 2004



More information on this simulation at
http://www.mpa-garching.mpg.de/galform/millennium/

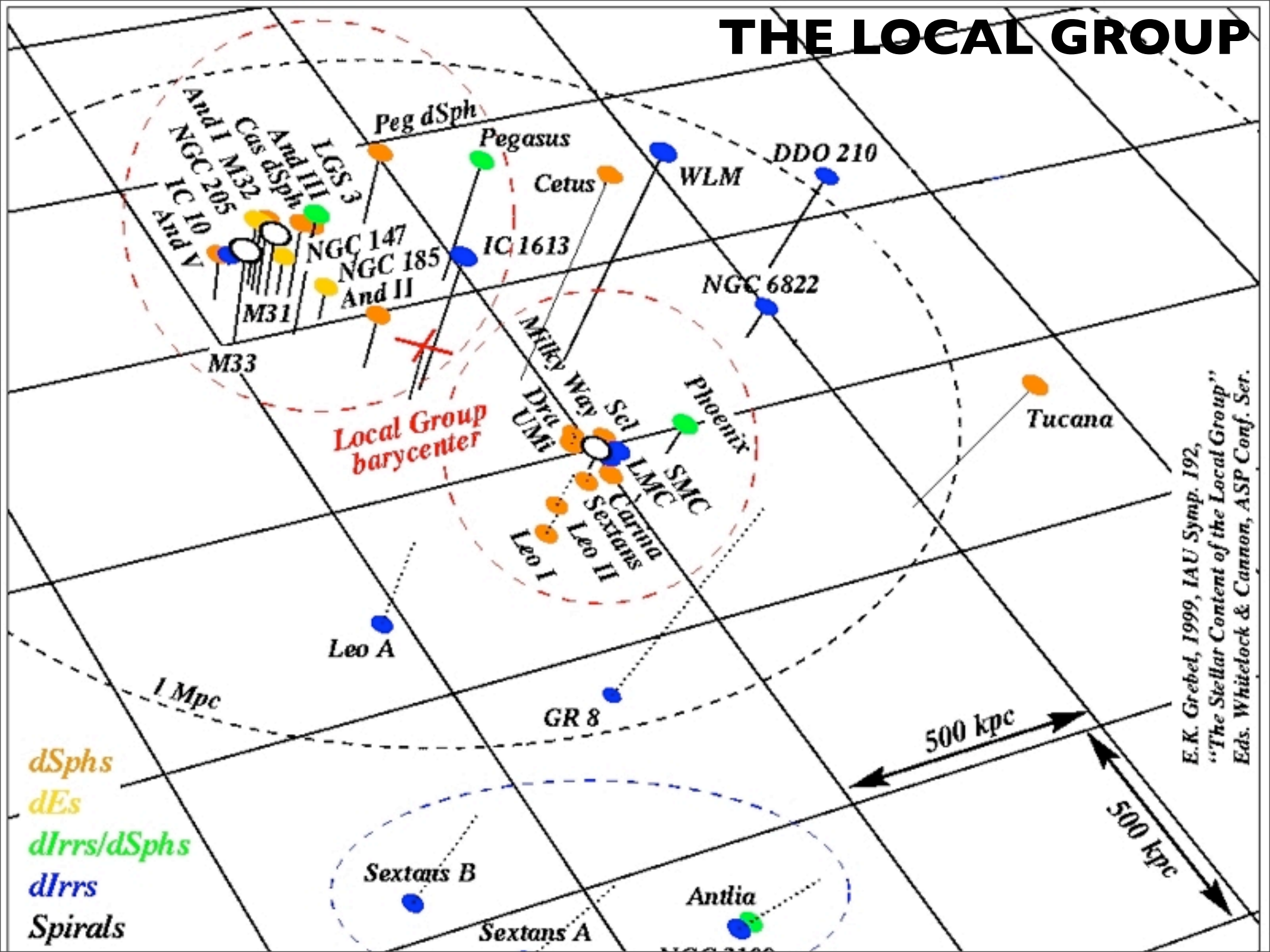


"Via Lactea", Diemand et al. 2007
High res. simulation of the structure of a Milky Way mass dark matter halo

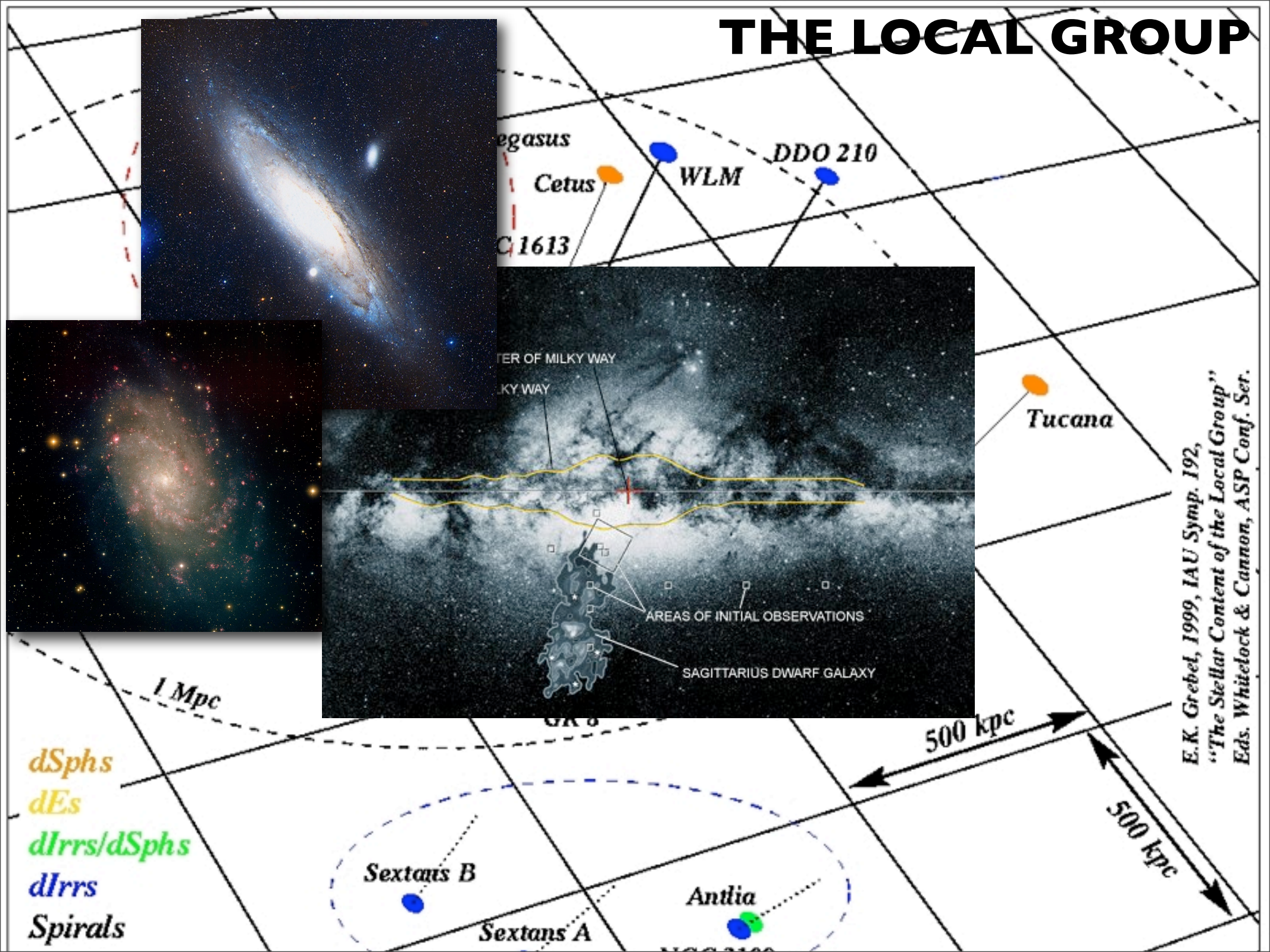
1. The Missing Satellites problem

More information on this simulation at
http://www.ucolick.org/~diemand/vl/

THE LOCAL GROUP



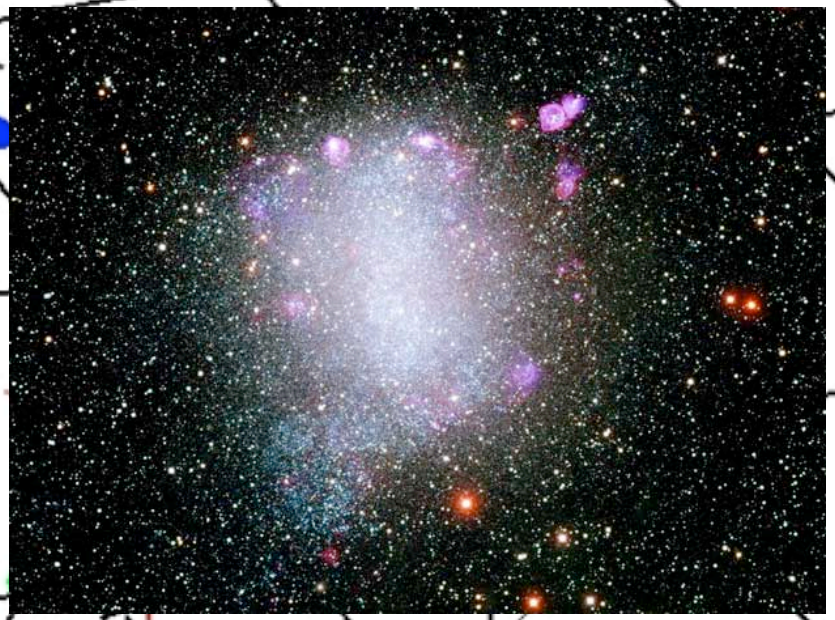
THE LOCAL GROUP



THE LOCAL GROUP

Dwarf irregular galaxies:

- Contain young stars, gas, other evidence of recent star formation
- Rotationally supported
- Preferentially found isolated



Dwarf spheroidal galaxies:

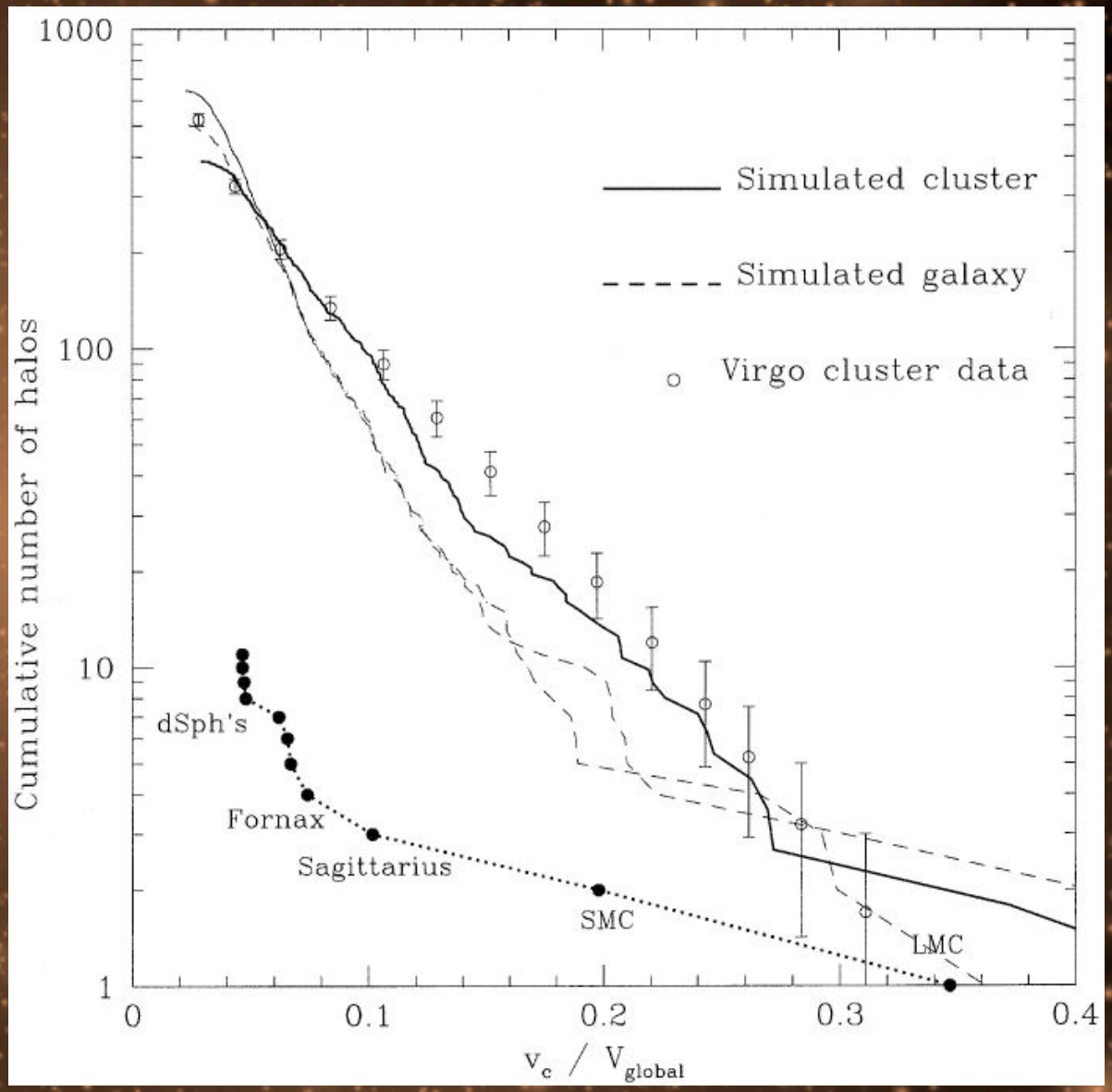
- No gas or young stars
- Pressure (velocity dispersion) supported
- Preferentially found as satellites to MW and M31

z=0.0

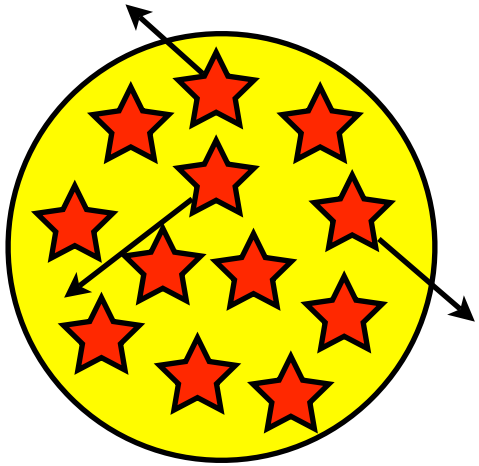
As of 2004/2005, the Milky Way and M31 each had ~12 satellite galaxies. Current simulations predict that they should have >>10 000.

Option 1: we're missing lots and lots of satellites...

Or option 2...

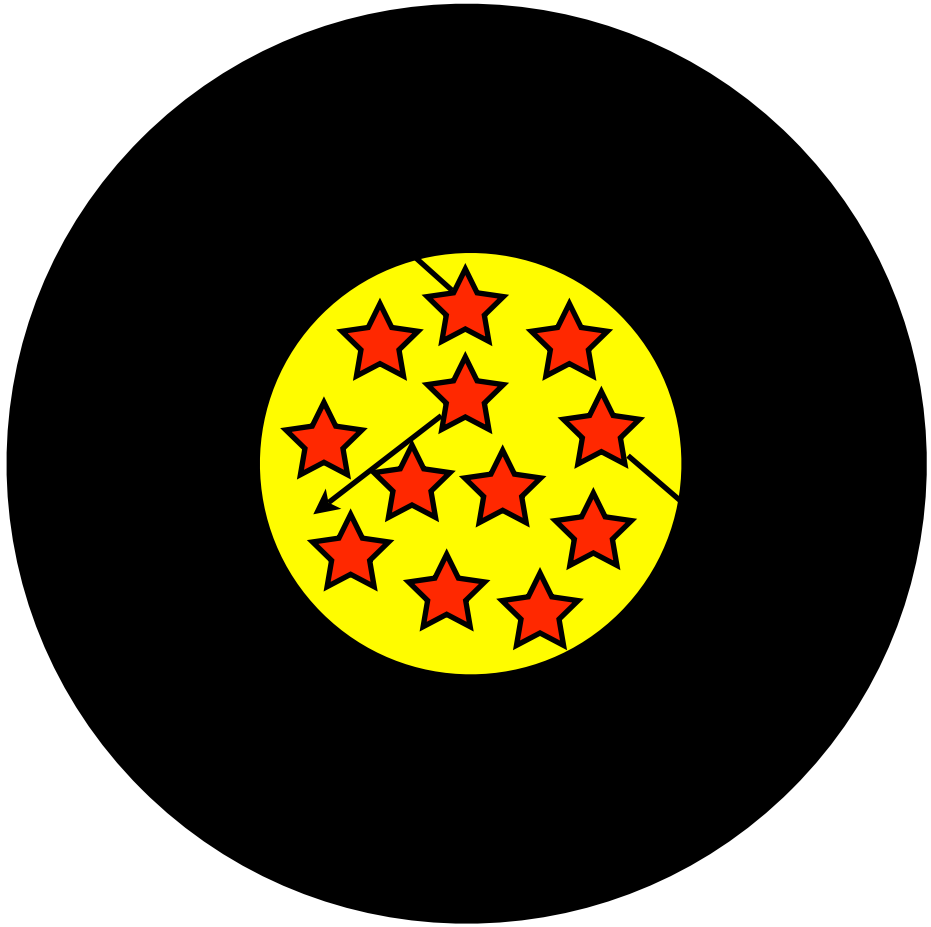


80 kpc



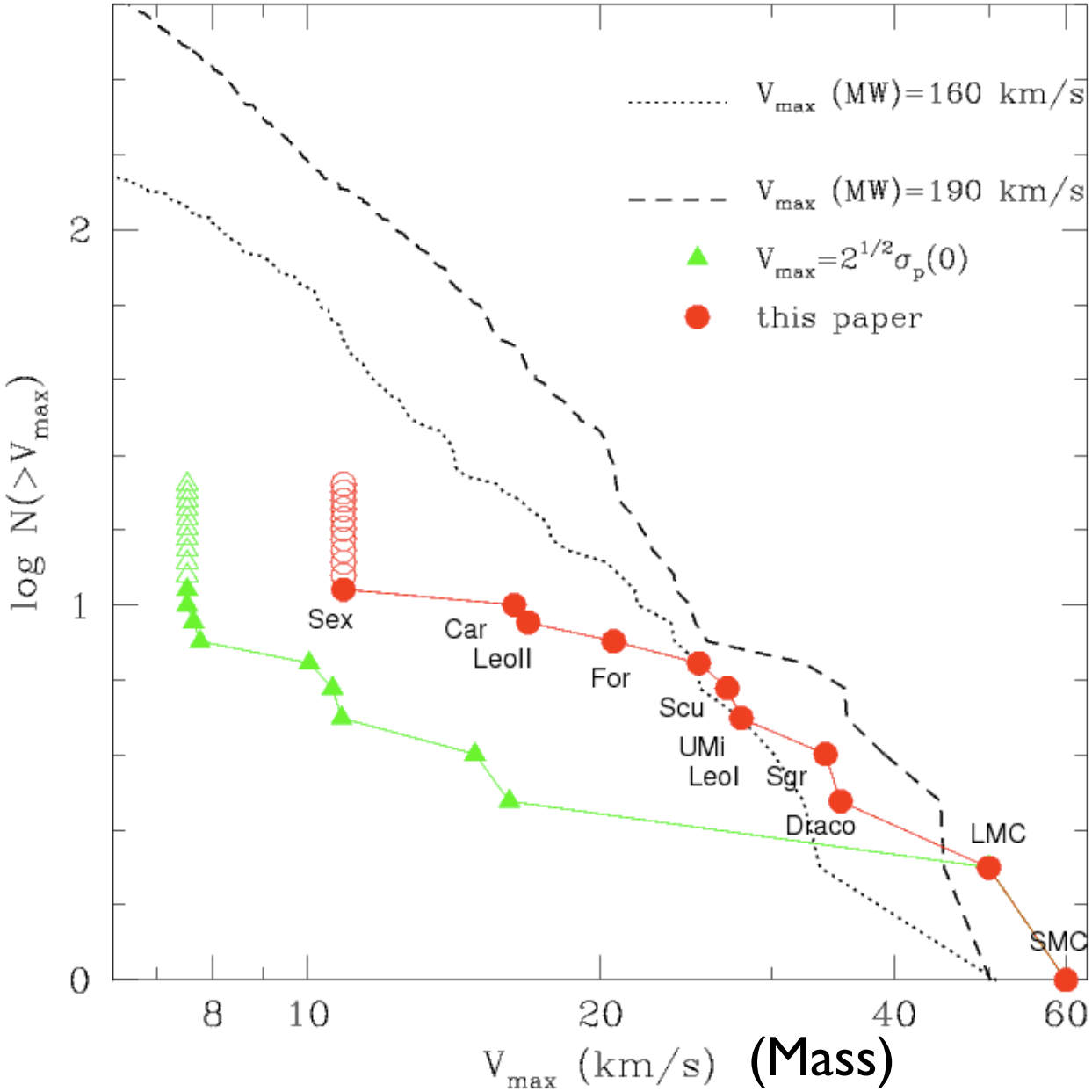
Stars move around in dwarf galaxy due to gravity from mass contained within light...get velocities, get mass within light

But what if the situation is more like this....

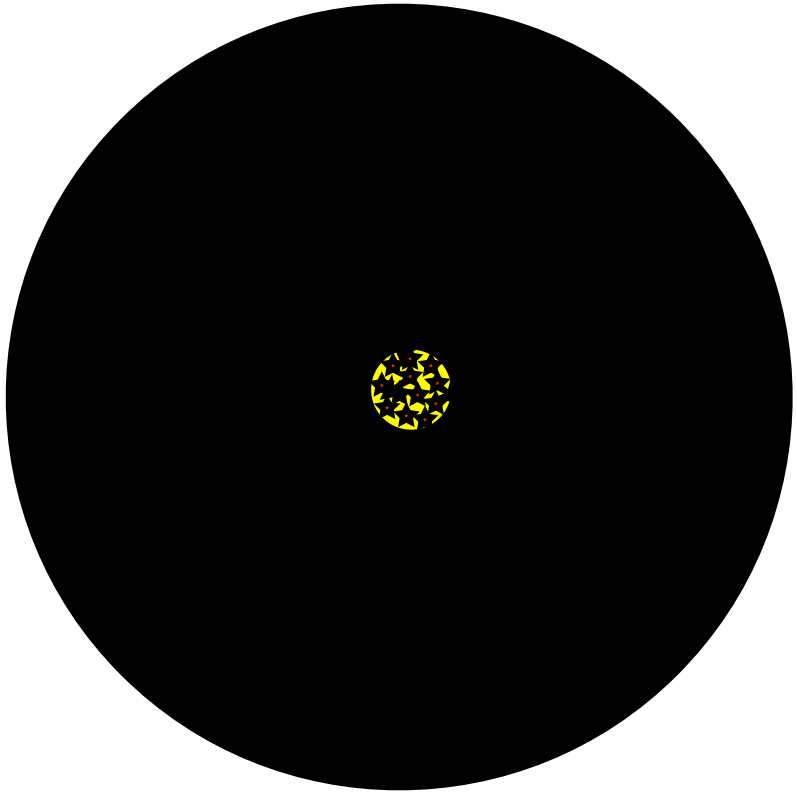


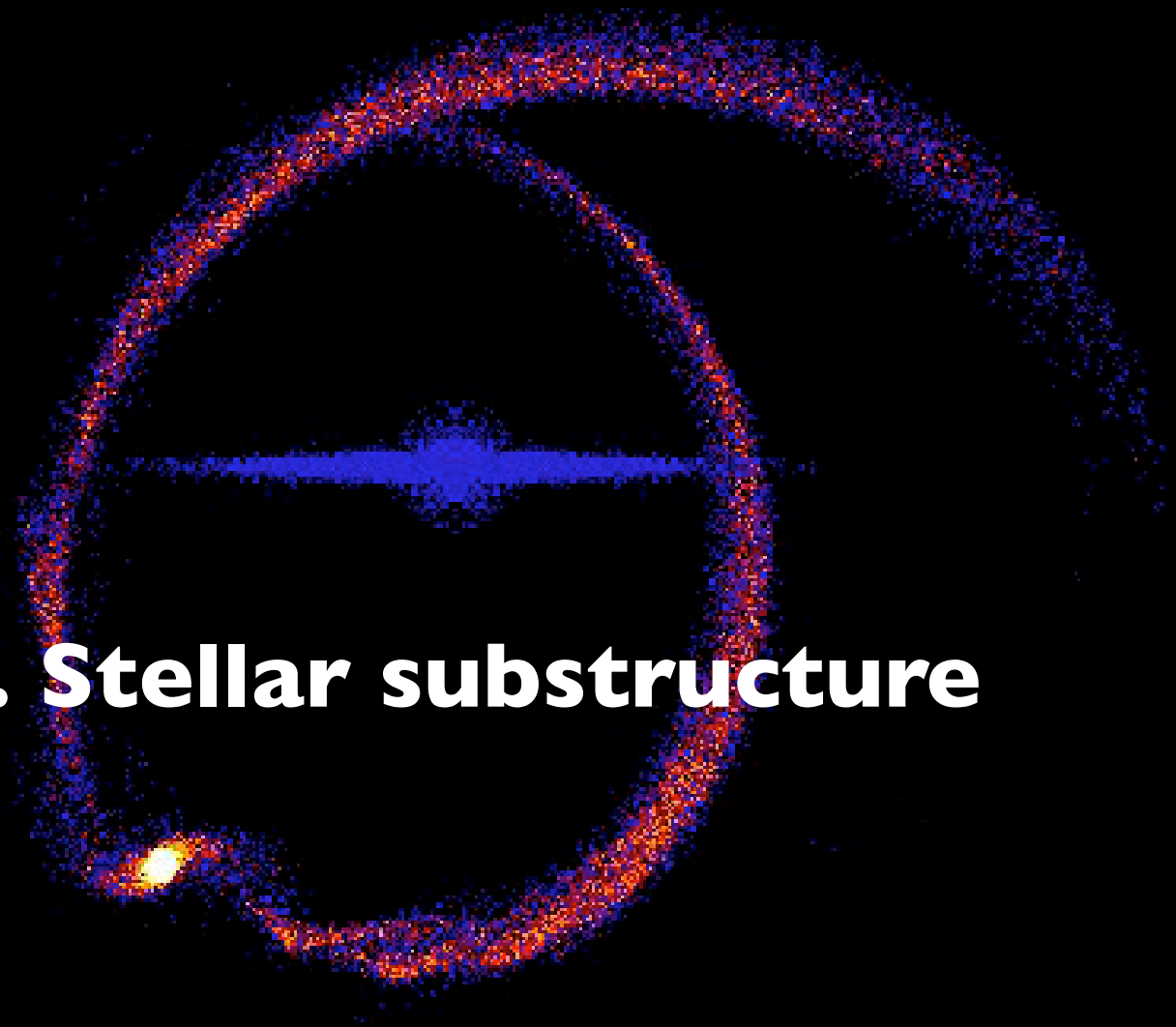
Use constraints from both dwarf galaxy observations and cosmological theory...

No disagreement down to a certain mass limit



(Mass)





2. Stellar substructure

NGC 5907

An Sc-class edge-on galaxy known as the Splinter Galaxy for its characteristic shape.

- **RA:** 15:16
- **Dec:** 56:19
- **Size:** 11.8x1.3'
- **Magnitude:** 10.3
- **Distance:** 40 Mly
- **Constellation:** Draco

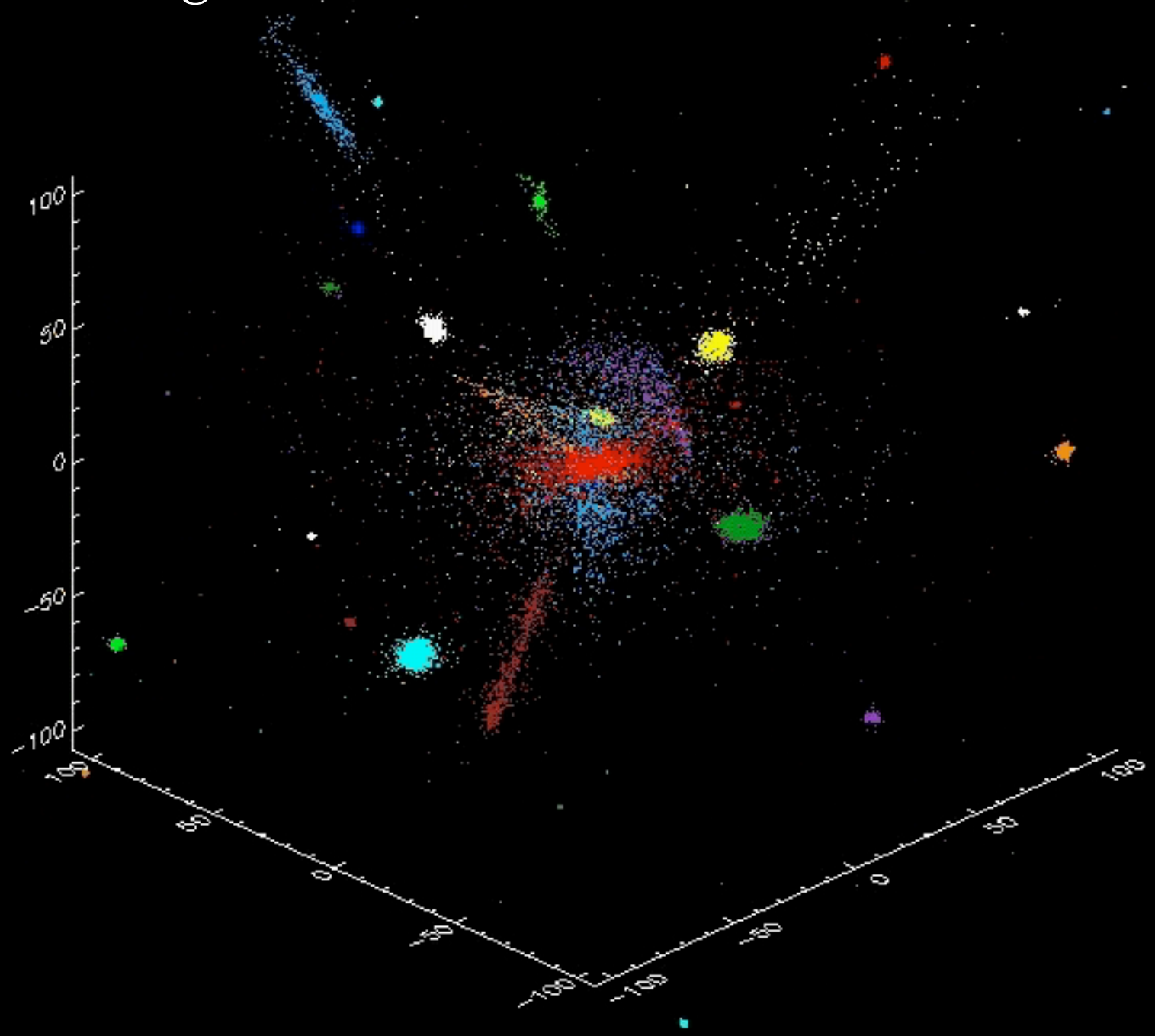
2.3. Black Bird Remote Observatory Telescope

Finally, we obtained very deep images of NGC 4013 with the f/8.3 Ritchey-Chretien 20-inch telescope of the Black Bird Remote Observatory (BBRO) situated in the Sacramento Mountains (New Mexico, USA) during different dark sky observing runs in the period UT 2006-11-06 though UT 2006-12-28. We used a Santa Barbara Instrument Group (SBIG) STL-1110 CCD camera, which yields a large field of view (27.7′ x 18.2′) and a plate scale of 0.45 ″pixel^{-1}. These data consist of multiple deep exposures through non-infrared clear luminance ($3500 < \lambda < 8500$) and red, green and blue filters from the SBIG custom scientific filters set[1]. The images were reduced using standard procedures for bias correction and flat-fielding. To enhance the signal-to-noise of the faint structures around NGC 4013, the image noise effects were filtered by means of a Gaussian blur filter (Davies 1990). The final image of NGC 4013 is shown in Figure 2. We have added the labels A through G to identify some photometric feature we discuss in the following Section.

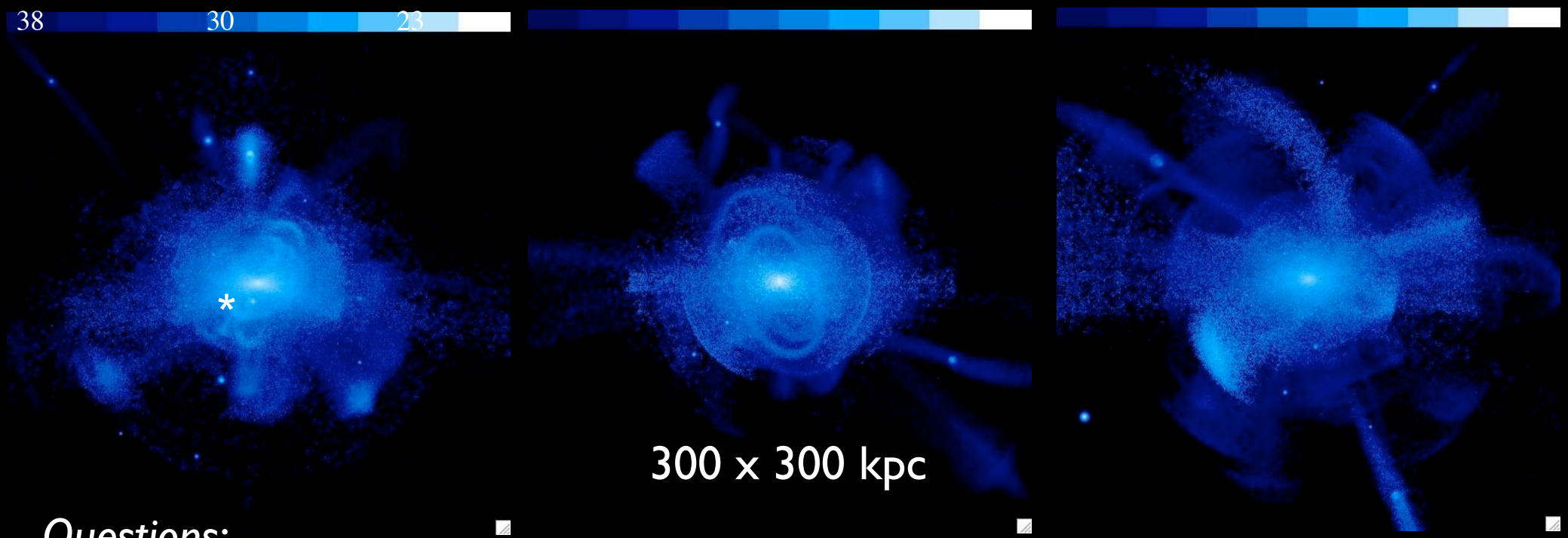
Also see http://apod.nasa.gov/apod/ap080207.html and links from that website

Martinez-Delgado et al. (2008)

Galactic indigestion?

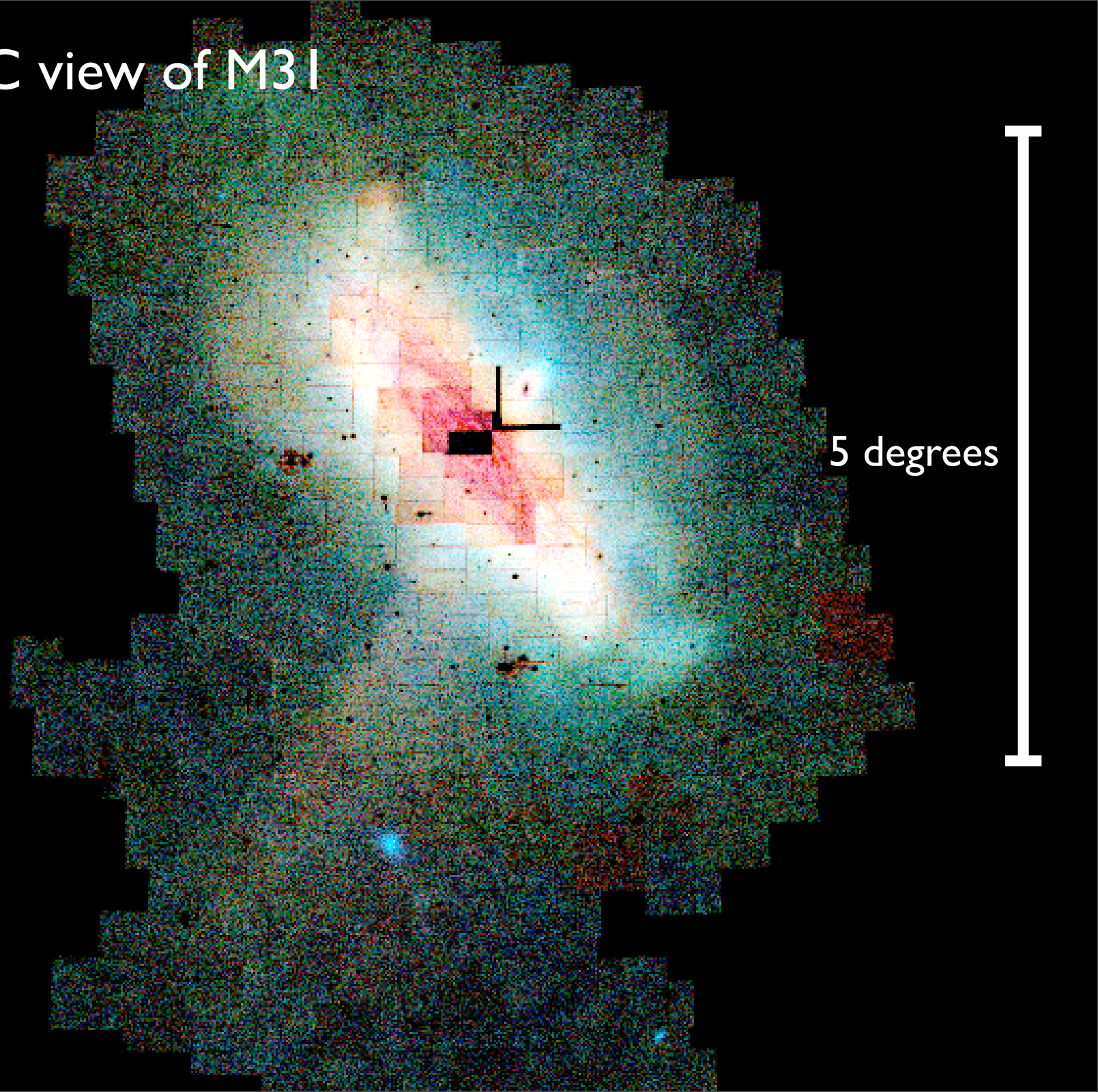


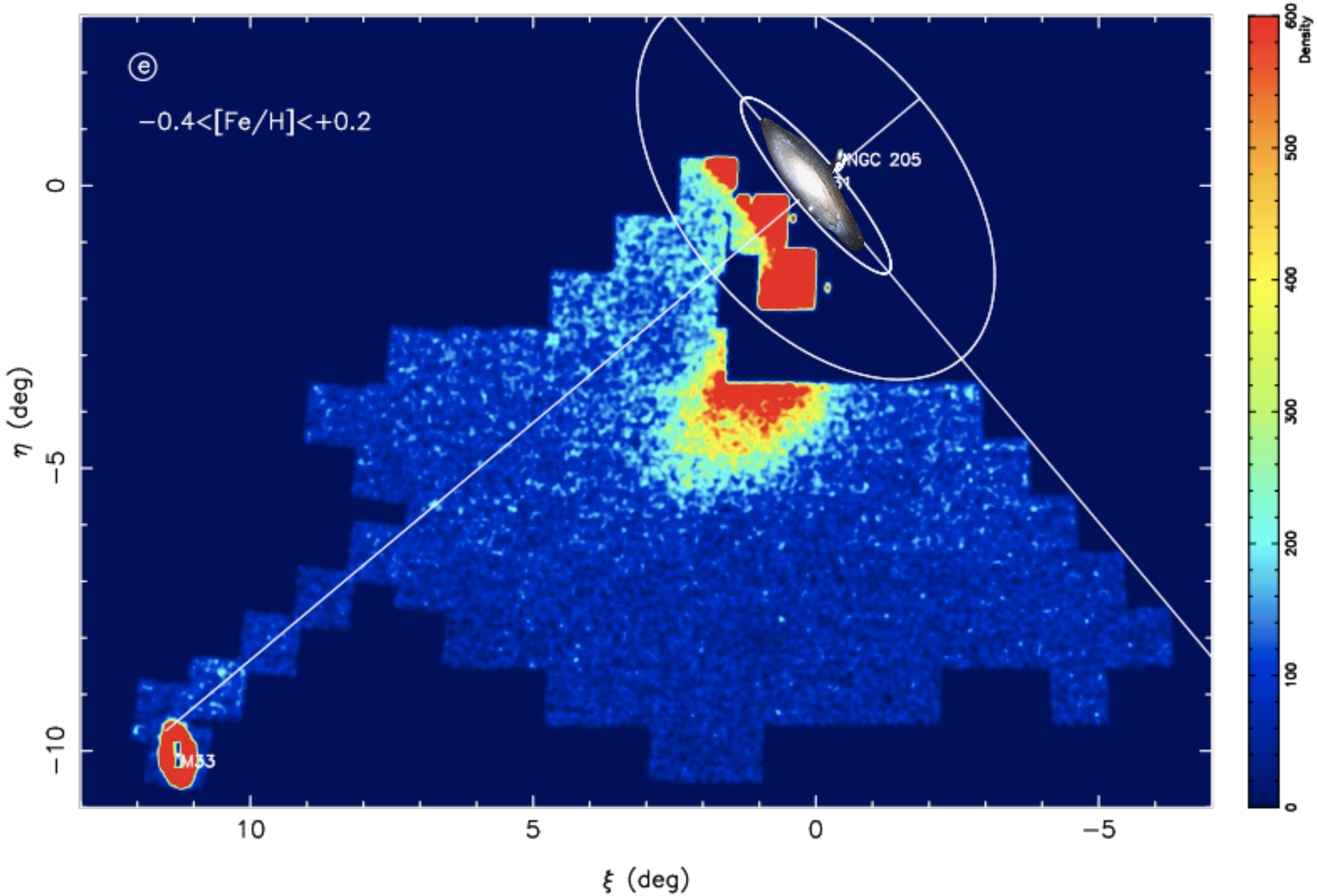
Solid predictions now exist for dark and luminous matter on small scales:
e.g., over half of stellar halo in place 8 Gyrs ago; effectively all in place 4Gyrs ago; stellar halo beyond 50kpc dominated by late accretions; late, massive accretions rare; stellar halo has power law index 3, 4, steeper than the dark matter; mildly triaxial

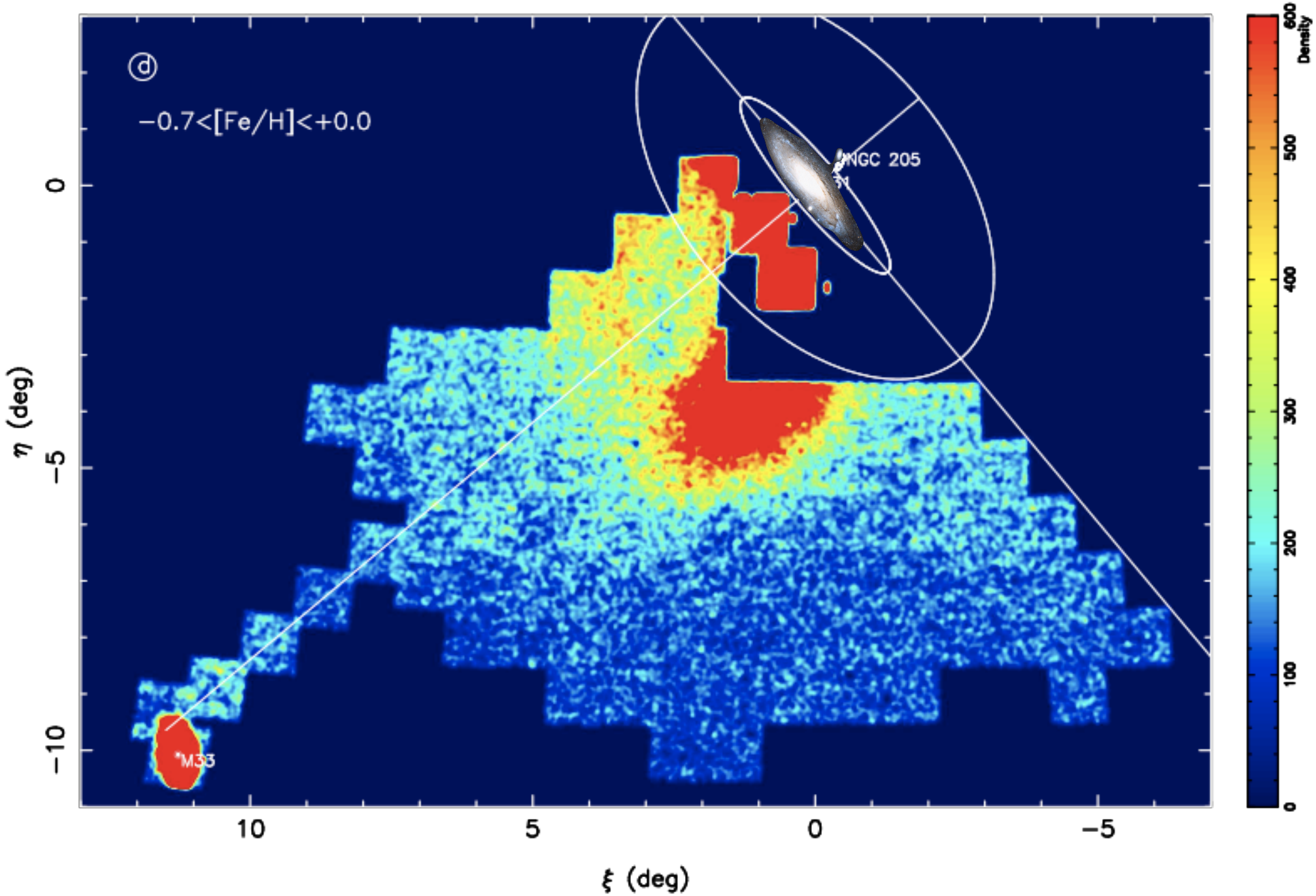


Questions:
How much substructure? Too much? Too little? Missing satellite problem.
What's the power spectrum of substructure? Early versus late accretions?
What is the global shape of the stellar haloes?
Follow-up imaging + spectroscopy: what is the accretion history of M31 and M33? SFH + chemical evolution of proto-galactic building blocks.

The INT WFC view of M31




e
−0.4<[Fe/H]<+0.2
NGC 205
M31
M33
η (deg)
ξ (deg)
0
−5
−10
10
5
0
−5
Density
0
100
200
300
400
500
600


d
−0.7<[Fe/H]<+0.0
NGC 205
M31
M33
η (deg)
ξ (deg)
0
−5
−10
10
5
0
−5
Density
0
100
200
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400
500
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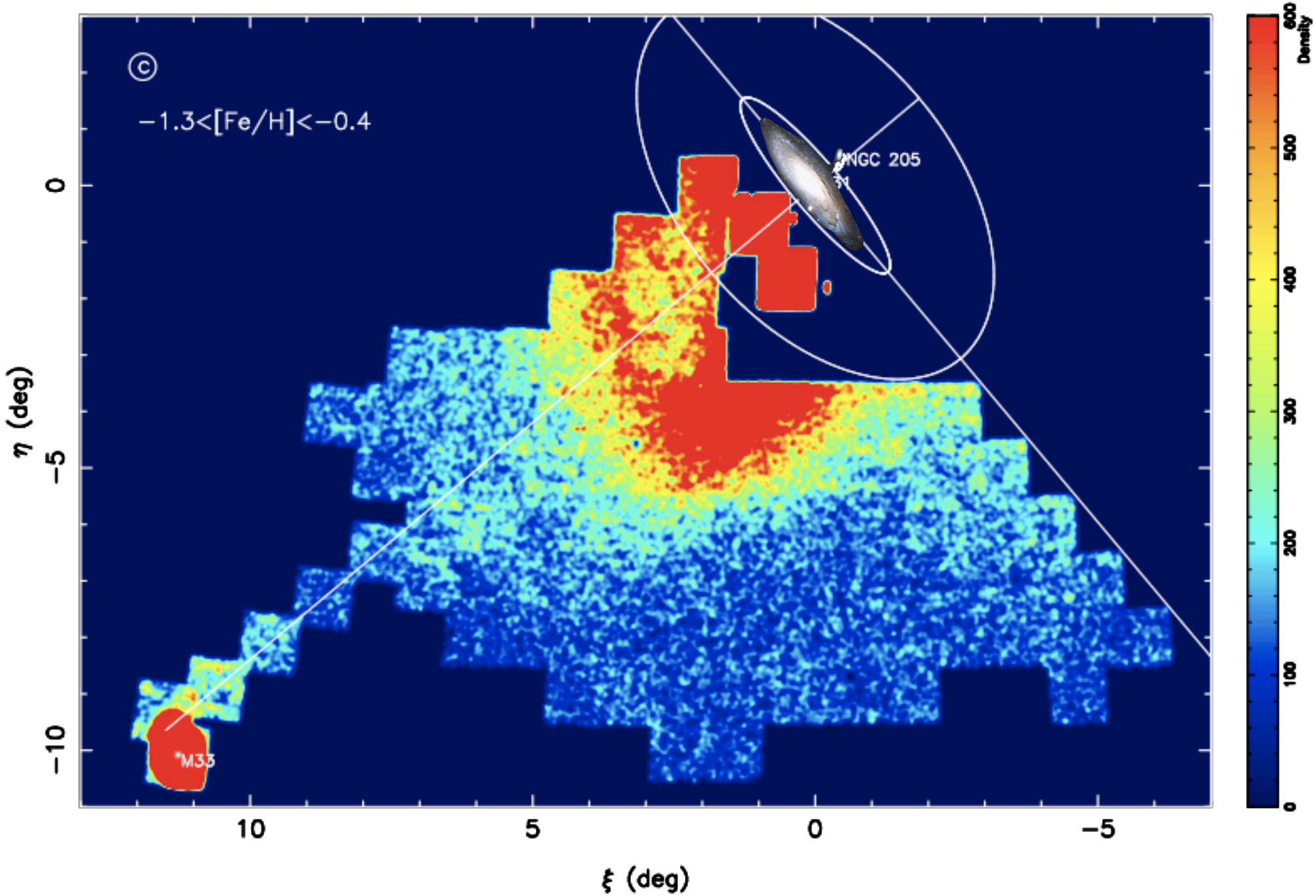
c
−1.3<[Fe/H]<−0.4
NGC 205
M31
M33
η (deg)
ξ (deg)
0
−5
−10
10
5
0
−5
Density
0
100
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300
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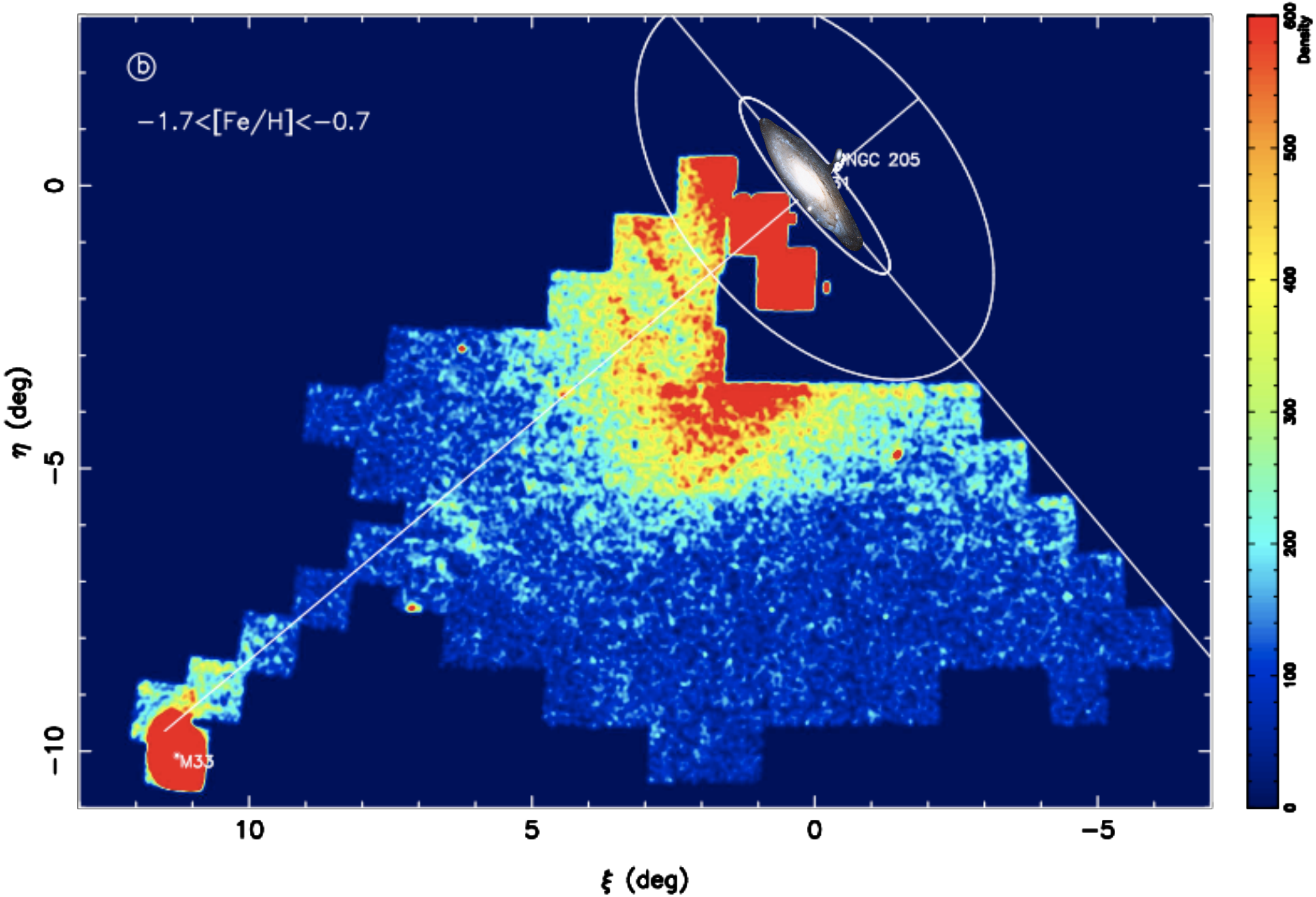
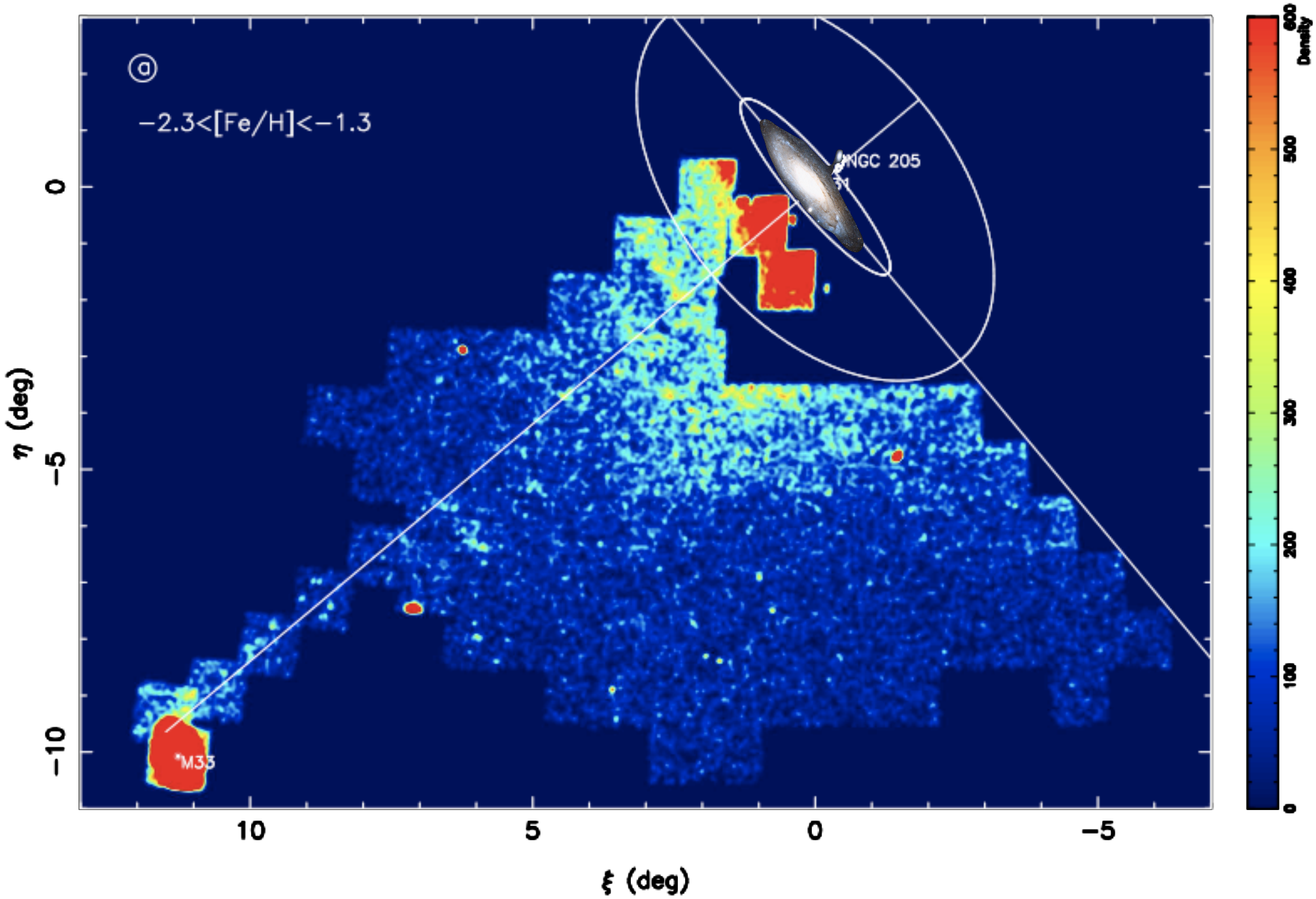
500
600


b
−1.7<[Fe/H]<−0.7
NGC 205
M31
M33
η (deg)
ξ (deg)
0
−5
−10
10
5
0
−5
Density
0
100
200
300
400
500
600


(a)
−2.3<[Fe/H]<−1.3
NGC 205
M31
M33
η (deg)
ξ (deg)
0
−5
−10
10
5
0
−5
Density
0
100
200
300
400
500
600

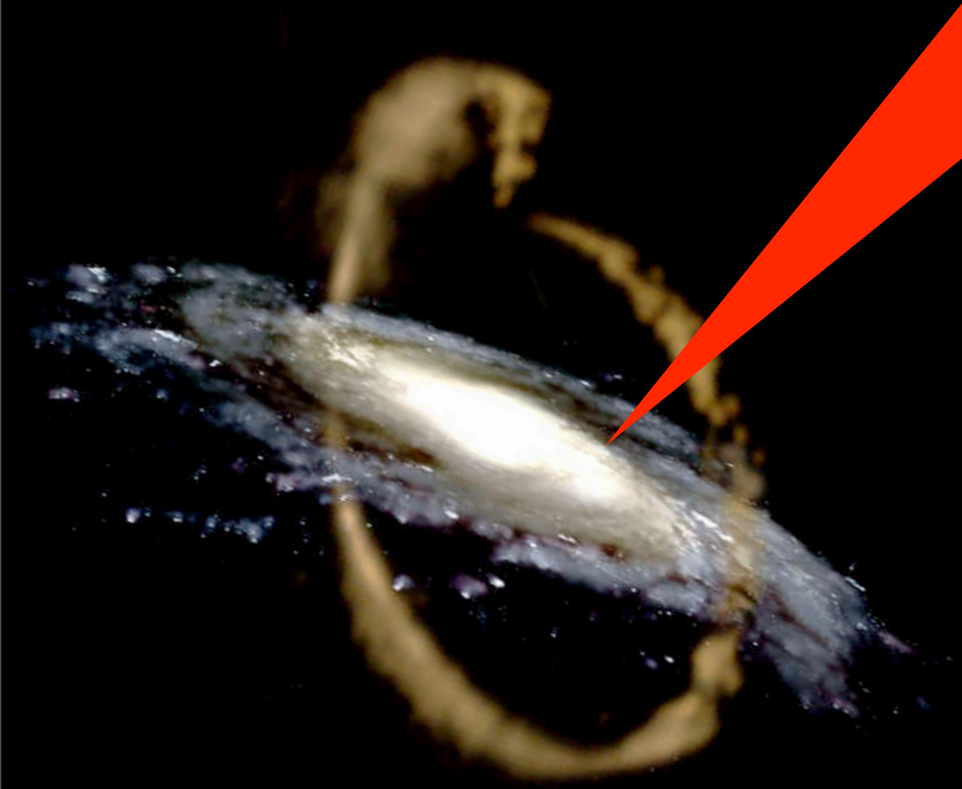
Sloan Digital Sky Survey

Mapping the Universe

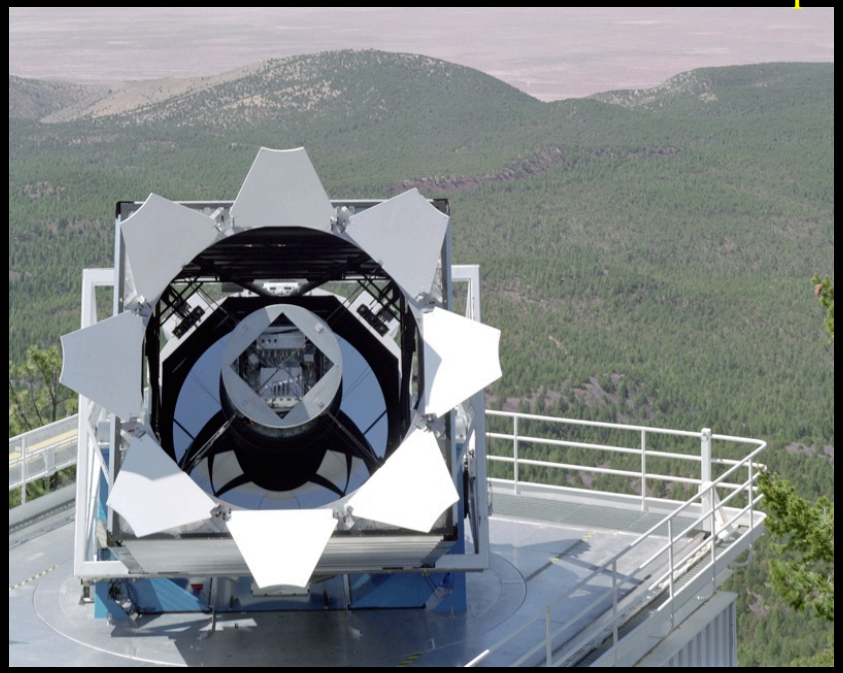
SEGUE

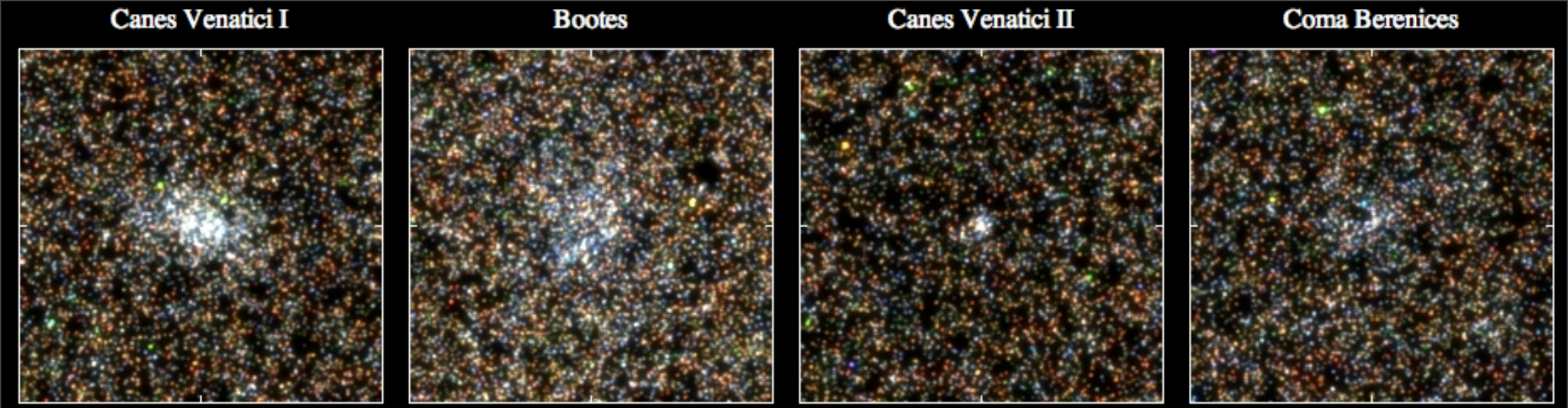
Mapping the Galaxy

See http://www.sdss.org/ for more information on this survey

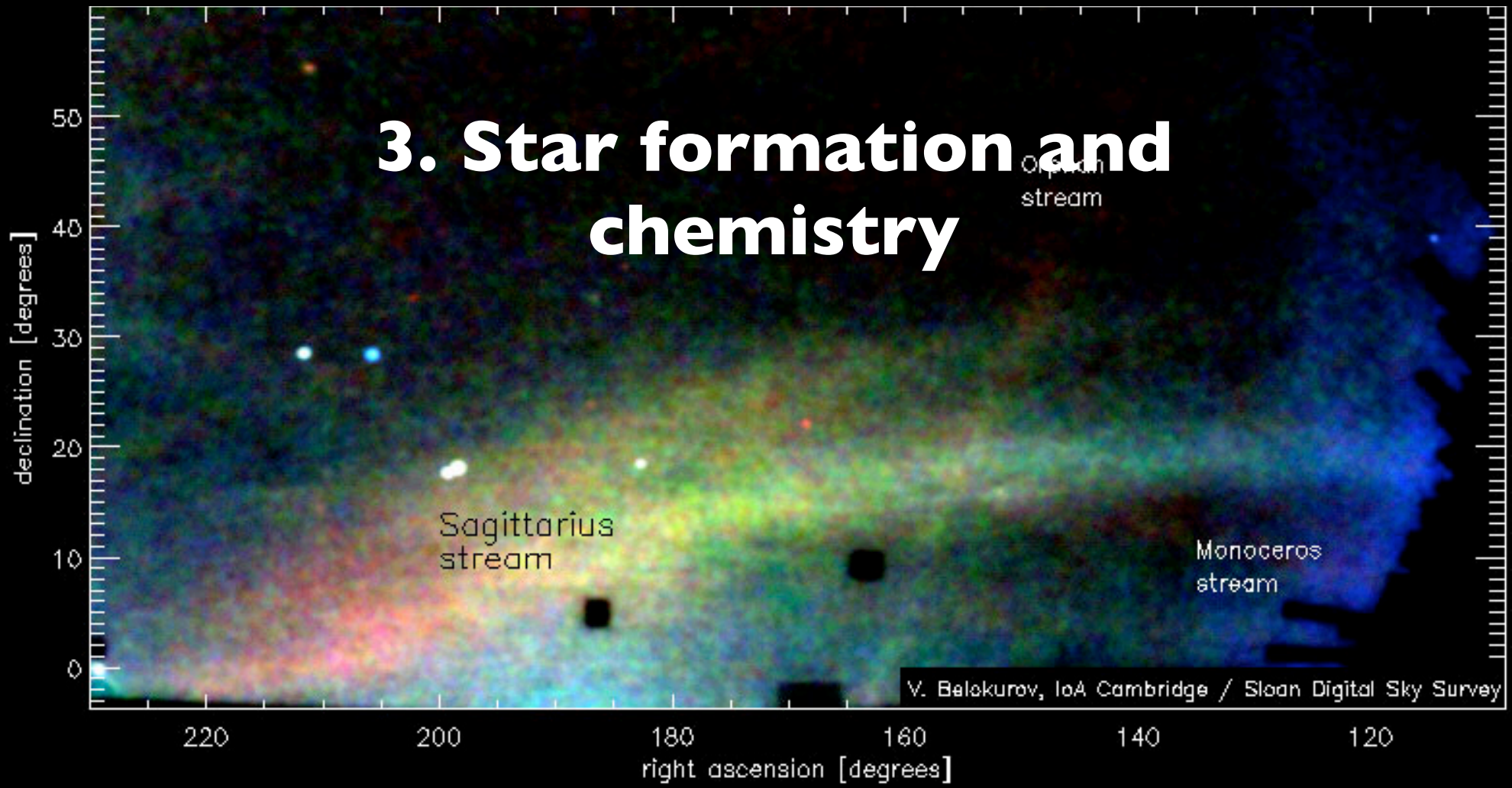


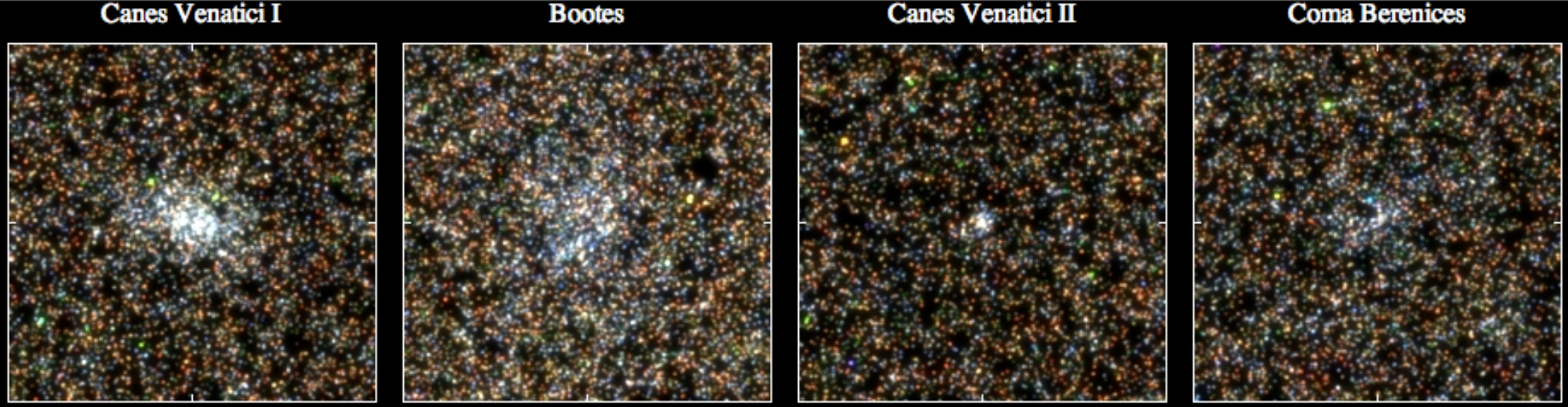
Apache Point Observatory
SDSS telescope





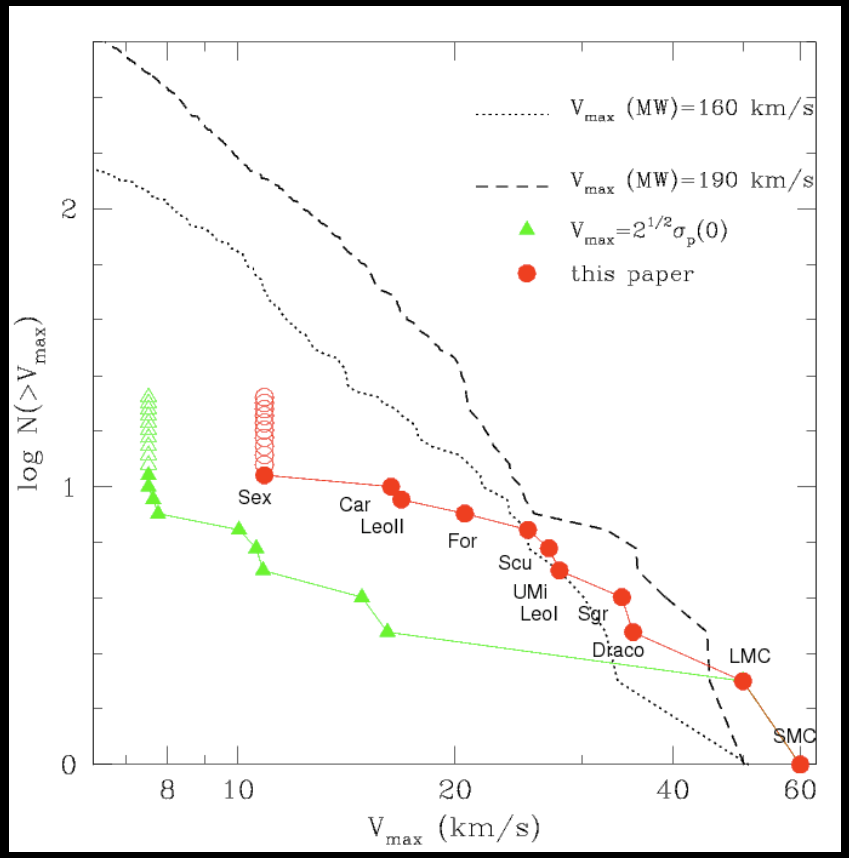
3. Star formation and chemistry

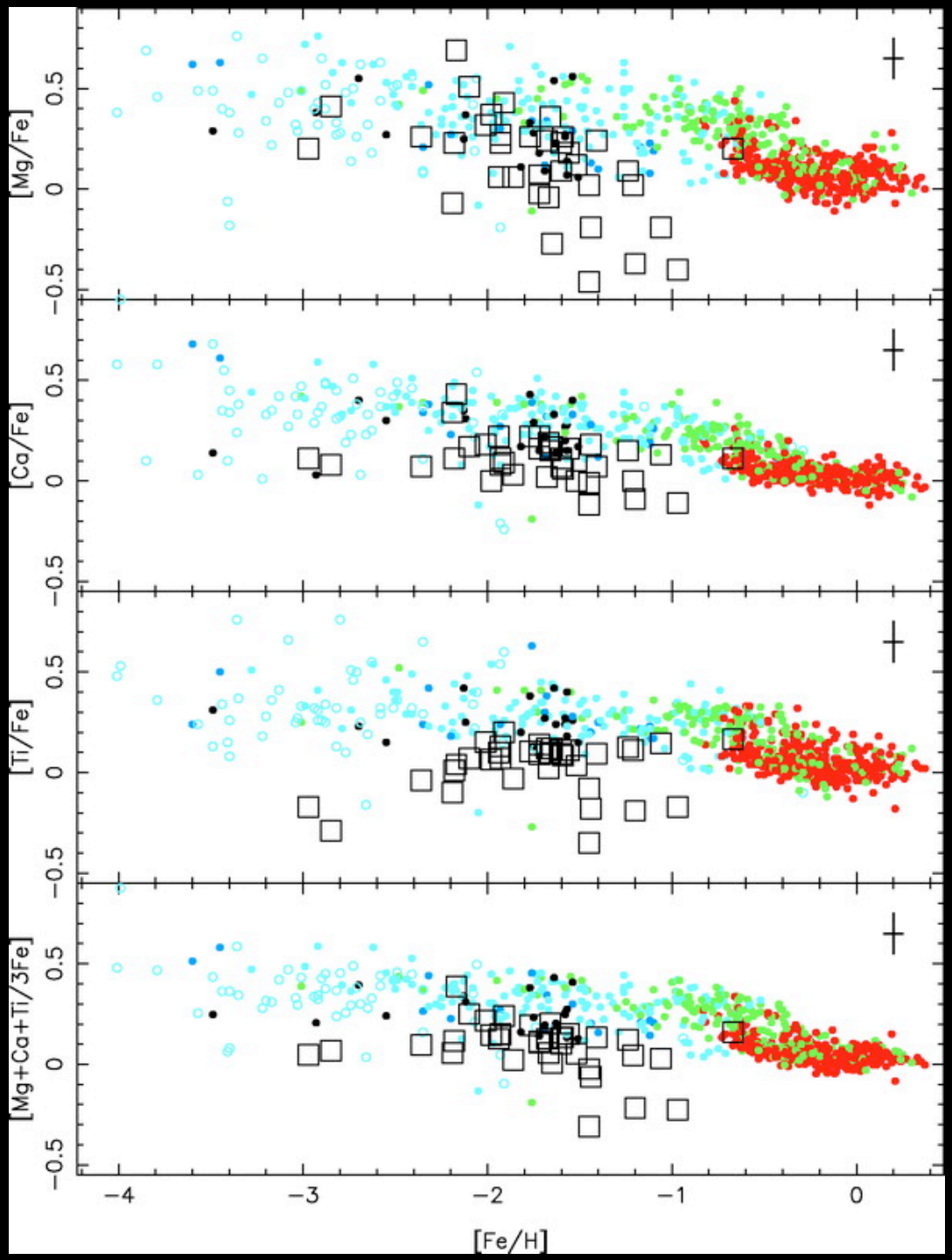




• Missing Satellites II

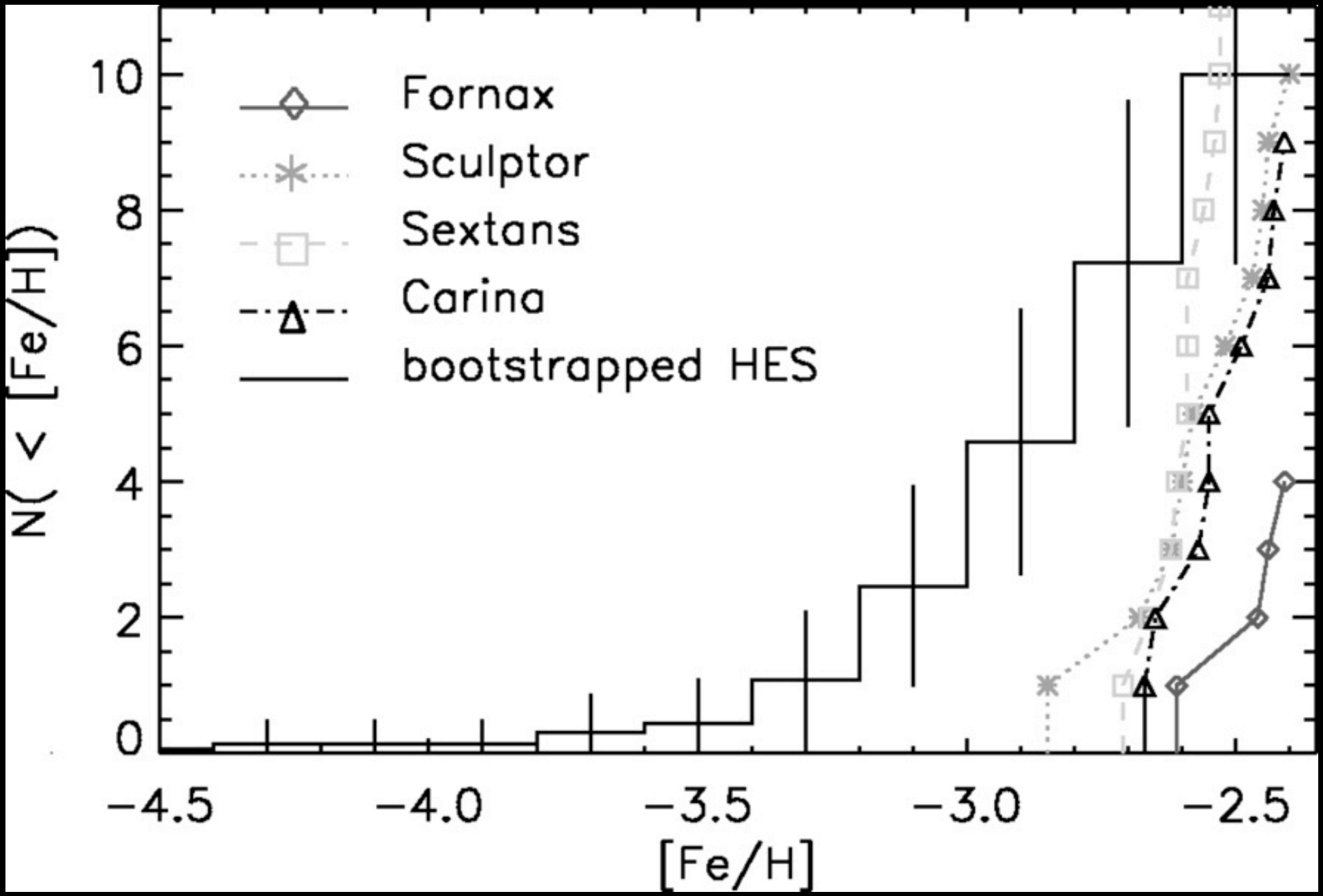
- DM haloes get more numerous at lower mass...presumably not every dark matter halo hosts a galaxy
- Lower limit to mass of halo which can host stars...
- Ultra-faint dwarfs are highly senstive probes of the mechanisms which form stars

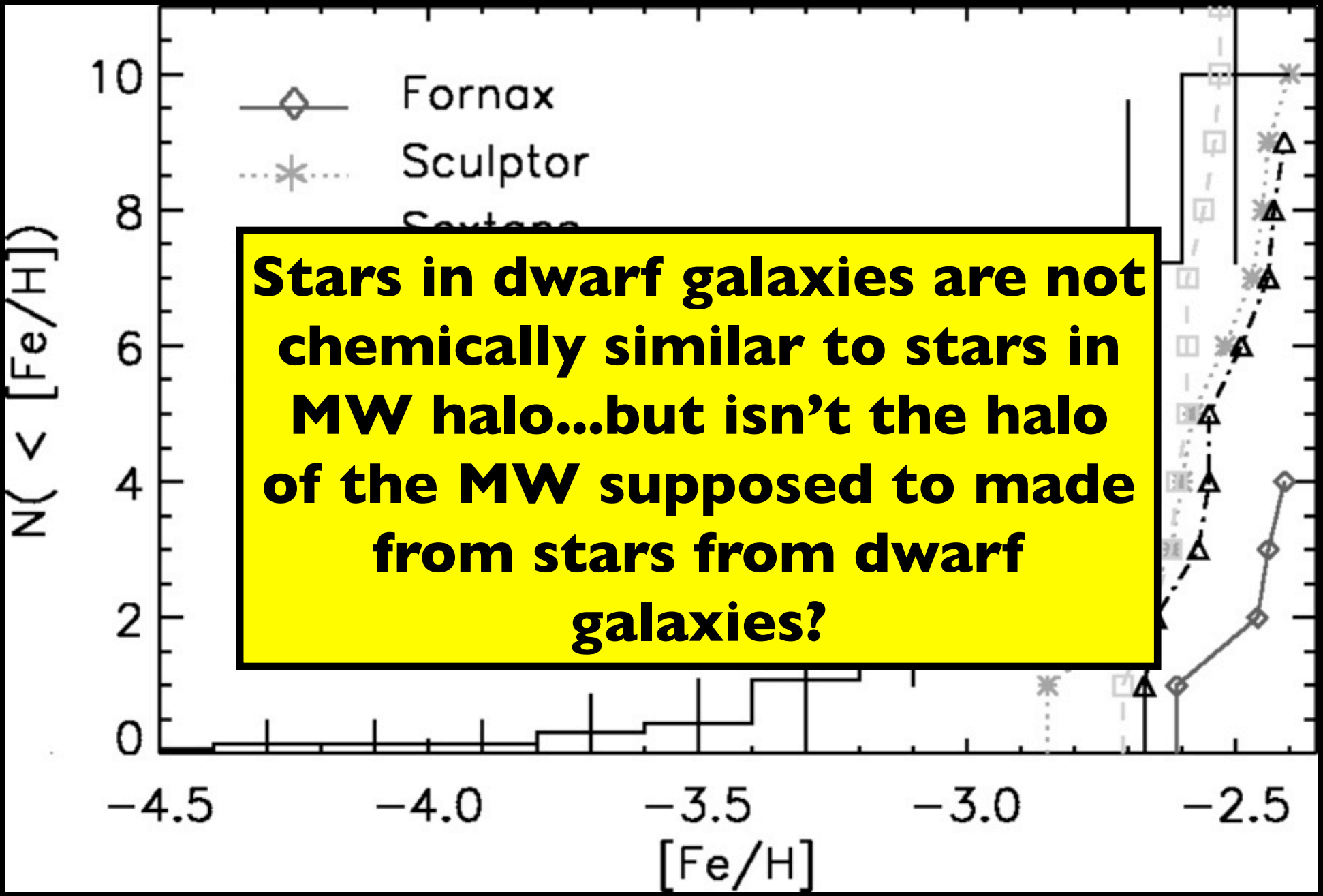




Detailed chemical abundances of stars provide clues into the possible connections between dwarf galaxies and stellar haloes.

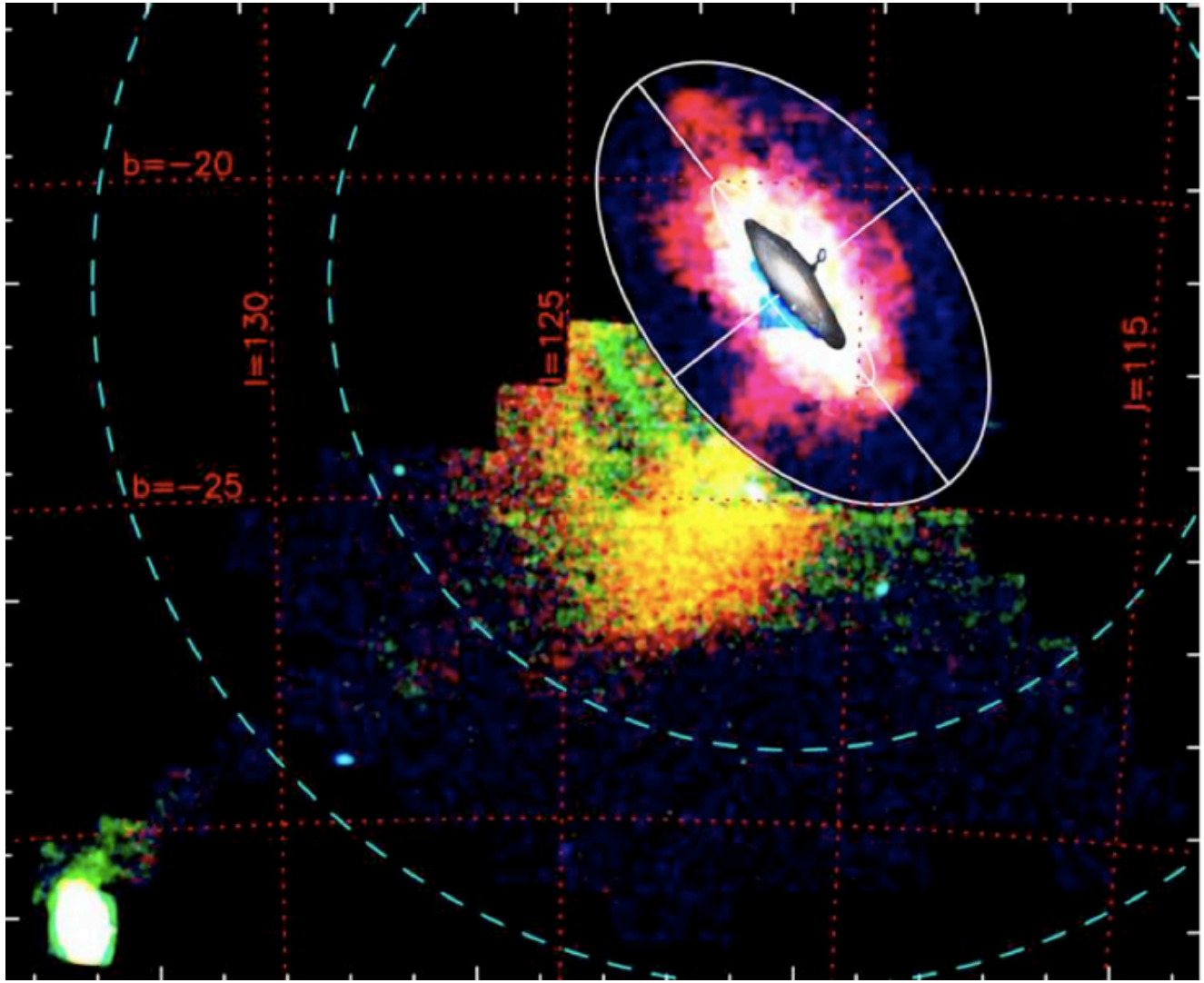
Squares: stars in dwarf galaxies
Cyan dots: stars in MW halo
Green dots: stars in MW TD
Red dots: stars in MW disk

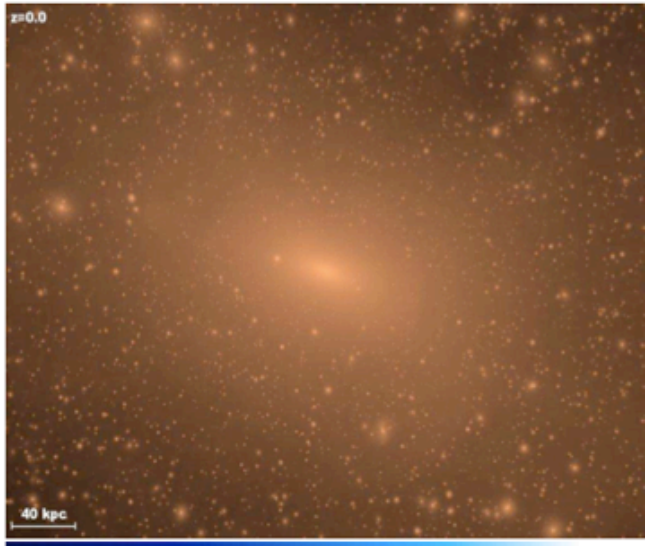

Fornax
Sculptor
Sextans
Carina
bootstrapped HES
N(< [Fe/H])
[Fe/H]
10
8
6
4
2
0
−4.5
−4.0
−3.5
−3.0
−2.5

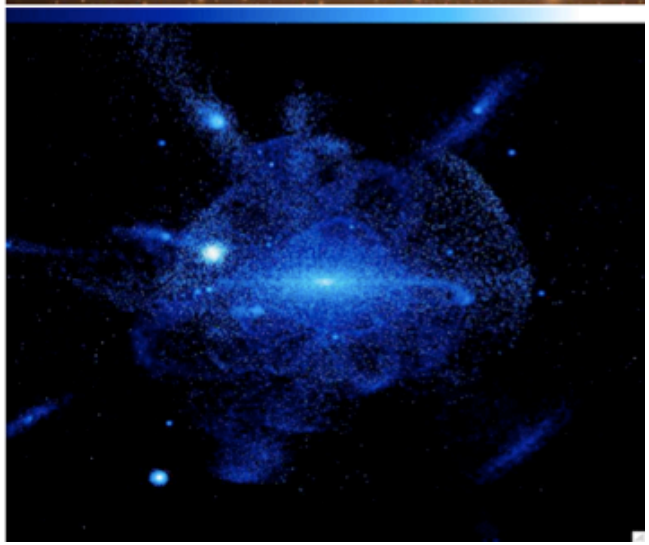


Stars in dwarf galaxies are not chemically similar to stars in MW halo...but isn't the halo of the MW supposed to made from stars from dwarf galaxies?

Summary







Summary

- Cosmological theories for galaxy formation highlight the key role of dwarf galaxies in the formation of the MW-mass galaxies

- "Near field cosmology" now providing some of the strongest constraints on the detailed structure of galaxies and their evolutionary processes

- Main uncertainties in these models relate to how the baryonic distribution in galaxies (ie light) relates to the dark matter properties

- Generic predictions of models are confirmed by observations (eg haloes form via merging - copious substructure/streams in M31 and the MW)

- Chemistry of stars in dwarfs show that the present generation of dwarf galaxies may be unrelated to the proto-galactic building blocks

- Detailed comparisons between observations and models are only now being started...watch this space!!