

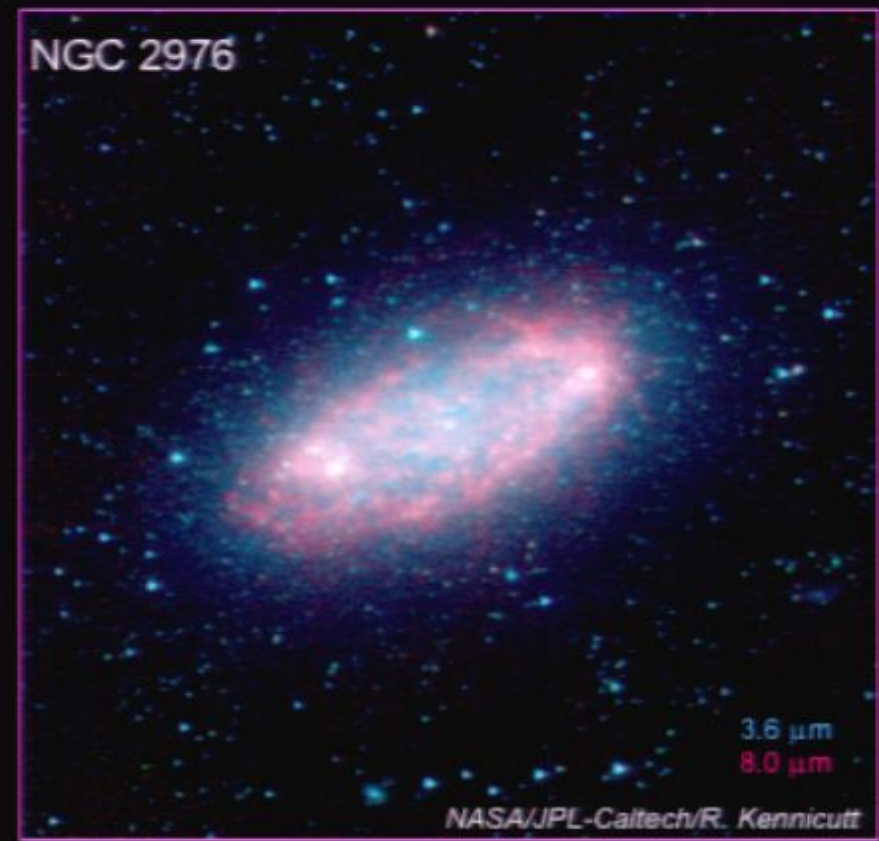
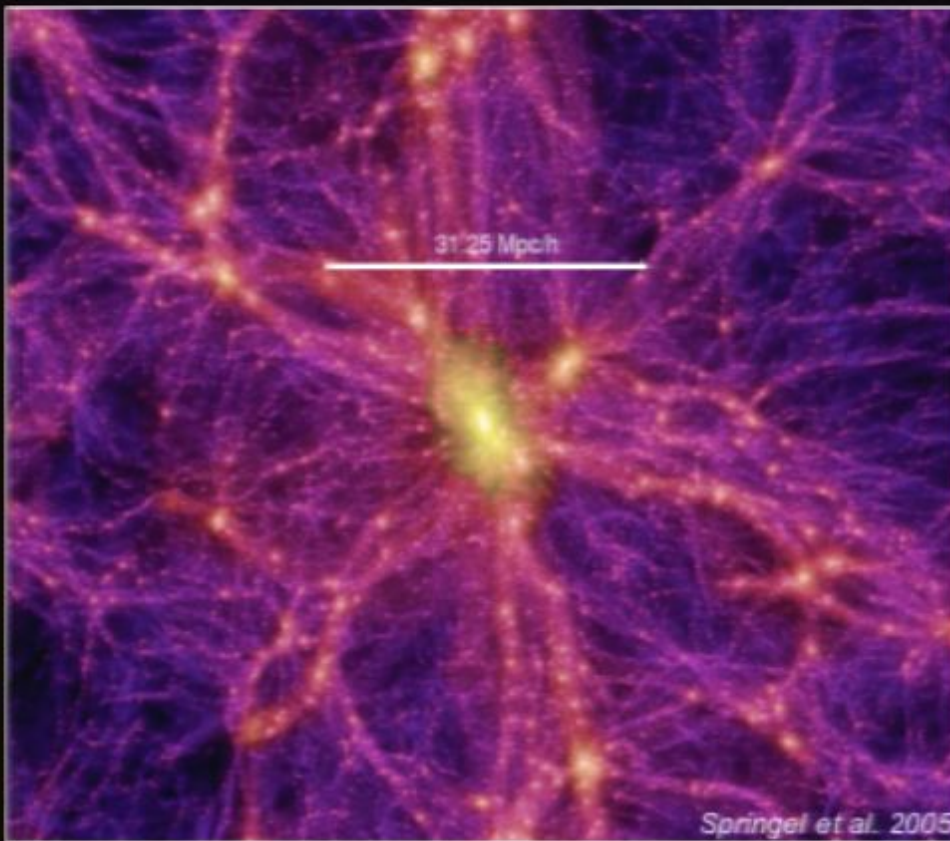
Title: The Tail that Wags the Dog: Observational Constraints on Dark Matter Halos in Nearby Galaxies

Date: Feb 20, 2009 11:00 AM

URL: <http://pirsa.org/09020040>

Abstract: The standard cosmological framework explains an impressive range of large-scale astrophysical phenomena, but an agreement between its predictions and the properties of the dark matter halos of nearby galaxies has not been established. In this talk, I will highlight some key observables that constrain galaxy structure and some key differences between cosmological predictions and halo properties inferred from these measurements. I will also discuss proposed 'observational' solutions to some of these discrepancies, such as the role of coherent non-circular motions in spiral galaxies and the measured abundance of gas-rich, starless halos in the nearby Universe.

The Tail that Wags the Dog: Observational Constraints on Dark Matter Halos in Nearby Galaxies



The Tail that Wags the Dog: Observational Constraints on Dark Matter Halos in Nearby Galaxies

Outline:

- Measuring nearby galaxy structure
- Disk galaxy theory vs. observations: open questions
- “Missing satellites” and the hunt for dark galaxies

In collaboration with:

R. Giovanelli, M. Haynes (Cornell), J. Sellwood, T. Williams
(Rutgers), J. Irwin (Queens) A. Saintonge (Zurich)

NGC 2976

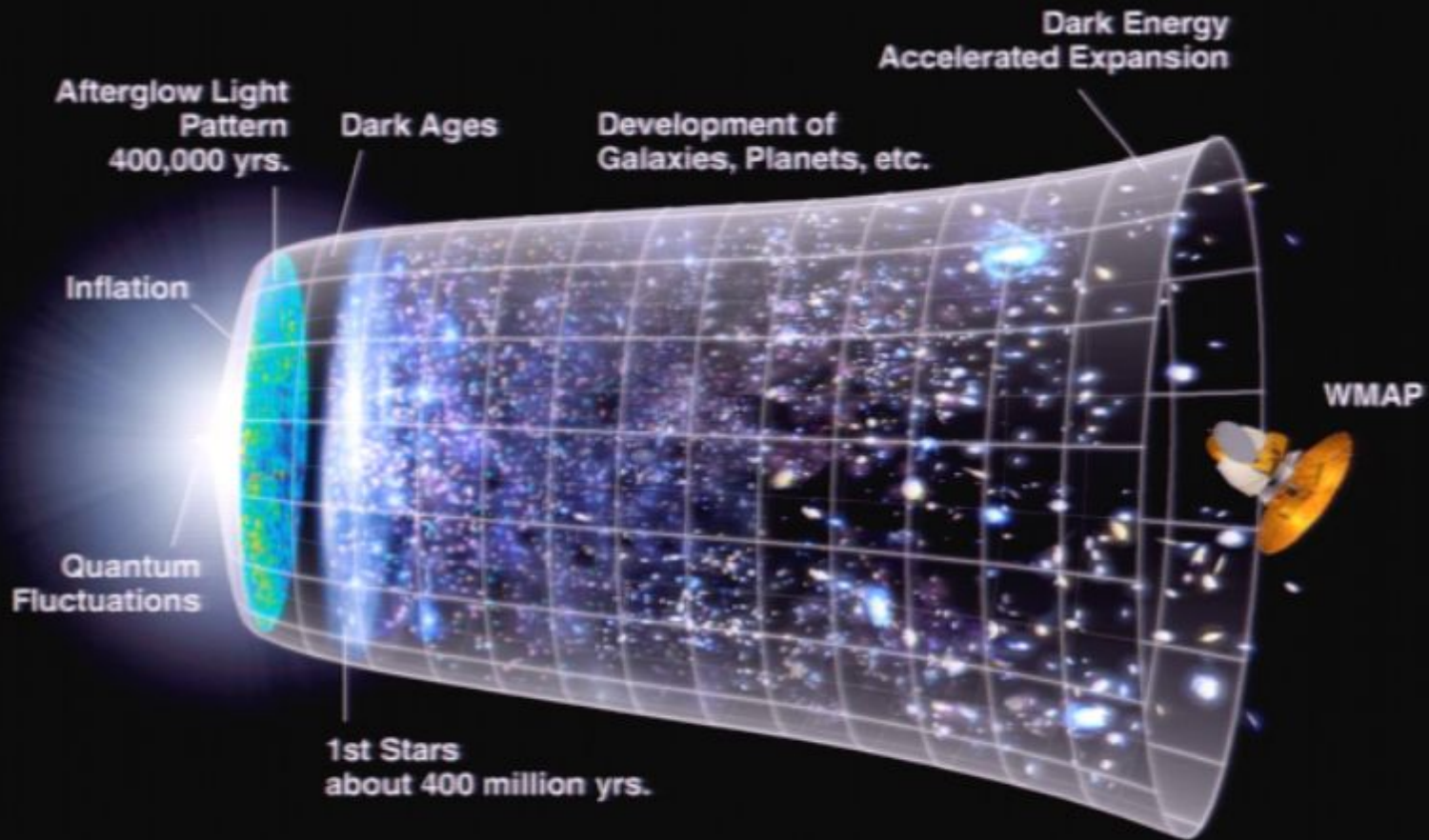


Springel et al. 2005

NASA/JPL-Caltech/R. Kennicutt

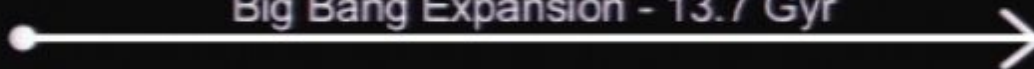


Timeline of the Universe

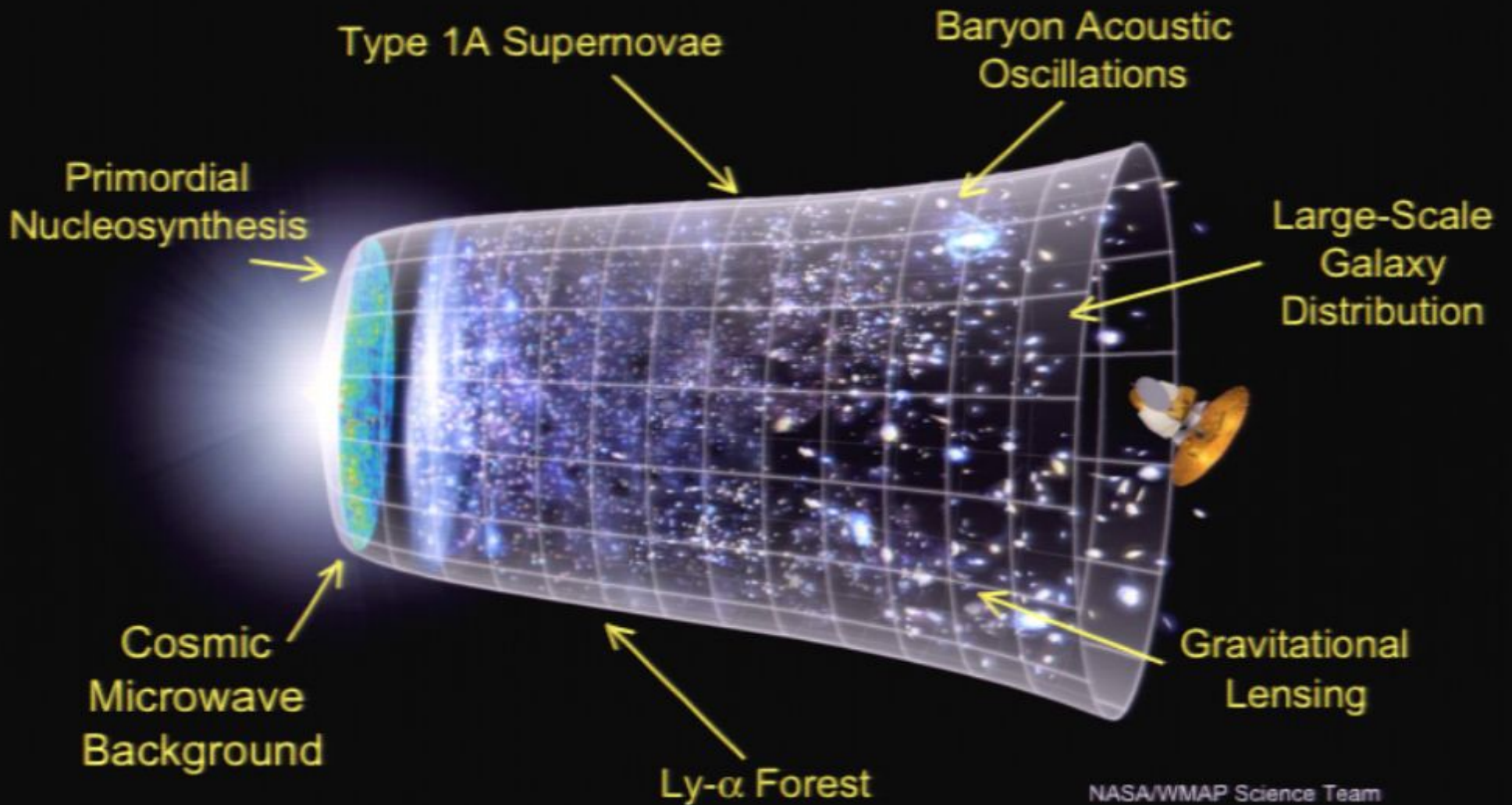


NASA/WMAP Science Team

Big Bang Expansion - 13.7 Gyr



Timeline of the Universe



NASA/WMAP Science Team

Big Bang Expansion - 13.7 Gyr

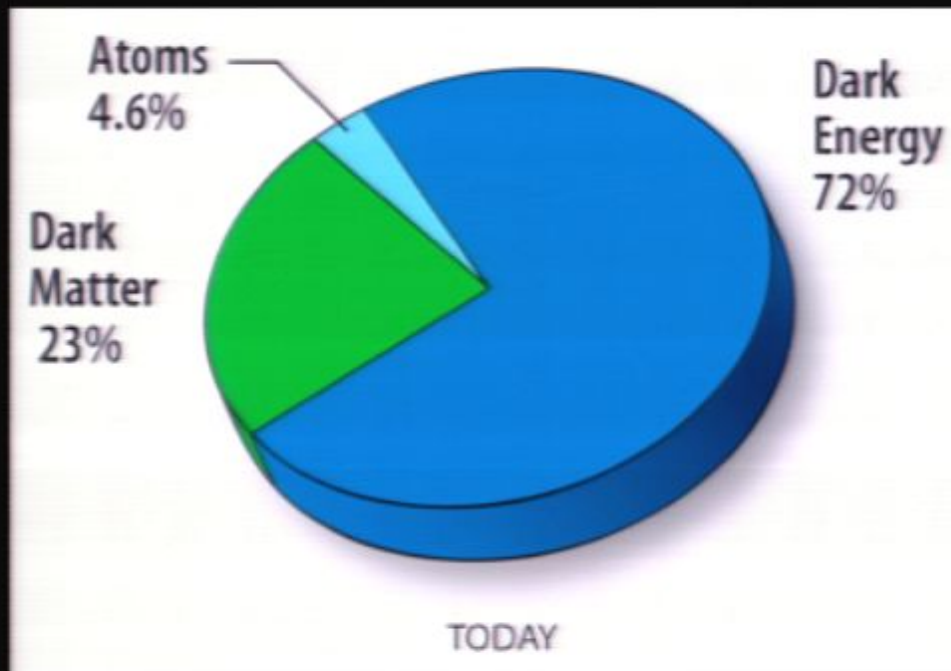


The LCDM Paradigm

Type 1A Supernovae

Baryon Acoustic Oscillations

Primordial Nucleosynthesis



Large-Scale Galaxy Distribution

Gravitational Lensing

Cosmic Microwave Background

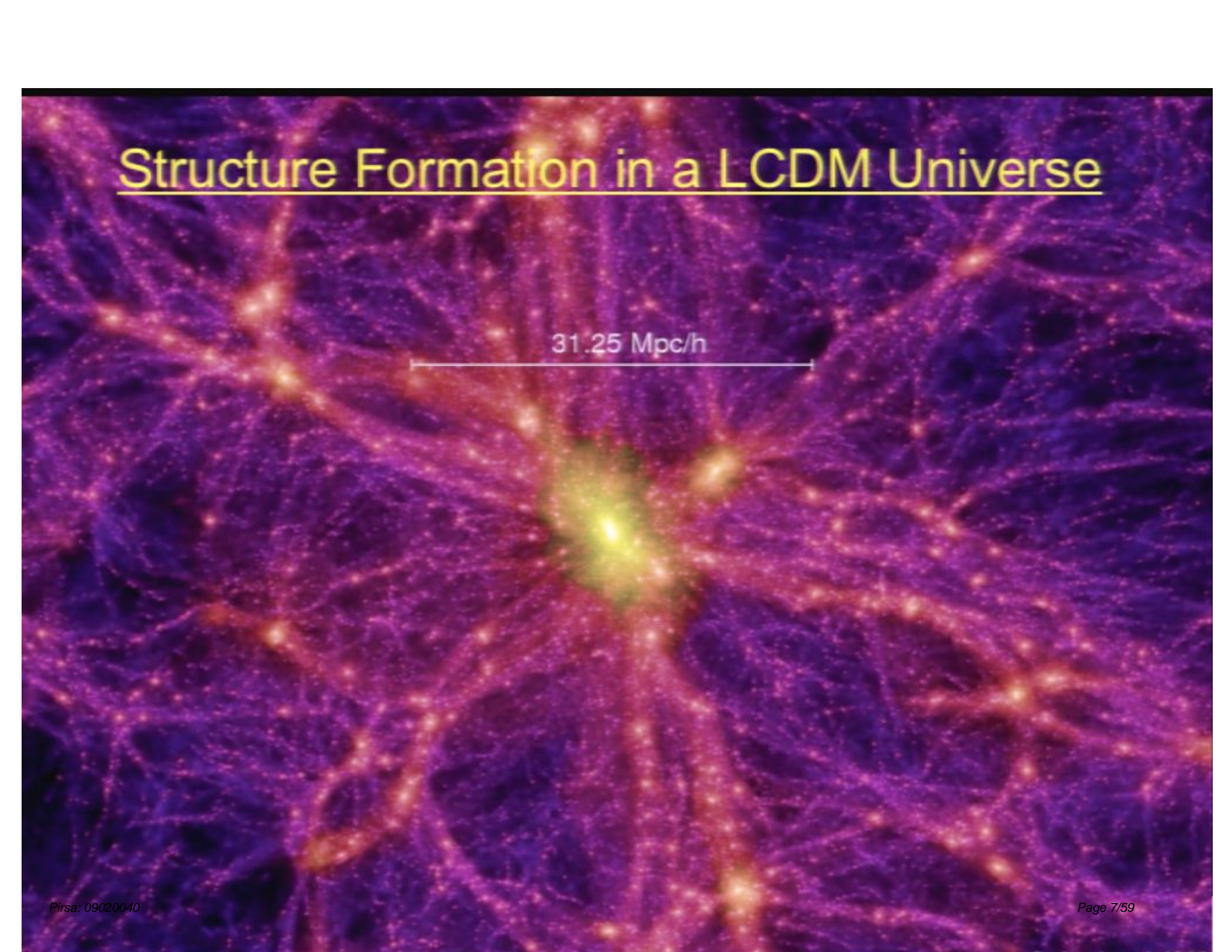
Ly- α Forest

“Era of Precision Cosmology”

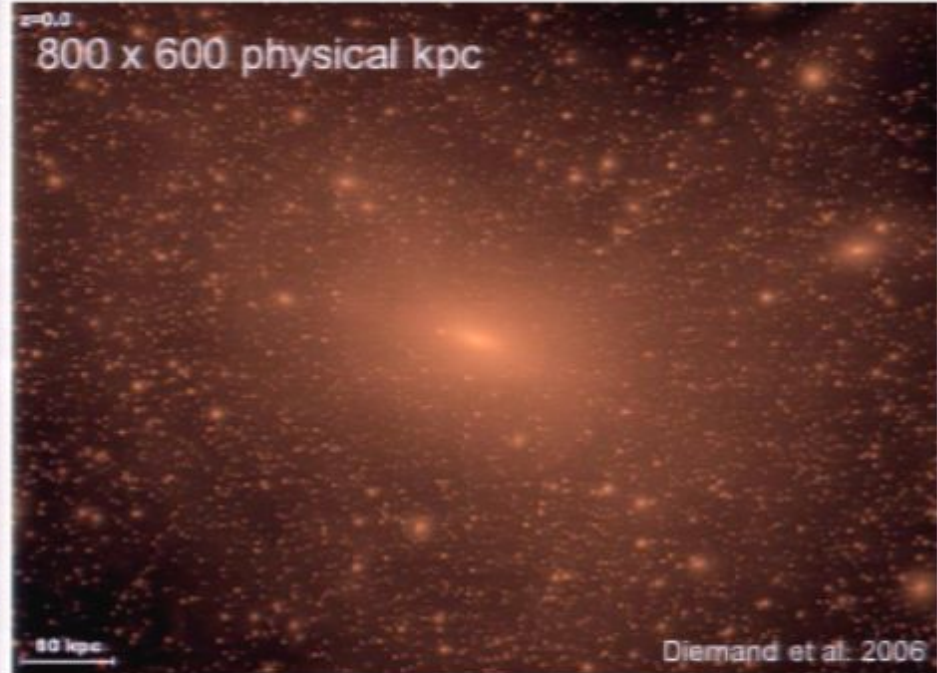


Structure Formation in a LCDM Universe

31.25 Mpc/h

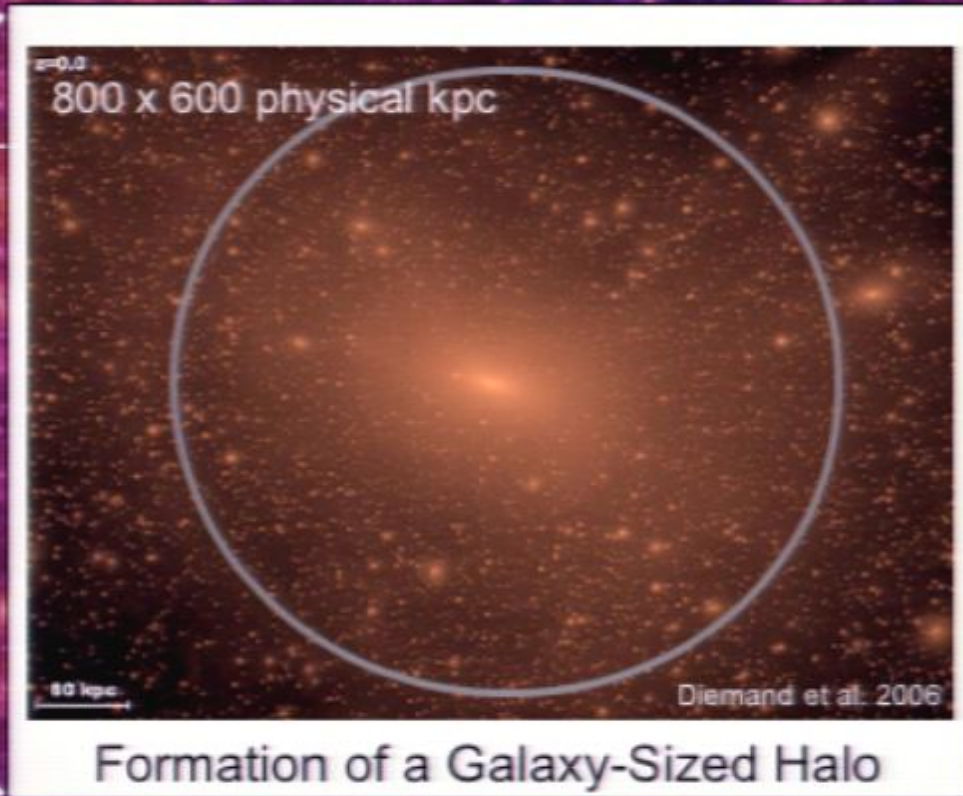


Structure Formation in a LCDM Universe

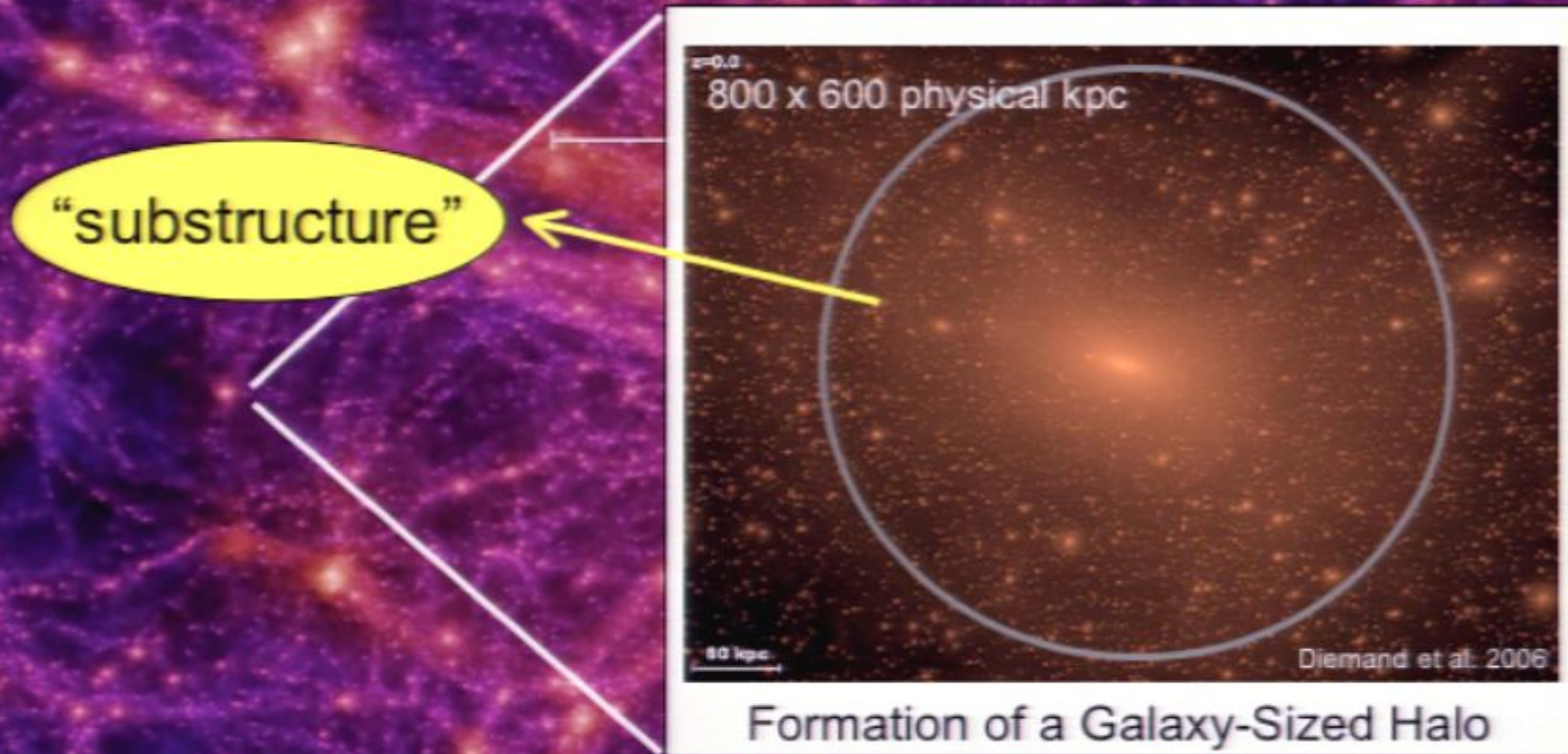


Formation of a Galaxy-Sized Halo

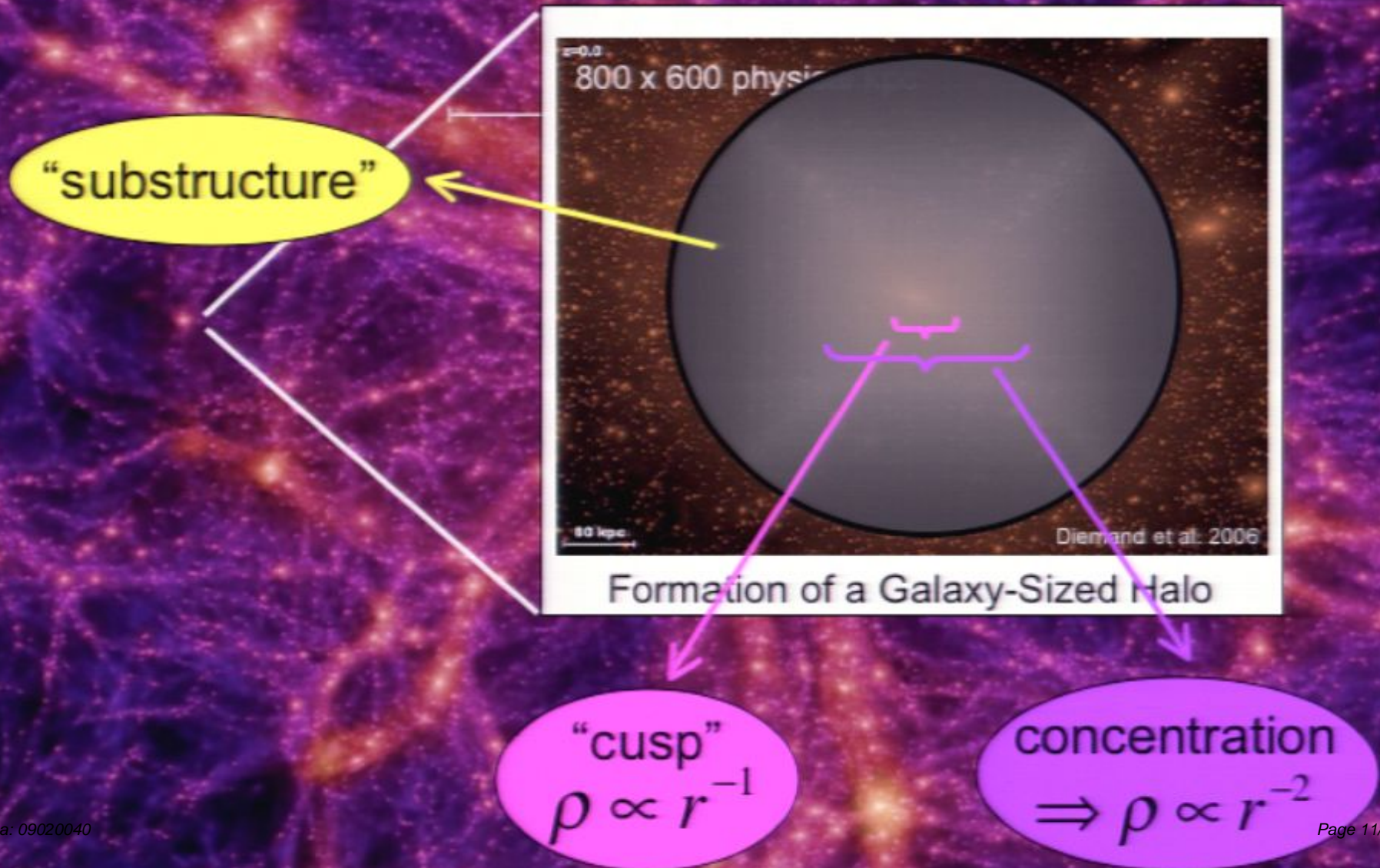
Structure Formation in a LCDM Universe



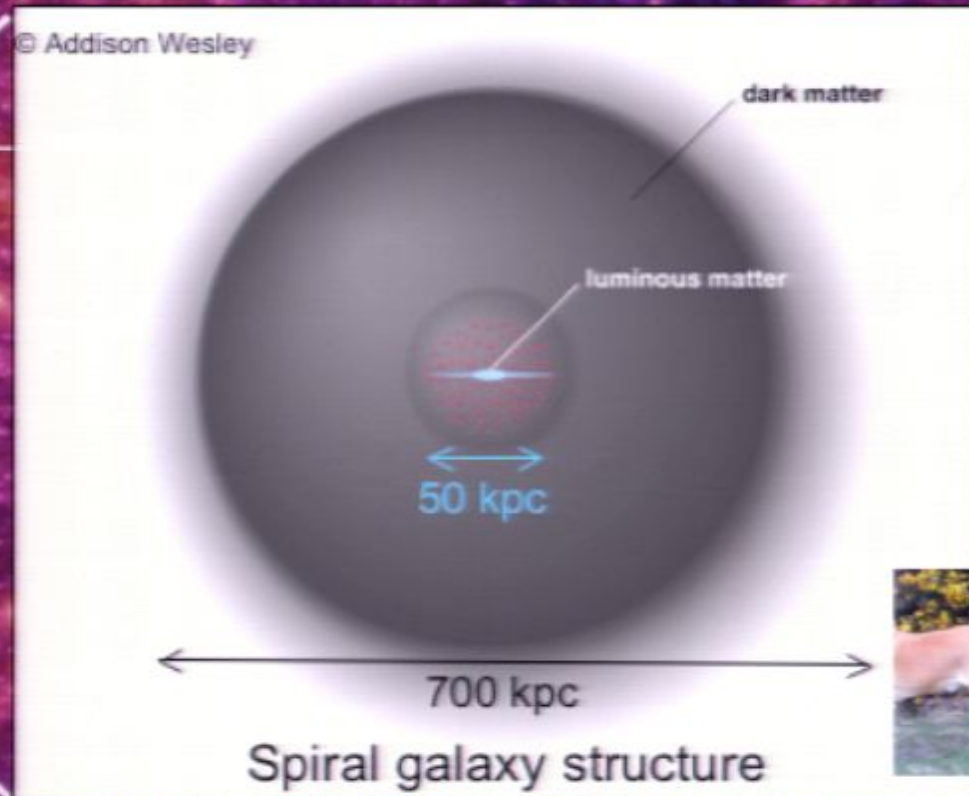
Structure Formation in a LCDM Universe



Structure Formation in a LCDM Universe



Structure Formation in a LCDM Universe

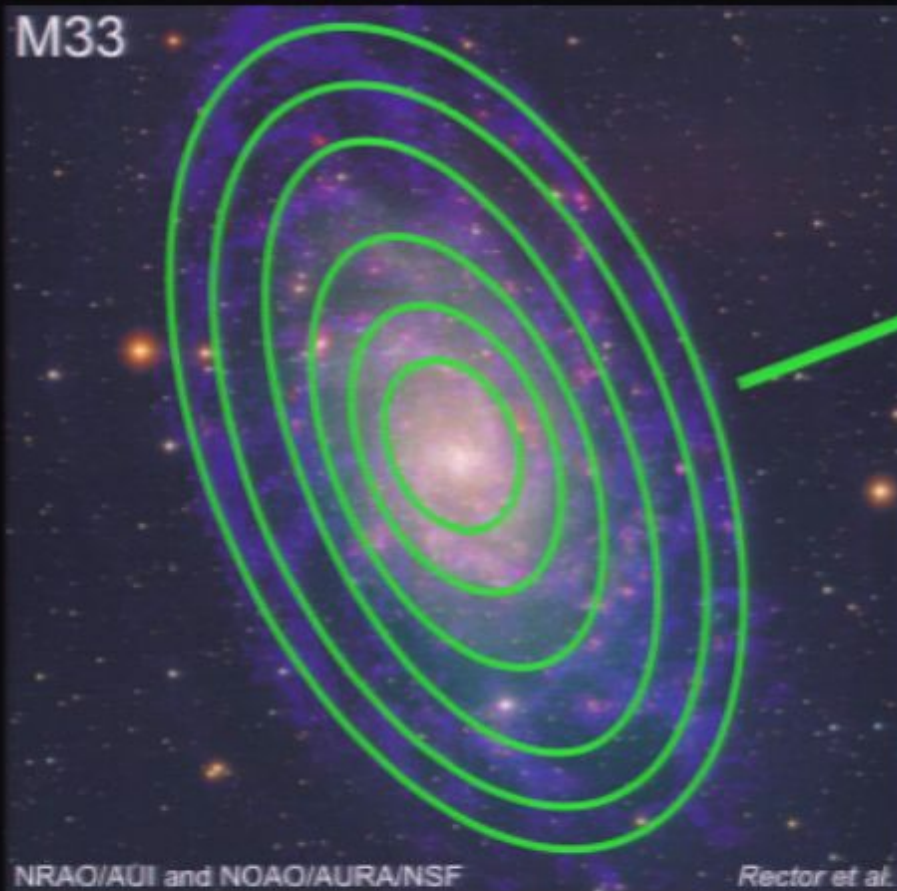


Disk galaxies: dissipative baryon collapse conserving specific AM

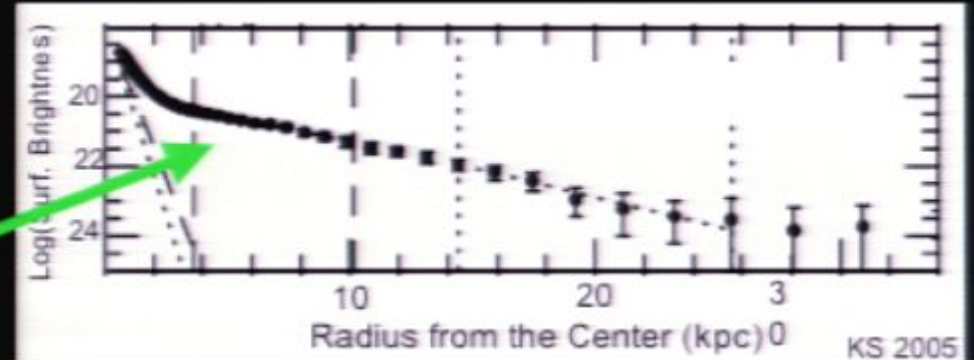
Measuring the Structure of Spiral Galaxies



Measuring the Structure of Spiral Galaxies



SURFACE BRIGHTNESS → BARYONIC MASS



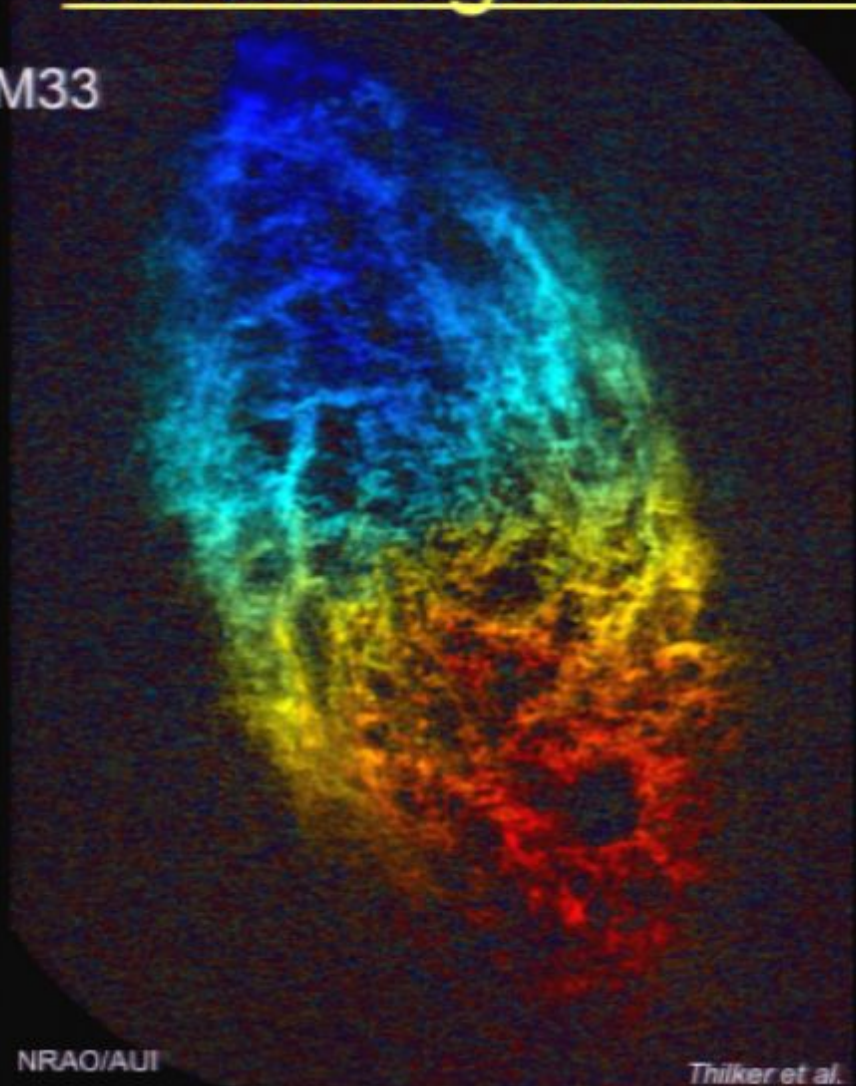
Measurables:

- surface brightness profiles in optical / near IR (50 pc resolution)
- disk “colours” → stellar populations, star formation history, dust



Measuring the Structure of Spiral Galaxies

M33



Measurables:

- Emission line doppler shifts:

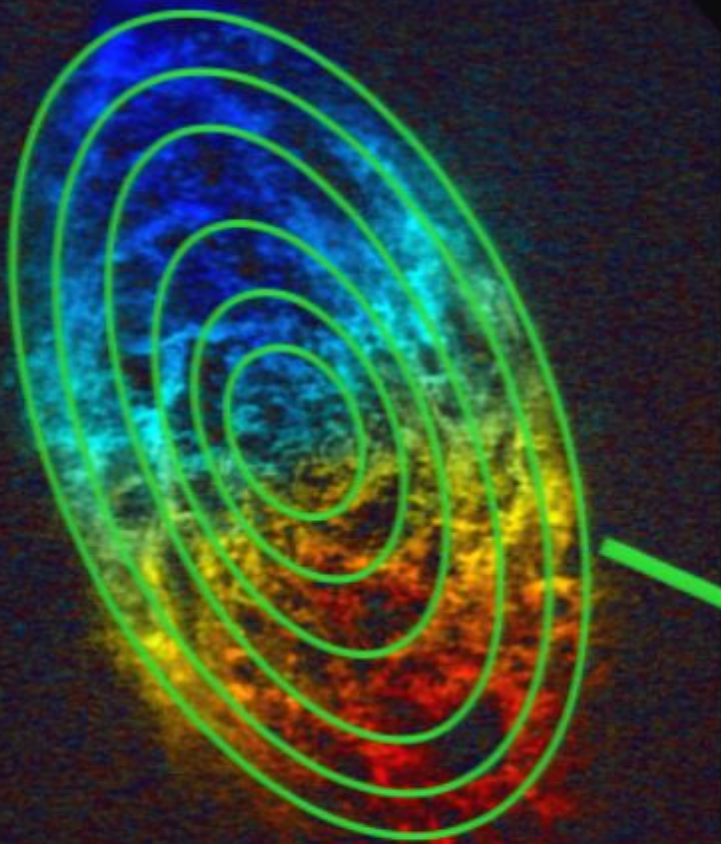
	T (K)	δV (km/s)	δx (pc)
H α	10,000	5	50
HI	500-10,000	1	500
CO	10-20	1	250

→ (collisional) orbital velocities, velocity dispersions



Measuring the Structure of Spiral Galaxies

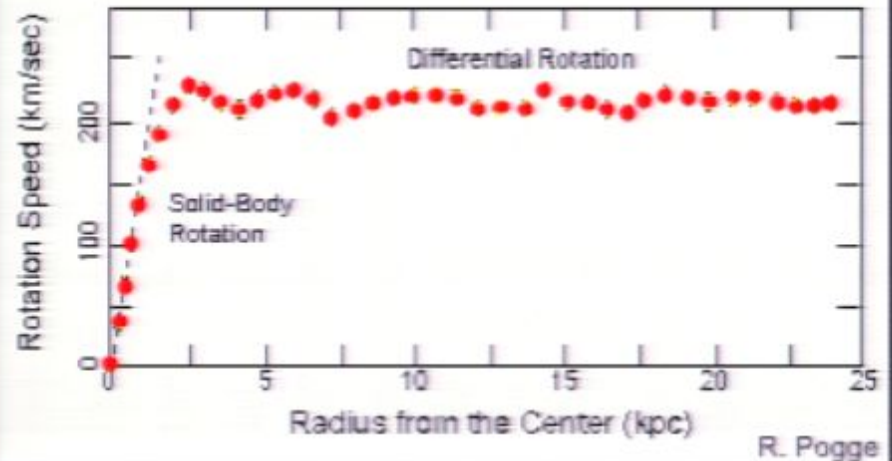
M33



NRAO/AUI

Thilker et al.

ROTATION CURVE → TOTAL MASS

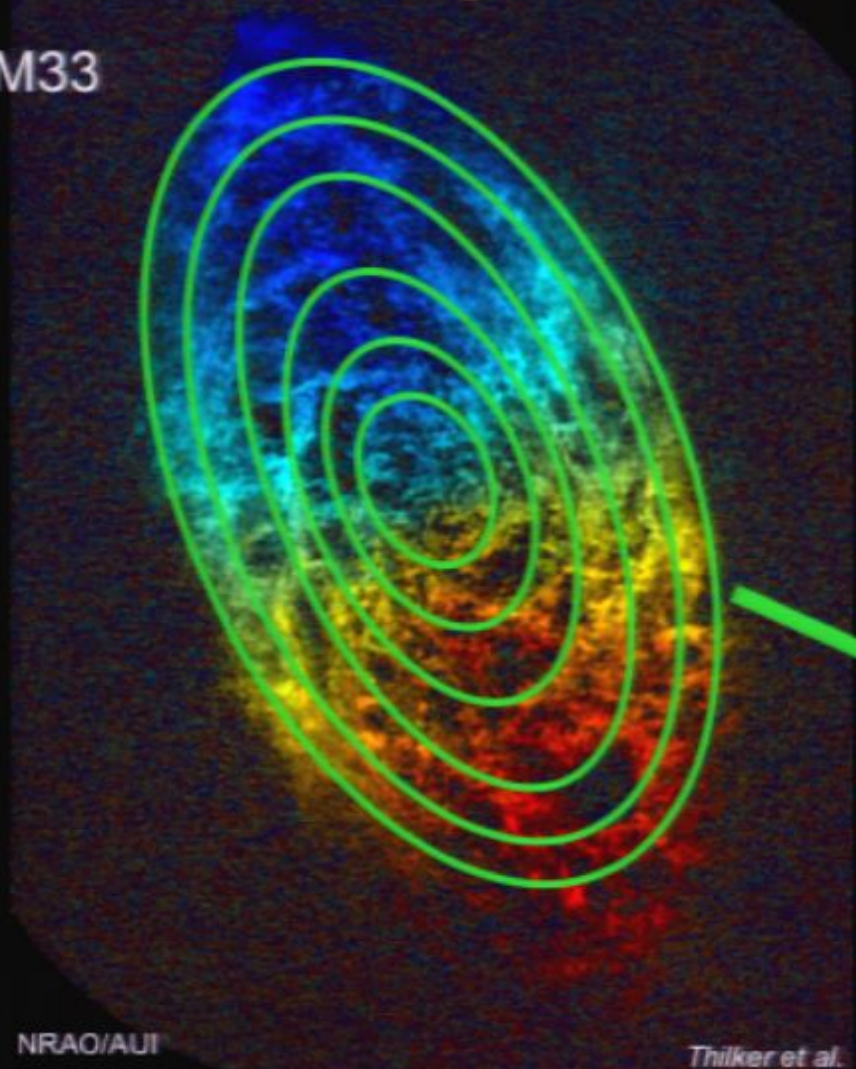


R. Pogge

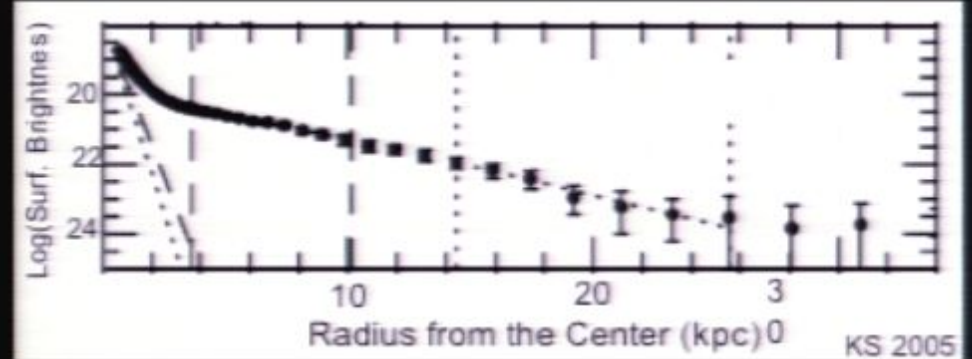


Measuring the Structure of Spiral Galaxies

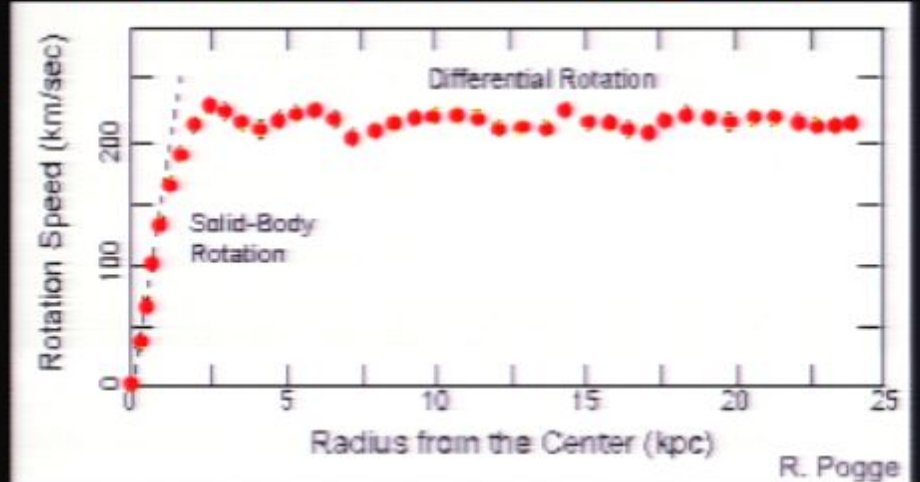
M33



SURFACE BRIGHTNESS → BARYONIC MASS



ROTATION CURVE → TOTAL MASS



Infer disk, halo structure from combination of photometry, kinematics



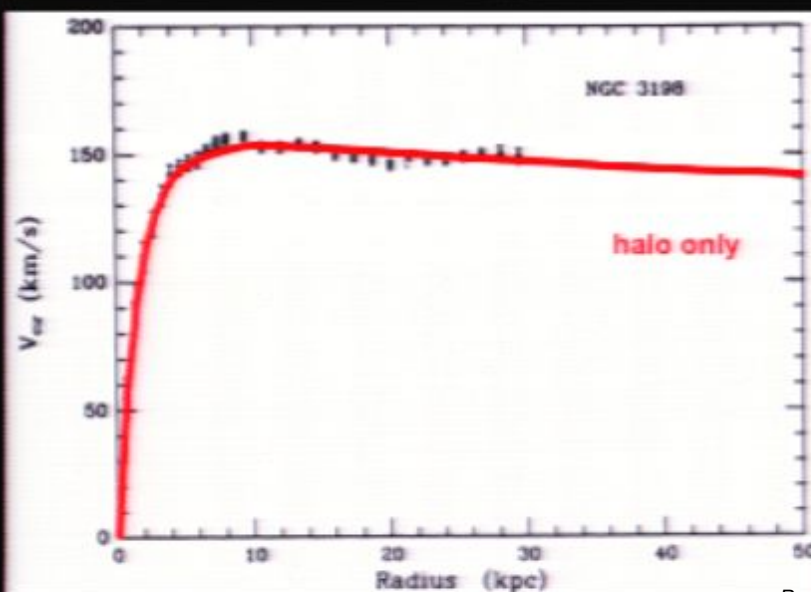
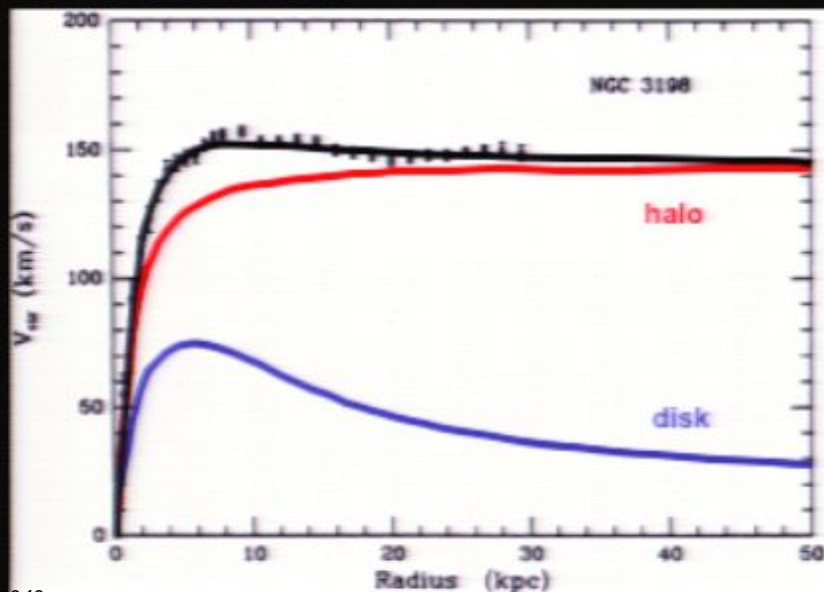
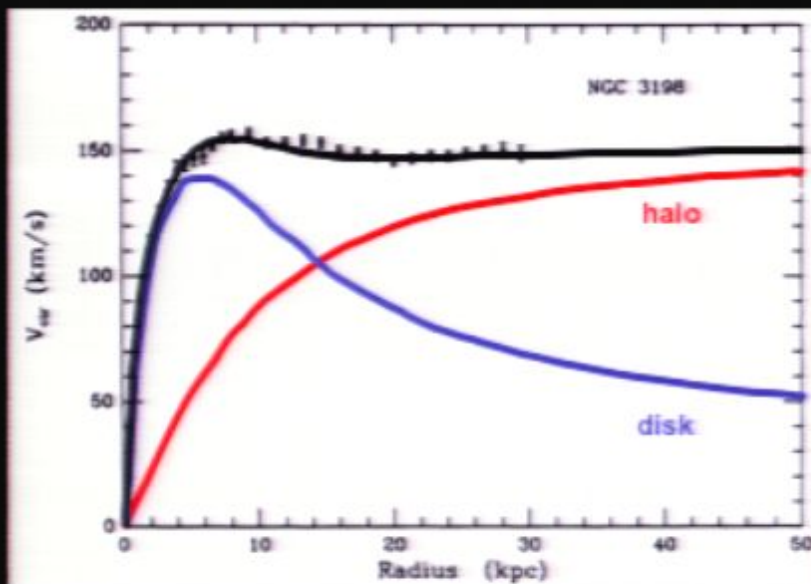
LCDM Halos and Spiral Galaxy Structure: Outstanding Questions



The Disk-Halo Degeneracy

How to disentangle the disk and halo contributions to the rotation curves of spirals?

van Albada et al. 1985



Structure Formation in a LCDM Universe



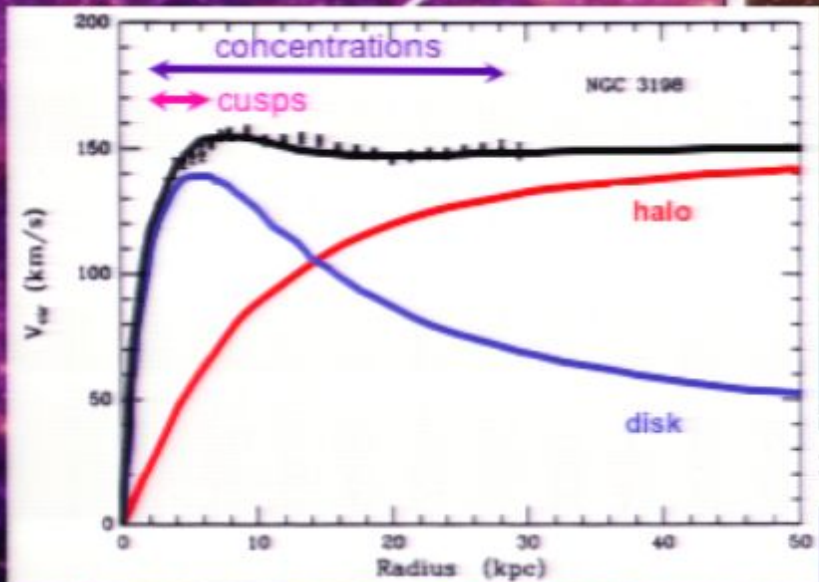
LCDM
halo properties

“cusp”
 $\rho \propto r^{-1}$

concentration
 $\Rightarrow \rho \propto r^{-2}$

Structure Formation in a LCDM Universe

Do disk galaxy halos have cusps?
The right concentrations?



“cusp”
 $\rho \propto r^{-1}$

concentration
 $\Rightarrow \rho \propto r^{-2}$

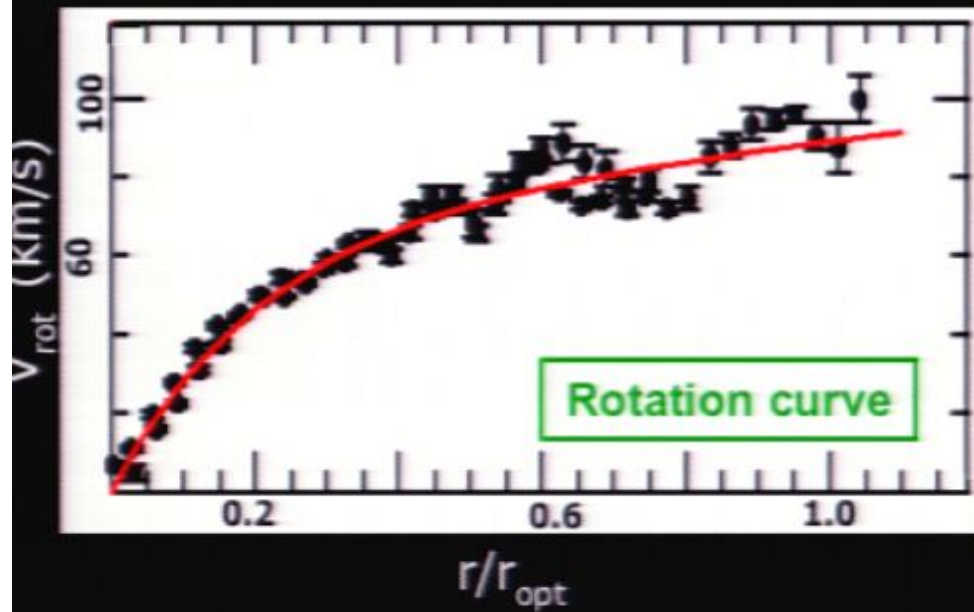
LCDM halo properties

Halo Profiles of Dwarf Galaxies

- Dwarf galaxies are dark matter dominated at all radii



Minimum disks

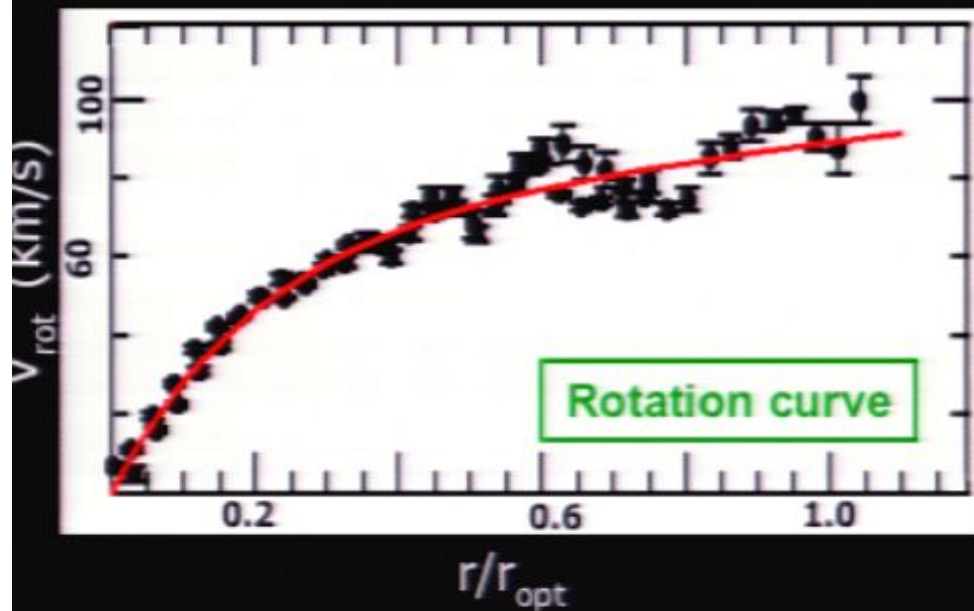


Halo Profiles of Dwarf Galaxies

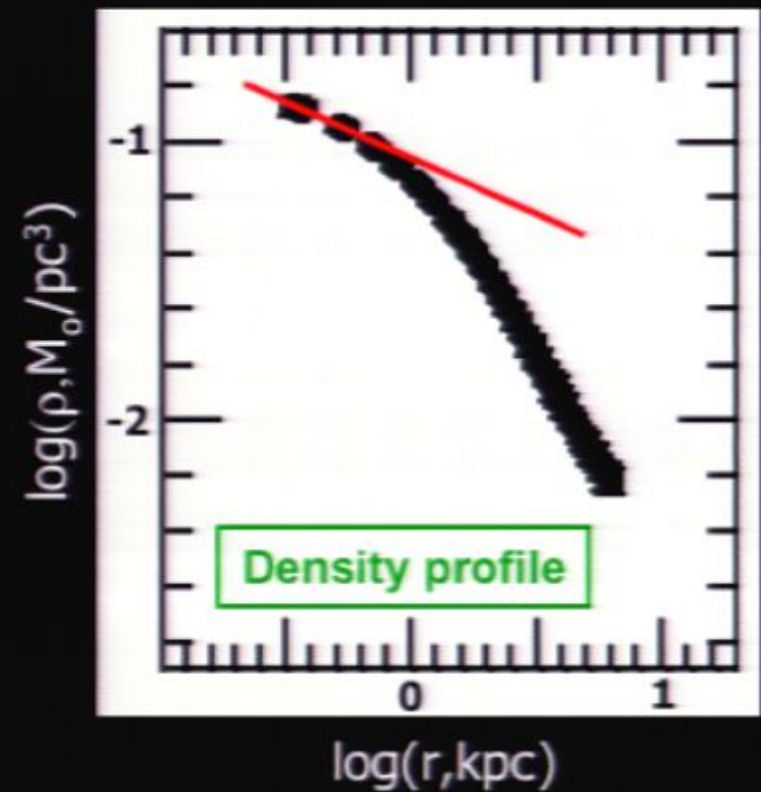
- Dwarf galaxies are dark matter dominated at all radii



Minimum disks



Poisson



Inner halo slope: $\rho \propto r^{-\alpha_m}$ (small r)



Dwarf Galaxies and the Cusp/Core Problem

Measure inner halo slopes of dark matter-dominated dwarfs:

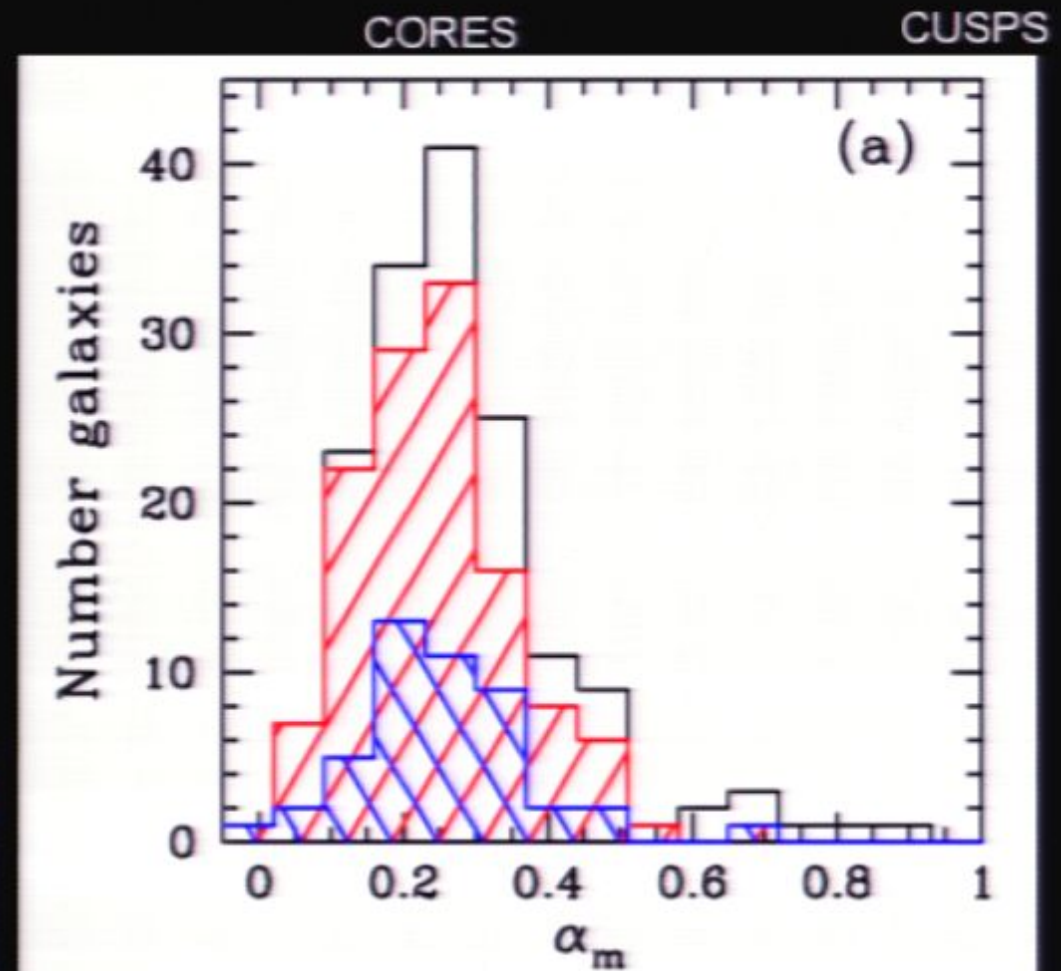
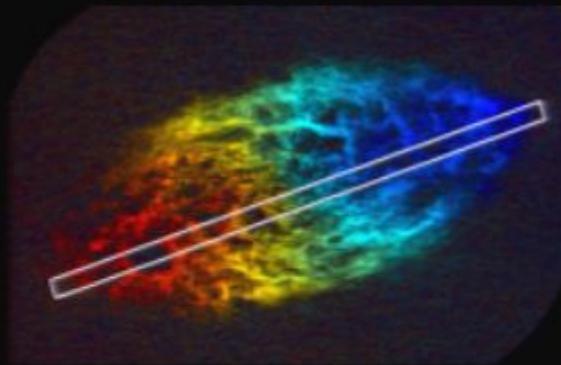
$$\rho \propto r^{-\alpha_m} \quad (\text{small } r)$$

“cusp/core problem”

LCDM predicts... $\alpha_{\text{int}} \sim 1$

Histogram peak... $\alpha_m \sim 0.25$

Simulate
impact of
observing and
data reduction
techniques...



KS et al 2005

Page 24/59



Dwarf Galaxies and the Cusp/Core Problem

Measure inner halo slopes of dark matter-dominated dwarfs:

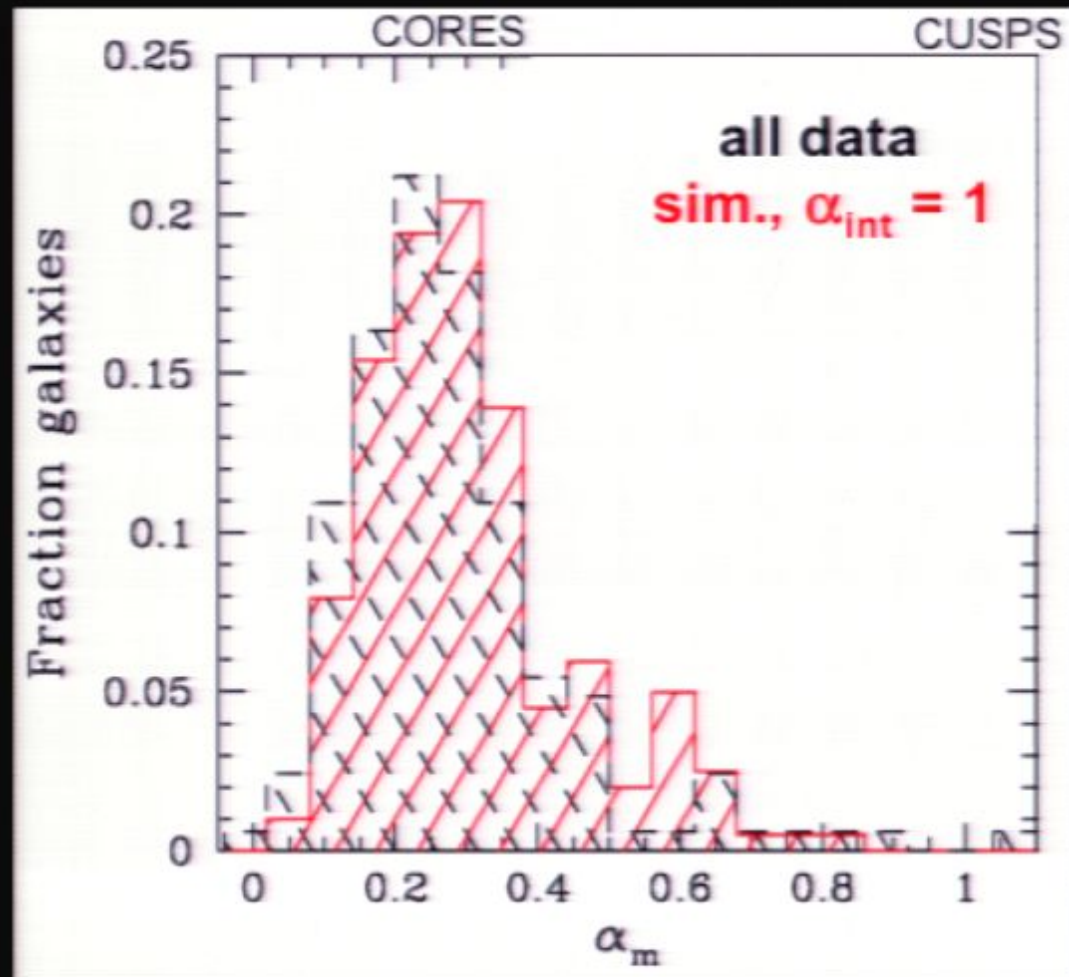
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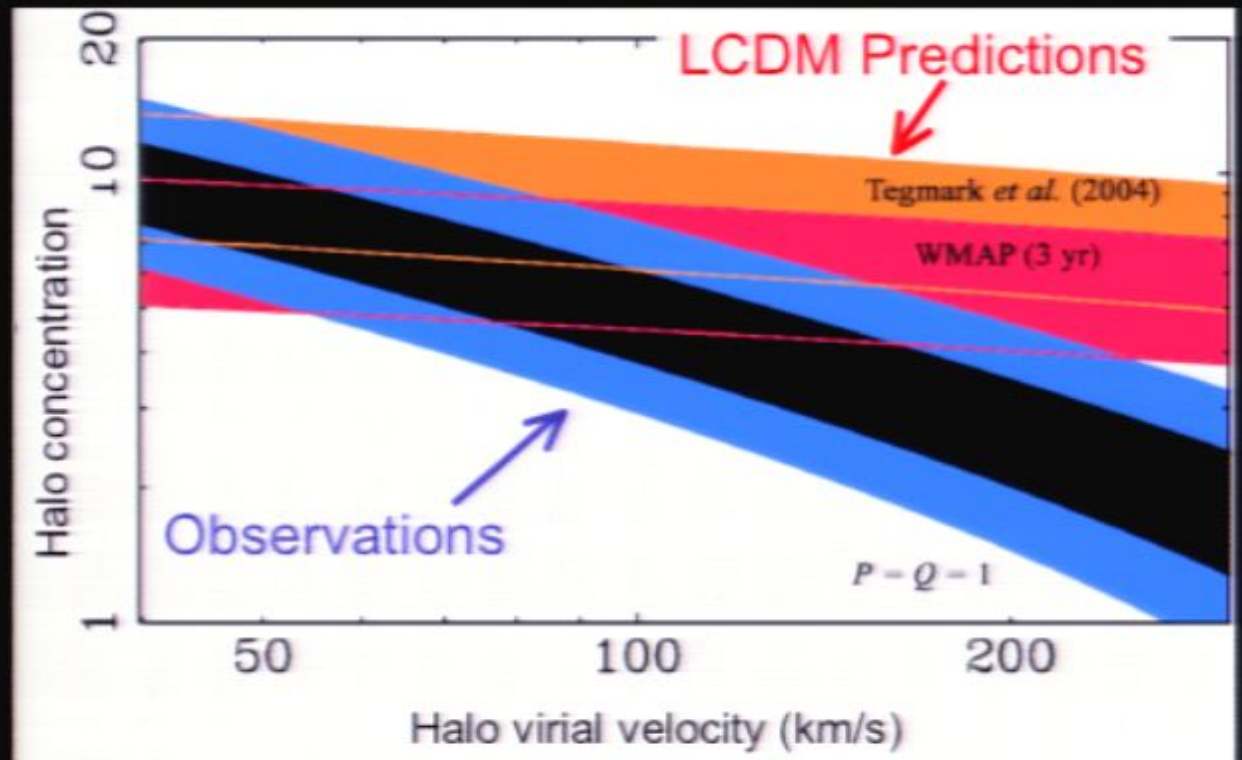
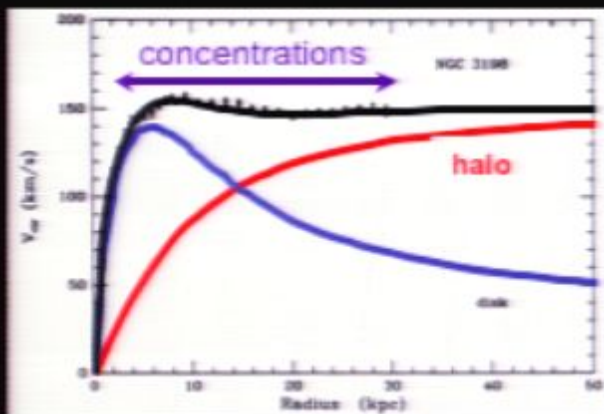
Histogram peak... $\alpha_m \sim 0.25$

Data consistent with both cuspy and core-like halos



Halo Concentrations in Disk Galaxies

- Halo concentrations are more reliably measured than cusps:

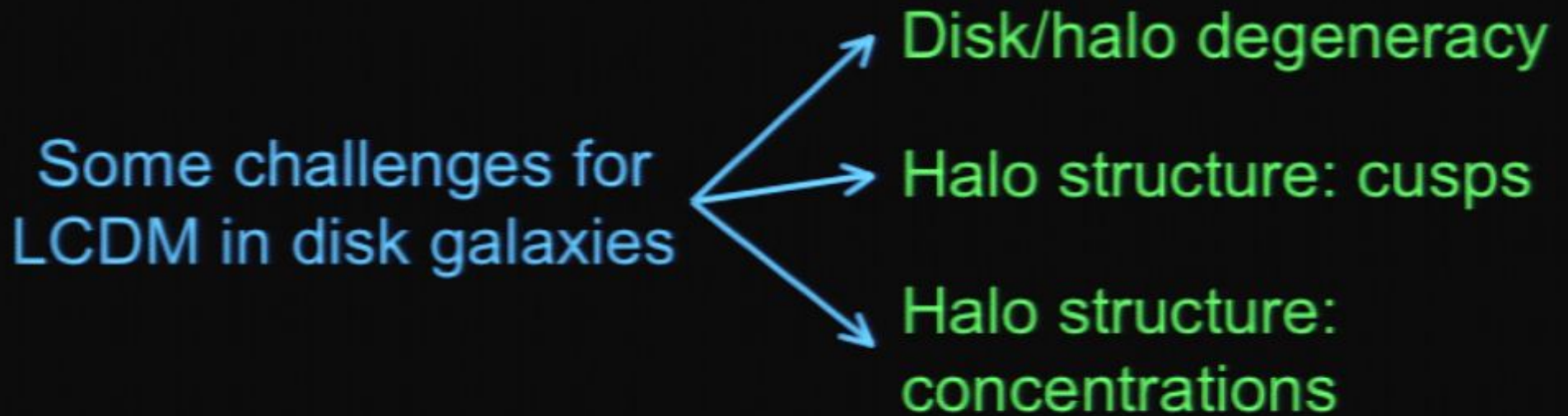


McGaugh et al. 2007

Halo concentrations of normal spirals systematically lower than predicted by LCDM



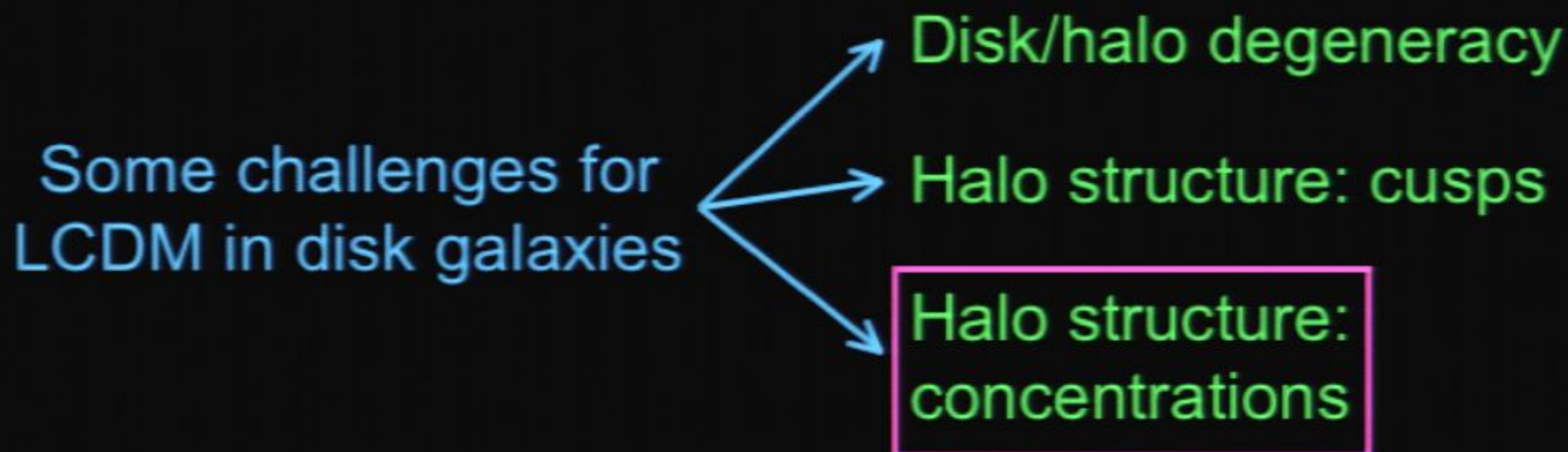
Precision Cosmology and Disk Galaxy Structure



Despite “era of precision cosmology”, we do not yet understand disk galaxy structure and evolution



Precision Cosmology and Disk Galaxy Structure



Despite “era of precision cosmology”, we do not yet understand disk galaxy structure and evolution



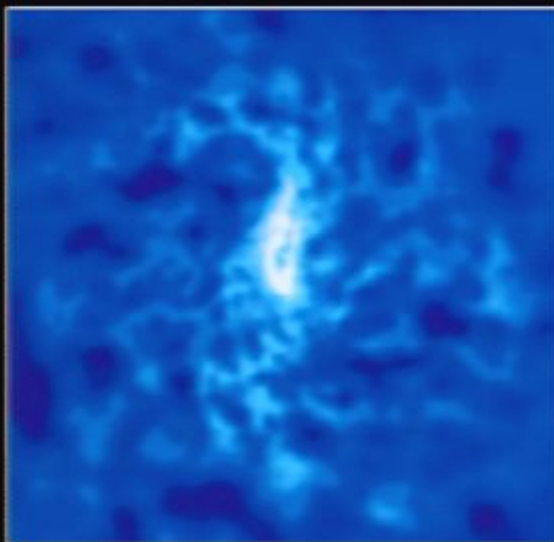
Understanding Disk Galaxy Structure

Is there a disconnect between derived “rotation curves” and actual central attraction?

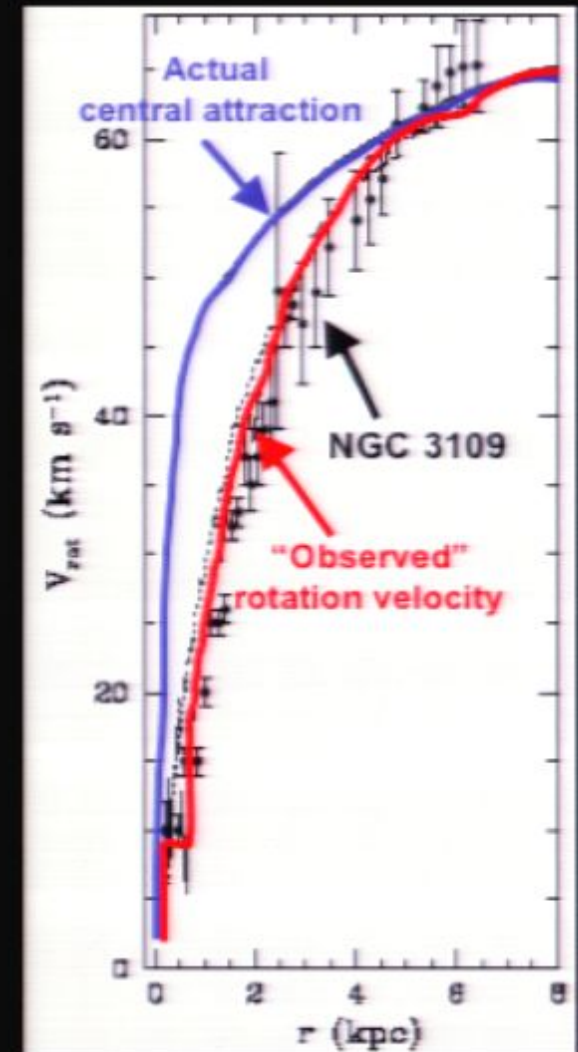
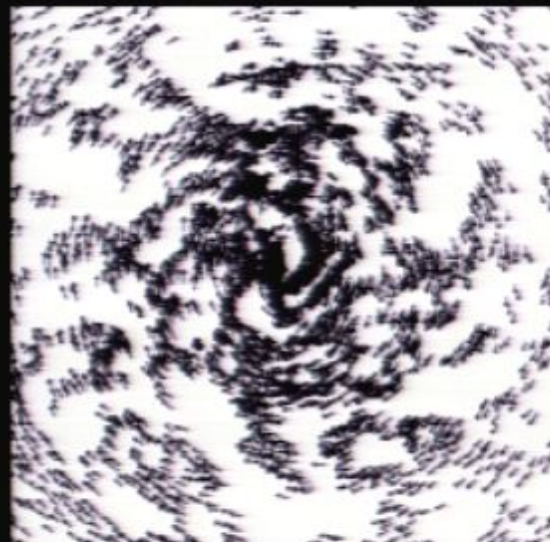
Hydrodynamical simulations:



GAS DENSITY



VELOCITY FIELD

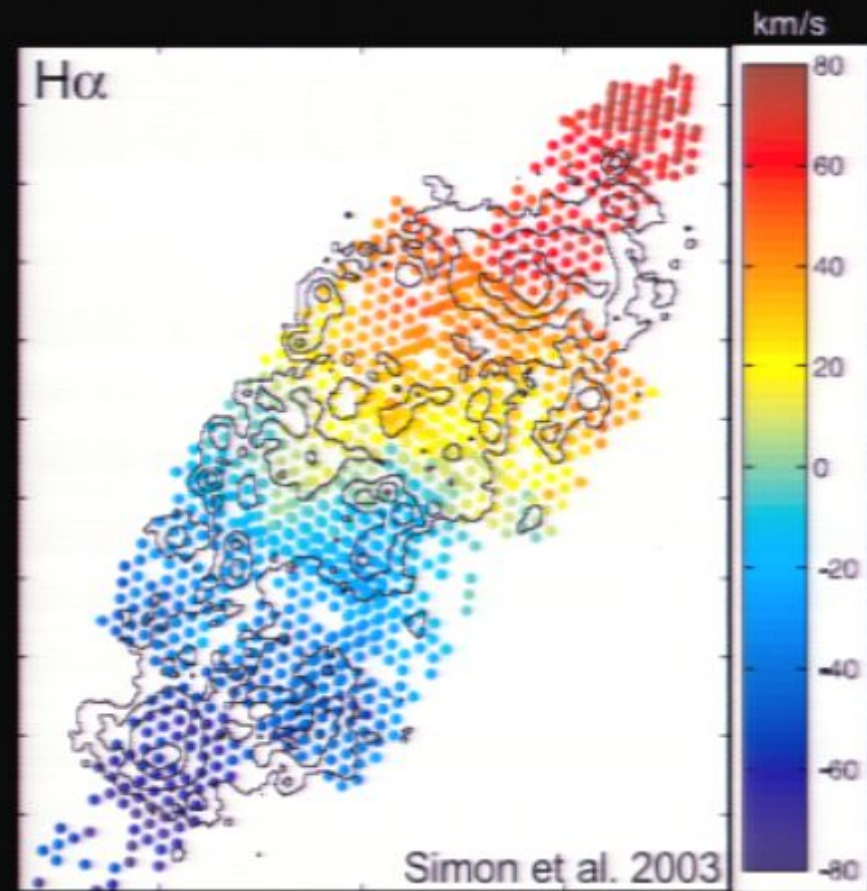


Valenzuela et al. 2007



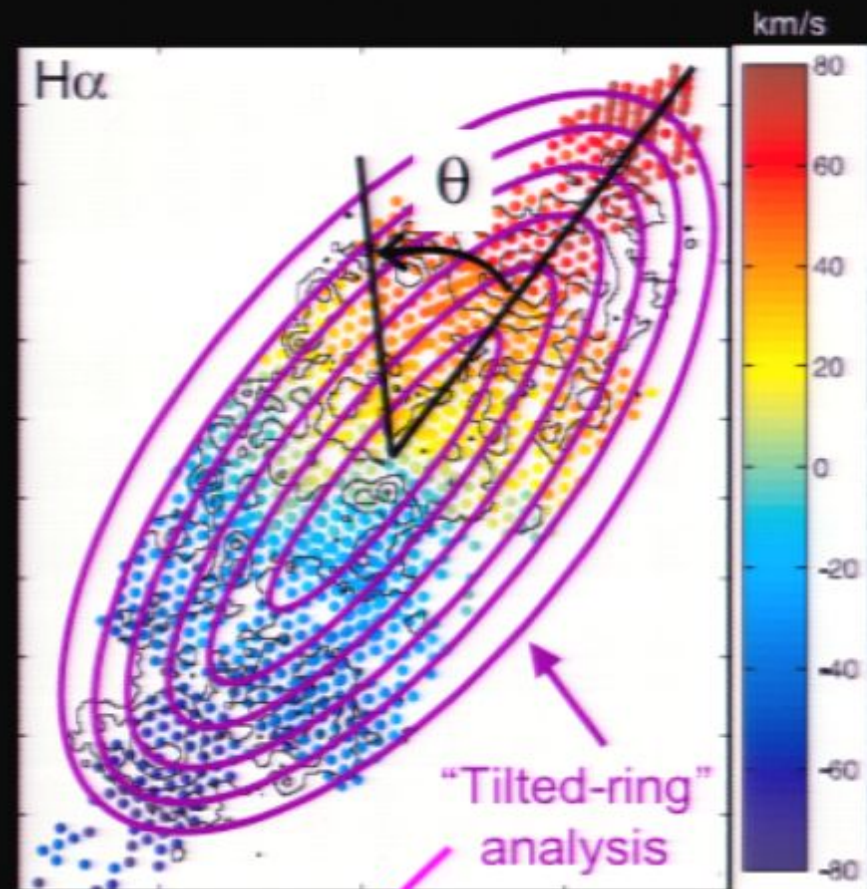
Non-Circular Motions in Low-Mass Galaxies

NGC 2976:



Non-Circular Motions in Low-Mass Galaxies

NGC 2976:



$$\frac{V_{obs} - V_{sys}}{\sin i} = \sum_1^m (c_m \cos \theta + s_m \sin \theta)$$



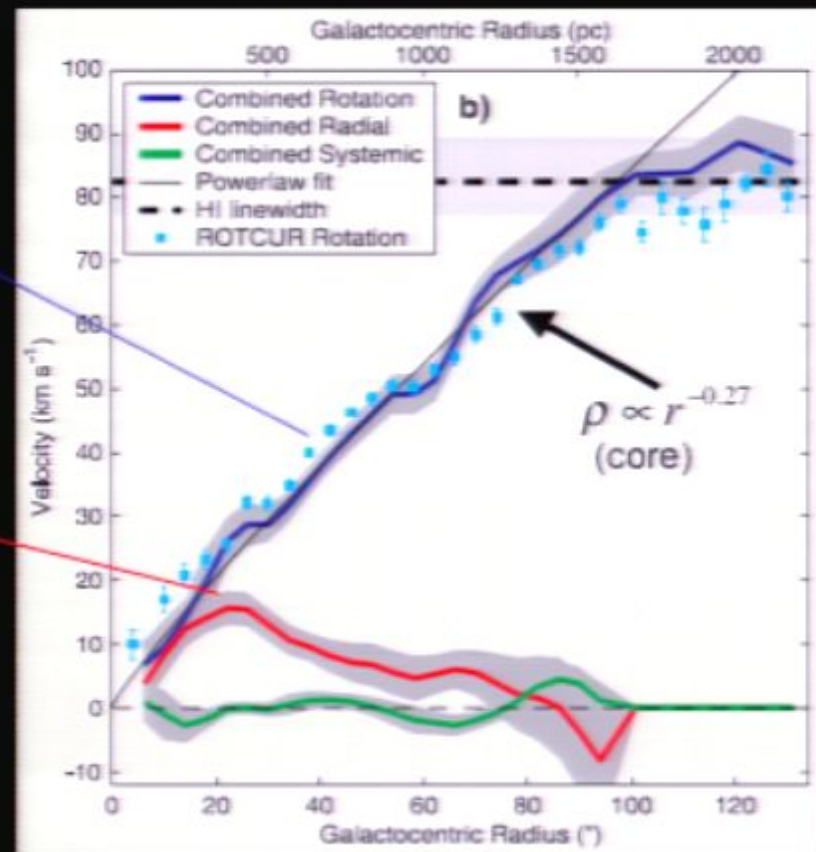
Non-Circular Motions in Low-Mass Galaxies

NGC 2976:



Non-Circular Motions in Low-Mass Galaxies

NGC 2976:



Simon et al. 2003

$$\frac{V_{obs} - V_{sys}}{\sin i} = V_{rot} \cos \theta + V_{rad} \sin \theta$$



Non-Circular Motions in Low-Mass Galaxies

NGC 2976:

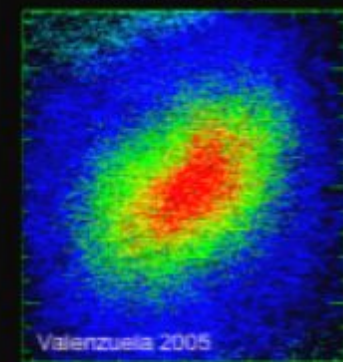


Can the non-circular motions detected in tilted ring analyses be explained by bar-like distortions?

stellar bar

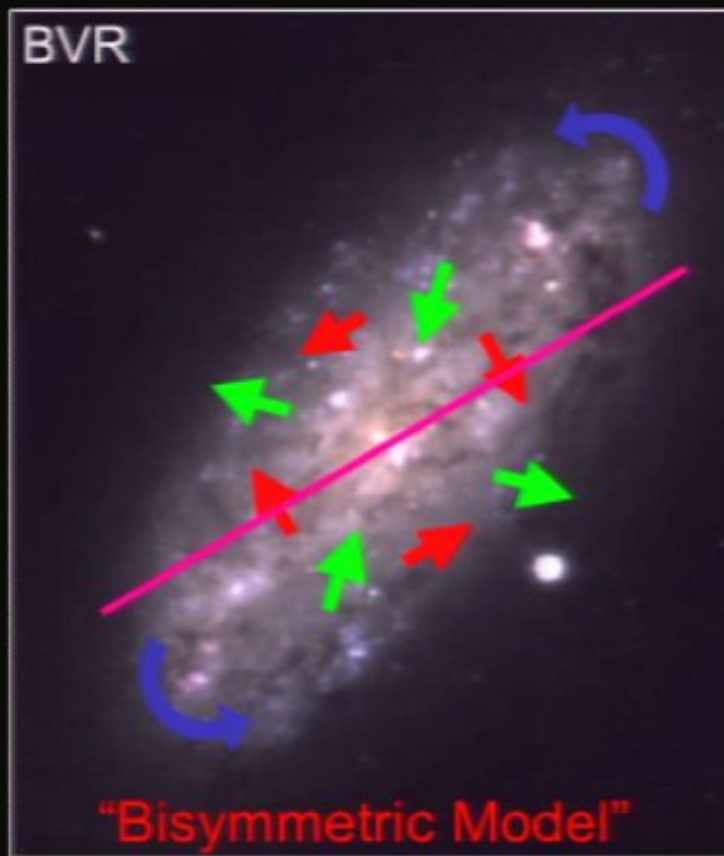


triaxial halo



Non-Circular Motions in Low-Mass Galaxies

NGC 2976:

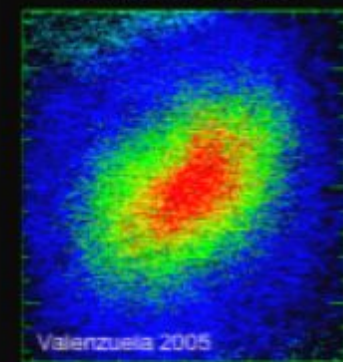


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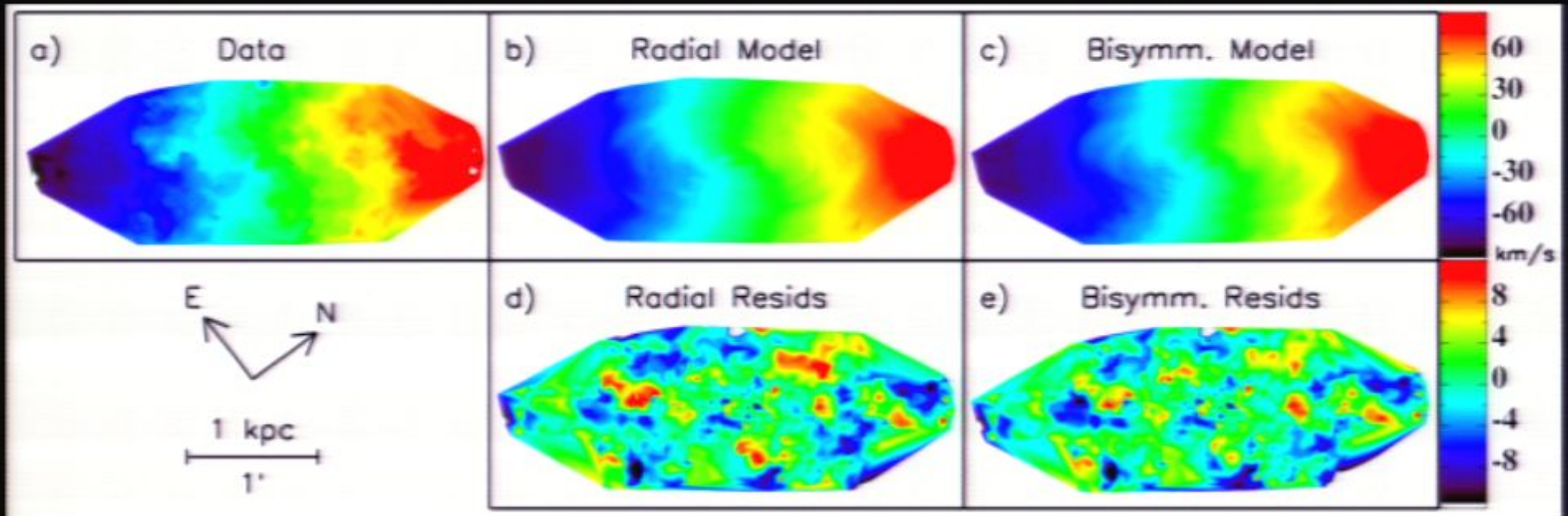


triaxial halo



Application to NGC 2976

- Fit CO + H α velocity field from Simon et al. 2003 with radial and (new) bisymmetric model:

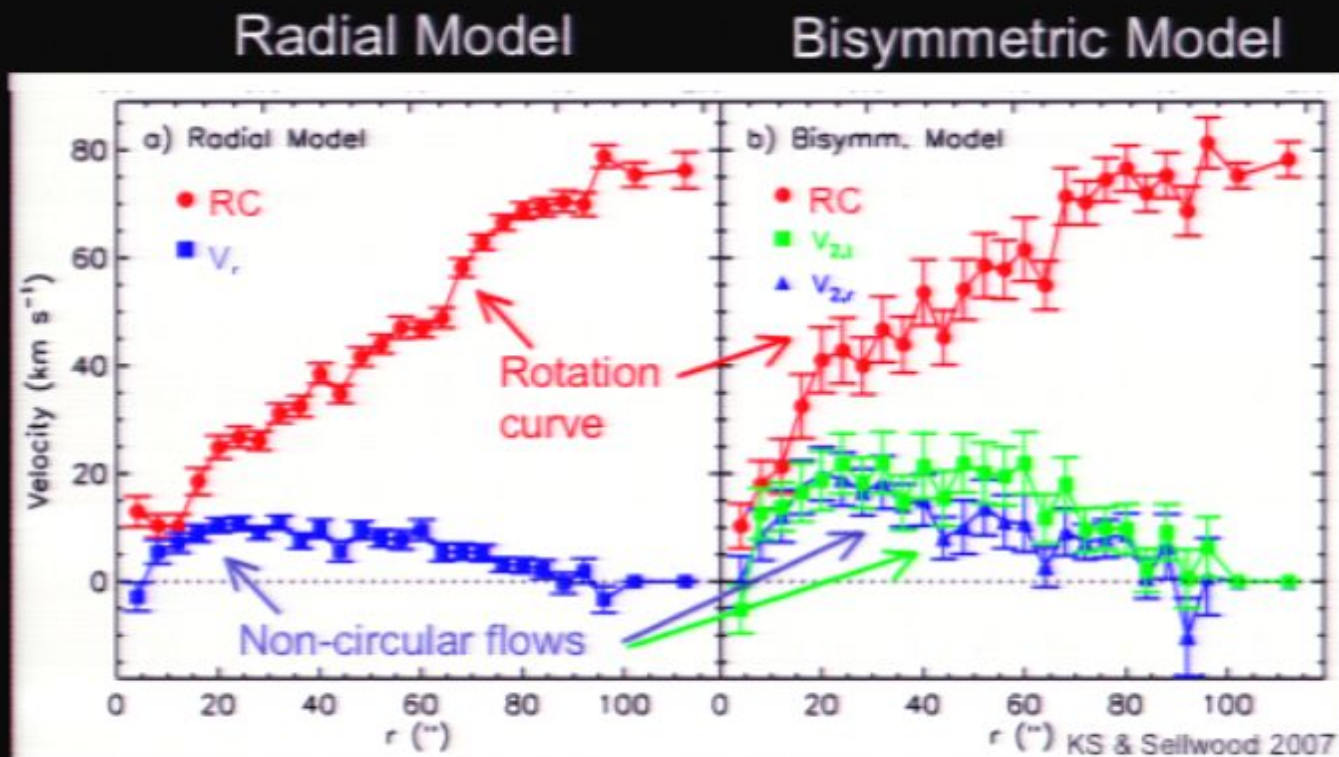


KS & Sellwood 2007



Bisymmetric Distortions in NGC 2976

Velocity field components:

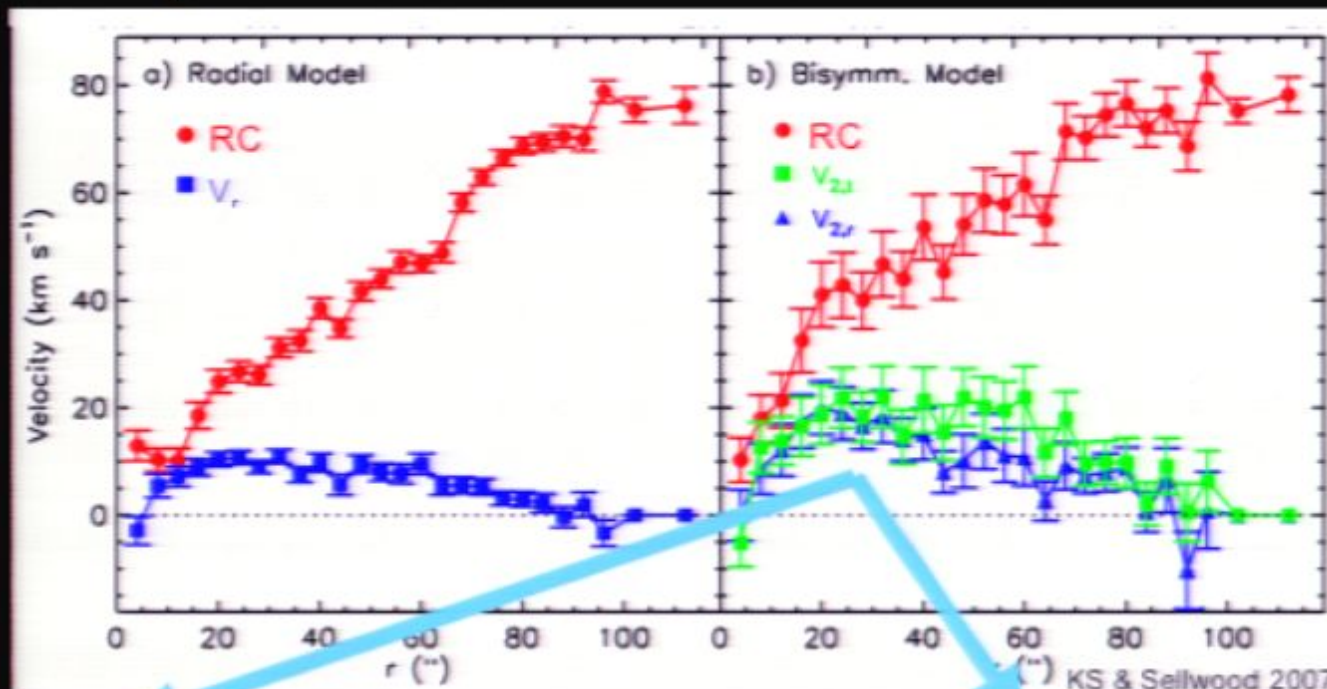


Bisymmetric model yields steeper rotation curve than radial model



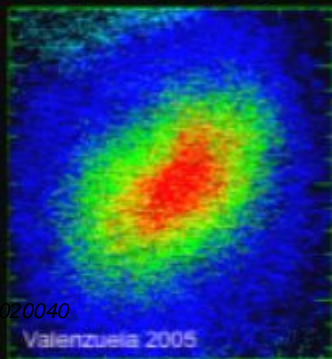
Implications for the Halo Structure

Velocity field components:



What drives non-circular motions?

triaxial halo



- minimum disk
- LCDM halo?

stellar bar

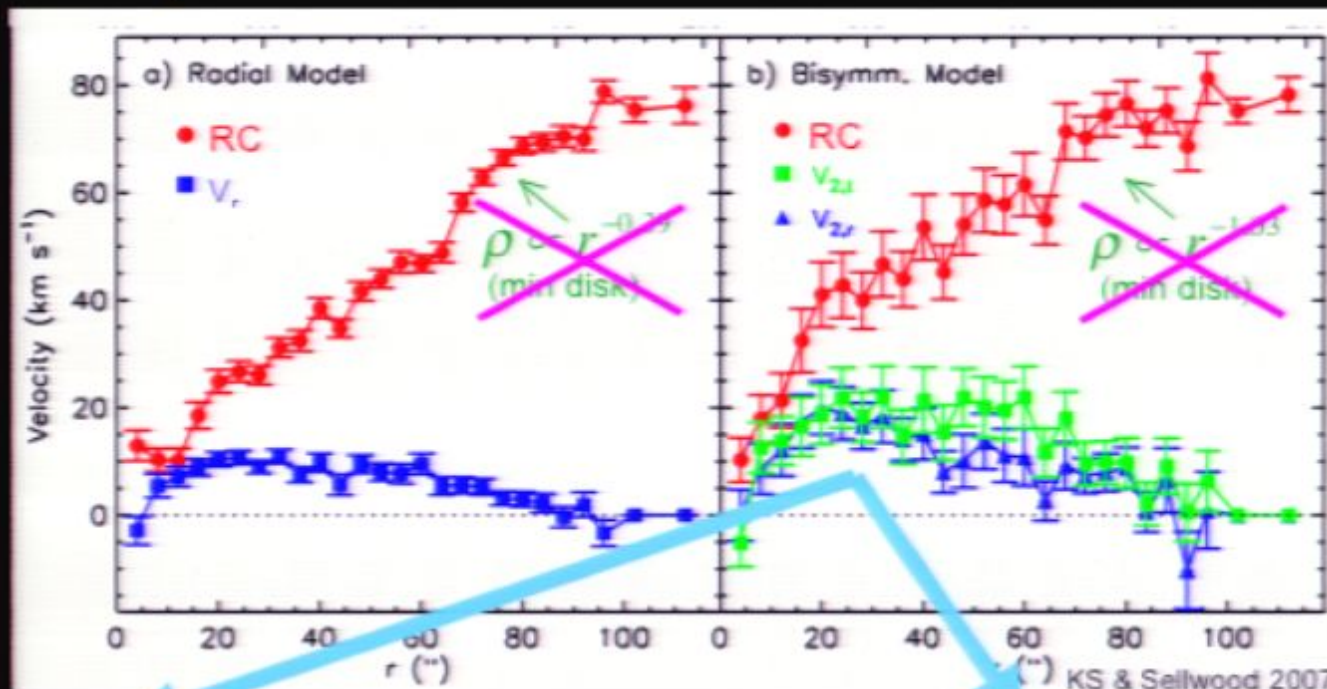


- maximum disk
- little dark matter?



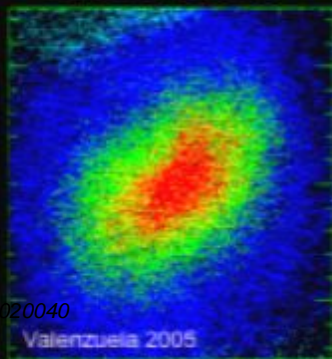
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triaxial halo



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stellar bar

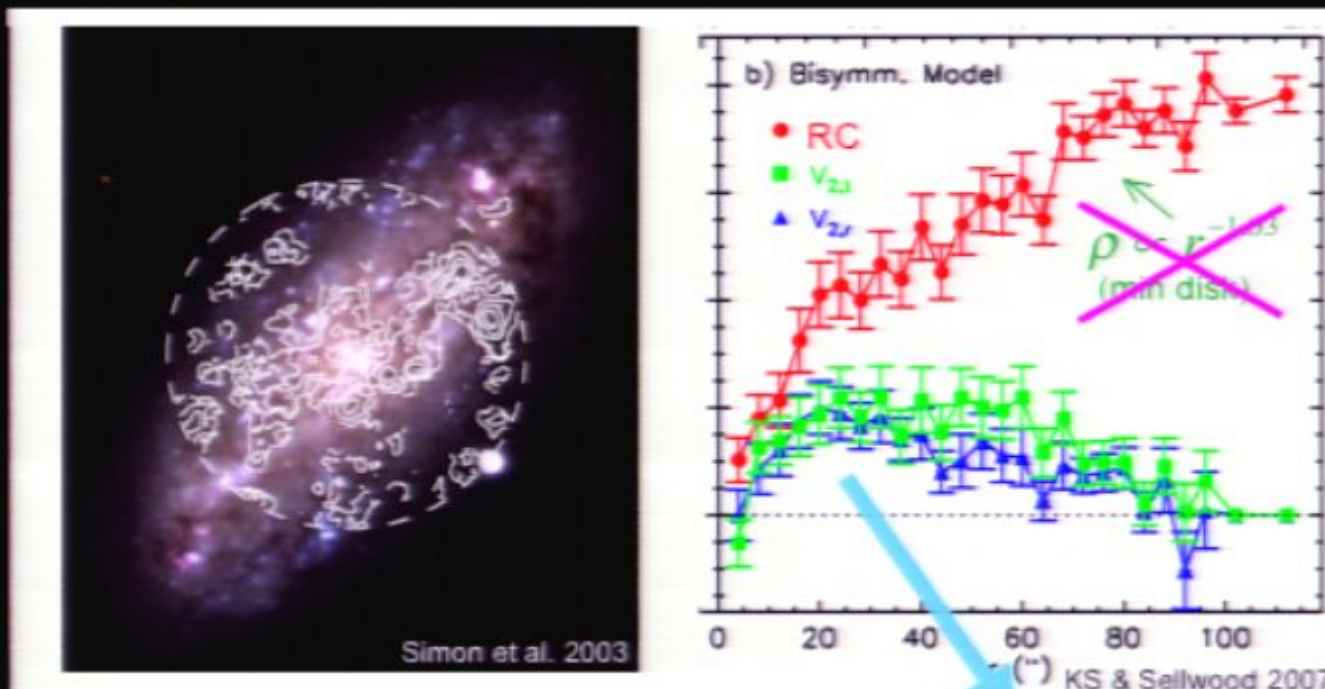


- maximum disk
- little dark matter?



Implications for the Halo Structure

Velocity field components:



What drives non-circular motions?

Despite steeper RC, halo concentration of N2976 is probably still low

stellar bar

NGC 1300

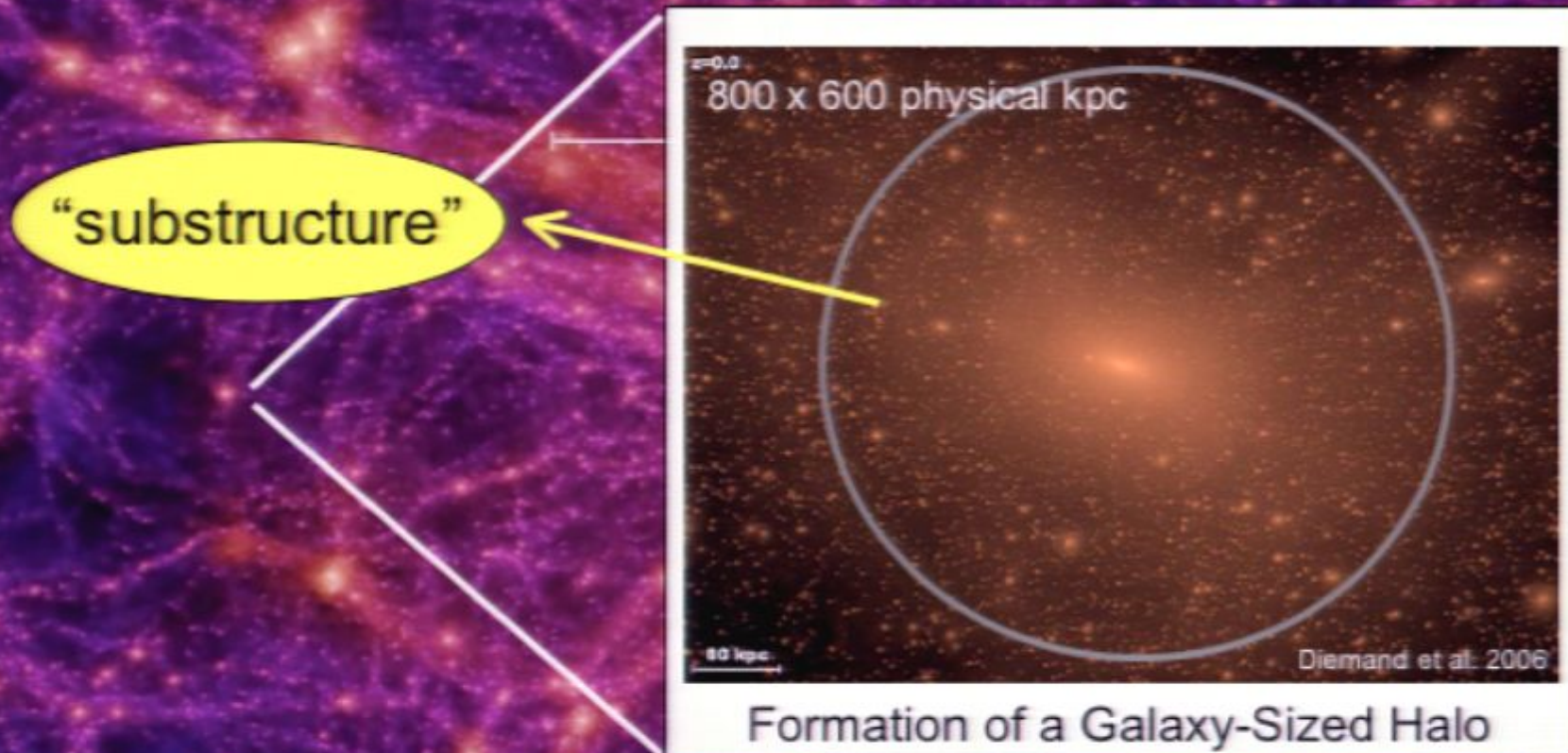
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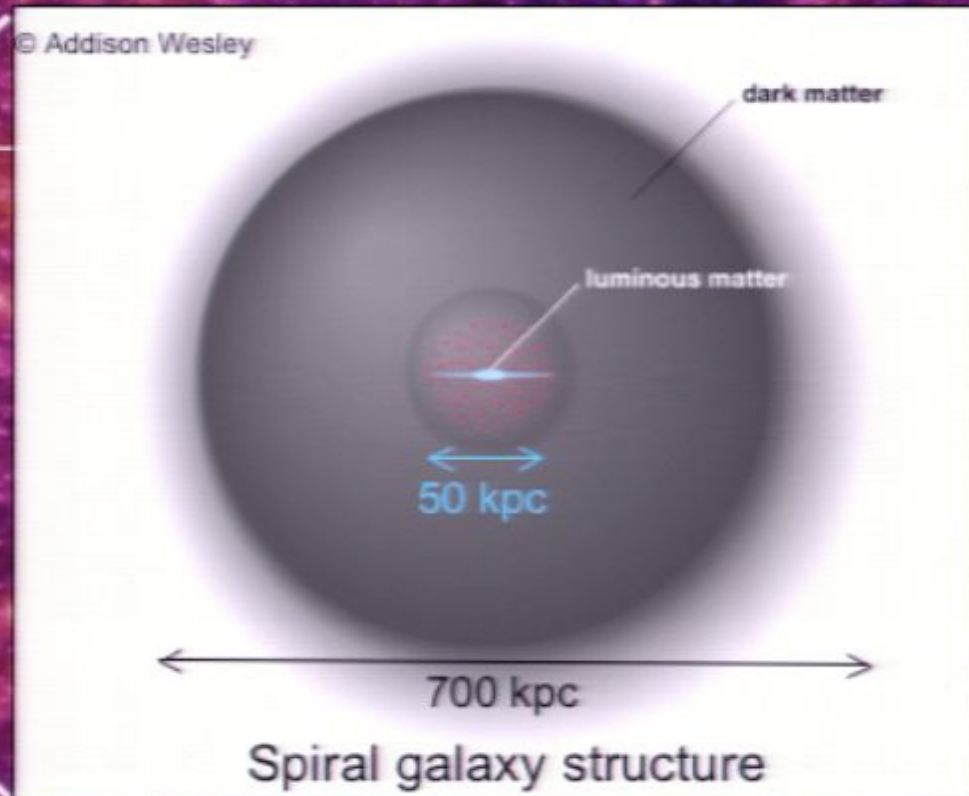
Missing Satellites and the Hunt for Dark Galaxies



Structure Formation in a LCDM Universe

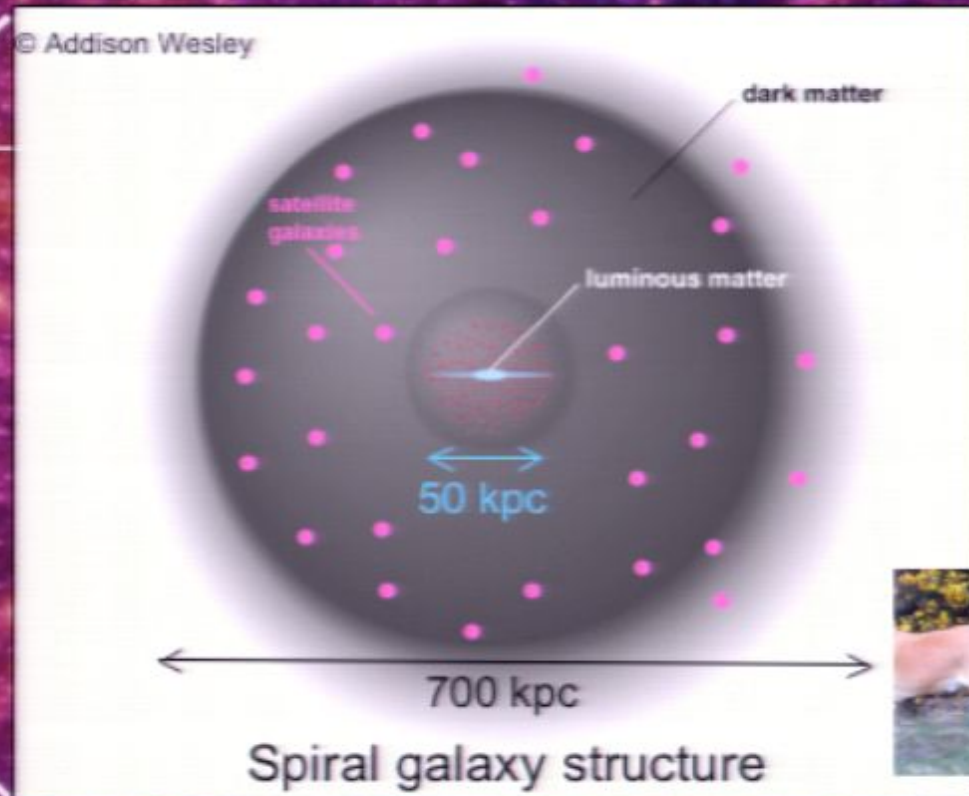


Structure Formation in a LCDM Universe



Disk galaxies: dissipative baryon collapse conserving specific AM

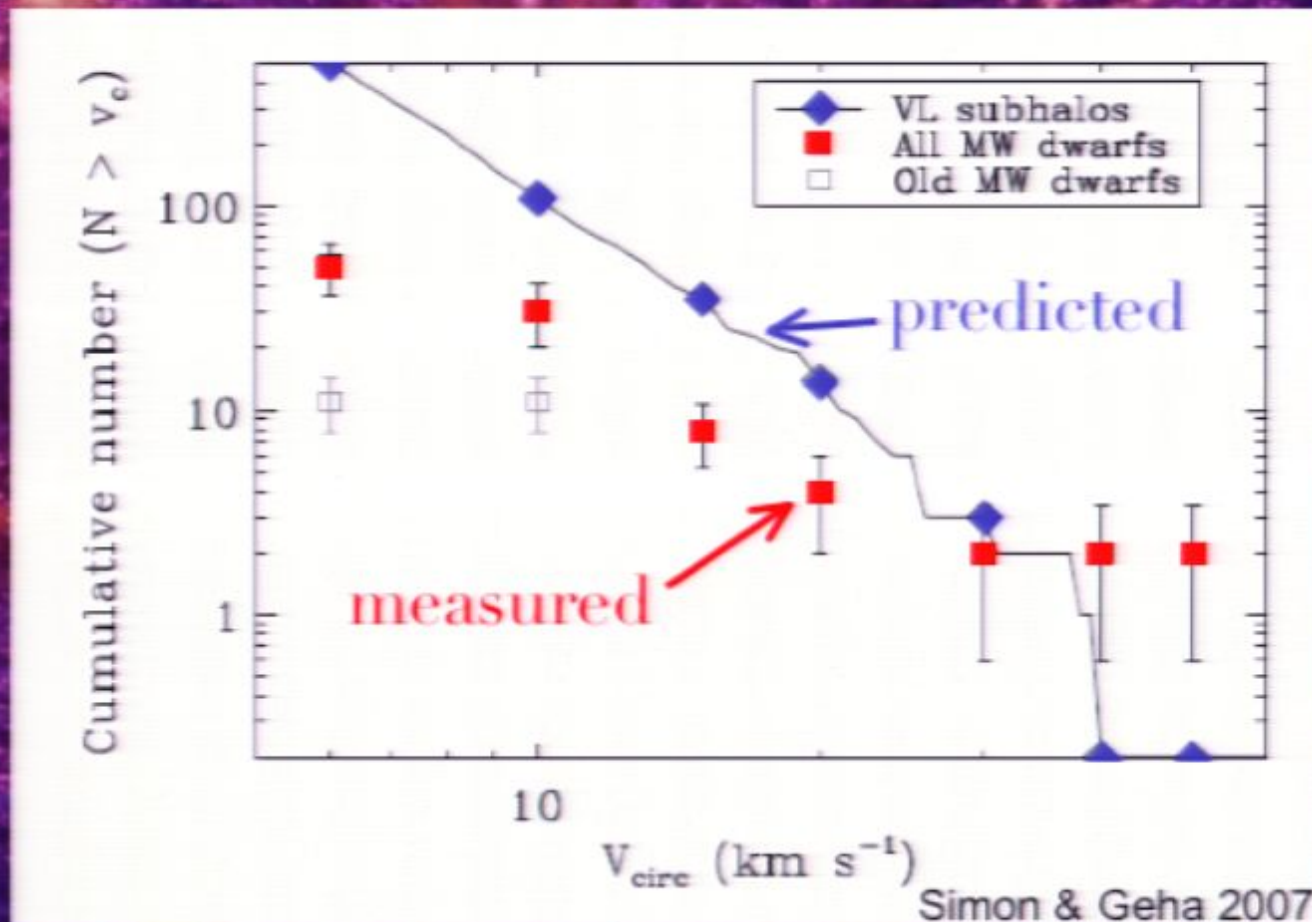
Structure Formation in a LCDM Universe



Disk galaxies: dissipative baryon collapse conserving specific AM

The Missing Satellite Problem



In the Milky Way:



Where are all of the low-mass galaxies?

Hunting for Dark Galaxies


Surveys for dark galaxies (with atomic gas but no stars):

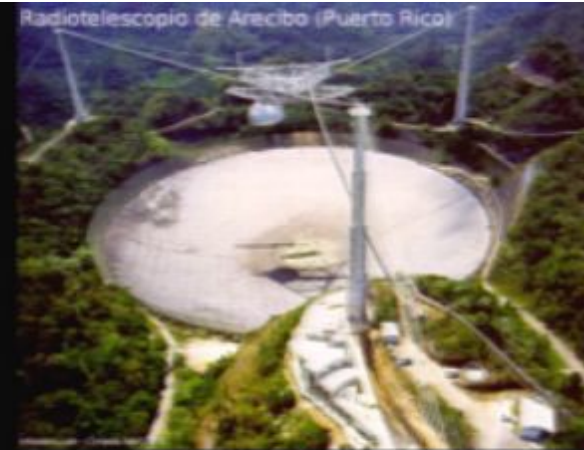
1. “Shallow” survey of nearby galaxy cluster 
2. Deep survey near individual galaxy 




~ 1 degree

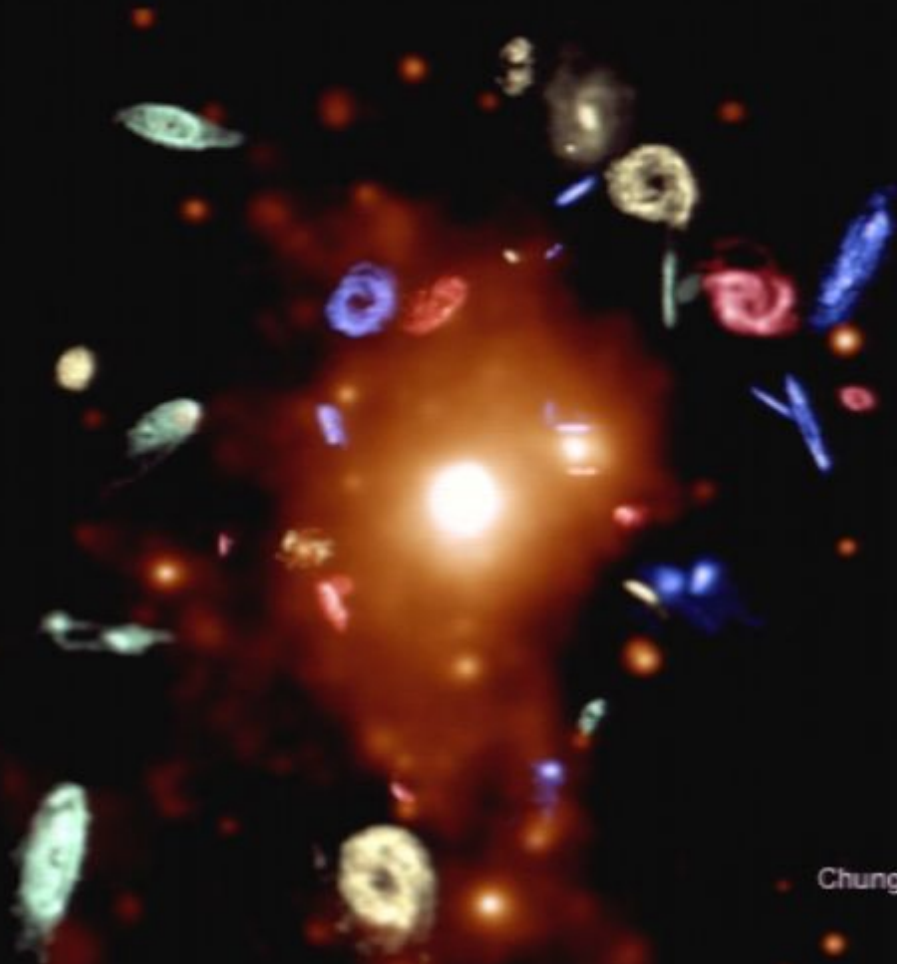



~ 10 degrees



Hunting for dark galaxies with ALFALFA

Blind HI survey at high galactic latitudes ($\sim 7000 \text{ deg}^2$)



Chung et al. 2005

<http://egg.astro.cornell.edu/alfalfa/>

Hunting for dark galaxies with ALFALFA

Blind HI survey at high galactic latitudes ($\sim 7000 \text{ deg}^2$)



Little evidence for HI-rich ($10^7 M_{\odot}$) dark galaxies in the Virgo Cluster

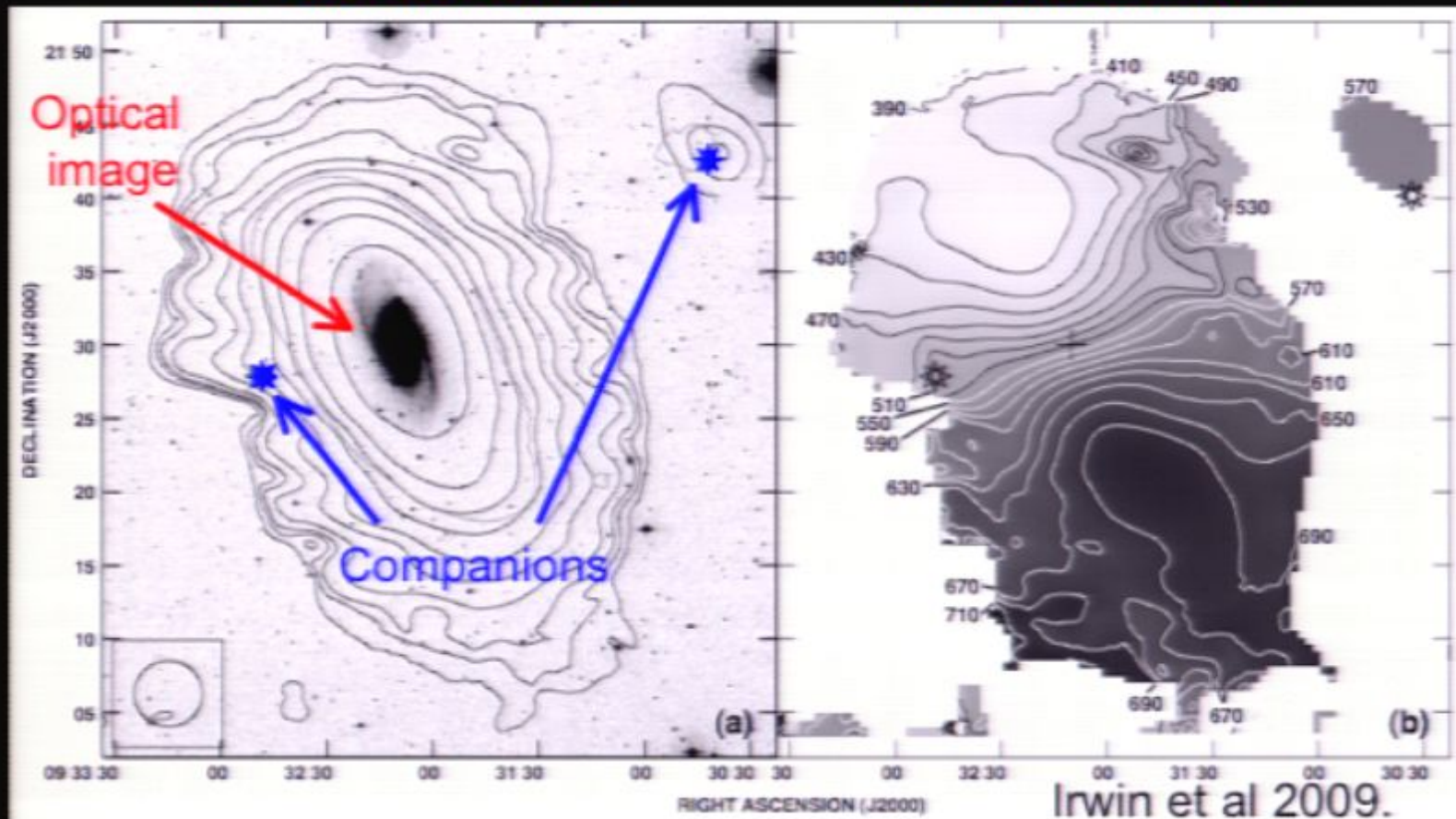


Hunting for Dark Galaxies with AGES

Deep survey near NGC 2903:

HI distribution

HI kinematics



Little evidence for HI-rich ($\sim 5 \times 10^5 M_{\odot}$)
dark galaxies near NGC 2903



Summary

1. LCDM is very successful on large scales, but no clear agreement between theory and observations on galactic scales
 - Halo cuspliness/concentrations, missing satellites
2. New observations are testing ideas for resolving known discrepancies in disk galaxies
 - Bisymmetric model
3. New legacy surveys with Arecibo are constraining number density of gas-rich dark galaxies
 - None in clusters, near disk galaxies?

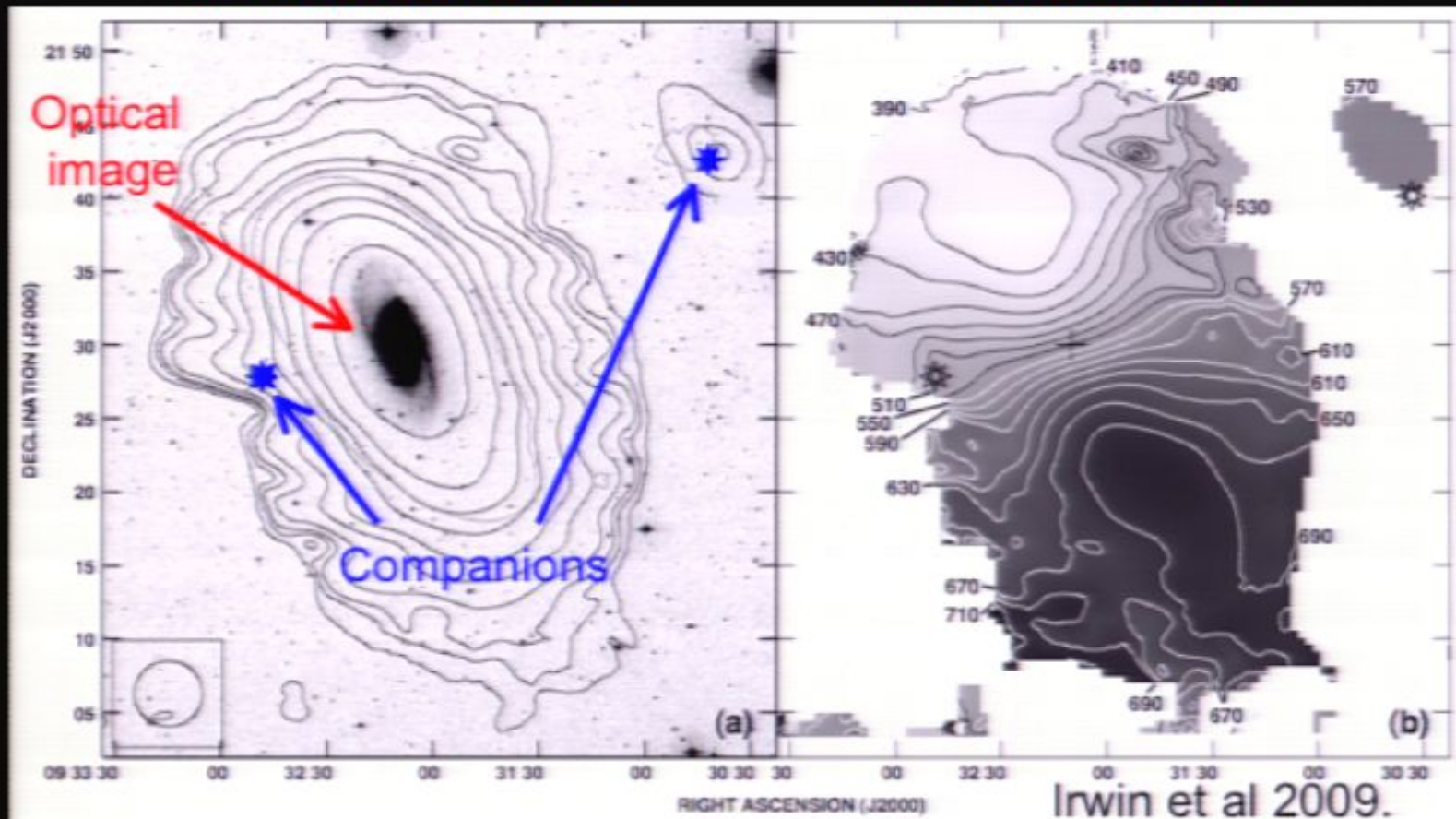


Hunting for Dark Galaxies with AGES

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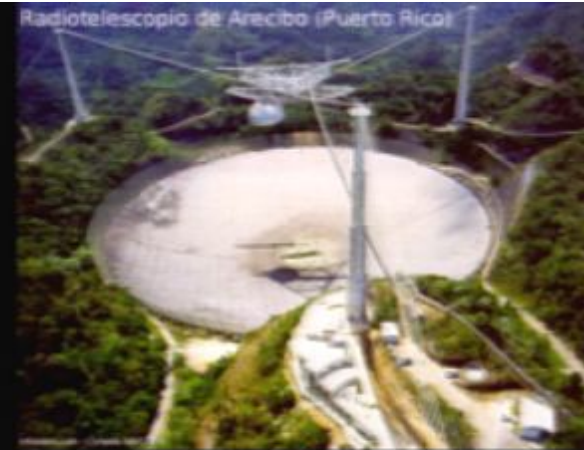
Hunting for Dark Galaxies


Surveys for dark galaxies (with atomic gas but no stars):

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2. Deep survey near individual galaxy 




~ 1 degree



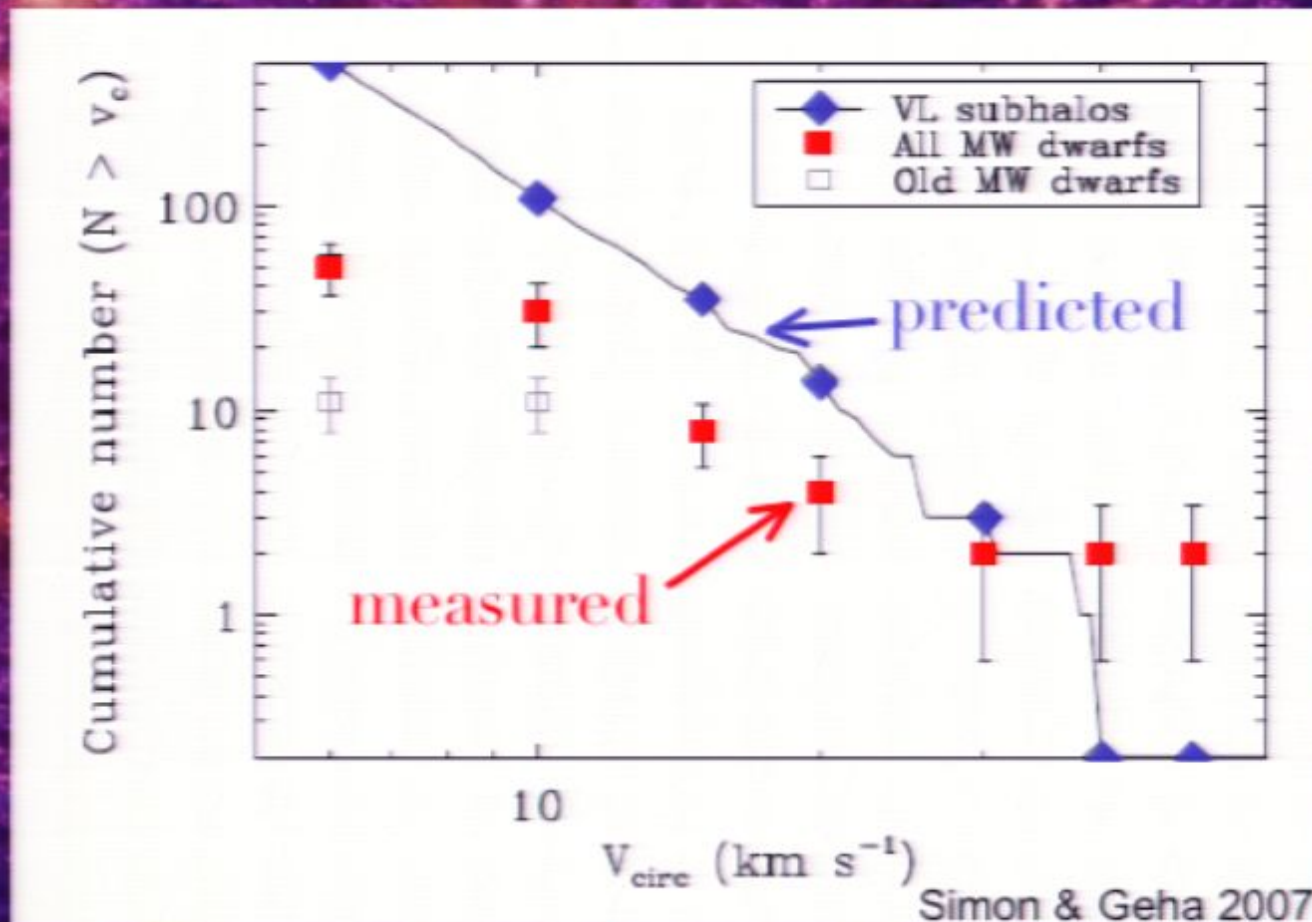

~ 10 degrees

survey: ALFALFA



The Missing Satellite Problem



In the Milky Way:



Where are all of the low-mass galaxies?

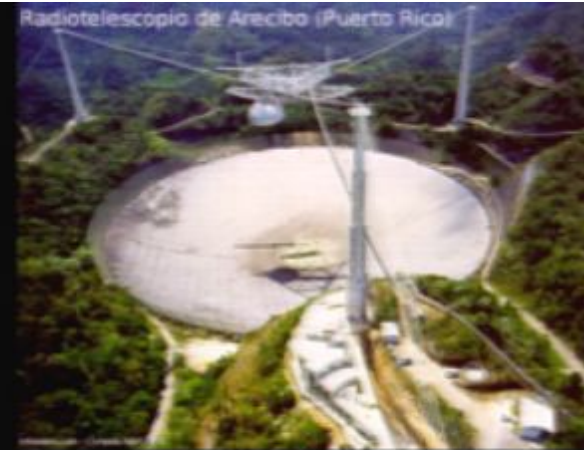
Hunting for Dark Galaxies


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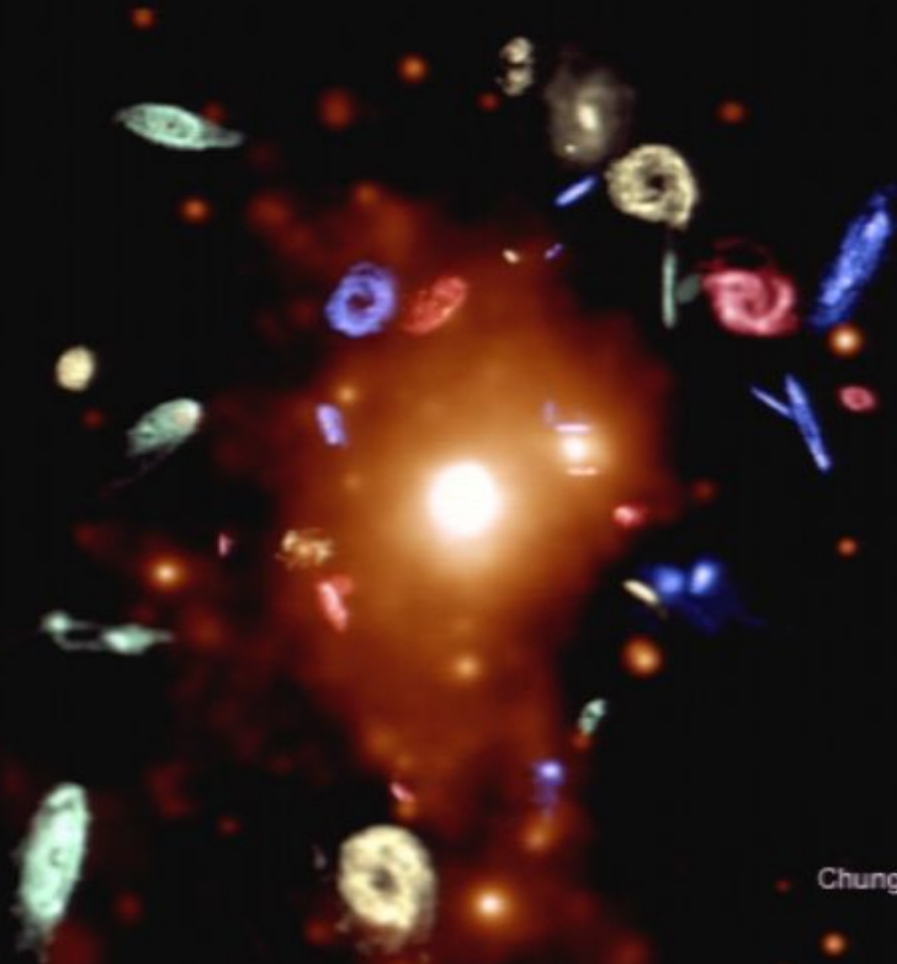

~ 10 degrees

survey: ALFALFA



Hunting for dark galaxies with ALFALFA

Blind HI survey at high galactic latitudes ($\sim 7000 \text{ deg}^2$)



Chung et al. 2005

<http://egg.astro.cornell.edu/alfalfa/>



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Hunting for dark galaxies with ALFALFA

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Kent et al. 2007

Chung et al. 2005

Little evidence for HI-rich ($10^7 M_{\odot}$) dark galaxies in the Virgo Cluster



Hunting for dark galaxies with ALFALFA

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Chung et al. 2005

Little evidence for HI-rich ($10^7 M_{\odot}$)
dark galaxies in the Virgo Cluster

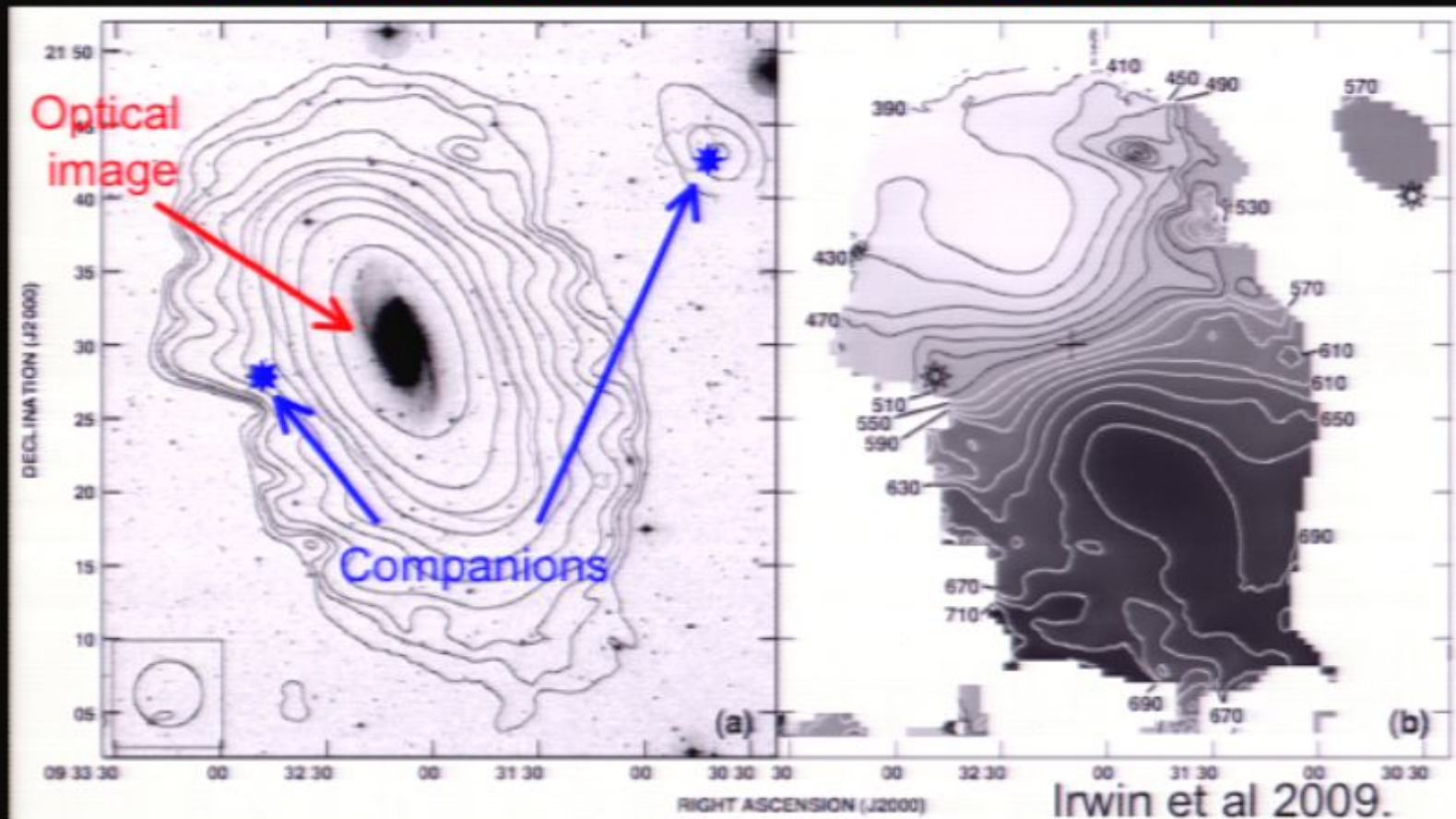


Hunting for Dark Galaxies with AGES

Deep survey near NGC 2903:

HI distribution

HI kinematics



Little evidence for HI-rich ($\sim 5 \times 10^5 M_{\odot}$)
dark galaxies near NGC 2903

