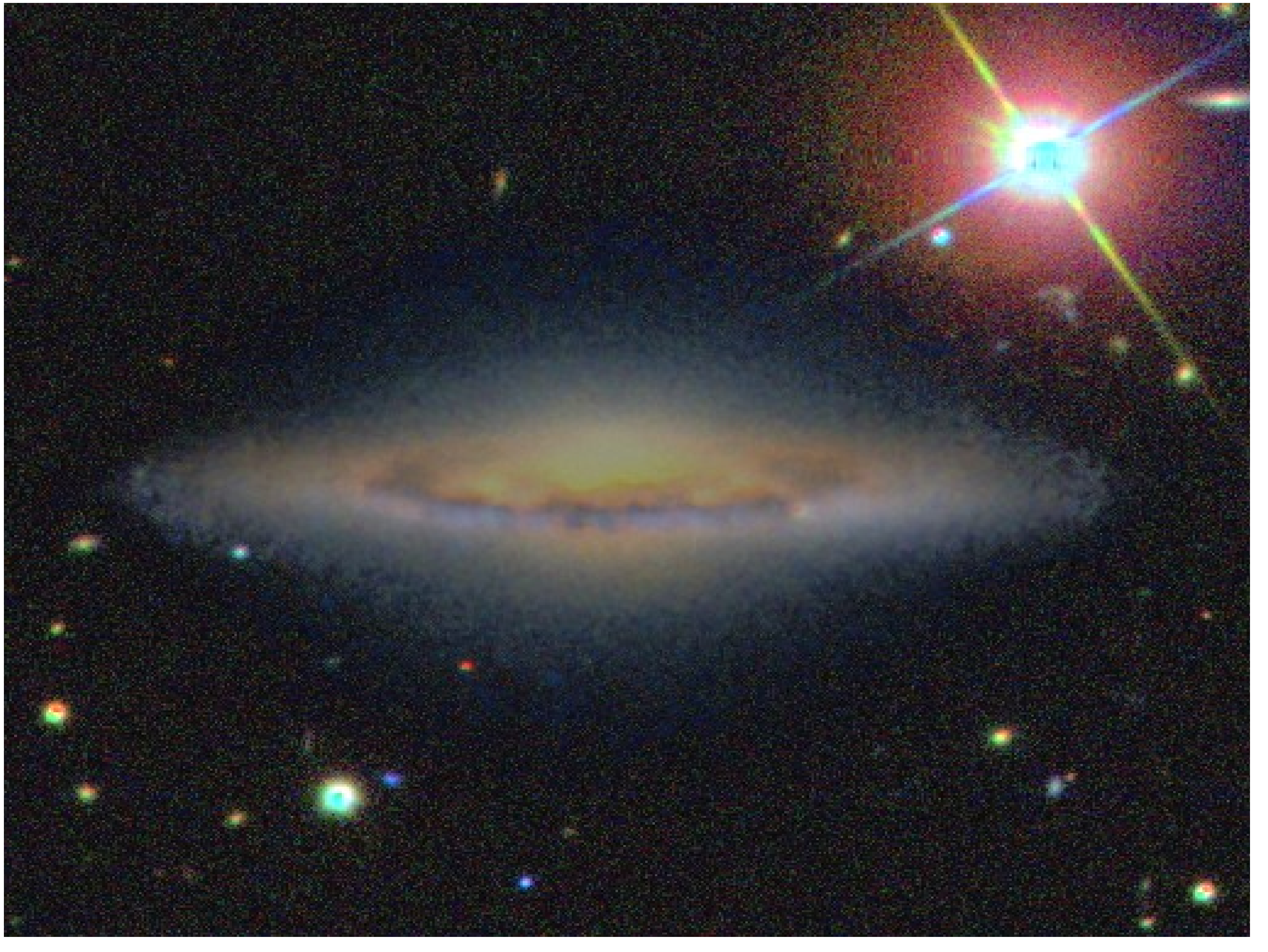
N-body/SPH Simulations of Galactic Disks



Thomas Quinn, University of Washington

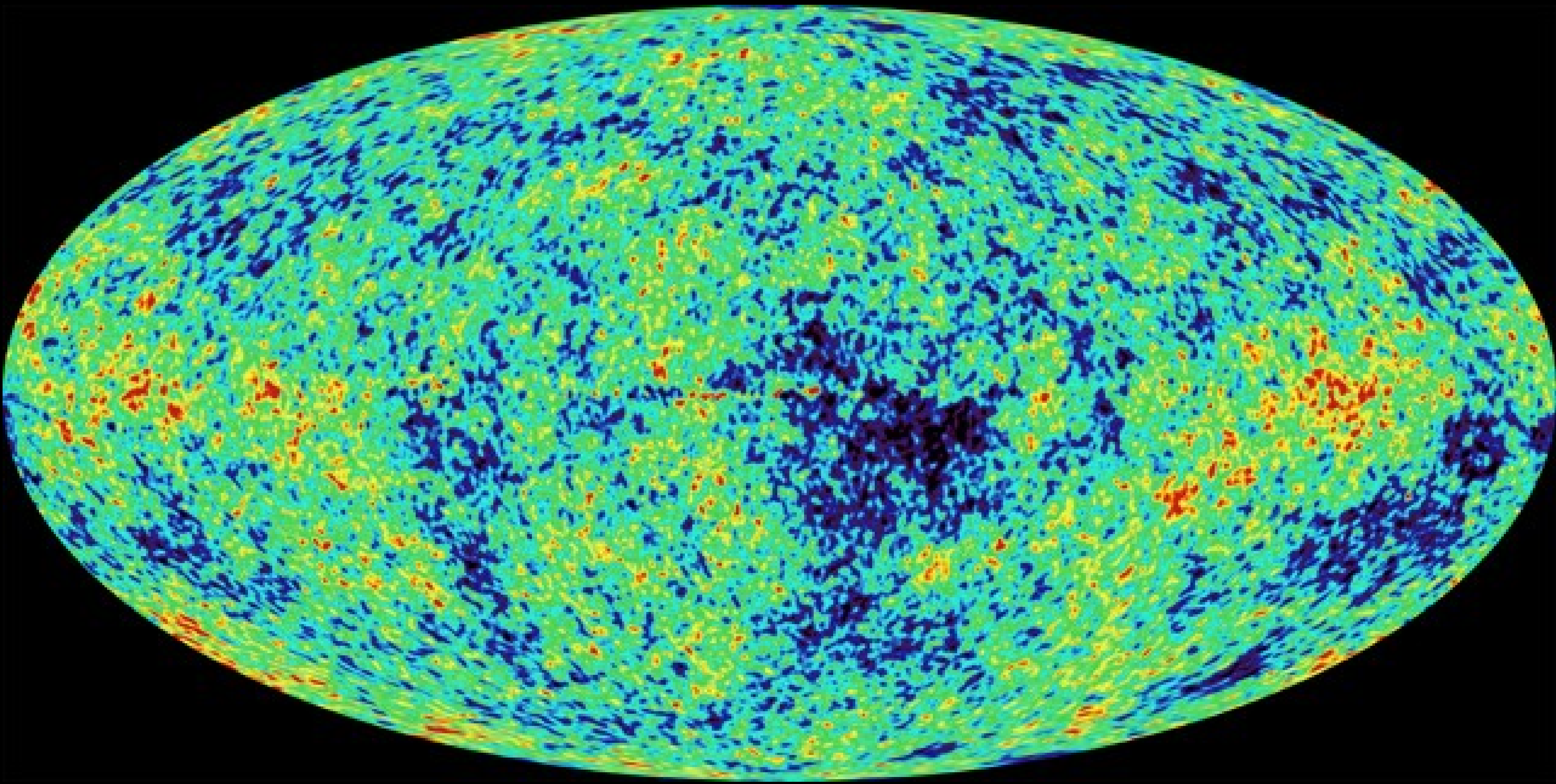
Greg Stinson, Charlotte Christensen, Alyson Brooks
Rok Roškar, Sarah Loebman

Fabio Governato, Chris Brook, Victor Debattista,

James Wadsley

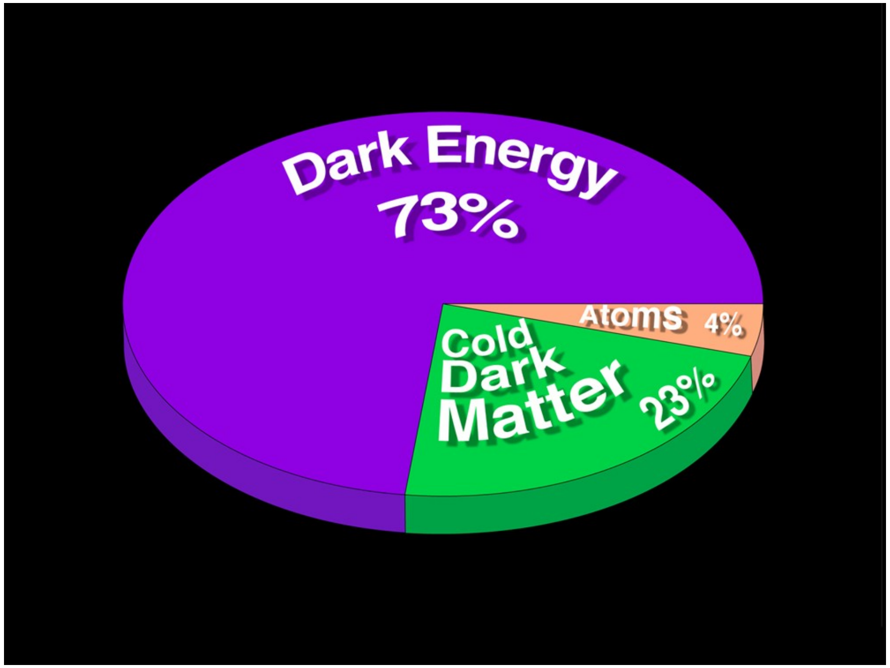
A short history of the Universe:

- The Big Bang
- Quantum era: the large structures we see today started as quantum froth
- Universe becomes transparent
- First stars form
- Galaxies form
- **Much later:** Sun and planets form



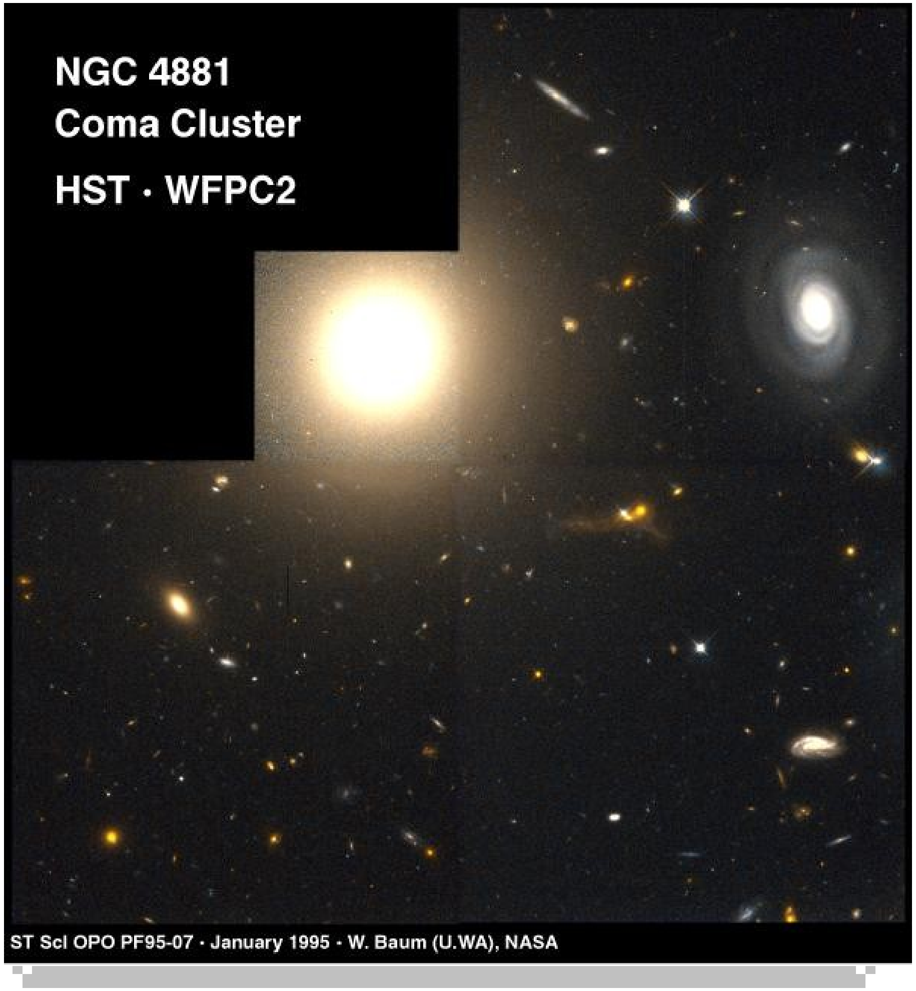
What is the Universe made of?

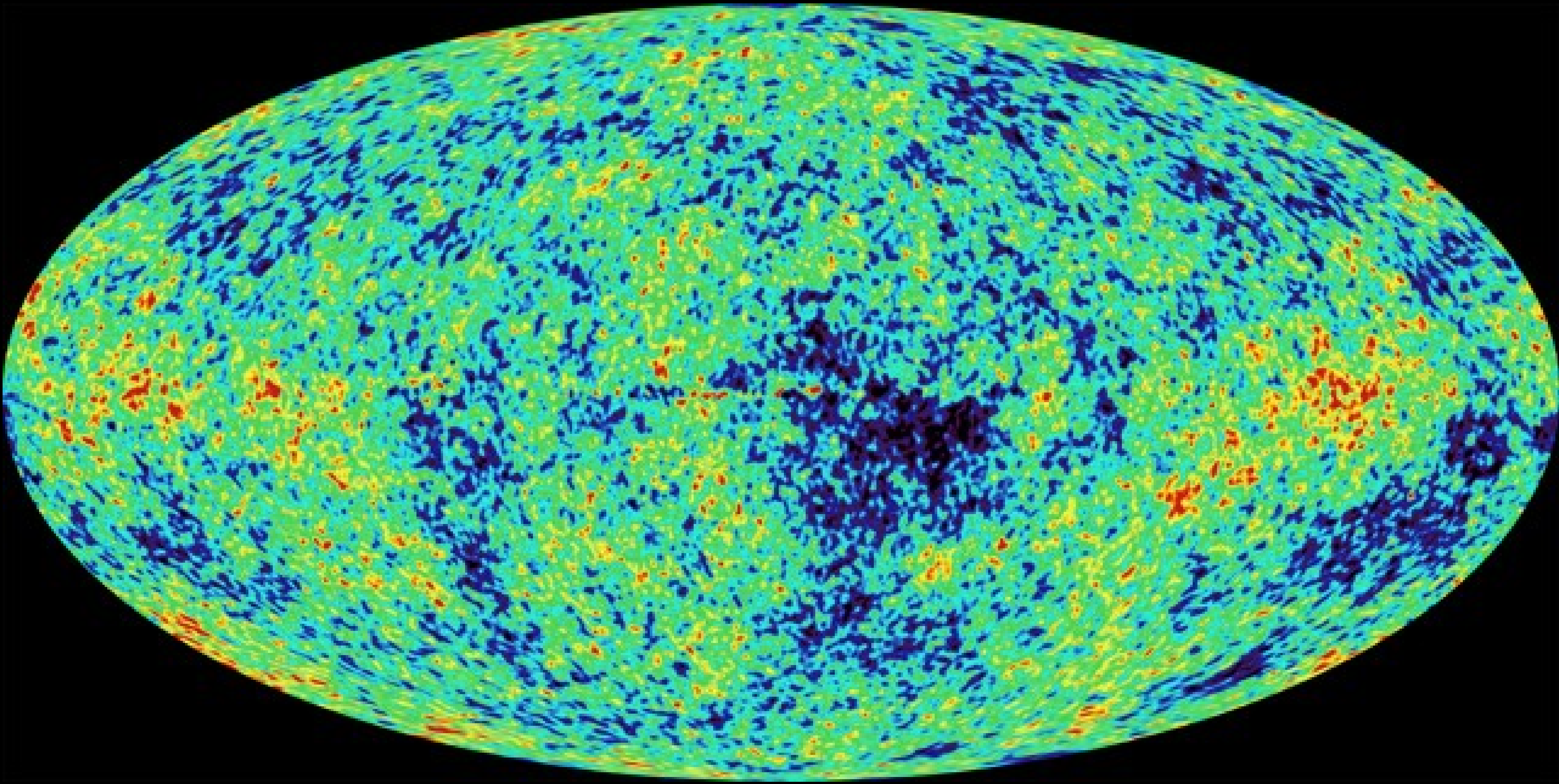
- Mostly not baryons
- Simulations show: not known neutrinos
- DM Candidates:
  - Sterile Neutrinos
  - Axions
  - Lightest SUSY Particle (LSP)



Evidence for Dark Matter

- Motions of Galaxies in Clusters
- $\langle v^2 \rangle \sim GM/R$
- $M_{total} \gg M_{stars}$





... turn into this?

Cosmology and Galaxies

- CDM implies structure at all scales
  - Hierarchical Merging
  - Substructure
- Angular momentum from tidal torques
  - 10's of Mpc for a galaxy halo
- Accretion evolves with time
- Galaxies form in a context

Simulating Galaxy Formation Requirements:

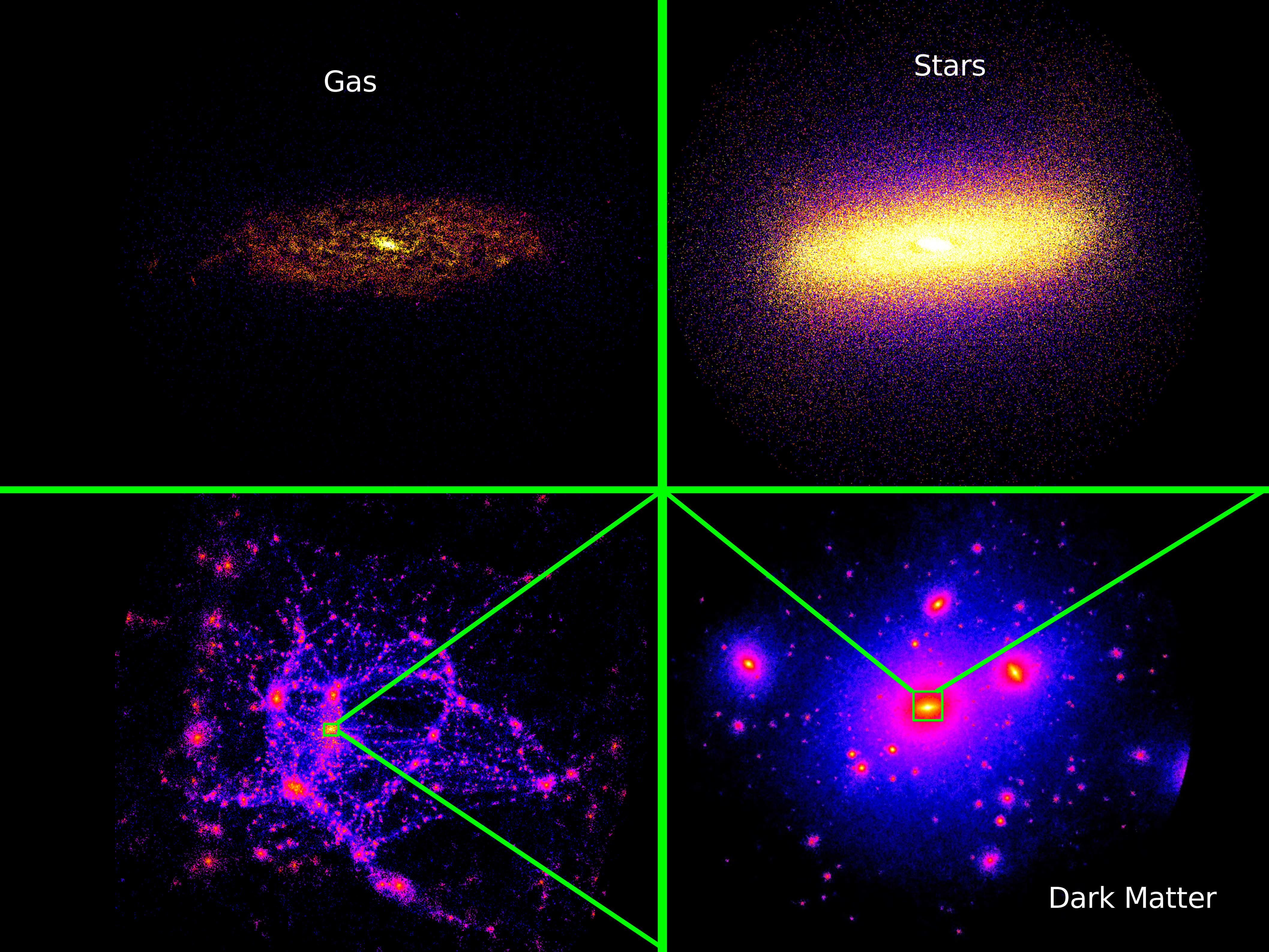
- Full cosmological context with high resolution
  - Dynamic range of 100,000 in time and space
  - Treecode/SPH or similar adaptive method is required.
- Physically motivated subgrid effects of star formation and feedback
- Complete simulations to present epoch.
- Analyze with multiple simulated observations

Simulation process

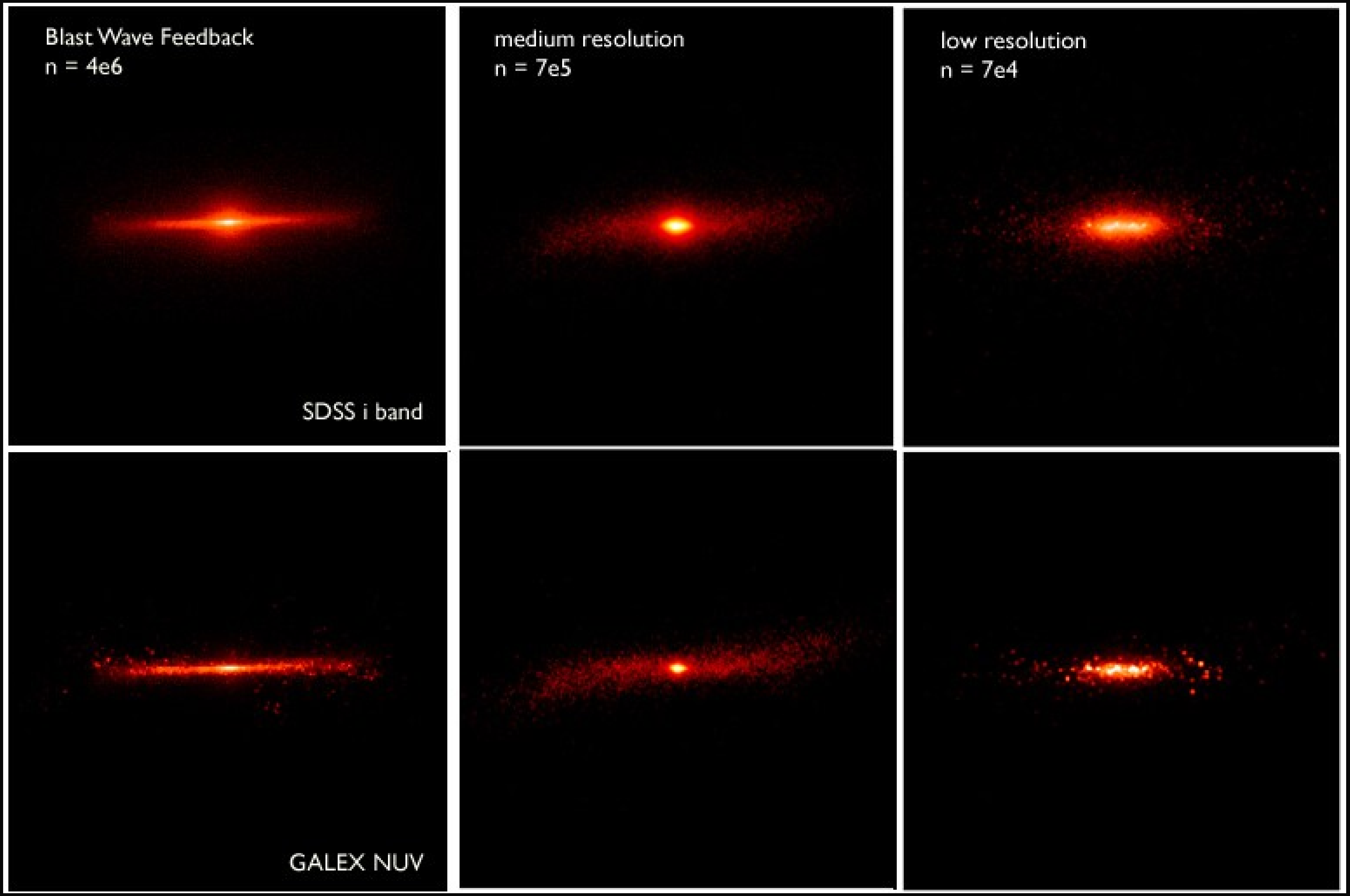
- Start with fluctuations based on Dark Matter properties
- Follow model analytically (good enough to get CMB)
- Create a realization of these fluctuations in particles.
- Follow the motions of these particles as they interact via gravity.
- Compare final distribution of particles with observed properties of galaxies.

Simulating galaxies: Procedure

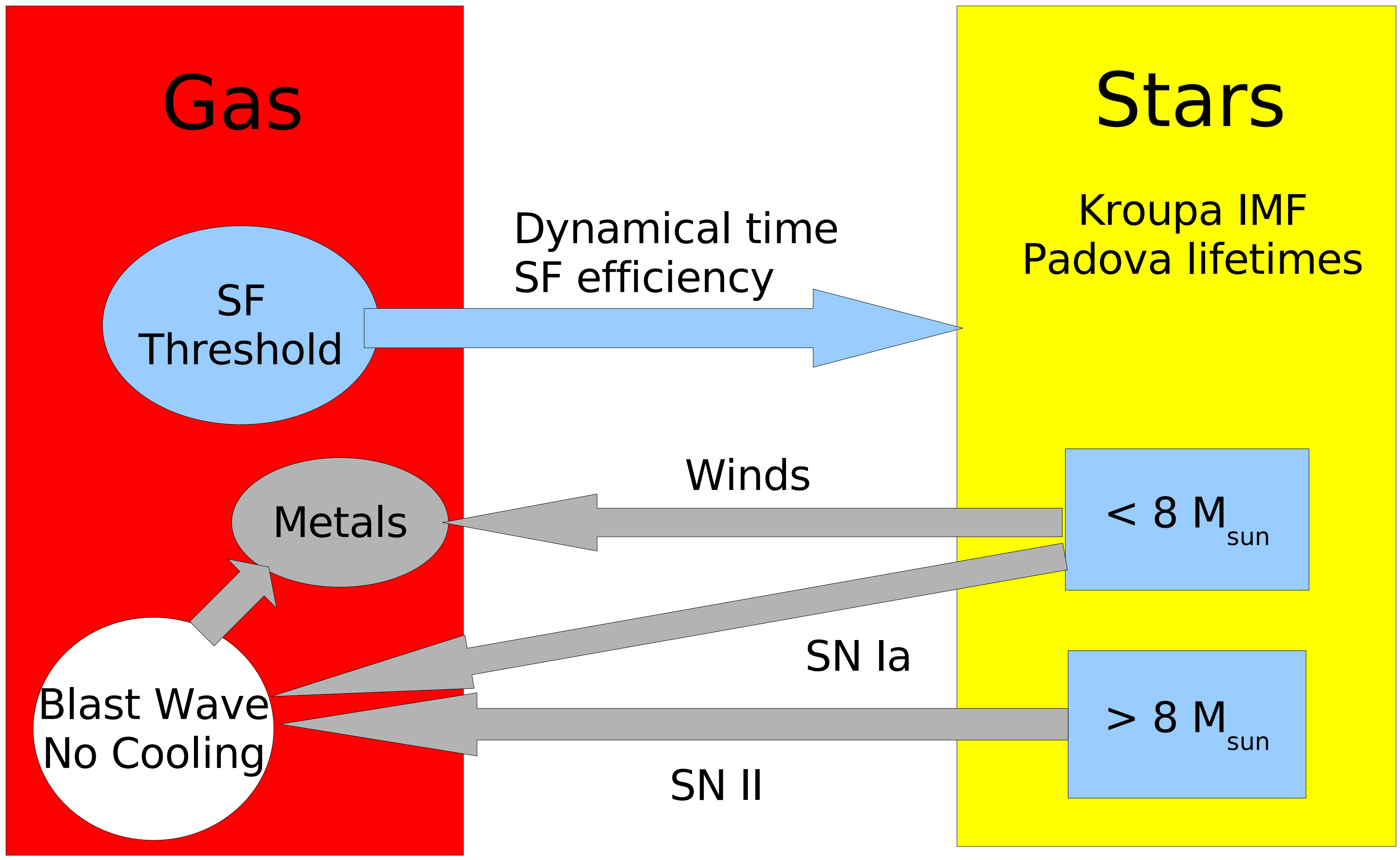
1. Simulate 100 Mpc volume at 10-100 kpc resolution
2. Pick candidate galaxies for further study
3. Resimulate galaxies with same large scale structure but with higher resolution, and lower resolution in the rest of the computational volume.
4. At higher resolutions, include gas physics and star formation.


Gas
Stars
Dark Matter

Effect of Increasing Resolution on the size of disks

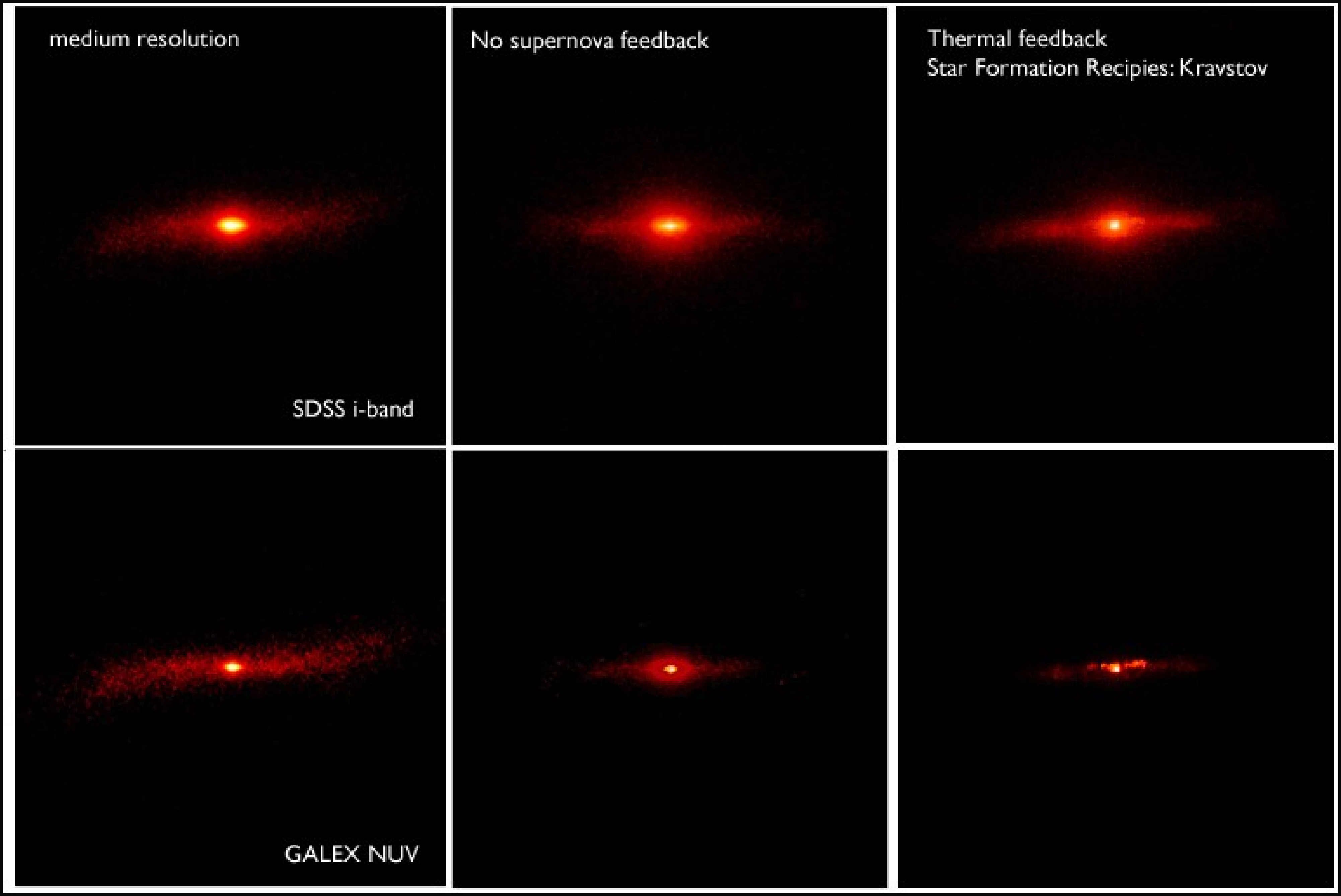


Star Formation/Feedback
implemented in GASOLINE (Wadsley et al 2004)



Stinson et al 2006

Effects of Feedback on Morphology

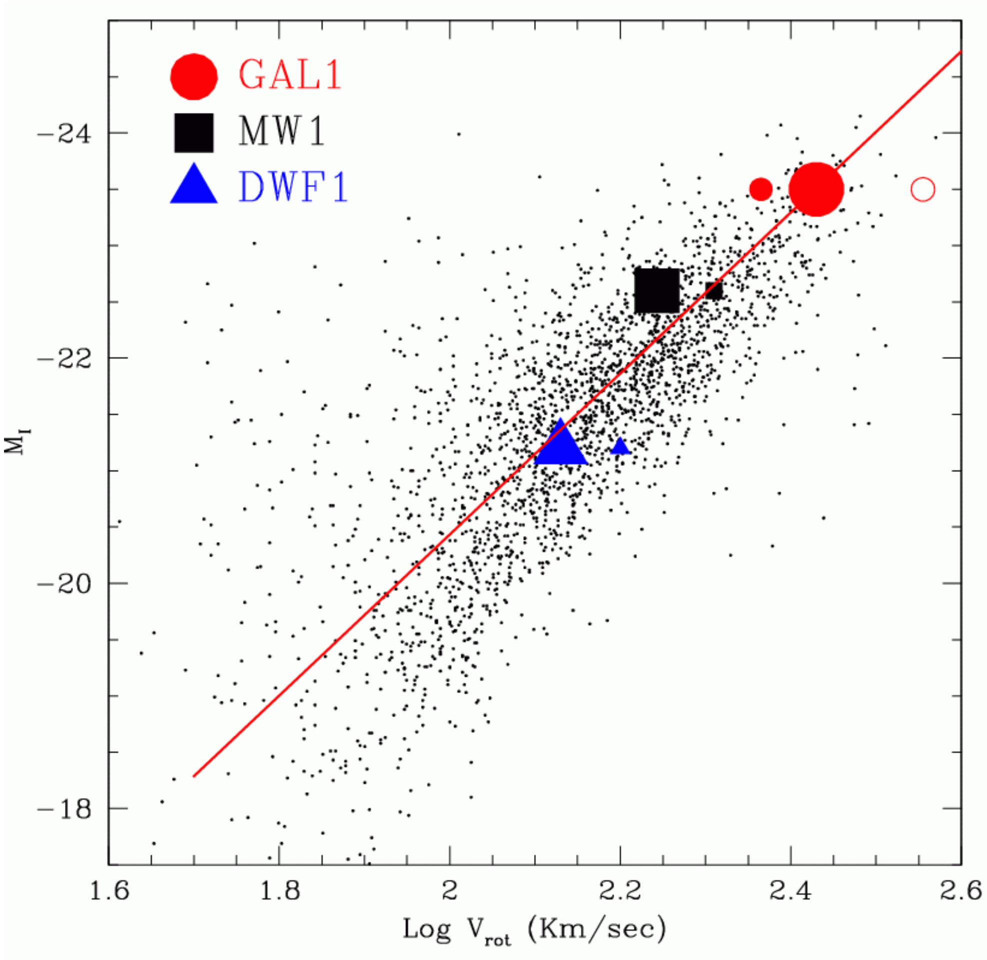


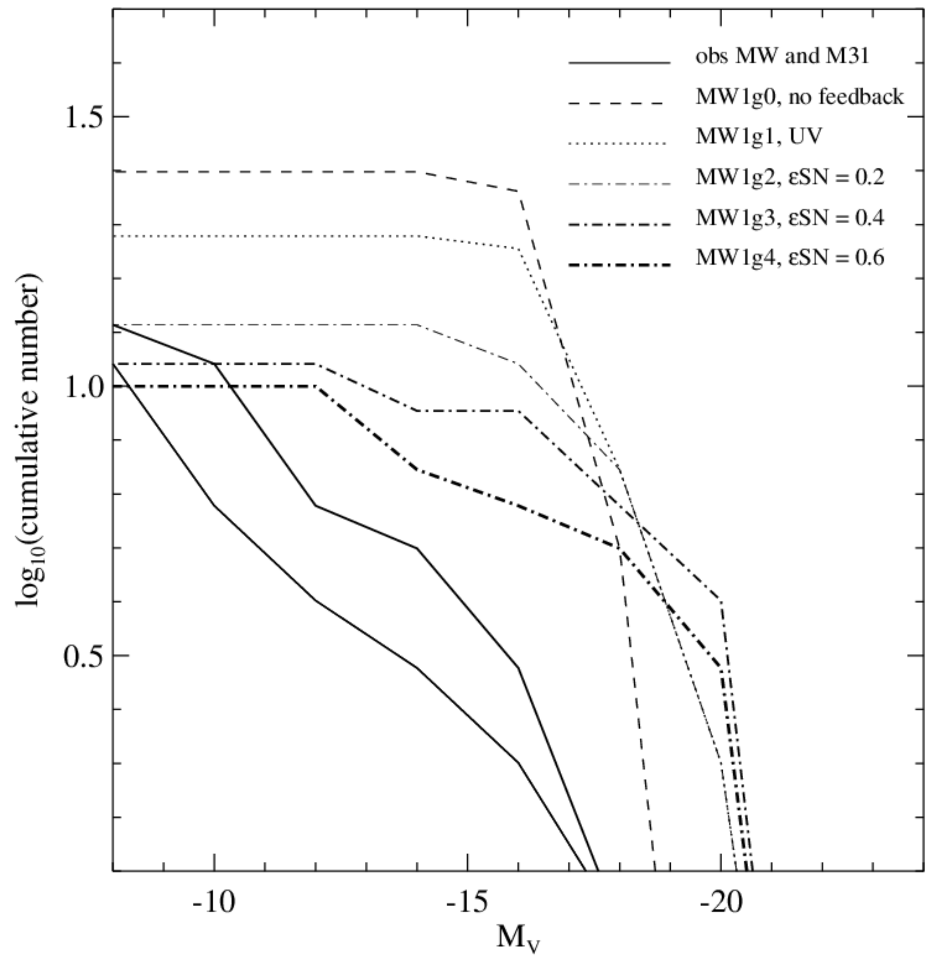
Simulation successes

In Large Disk galaxies:

- Number and luminosity of MW satellites
- Star formation history vs. mass (downsizing)
- Galaxy Luminosity vs. Mass (Tully-Fisher)
- Disk scale length
- Mass-Metallicity relation

Tested the CDM Galaxy Formation Model over a wide range of Observational

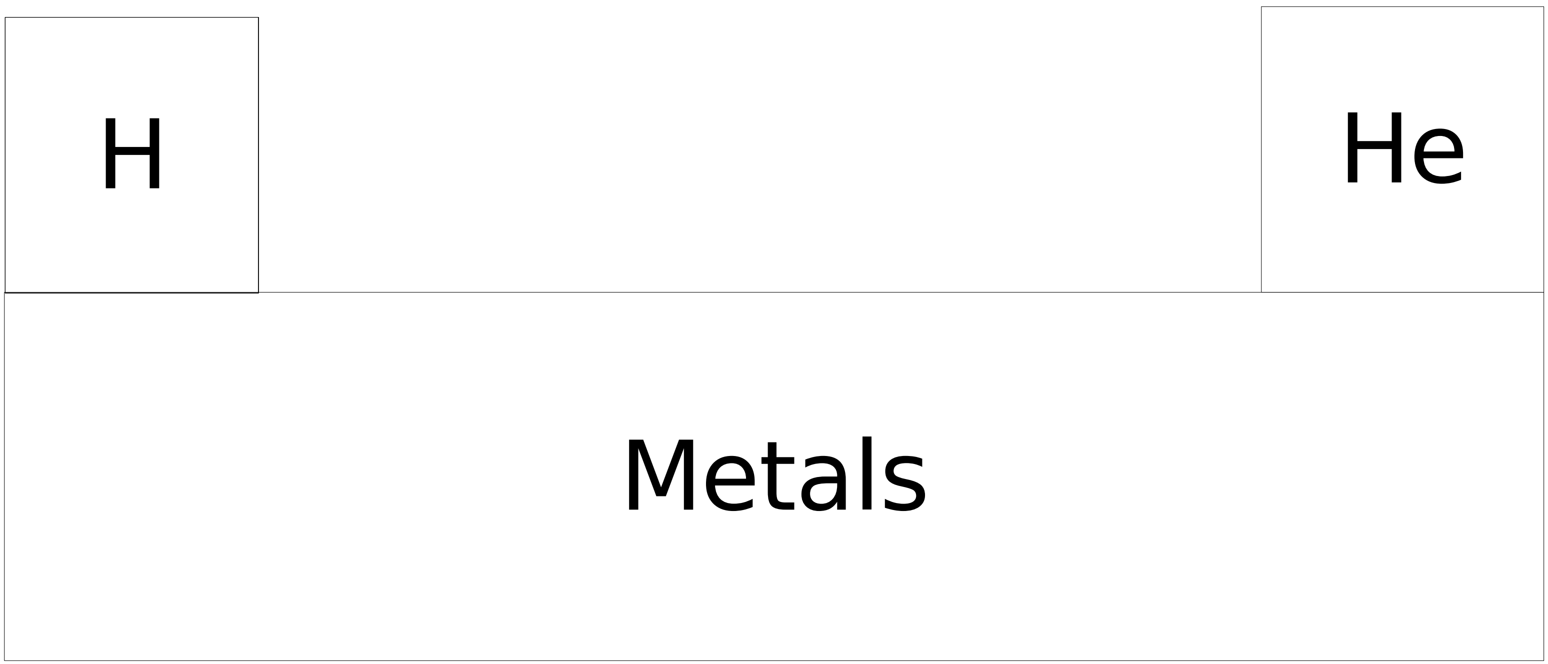




Data from Giavanelli

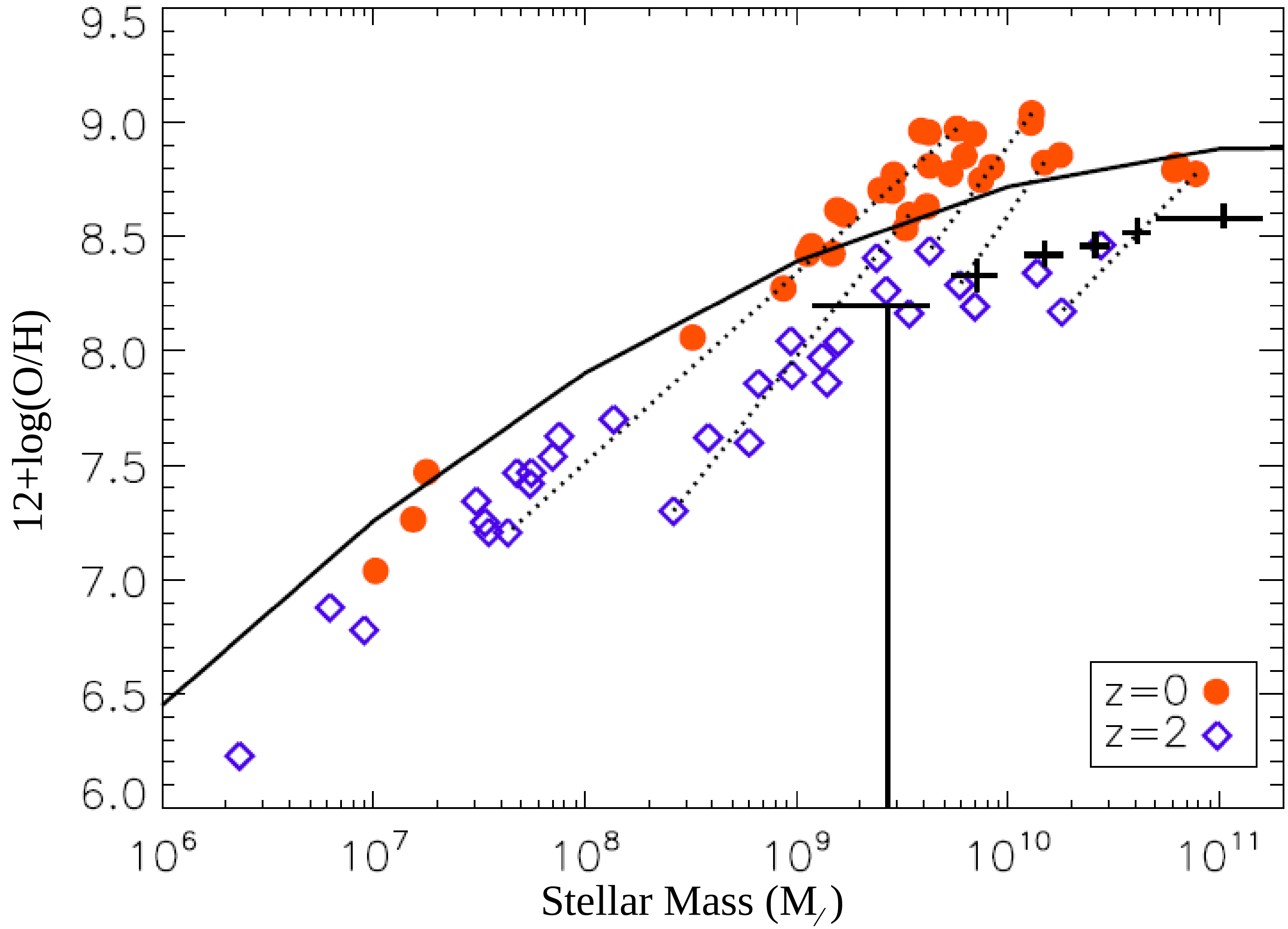
Governato et al 07

The Astronomer’s Periodic Table



MZR

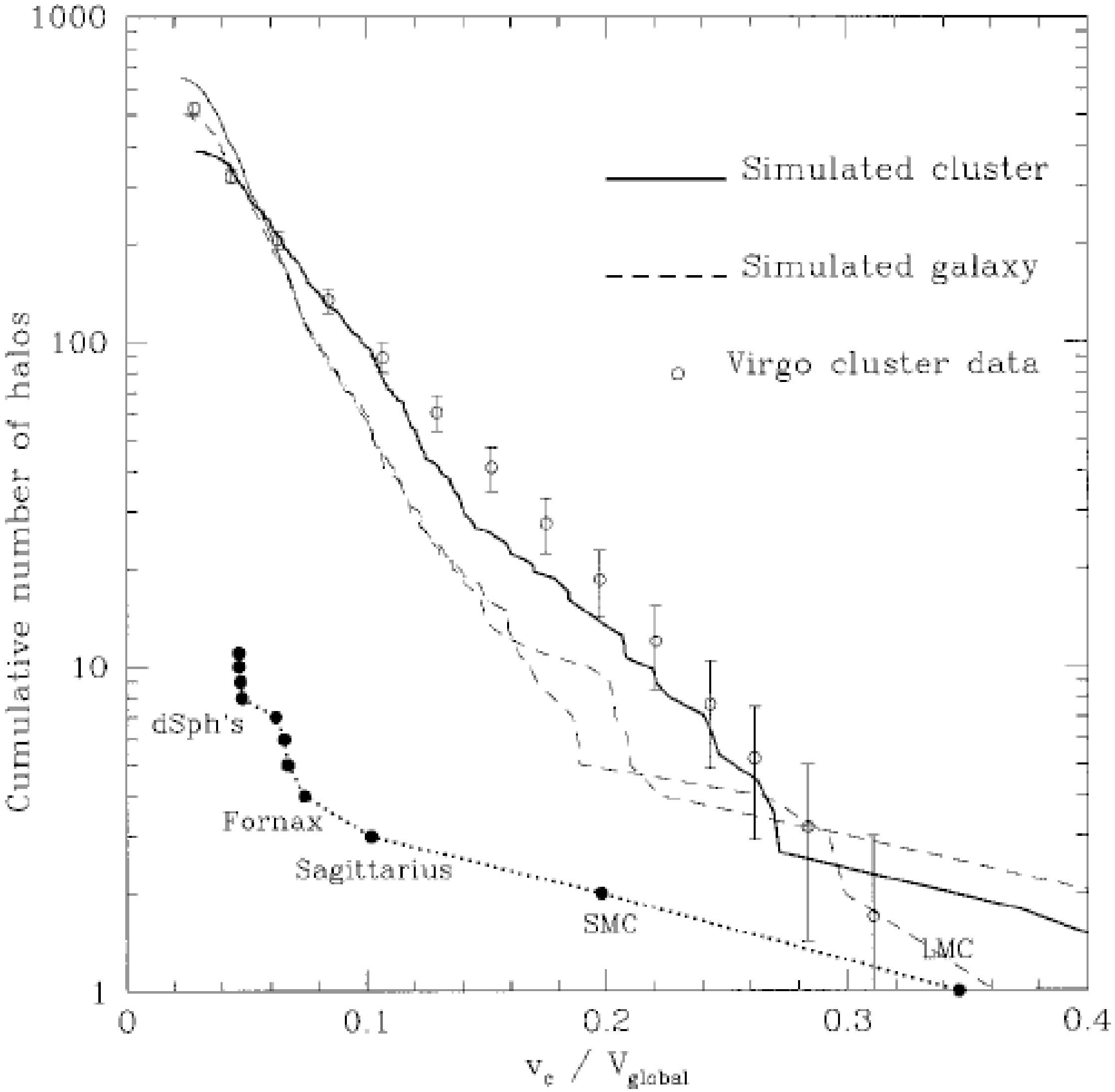
The Mass-Metallicity Relationship for Galaxies



Dwarf galaxies: CDM's hurdle

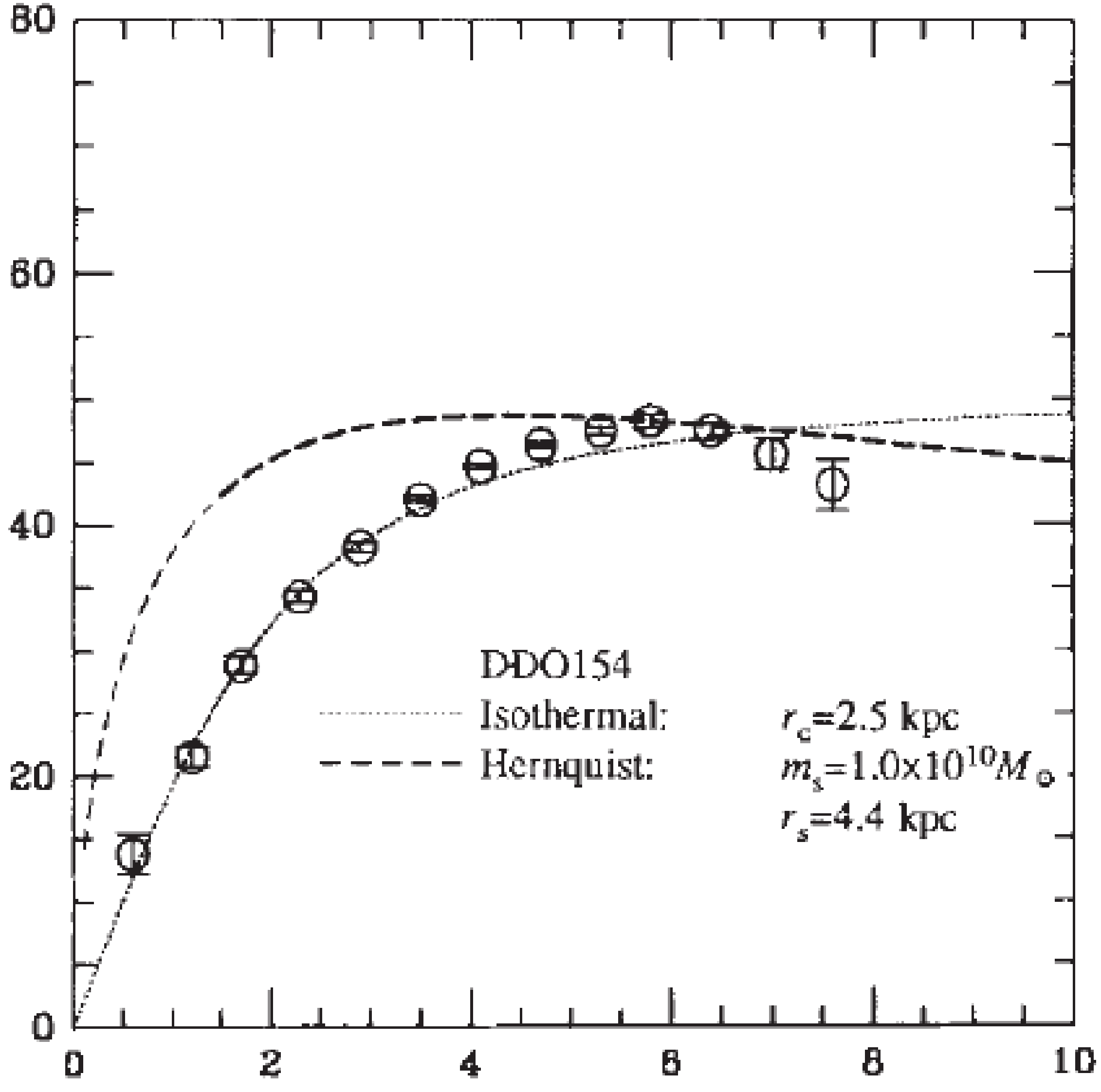
- Substructure problem
- Core/cusp problem
- Angular momentum problem
- Bulge/Disk ratio
- Can Baryon/Disk physics solve these?

The CDM Substructure Problem



Moore et al 1998

Core/Cusps in Dwarfs



Moore 1994

Angular momentum Problem

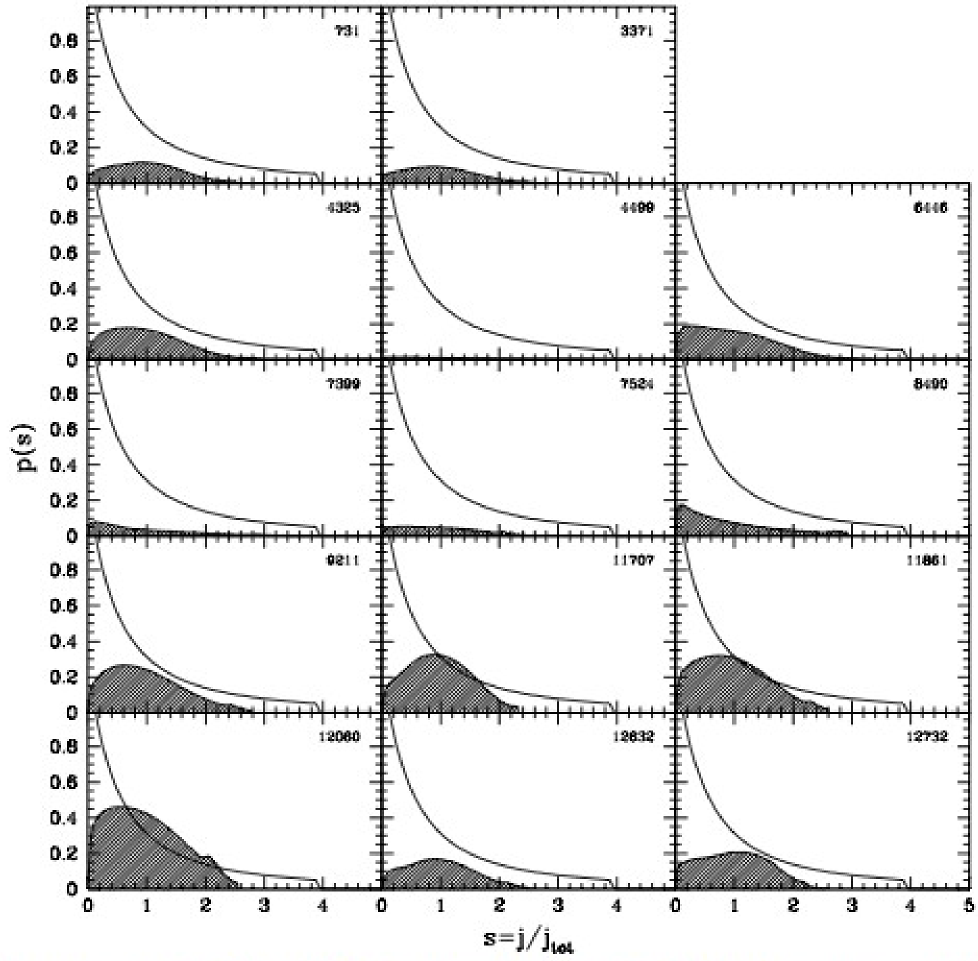


Figure 4. The shaded areas indicate the $p(s)$ of the AMDs for the 14 disc galaxies in our sample, normalized to $f_{\rm disc}/f_{\rm bar}$. For comparison we plot $p(s)$ of equation (11) with $\mu = 1.25$ (normalized to unity), and which represents the median of the AMDs of ΛCDM haloes. Under the standard assumption that baryons conserve their specific angular momentum the difference between the two distributions reflects the AMD of the baryonic matter that is not incorporated in the disc. Note that it is preferentially the baryonic matter with both the highest and the lowest angular momenta that is absent in the discs.

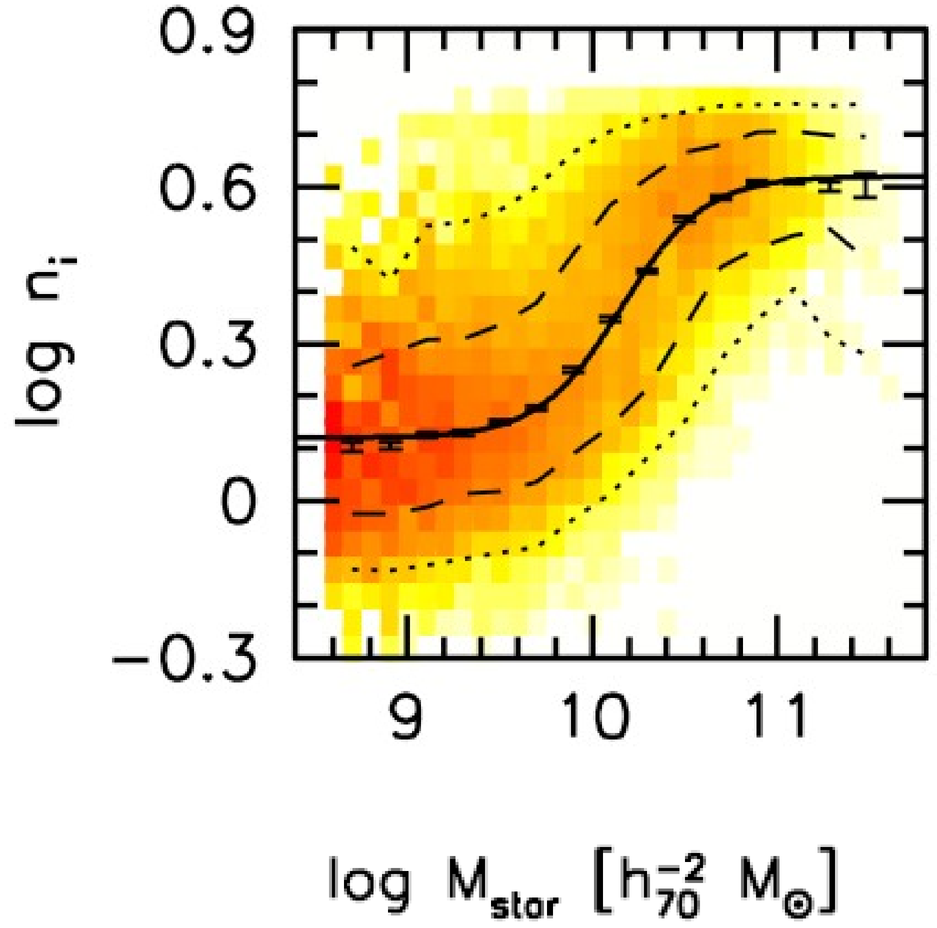
Too few low-J baryons

Van den Bosch 01
Bullock 01

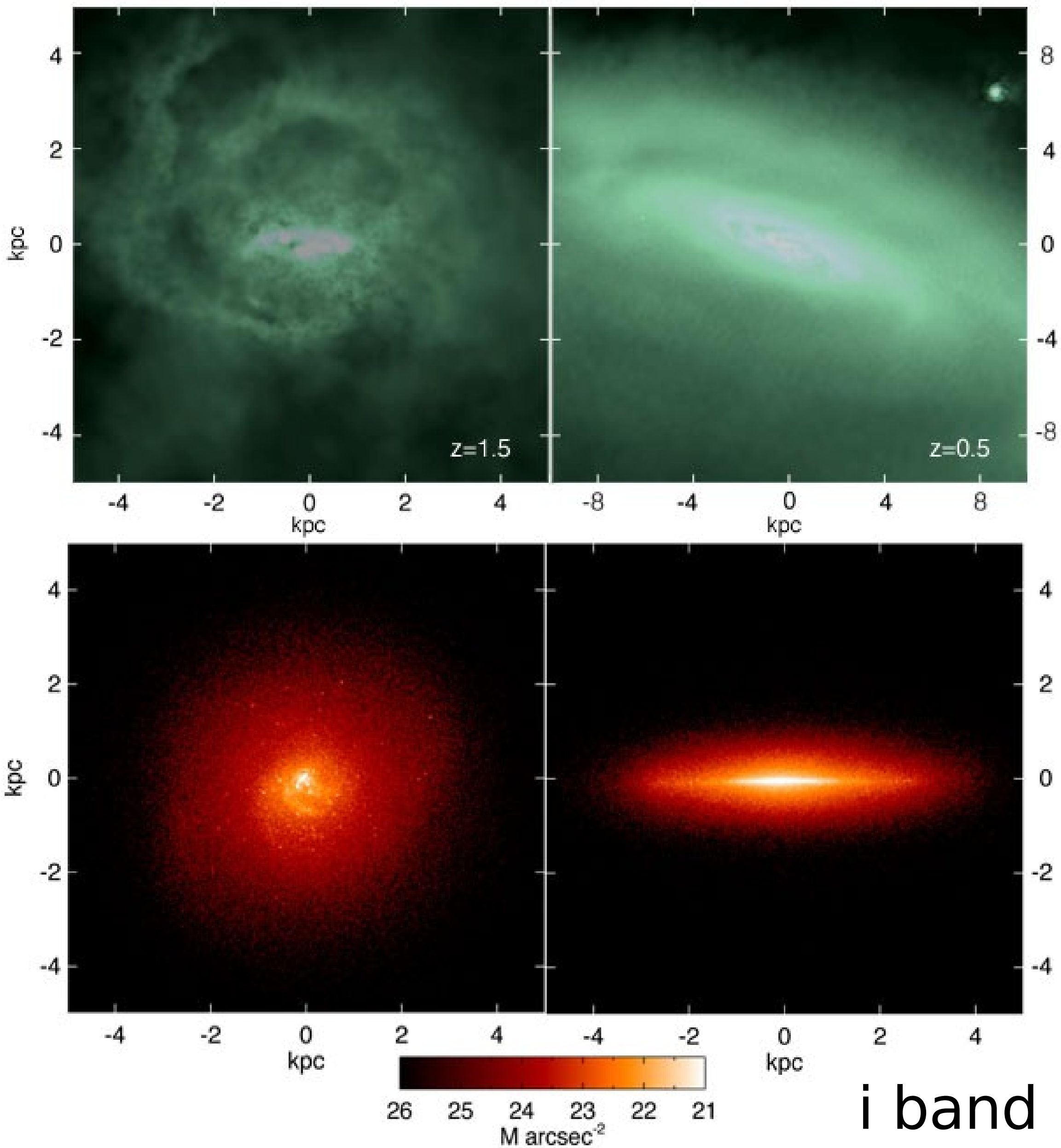
Bulge/Disk ratio

- Disk dominated
- Sersic n ~ 1
- Blue: g – r < 0.6

Dutton 08



Dwarf simulated to z=0



Stellar mass = 5e8 M_{sun}

$M_i = -16.8$

g - r = 0.53

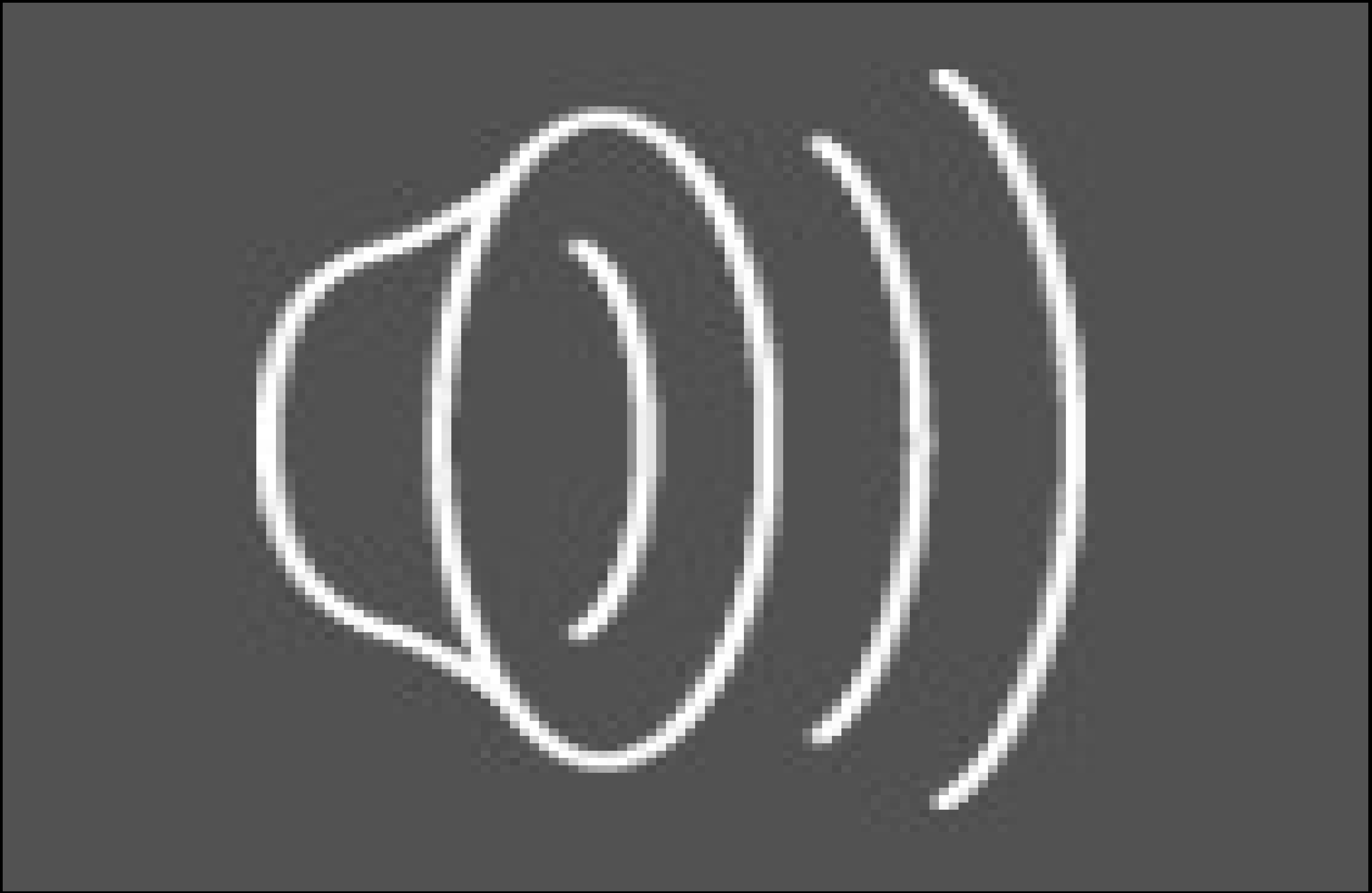
V_{rot} = 55 km/s

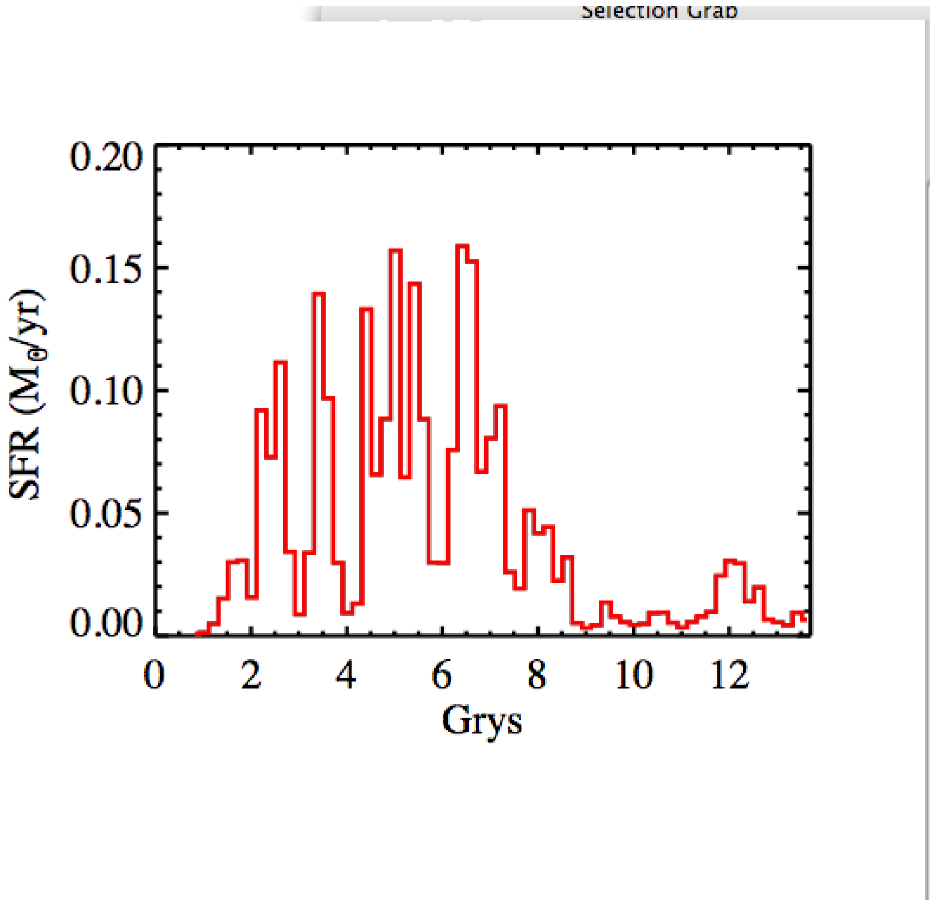
R_d = 1 kpc

$M_{HI}/M_* = 2.5$

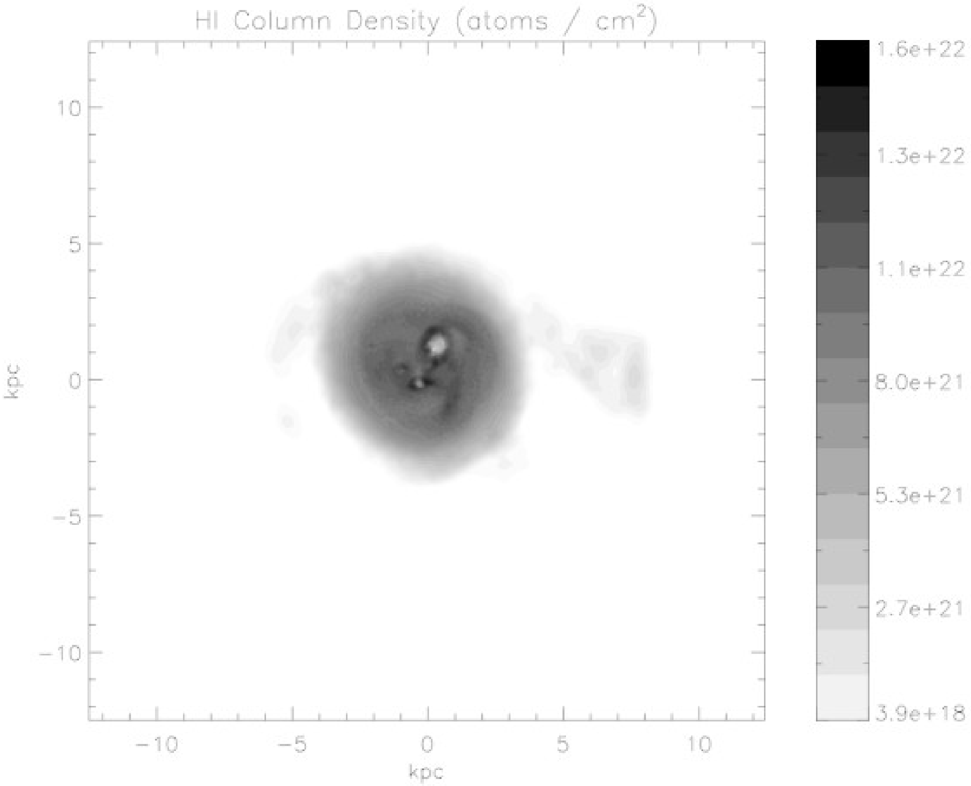
$f_b = .3\ f_b$ cosmic

i band image



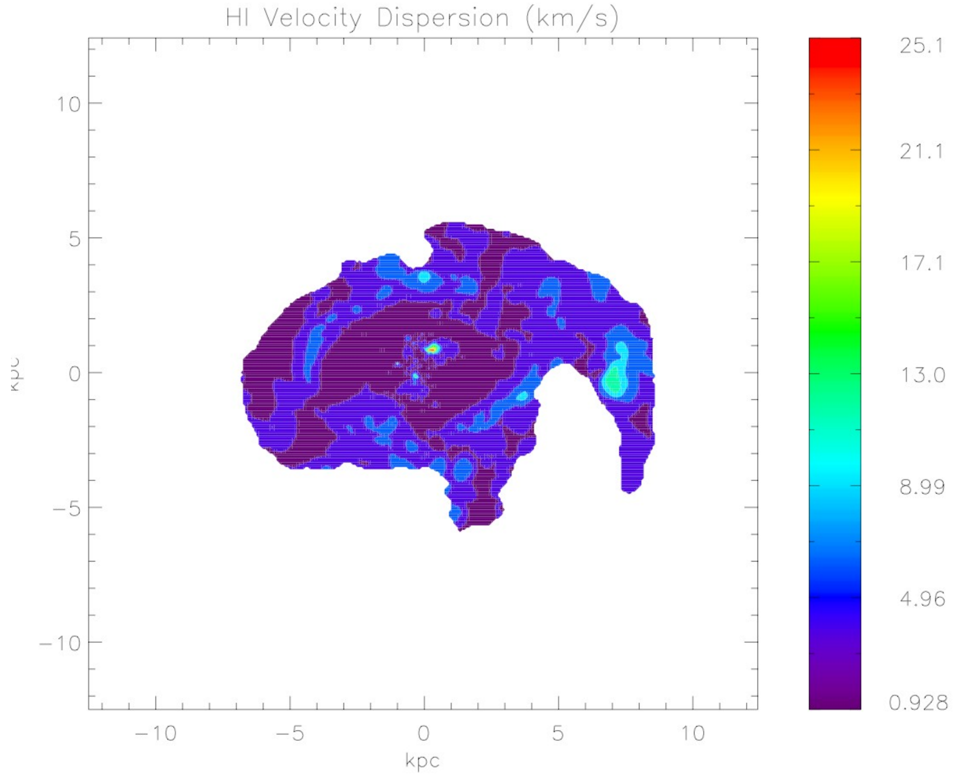

Selection Grab
SFR ($M_\odot$/yr)
0.20
0.15
0.10
0.05
0.00
0
2
4
6
8
10
12
Grys

Dwarf Galaxy Properties



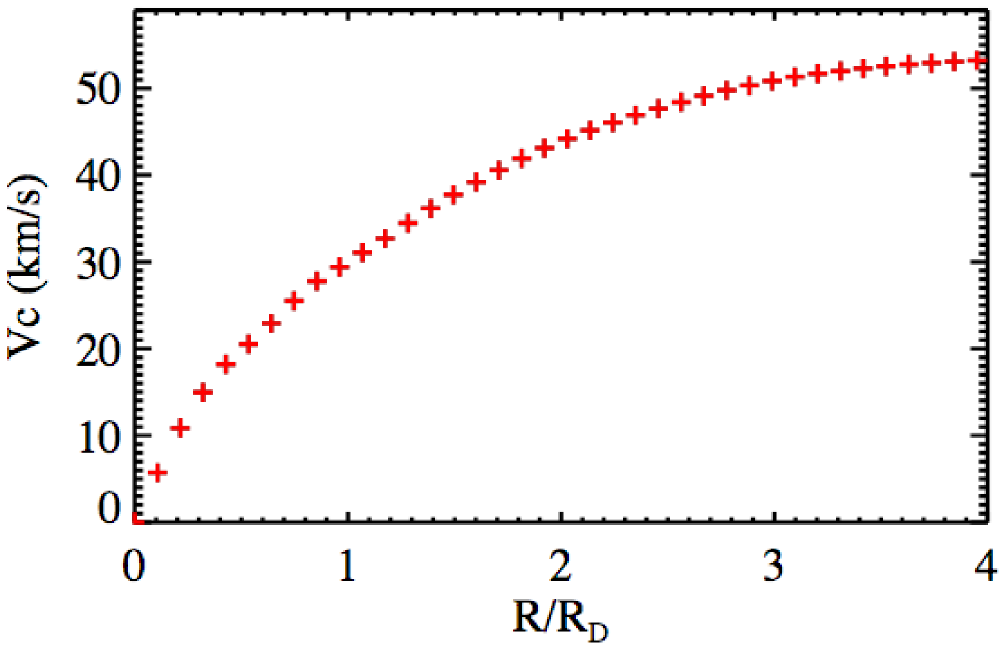
- Bursty SF
- Holes in HI
- HI turbulence 5-10 km/s
- Rising rotation curve
- Low specific SF rate
- Low baryon fraction

Dwarf Galaxy Properties



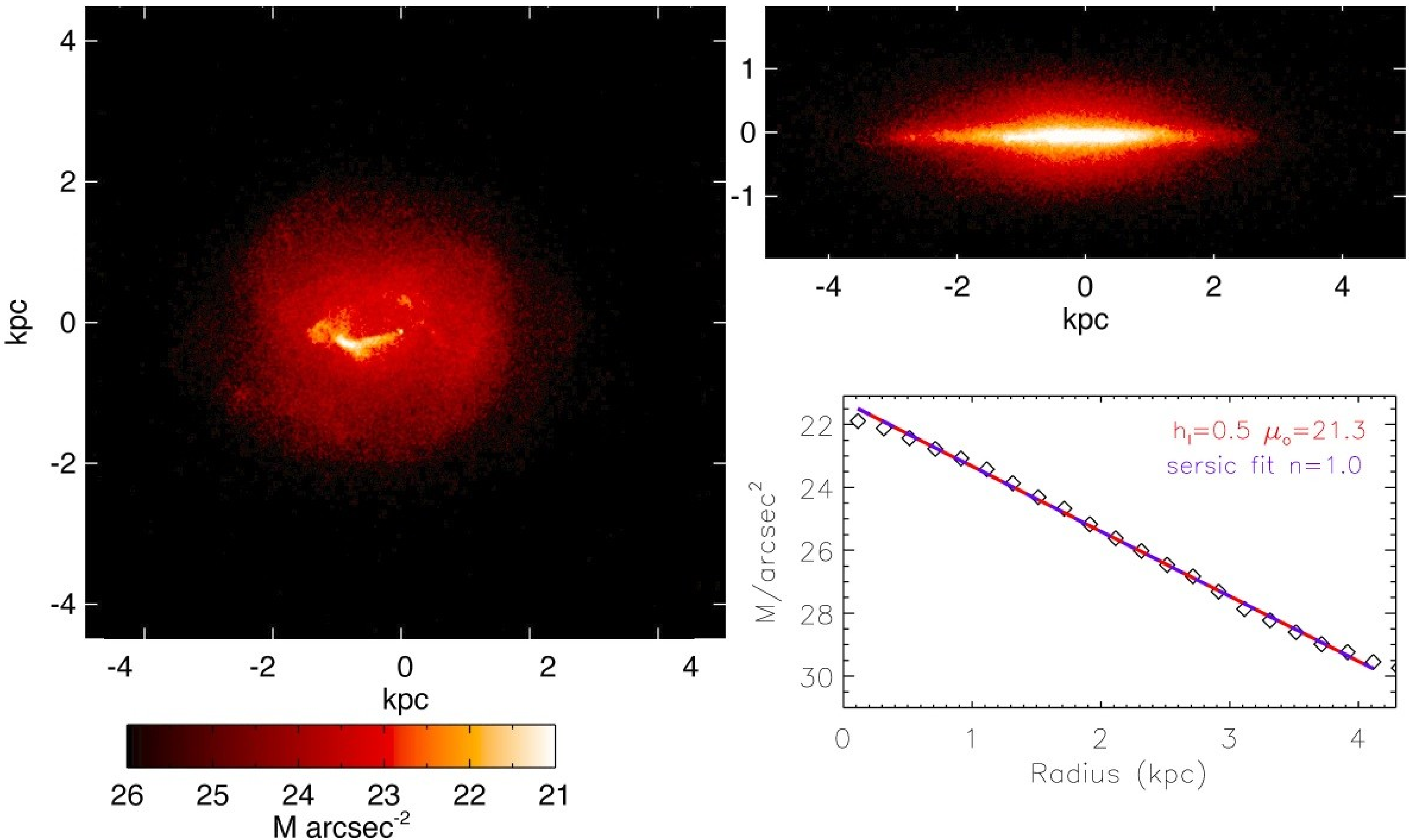
- Bursty SF
- Holes in HI
- HI turbulence 5-10 km/s
- Rising rotation curve
- Low specific SF rate
- Low baryon fraction

Dwarf Galaxy Properties

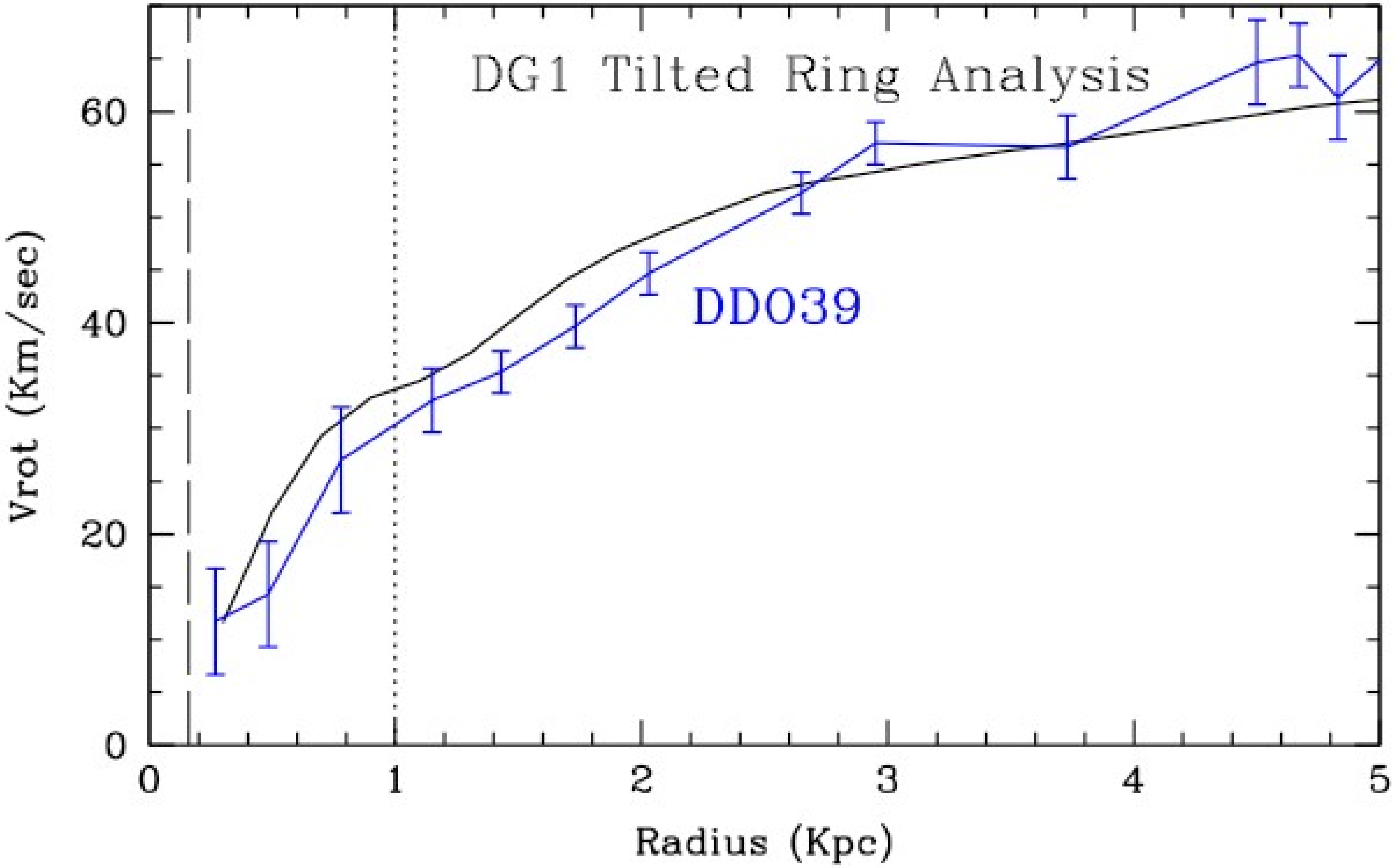


- Bursty SF
- Holes in HI
- HI turbulence 5-10 km/s
- Rising rotation curve
- Low specific SF rate
- Low baryon fraction

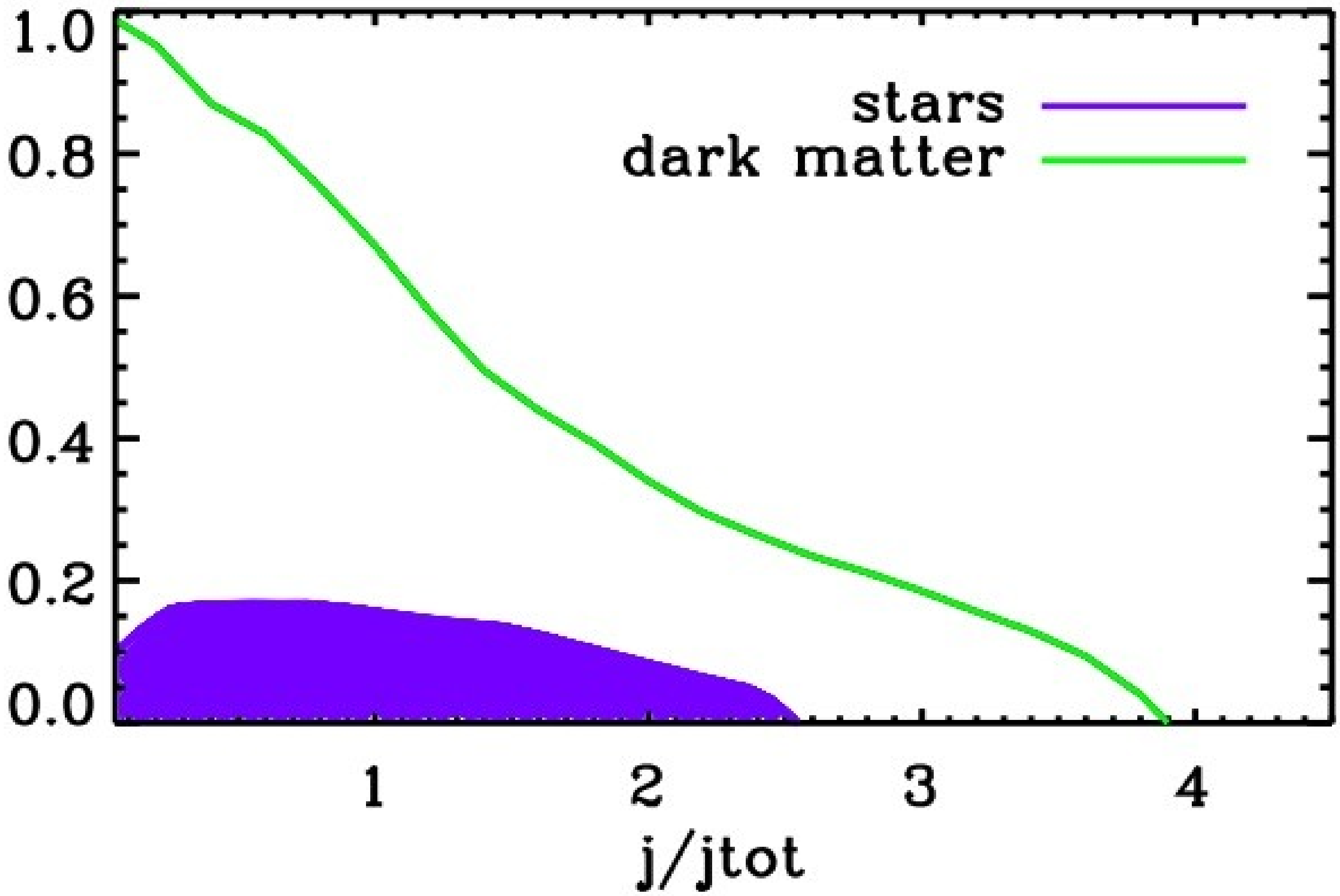
Dwarf Light Profile



Rotation Curve

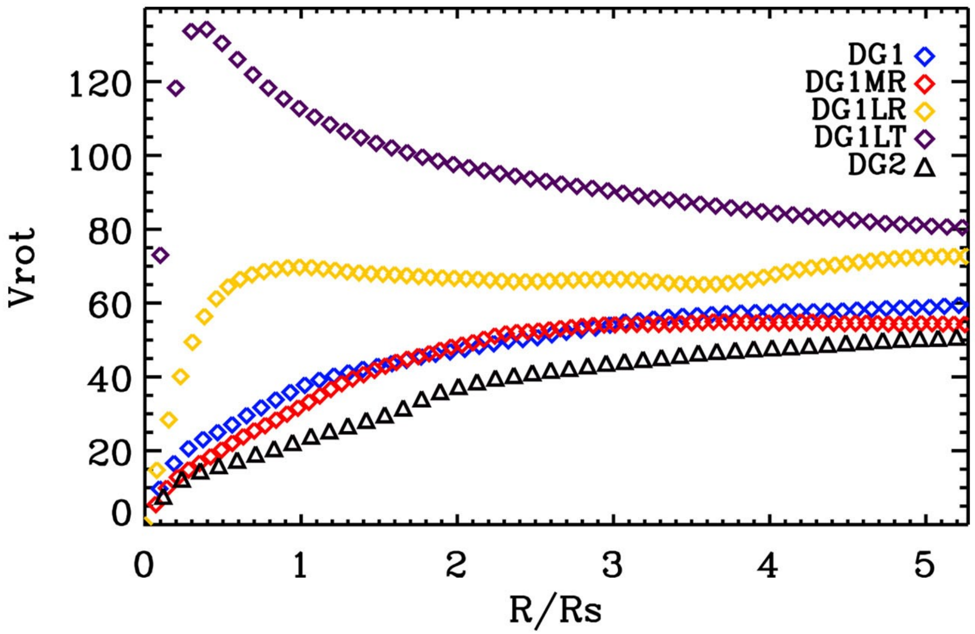


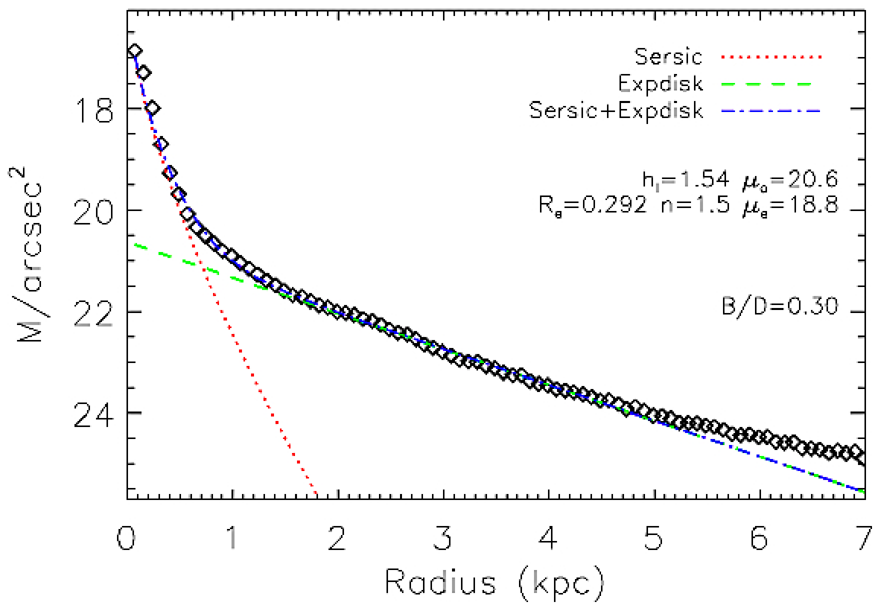
Angular Momentum



Outflows preferential remove low J baryon

Resolution effects





Low resolution: bad

Low resolution star formation: worse

Simulation Issues

- Resolution: Large particle number/high force resolution
- Understanding star formation/feedback
- Resolution: H2 regions need to be resolved
- Understanding ISM physics
- Resolution
- Constraining formation scenarios with Stellar Kinematics
- Resolution

Aquila project

- Comparison of a Milky Way size galaxy
- Range of Resolutions
- Variety of codes
  - Models of subgrid physics
    - Hybrid particles
    - No subgrid model
  - Hydrodynamic algorithms
    - SPH/Moving Mesh/Eulerian