Toward the Formation of Realistic Dwarf Galaxies

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with C. Christensen, F. Governato, A. Pontzen, A. Zolotov, & the N-Body Shop collaboration

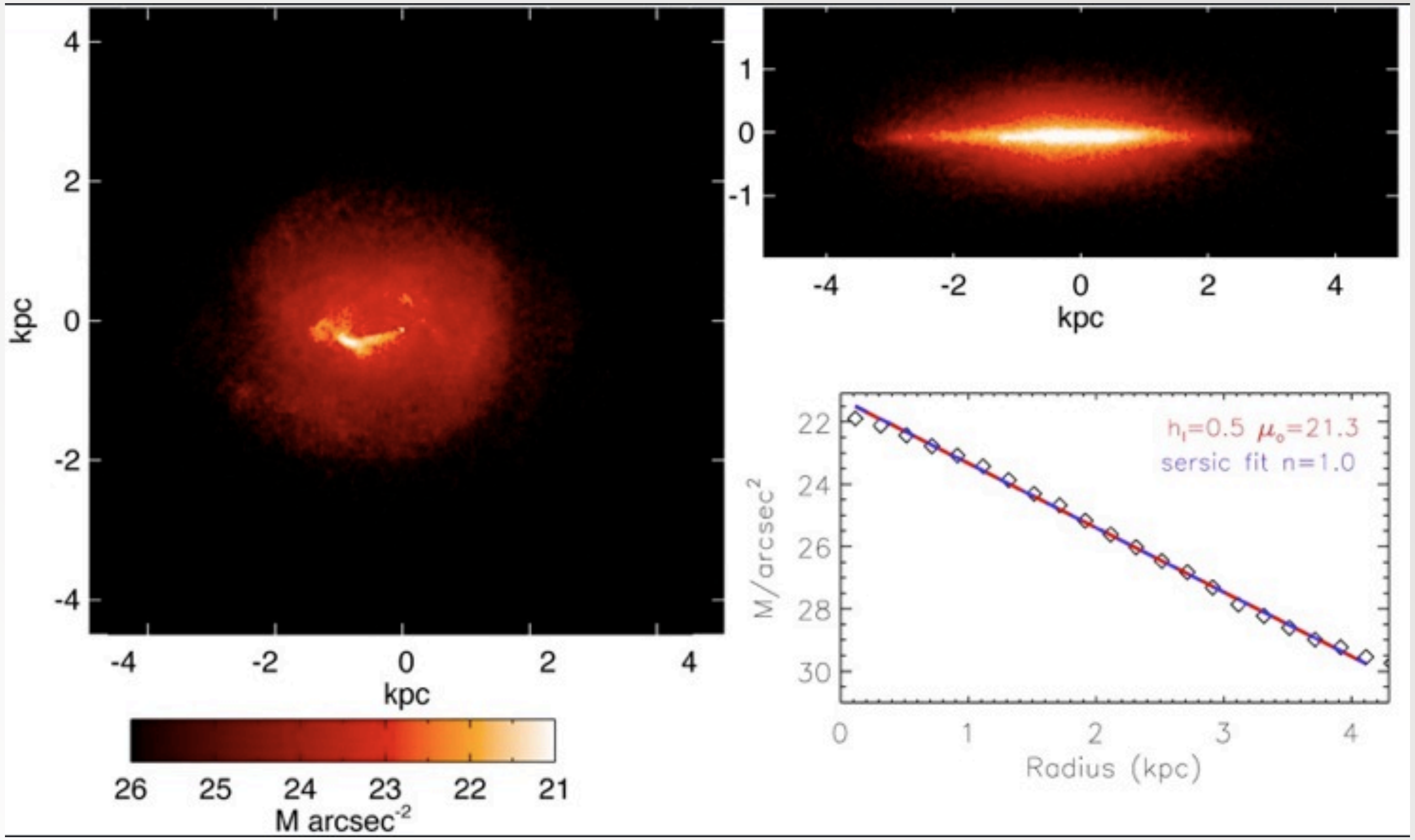
Outline of This Talk

The matter with dwarf galaxies:
CDM's small scale crisis

What's new?
How high resolution and a realistic treatment of SF affect simulation results

The creation of DM cores:
a new view on galaxy trends with stellar mass

What do I mean by dwarf galaxy?



- Bulgeless!
- Exponential stellar disk, R_d ~ 1 kpc
- Gas rich
- V_c < 60 km/sec
- bursty SFH
- SFR ~ 0.01 M_{sun}/yr

"typical" field dwarf

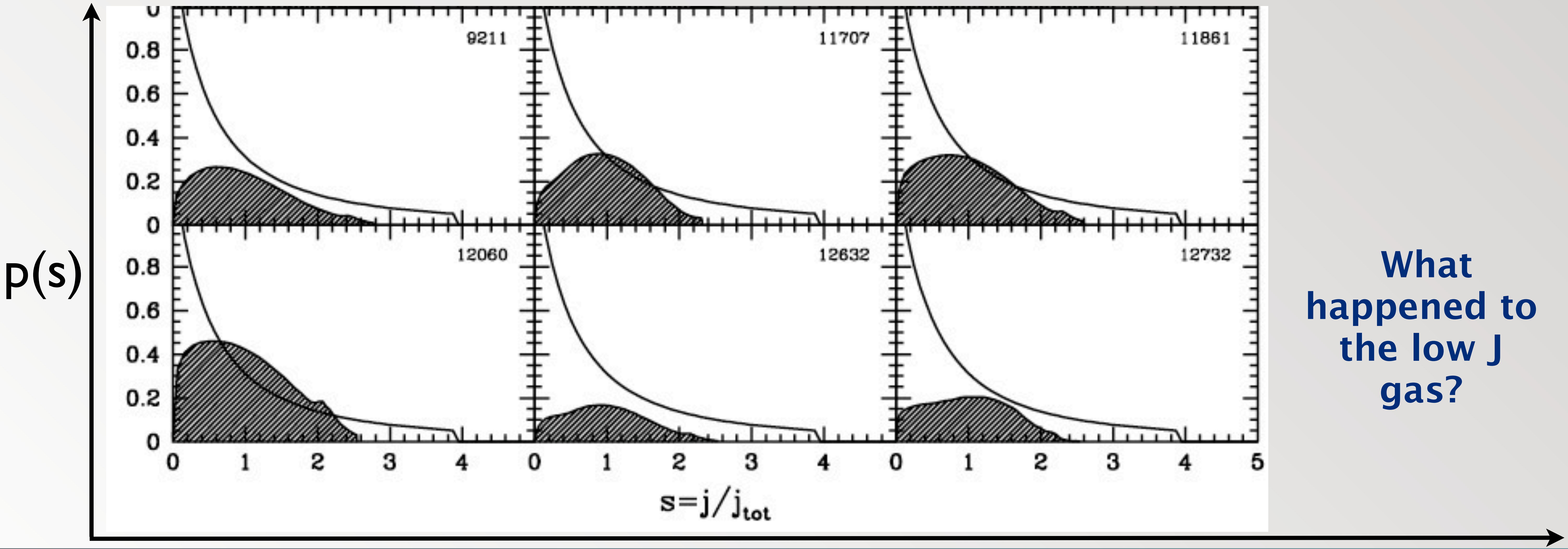
The “small-scale crises” of Cold Dark Matter:

- The Substructure Overabundance Problem
- Too Much Central Mass
- Cored DM Density Profiles in Dwarf Galaxies

The "small-scale crises" of Cold Dark Matter:

- The Substructure Overabundance Problem
- **Too Much Central Mass**
- Cored DM Density Profiles in Dwarf Galaxies

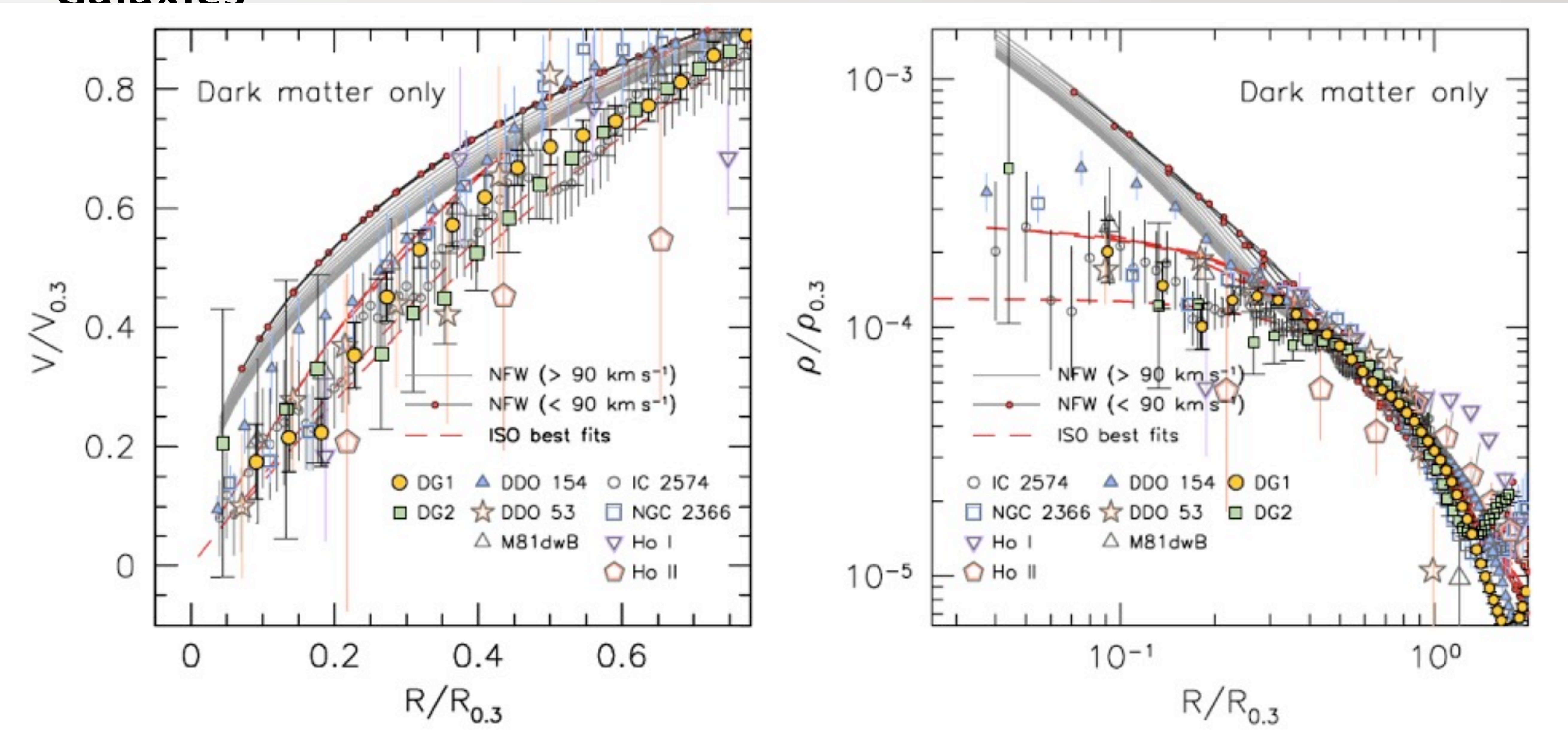
CDM predicts bulges we don't observe



What happened to the low J gas?

The "small-scale crises" of Cold Dark Matter:

- The Substructure Overabundance Problem
- Too Much Central Mass
- **Cored DM Density Profiles in Dwarf Galaxies**



rho ~ $\rho^{-\alpha}$

α~1 in DM simulations "cuspy" NFW

α~0 in observations "cored" isothermal

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Gasoline

Gasoline:

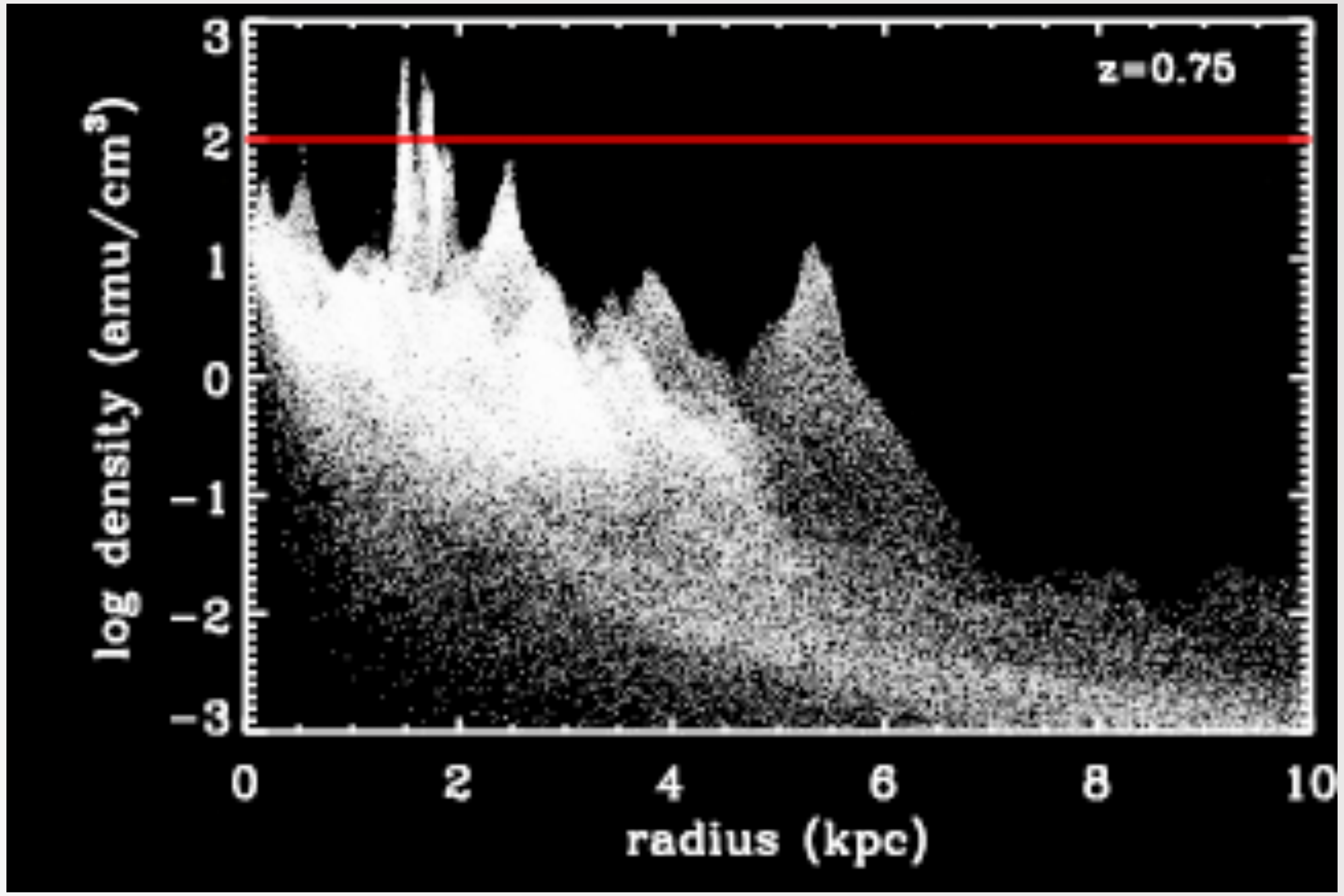
- N-Body + Smoothed Particle Hydrodynamics (SPH)
- Uniform UV background (mimics reionization)
- Star particles born with Kroupa IMF
- "Blastwave" feedback model
- SN energy coupled to gas as thermal energy only
- Cooling shutoff in neighbor gas particles (adiabatic phase) for few Myr

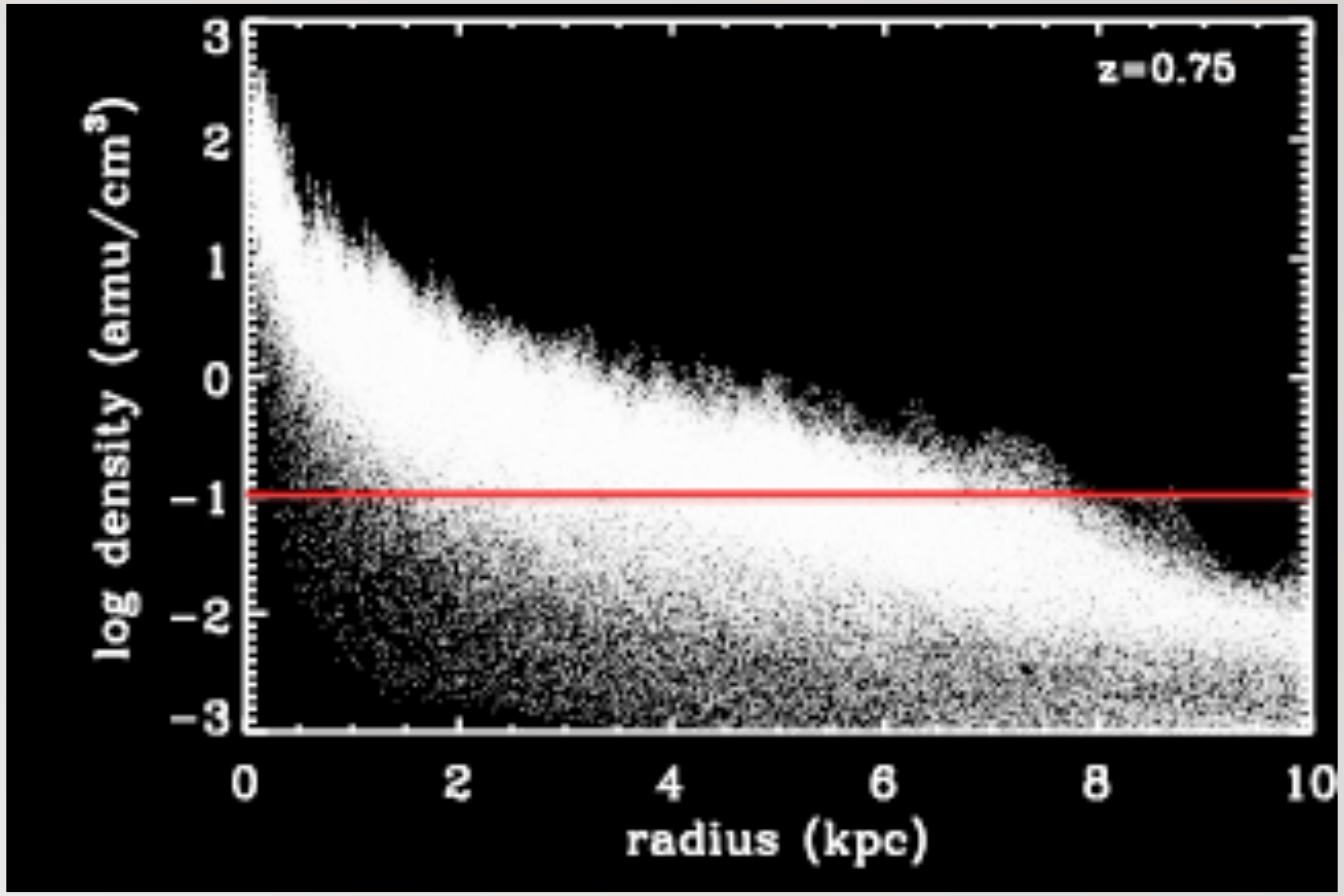
Latest "zoomed-in" runs:

- Resolution 50-160pc ~ 'resolved' SF regions
- Star particles ~ 1000-10000 M_{sun}
- Radiative cooling (with metal lines) down to 200K
- H2 cooling and H2 based SF
- Several million particles per (main) galaxy at z=0.

Wadsley et al. (2004), Stinson et al. (2006), Shen et al. (2010)

"Resolving" Star Formation Regions





High Threshold

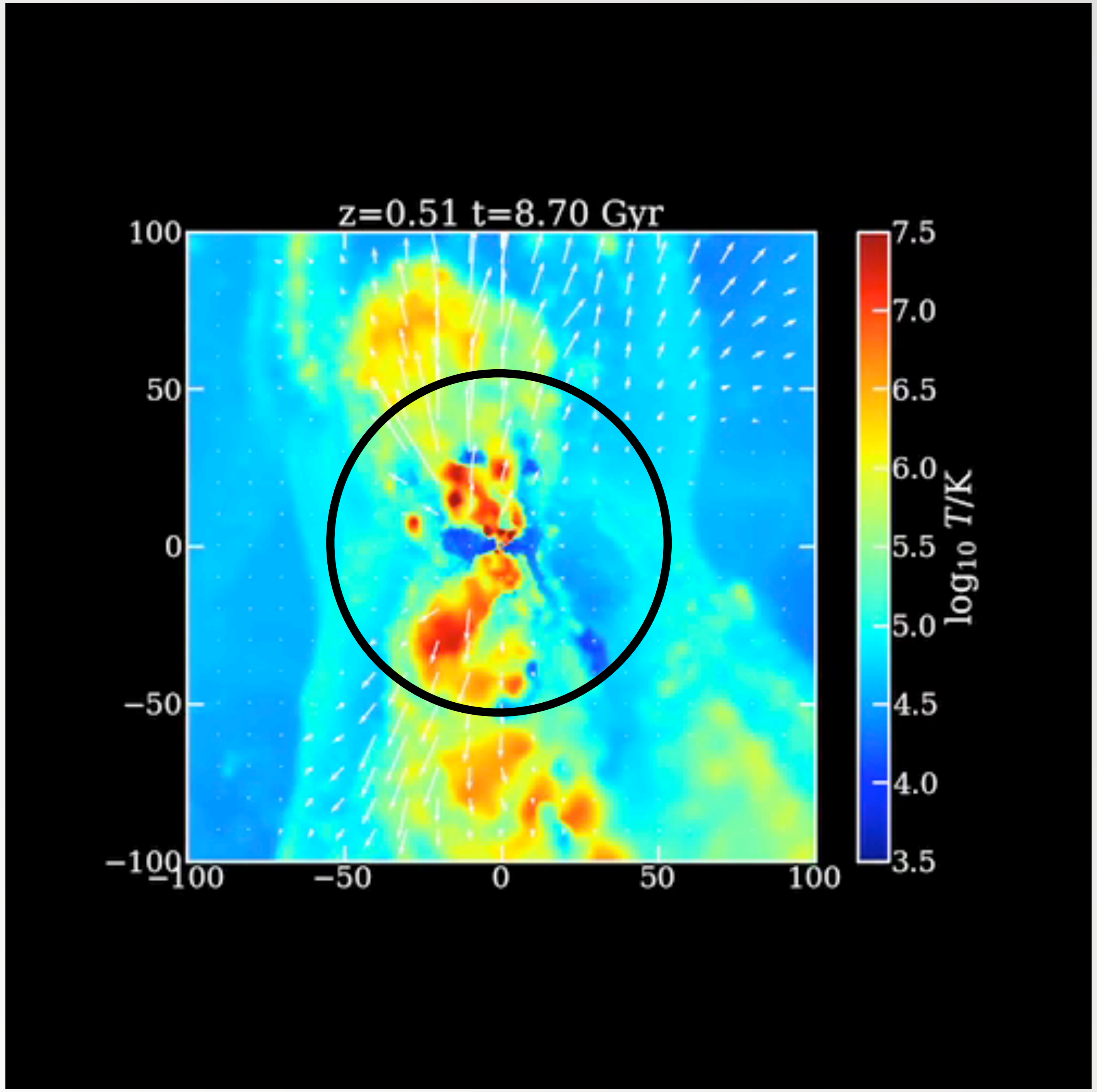
Low Threshold

Feedback becomes more efficient

(more outflows per unit mass of stars formed)

see also: Ceverino & Klypin (2008), Robertson & Kravtsov (2008), Tasker & Bryan (2008)

Outflows!



Edge-on disk orientation

(arrows are velocity vectors)

Brook et al. (2011)

Outflows!

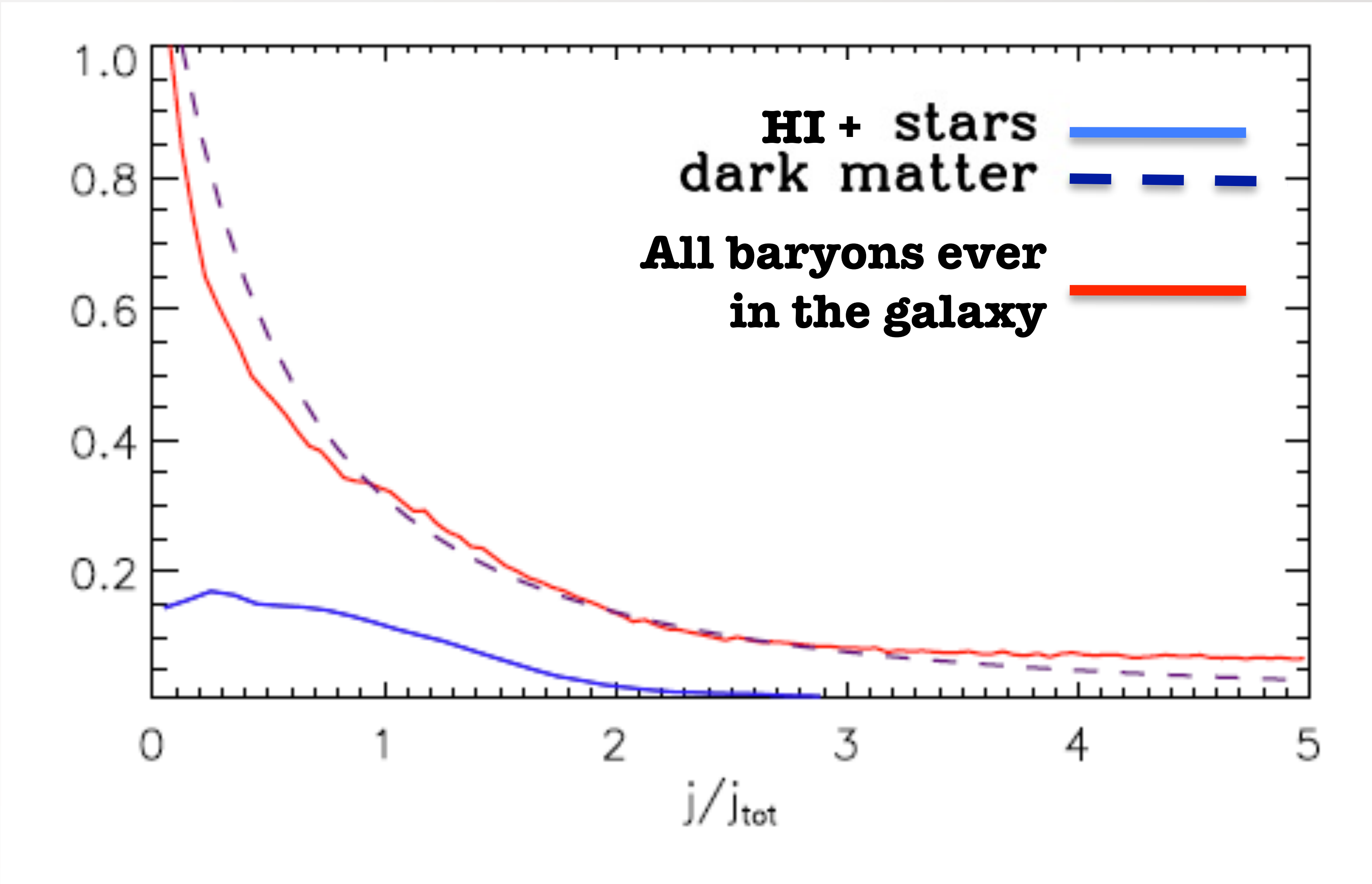
Hot gas explodes out of young dwarf galaxies

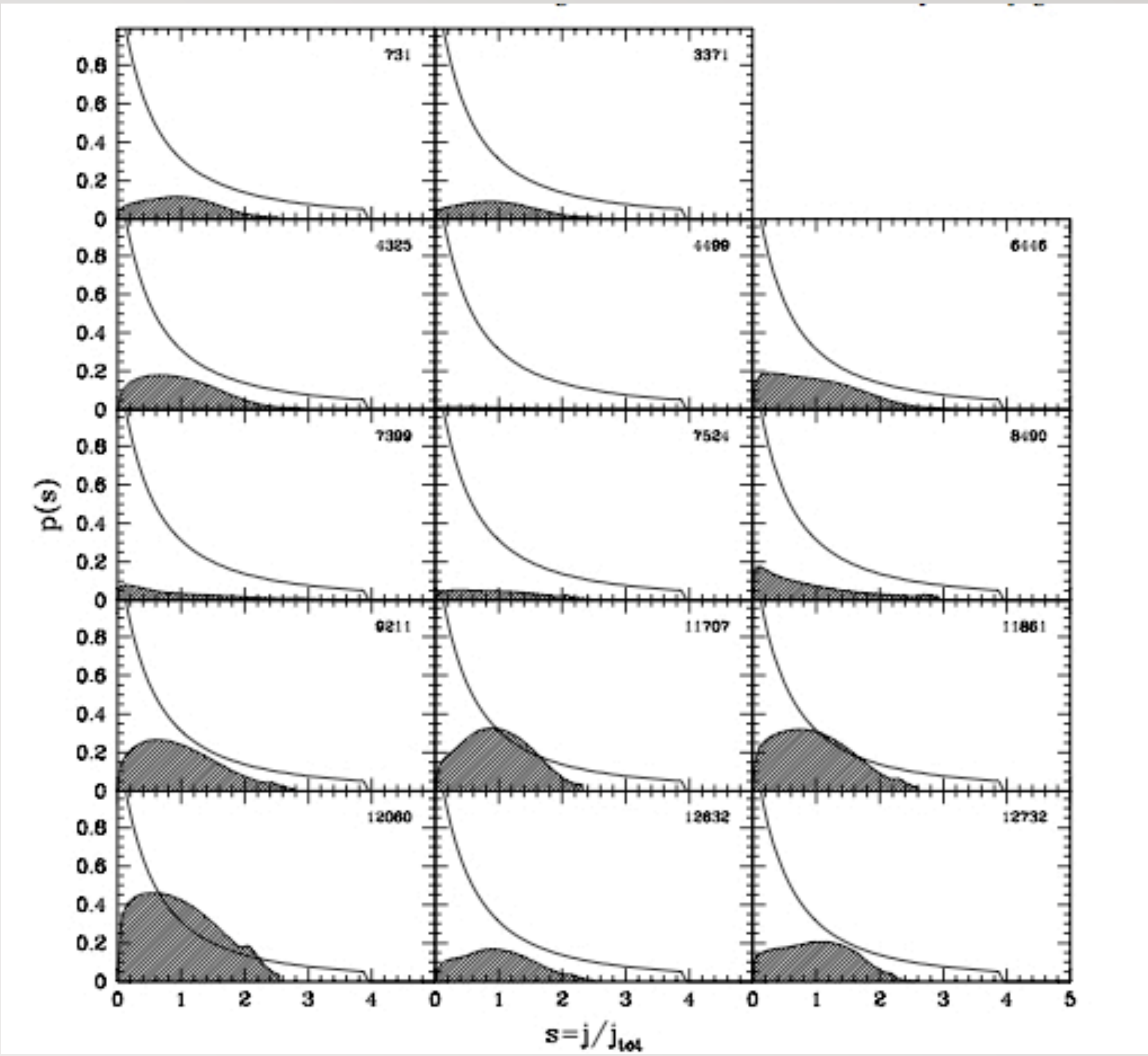
Simulation by **Andrew Pontzen**, **Fabio Governato** and **Alyson Brooks** on the **Darwin Supercomputer**, Cambridge UK.

Simulation code **Gasoline** by **James Wadsley** and **Tom Quinn** with metal cooling by **Sijing Sheng**.

Visualization by **Andrew Pontzen**.

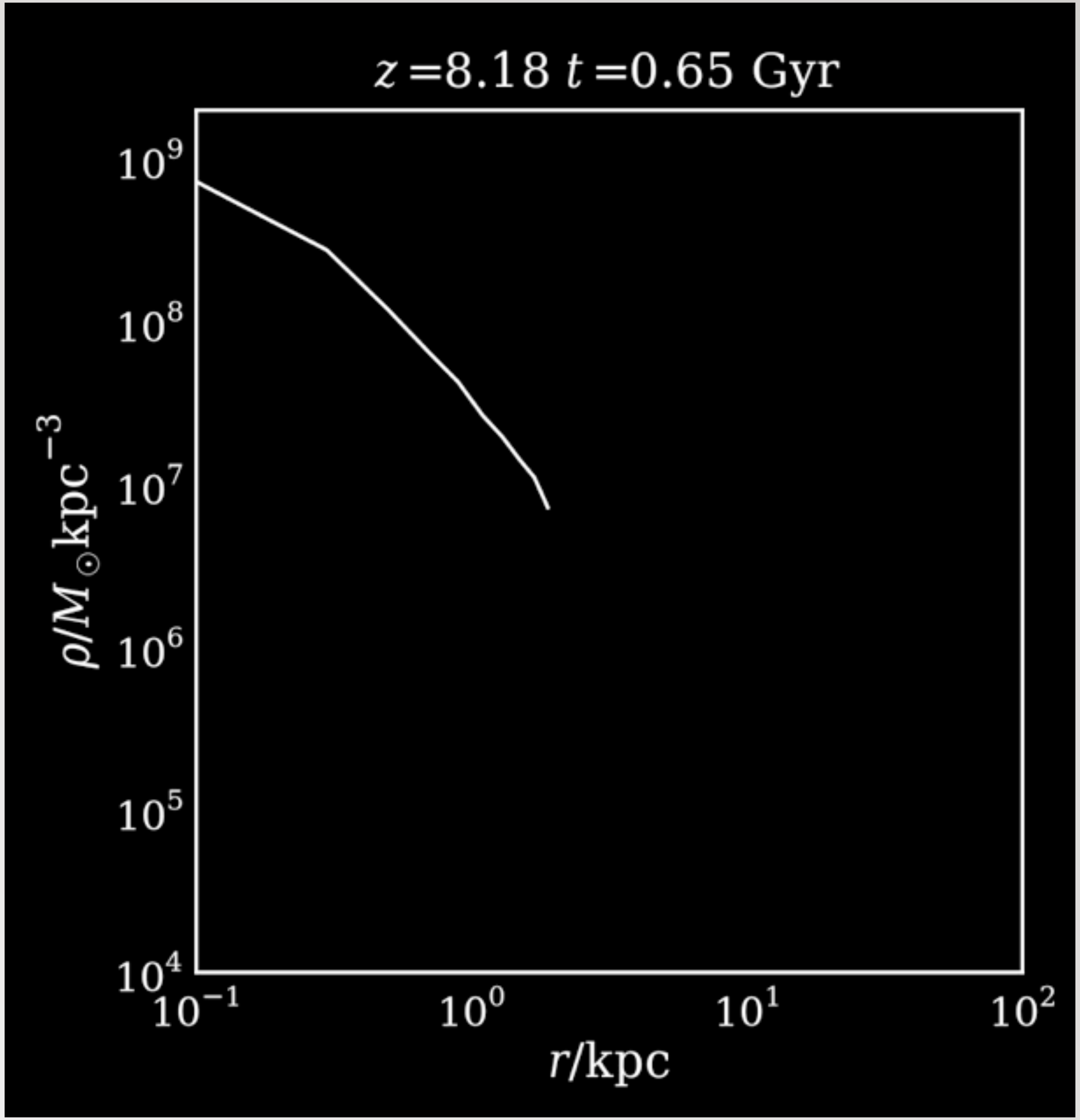
Outflows Remove Low Angular Momentum Gas



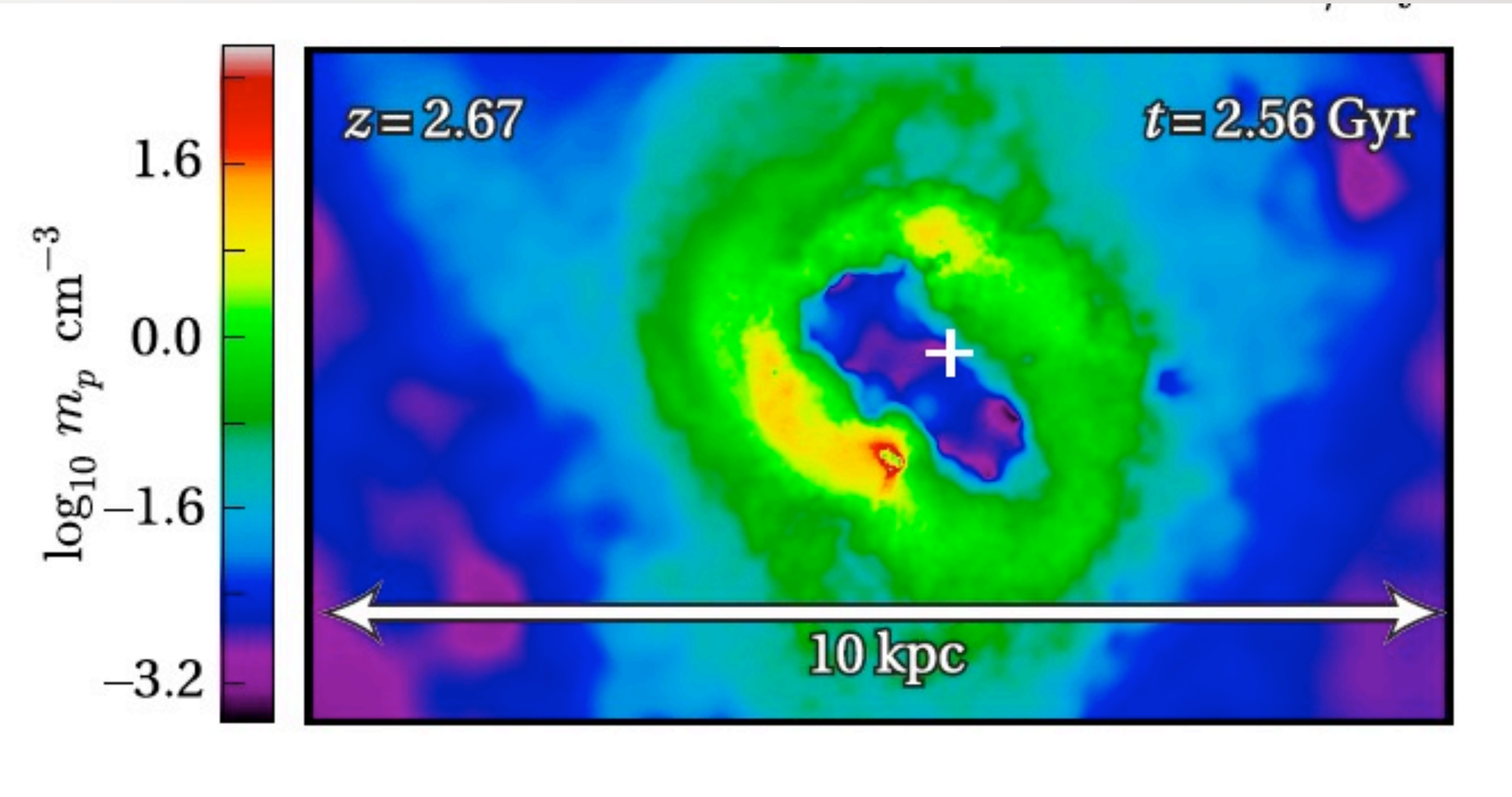


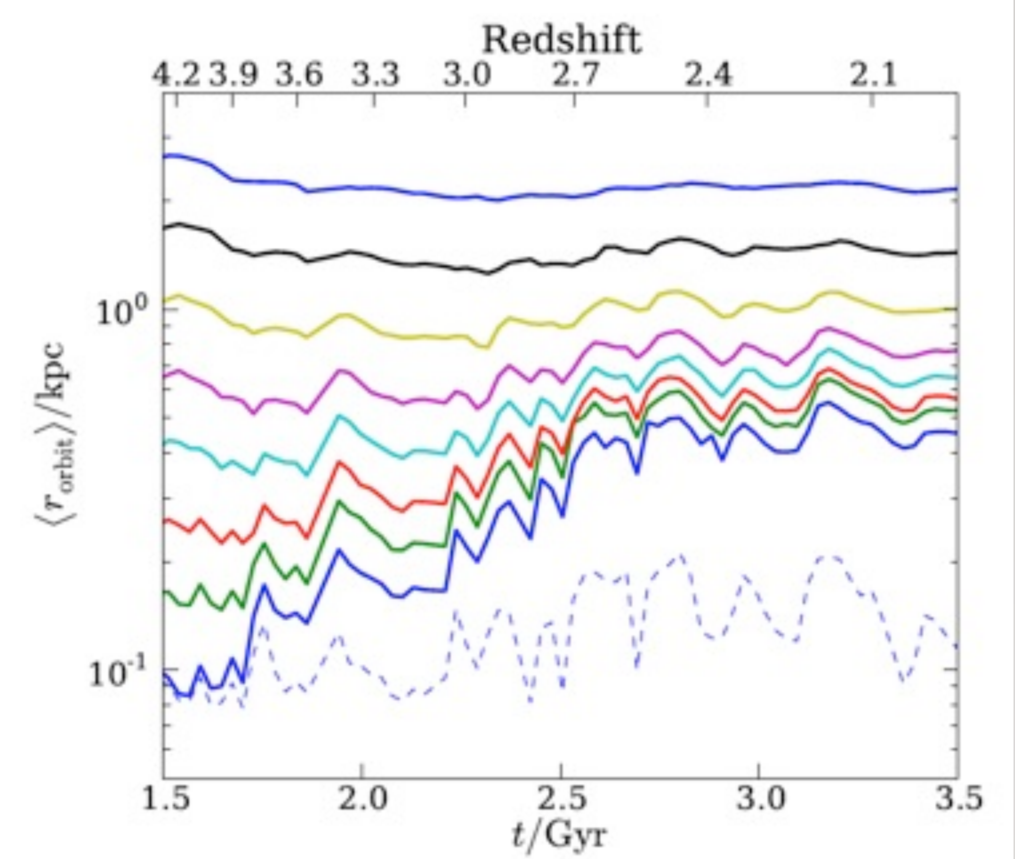
Outflows Flatten the DM Density Profile

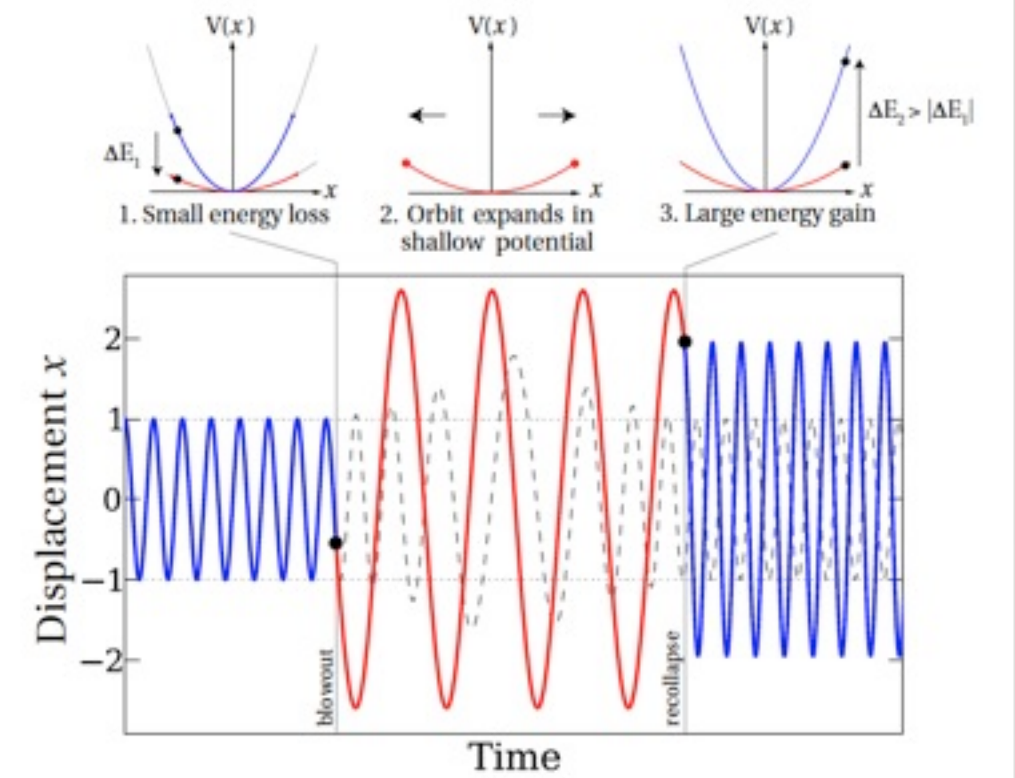
Core Creation!



How Are Cores Created?







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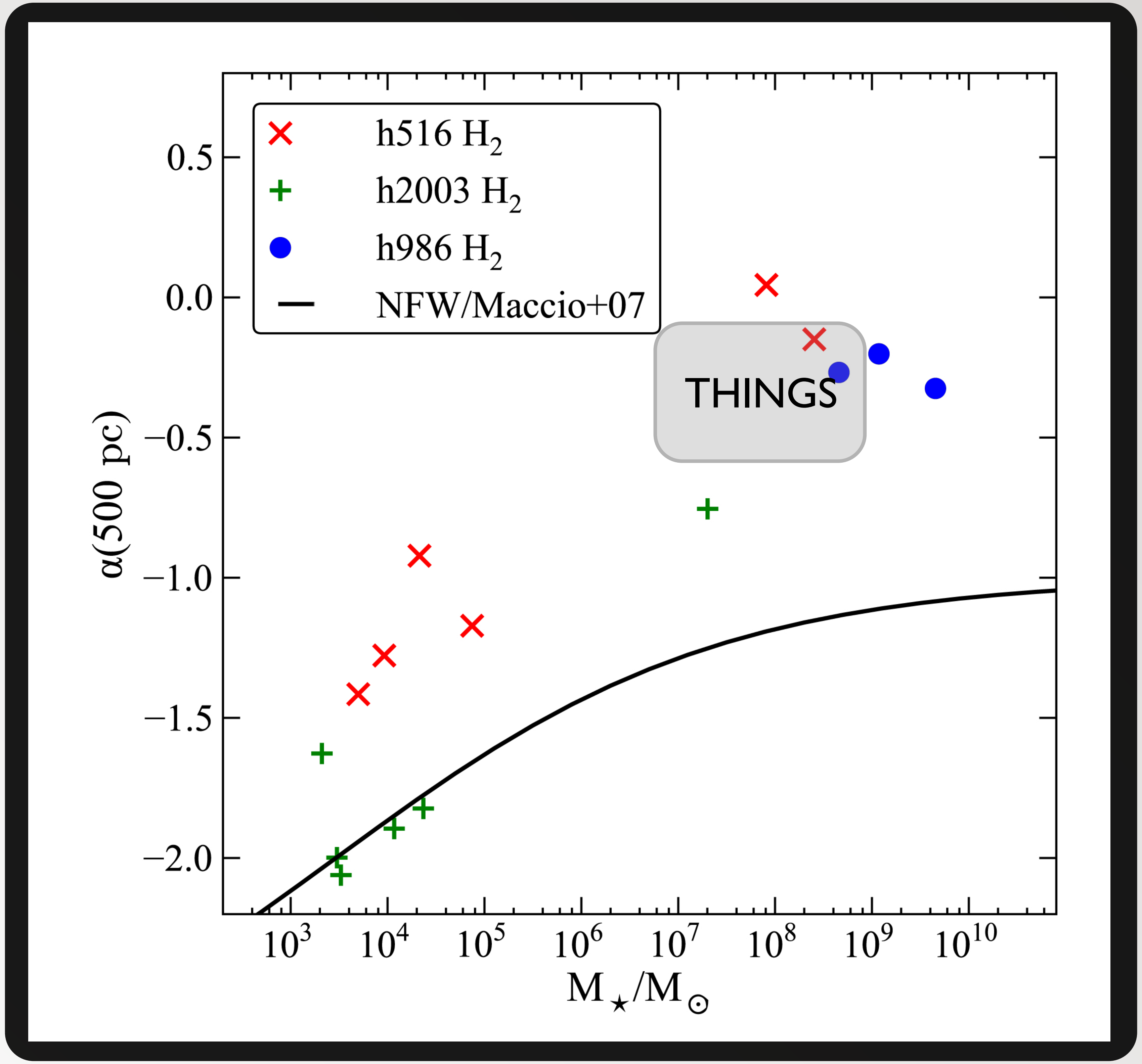
Core Creation varies with Mass!

because SF varies with mass



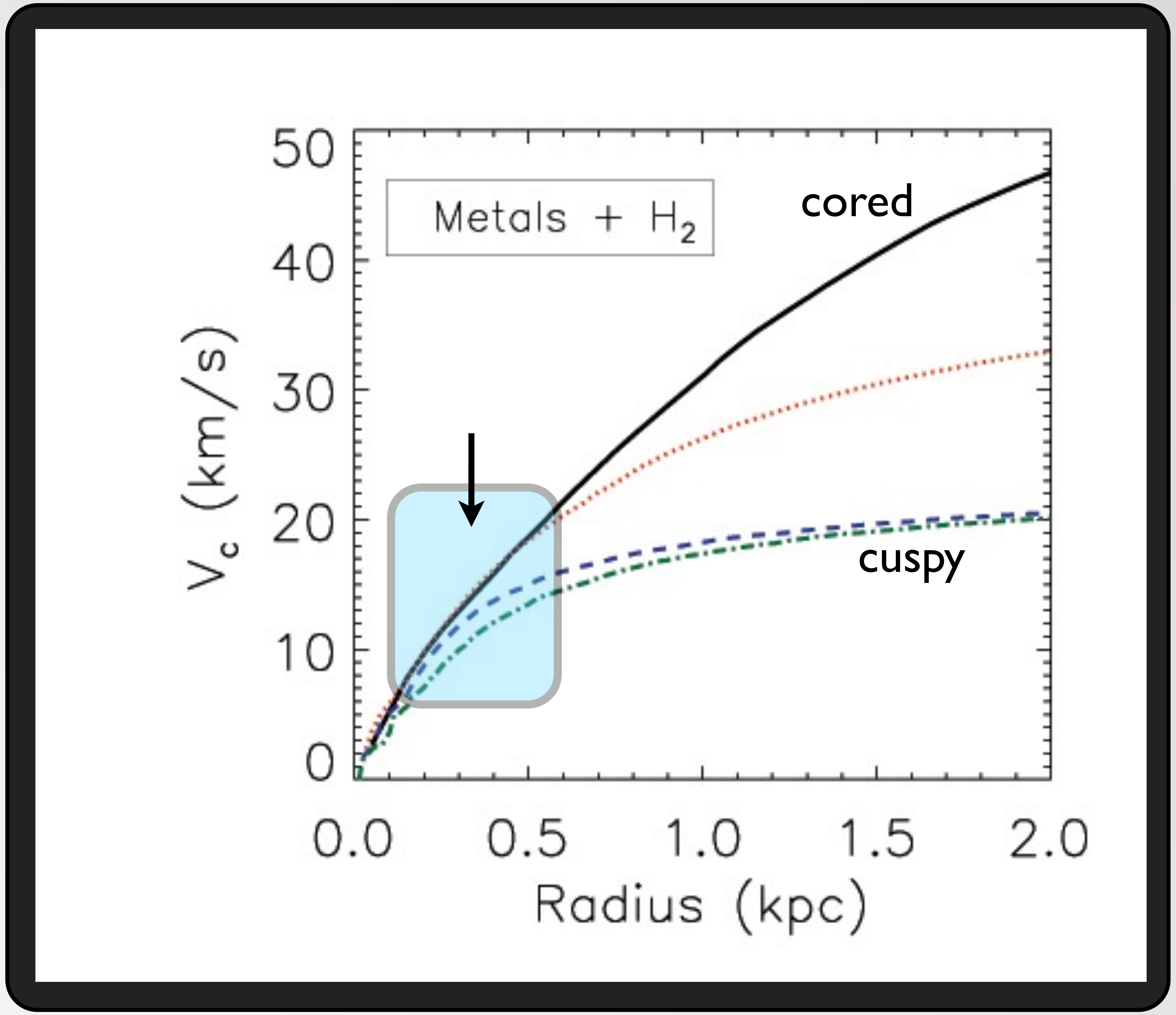
Galaxies in the THINGS survey have average α~-0.3

Lower mass galaxies do not undergo repeated bursts of SF; retain cusps

Rotation Curves at Varying Mass

More massive galaxies (cored) have slowly rising rotation curves

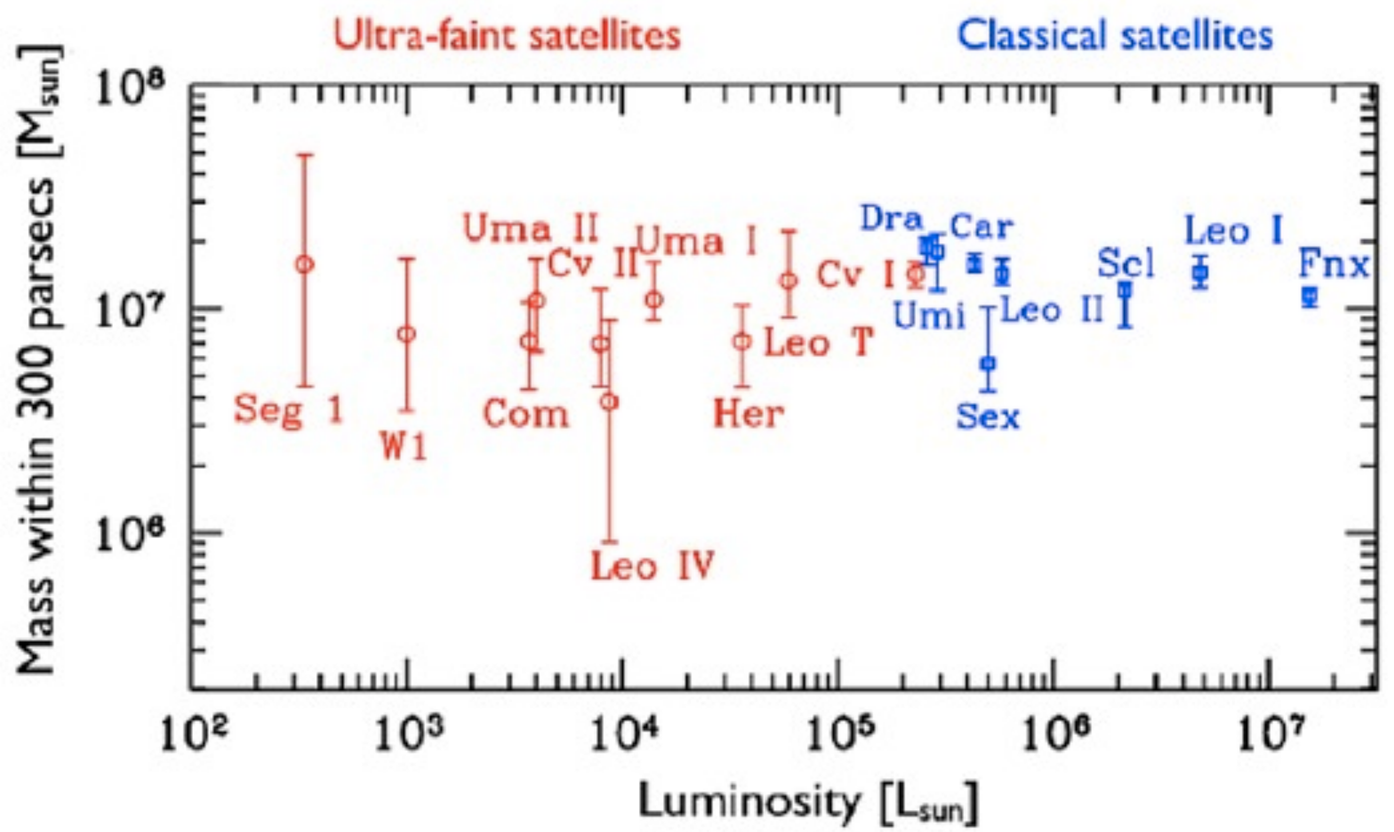
Lower mass galaxies stay cuspy, so they have steeply rising rotation curves

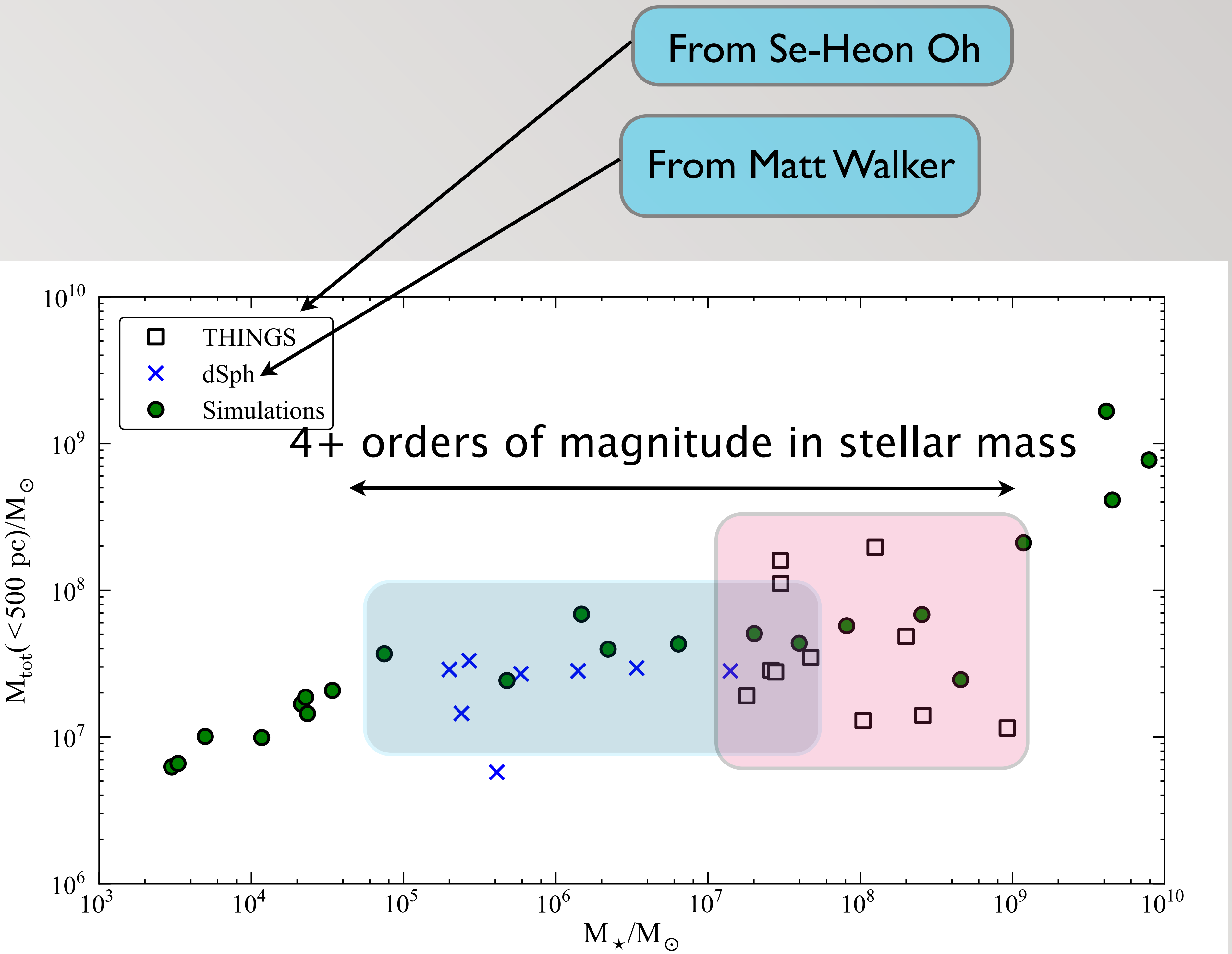


rotation curves have nearly similar values at ~300pc

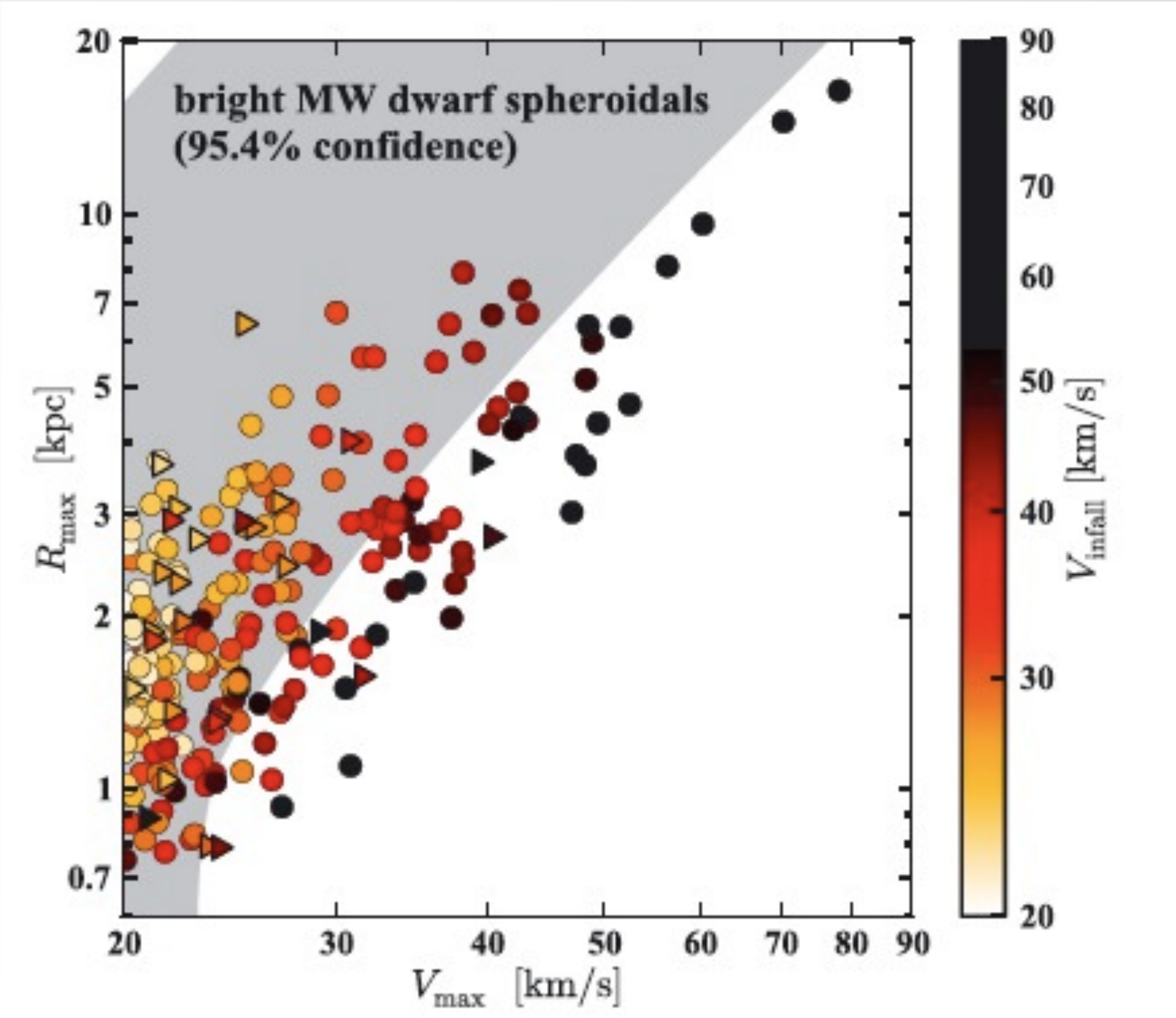
The "Strigari" Relation: aka The Common Mass Scale

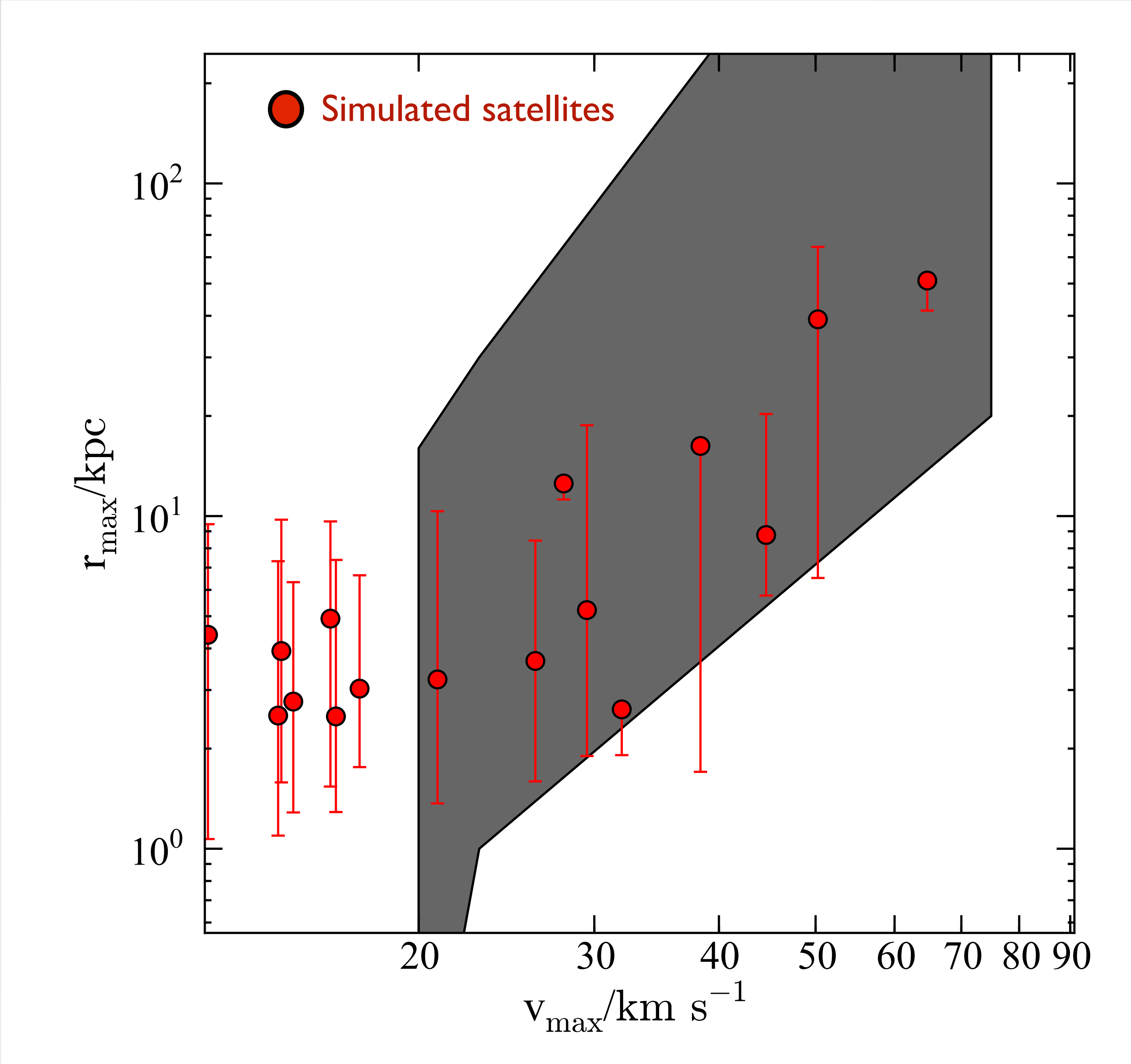
- "a hint of a new scale in galaxy formation" **cosmic UV background?**
- "a characteristic scale for the clustering of dark matter" **WDM?**





CDM predicts denser satellites than we observe





Conclusions

Simulations keep improving! (motivated by higher resolutions)

A more realistic treatments of SF leads to more realistic galaxies

Rapid and repeated gas removal transforms ‘cuspy’ NFW profiles into DM cores

Core creation varies with mass (because SF varies with mass): low mass galaxies that are inefficient at creating stars keep cuspy profiles

Core formation as a function of mass can explain
(1) the common mass scale for galaxies
(2) the lack of high density, massive subhalos in the MW

End the small scale crisis: We must understand the impact of baryonic physics on galaxy formation!