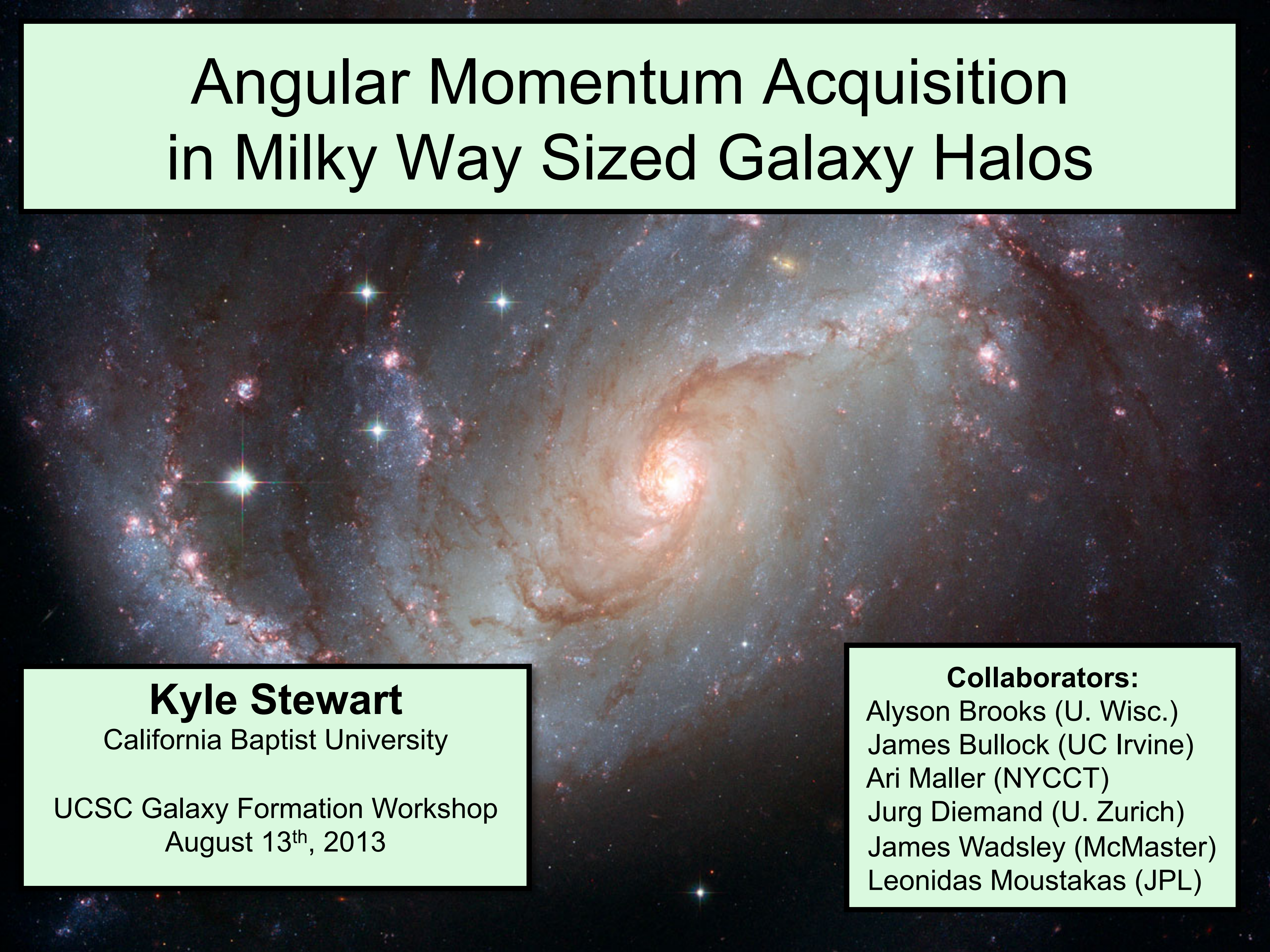
Angular Momentum Acquisition in Milky Way Sized Galaxy Halos



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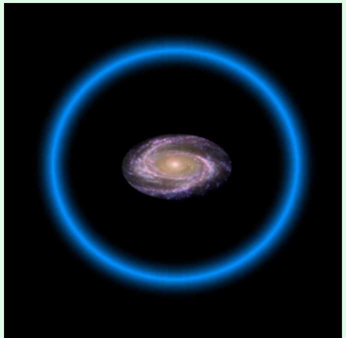
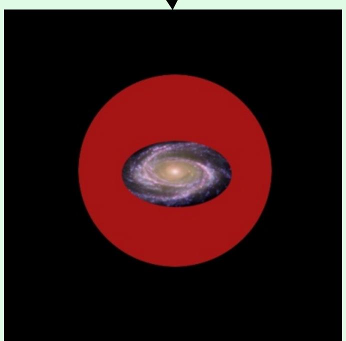
The “Canonical” Picture of Angular Momentum Acquisition

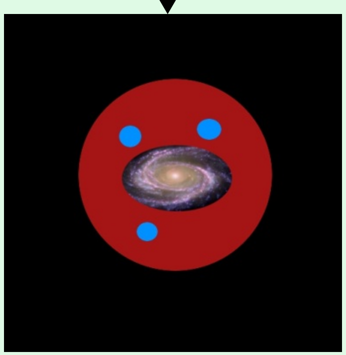


Step 1: Proto-galaxy with gas inflow from the cosmic web. Angular momentum of dark matter and gas are identical; both set by large scale tidal torques



Step 2: Gas shock-heats to a characteristic “virial” temperature of halo. Both the dark matter and shocked gas gradually acquires the spin of halo.

$$\boxed{\lambda_x \equiv \frac{j_x}{\sqrt{2}V\,R}}$$



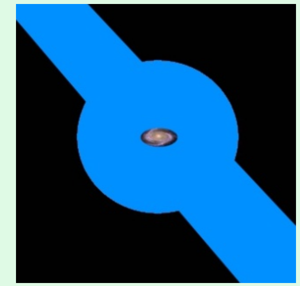
Step 3: Cool gas clouds condense out of the hot halo, sink to the center and build the galaxy. (Amount of angular momentum works out about right to make rotating galaxies of reasonable size.)

The “Canonical” Picture of Angular Momentum Acquisition

A few problems with this picture:

1) Shock-heat picture not always valid → “cold-mode” gas accretion

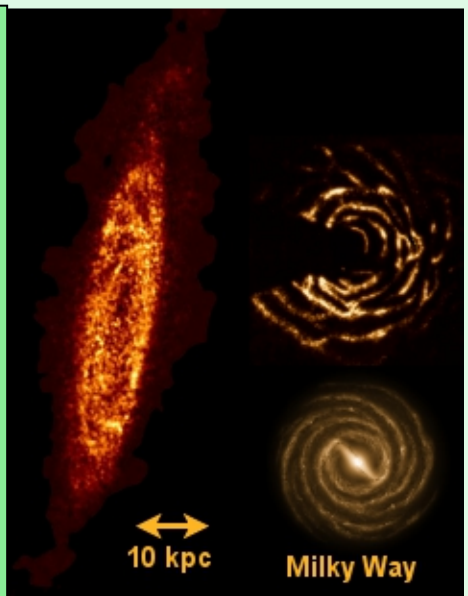
Massive high z galaxies



Moderate/low mass galaxies at all z

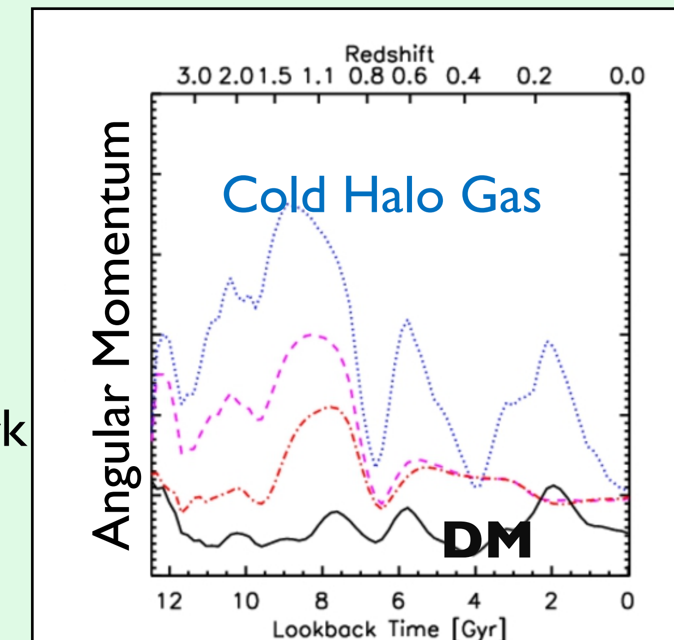
2) How is it possible to build very extended disk structures? (e.g. extended HI or XUV disks?)

NGC 7331 (THINGS survey)



3) Simulations show gas in the halo has **more** angular momentum than dark matter does!

(e.g. Stewart+ ’11, Kimm+ ‘11)

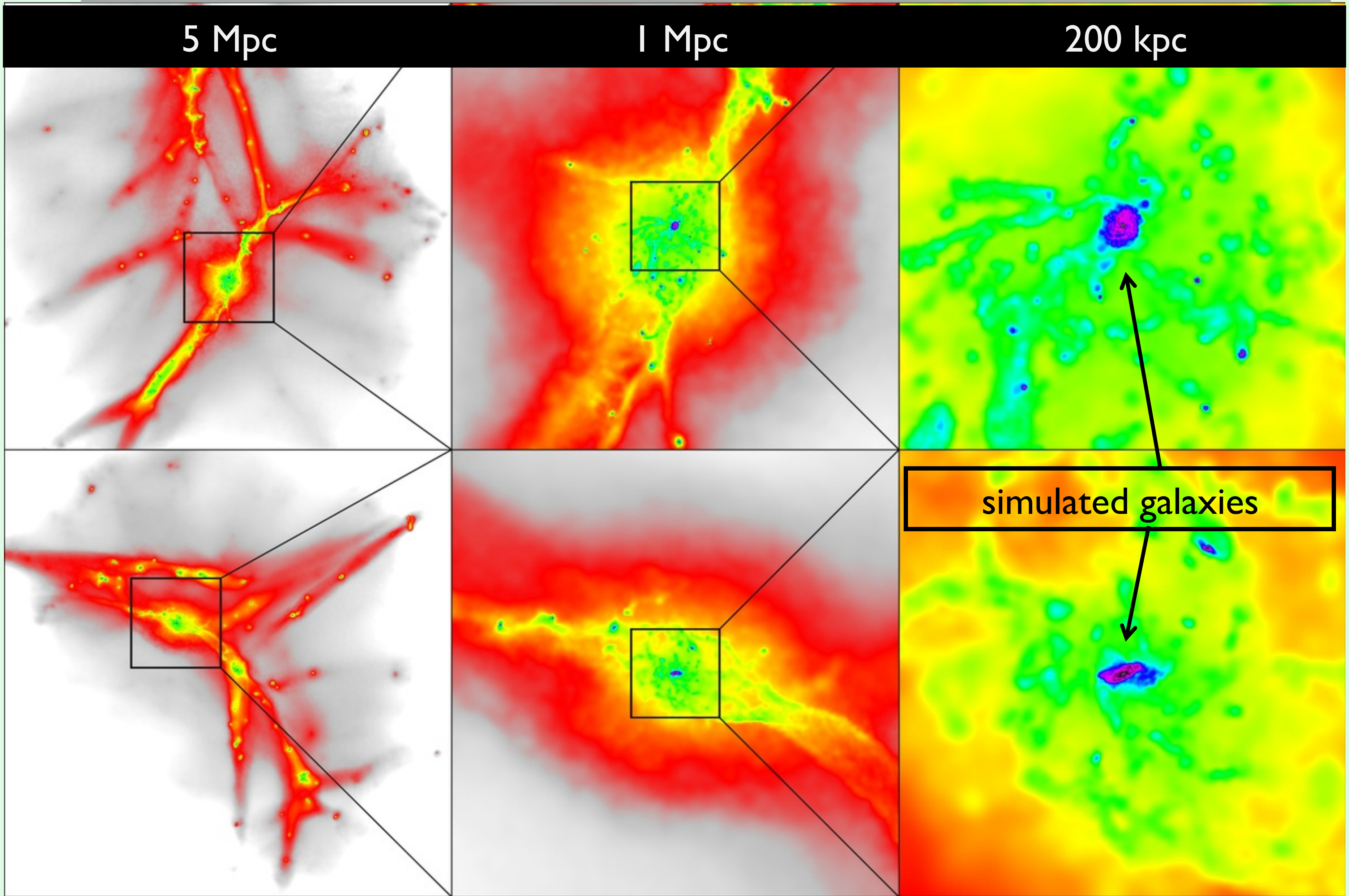


Our Goal:

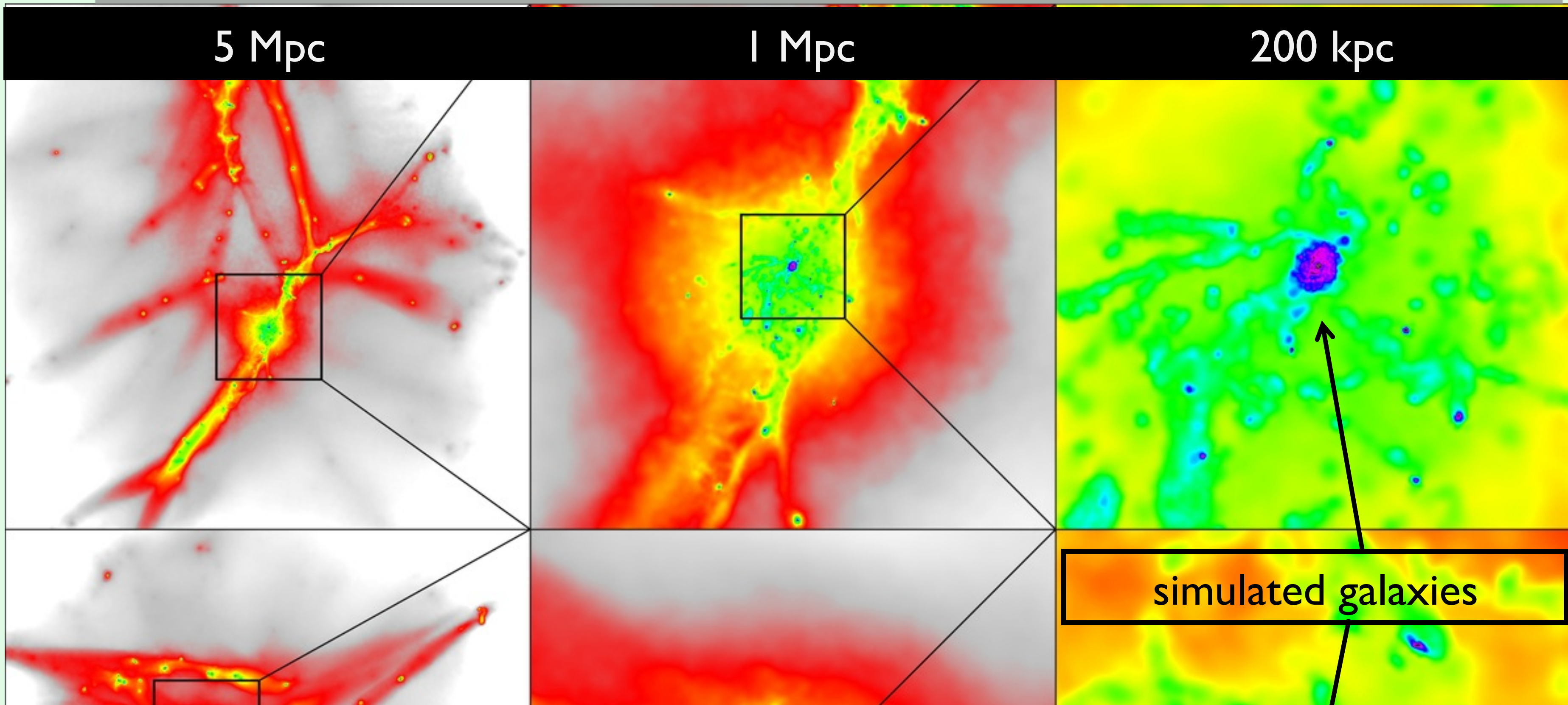
Study angular momentum acquisition in simulated galaxy halos. Focus on the following questions:

1. How/why does the angular momentum of inflowing gas differ from dark matter (if at all)?
2. What about cold vs. hot "modes" of gas accretion?
3. Is there a <u>more consistent model</u> for how galaxies / galaxy halos acquire angular momentum?

Our Simulations



Our Simulations



4 cosmological zoom-in simulations (sph-GASOLINE):

Roughly Milky-Way size galaxy halos: M_{vir} (z=0)~10^{12} M_{sun}
Gas mass resolution ~$3x10^5$ M_{sun} Spatial resolution ~ 300 pc.
No galaxy scale winds → our results all focus on gas *accretion*

Angular Momentum in Dark Matter Halos:

A halo's angular momentum is often characterized by dimensionless "spin parameter," λ

$$\lambda_x \equiv \frac{j_x}{\sqrt{2}V\,R}$$

Bullock+ '01

j = J/M = specific angular momentum of a component (dark matter, gas, etc.) within a sphere of radius R.

V = the circular velocity at R.

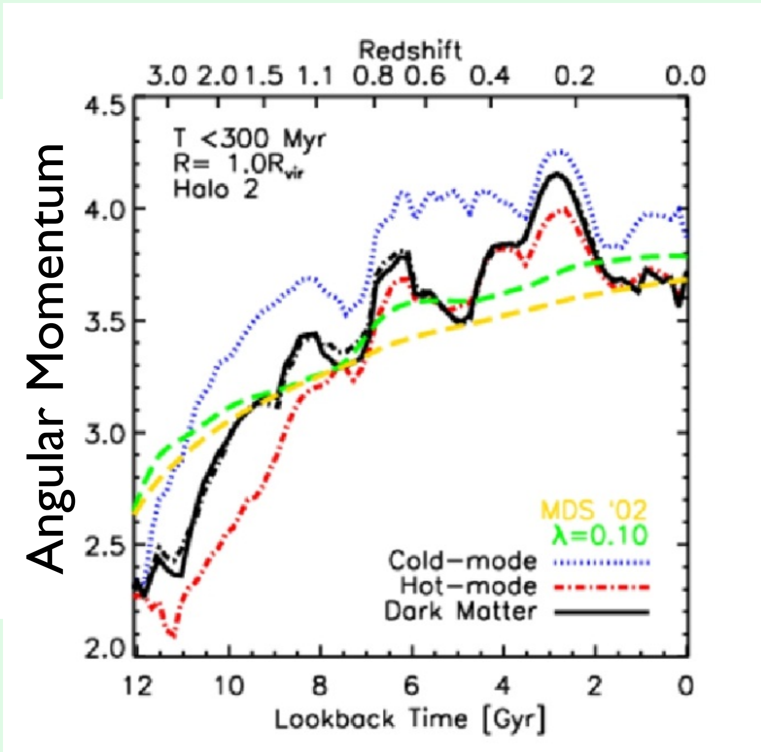
Spin parameter well studied in N-body simulations

Roughly constant over time for dark matter halos: λ~**0.04** (e.g. Maccio+ '07, Bett+ '10)

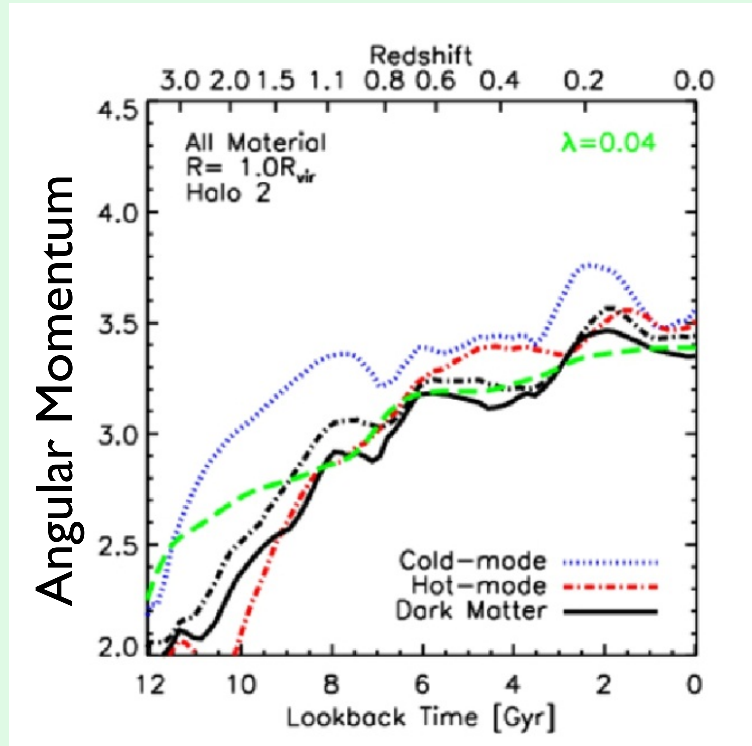
But V, R both increase with time for any given galaxy

→ **newly accreted material *must* have higher j**

Angular momentum at First Infall to Halo:



vs.



Angular momentum for "**fresh**" accretion to the halo is higher

Angular momentum for **all** material in the entire halo agrees with N-body

In both cases, **cold-mode gas has more angular momentum.**
Hot-mode gas / dark matter are comparable to each other.
("Inward flowing" material similar to "fresh" accretion)

Angular momentum of Accreted Gas:

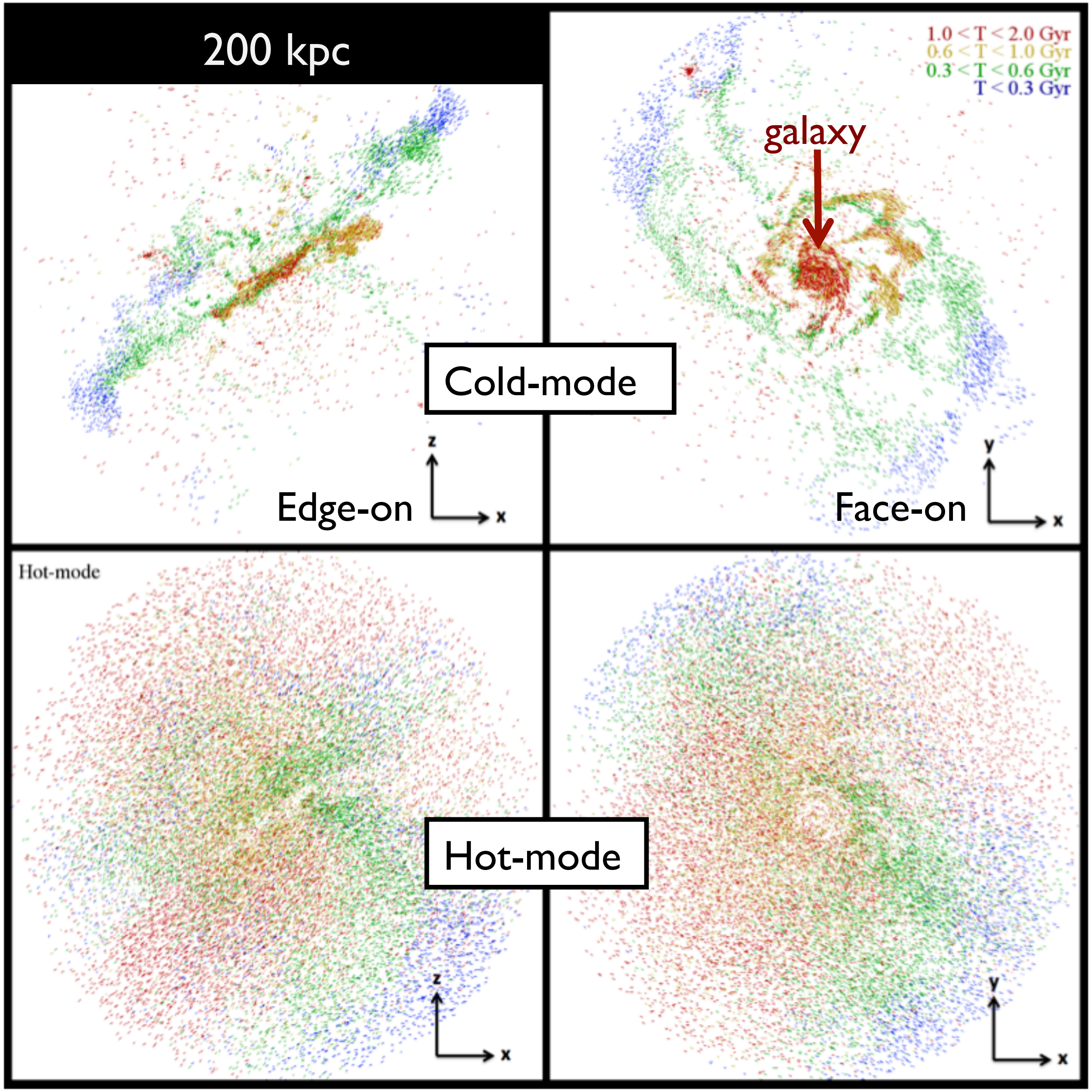
Why does cold-mode gas carry more angular momentum?

1) It samples a spatially distinct supply of material → along filaments

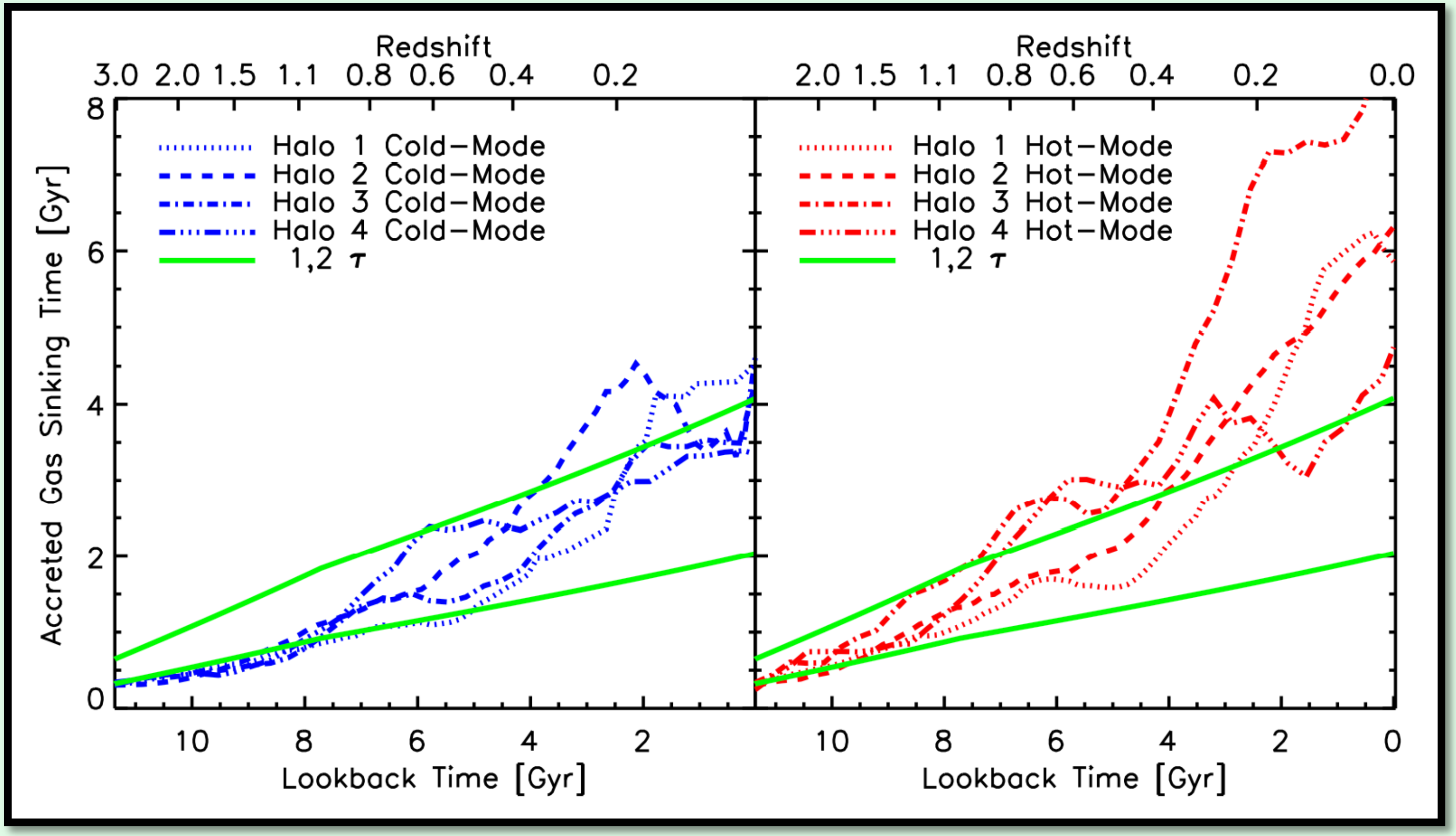
2) Shows coherent structure, rotation direction (co-rotates with galaxy)

3) Sinks quickly

Note: infall is *not* purely radial at R_{vir}. Average infall angle ~30-50°



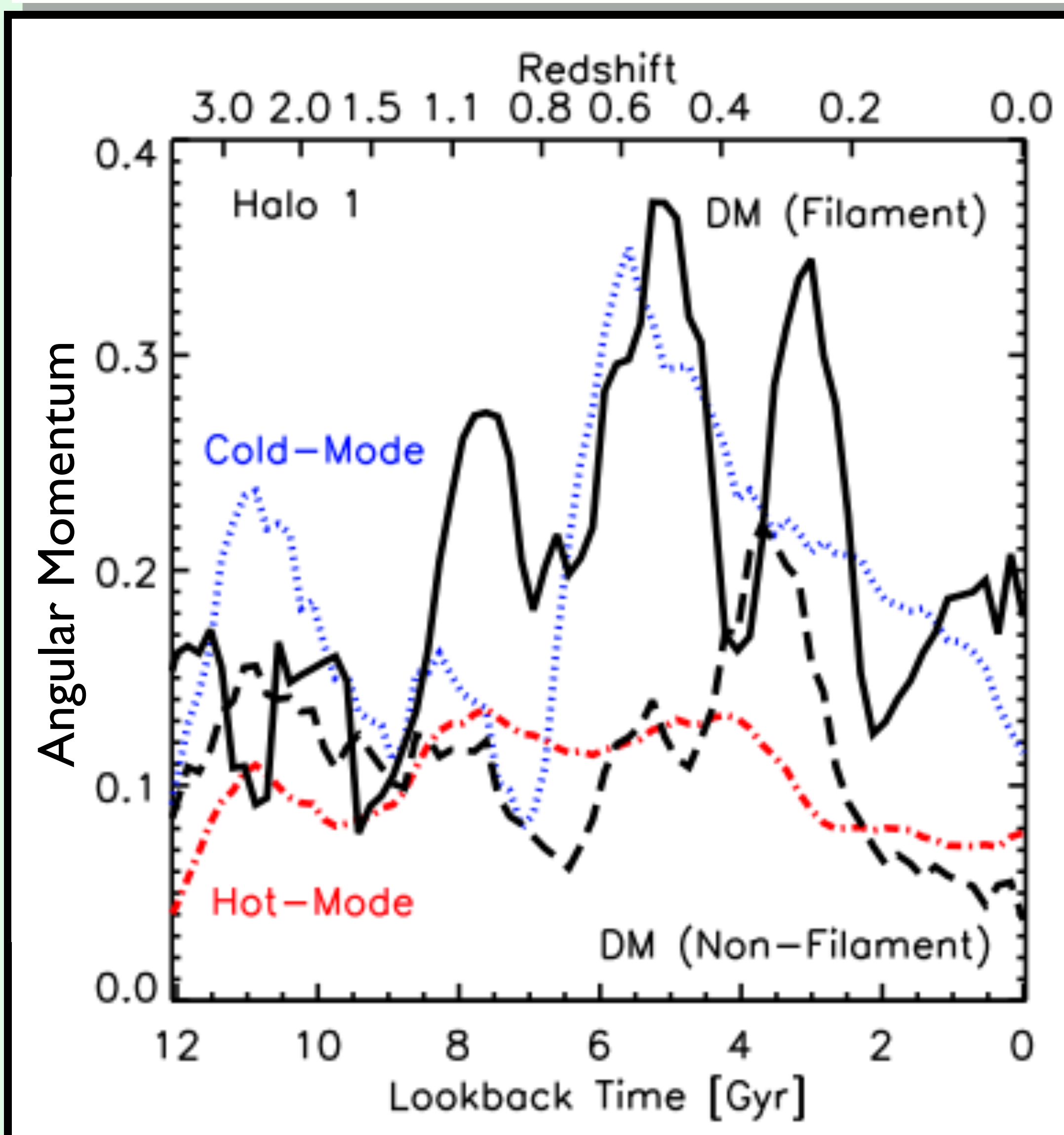
Sinking Time of Accreted Gas:



Cold-mode gas sinks in < **3 Gyrs** (~1-2 times the free-fall time, τ).
Hot-mode gas is ~1-2 times longer.
Mean accretion time (at z=0) for DM is ~**8-9 Gyr** ago.

→ Cold-mode halo gas probes recent gas accretion

Spin of Dark Matter vs. Cold Halo Gas



Does filamentary origin of cold-mode gas explain its angular momentum?
→ Look at dark matter.

Compare the angular momentum of ***only recent, filamentary dark matter*** to recent non-filamentary dark matter.

Filaments → cold-mode gas

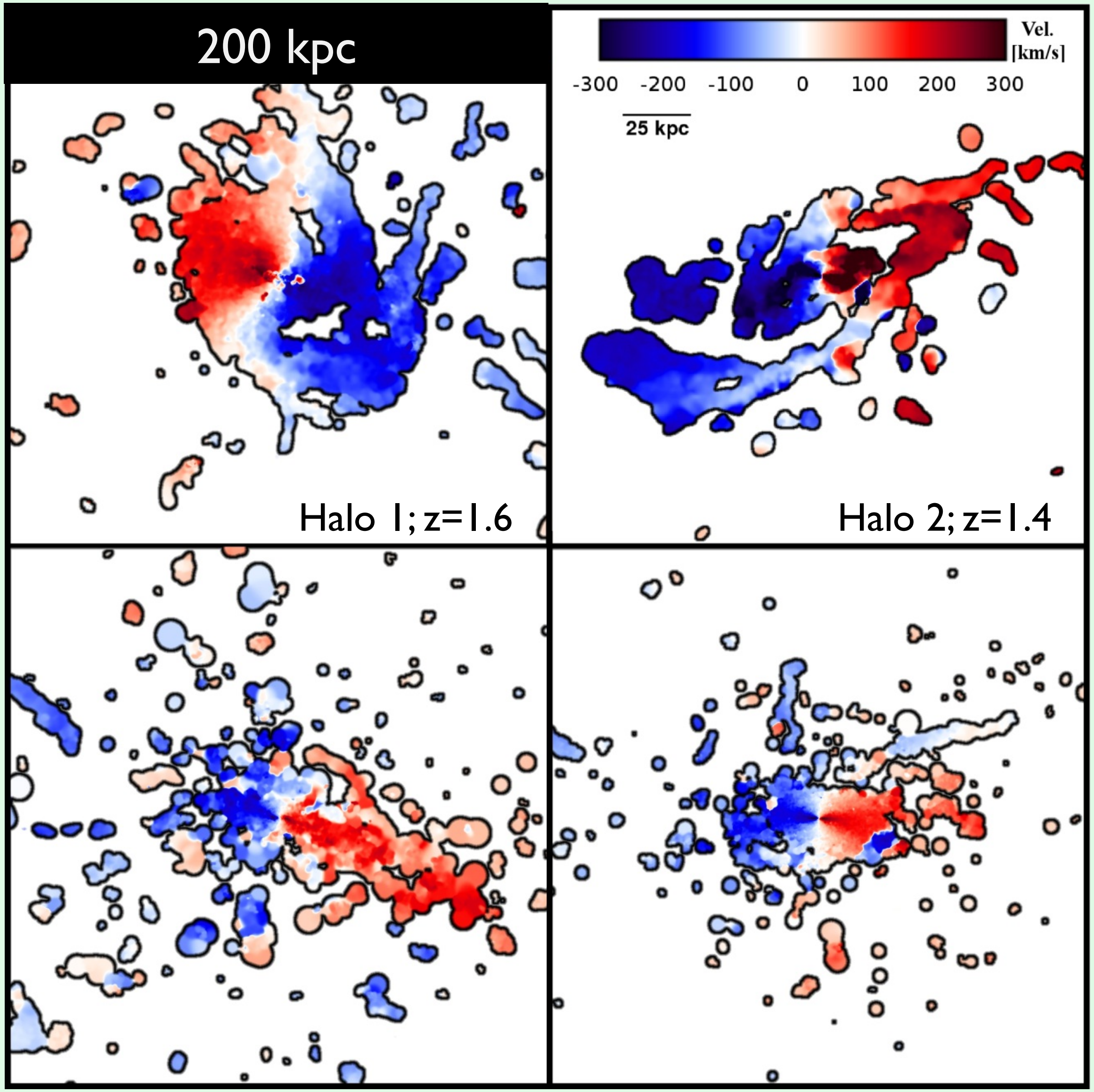
Non-filaments → hot-mode

Extended HI disks = “cold flow” disks?

High angular momentum gas *inflow*
+
Short sinking time
+
Coherent spatial & velocity flow, set by cosmic filament direction
=
“cold flow disks”

(Present for several Gyr in all 4 simulations.)

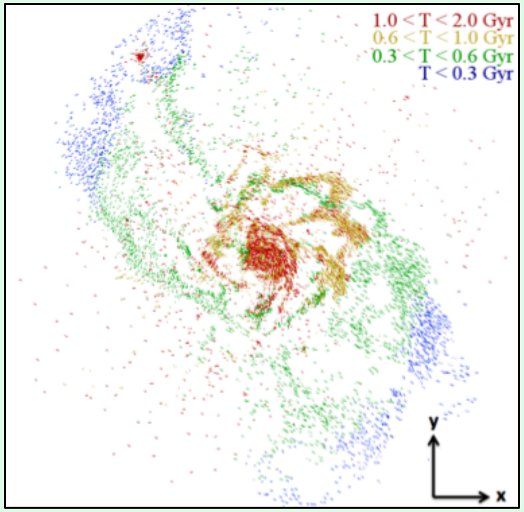
Extended gas (HI) disks: *natural result of angular momentum acquisition* via cold-mode accretion

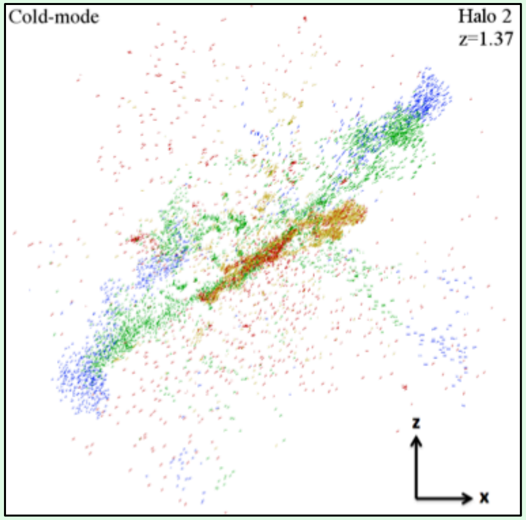


Halo 3; z=0.7

Halo 4; z=0.2

Summary: A New Cold-mode Scenario of Angular Momentum Acquisition





1) Fresh accretion has *2-3 times more angular momentum* than the cumulative total

2) Cold-mode gas *flows in along filaments*, more coherently, resulting in *higher angular momentum* than non-filamentary accretion.

3) Cold-mode gas *sinks quickly* onto the galaxy (1-2 free-fall times).

4) Vector cancellation & non-uniform infall alignments over long timescales leads to a lower spin for DM halo/galaxy as a whole

→ Naturally explains extended HI disks: "cold flow disks" of accretion