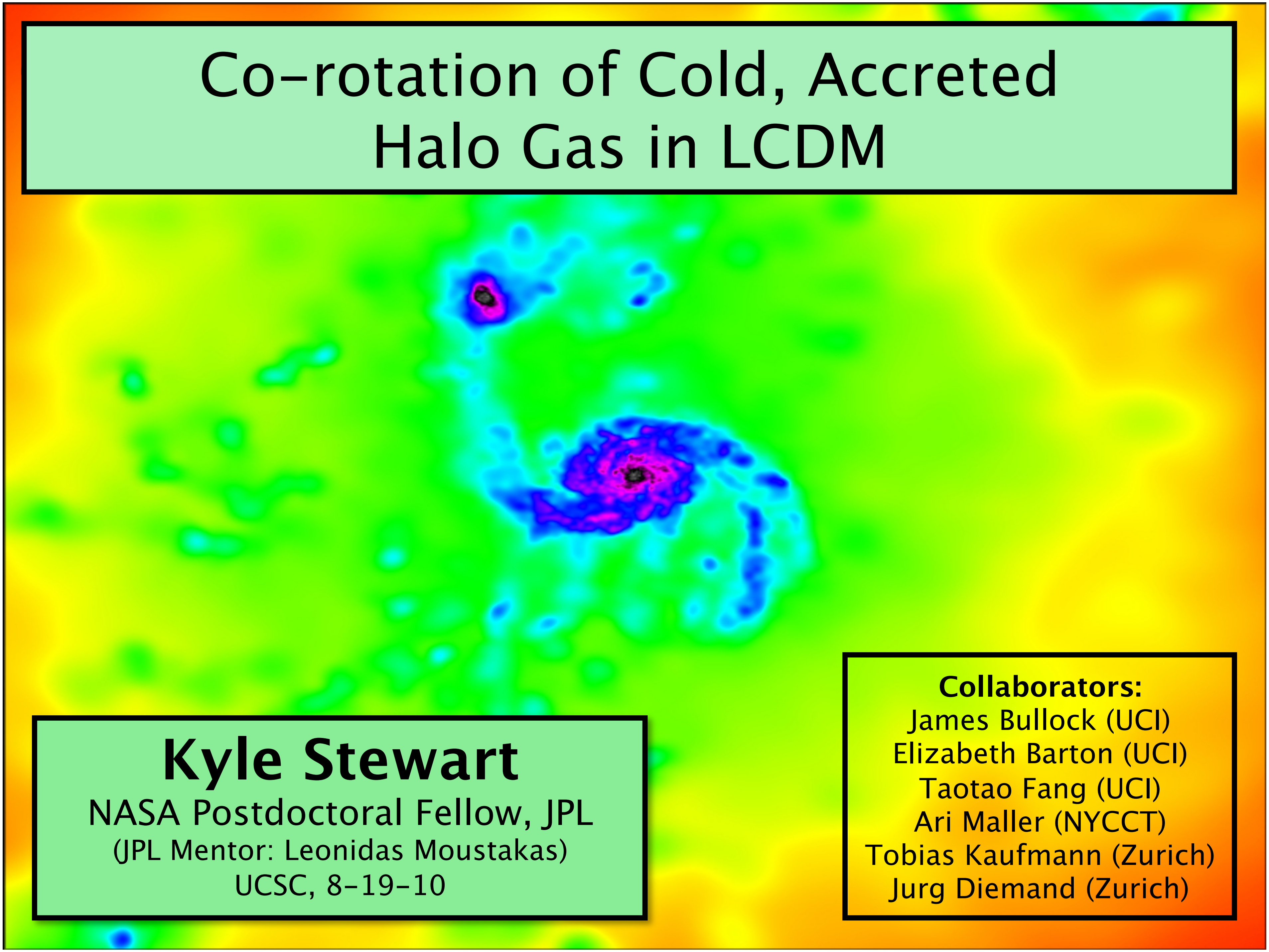
Co-rotation of Cold, Accreted Halo Gas in LCDM



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UCSC, 8-19-10

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Elizabeth Barton (UCI)

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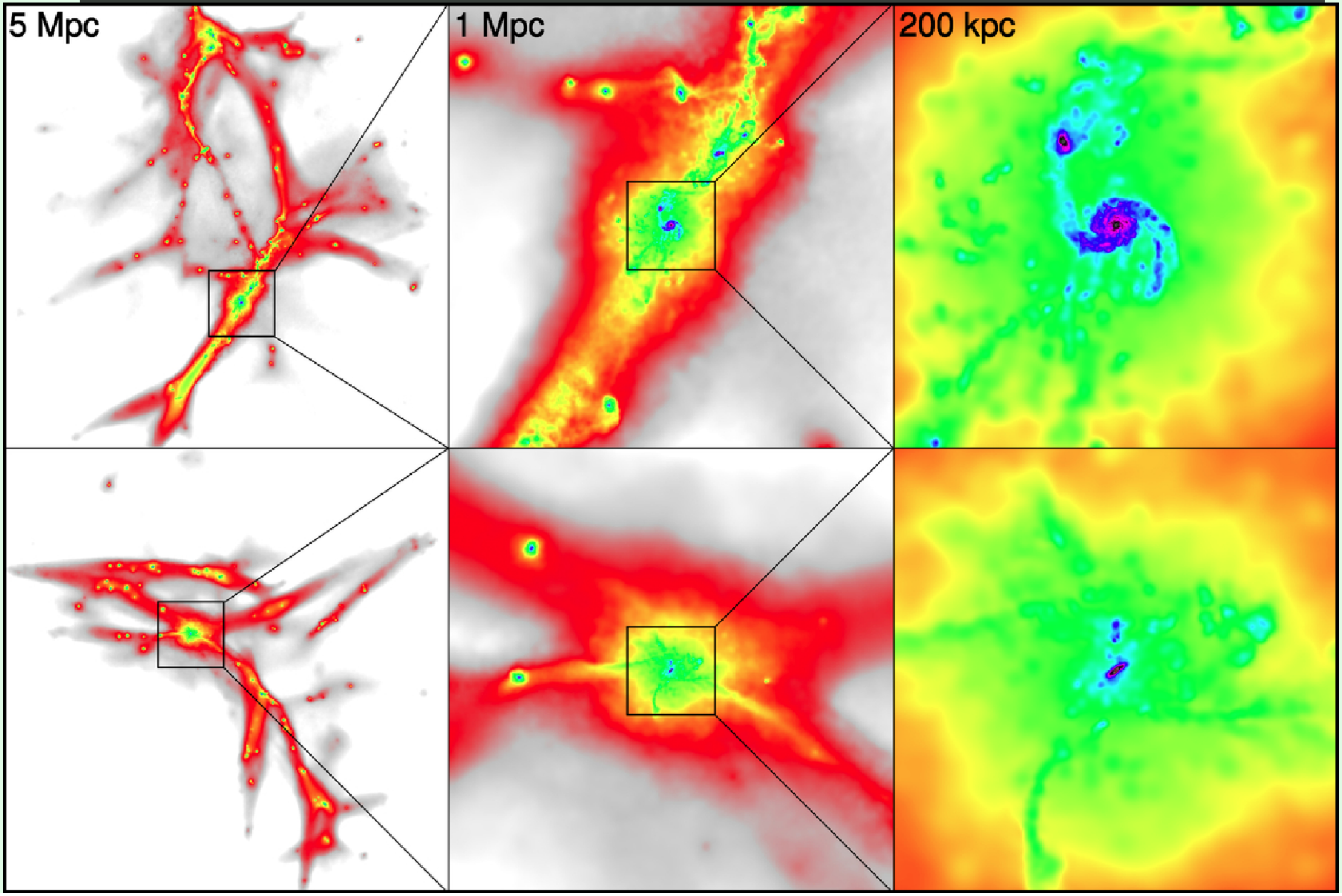
Tobias Kaufmann (Zurich)

Jurg Diemand (Zurich)

Motivation:

- Cold gas accretion is expected in LCDM, but so far, no clear observational signature. (Can we find one in gaseous halo properties?)
- How are cold gaseous halos built and maintained? Smooth? Mergers?
- What are their properties? Redshift evolution? Radial dependence?
- Can theoretical properties be confirmed by observations?

Our Simulations



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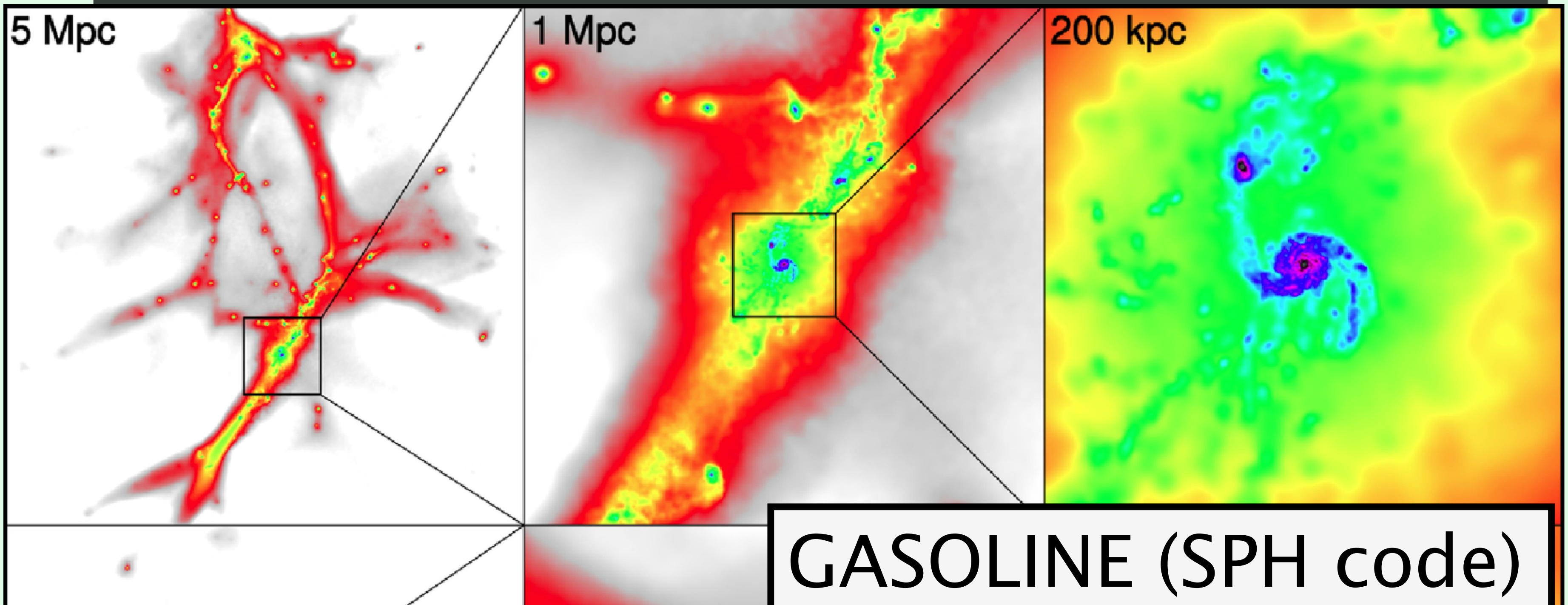

GASOLINE (SPH code)

Some stats:

WMAP3 cosmo: Ω_0=0.24, Λ=0.76, h=0.73, σ_8=0.77, Ω_b=0.042
m_{DM}, m_{gas}, m_{star} ~3e5, 4e5, 1e5 M_{sun}, Np~4 million,
resolution ~ 332 pc. Final (z=0) halo mass M_{vir}~2.e12 M_{sun}

'Blast-wave' feedback of Stinson et al. '06; Haardt & Madau '96 UV field; NOTE: no strong galactic outflows here.

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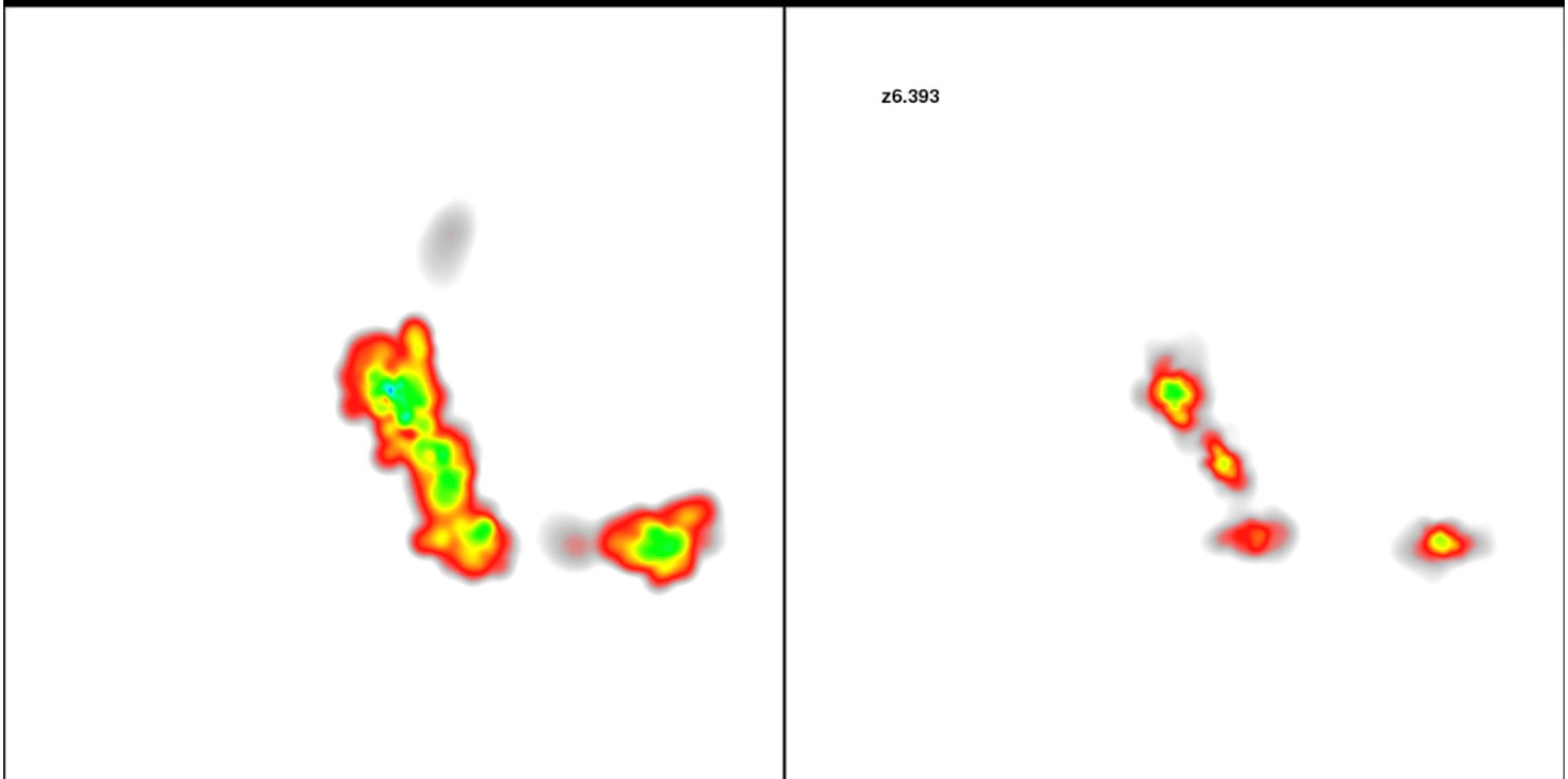
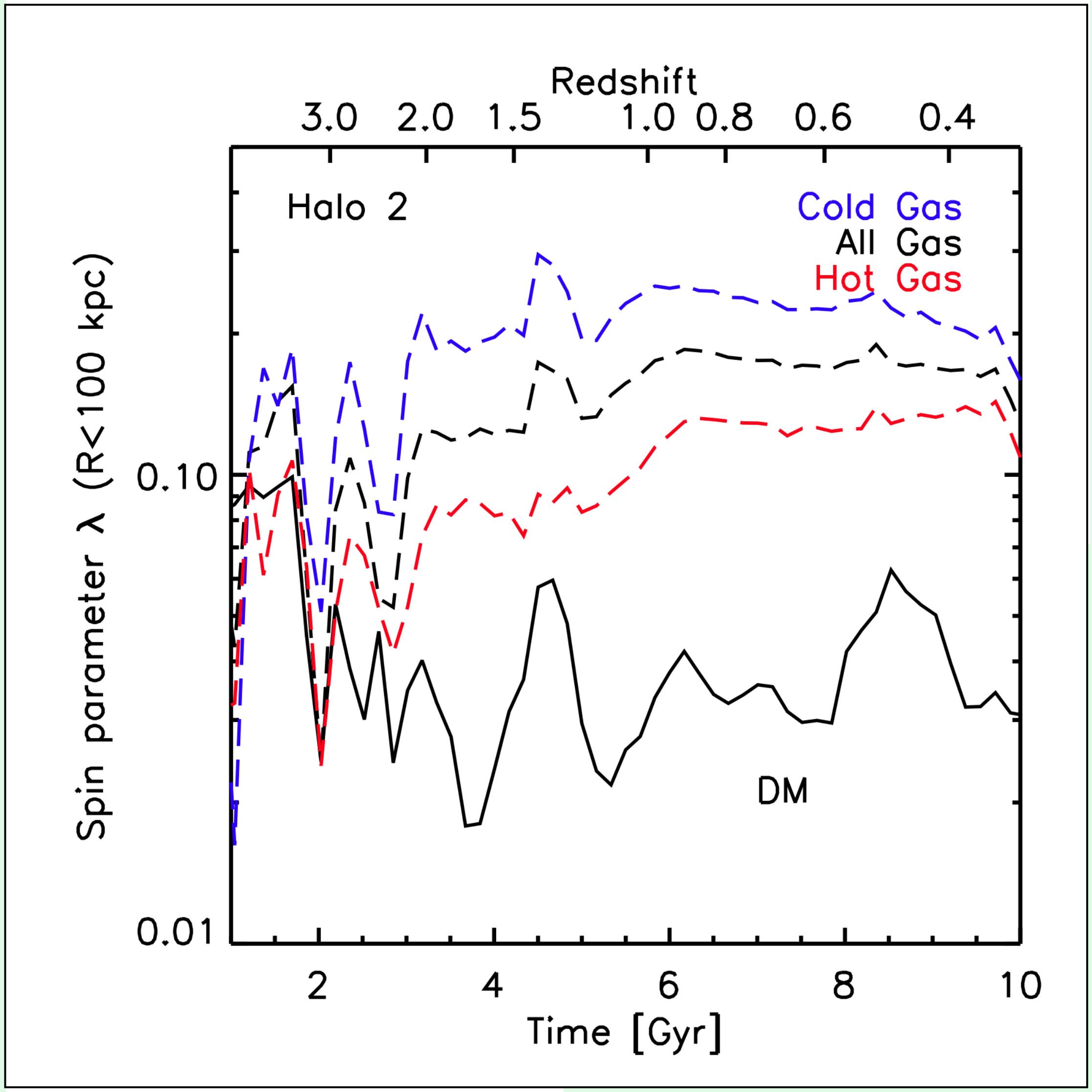


Cold Gas Stars

Galaxy + Halo properties:

(Motivation for choice of R<100 kpc next slide)



λ_{DM} ~ 0.04 as expected

λ_{gas} ~ **0.1–0.2**

Much harder to lose high ang. mom. gas after mergers

Galaxy + Halo properties:

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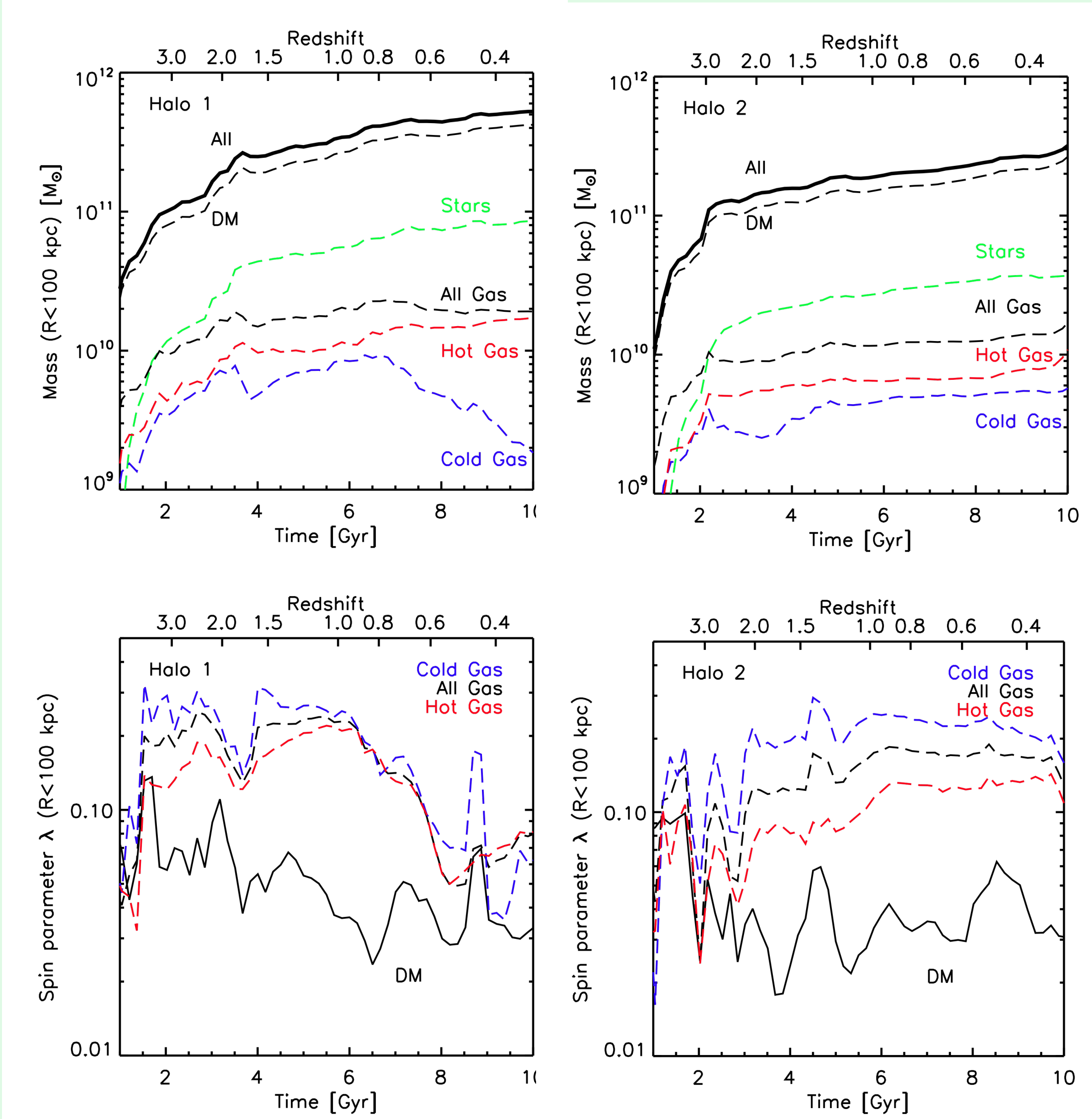


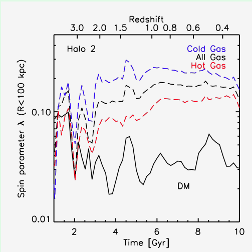
Note: different merger histories, impacts halo gas. $M_{gas} \sim 10^{10}\ M_{sun}$

"Cold" : $< 10^5$ K
"Hot" : $> 10^5$ K

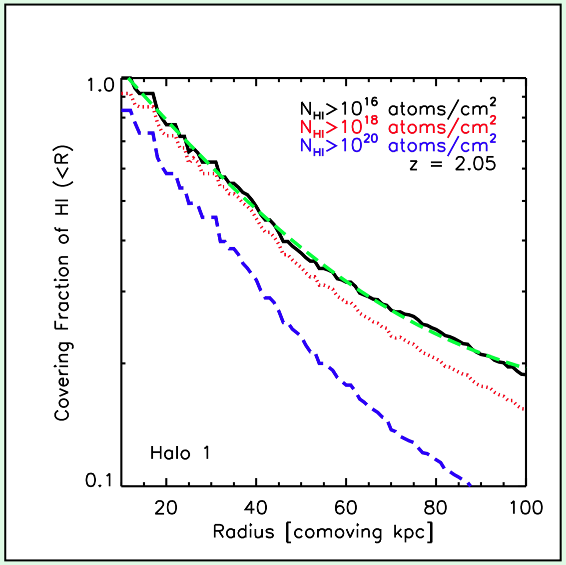
$\lambda_{DM} \sim 0.04$ as expected

$\lambda_{gas} \sim$ **0.1–0.2**

Much harder to lose high ang. mom. gas after mergers



Observational Aside: CF vs. R, z

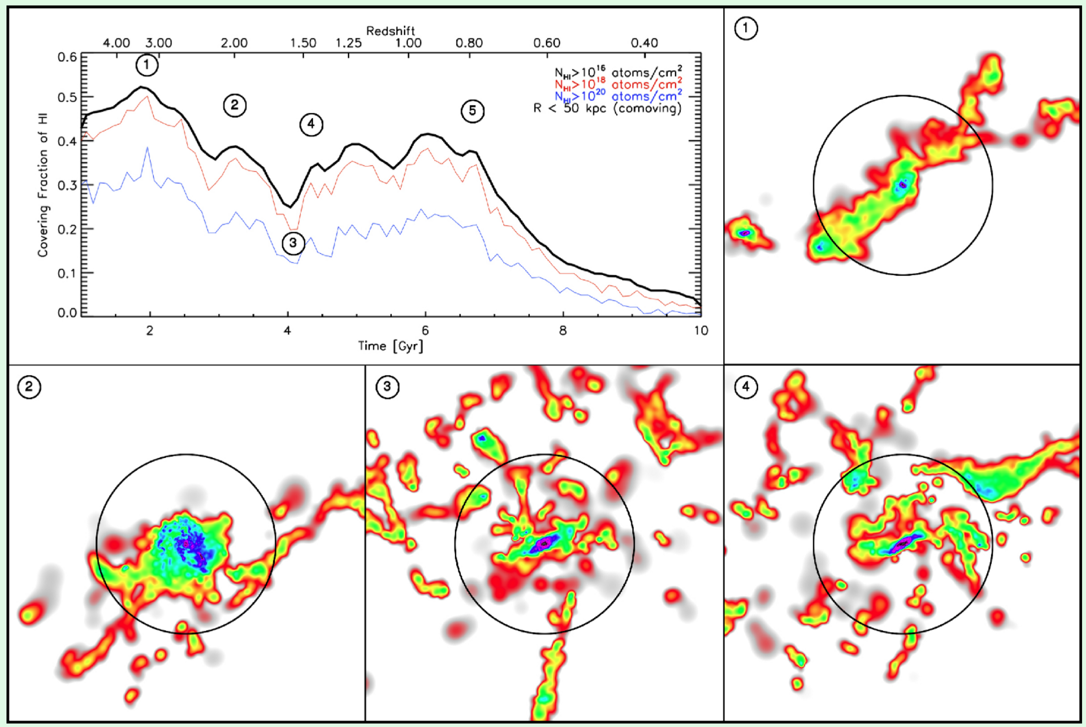


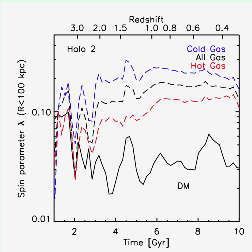
Covering Fraction of HI (fractional area where $N_{HI} > 10^{16}$ atoms/cm²) depends strongly on which radius you choose.

CF(<R) ~ $e^{-R/Rgas}$; Rgas ~30-80 kpc (comov)

CF (within fixed radius) varies strongly with recent gas accretion activity

Minor gas-rich mergers increase CF for longer





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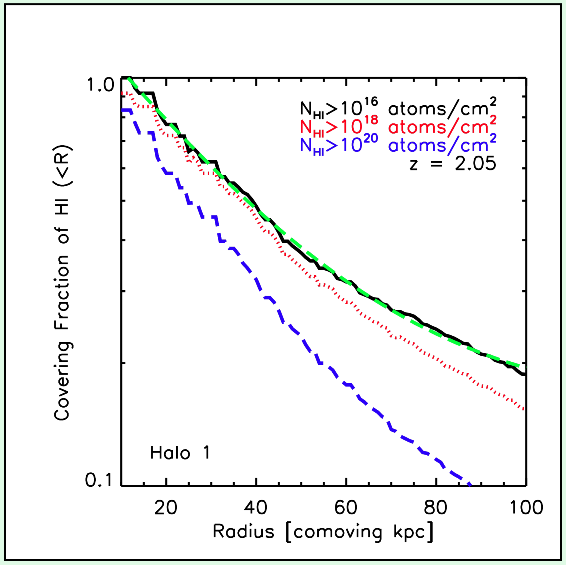

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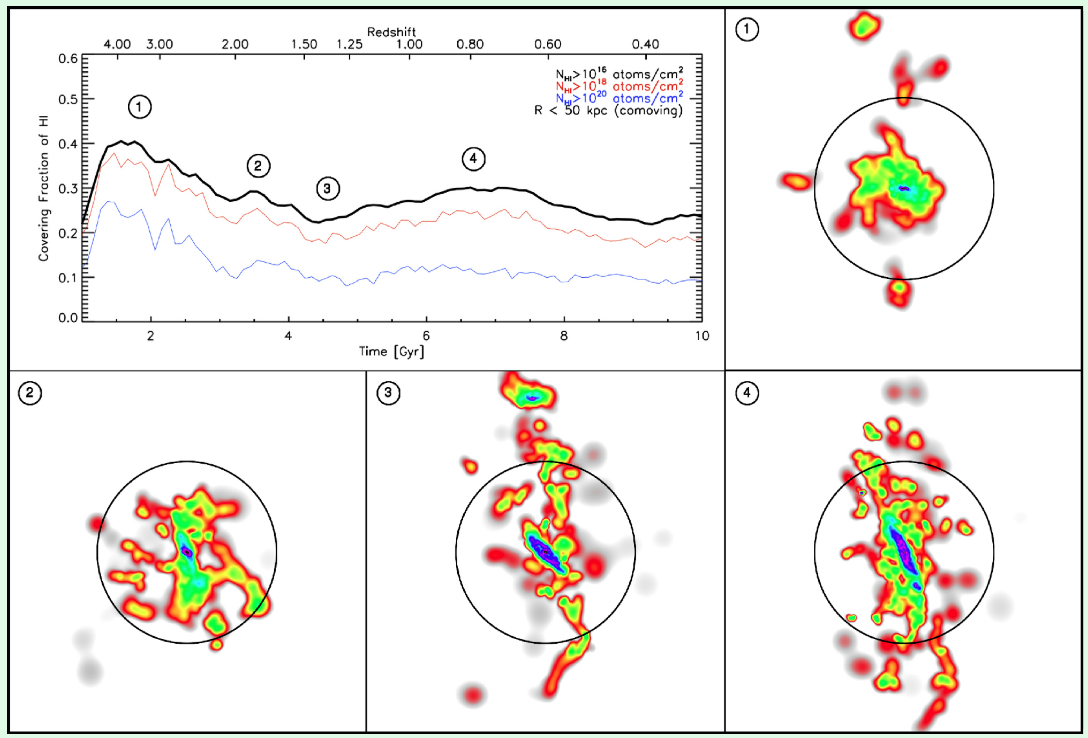
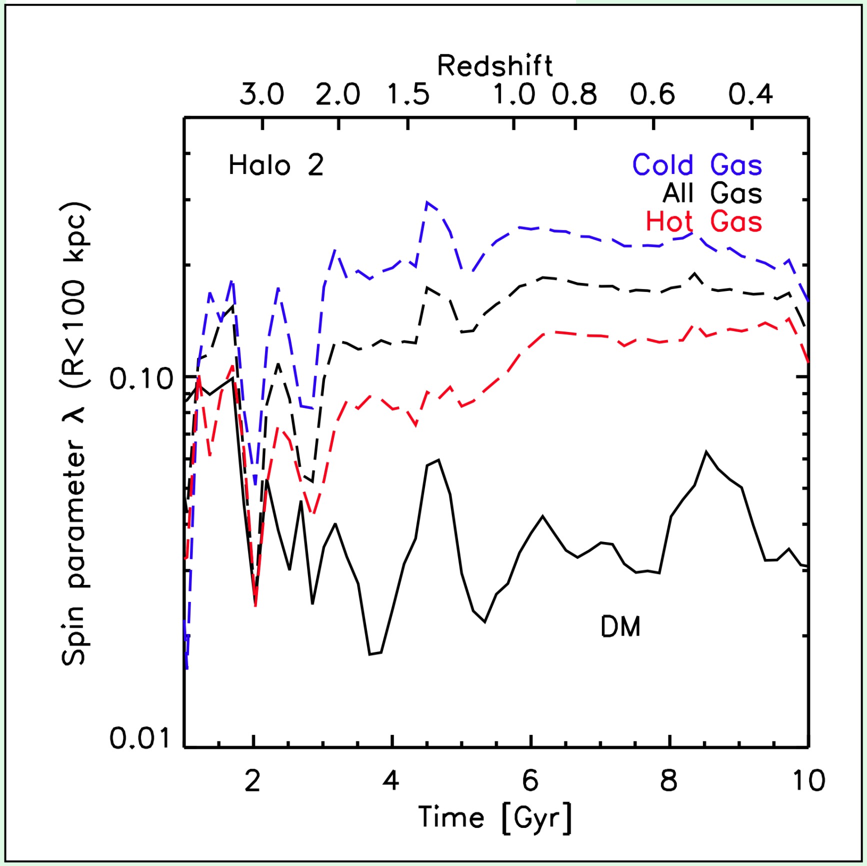


Galaxy + Halo properties:



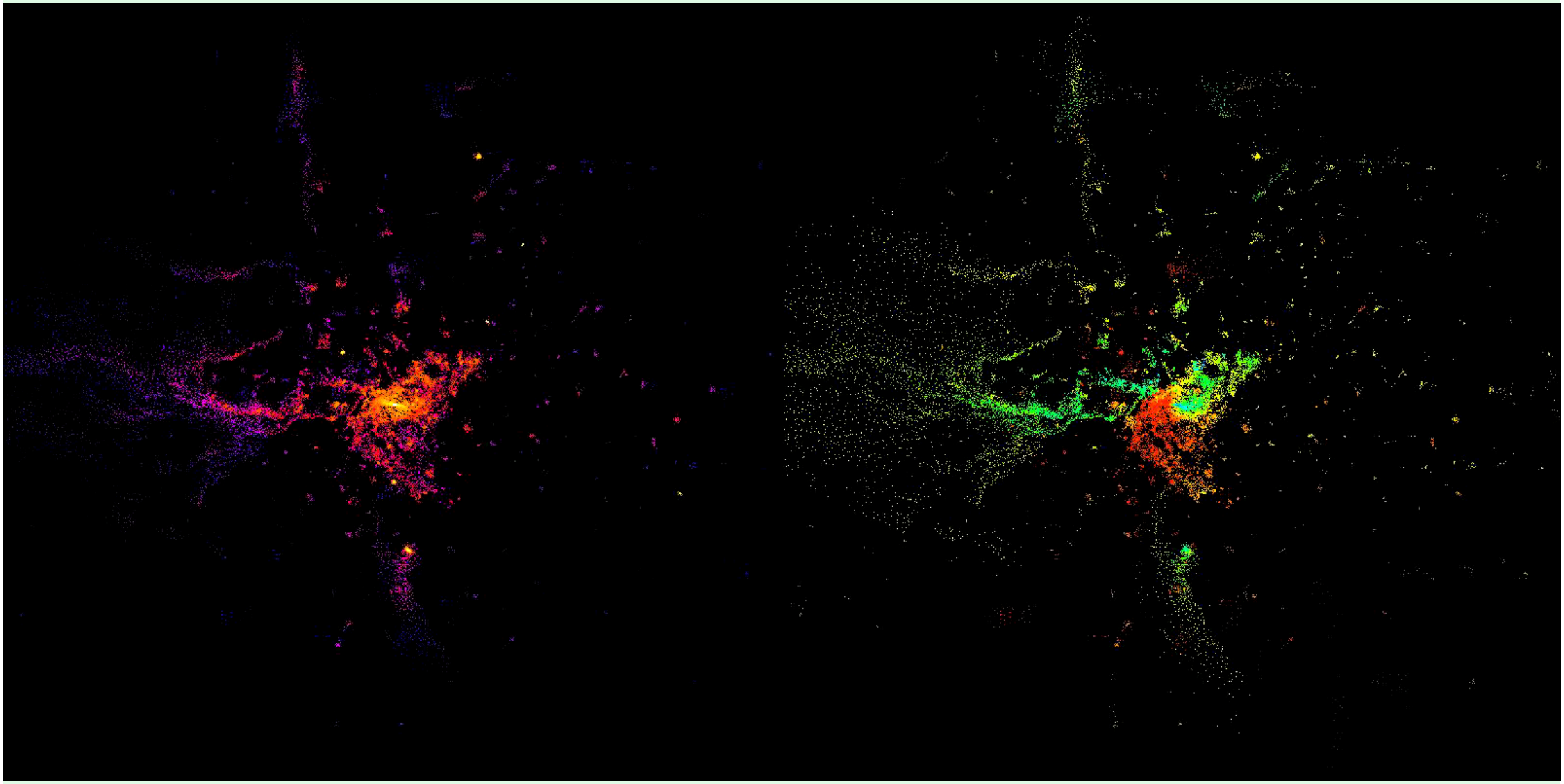
All this high angular momentum, cold halo gas is from accreted gas (no outflows)…

With λ_{gas} so high, is there there any coherent rotation of halo gas?

This gas eventually falls on to the disk and forms stars…

Any correlation between the halo gas kinematics and the rotation of the galactic disk?

Example: z=0.8



3d gas density

LOS velocity

Can cold halo gas be observed?

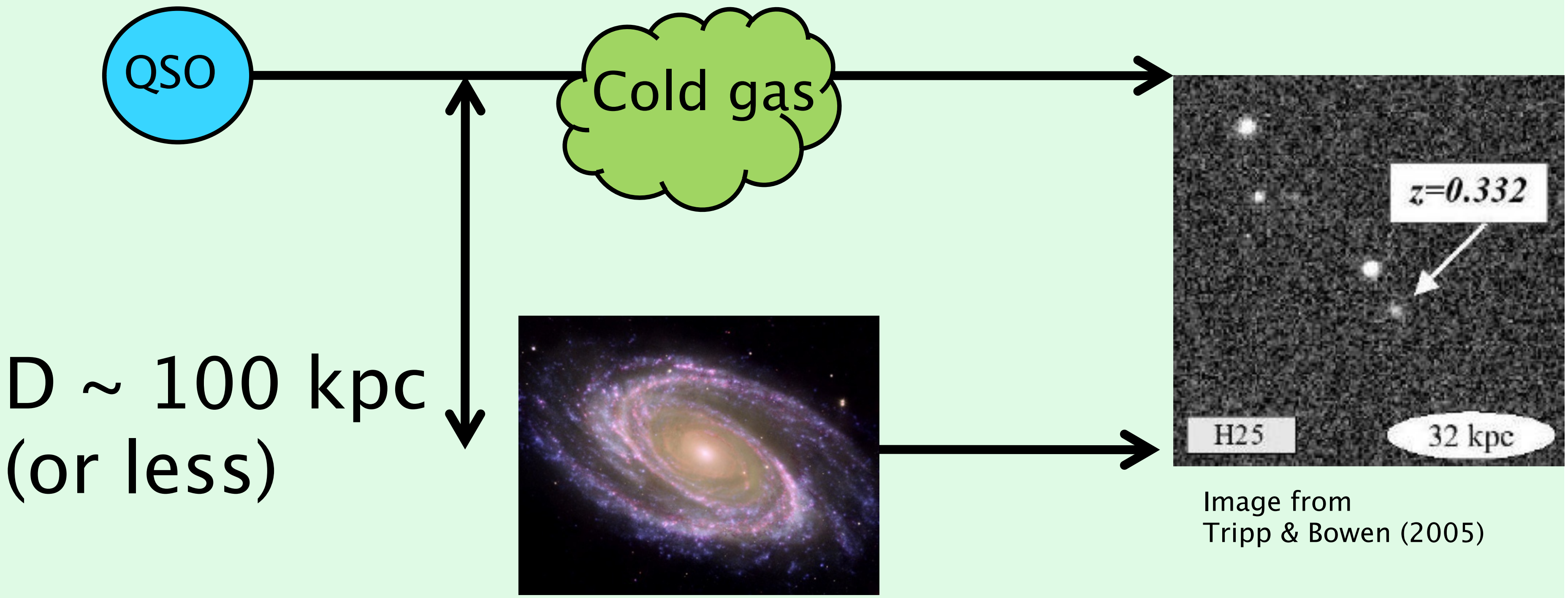


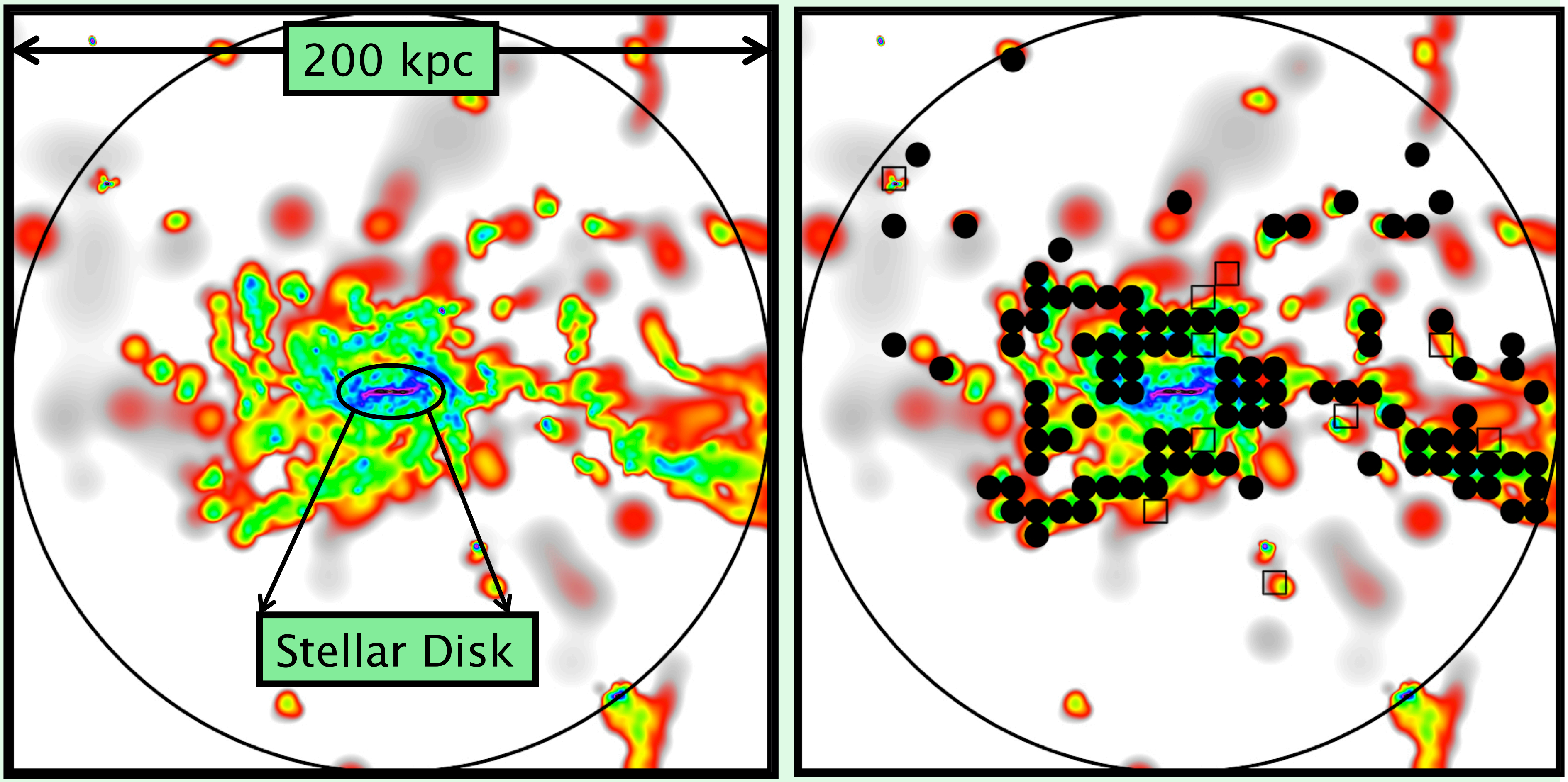
Image from
Tripp & Bowen (2005)

Yes, in absorption

Halo Gas Kinematics (Example)

R < 100 co-moving kpc ; z=0.8
% of observable LOS that rotate : ~ 90%
% of rotating lines that co-rotate: ~ 70%

Open Squares: Non-rot
Filled Circles: Rotation
(in either direction)



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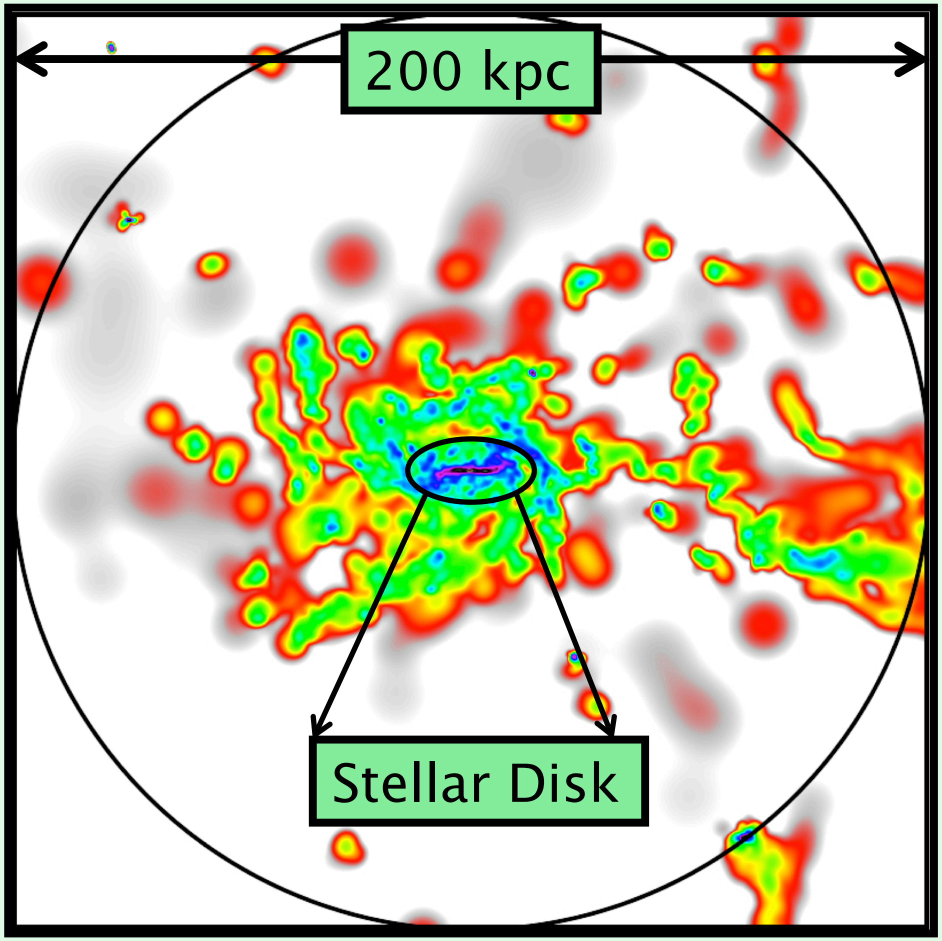
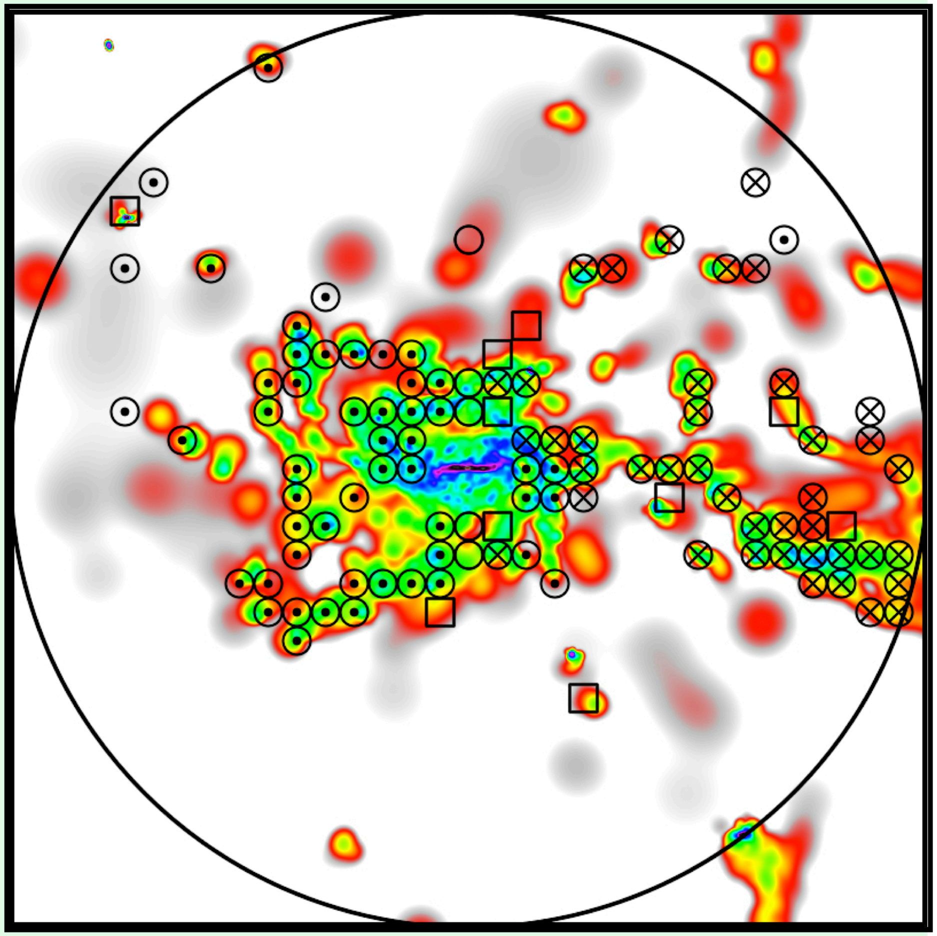
Circle-dot: Co-rotation
Circle-X: Anti-rotation





Dependencies:

	Orientation	Merger History?	Radius
Cover Fraction	Weak	STRONG	STRONG
Rotation	Weak	None	None
Co-rotation	STRONG	STRONG	Weak

High Cover Fraction: small R, recent/fresh gas accretion

High Rotation : ubiquitous? Not dependent on merger history/orientation/radius. Universally high for $z<3$.

High Co-rotation : recent gas accretion (particular orientations)

Can this co-rotation be observed?

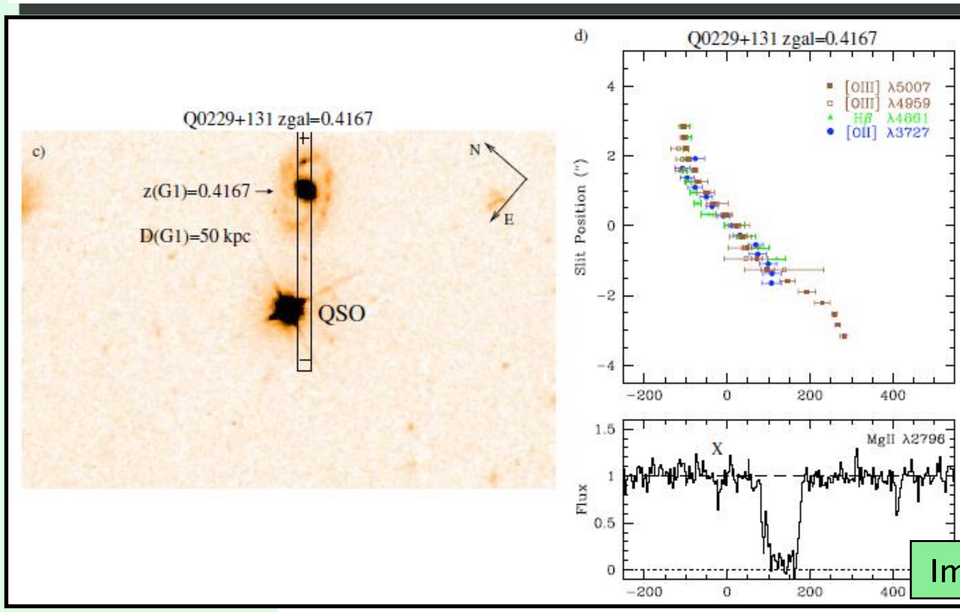


Image from Kacprzak+ '10

Steidel+ 2002; Kacprzak+ 2010;

Compared kinematics of cold absorption gas (using Mg II lines) to galaxy rotation curve.

It has already been observed!

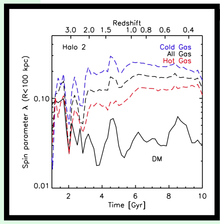
Our simulations (ranges give typical viewing angle variation):

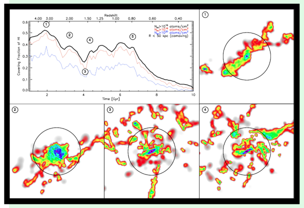
Non-rotation: **5-15%**
Rotation: **85-95%**
  Co-rotation: **50-90%**
  Anti-rotation: **10-50%**

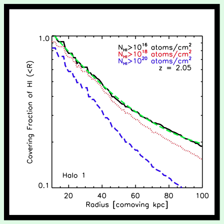
Observations (Combined sample of Steidel+ 02 & Kacprzak+ 10):

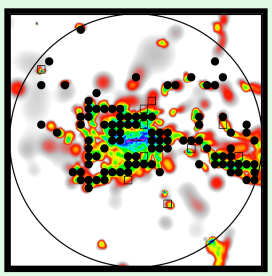
Non-rotation: **~25%**
Rotation: **~75%**
  Co-rotation: **~70%**
  Anti-rotation: **~30%**

Summary









Steidel+ '02
Kacprzak+ '10

- λ_{gas} ~ 2-4 times higher than λ_{DM}. This gas is spun up by mergers, and fed by continuous, fresh infall.
- M_{gas} ~ 10^{10} M_{sun} for MW progenitors (R<100 kpc).
- Covering fraction (<R) of cold halo gas falls off exponentially, but still detectable out to ~100 kpc
- Covering fraction depends strongly on recent merger/ gas accretion history of the galaxy.
- Cosmological gas accretion in LCDM inevitably leads to rotation (co-rotation) of halo gas with the galactic disk.
- This signature can be observed. The (limited) observations of Steidel+02 & Kacprzak+10 agree quite well with our simulations.