Title: Turbulence-Dominated versus Thermal Energy-Dominated CGM: Implications for Galaxy Evolution

Speakers: Johnathan Stern

Collection/Series: Cosmic Ecosystems

Subject: Cosmology

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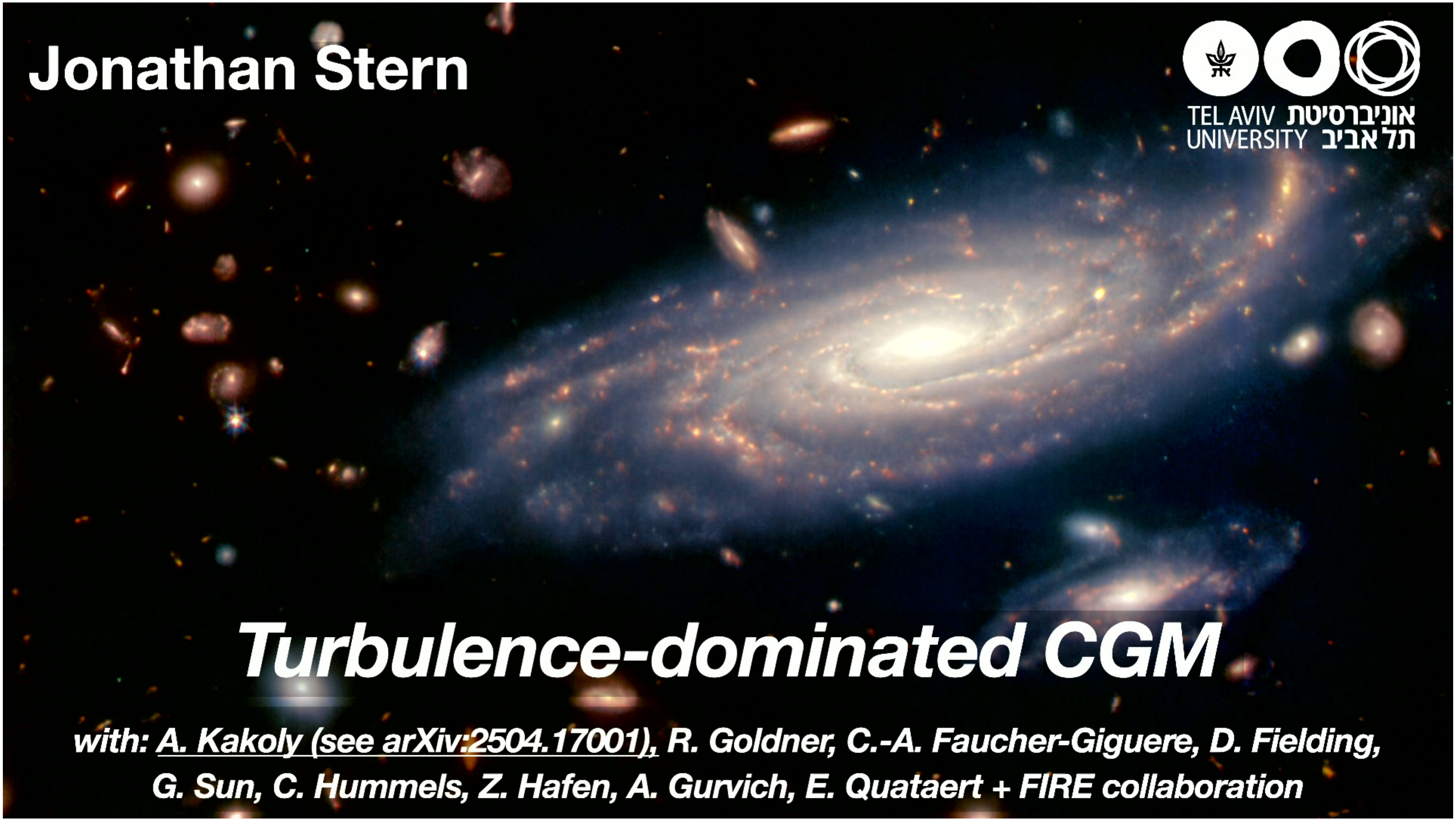
Abstract:

I will present evidence from both simulations and observations that the inner CGM ($\lesssim$0.3 Rvir) of $\lesssim$L* galaxies departs significantly from the conventional paradigm of cool clouds embedded in a volume-filling hot phase. Instead, these regions are characterized by a supersonically turbulent medium in which kinetic energy dominates over thermal energy, with gas temperatures 10^4 –10^5 K and wide lognormal density distributions. I will show that UV absorption features observed at redshifts $z \lesssim 1$, as well as DLAs at $z \gtrsim 2$, support this turbulence-dominated CGM framework. I will also discuss the broader implications of the transition from kinetic to thermal energy dominance for models of galaxy accretion, feedback processes, and the evolution from thick to thin star-forming disks.


Jonathan Stern
TEL AVIV UNIVERSITY אוניברסיטת תל אביב
Turbulence-dominated CGM
with: A. Kakoly (see arXiv:2504.17001), R. Goldner, C.-A. Faucher-Giguere, D. Fielding,
G. Sun, C. Hummels, Z. Hafen, A. Gurvich, E. Quataert + FIRE collaboration

CGM physics: a 0-th order question

- **Intracluster Medium** — ***Thermal*** energy dominates
- **Milky-Way ISM** — ***Rotational*** energy dominates
- **Molecular Cloud** — ***Turbulent*** energy dominates
- **Circumgalactic Medium** — ***???***

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- **Intracluster Medium** — ***Thermal*** energy dominates

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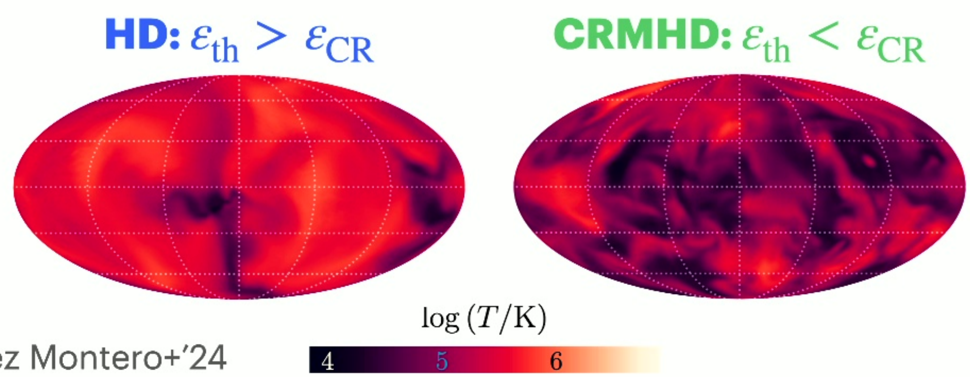
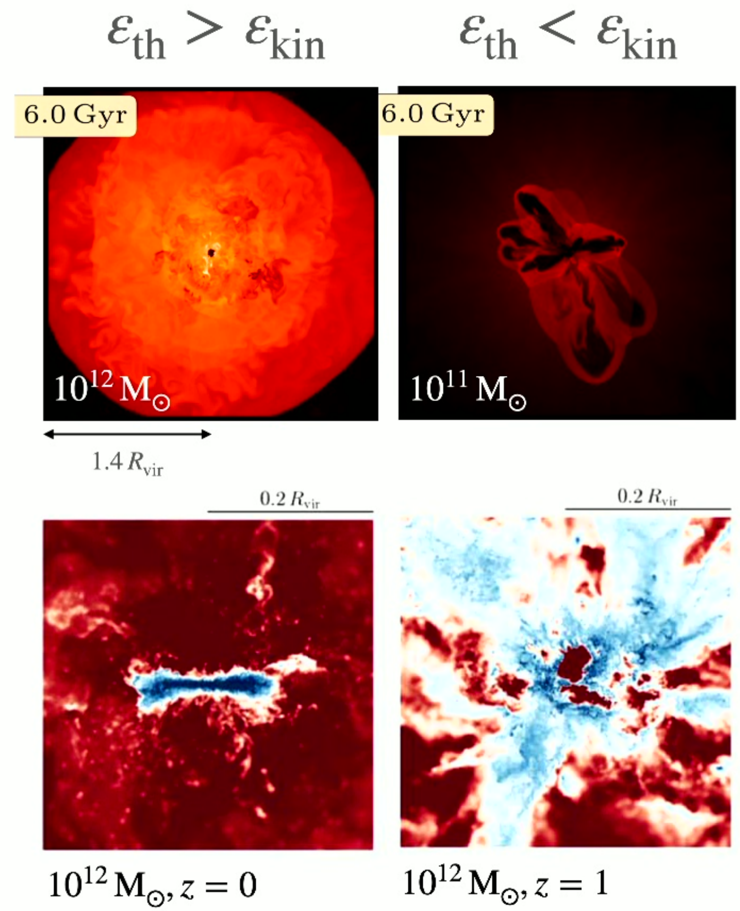
- **Circumgalactic Medium** — ***???*** **versus** $M_{\rm halo}, z,$ **and *radius***

Which energy term dominates?

- **MW-mass and above at $z \sim 0$:** sims and observations (X-ray, SZ, low HVC covering fraction) suggest ***thermal energy*** dominates
- ***Lower mass/higher z:*** sims indicate ***kinetic energy*** may dominate
- **CRMHD sims: *CR energy*** may dominate
  (e.g. Ji+'20, Butsky+'22, Rodriguez Montero+'24, see Irina's talk)



Rodríguez Montero+'24



Top: Idealized sims (Fielding+'17)
Bottom: FIRE sims (**JS**+'21)

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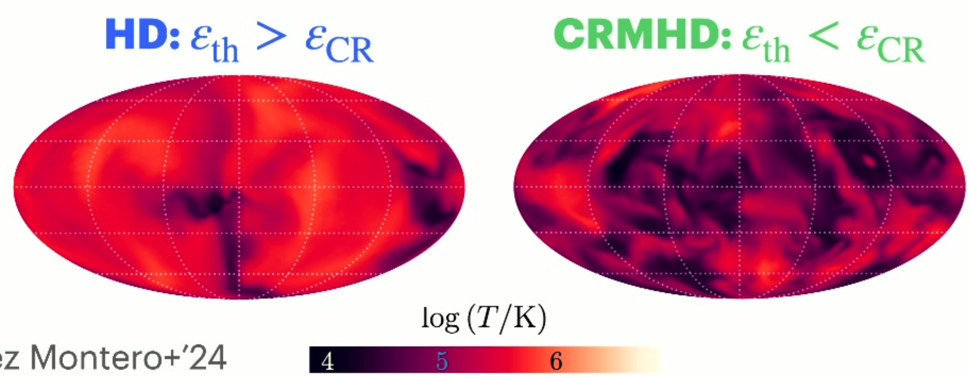

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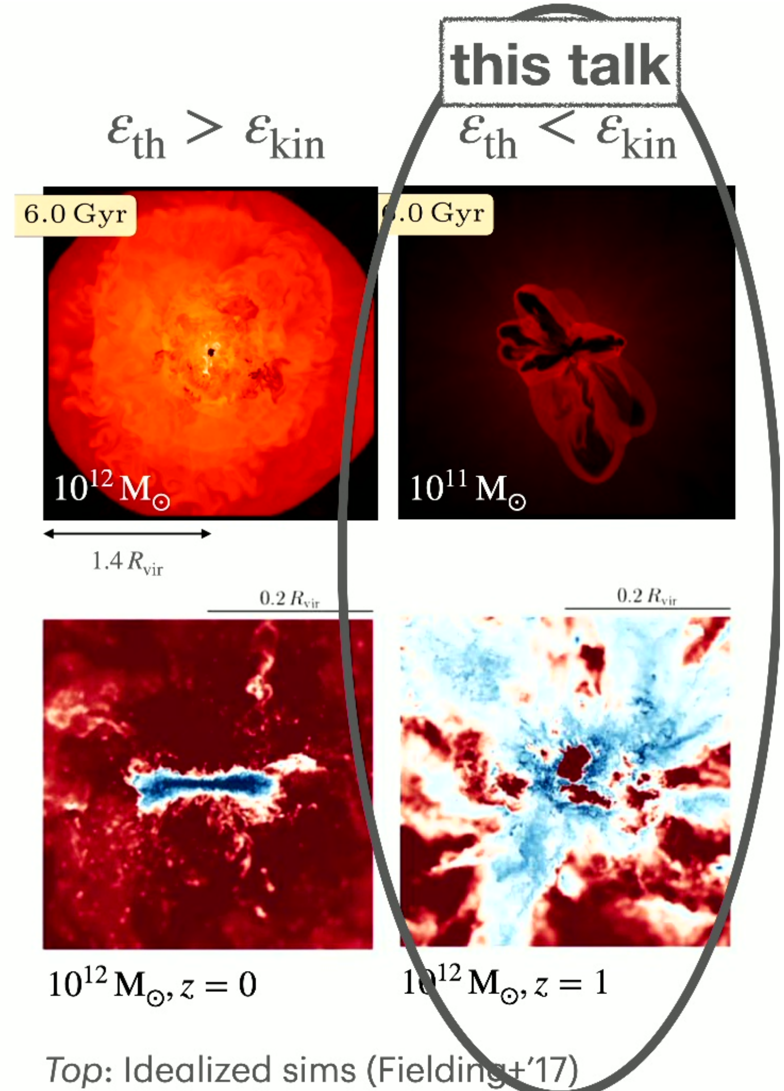

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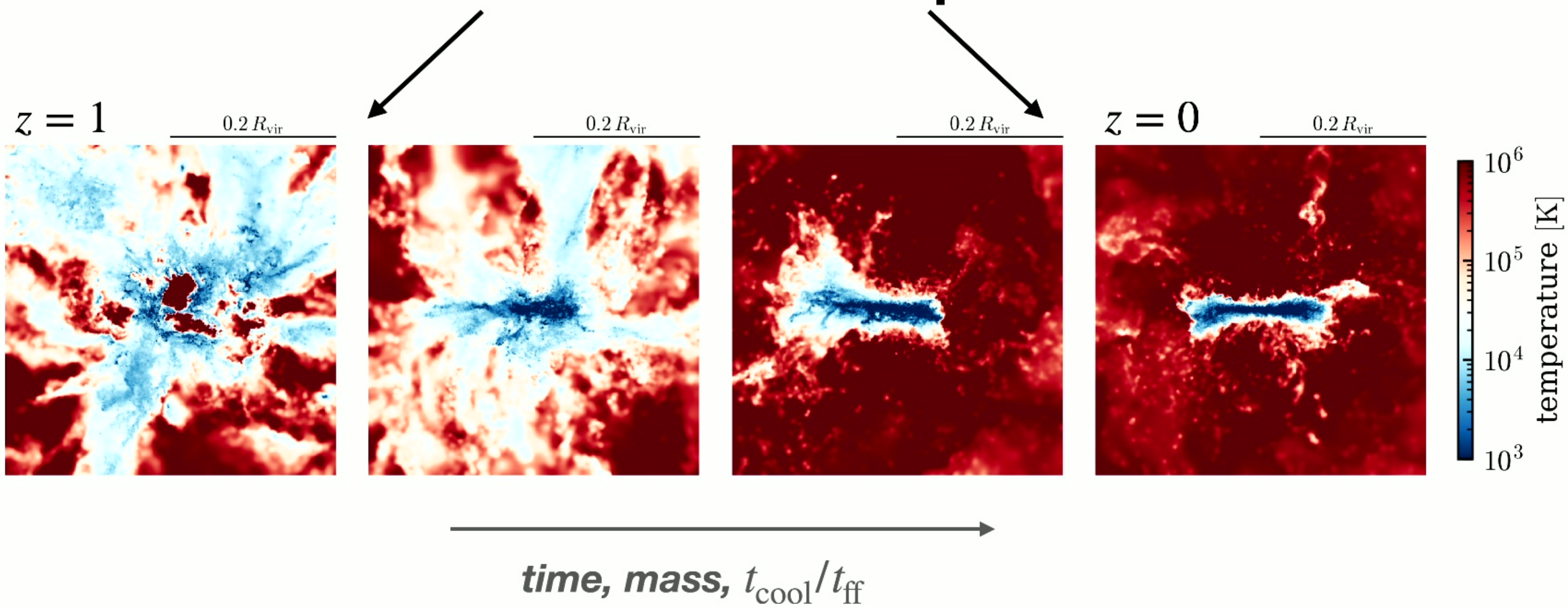
This talk: inner CGM in MW-mass halos versus time:

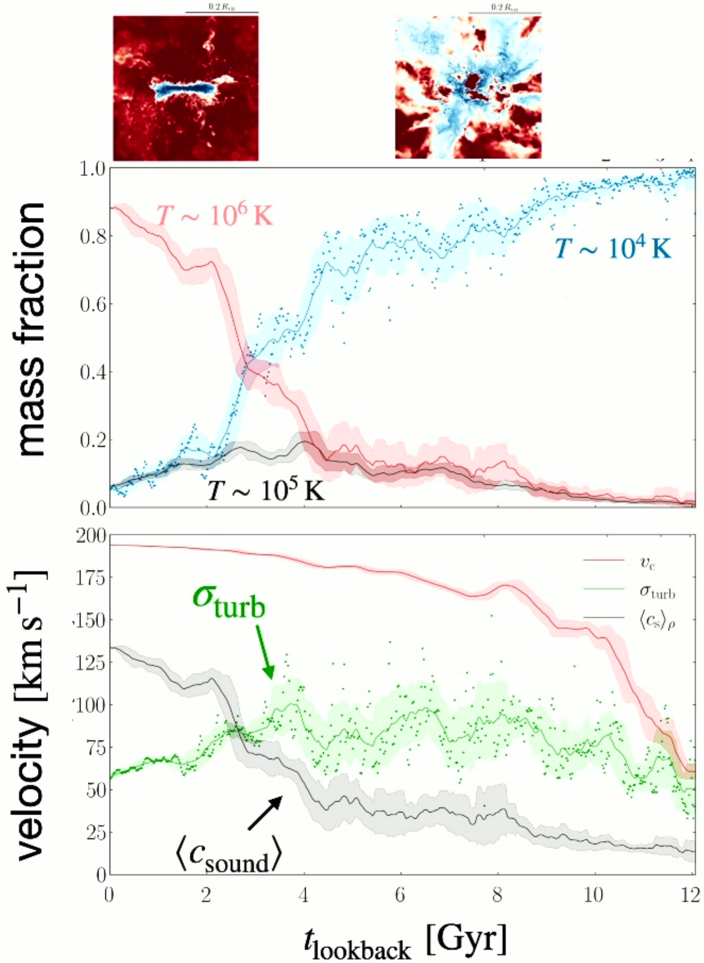
cool & turbulent → hot & quasi-static



FIRE zoom simulation, $M_{\rm halo}(z=0) = 10^{12}\,{\rm M}_{\odot}$

JS+(2021)

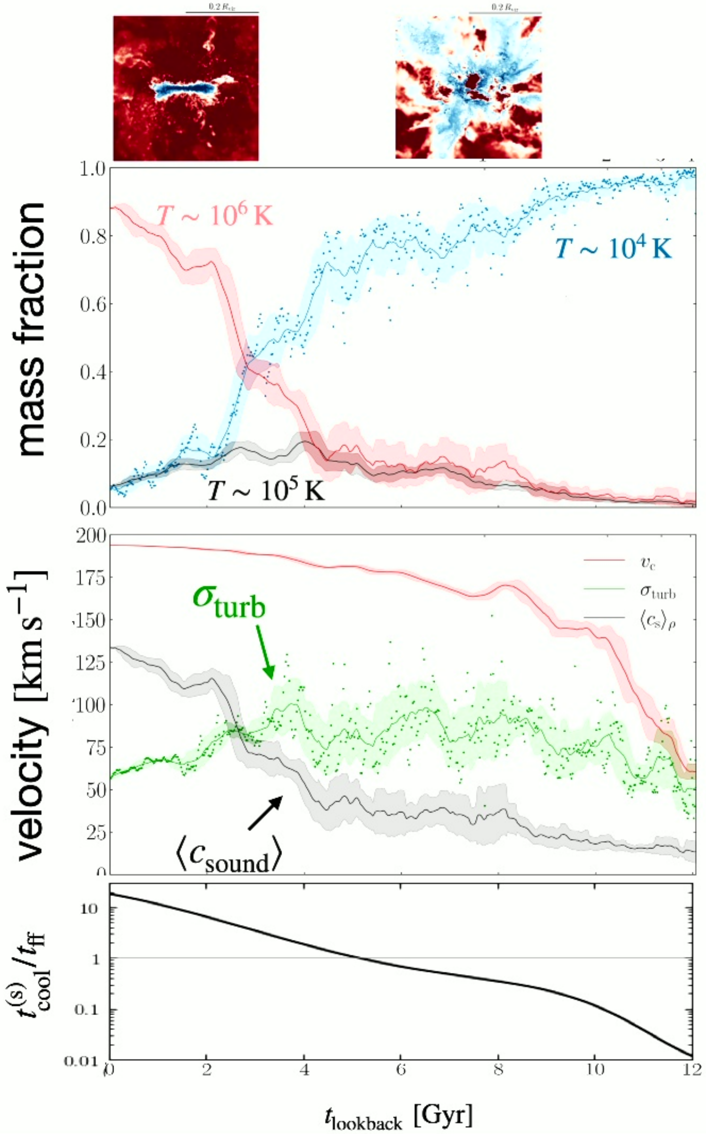
MW-mass, inner CGM, early times:



most of the gas is cool

turbulence velocity exceeds mean sound speed

Kakoly, **JS**+(2025)



MW-mass, inner CGM, early times:

most of the gas is cool

turbulence velocity exceeds mean sound speed

rapid cooling

Kakoly, **JS**+(2025)

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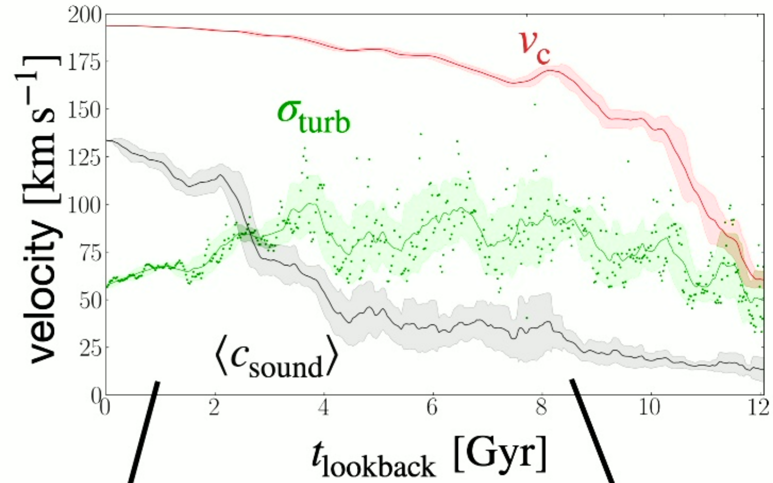
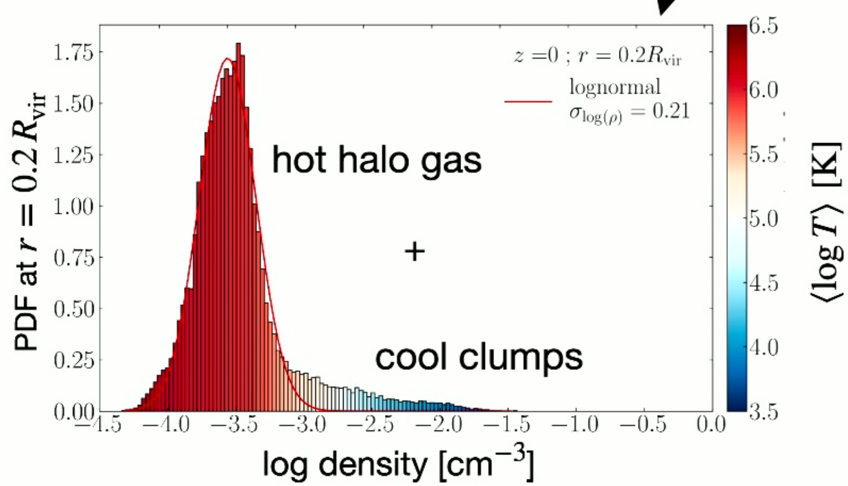
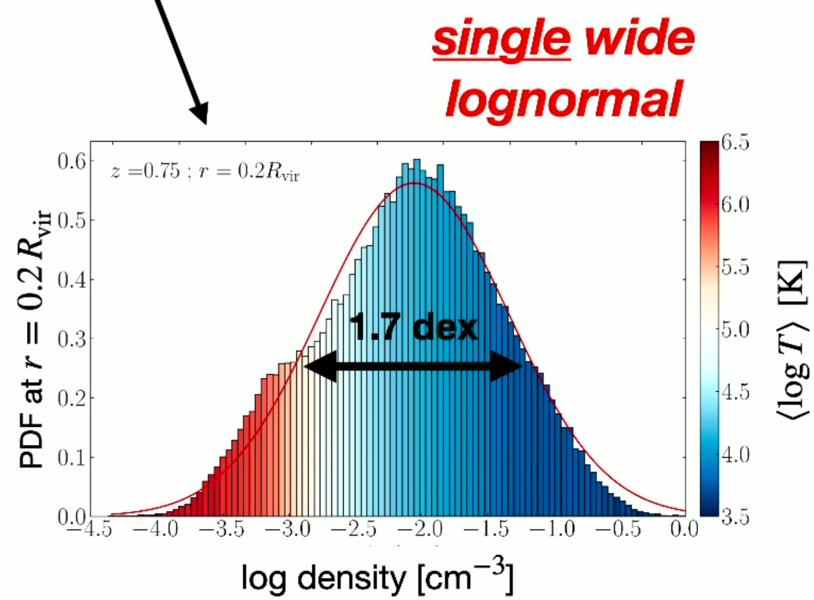
How does turbulence affect the CGM ***density distribution***?

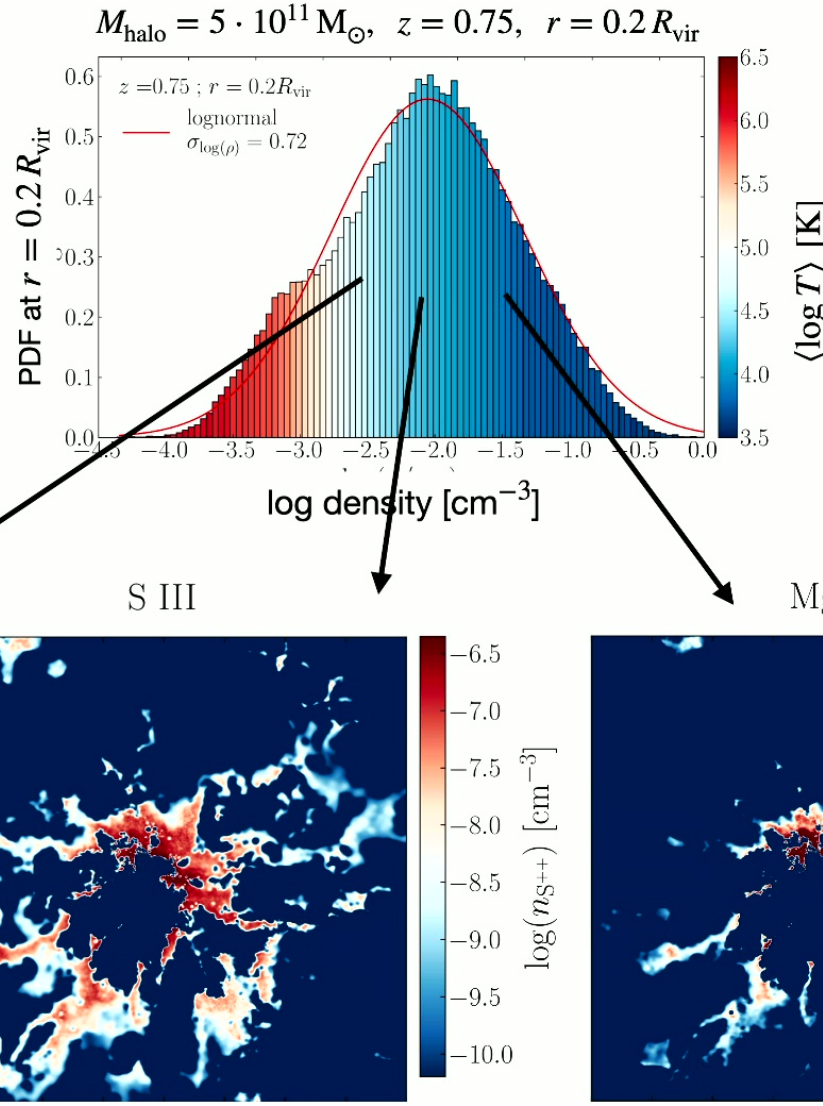






Kakoly, **JS**+(2025)

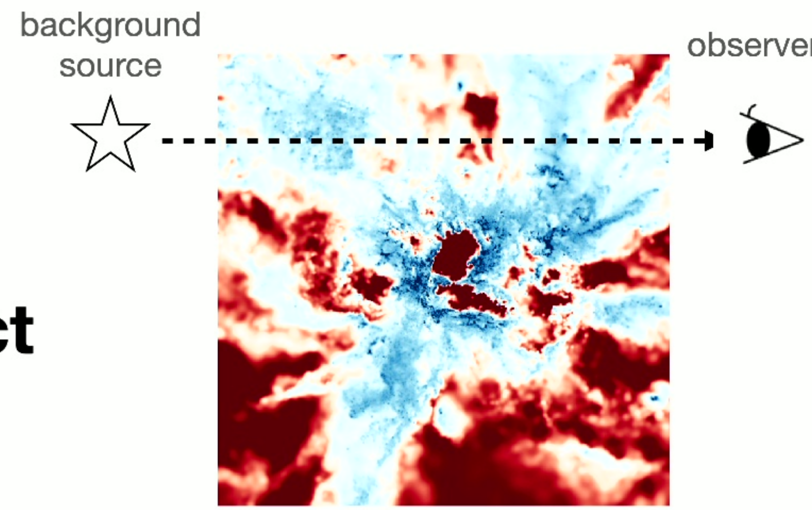
mid- and low-ions trace turbulent velocity field, not clouds+interfaces

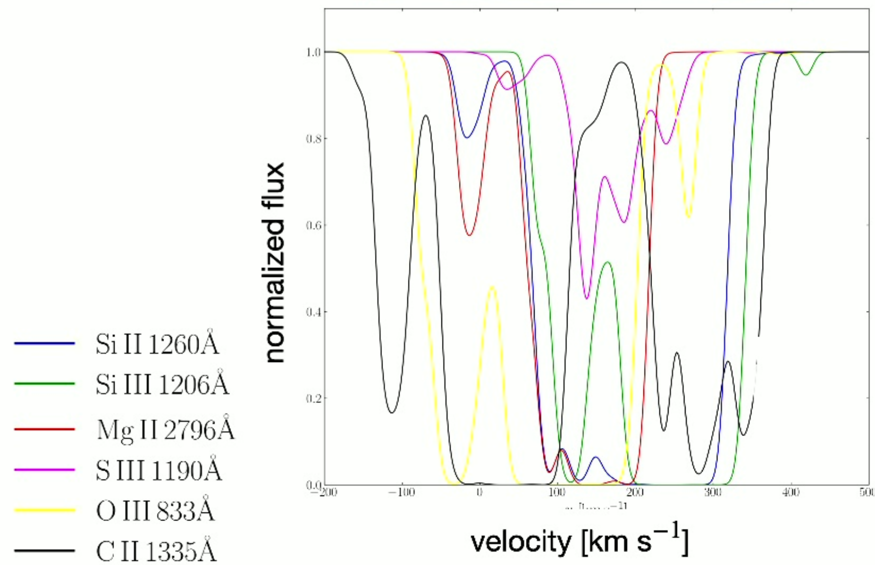


Cool & turbulent inner CGM predict

$$W_\lambda \sim \lambda \frac{v_{\rm c}}{c} \sim 1\text{Å}$$

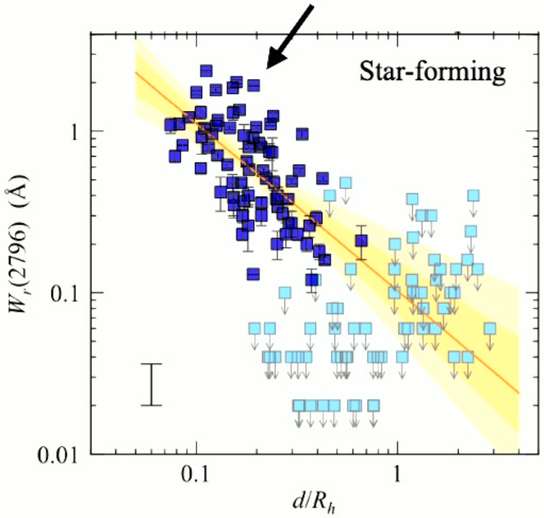
in strong UV transitions



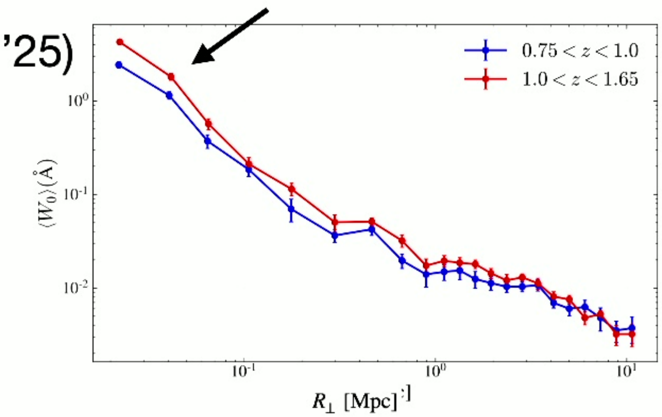


Kakoly, **JS**+(2025)

Huang+'21



DESI (Wu+'25)

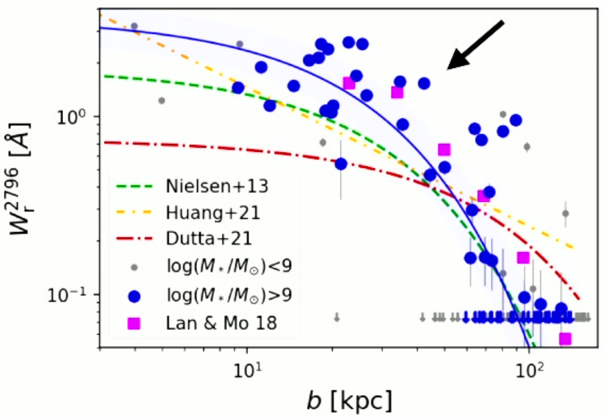


predicted $W_\lambda \sim 1\text{Å}$

repeatedly observed

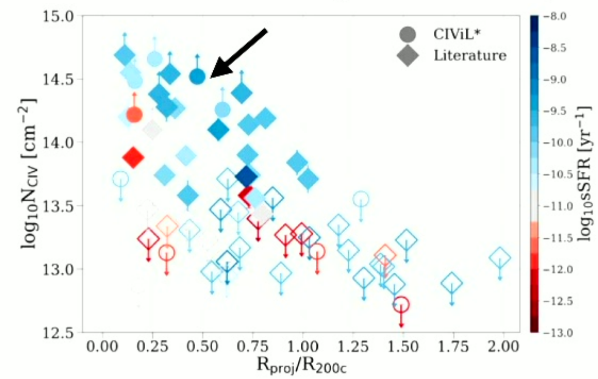
in inner CGM of SF

$\sim L^\star$ galaxies

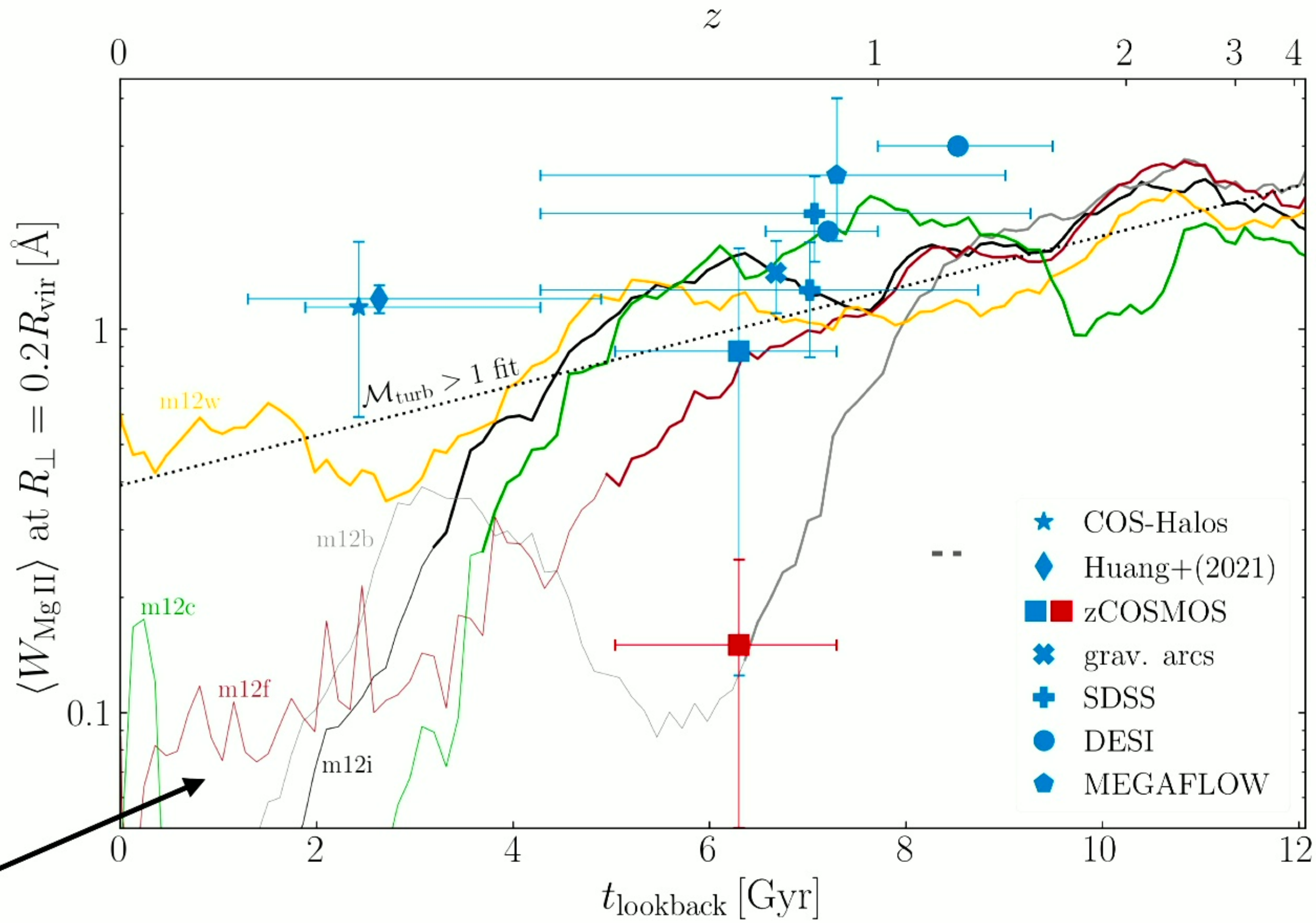


MEGAFLOW (Cherrey+'25)

COS-Halos (Garza+'25)



Inner CGM of blue $\sim L^\star$ galaxies is turbulence-dominated

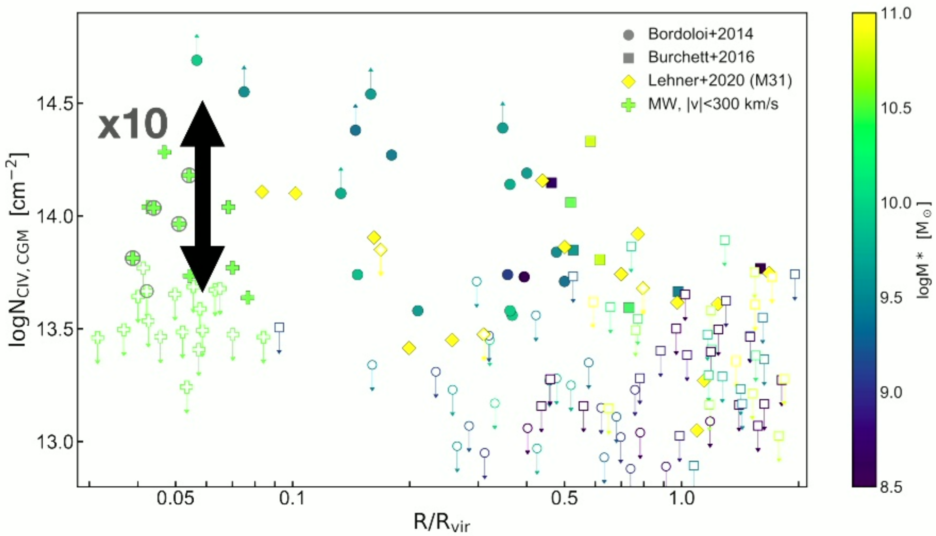


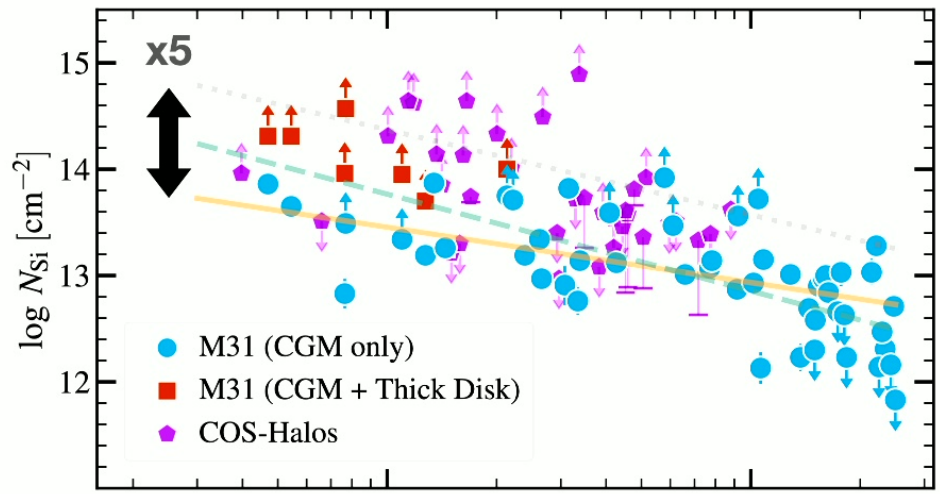
Where are the SF galaxies with a hot quasi-static CGM?

Kakoly, **JS**+(2025)

MW & M31: cool gas columns ≪ COS-Halos in inner CGM, ***consistent with volume-filling hot phase***

QuaStar (Bish+'21)





AMIGA Insider (Lehner+'25, see Nicholas' talk)

Conclusion:

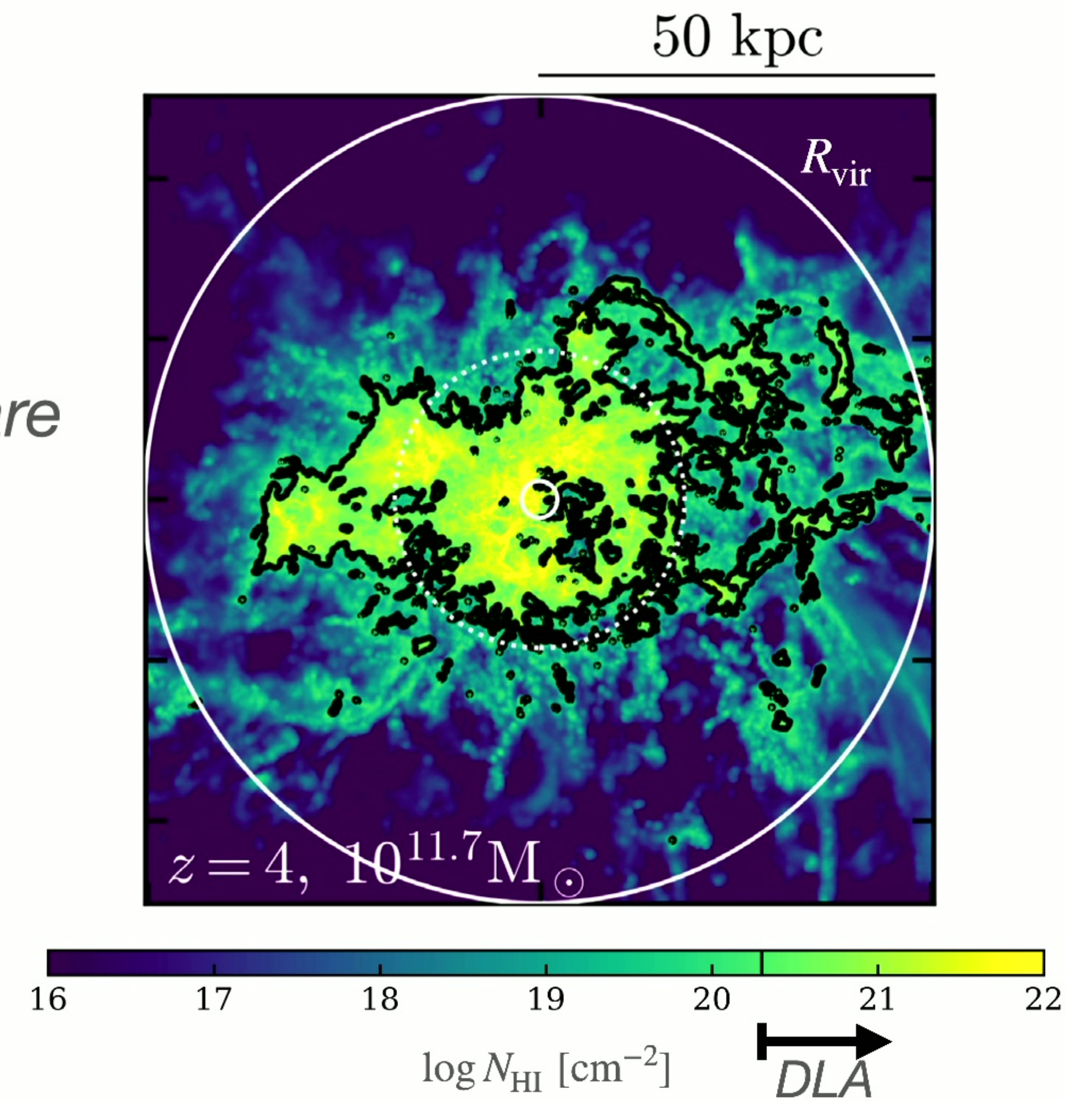
Inner CGM of blue $\lesssim L^\star$ galaxies is ***cool & turbulent***, ***qualitatively distinct*** from massive disks with hot & quasi-static inner CGM (e.g. MW, M31)

Next:

1. High-z observations
2. What drives the turbulence?
3. Implications for galaxy evolution

at high redshift ($z \gtrsim 2$) turbulence-dominated CGM are neutral, implying most

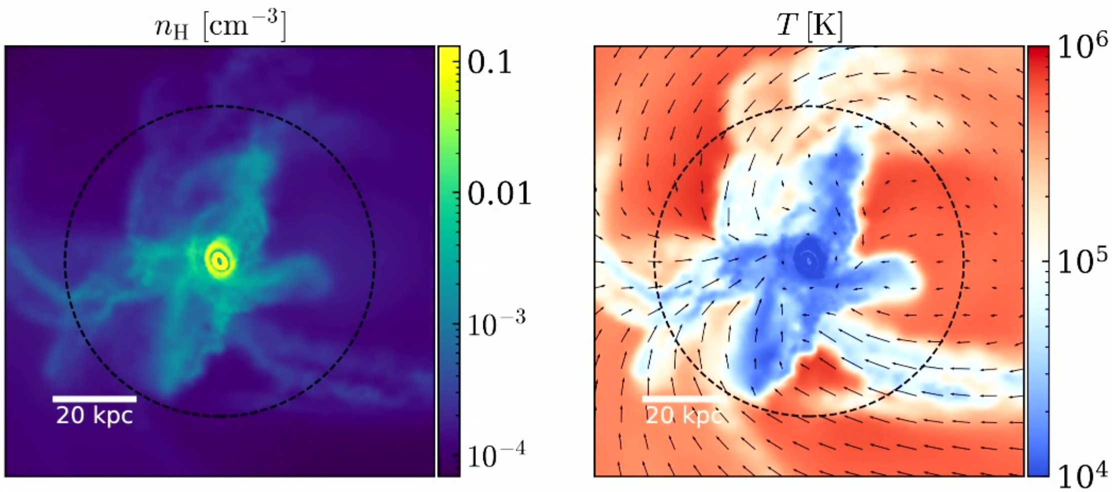
DLAs originate in CGM

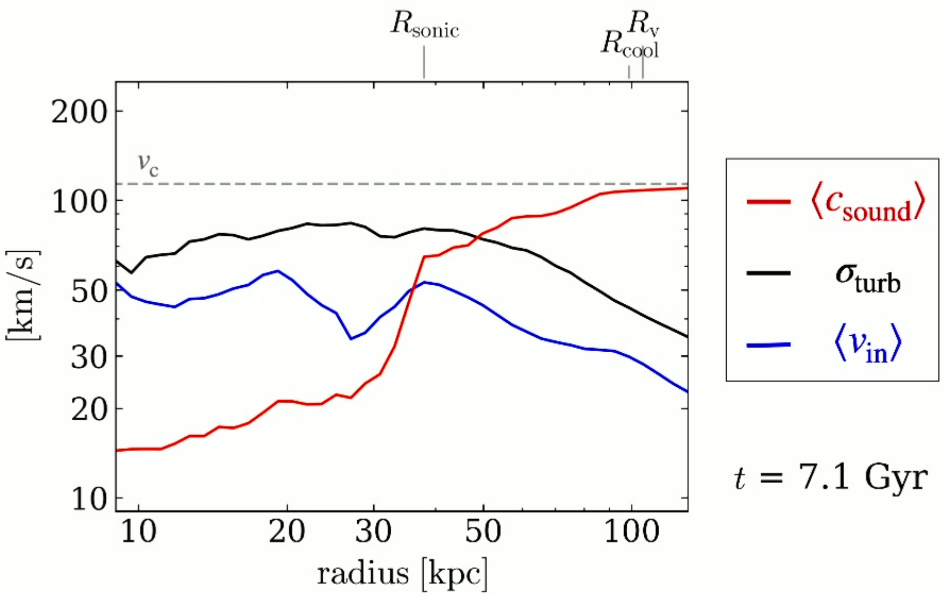


JS+(2021b)

What drives the turbulence?
(preliminary)

step #1: accretion-only





Goldner, **JS+**(in prep.)
Based on Robertson & Goldreich (2012) theory for SF clouds

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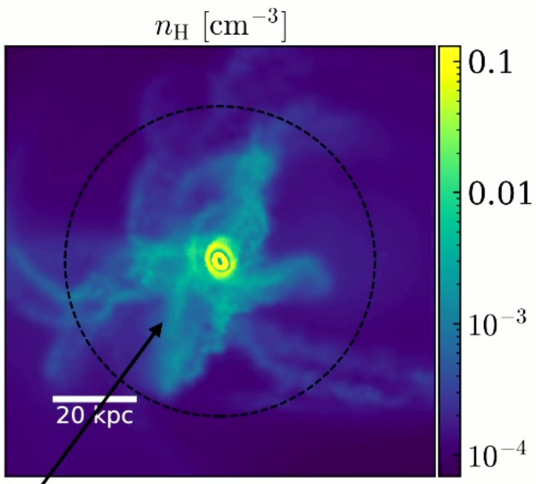
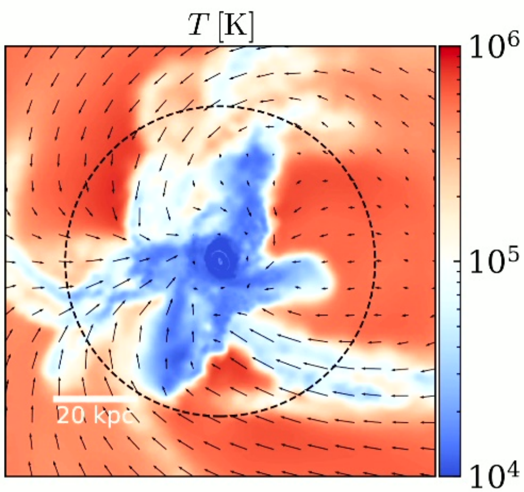
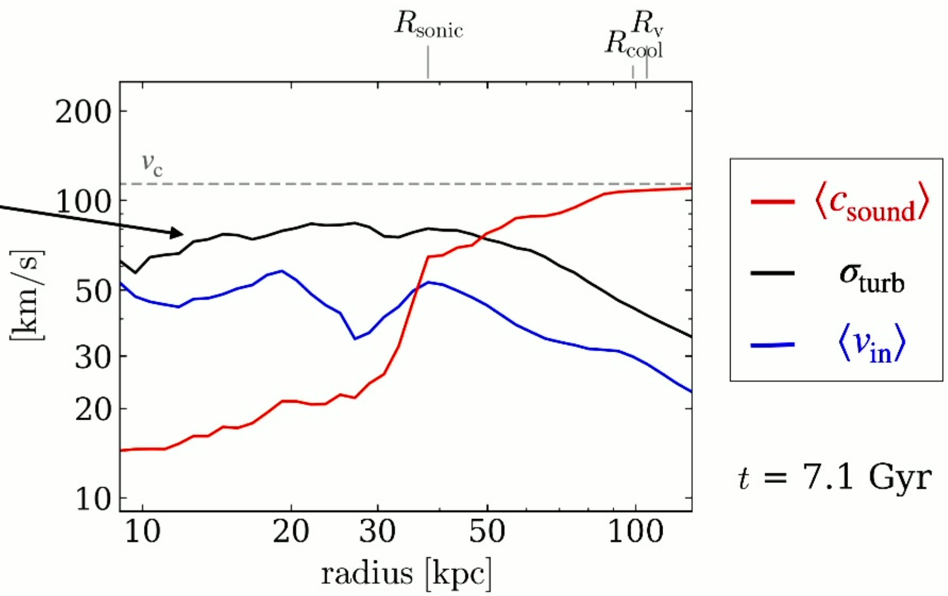




Turbulence dominates in inner CGM even without feedback



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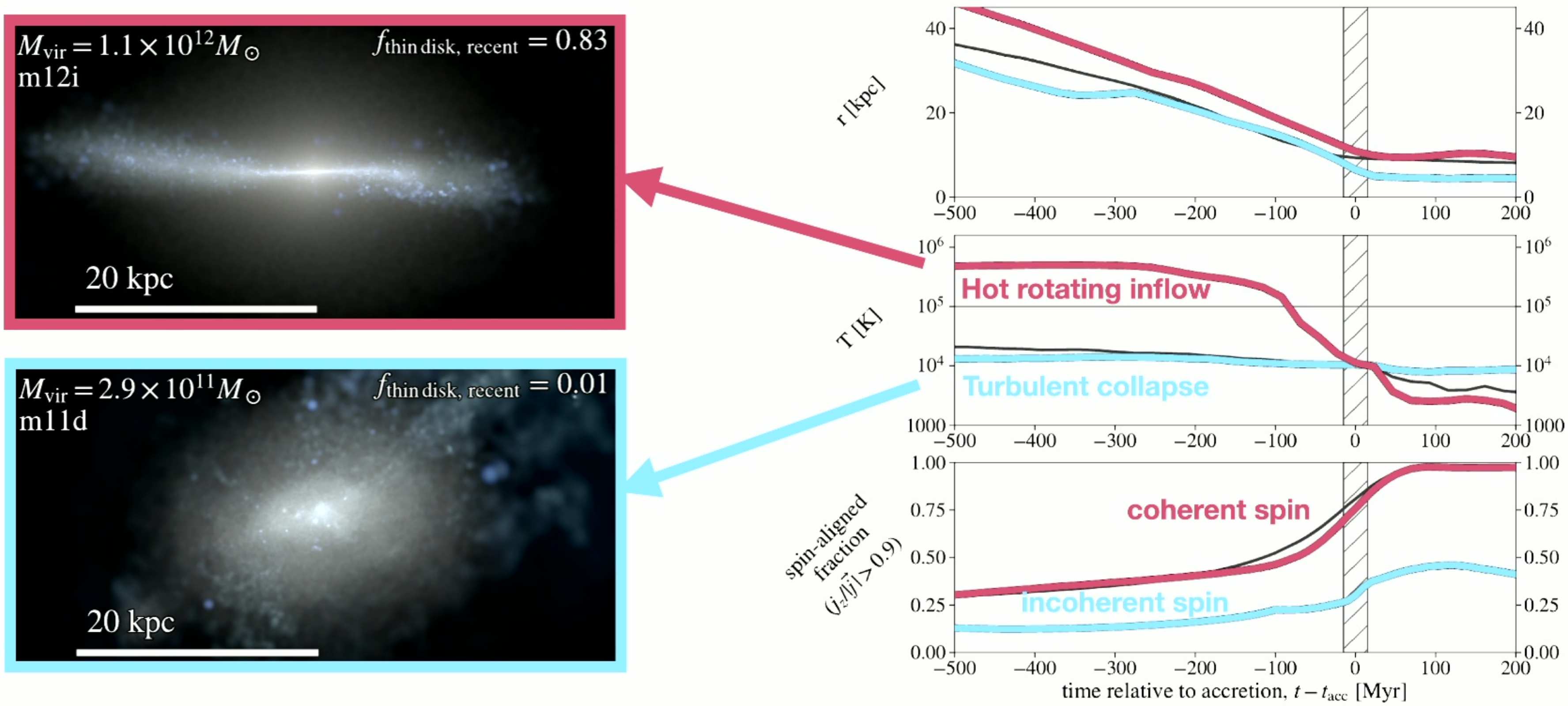
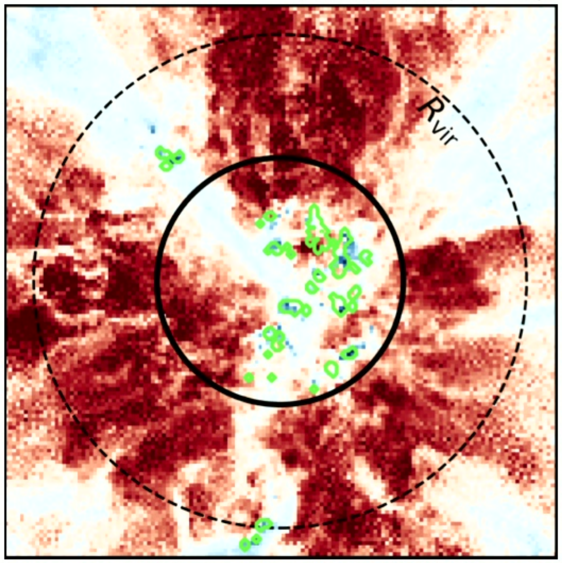


Averages of FIRE galaxies at z=0. Hafen, **Stern**, + (2022)

FIRE sims: thin disks fed by hot CGM (see Claude-Andre's talk)
thick disks/irregulars fed by turbulent collapse

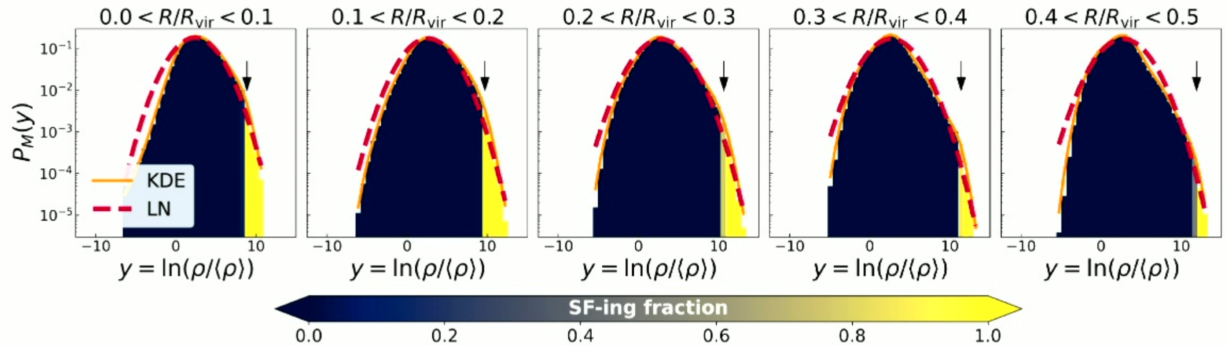
A turbulent framework for SF in high-z galaxies

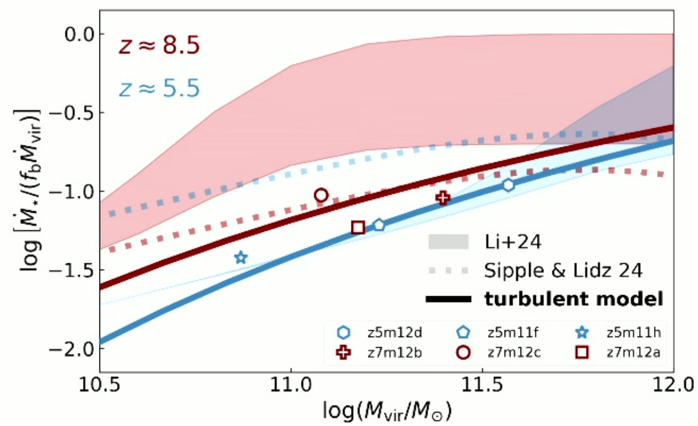
z5m11h (z = 6)



SF occurs in ***turbulence-dominated*** medium extending to halo scale

SF in high-density tail of a roughly ***lognormal*** gas density PDF





G. Sun, C.-A. Faucher-Giguère & **JS** (in prep.)

Summary

1. Simulations & UV observations:
   turbulence dominates the inner CGM of blue $\lesssim L^{\star}$ galaxies,
   qualitatively distinct from massive disks with hot, quasi-static inner CGM

2. High-z DLAs originate in the CGM

3. Accretion alone drives significant CGM turbulence

4. Turbulent CGM create thick disk/irregulars, and SF can extend into inner CGM