Kimm+(25, on arXiv)

Confronting Lyman alpha properties of galaxies with simulations with strong stellar feedback

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in collaboration with

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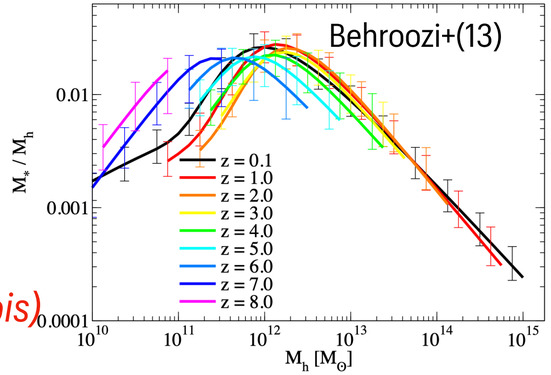
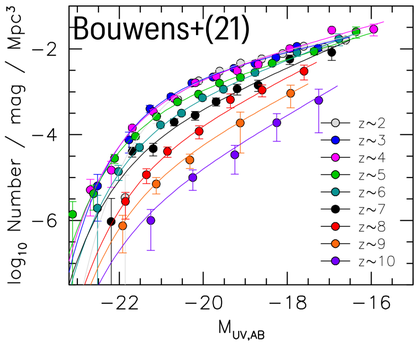
18/Jul/25

Investigating baryonic cycle through various "observables"

Stellar-to-halo mass



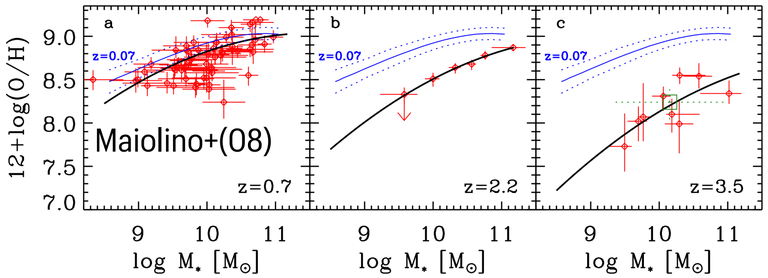
(talks by A. Pillepich, Y. Dubois)



Luminosity Functions

(talk by S. Tacchella)

Mass-**Metallicity** relations

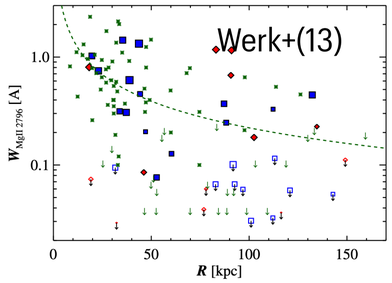


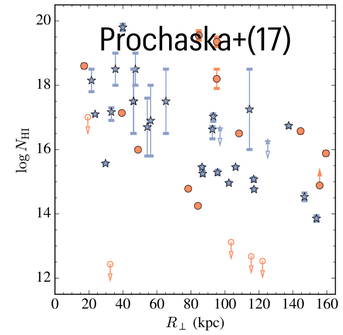
(talk by N. Choustikov..)

Galactic outflows (**CGM**)

- metal absorption/emission
- hydrogen

(talks by H.-W. Chen, C. Peroux, N. Bouche posters: M. Rey, D. DeFellippis...)

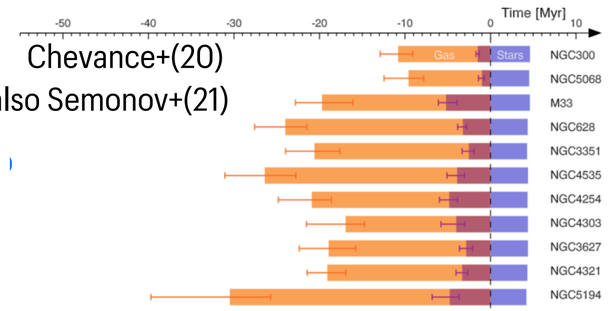




GMC **disruption timescale**

(discussion by A. Kravtsov)

Chevance+(20)
see also Semonov+(21)

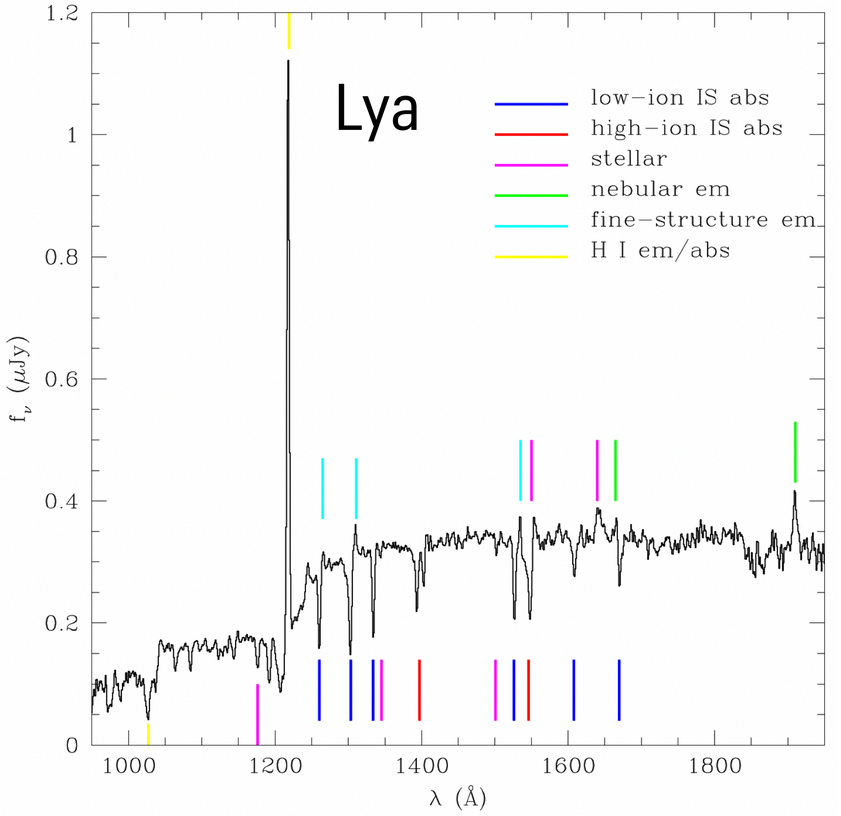


+Rotation curves, galaxy sizes, etc

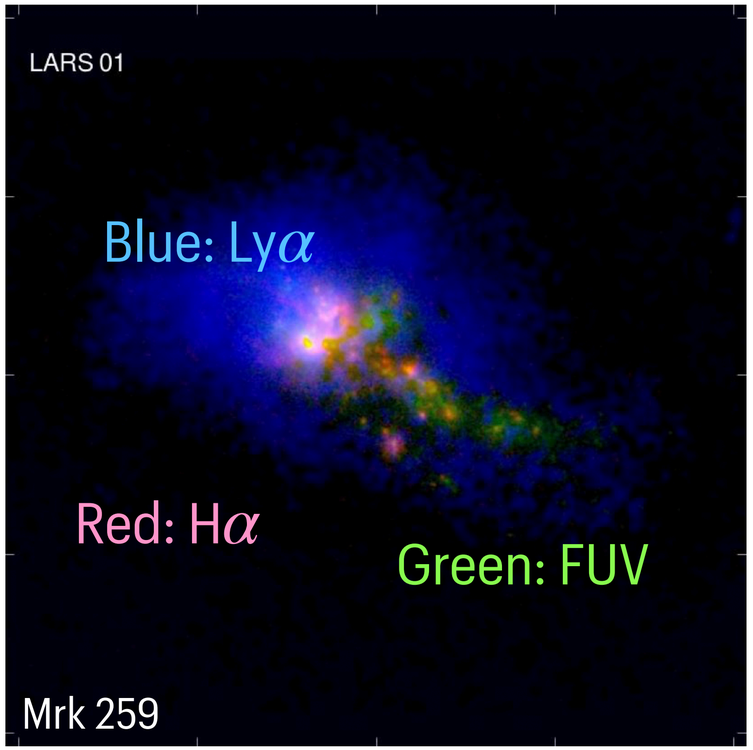
(challenging but) interesting avenue:

Lyman alpha (+ LyC)

Lyman-α in and around star-forming galaxies

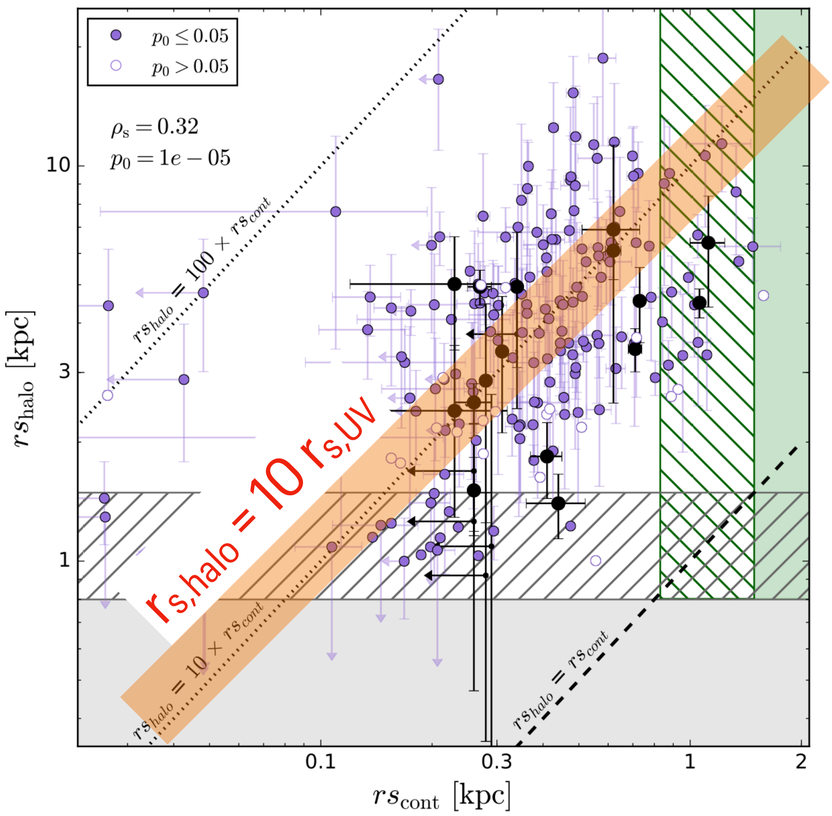


Shapley et al. (03)



Hayes et al. (13)

(GALEX+HST, 0.03<z<0.18, -22 < M_{UV}<-15)



Leclercq et al. (17) (**MUSE**, 3<z<6, -22 < M_{UV}<-15)

(see also Rauch+08; Steidel+11, Wisotzki+18)

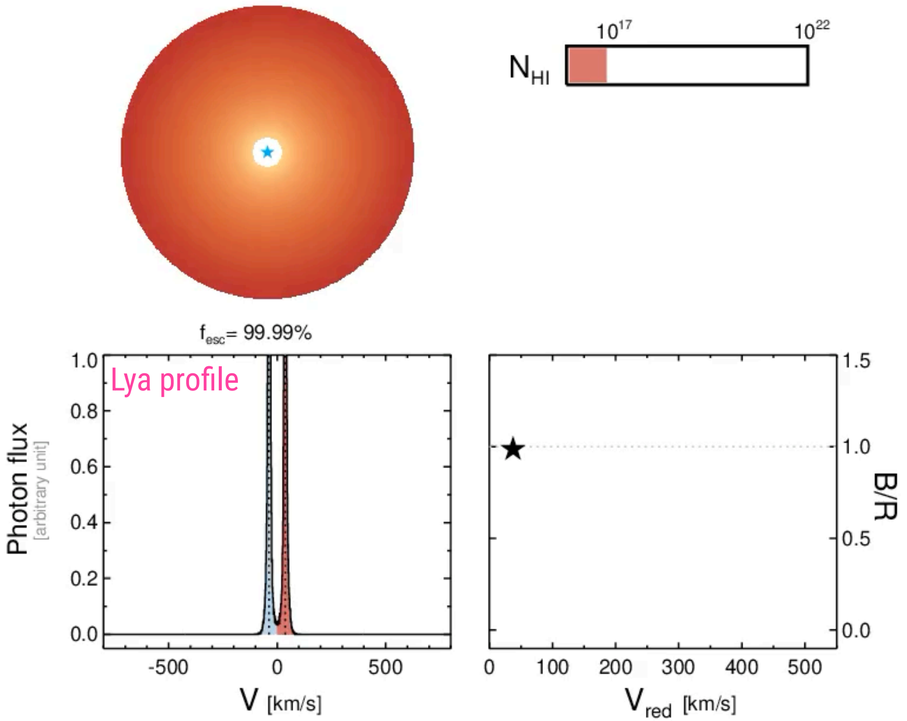
Lyman-α is **bright**

(e.g., Ouchi+2020, ARAA)

Extended warm/neutral hydrogen produced/influenced Lyman-α

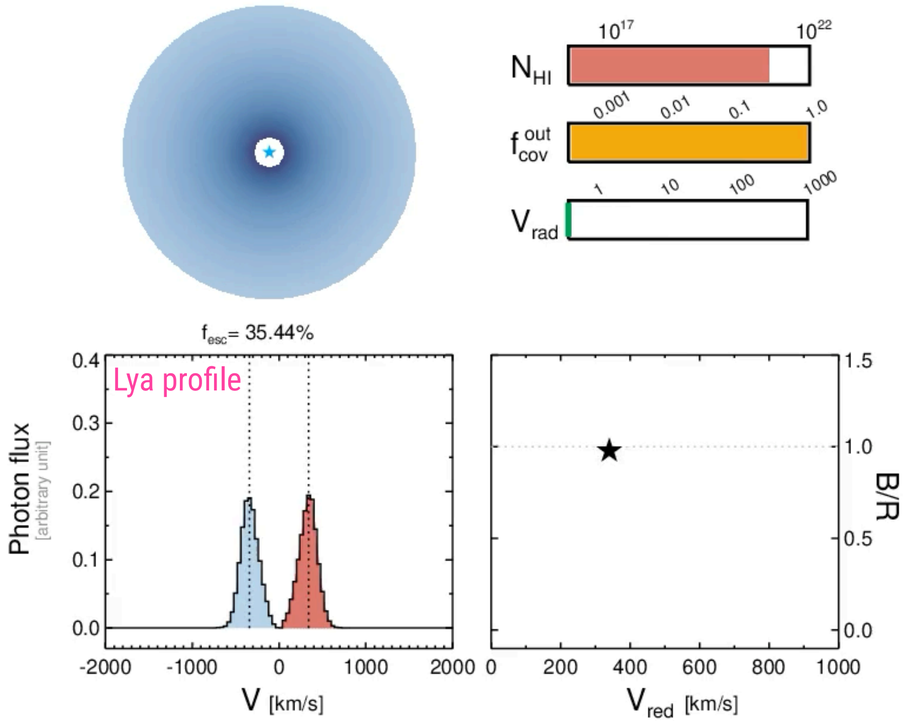
Resonant nature: Ly-α profiles are sensitive to N_{HI} and velocity

Dependence on HI optical depth



Separation of the double Ly-α peaks is sensitive to **optical depth**

Dependence on outflow velocity

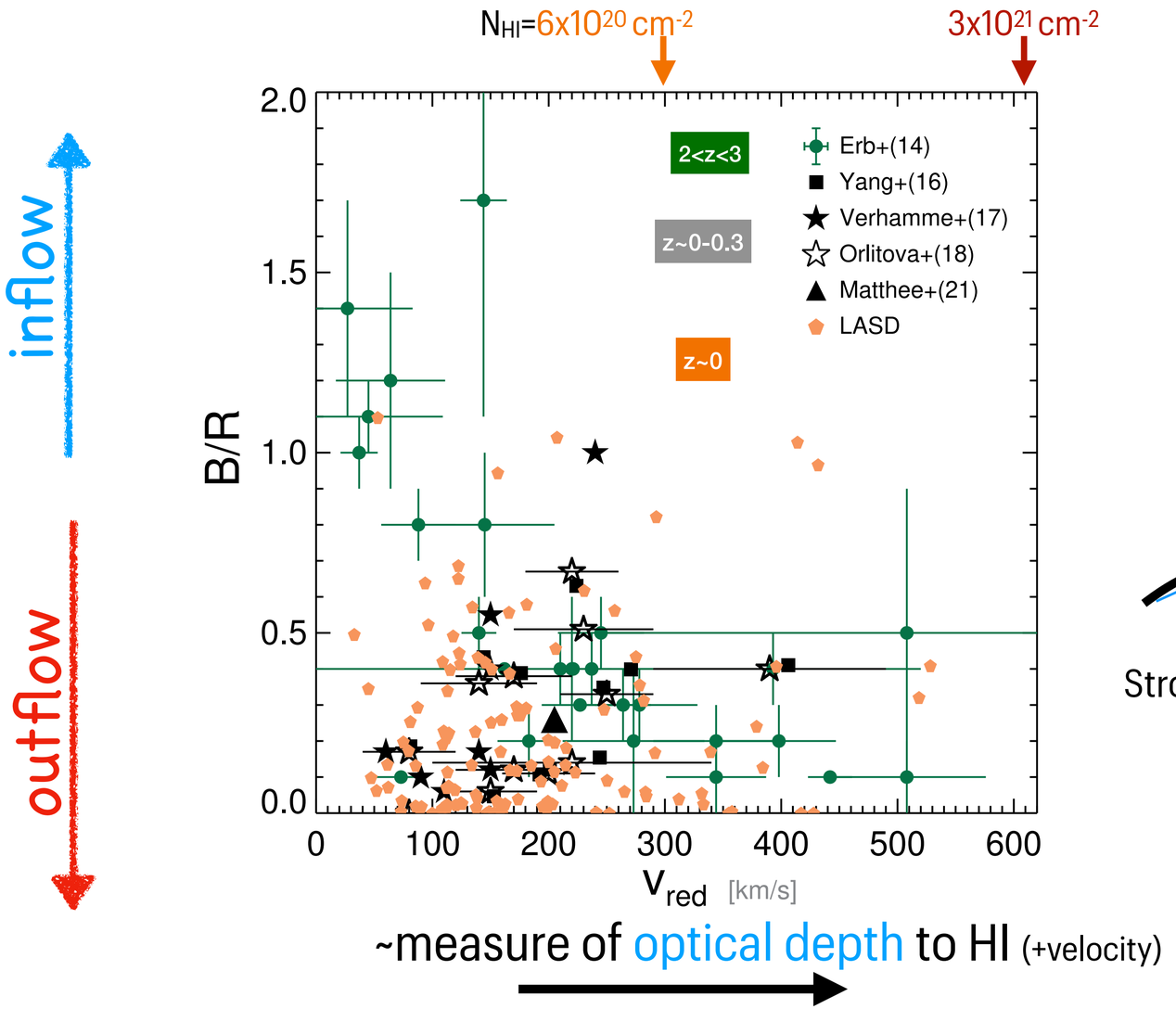


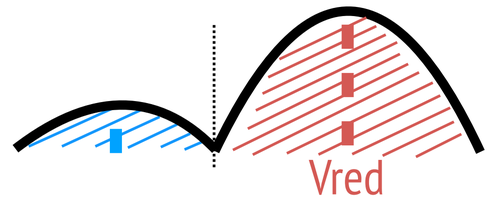
Blue/Red flux ratio (**B/R**) is sensitive to **gas kinematics**

n.b. very idealized

see also Ahn+(03), Dijkstra+(06), Verhamme+(06), Gronke+(15, 17), Michel-Dansac+(20), Seon+(20), Chang+(23)

Actively SF galaxies show outflowing features





Strong outflows in actively SFGs

Simple expectations for galaxies with weak or strong feedback

inflow

outflow

Without dust

B/R

1

Over-cooled galaxies

galaxies with strong outflows

if optically thick (HI)

Vred

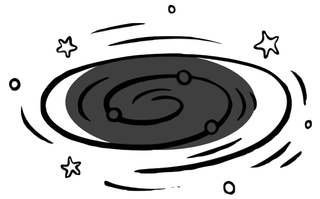
With destruction by dust

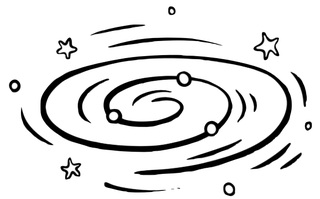
B/R

1

Over-cooled galaxies

galaxies with strong outflows





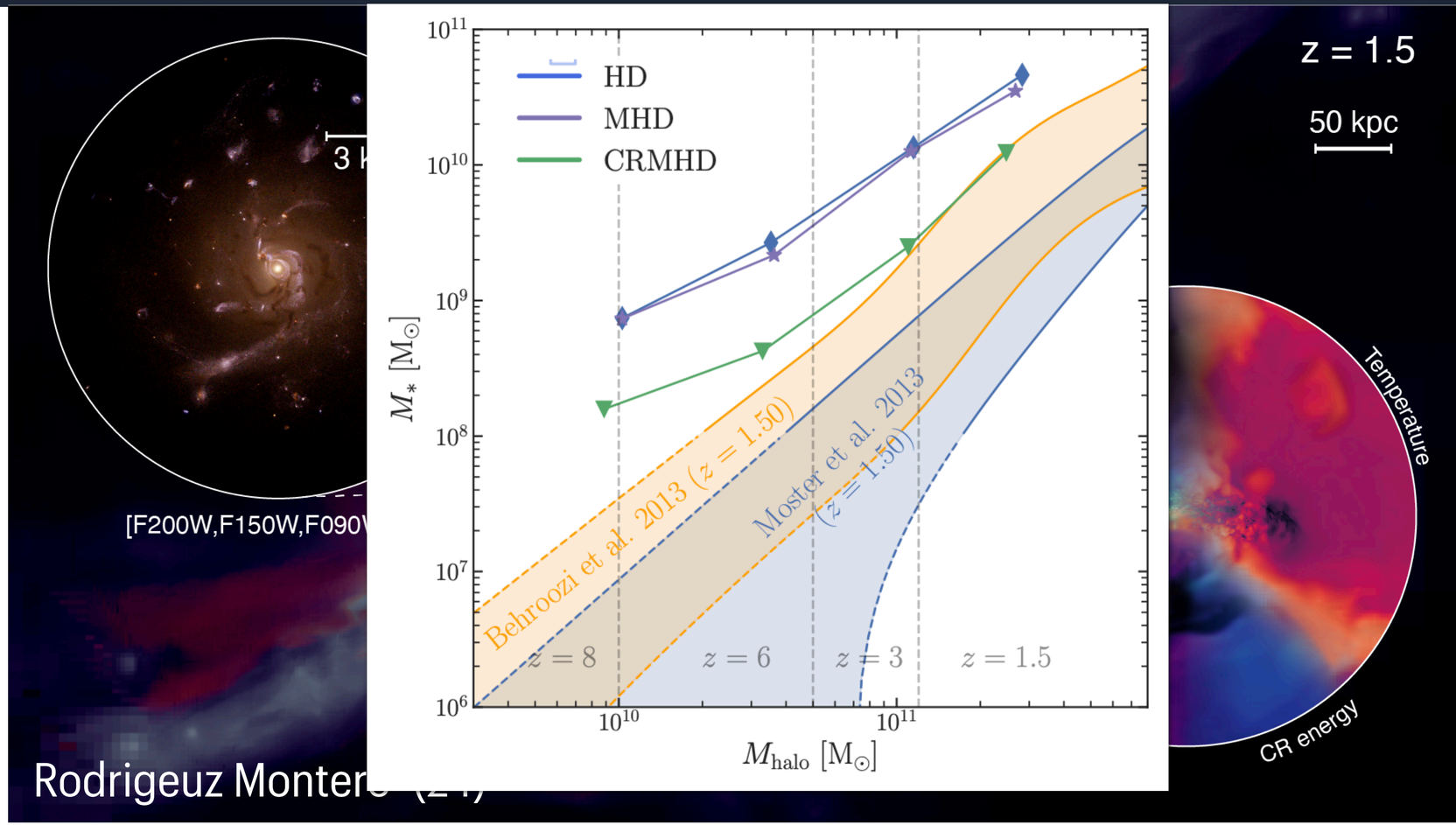
Vred

if dusty & optically thick

Simulation with CR feedback

Cosmological MHD simulation of a MW-sized halo (Rodriguez Montero+24)

- RAMSES (Teyssier 02)
- Mechanical Type II Supernova
- Multi-freefall based SF
- Magnetic fields
- w/ or w/o Cosmic rays (CRs)
- CR anisotropic diffusion + streaming
- $\kappa = 3 \times 10^{28}\,\mathrm{cm^2\,s^{-1}}$



Simulation	Solver	CR physics
HD	Hydro	✗
MHD	MHD	✗
CRMHD	CRMHD	Streaming and $\kappa = 3 \times 10^{28}$ cm^2 s^{-1}

see also Salem & Bryan (14), Girichidis+(17, 20, 21), Ruszkowski+(17), Chan+(19), Dashyan & Dubois (20), Ruszkowski & Pfrommer (23), Armillotta+(22,24), Thomas+(24), Weber+(25)

At $2 \lesssim z \lesssim 4$

$10.8 \lesssim \log M_{\rm vir} \lesssim 11.5 \quad 9.2 \lesssim \log M_{\rm star} \lesssim 10$

$-20 \lesssim M_{UV} \lesssim -17$ (for CRMHD)

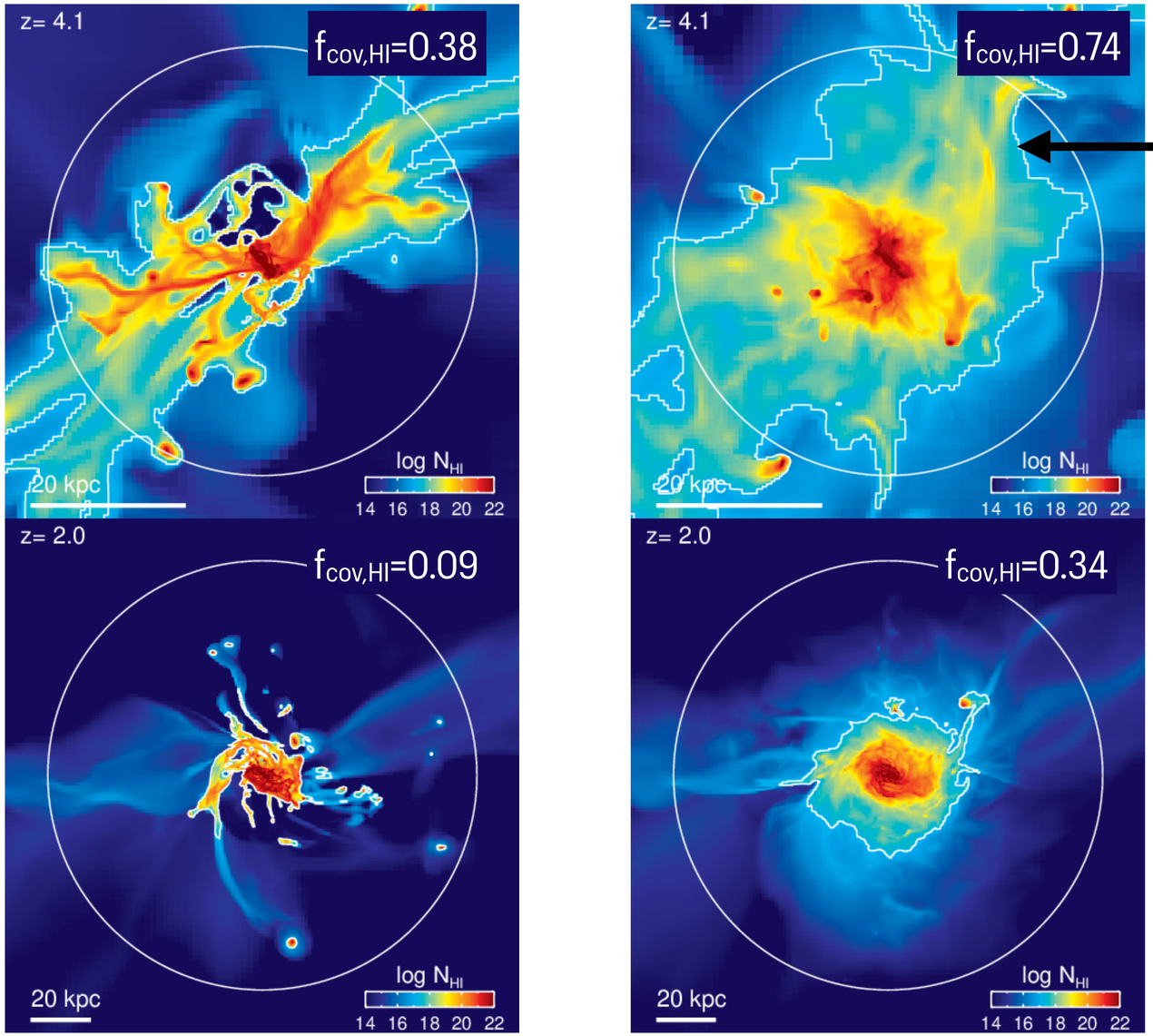
HI Covering fraction is increased with CR feedback

MHD

MHD+CR feedback

z=4

z=2



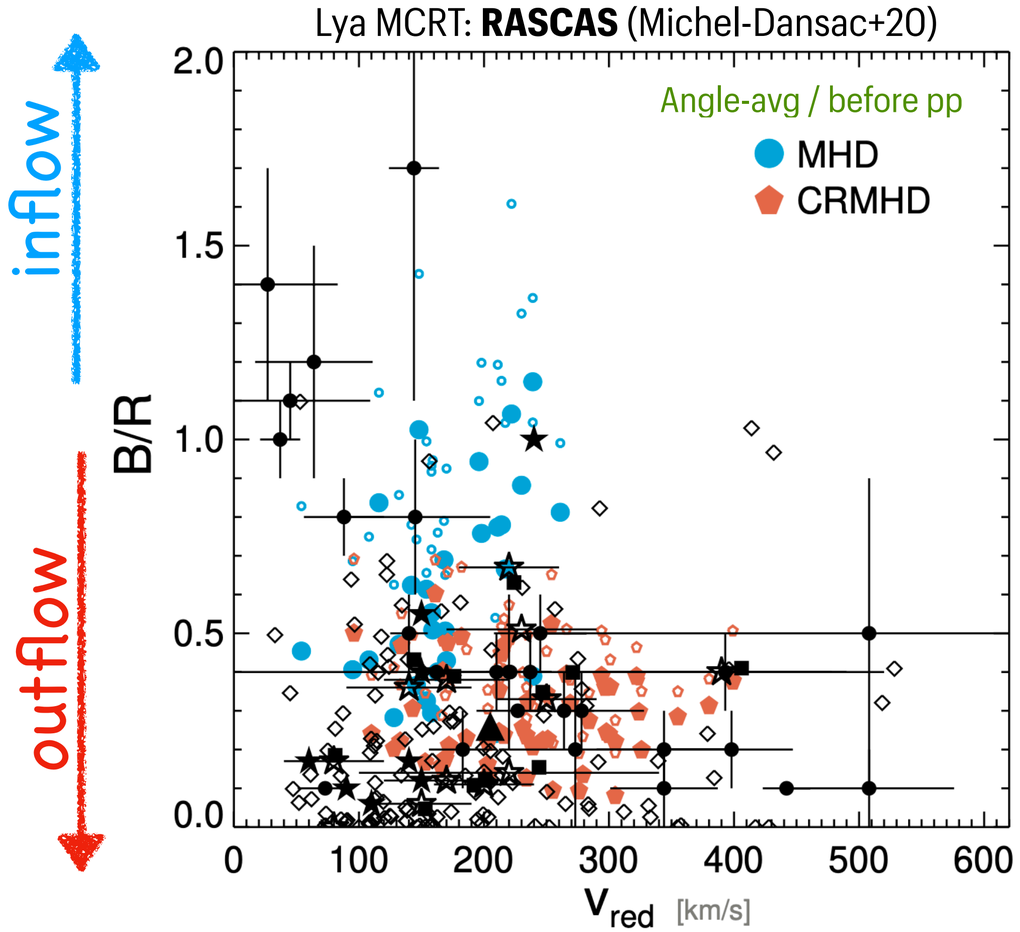
Covering fraction of $N_{HI}>10^{17.2}$ cm^{-2}

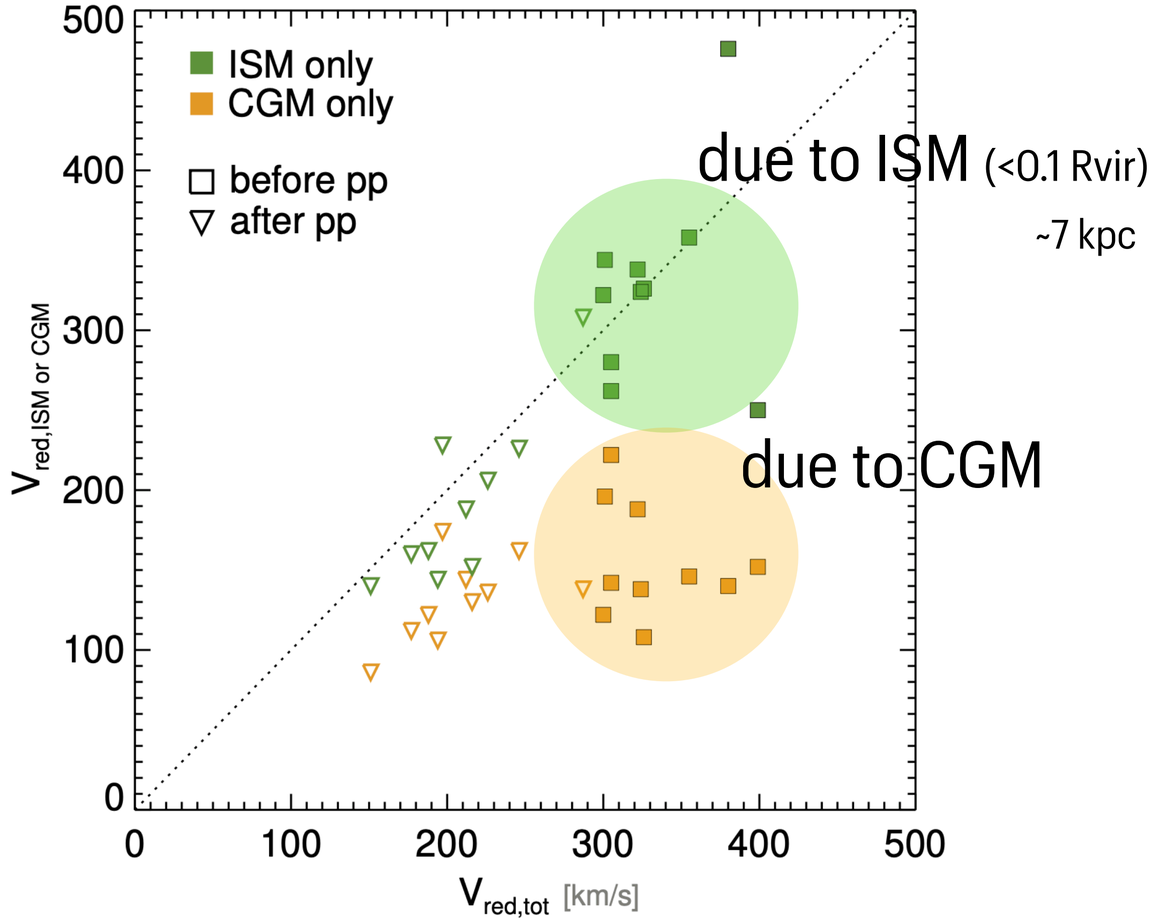
With CR feedback

- Simulated galaxy is less compact
- More HI is in the CGM
- Velocities of the neutral gas are ~100 km/s (c.f. ~< 50 km/s w/o CR)

(n.b. before RT post-processing)

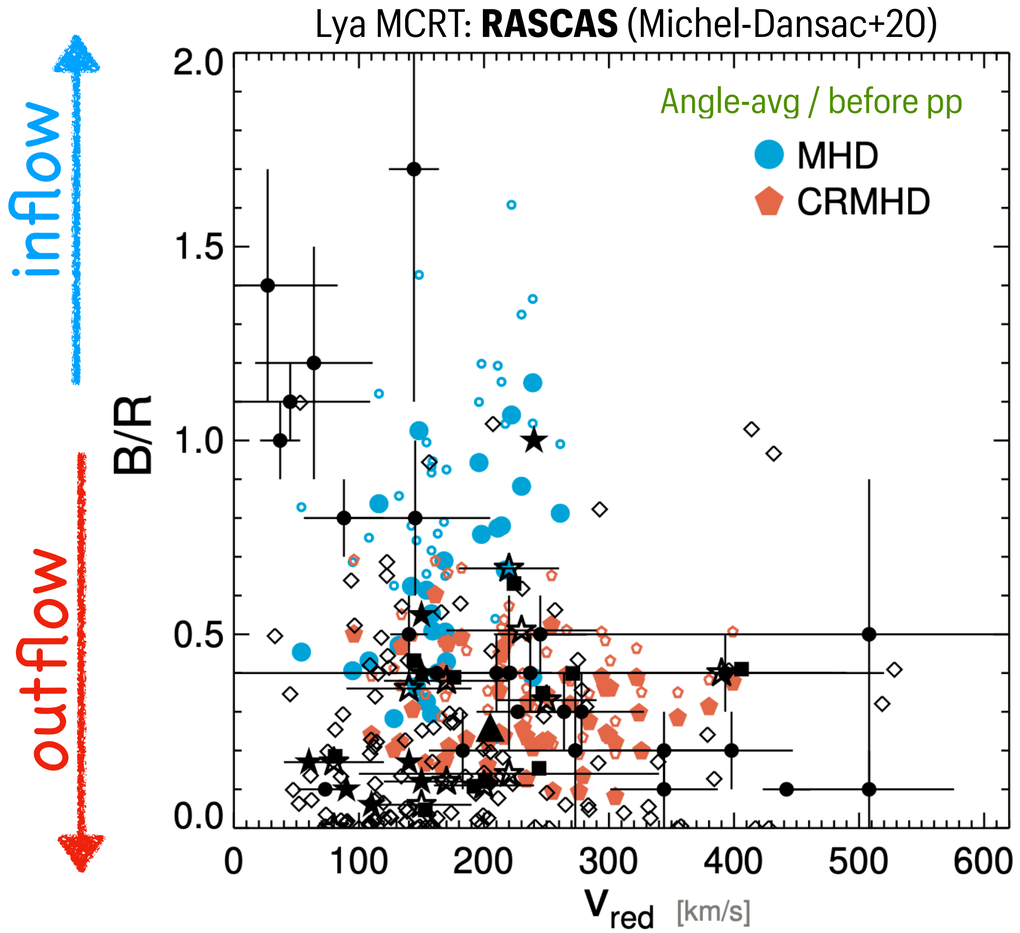
Impact of CR feedback - lower B/R & larger v_{red}



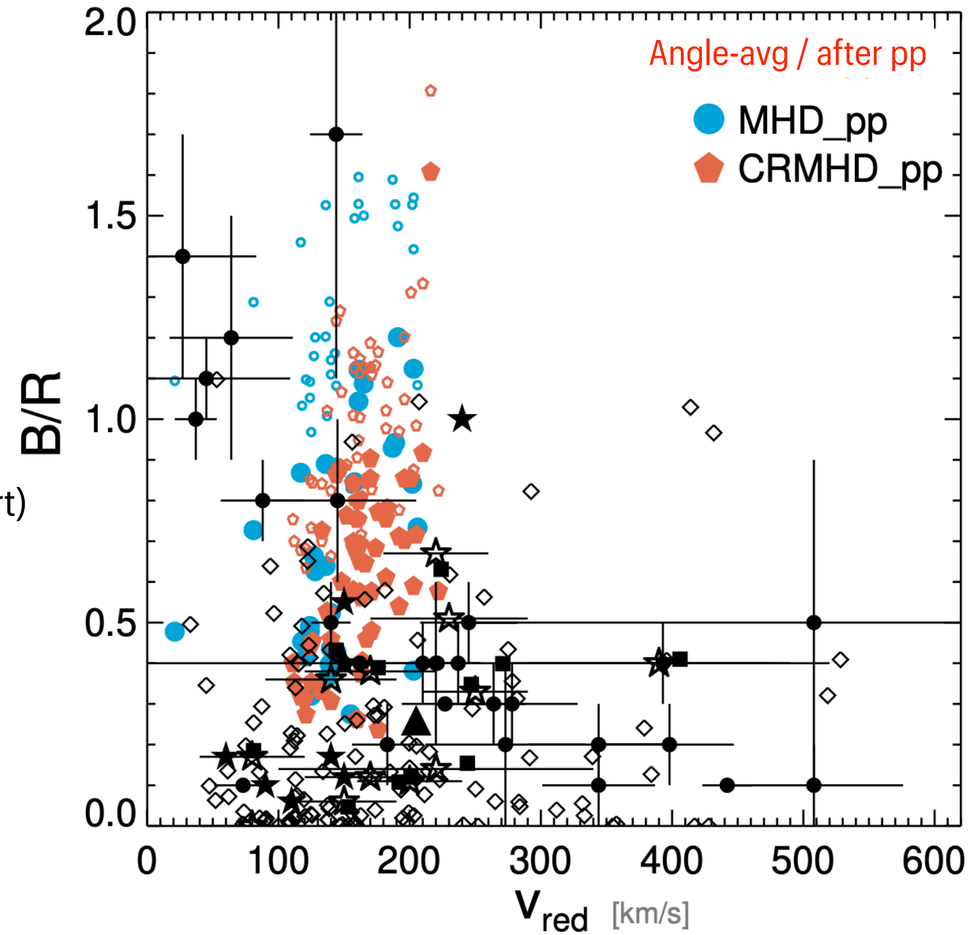


A large v_{red} is mostly due to the scattering with the gas in the inner region (<0.1 Rvir), while the (outflowing) CGM helps reduce B/R

Low-density channels created by ionizing photon reduce LyA scattering



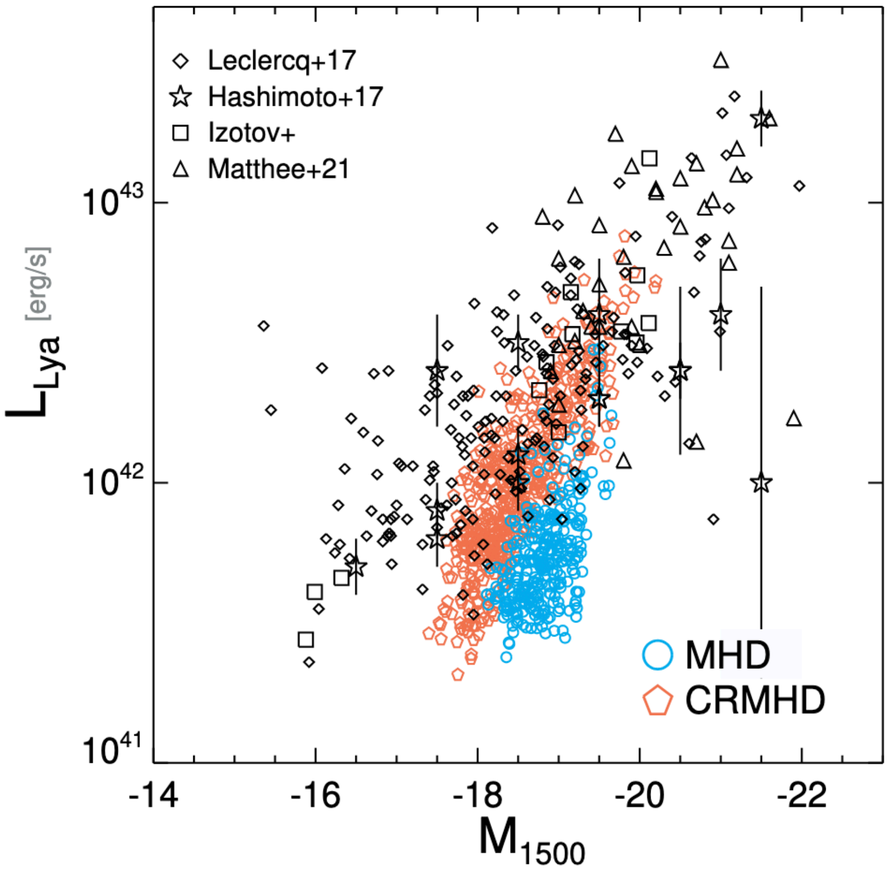
LyC RT
post-processing; ramses-rt)

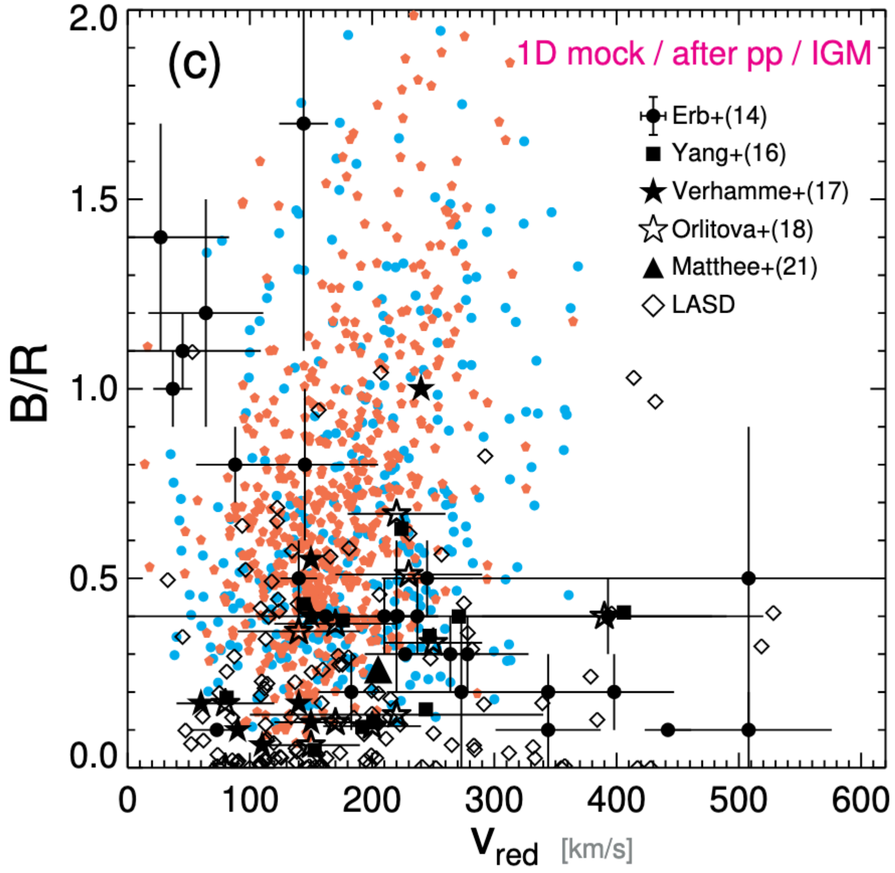


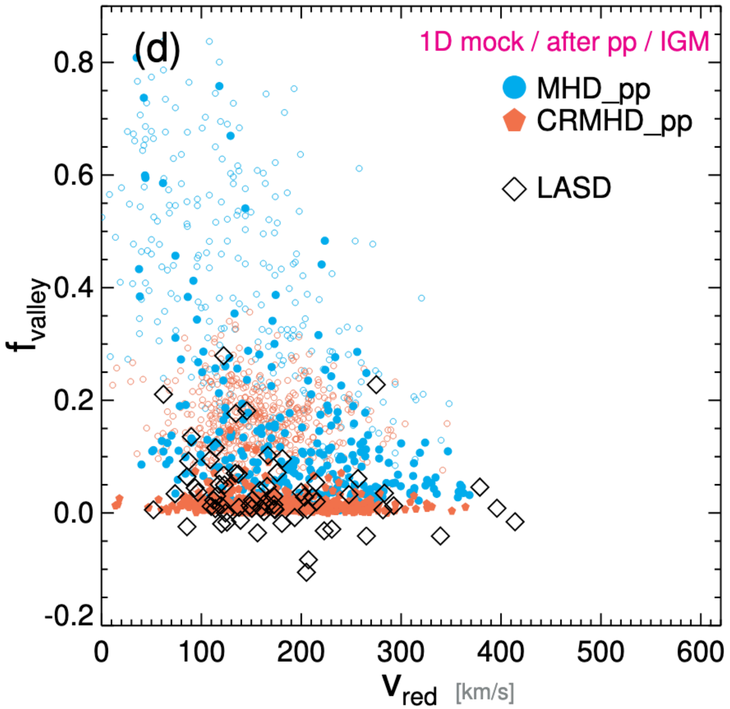
(what would happen if ISM/CGM becomes even more clumpy?)

Orientation effect complicates the interpretation

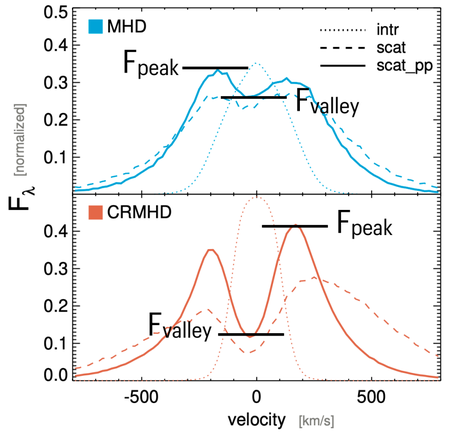
(see also Blaizot, TK+23)





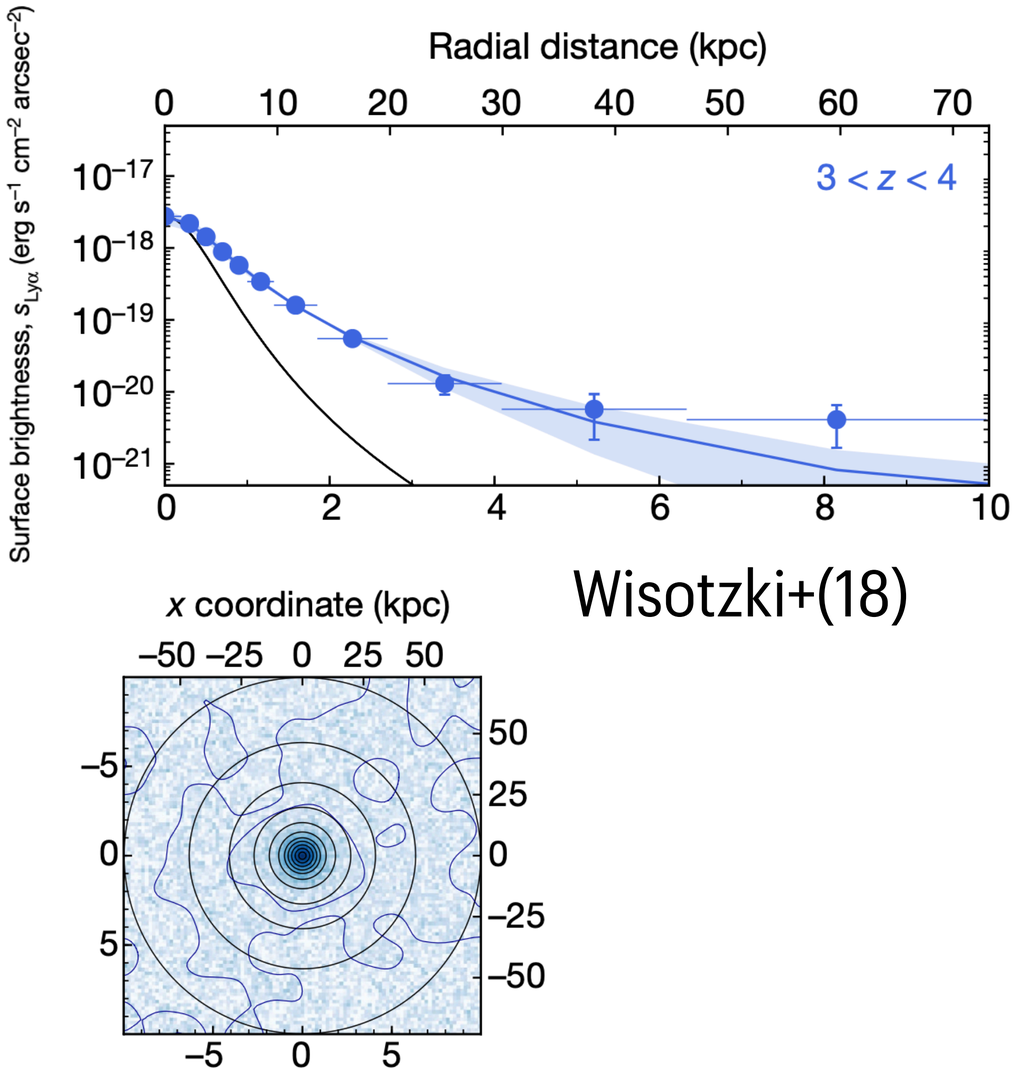


$$f_{\rm valley} = \frac{F_{\rm peak}}{F_{\rm valley}}$$

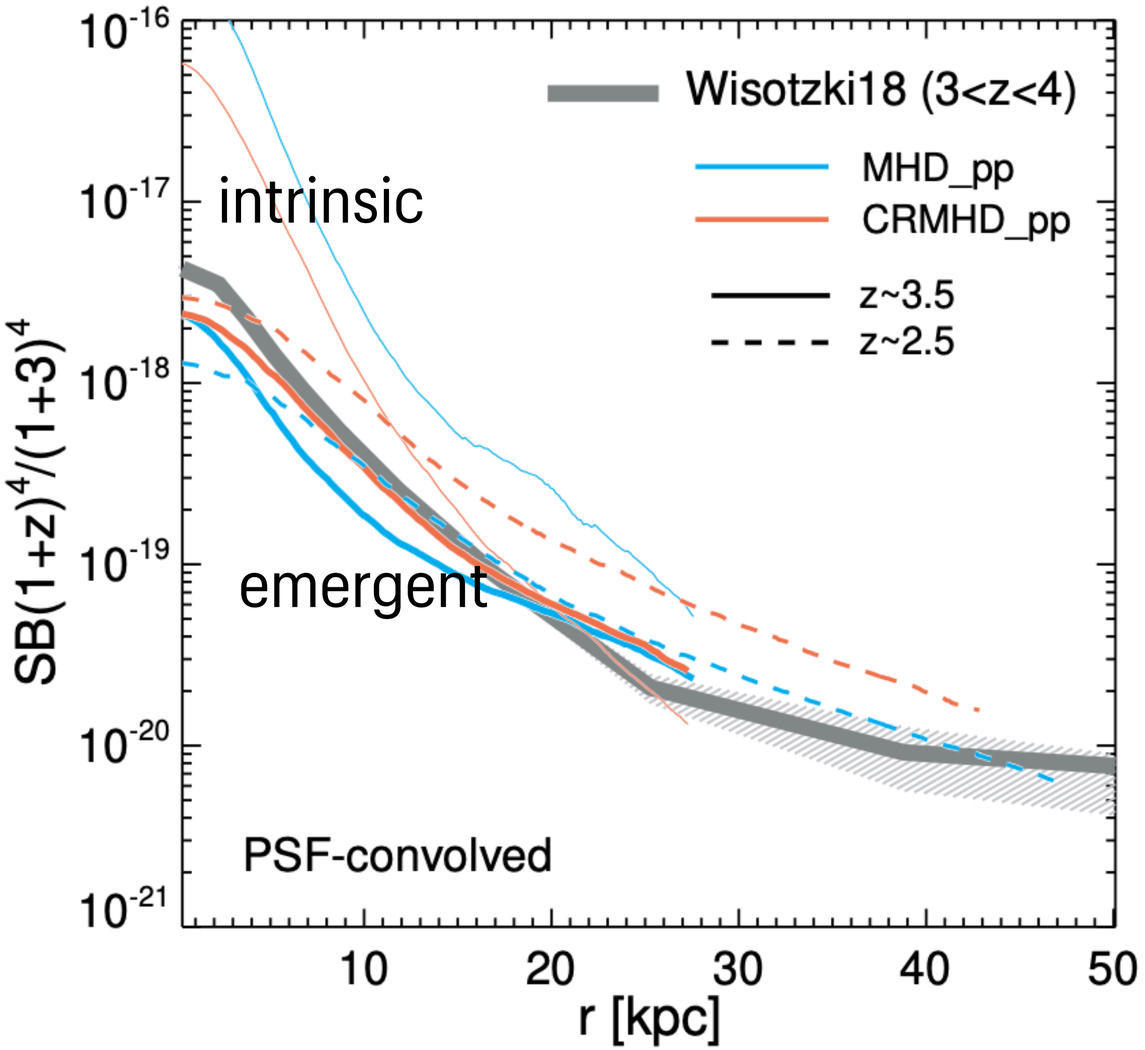


(see Gronke+18)

Median-stacked Lya surface brightness profiles

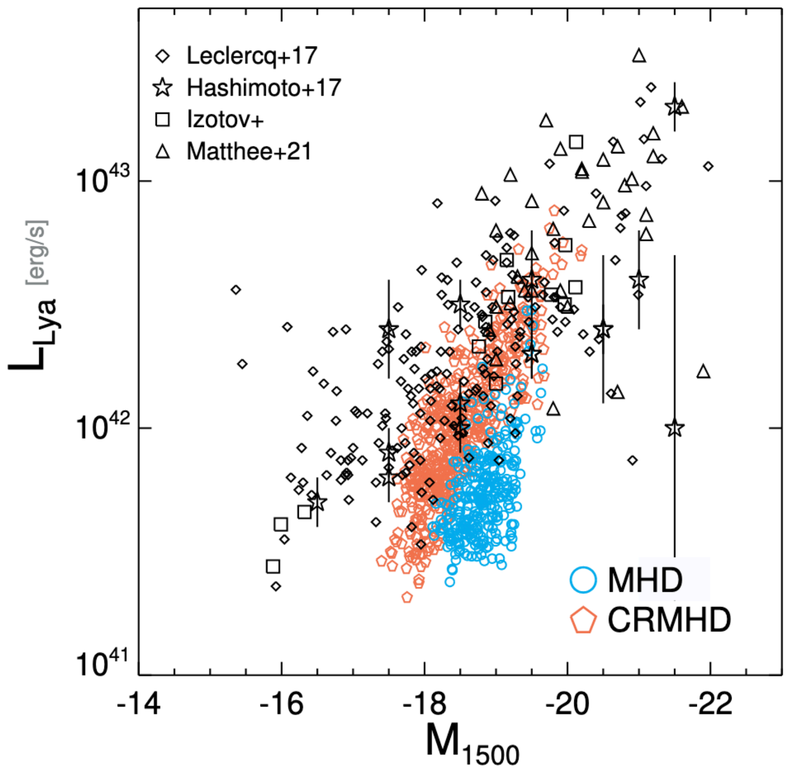


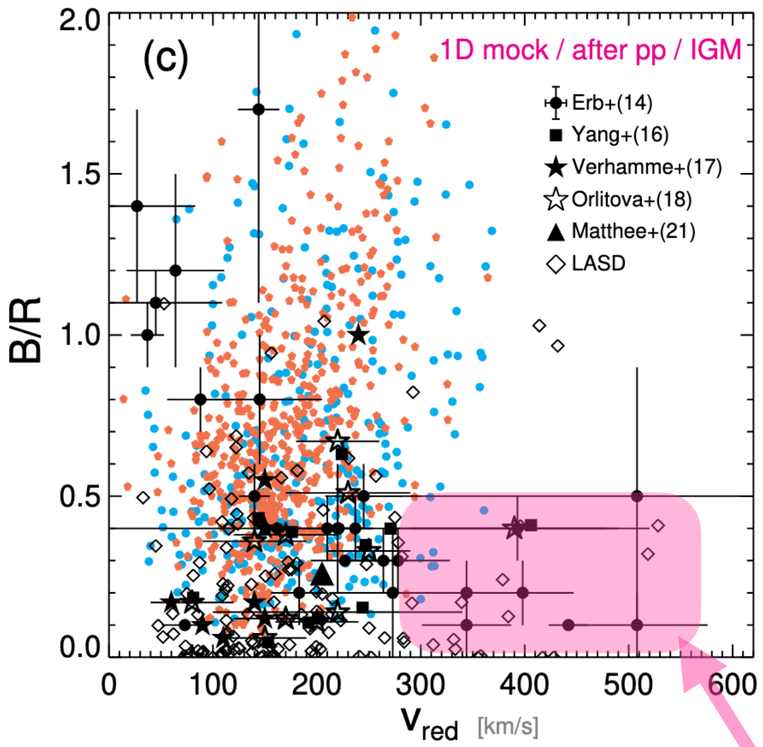
Wisotzki+(18)

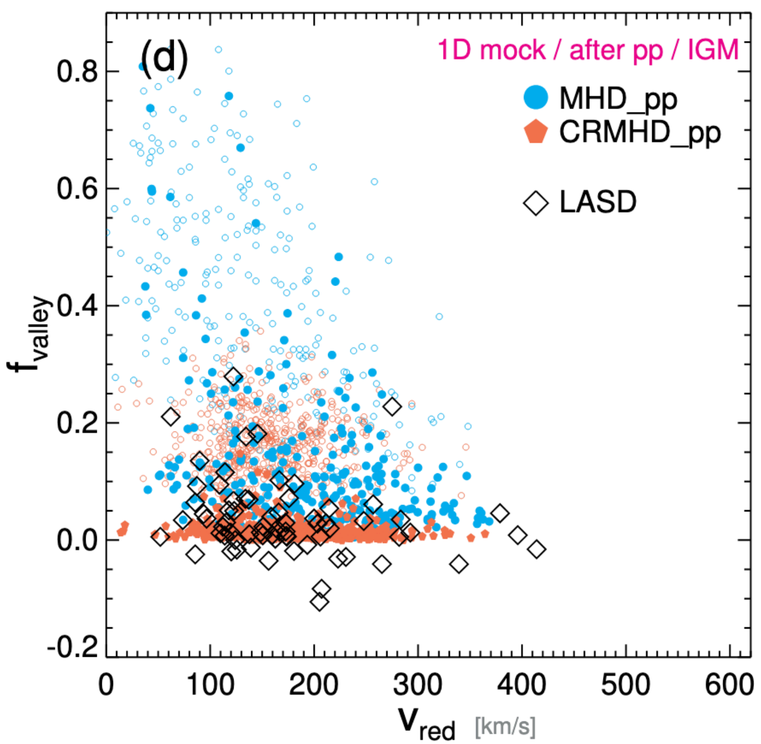


(see also Mitchell+21, Byrohl+21)

Is CR feedback strong enough?







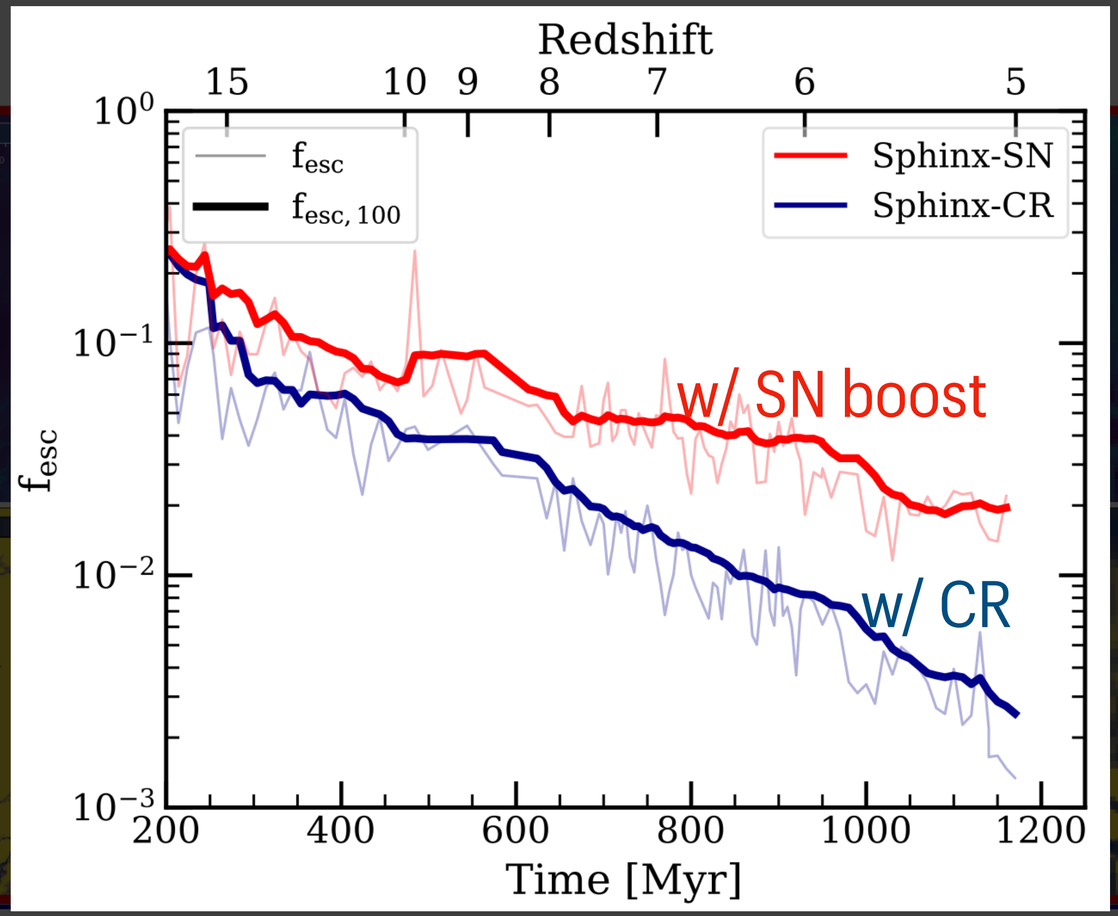
CRMHD run (1) L_{Lya}
(better) (2) mean properties of (B/R, V_{red}, f_{valley})
reproduces (3) (Surface brightness profiles)

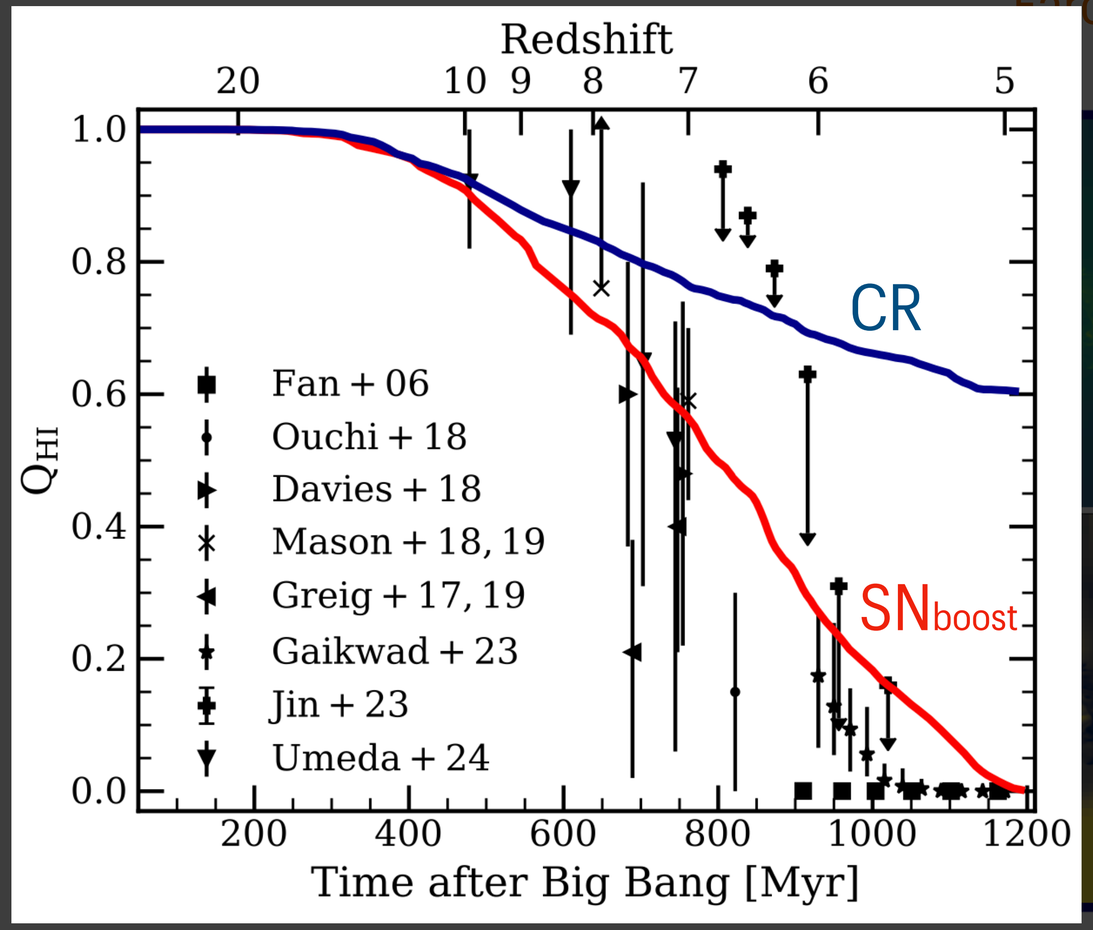
- Are we missing optically thick and/or fast (~200-300 km/s) neutral galactic outflows?
  (n.b. this is just one galaxy at different redshifts)

(see DeFellippis+24 for other metal absorptions)

Reionization is not complete in sim with CR feedback

Farcy, TK+(25)

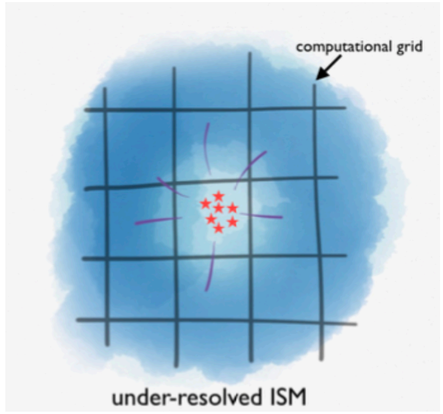




Improving star formation models in galaxy formation

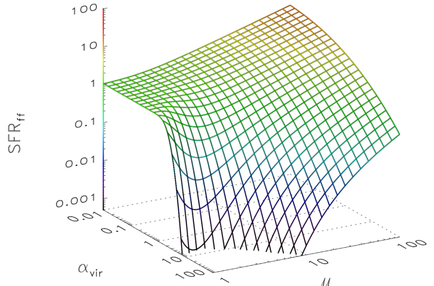
Multi-freefall star formation model

(e.g. **G**ravo-**T**hermo-**T**urbulent model)
Kimm+(17); Rosdahl+(18,22)



$$\frac{dM_\star}{dt} = \epsilon_{\rm ff}\frac{M_{\rm gas}}{t_{\rm ff}}$$

Federrath & Klessen (12)



see also Hennebelle & Chabrier (11)
Padoan & Nordlund (11)

Sink particle algorithm

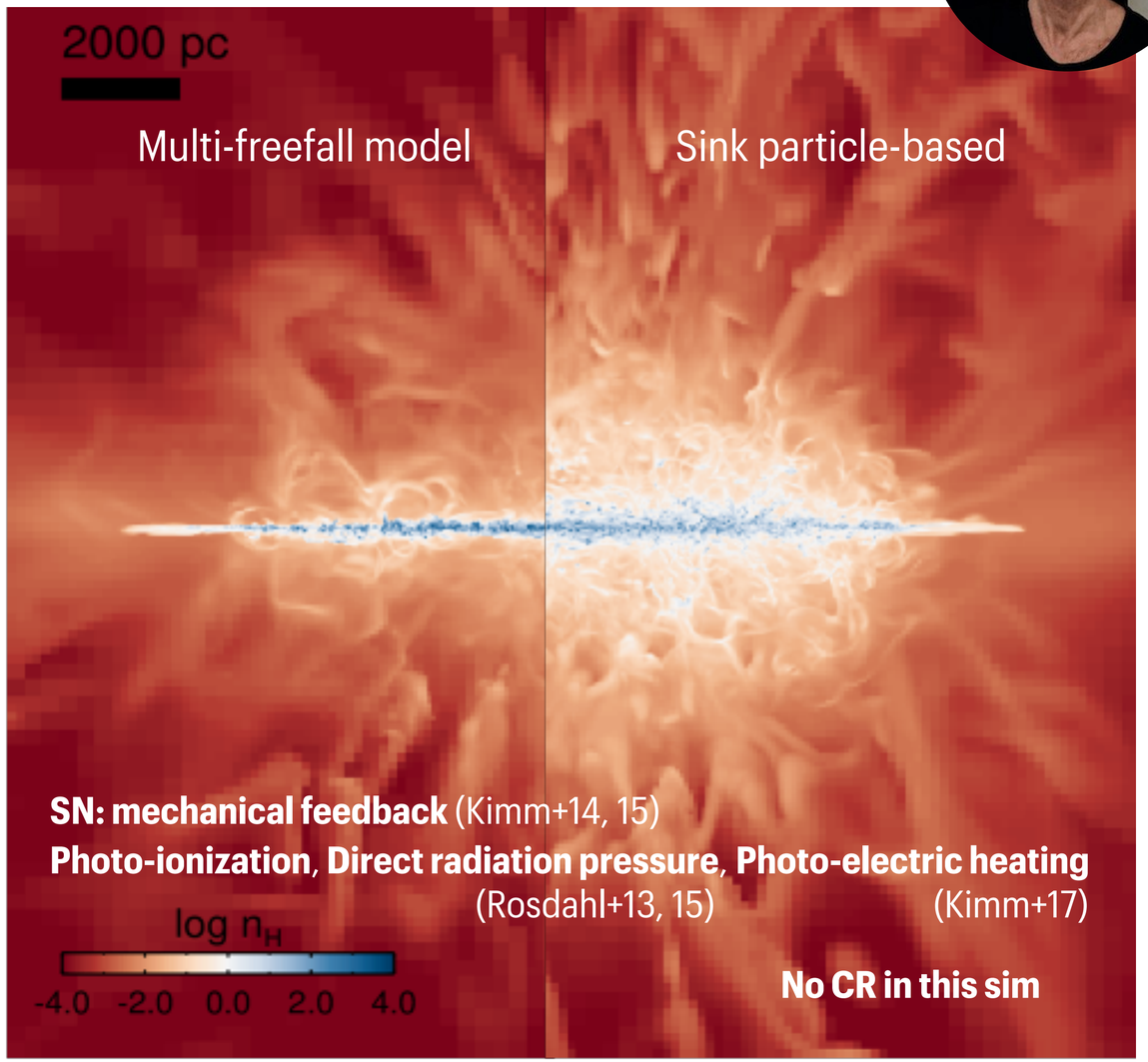
Bleuler & Teyssier+(14,15), **Kang**+(25)

(see poster by Cheonsu Kang)

Accreted flux onto sink particles -> (efficient) star formation

See also SILCC, TIGRESS simulations, +

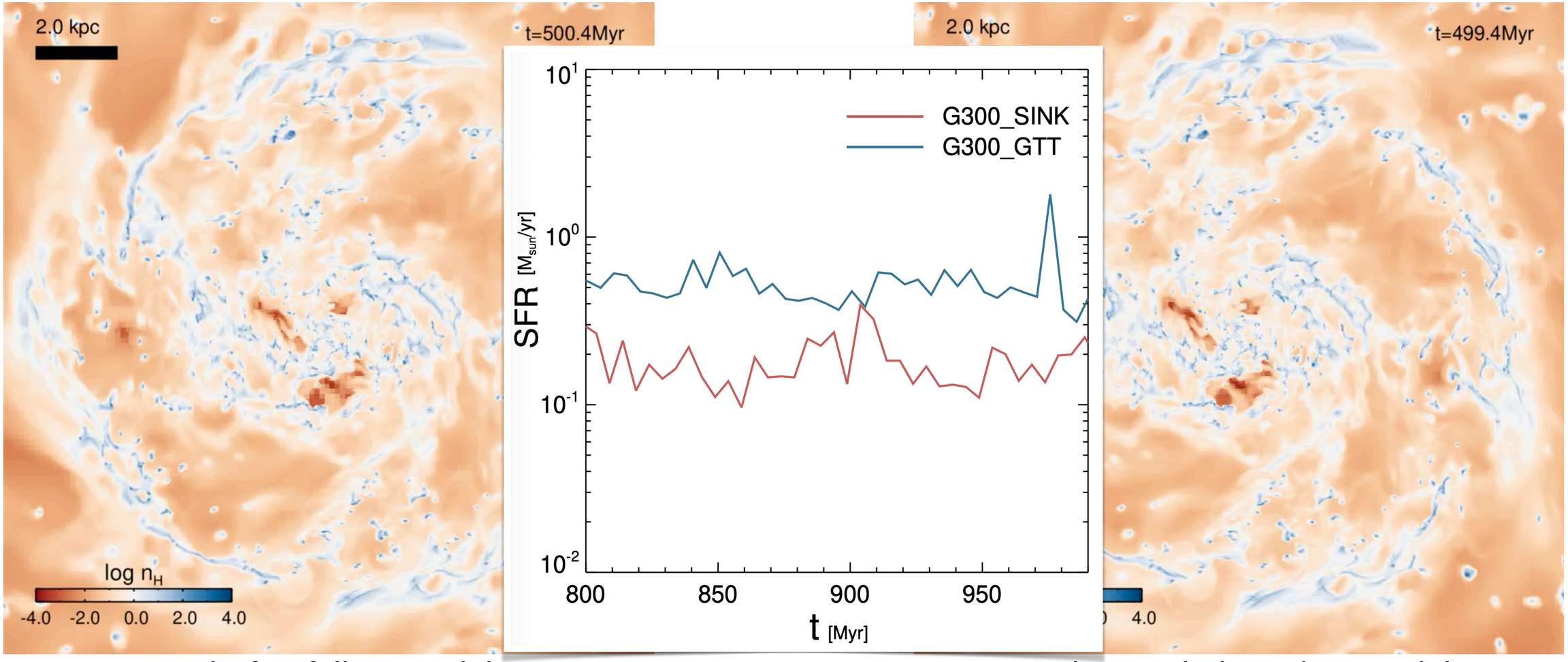
10^{11} $M_{\rm sun}$ DMH (**Rey**, TK in prep)



SF clumps are more rapidly destroyed with accreting sink particles

- **RHD** simulation of an isolated disk in **4x10^{11} M$_{sun}$** DMH (~NGC 300)
- Δx_{min} ~ 7 pc

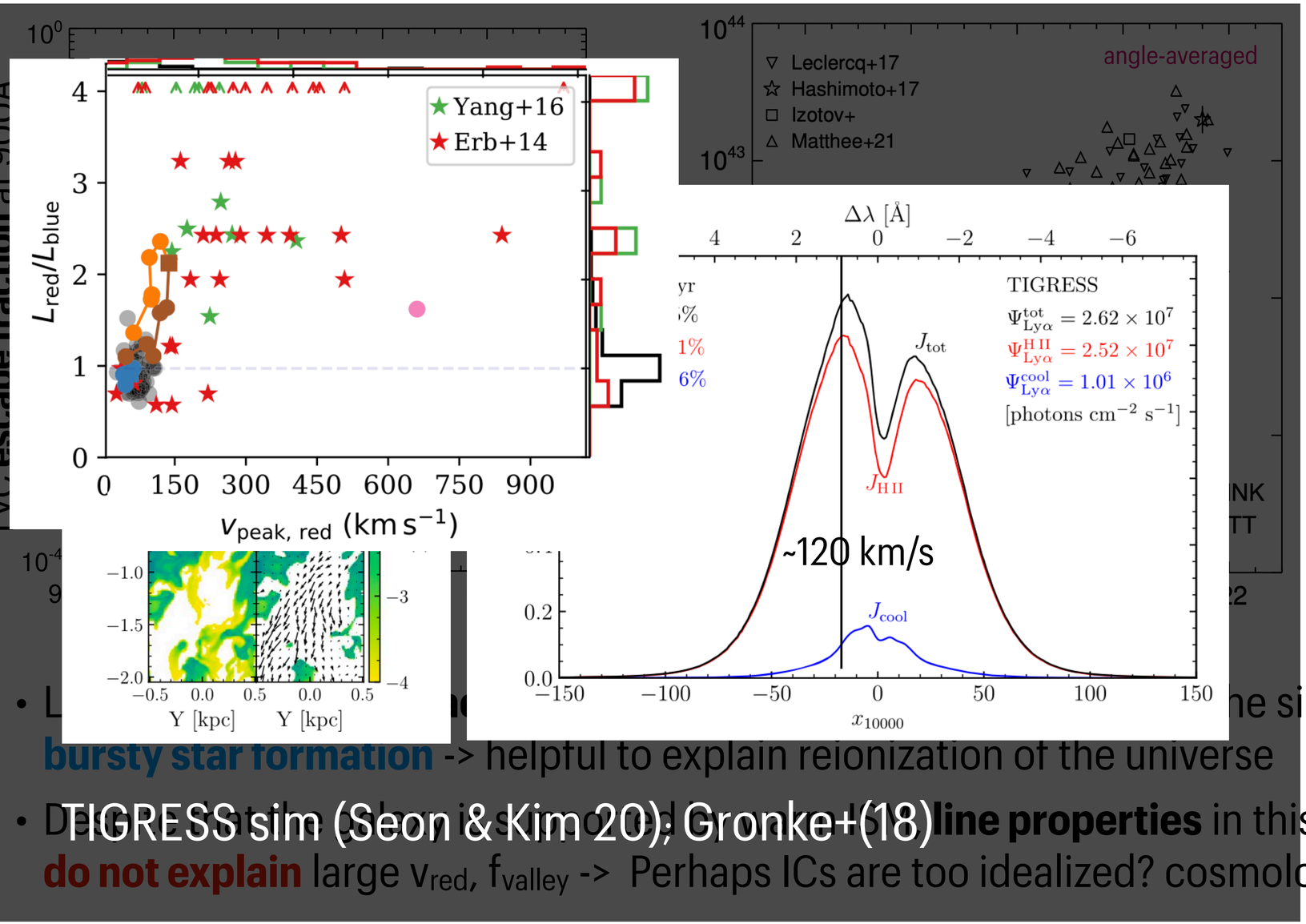
Han, **TK**+ (in prep)

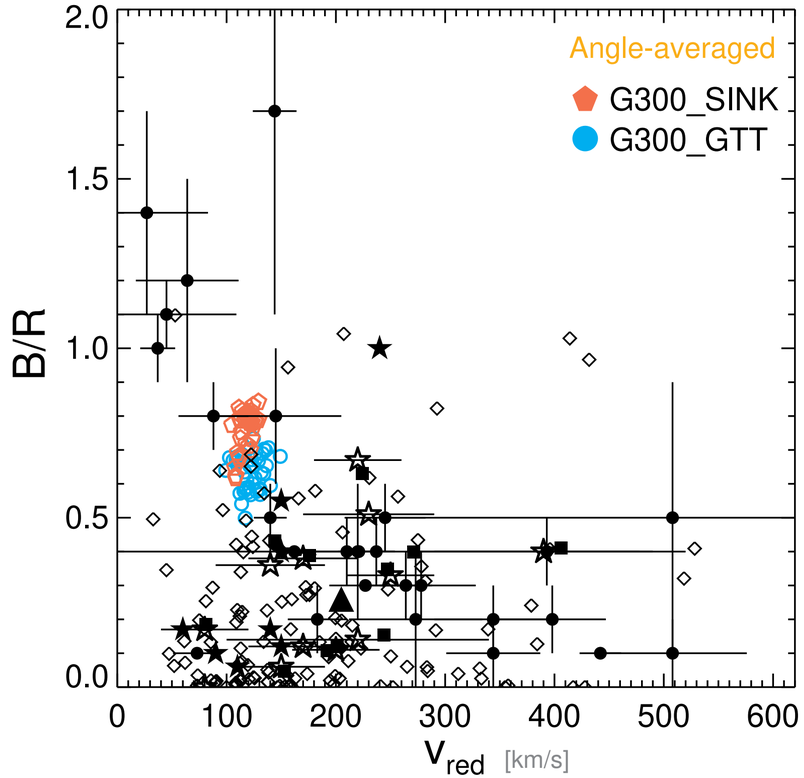


Multi-freefall SF model

Sink particle-based SF model

LyC and LyA properties with bursty SF model (sink)





- L… …he simulation with (more self-consistent) **bursty star formation** -> helpful to explain reionization of the universe
- D… …**line properties** in this idealized simulation **do not explain** large v_{red}, f_{valley} -> Perhaps ICs are too idealized? cosmological sim w/ sink+CR needed!

TIGRESS sim (Seon & Kim 20); Gronke+(18)

Summary

- Lya line properties (L_{Lya}, f_{valley}, B/R, v_{red}) provide useful insights into galaxy formation models

- **Cosmological simulations with CR:**

  - Sim with **CR feedback** better reproduces the M_{1500}-L_{Lya}, f_{valley} by reducing gas column density around young stars (not via extended HI in the CGM)

  - Are we missing Lya spectra with large v_{red} and low B/R? -> more powerful outflows?

- **Idealized disk simulations with a more self-consistent SF model (sink particle)**:

  Sim with bursty SF effectively destroys GMCs and allow **more efficient escape** of Lya and LyC photons -> will be useful to explain **reionization**, but some line properties (large v_{red}, low B/R, low f_{valley}) not easily reproduced

- Future work: high-res cosmological sims with  feedback