Overview of the FIRE simulations, selected CGM results, and UVB update

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Outline

- Overview of FIRE and basic properties of galactic winds

- FIRE results on Lyman limit systems at high and low *z*

- Preview: new UVB model

- More from FIRE later:
  - D. Kereš (next) — halo properties, cosmic rays
  - C. Esmerian (today) — hot halos and precipitation
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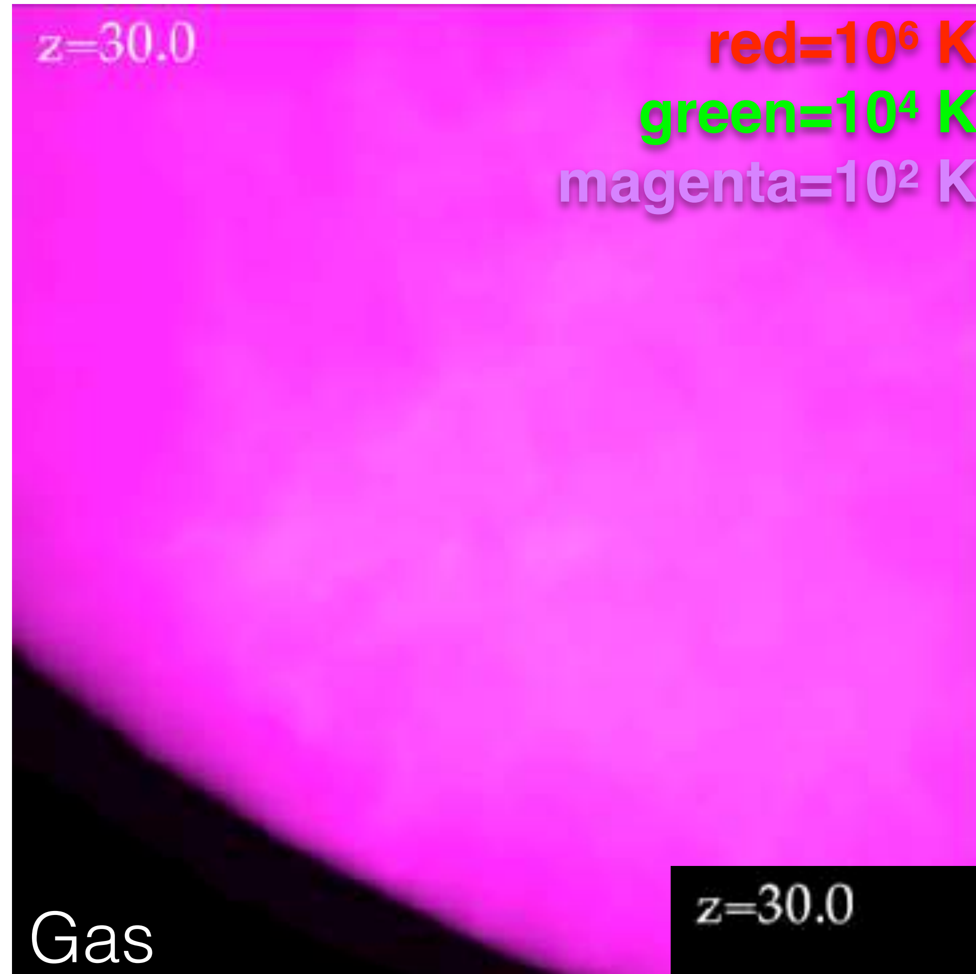
FIRE: Feedback in Realistic Environments

- Cosmological zoom-ins resolving GMCs
- Metal and molecular cooling to T~10 K; SF in dense, self-grav. gas
- Stellar feedback (SNe, photoion, stellar winds, rad. P) based on SB99
- Galactic SF rates, outflows, etc. emerge from energy injection on the scale of star-forming regions



GIZMO

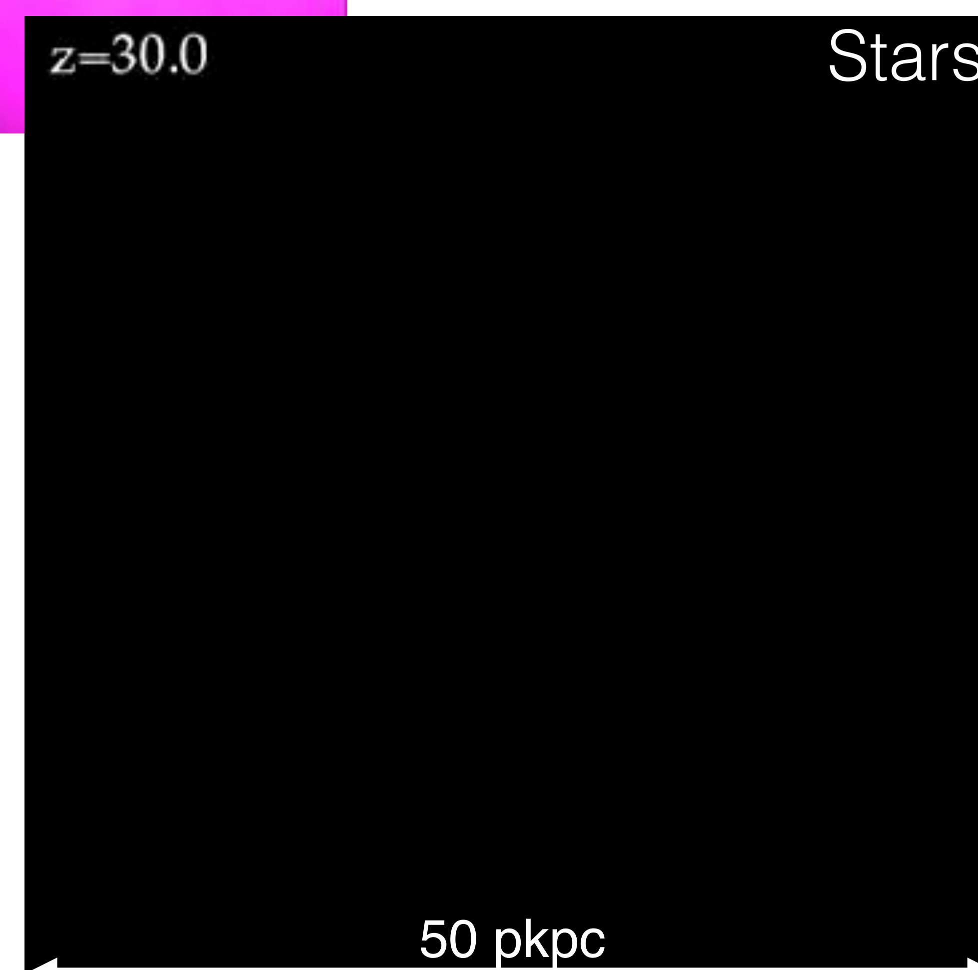
(Hopkins 15)

$M_{\mathrm{h}}(z=0) \sim 10^{12}\ \mathrm{M_{sun}}$

$m_{\mathrm{gas}} \sim 10^{4}\ \mathrm{M_{sun}}$

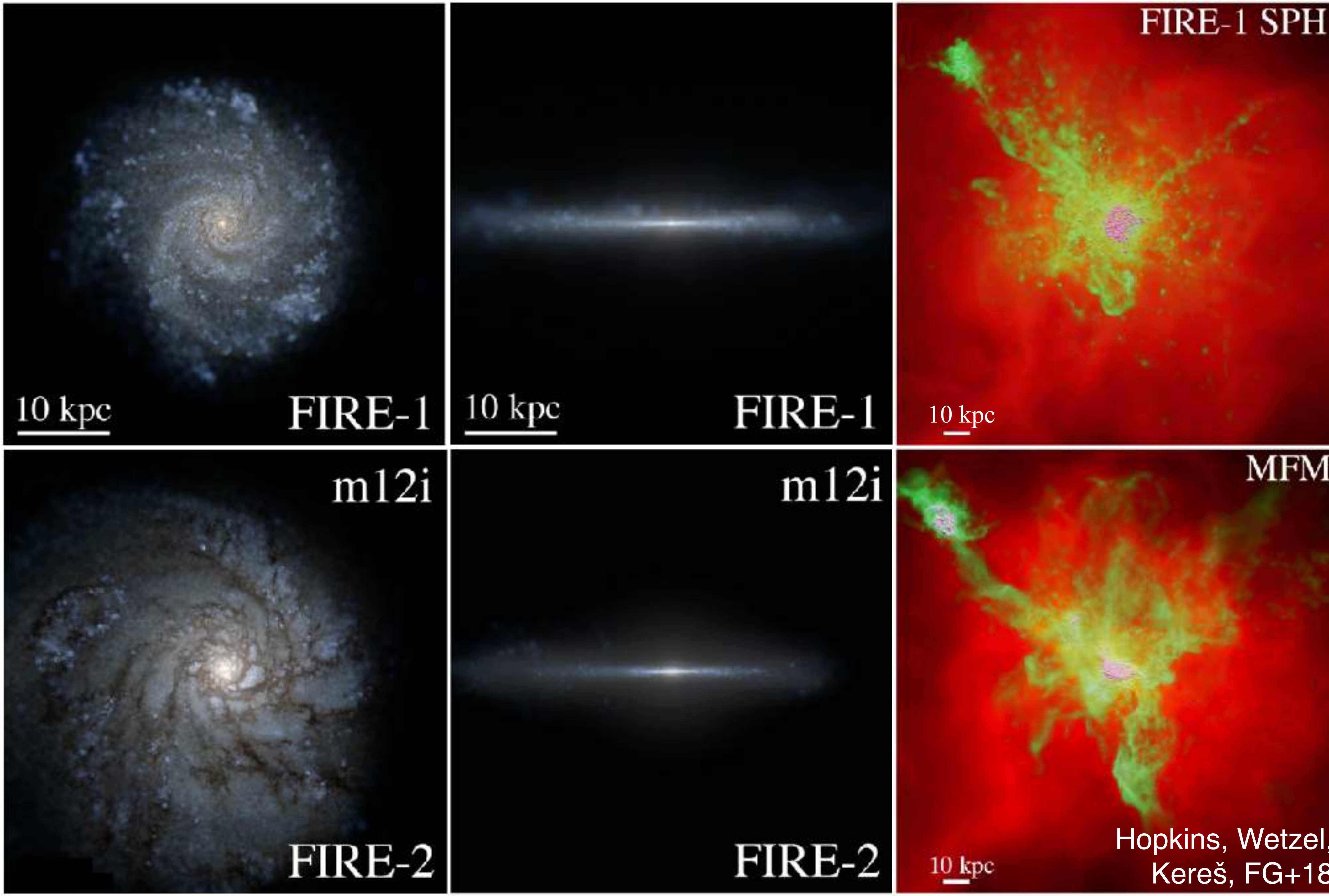
$\varepsilon_{\mathrm{gas}} \sim 10$ pc

← outflows interact with inflows



Project web site: http://fire.northwestern.edu

FIRE-1 vs. FIRE-2: same basic physics, different hydro

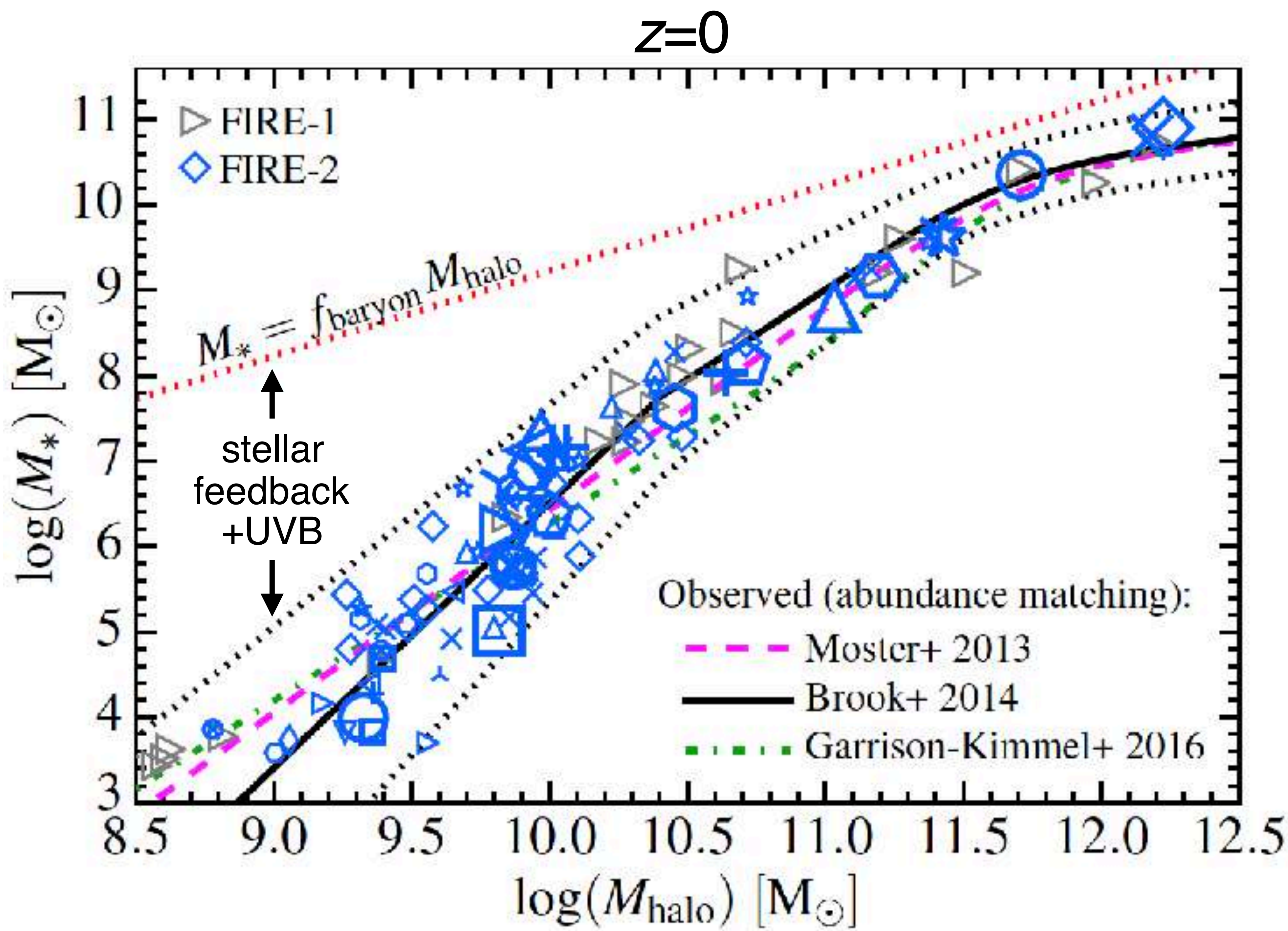


Hopkins, Wetzel, Kereš, FG+18

FIRE-1 vs. FIRE-2

So far, broadly consistent results between FIRE-1 and FIRE-2, with some quantitative differences

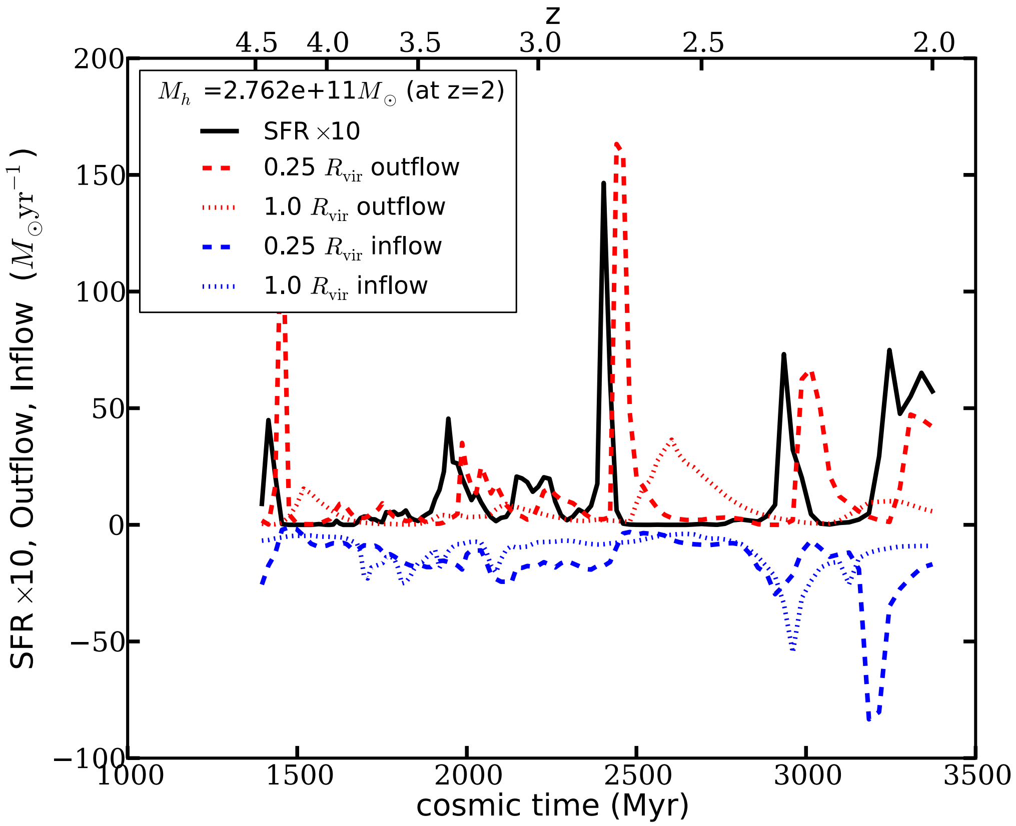
MFM solver in FIRE-2 allows for more accurate extra physics (*B* fields, cosmic rays, conduction, radiation) — key future directions

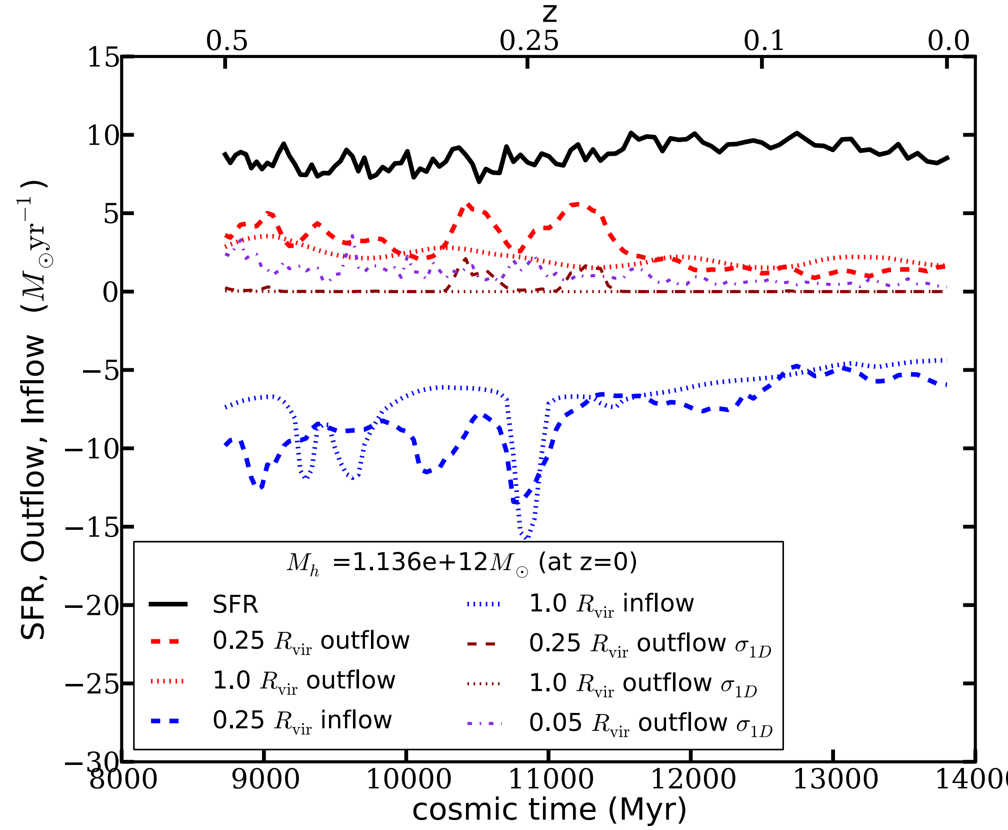


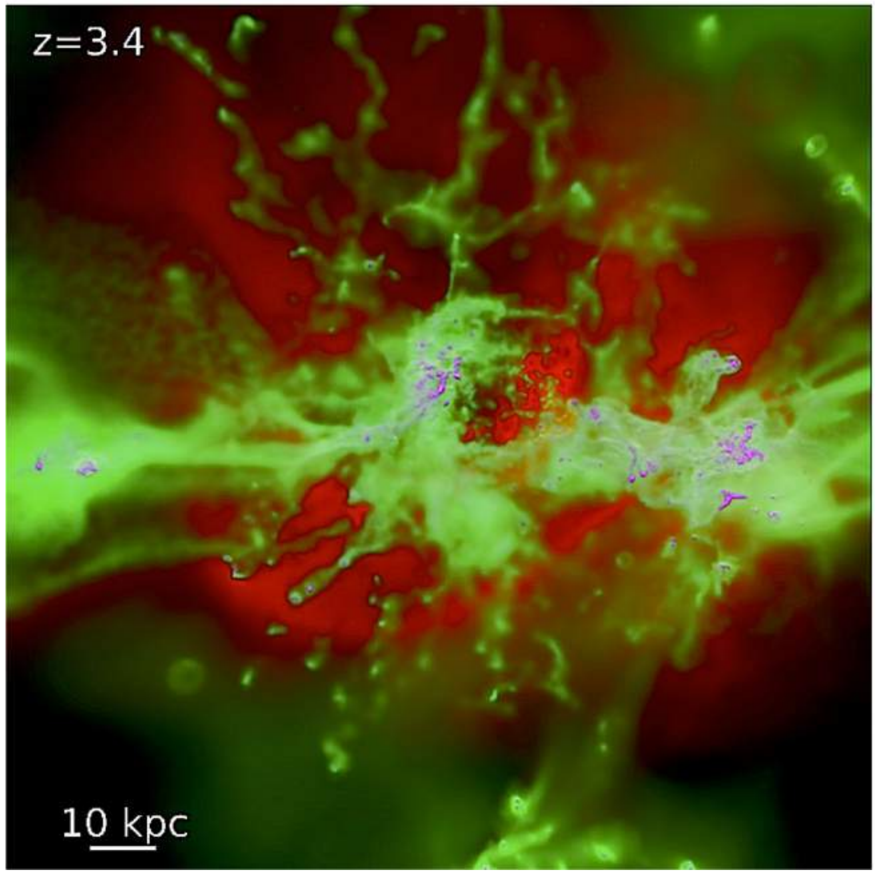
in this talk, will focus primarily on FIRE-1 CGM results

Hopkins, Wetzel, Kereš, FG+18

From high-*z* bursts to low-*z* steady state







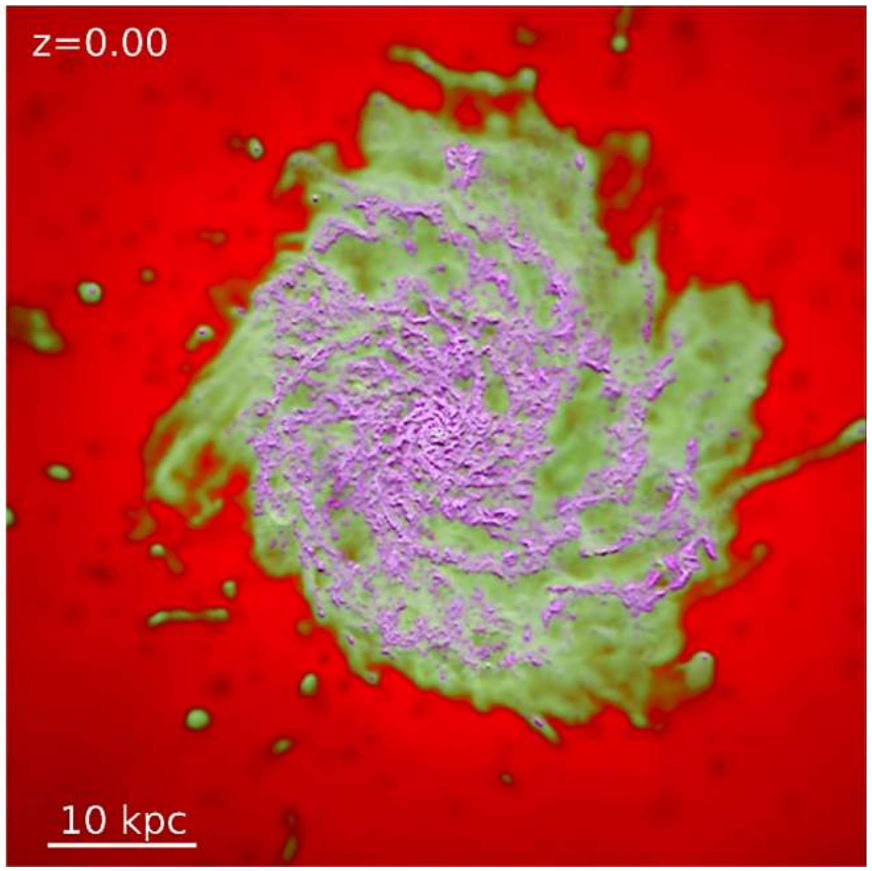
universe expands

inflows decline

f_{gas}, SFRs decline

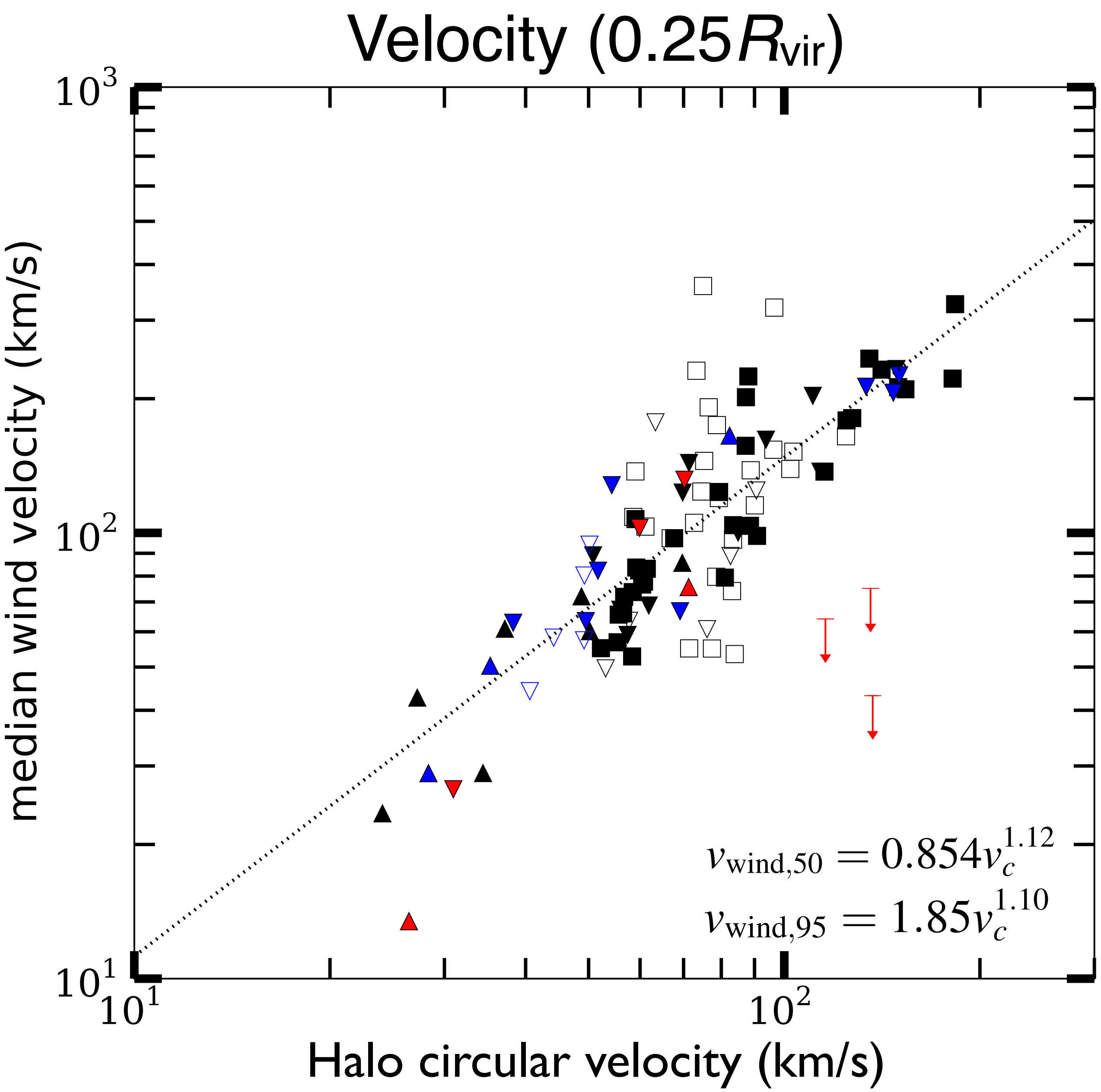
bursty → steady

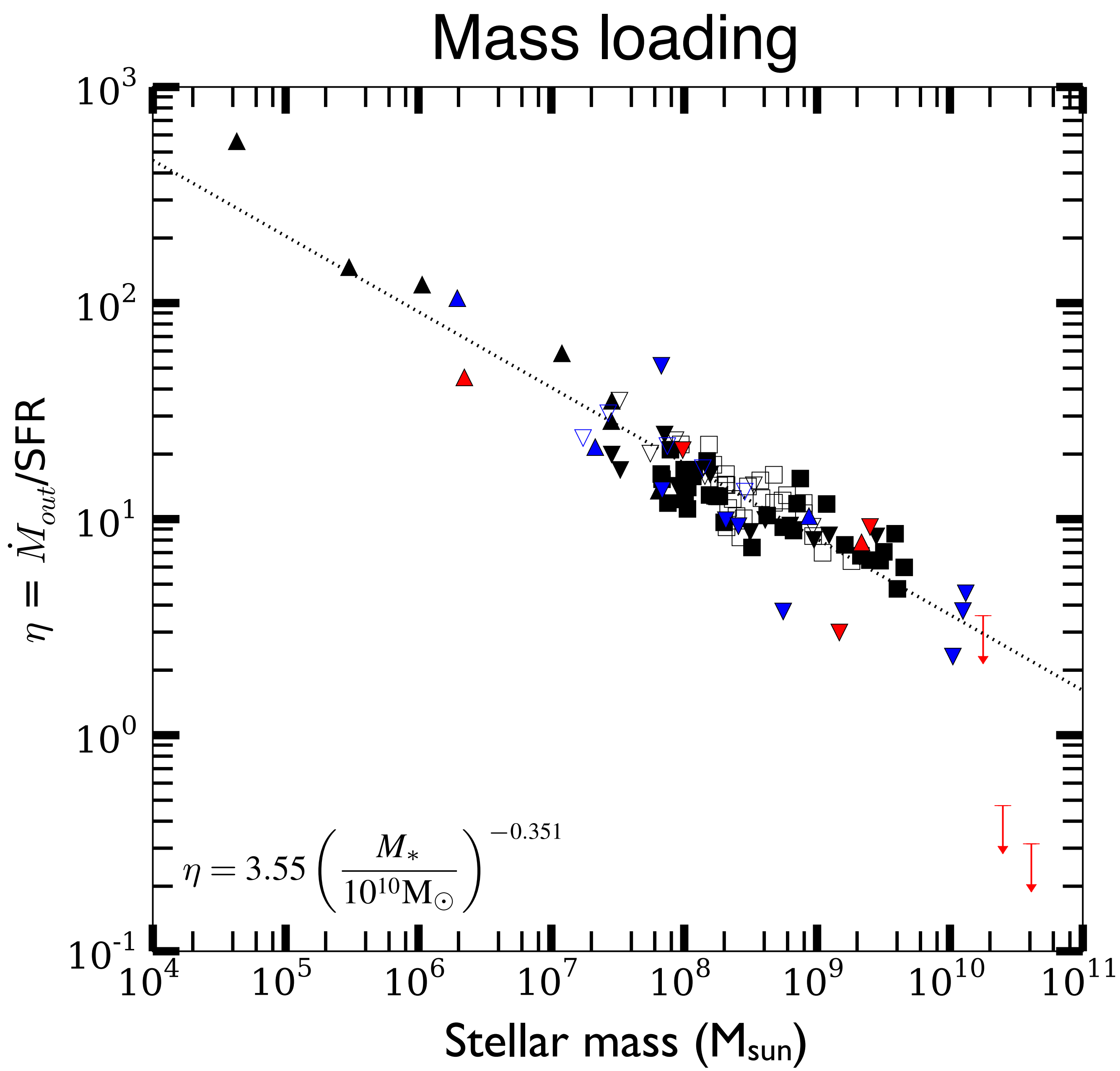
chaotic → stable disk



Muratov, Kereš, FG+15; Sparre+17; FG18

Bulk properties of FIRE galactic winds

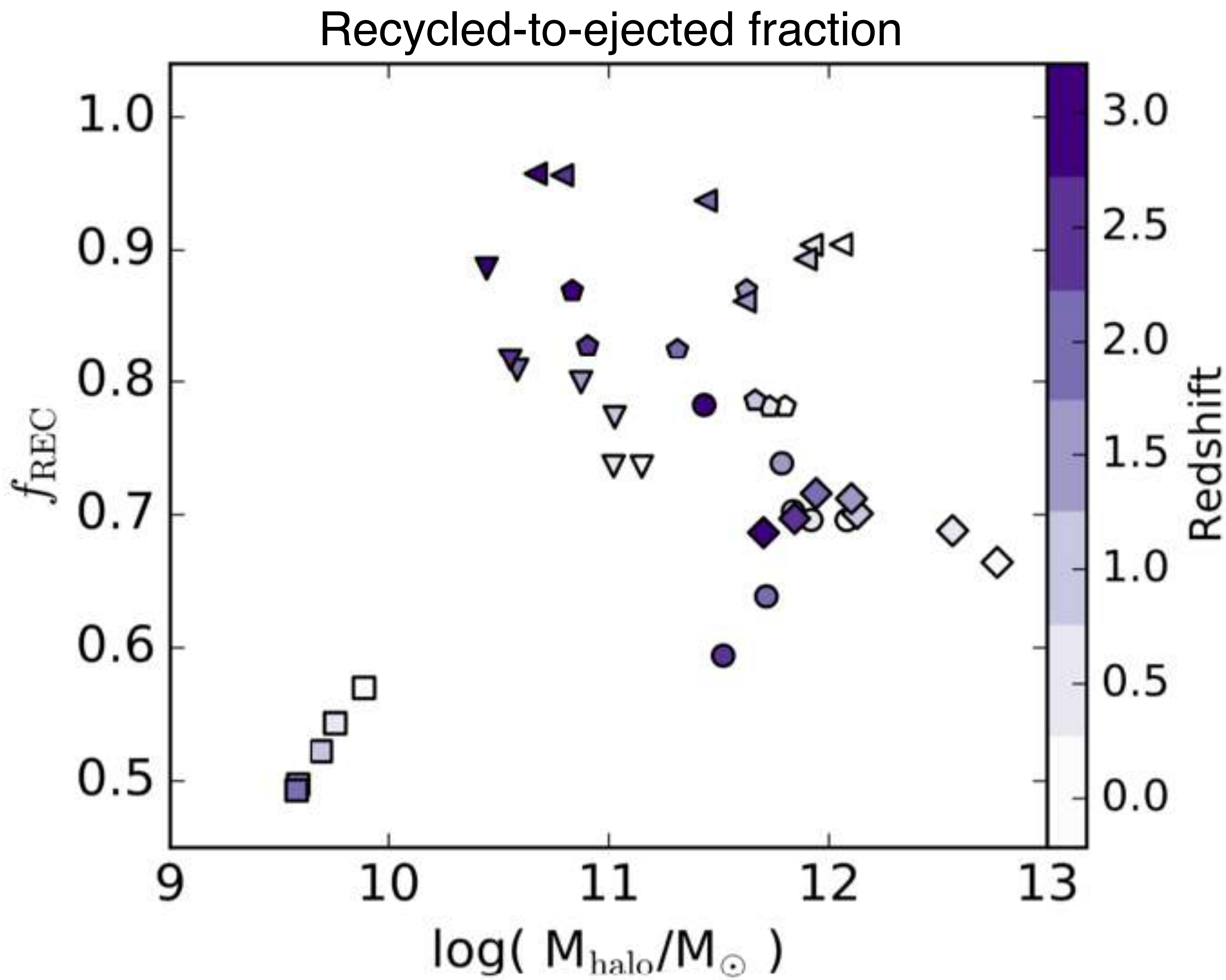




0<z<0.5, 0.5<z<2, 2<z<4

Muratov, Kereš, FG+15

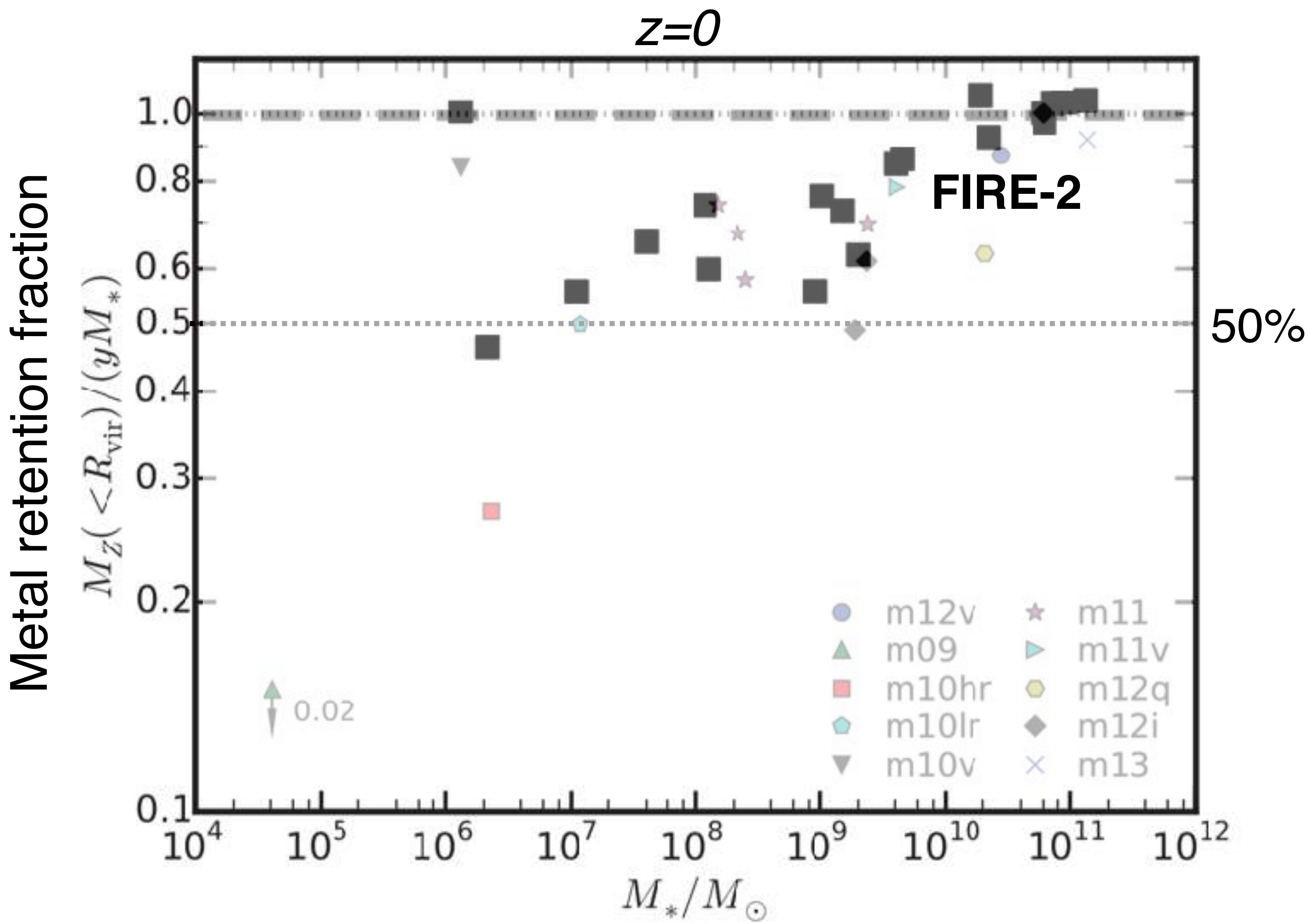
Most of the wind mass recycles



6 simulated halos at different redshifts

Anglés-Alcázar, FG+17

Halos retain most of their metals, except low-mass dwarfs



Ma, Hopkins, FG+16 (FIRE-1); Hafen+, in prep. (FIRE-2)

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- **FIRE results on Lyman limit systems at high and low *z***
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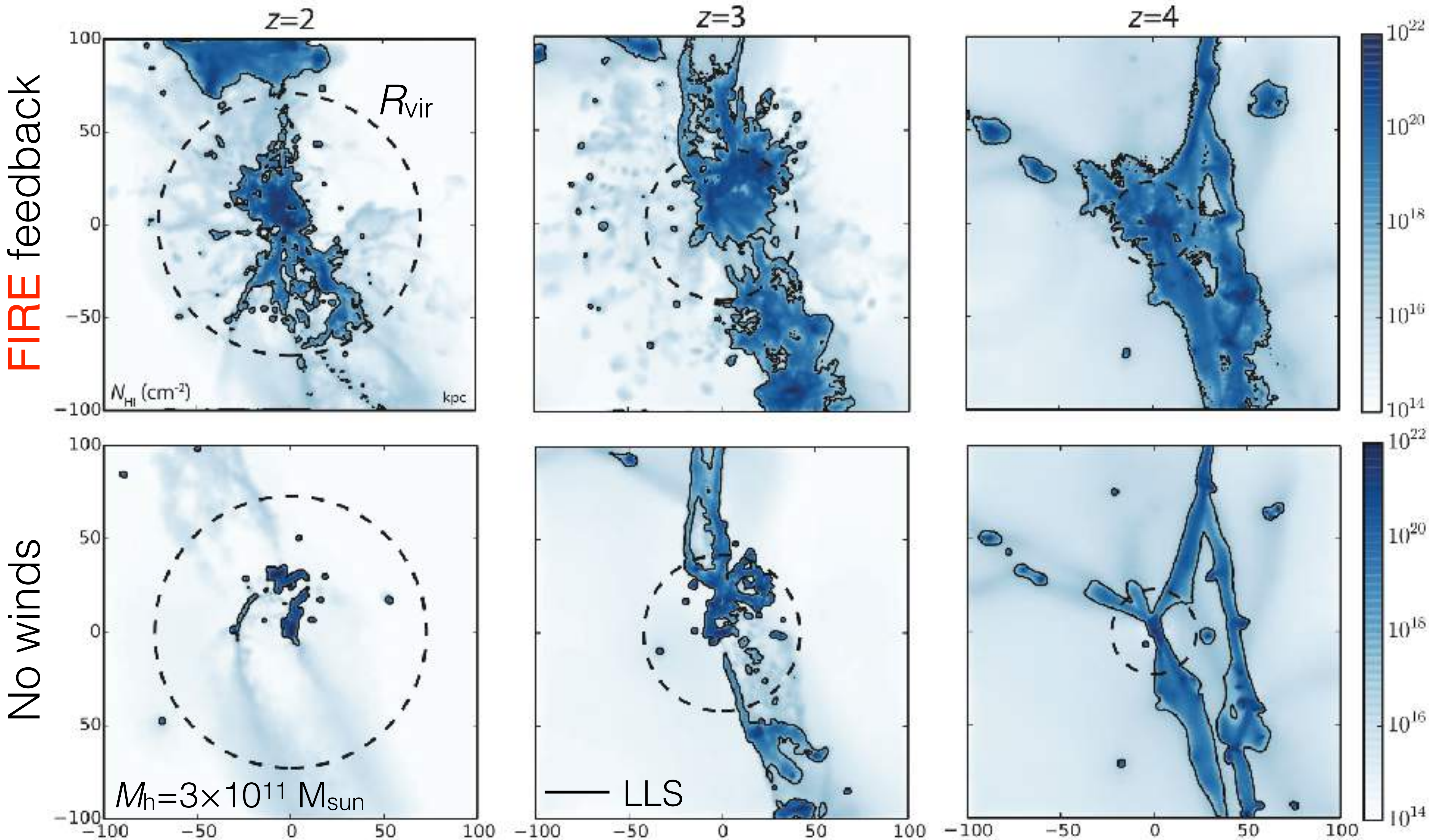
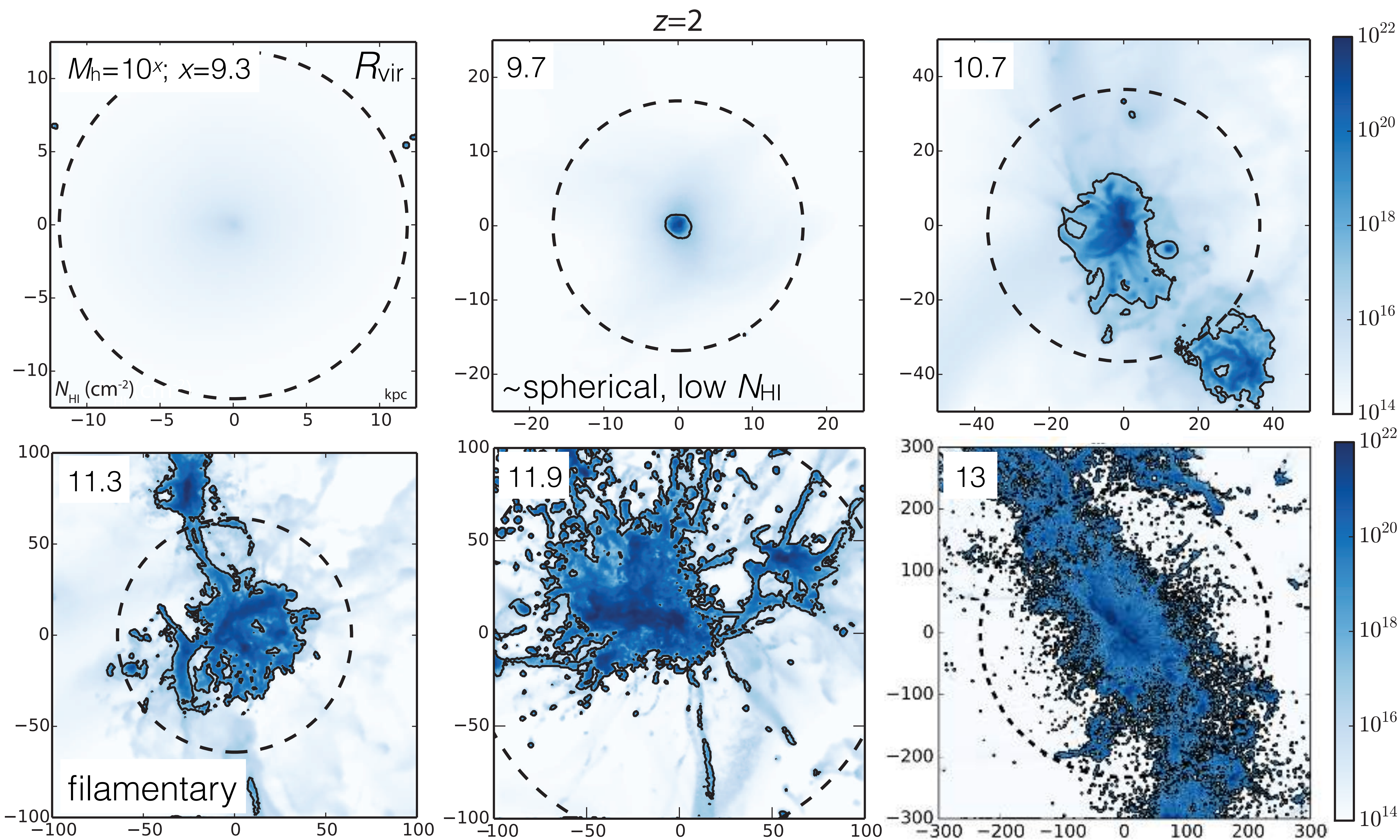
High *z*: testing winds with HI covering fractions



→ cool gas ejection + interaction with infalling filaments

FG+15

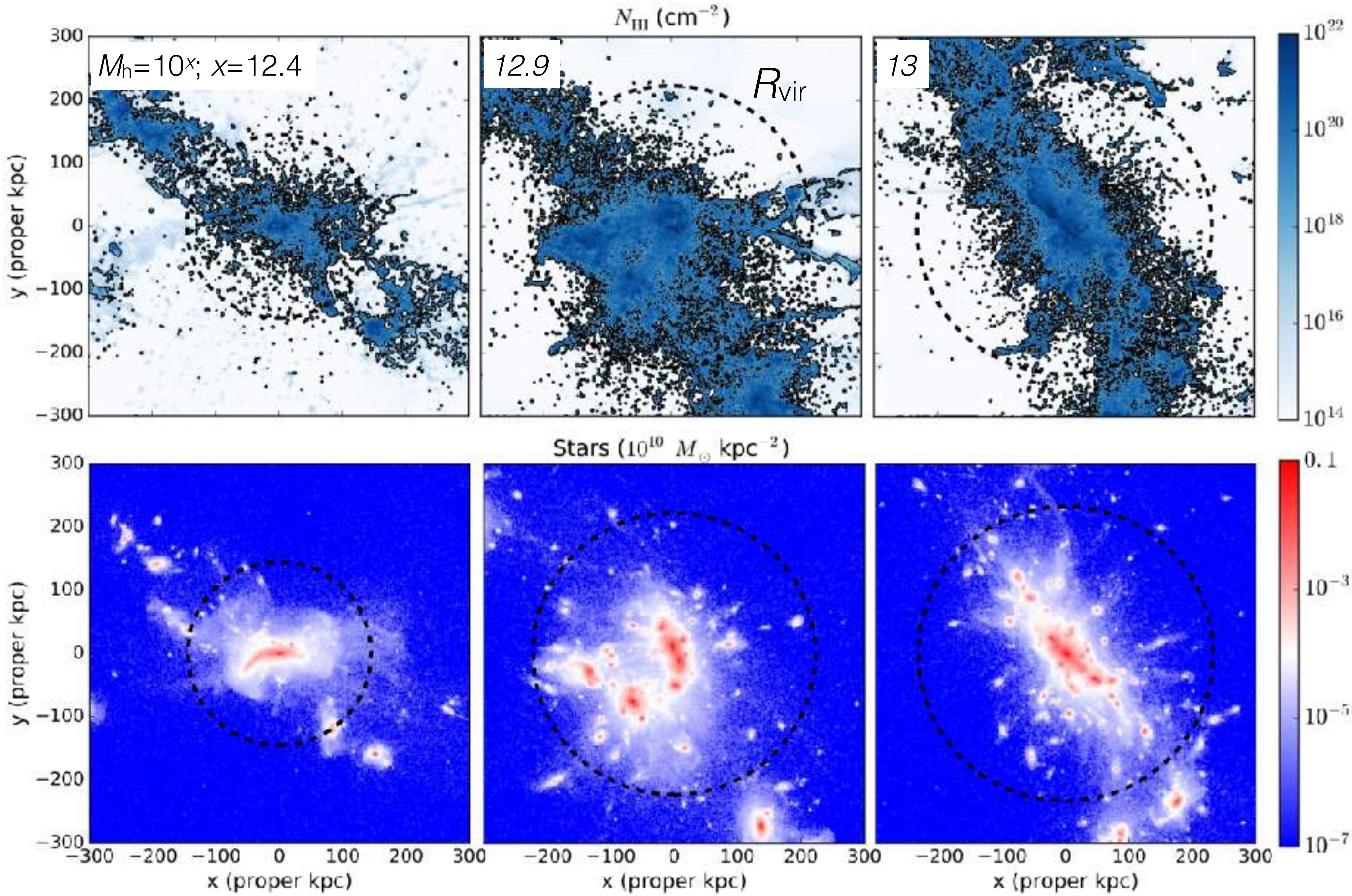
Lyman limit systems peak in massive halos



—— Lyman limit systems

FG+15, 16

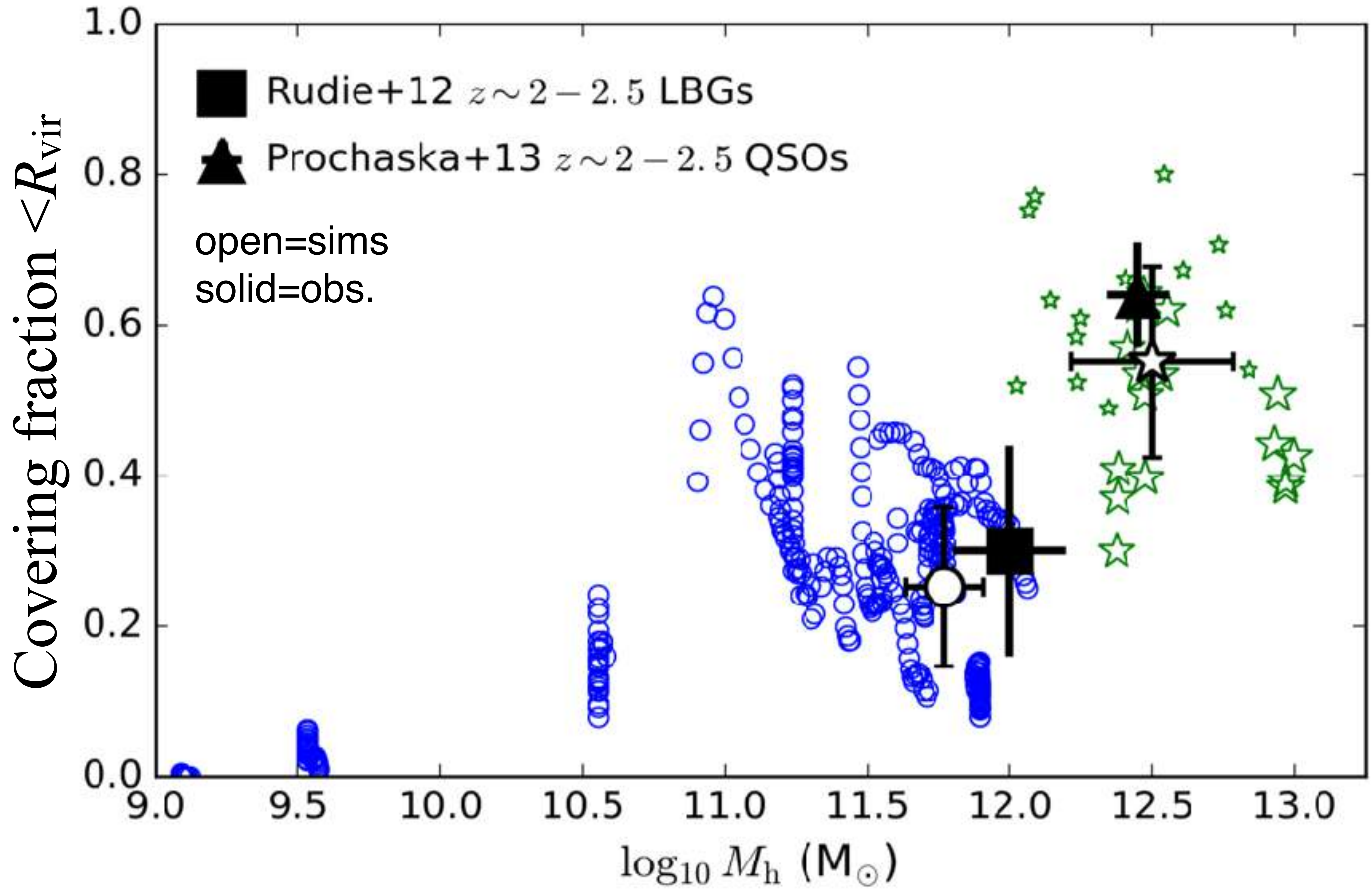
Satellite winds important for LLSs: z~2 QSO-mass halos



→ Anglés-Alcázar+17 and Hafen+ (in prep.) quantify contributions of satellite winds to galaxy growth and CGM mass — talks Friday

FG+16

High-z Lyman limit system covering factions vs. observations

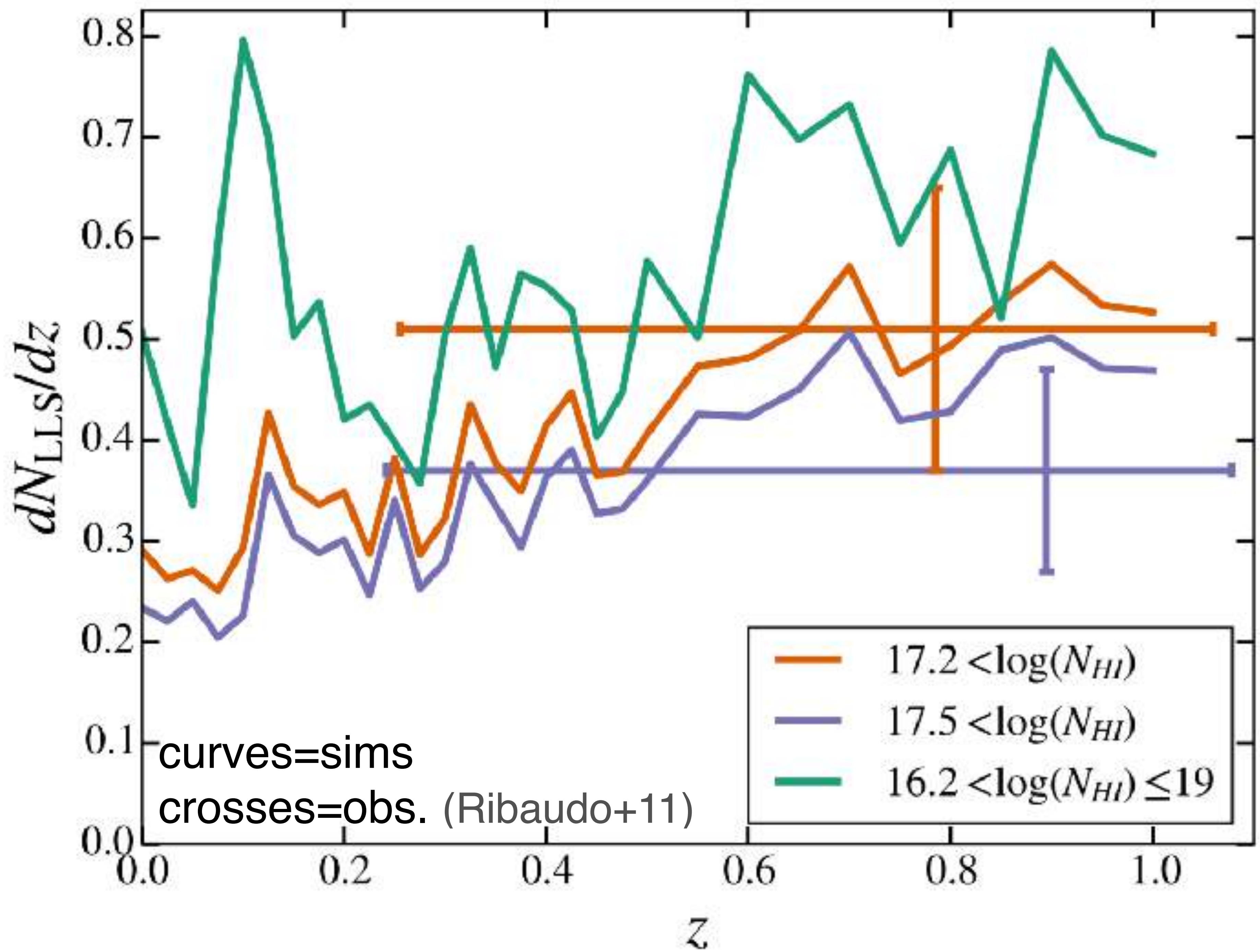


→ simulations do not include AGN — not *needed* to explain QSO covering fractions

FG+15, 16

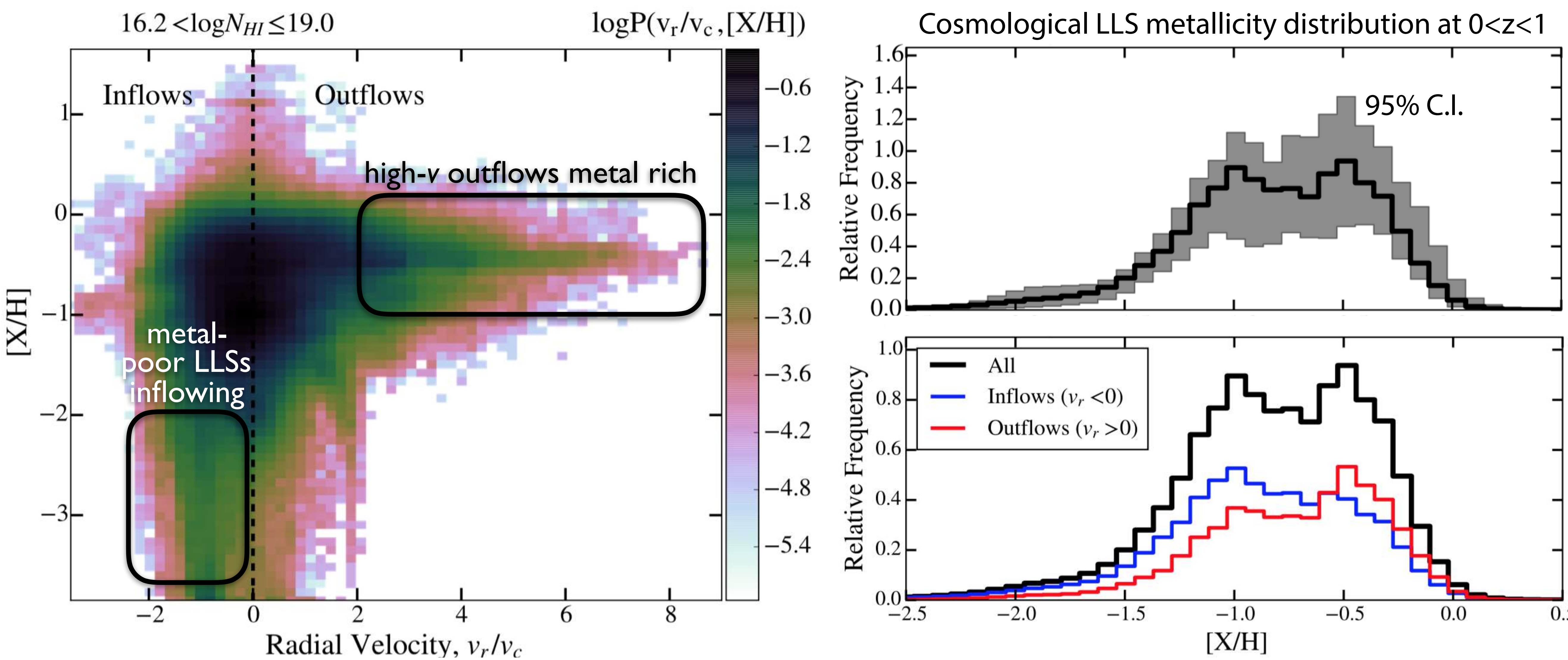
Low z: FIRE consistent with cosmological LLS incidence at z<1

14 zoom-ins convolved with dark matter halo mass function to model cosmological statistics



Hafen, FG+17

z<1 LLS metallicities in FIRE vs. radial kinematics



- Instantaneous inflows & outflows overlap strongly in metallicity — no statistically significant evidence for bi-modality (cf. Lehner+13, Wotta+16)
  - broad range of halos contribute, wind recycling: outflows → inflows
- Separate from bi-modality issue, FIRE-1 simulations appear to be missing observed low-metallicity, [X/H]≲-1.5 LLSs

Hafen, FG+17

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New UVB model

PRELIMINARY

Large number of improved empirical constraints relative to FG+09

[removed quantitative figures on the UVB since the models are still being refined — ask me if interested]

FG, in prep.

AGN-dominated UVB at low *z*

PRELIMINARY

[removed quantitative figures on the UVB since the models are still being refined — ask me if interested]

FG, in prep.

Galaxies reionize HI at high z

PRELIMINARY

[removed quantitative figures on the UVB since the models are still being refined — ask me if interested]

FG, in prep.

Full spectra

PRELIMINARY

[removed quantitative figures on the UVB since the models are still being refined — ask me if interested]

FG, in prep.

Summary

- FIRE simulations predict bursty inflow-SF-outflow cycles at high *z*, emergence of ordered disks in ~*L** galaxies at low z (dwarfs continue to be bursty)

- Powerful galactic winds appear to correlate with bursty SF and disappear in low-redshift massive galaxies

- Most of the wind mass recycles

- By z=0, galaxies with $M_\star \gtrsim 10^7$ M_{sun} retain most of the metals they produced in their halos — winds recycle efficiently

- Simulations consistent observed LLS covering fractions around z~2-2.5 LBGs and QSOs. Winds from both centrals and satellites are important

- At z<1, simulations are consistent with observed LLS incidence, but appear to be missing a significant number of low-metallicity systems. No statistically significant metallicity bi-modality

- New UVB model (in prep.)