Supernovae-driven Outflows
&
(Warm-)Hot Circumgalactic Medium

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Background

- Missing baryon & missing metals problems
- Supernovae (SNe): produce most energy and metals
- Circumgalactic medium (CGM): bears info about feedback
- Cosmological simulations: feedback models *ad hoc*, fine tuned
- More physical feedback needed — recent progress on how SNe drive outflows from multiphase ISM

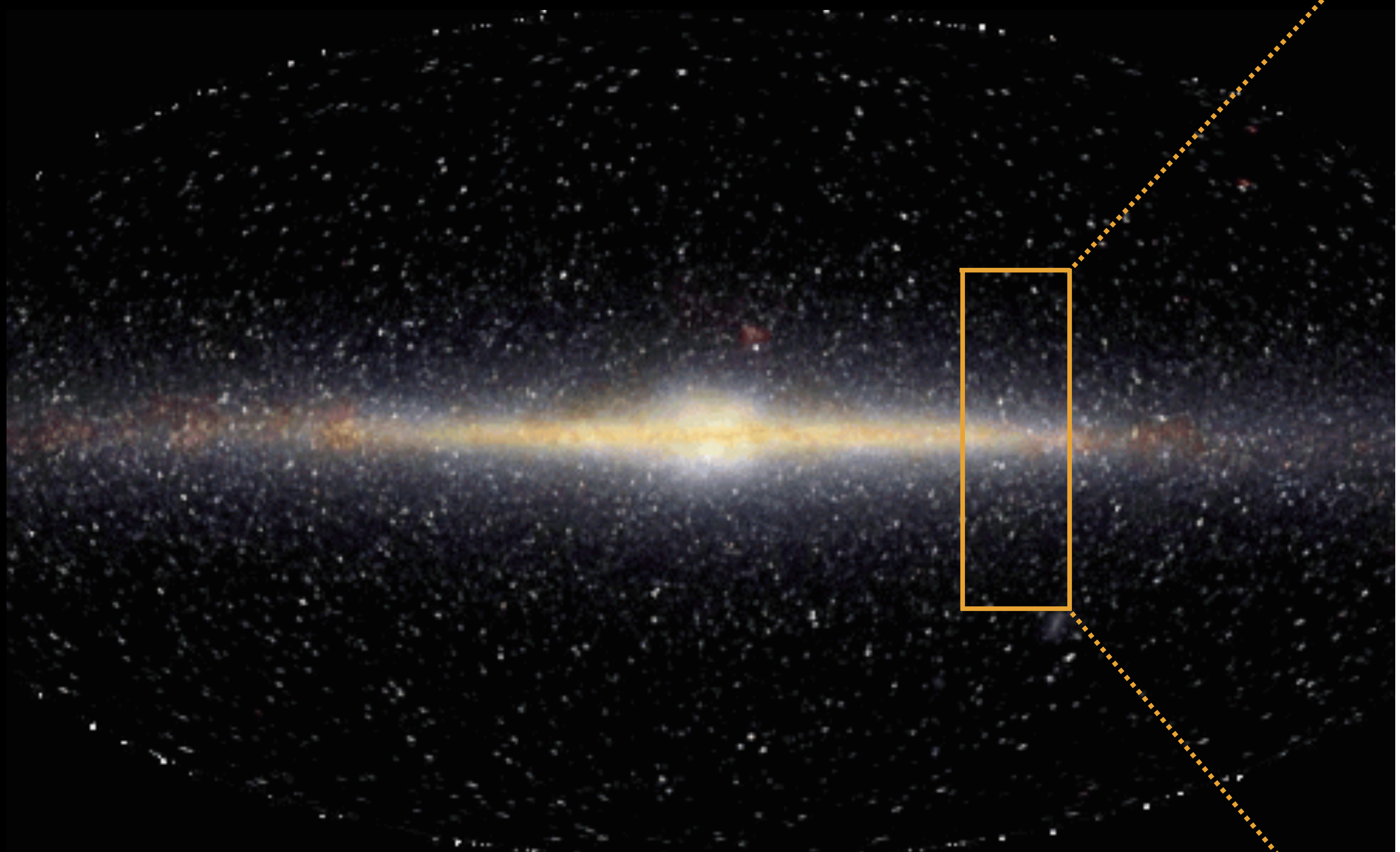
Outline

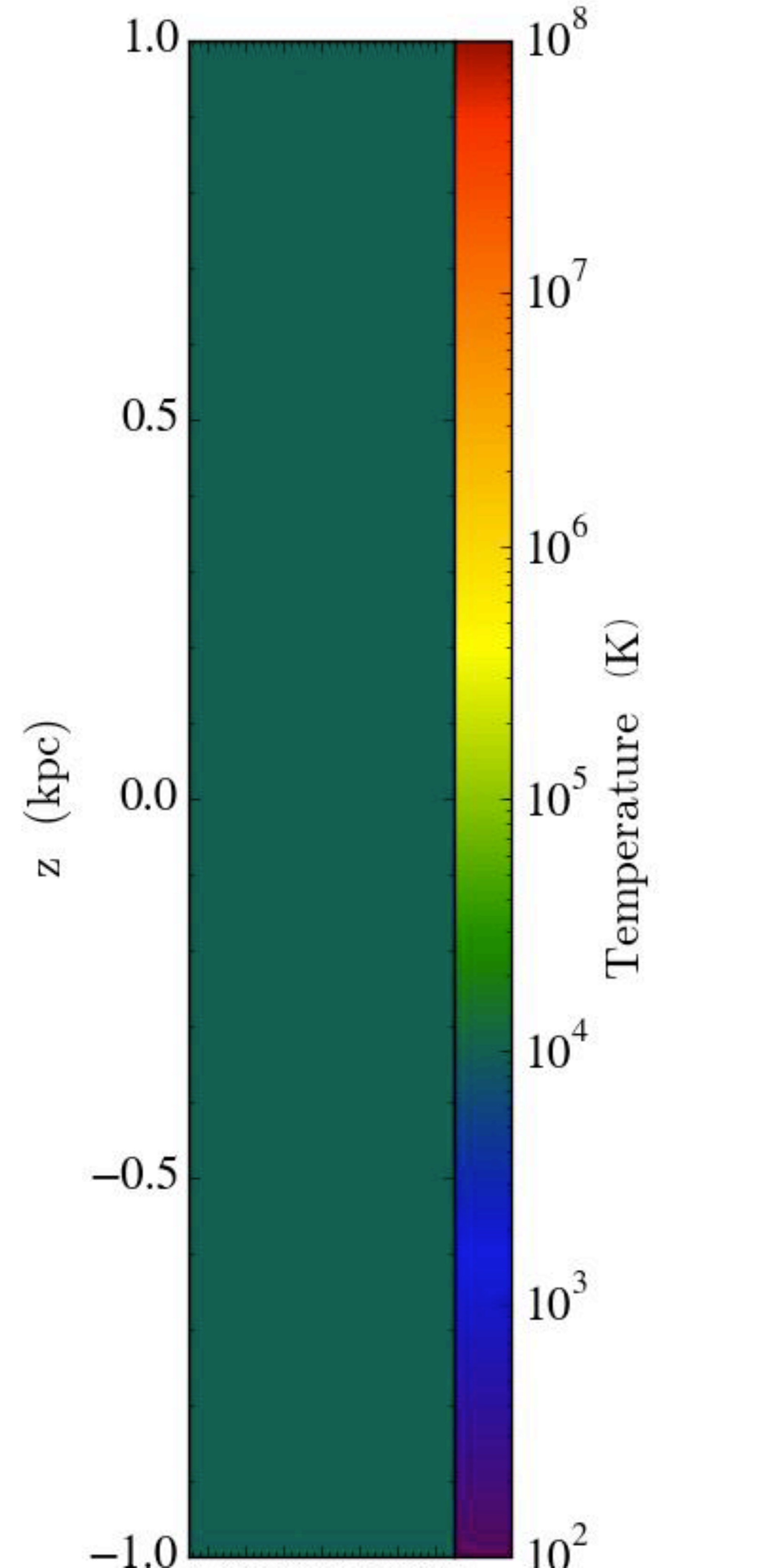
- What do we learn from recent small-box simulations on **SNe-driven galactic outflows** ?

- Using outflow models from small-box results, how do SNe-driven outflows impact CGM?

- X-ray emission and absorption of CGM

Small boxes:
kpc patch of disk galaxy



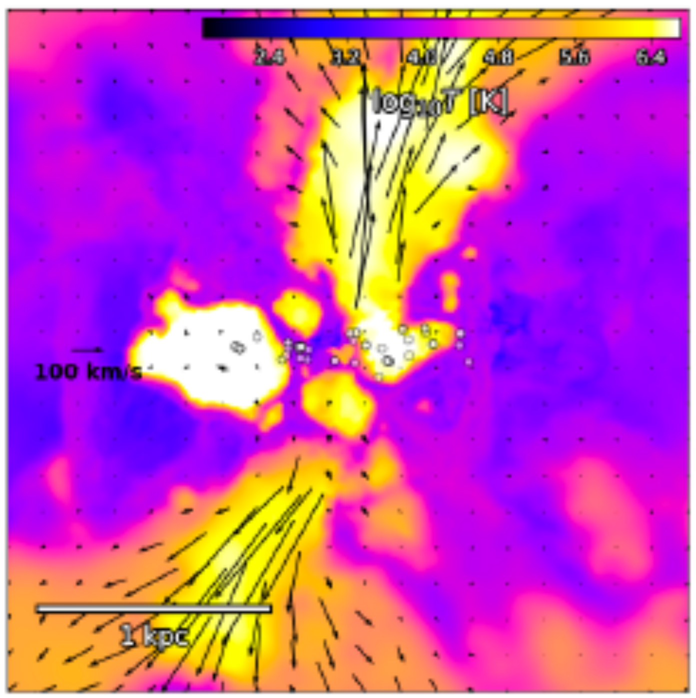


- Resolving SN remnants evolution
- Quantify Multi-phase Outflows

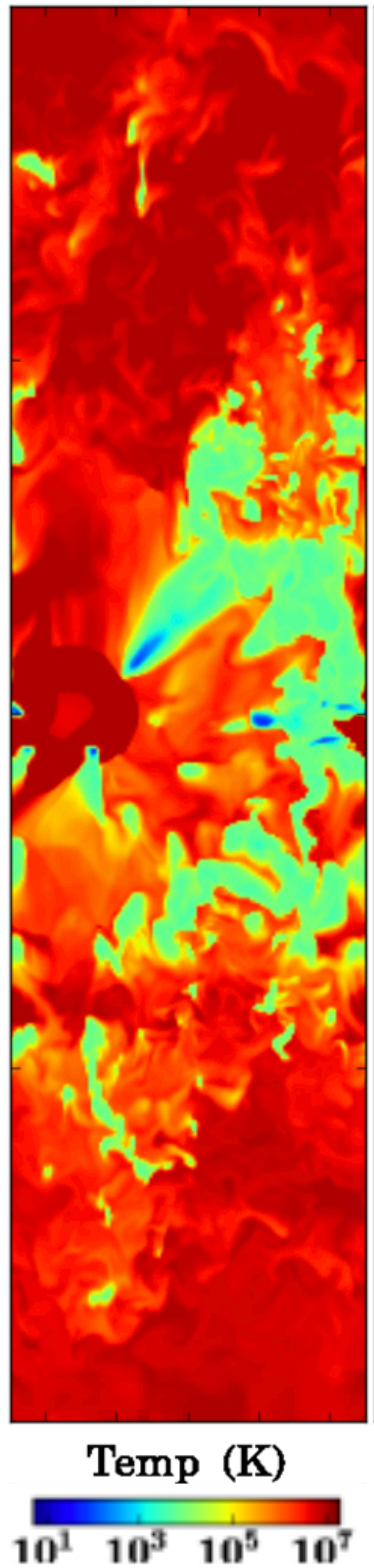
Li, Bryan & Ostriker+17a

image: scienceblog.com

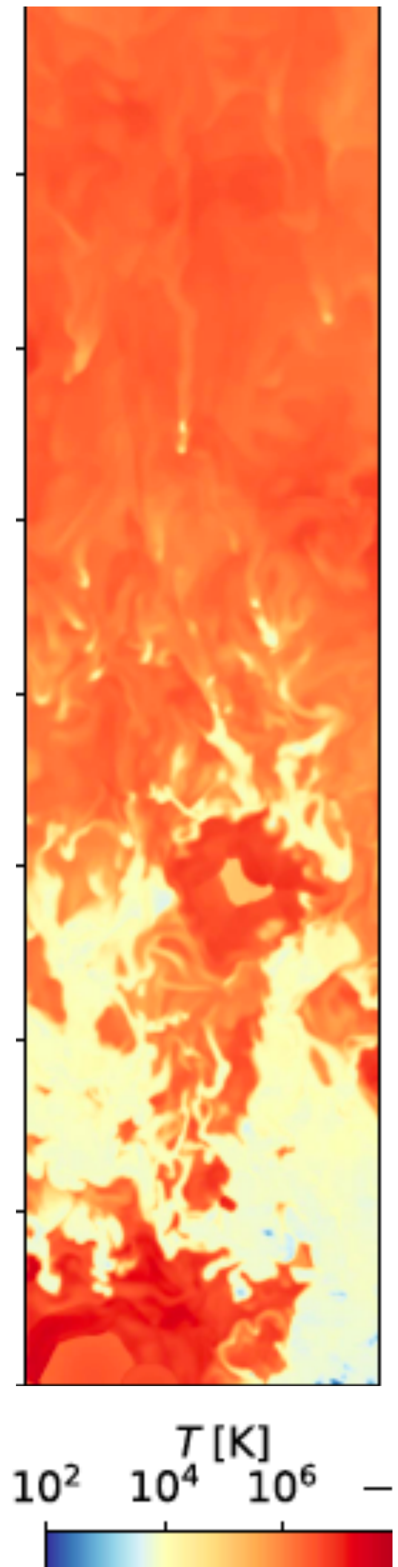
Outflows are multiphase; **hot** outflows occupy large volume



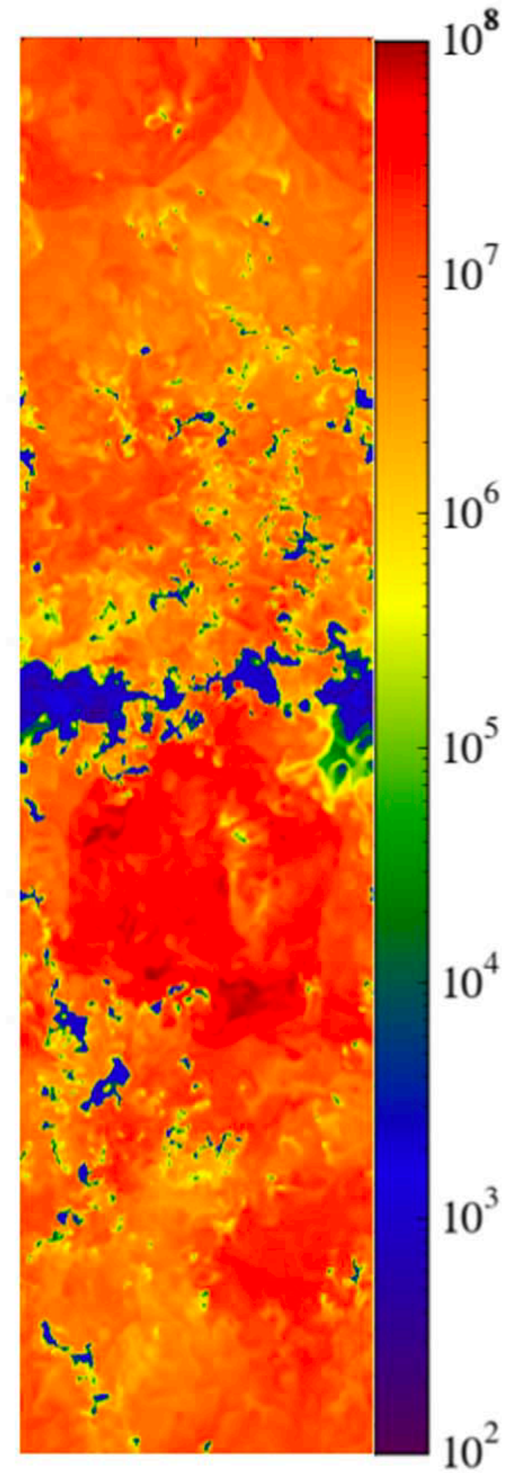
Hu18



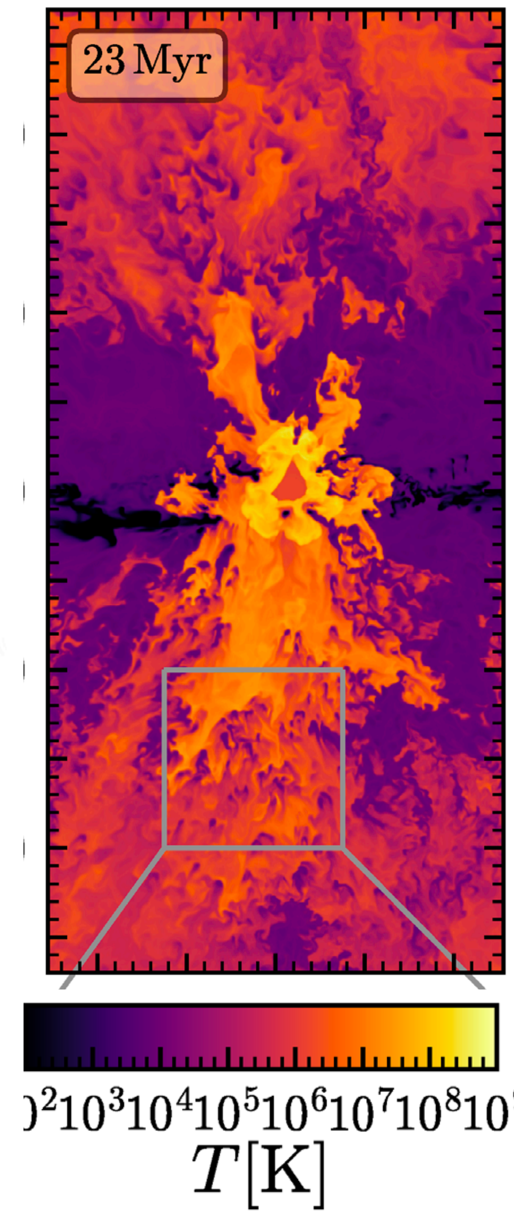
Gatto+15



Kim+18

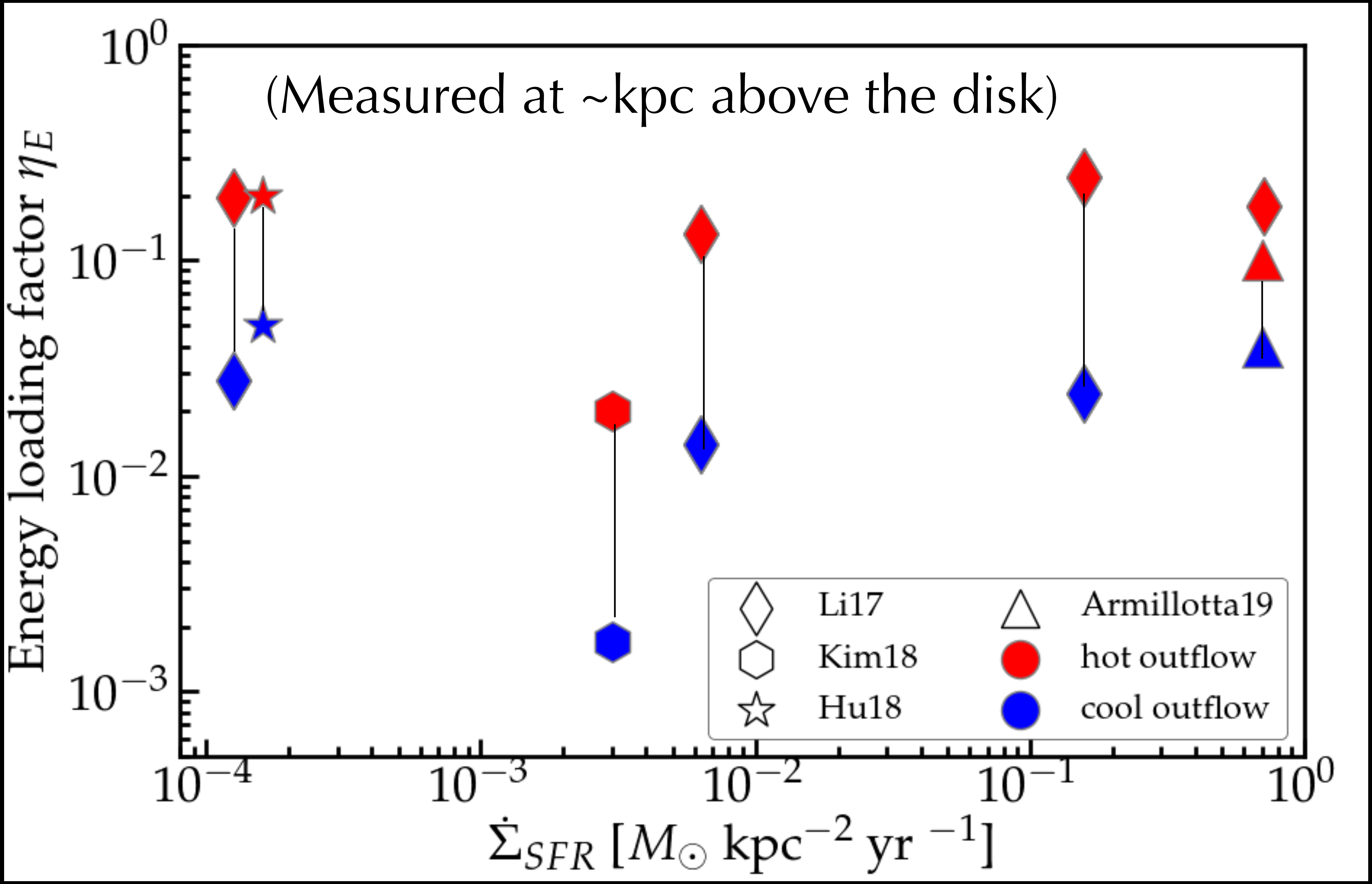


Li+17



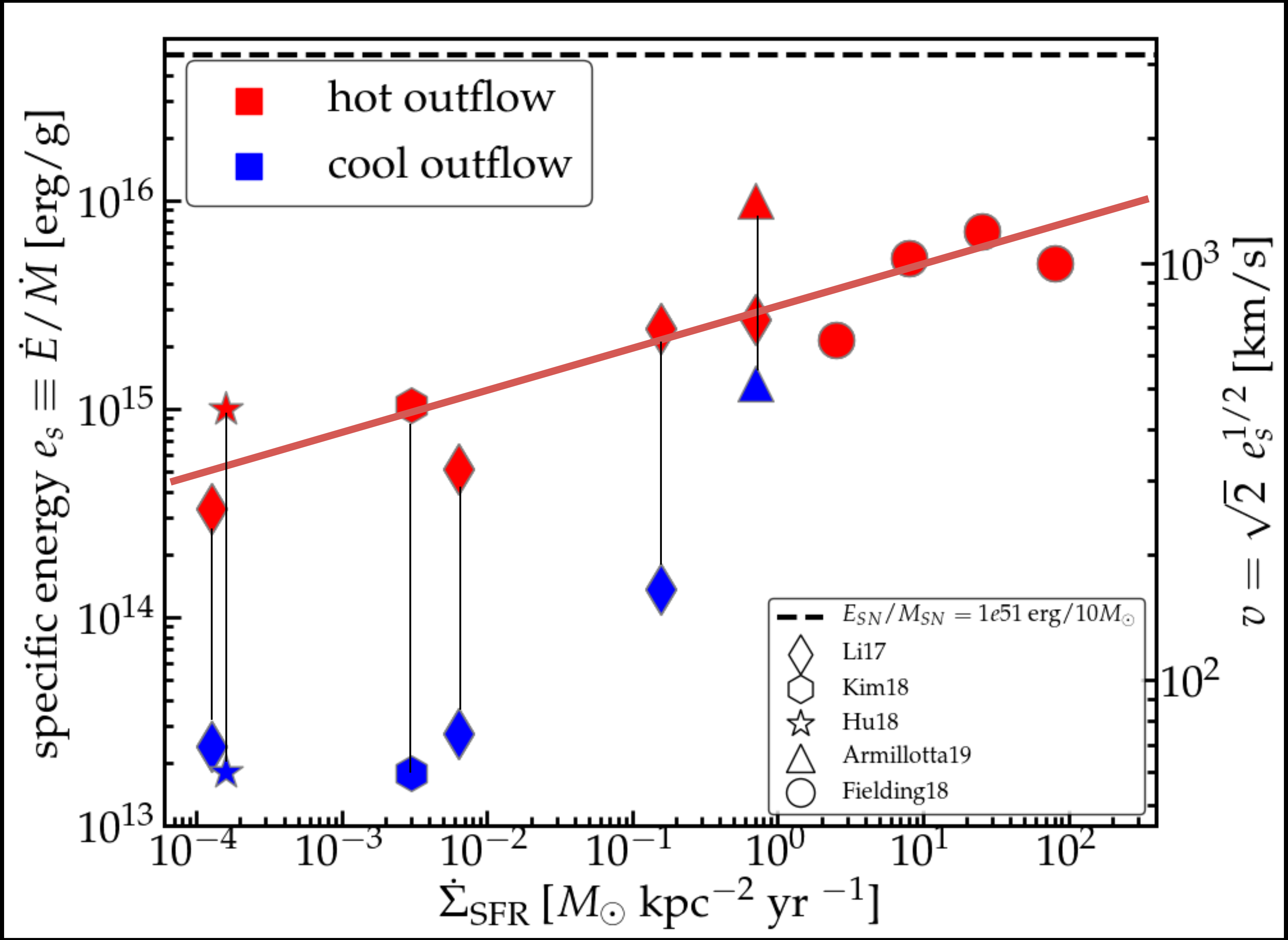
Fielding+18

Hot outflows (~10^6-7 K) carry most SNe energy



Li+, *in prep*

Hot outflows: much larger specific energy, can travel much further



Specific energy increases (slowly) with $\Sigma_{\rm SFR}$

Li+, *in prep*

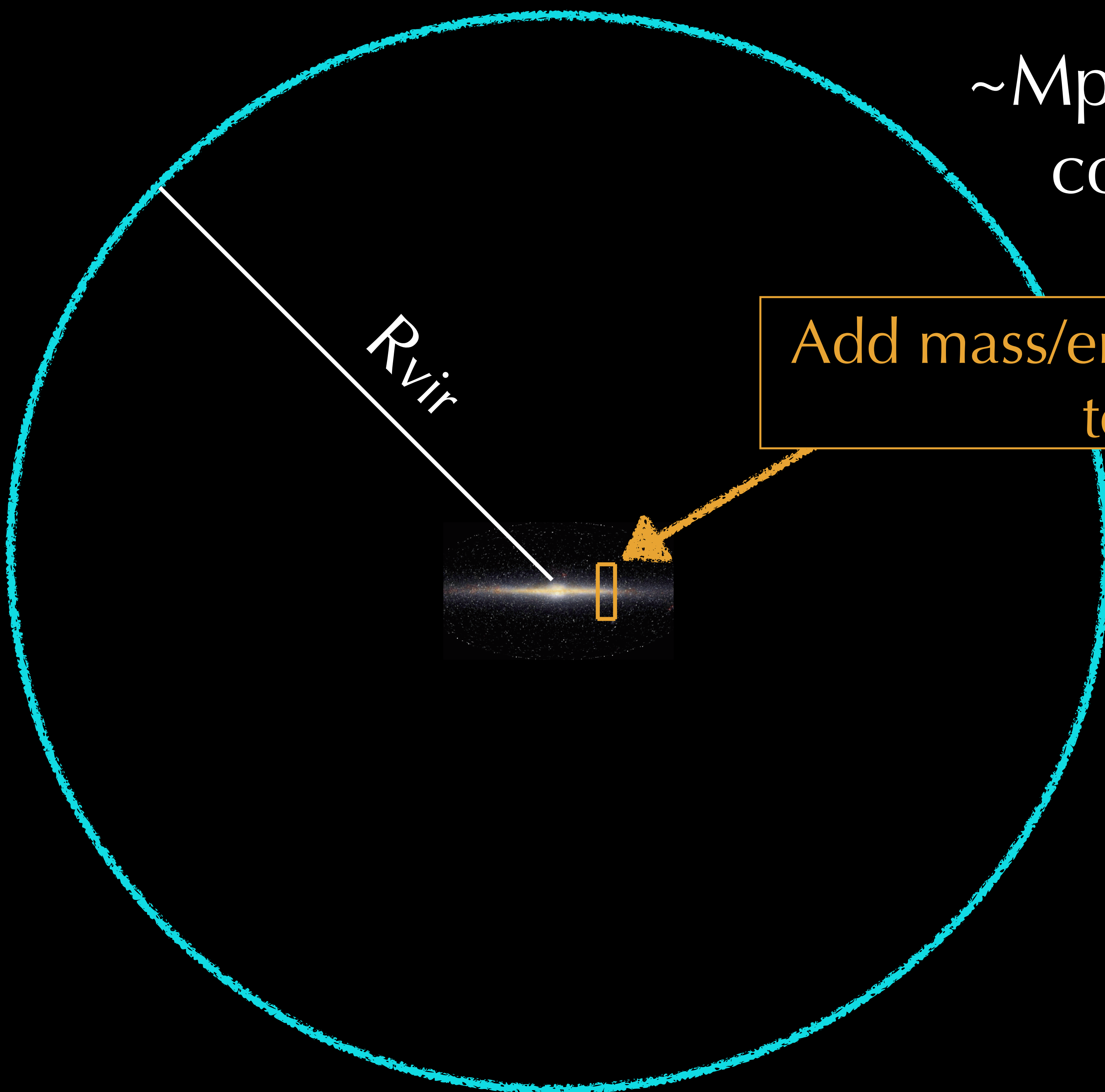
From small boxes

Hot outflows

- carry the majority of SNe energy
- Can travel much further
- Highly metal-enriched, take away ~half metals produced by SNe (Li+17a)

How will hot outflows evolve on large scale?

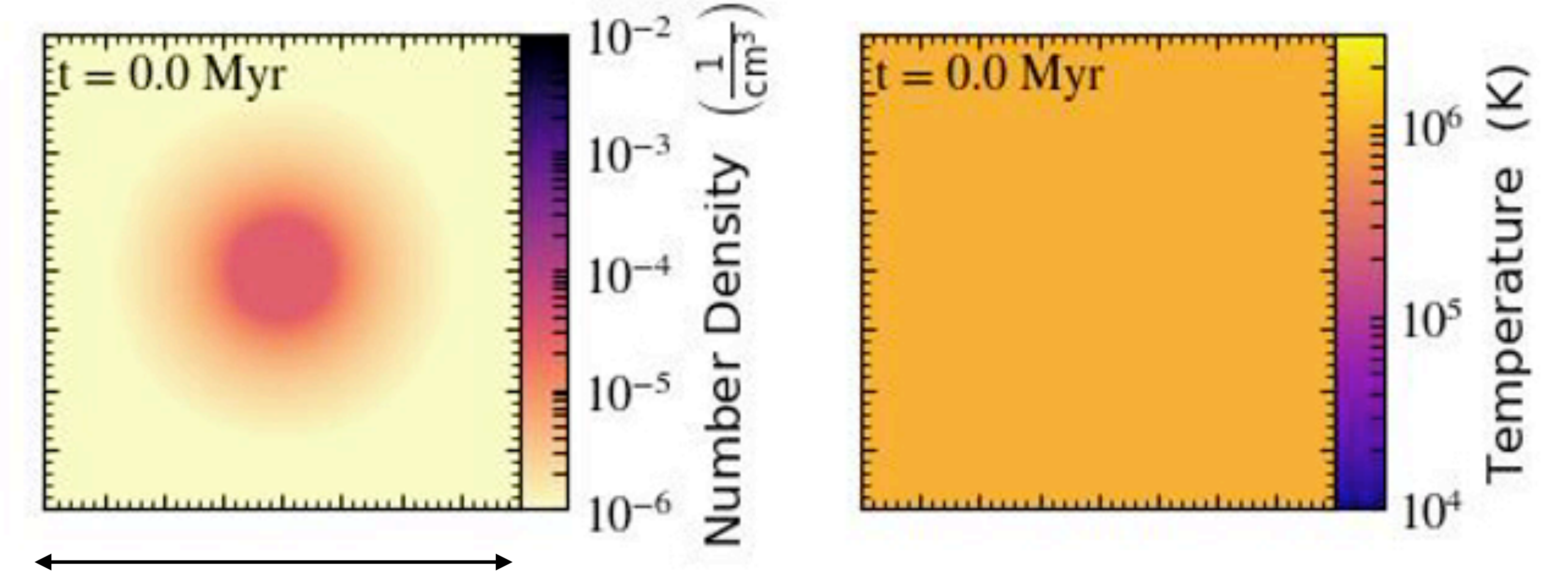
~Mpc box for 10^12 M_{sun} halo,
coarser resolution (0.5kpc)



Add mass/energy/metals fluxes according to small-box results

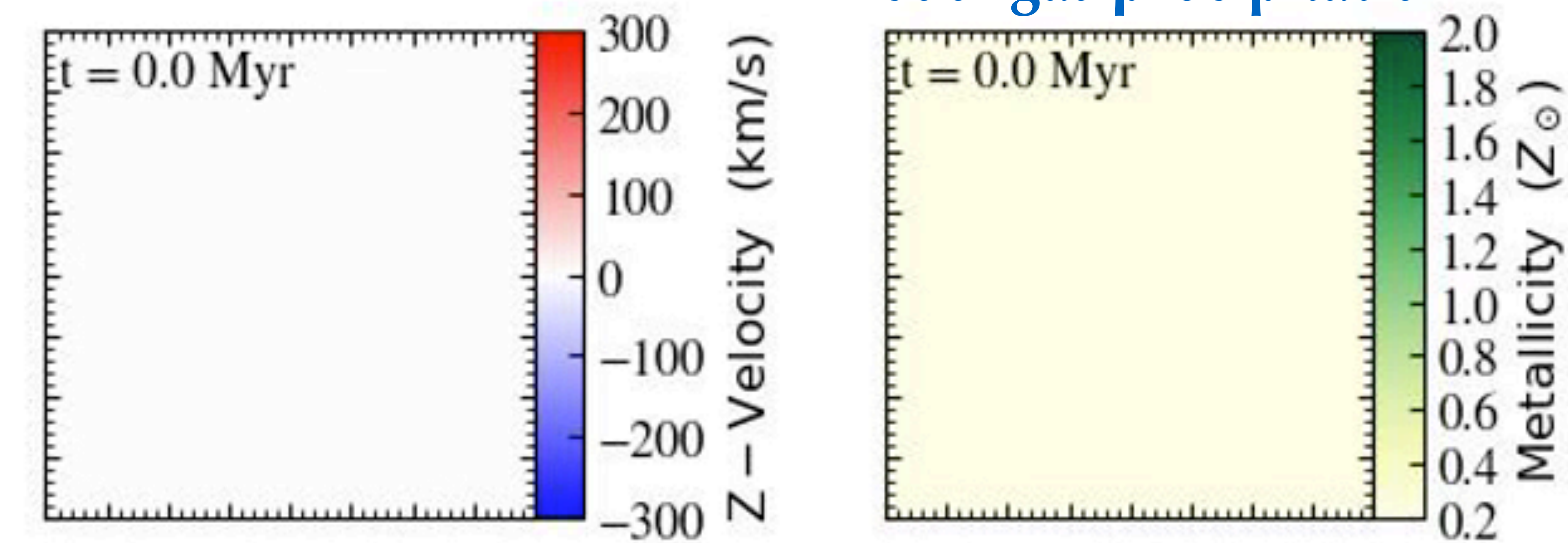
- pre-existing halo gas
  - Mass: free parameter
  - $T=T_{vir}$, $0.2Z_\odot$

image: scienceblog.com



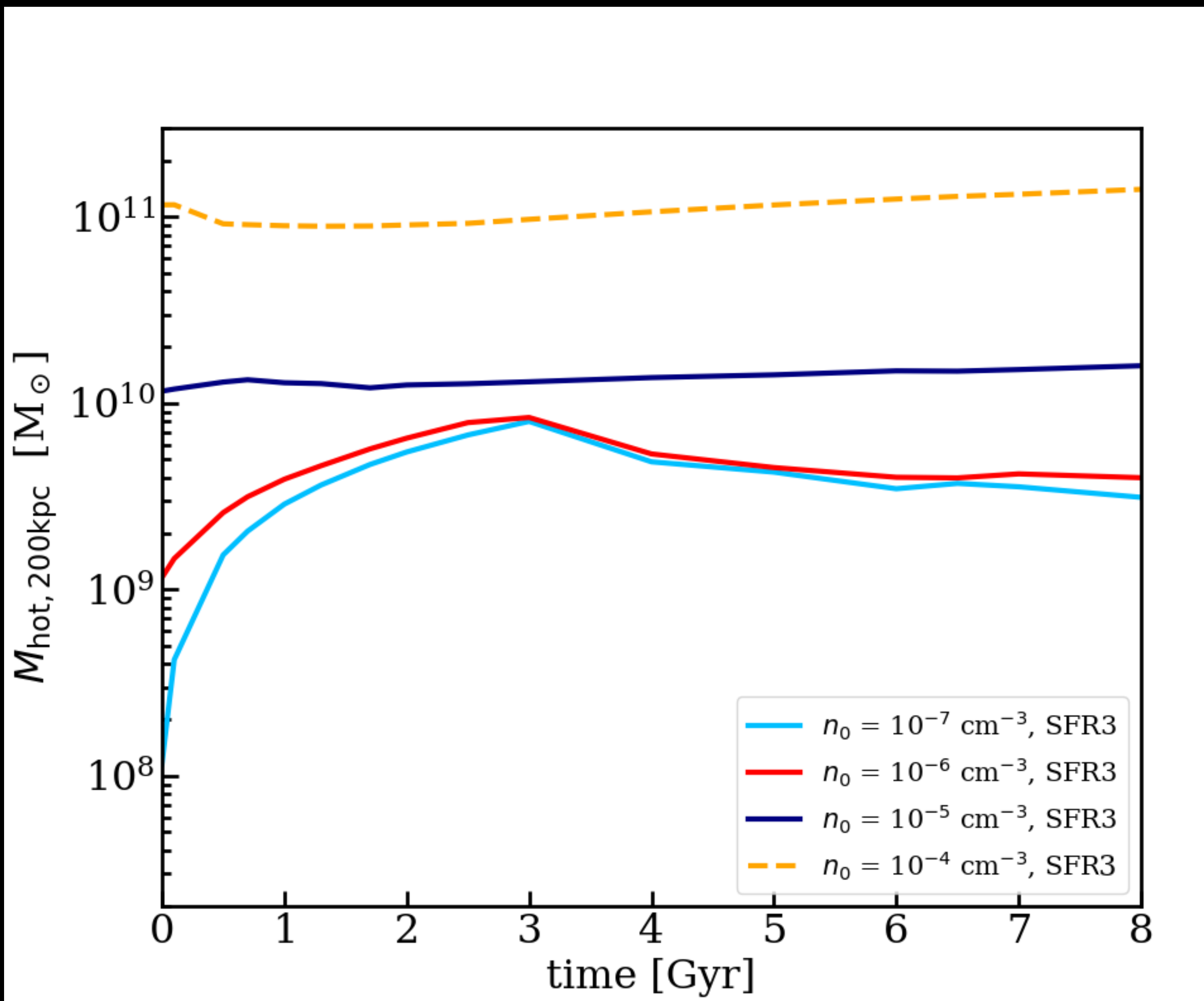
400 kpc
Edge-on view
MW setups, SFR 3 M⊙/yr

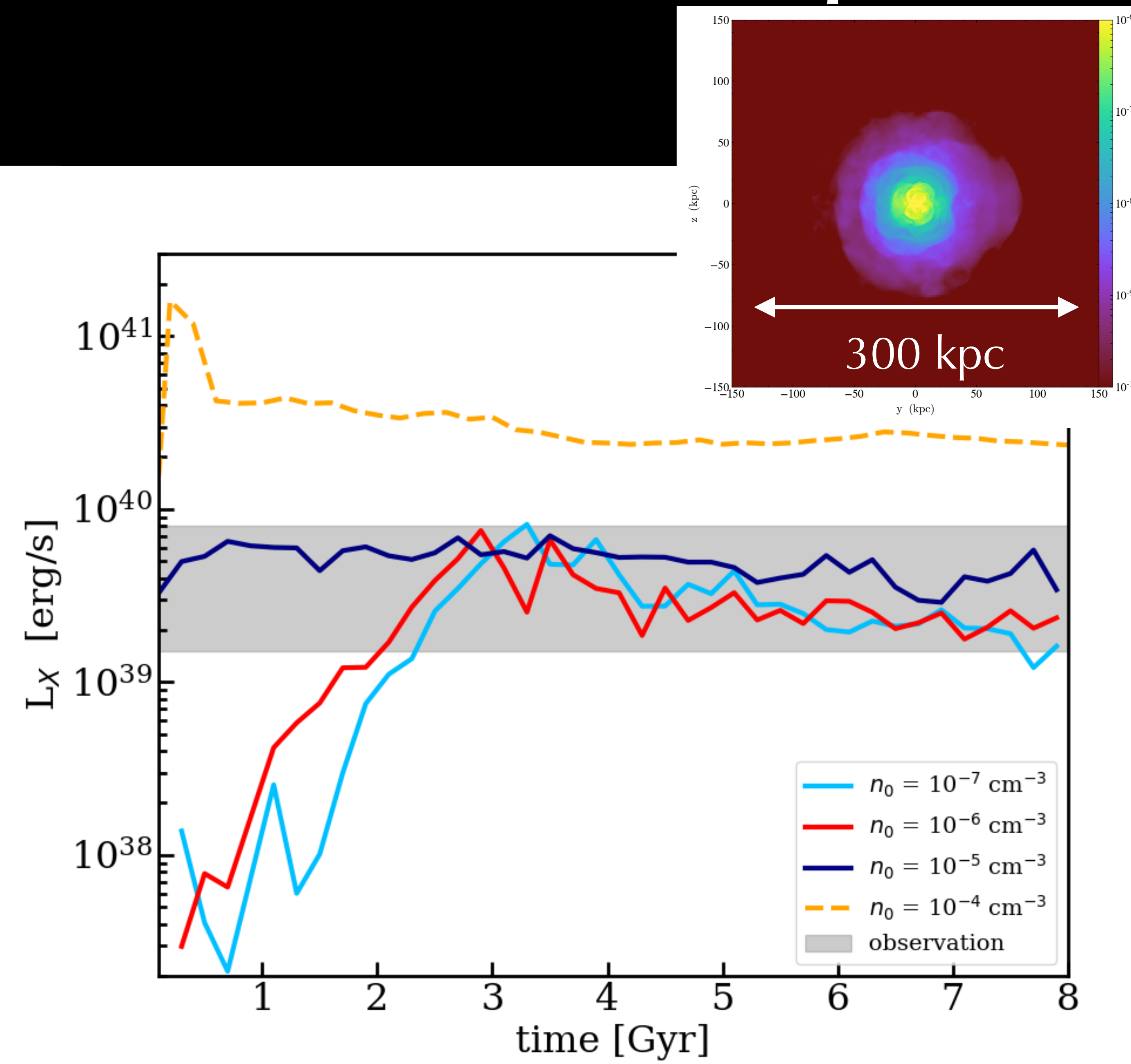
- Fountain flow, metals go R~130 kpc
- **Hot gas saturation & cool gas precipitation**



CGM mass at R<200 kpc

Most X-ray emission: < several 10s kpc



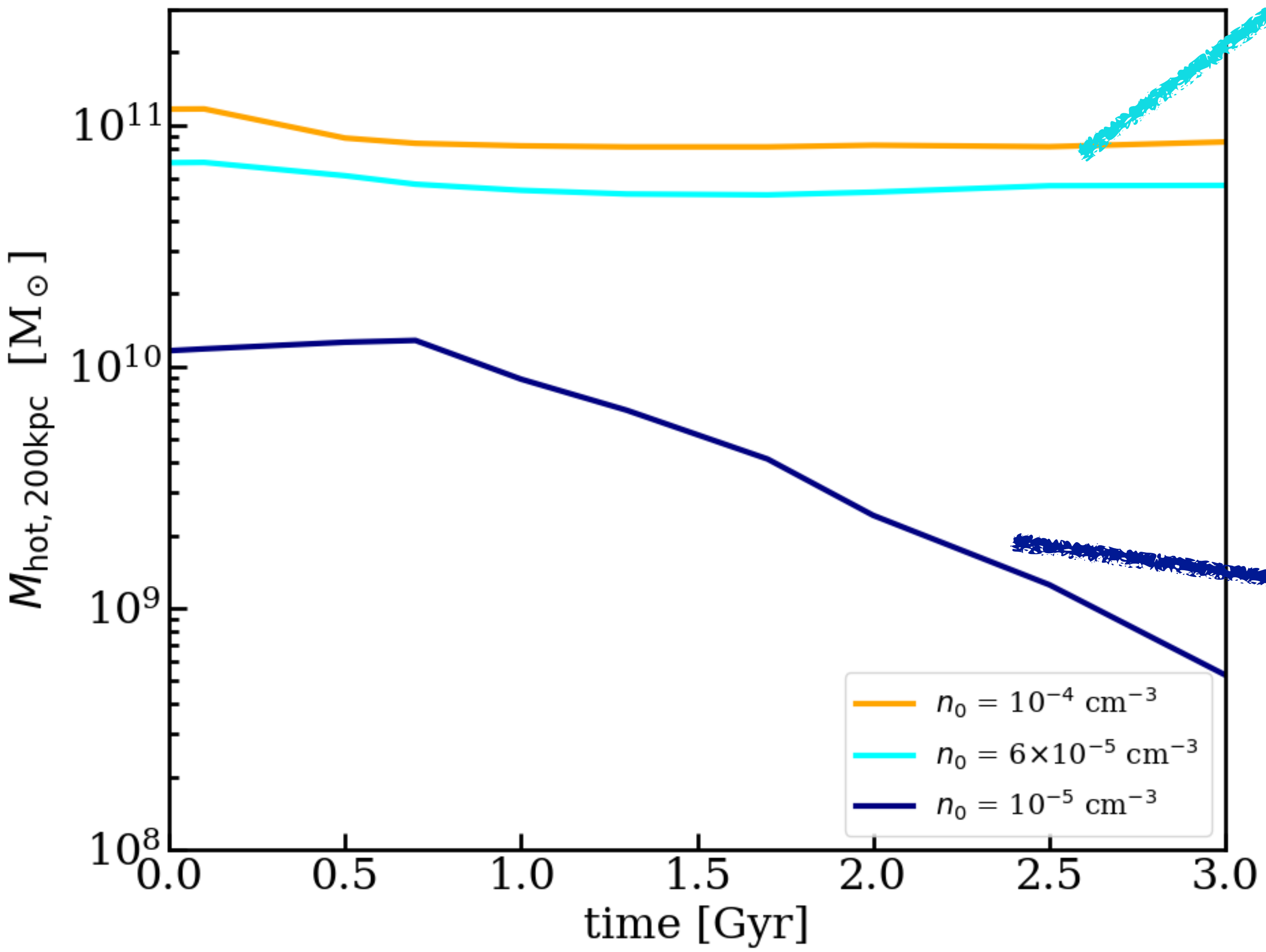


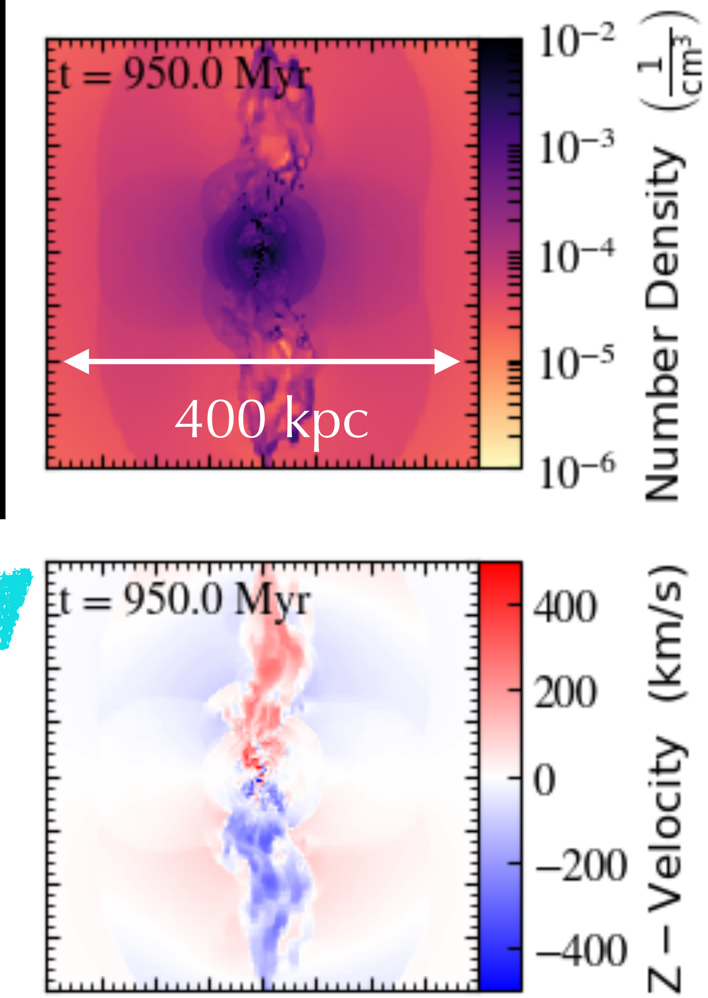
Lx: reflects total warm-hot mass in DM halo

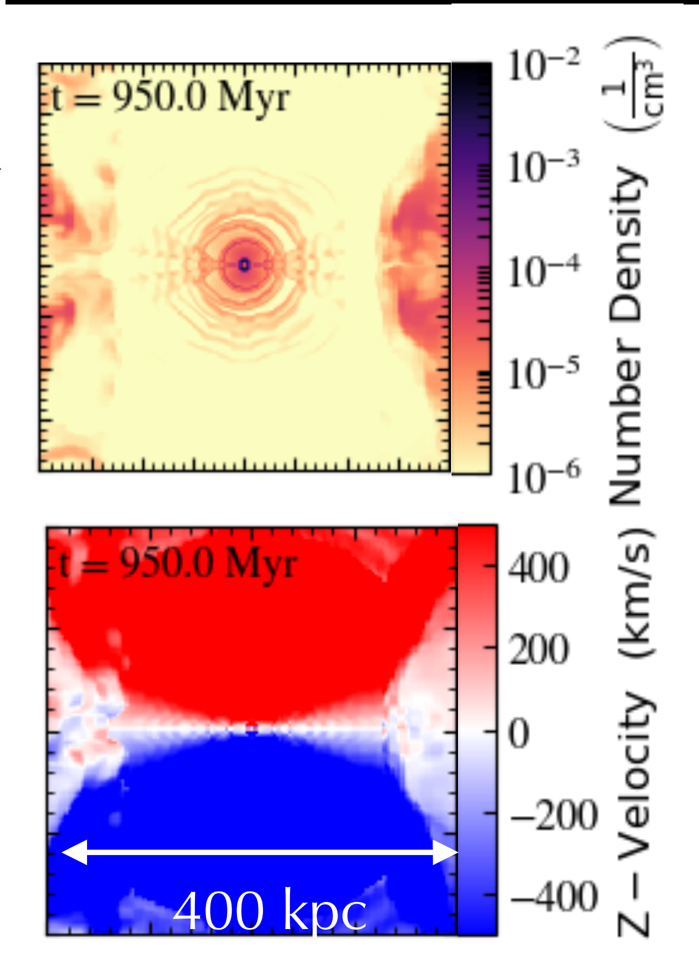
Li+, *in prep*

When outflows are unbound…

SFR=10 Msun/yr, large ΣSFR







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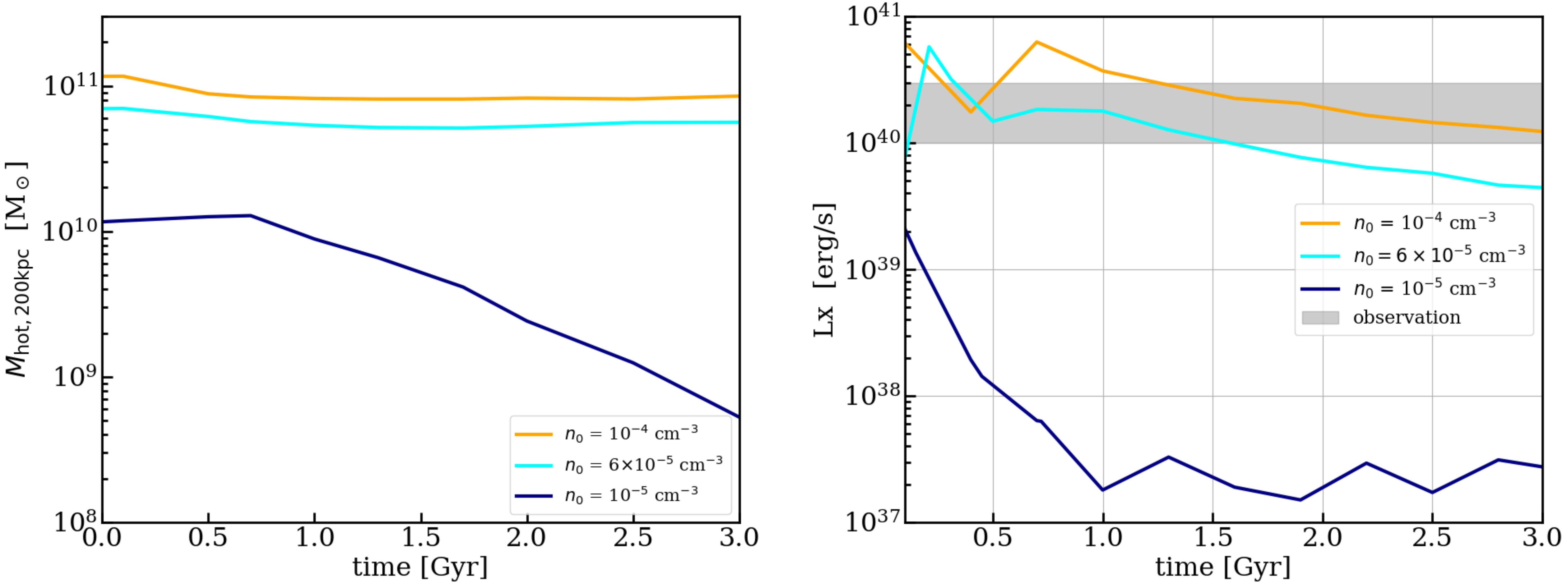
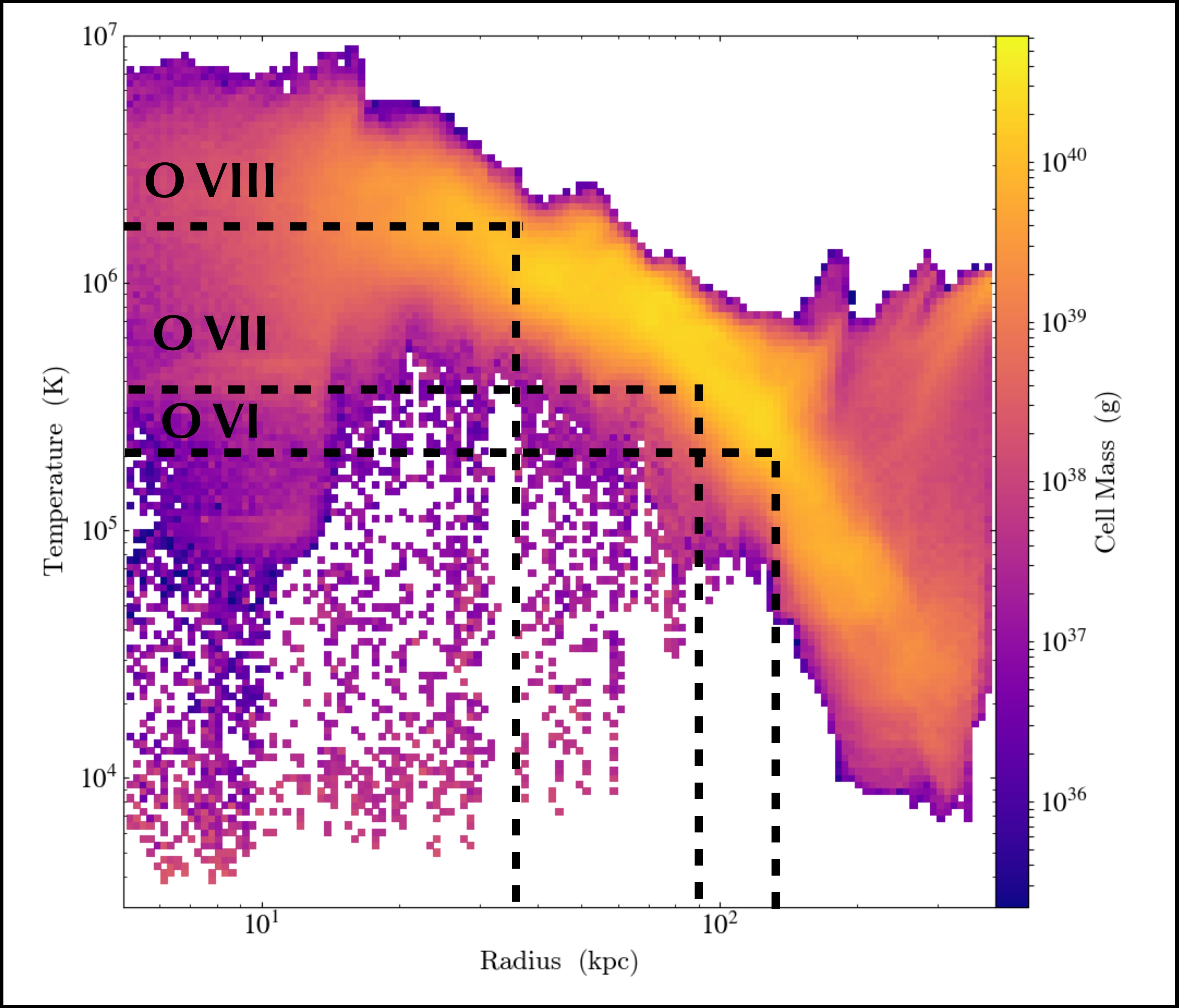


Lx supports a large CGM mass, close to cosmic baryon fraction.
(see Das+18 observation of NGC 3221 reaching similar conclusion)

Absorption lines
(Milky Way case)

fountain flow: T decreases with radius



Due to Adiabatic expansion

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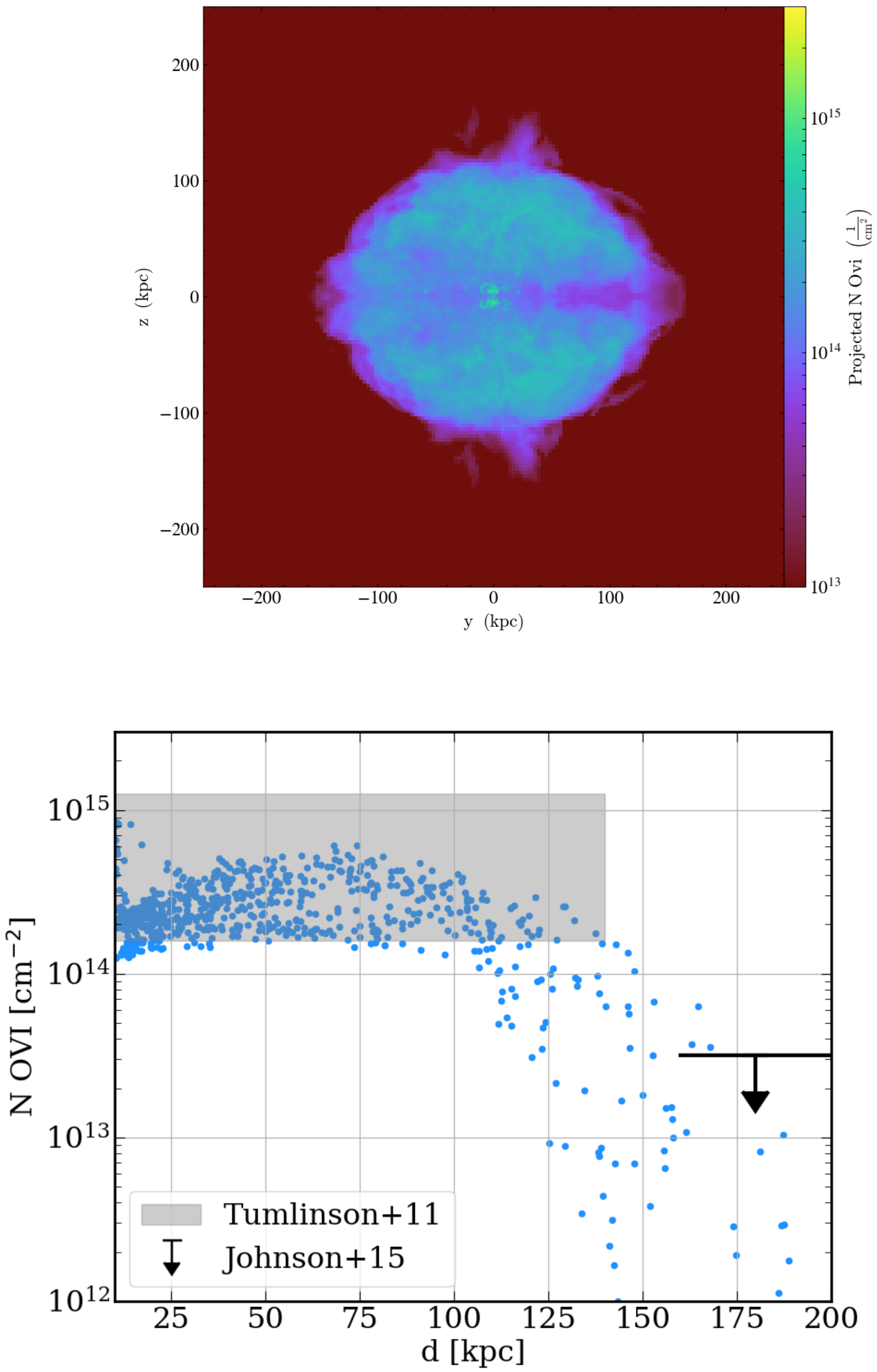
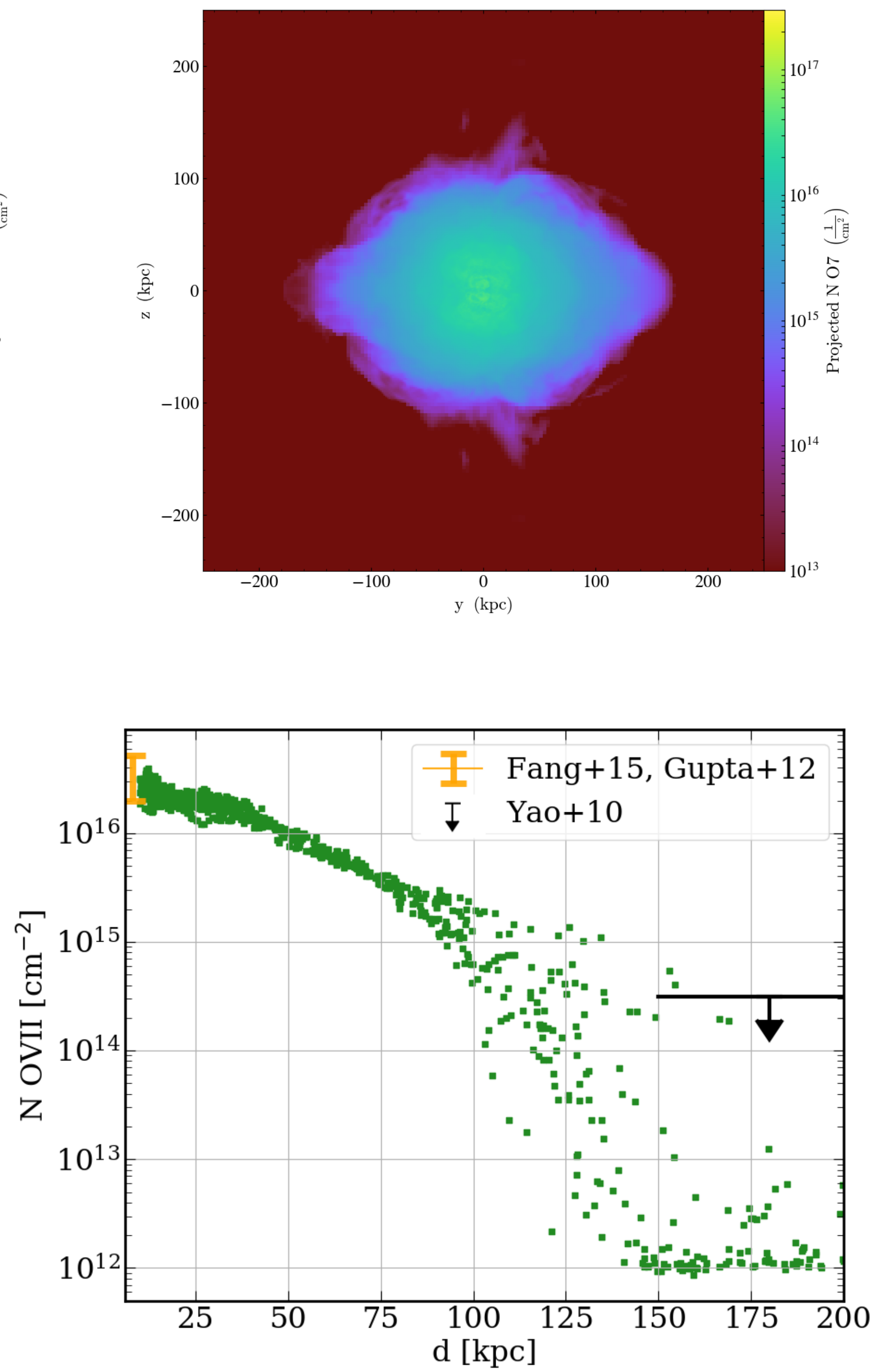
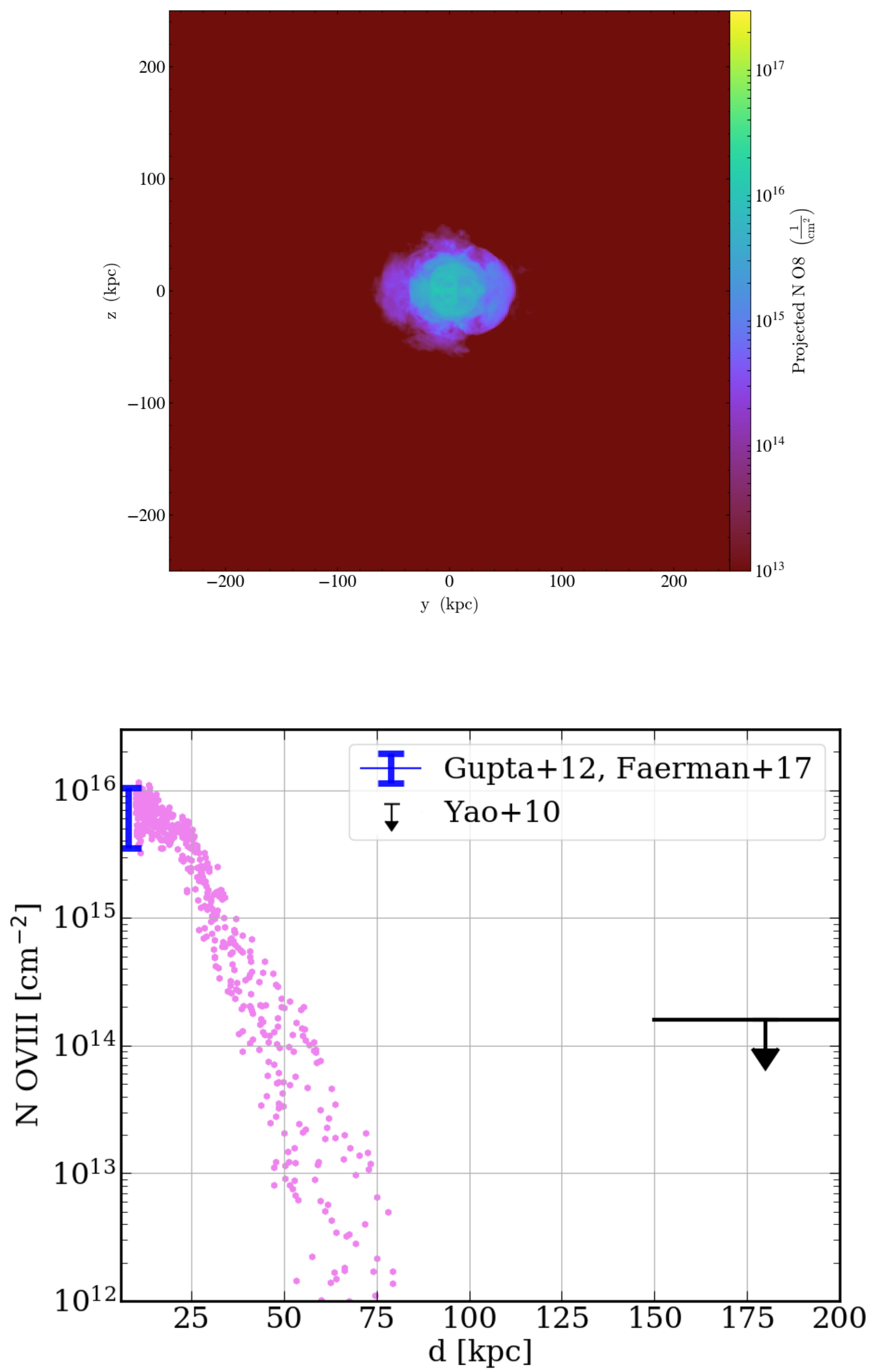
N OVI



N OVII



N OVIII



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Today

- hot outflows dominates the energy flux
- Bound vs. unbound outflows -> spherical fountain vs. (bipolar) breakout
- Lx probes total baryon mass in the halo
- Column densities of different ionization states, e.g., O VI, O VII, O VIII, probe T profile

Future — Feedback physics, missing baryon, missing metals

- **eV resolution @ 0.7keV— line studies for CGM of star-forming galaxies**
  - **Velocity: several 100s km/s**
  - **Metal abundances**
- **Higher sensitivity & large area — emission at larger radii**

Fountain flow case