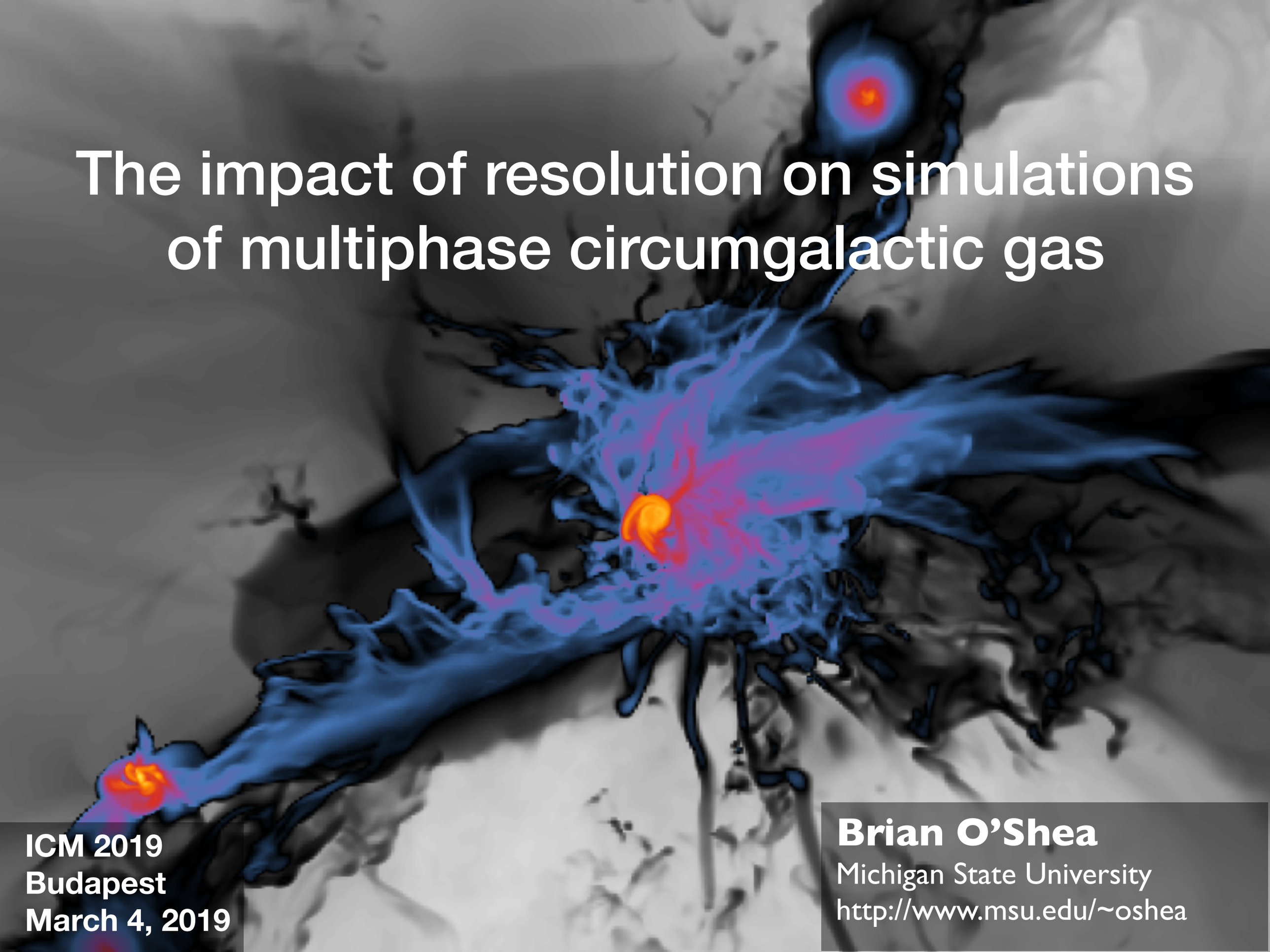
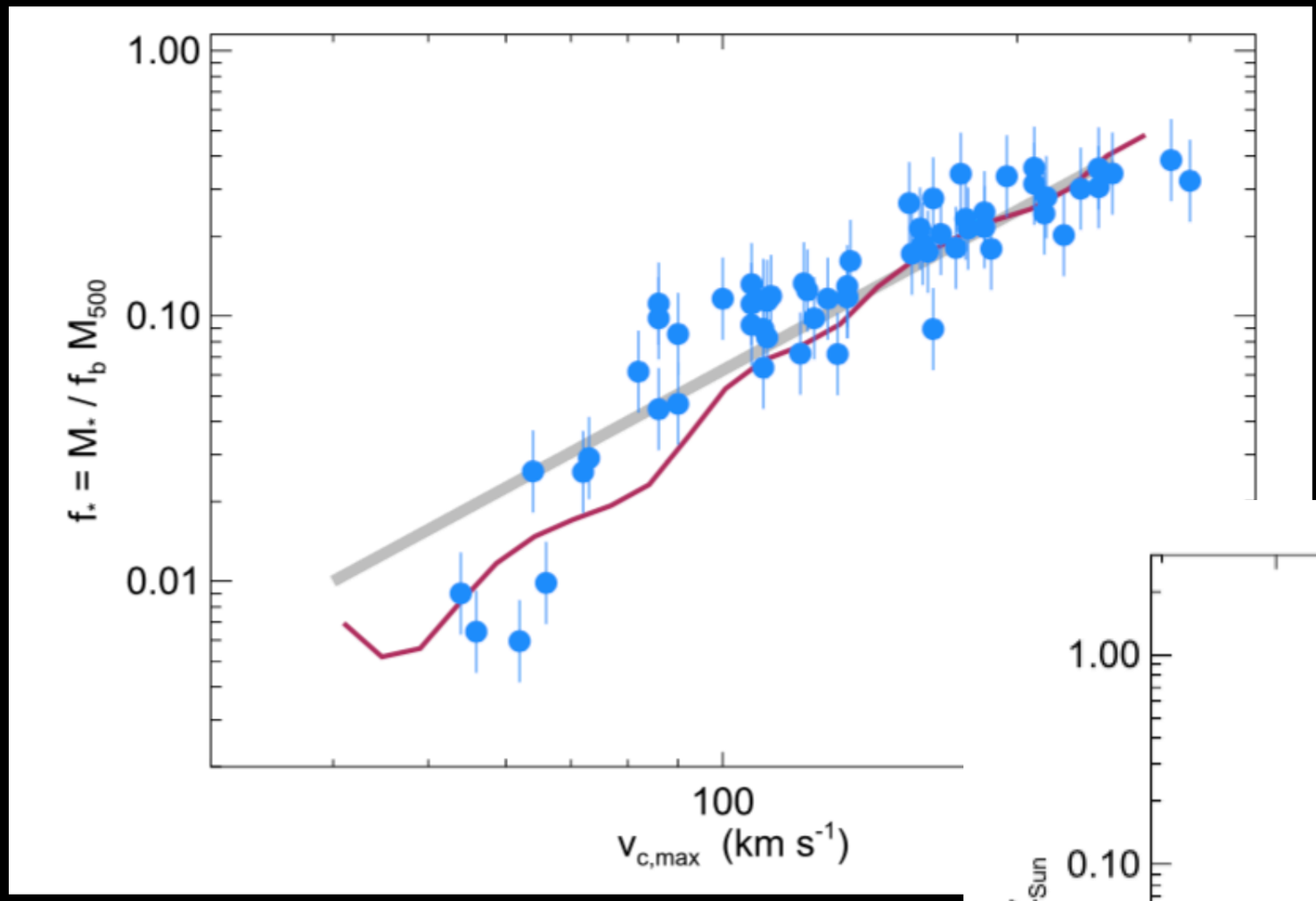
The impact of resolution on simulations of multiphase circumgalactic gas

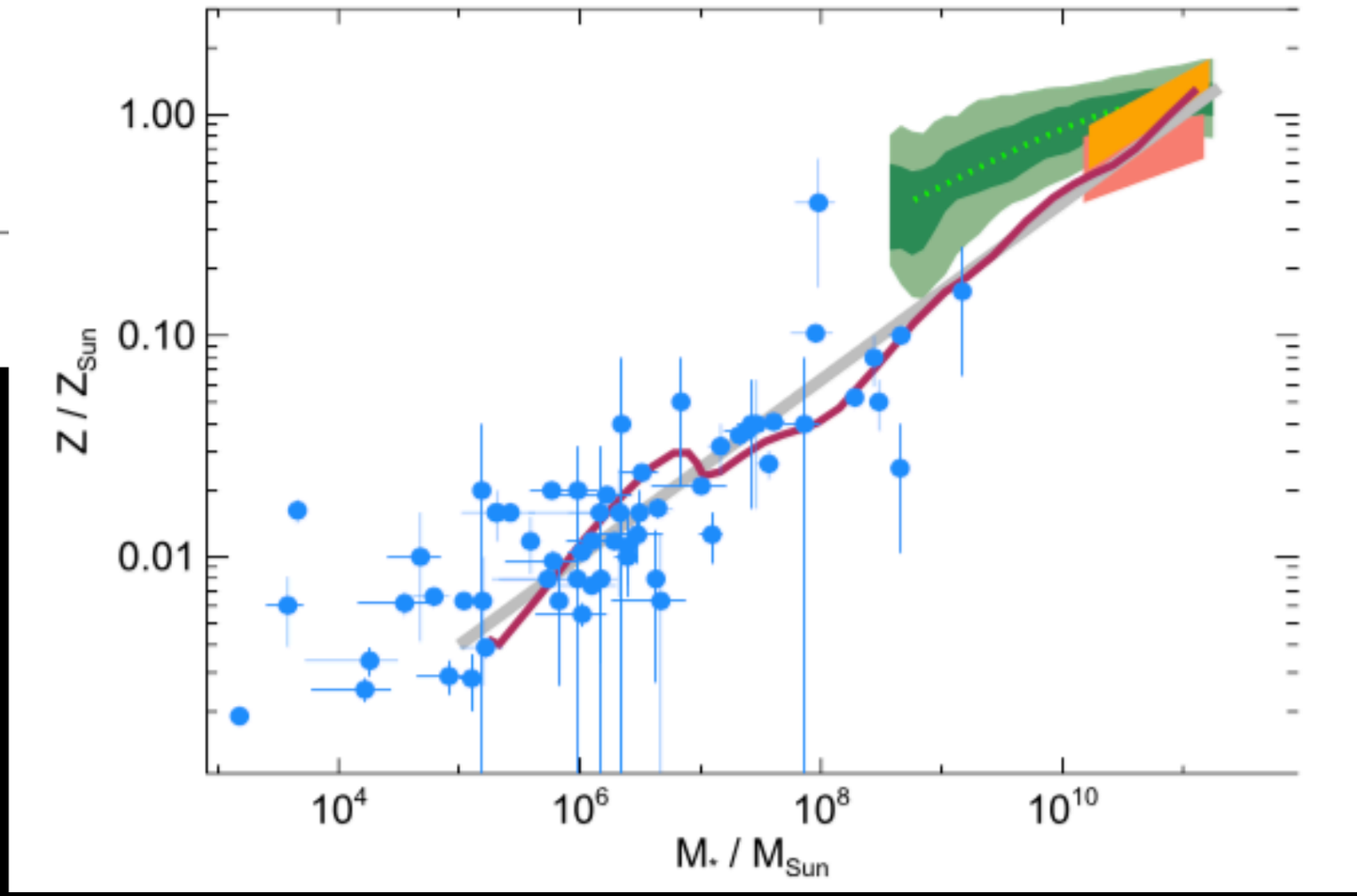


ICM 2019
Budapest
March 4, 2019

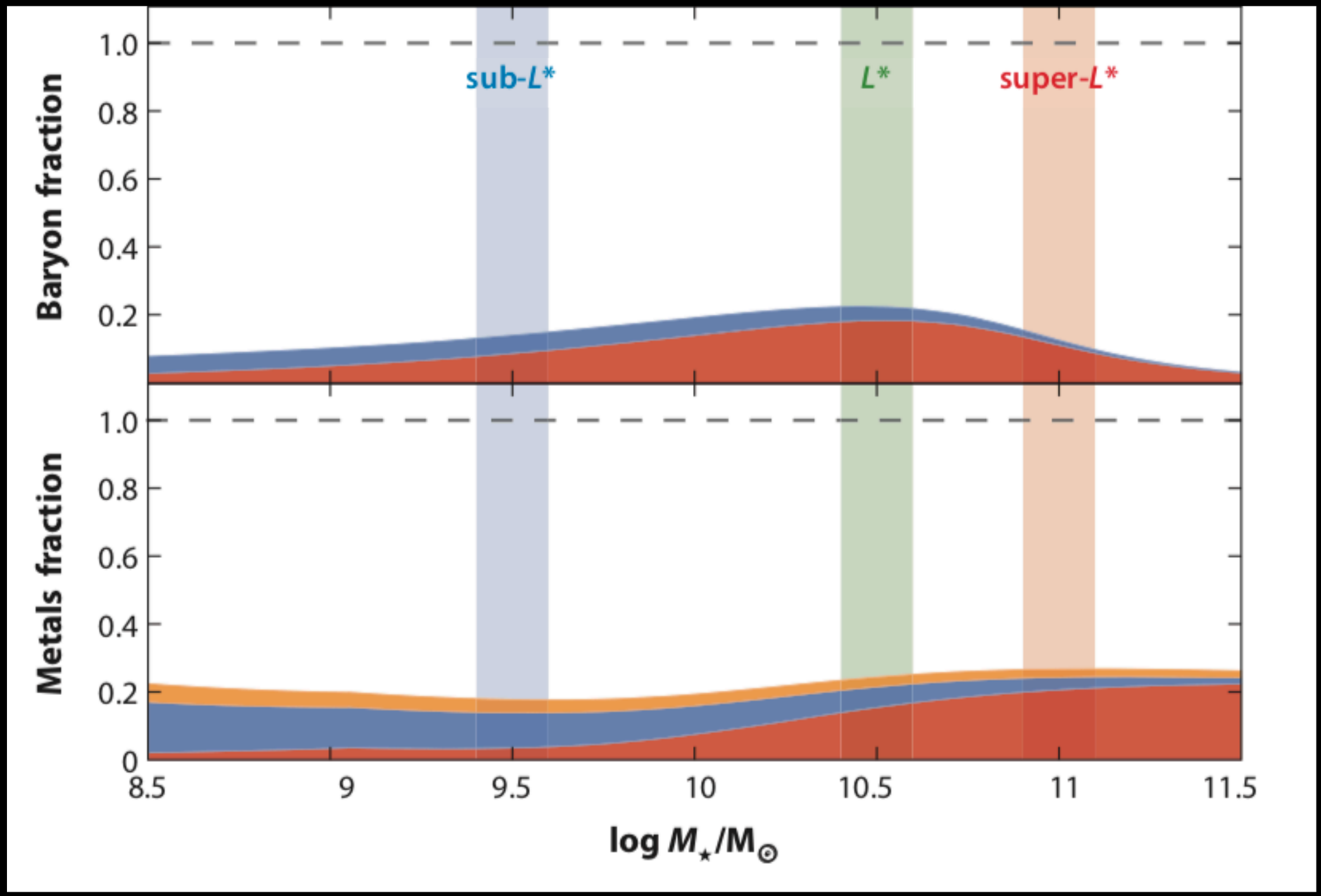
Brian O'Shea
Michigan State University
http://www.msu.edu/~oshea

Galaxies and the CGM





Voit et al. 2015, ApJL, 808:L30



Galactic (disk) baryon fraction

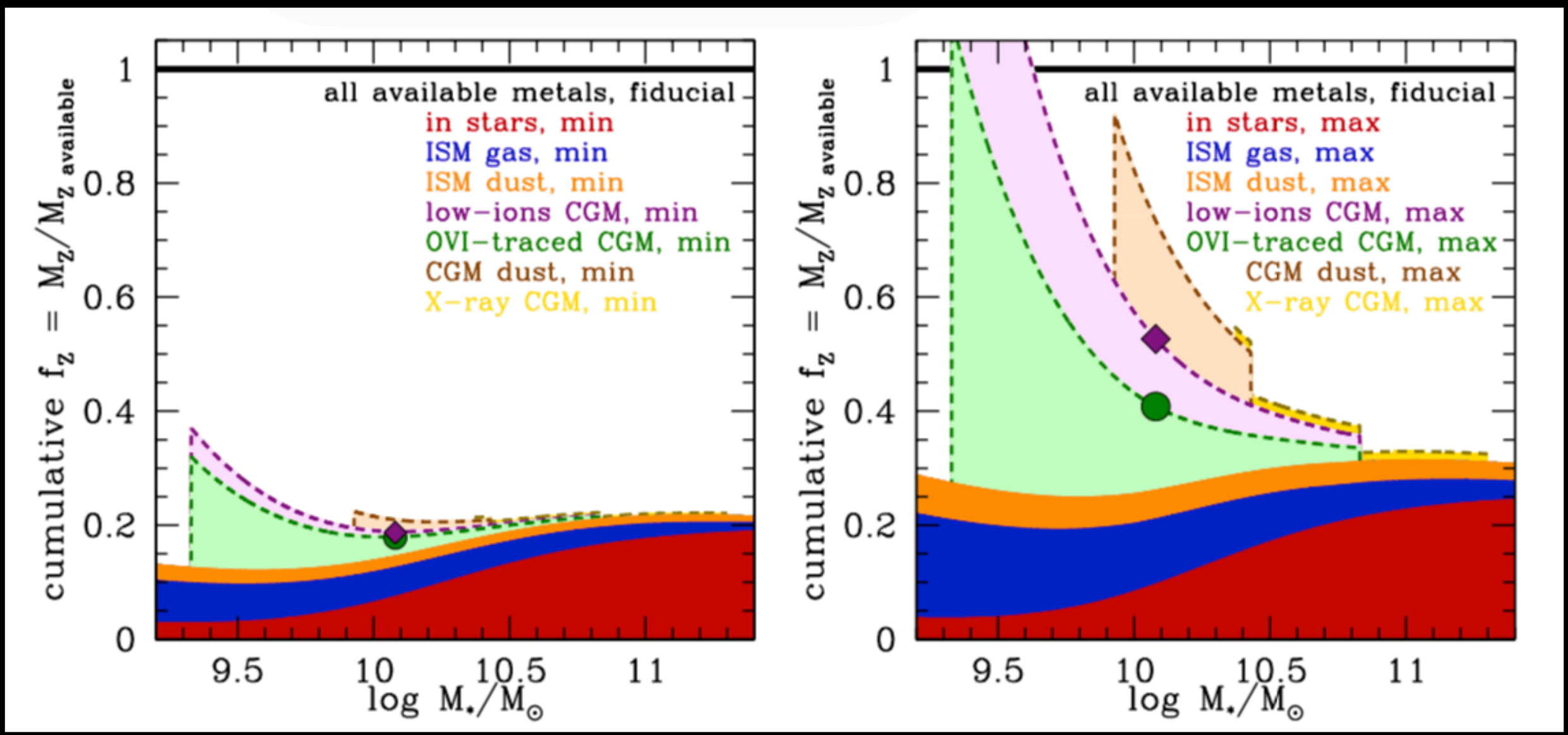
"retained metals" fraction

Stars

ISM gas

ISM Dust

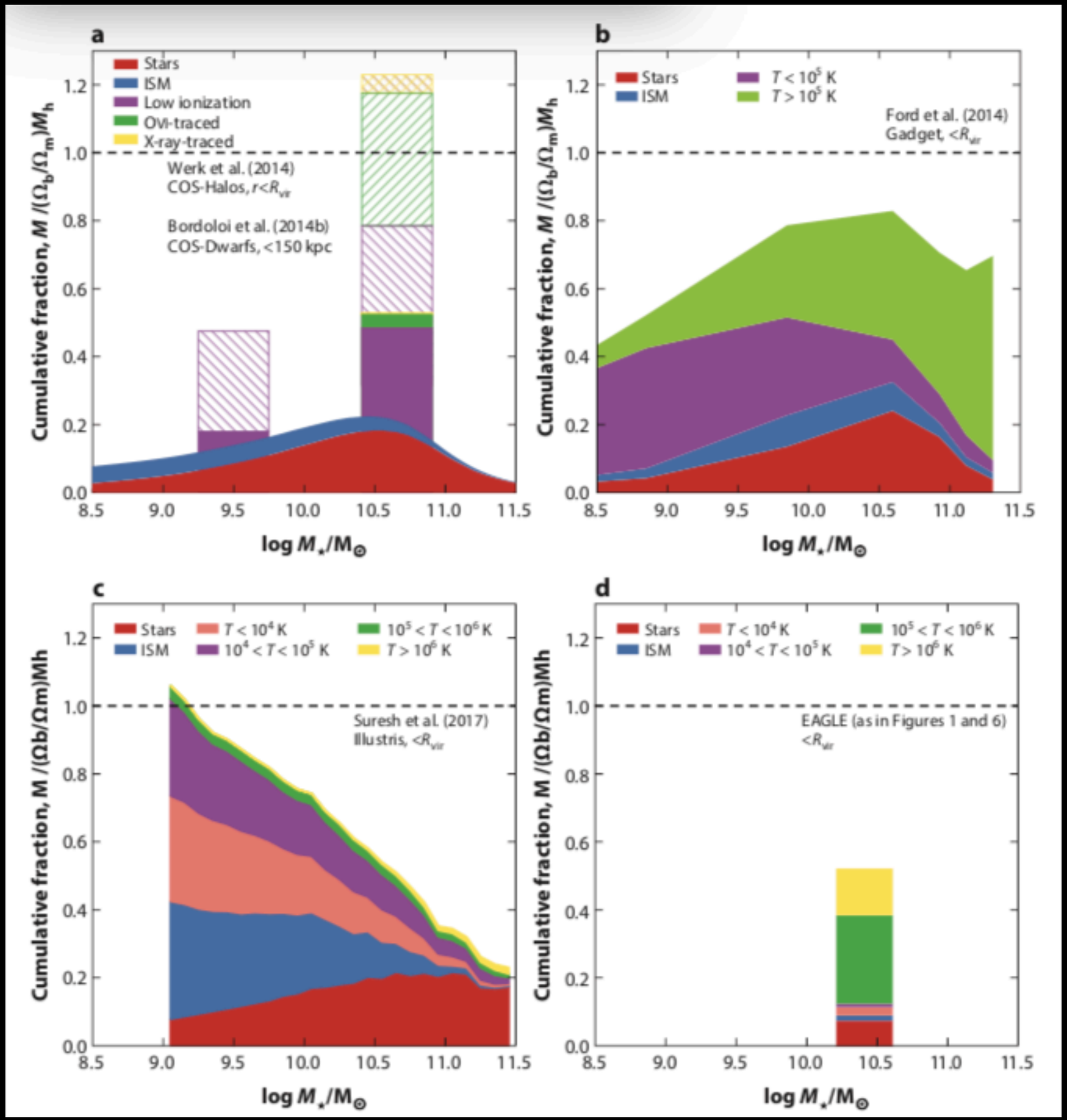
Tumlinson, Peeples & Werk (2017), ARA&A



Peeples et al. 2014, ApJ, 786:54

Do simulations agree with these observations?

Observations



Ford+ 2014 Simulations

Illustris Simulations

EAGLE Simulations

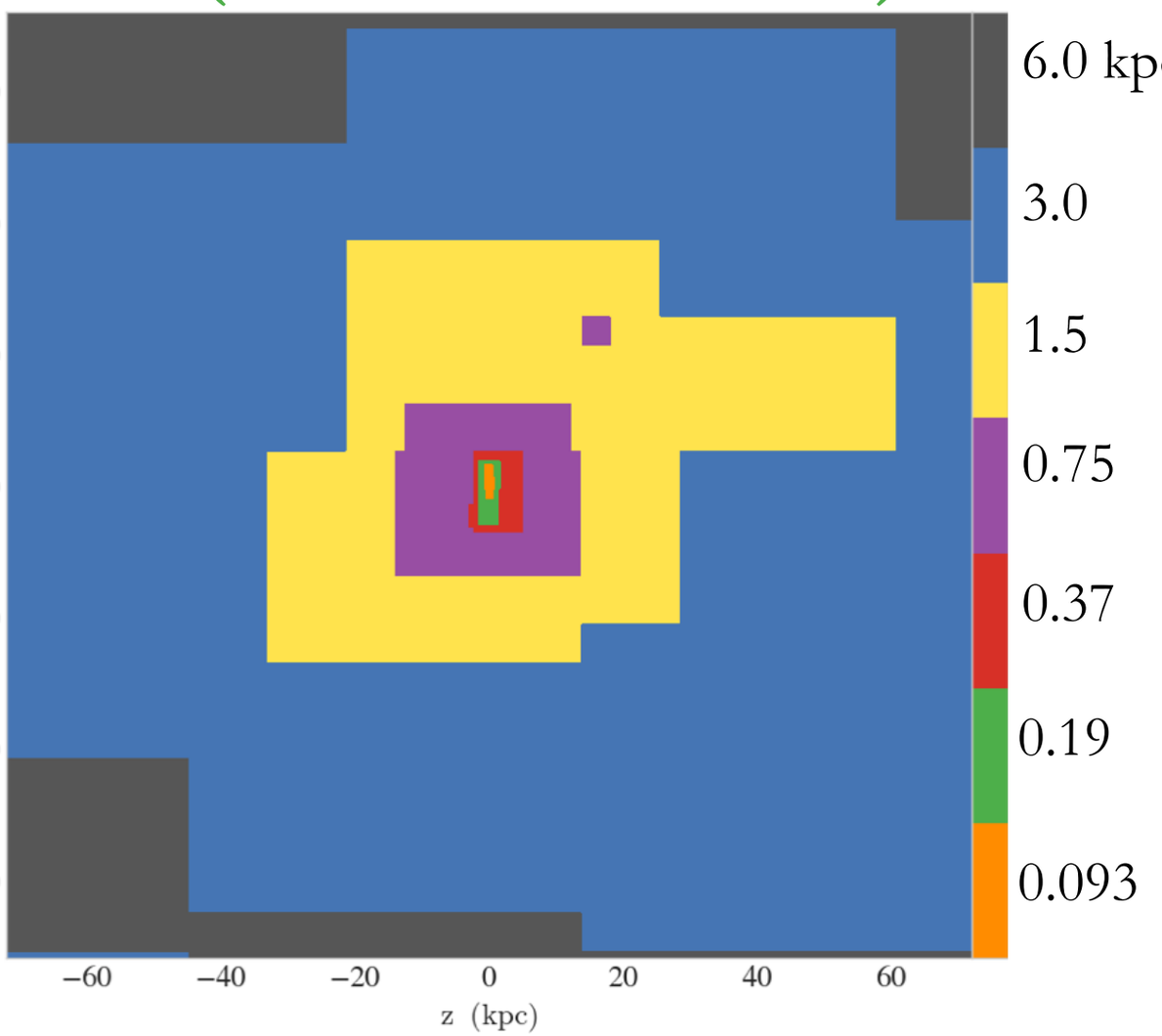
Tumlinson, Peeples & Werk (2017), ARA&A

Our attempts to understand the CGM with (cosmological, AMR, very highly resolved) simulations

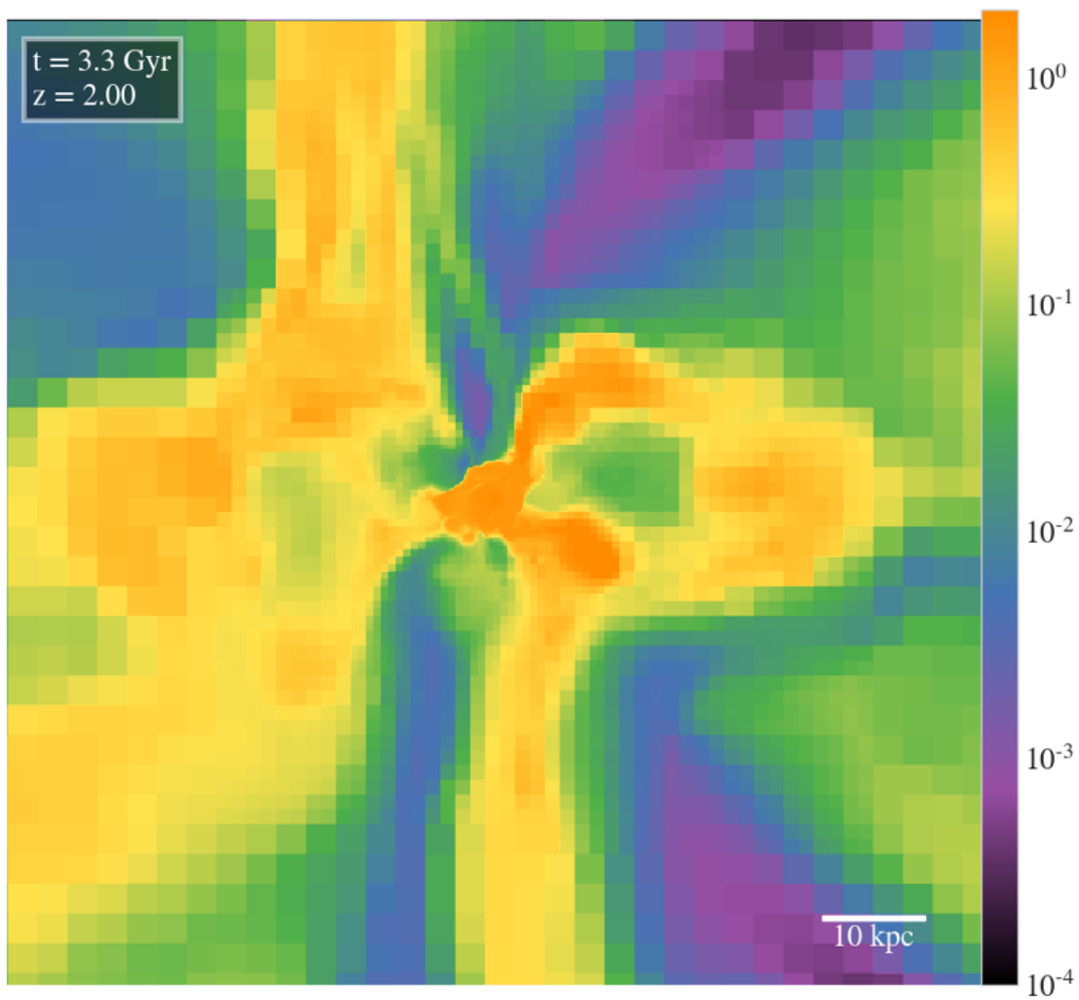
Peeples et al. 2019 (ApJ, accepted; arXiv:1810.06566)
Corlies et al. 2019 (ApJ, submitted; arXiv:1811.05060)
Hummels et al. 2019 (ApJ, submitted; 1811.12410)

Forcing high resolution

Spatial size of "cells" (resolution elements):

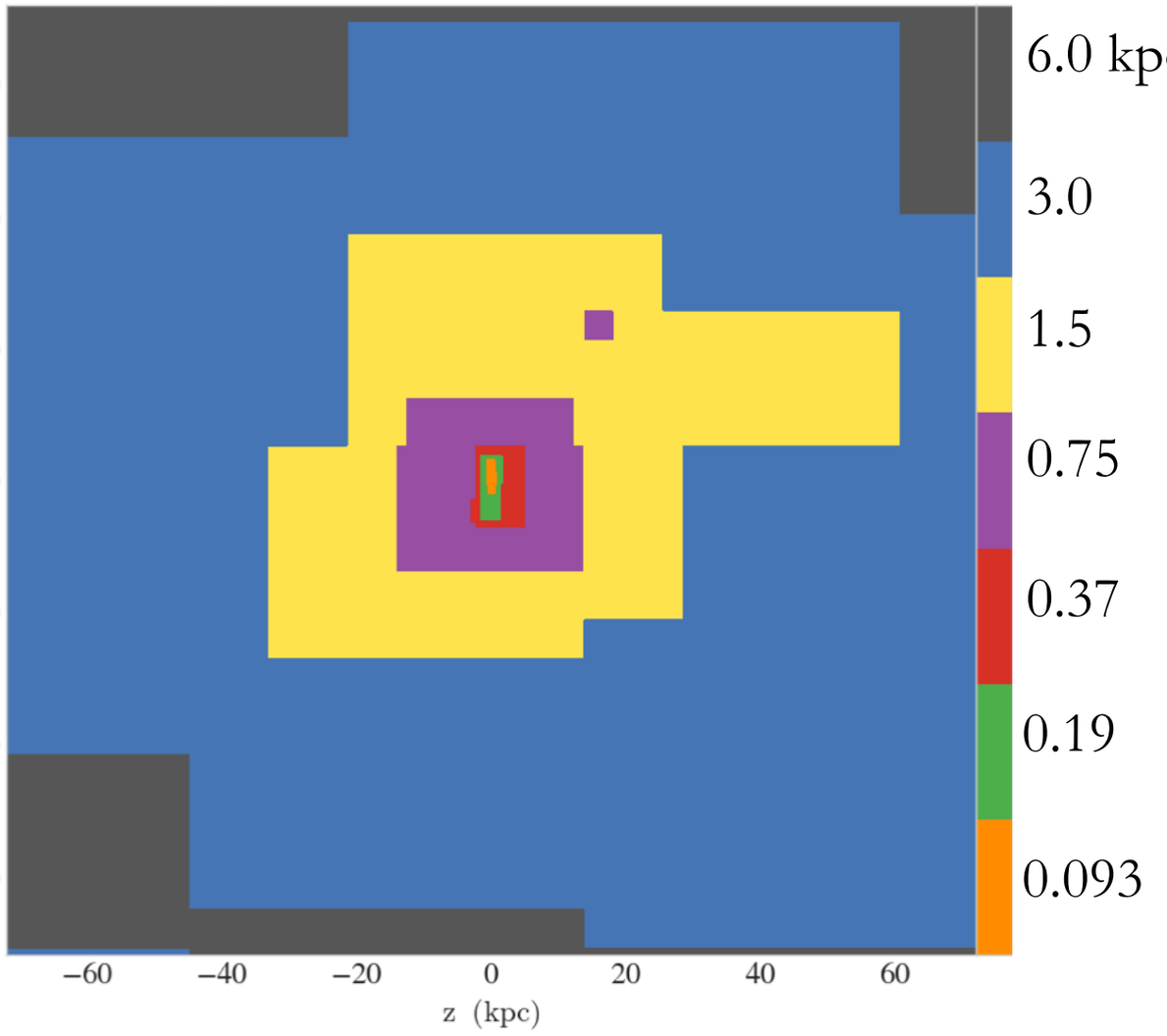


Slice of gas metallicity:

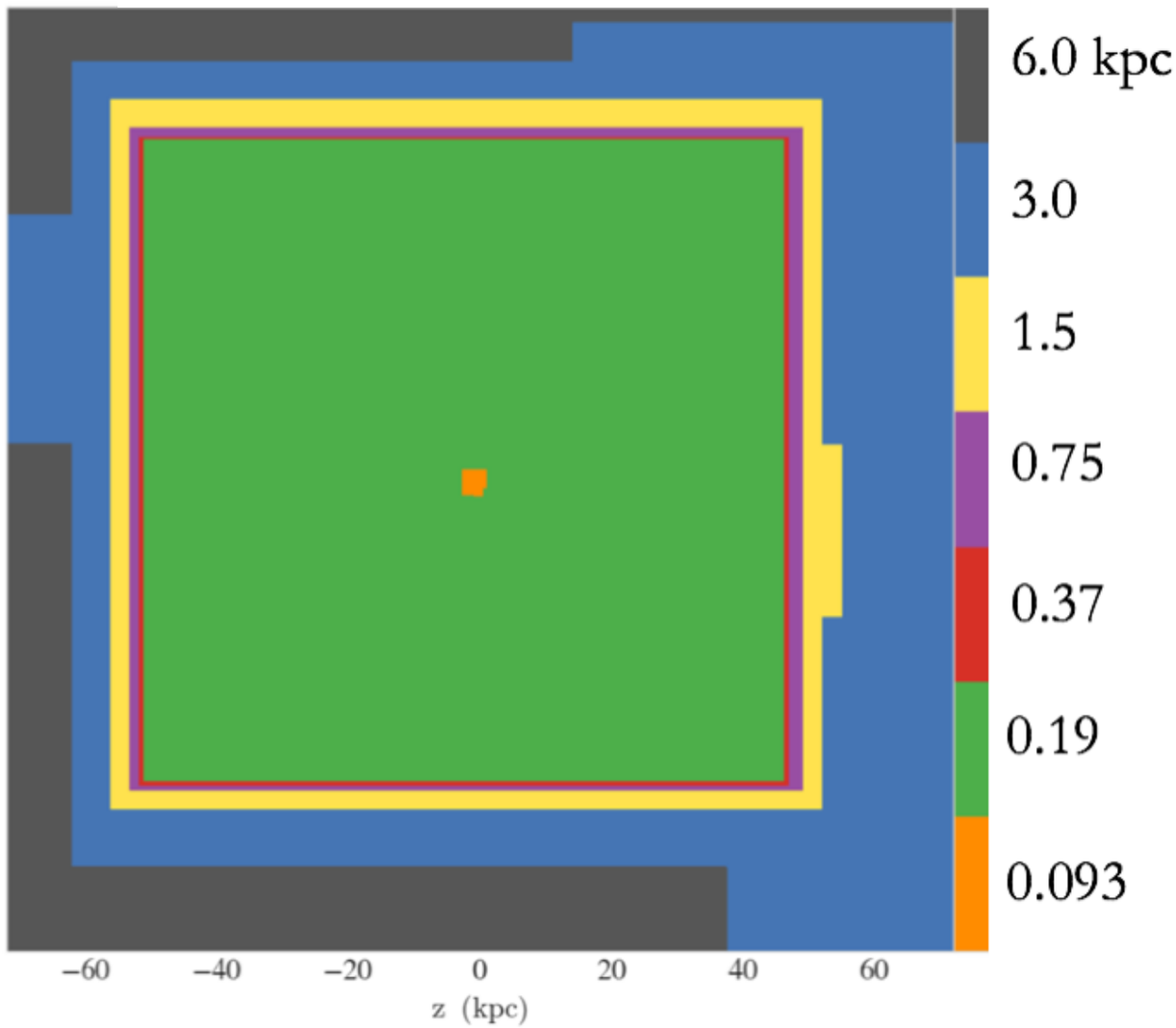


Forcing high resolution

Spatial size of "cells" (resolution elements):



Forced to 200 pc resolution



Better spatial resolution = Better mass resolution!

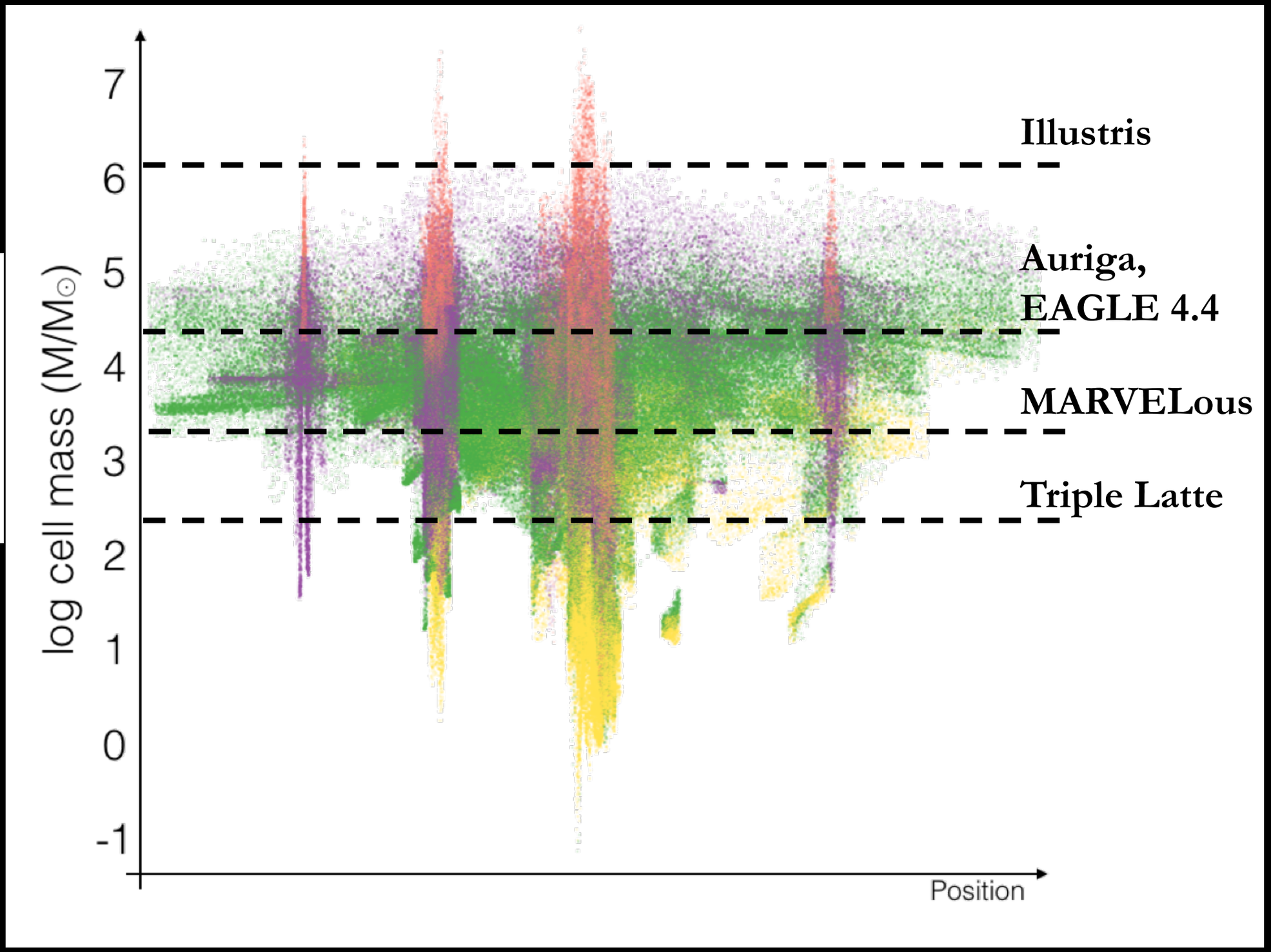
Cold, $T < 10^4$

Cool, $10^4 < T < 10^5$

Warm, $10^5 < T < 10^6$

Hot, $T > 10^6$

"Standard" simulation



Better spatial resolution = Better mass resolution!

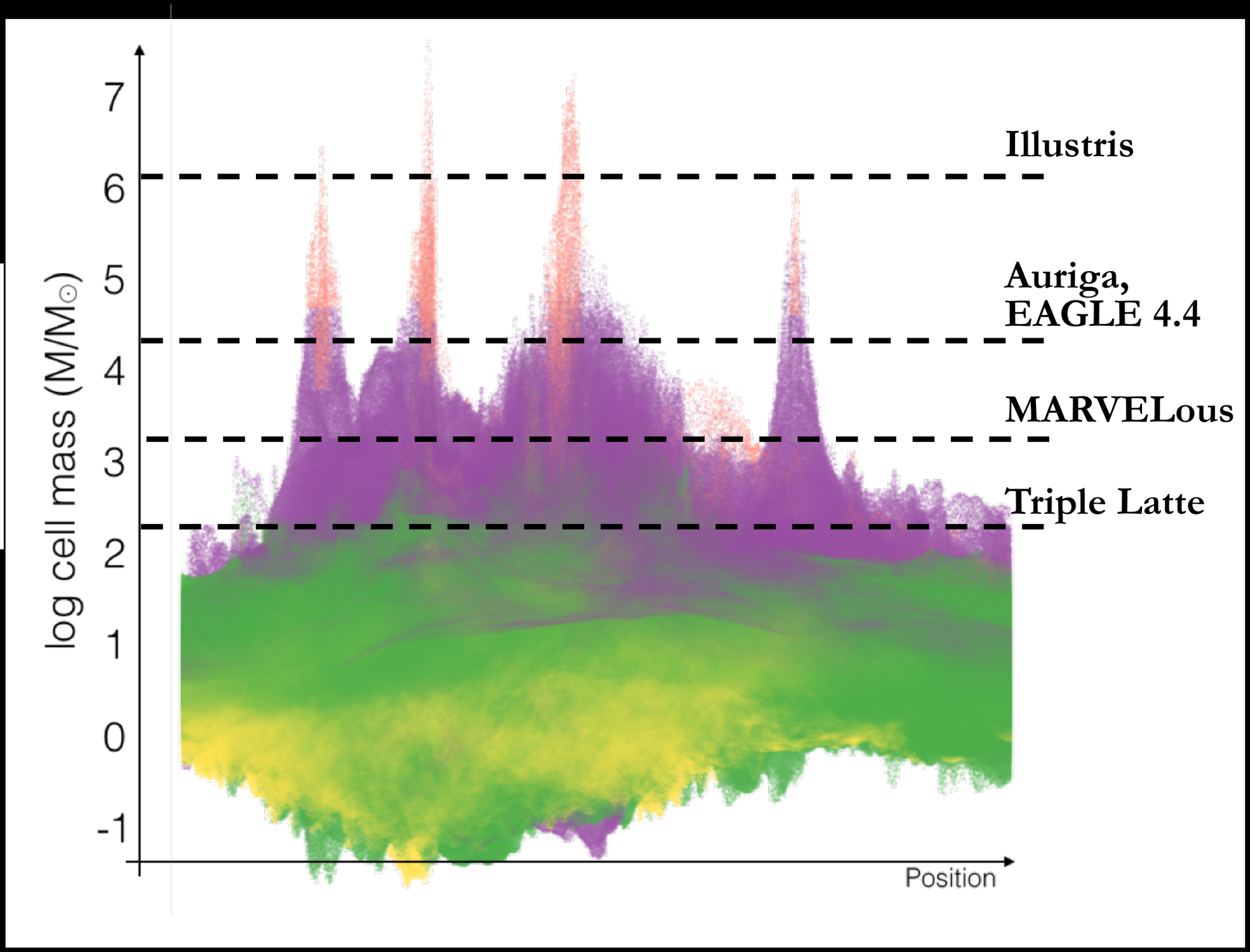
Cold, $T < 10^4$

Cool, $10^4 < T < 10^5$

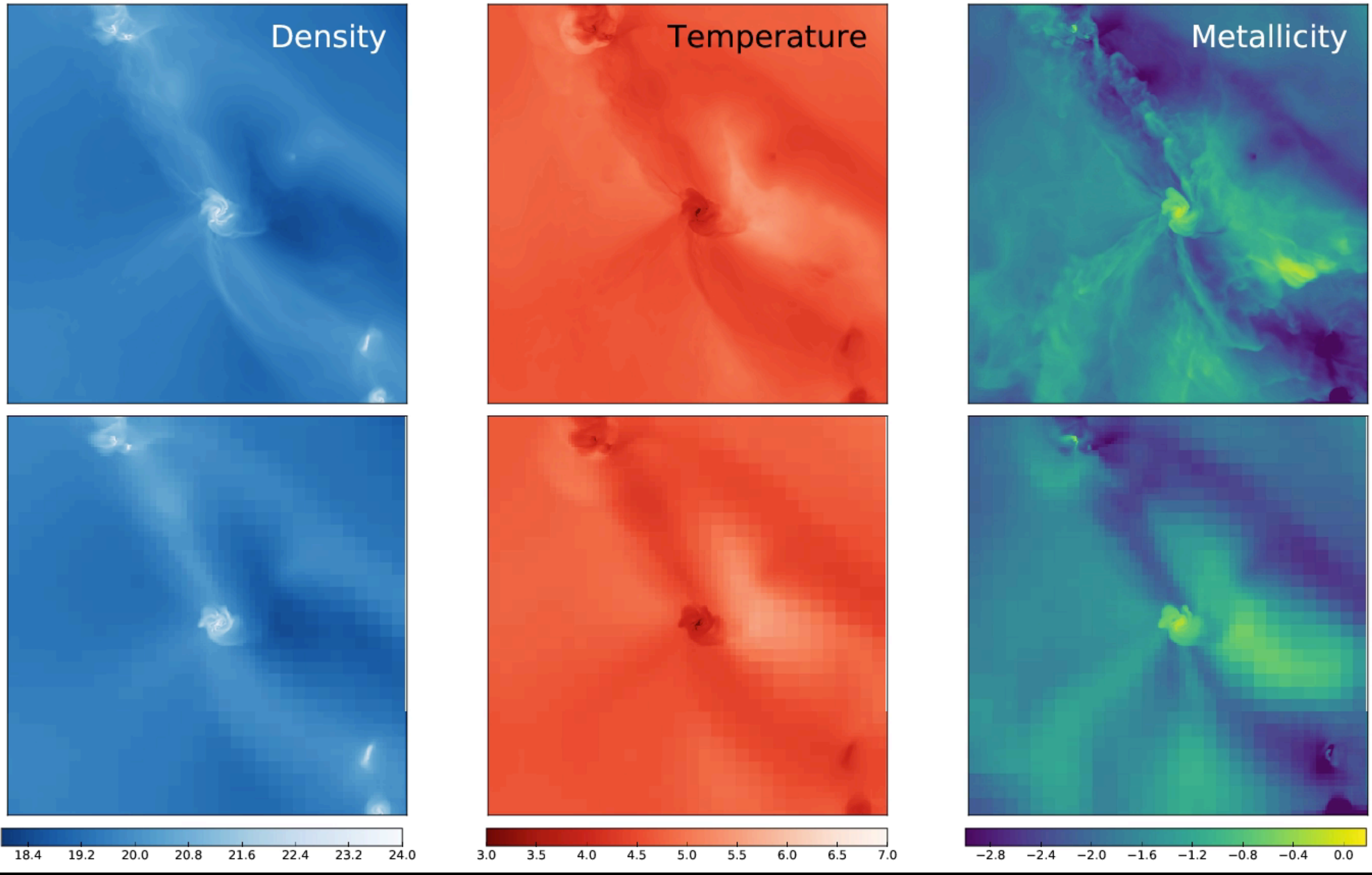
Warm, $10^5 < T < 10^6$

Hot, $T > 10^6$

"Forced refinement" simulation



“Forced” spatial resolution



Density-based refinement

Standard simulation

Refined everywhere

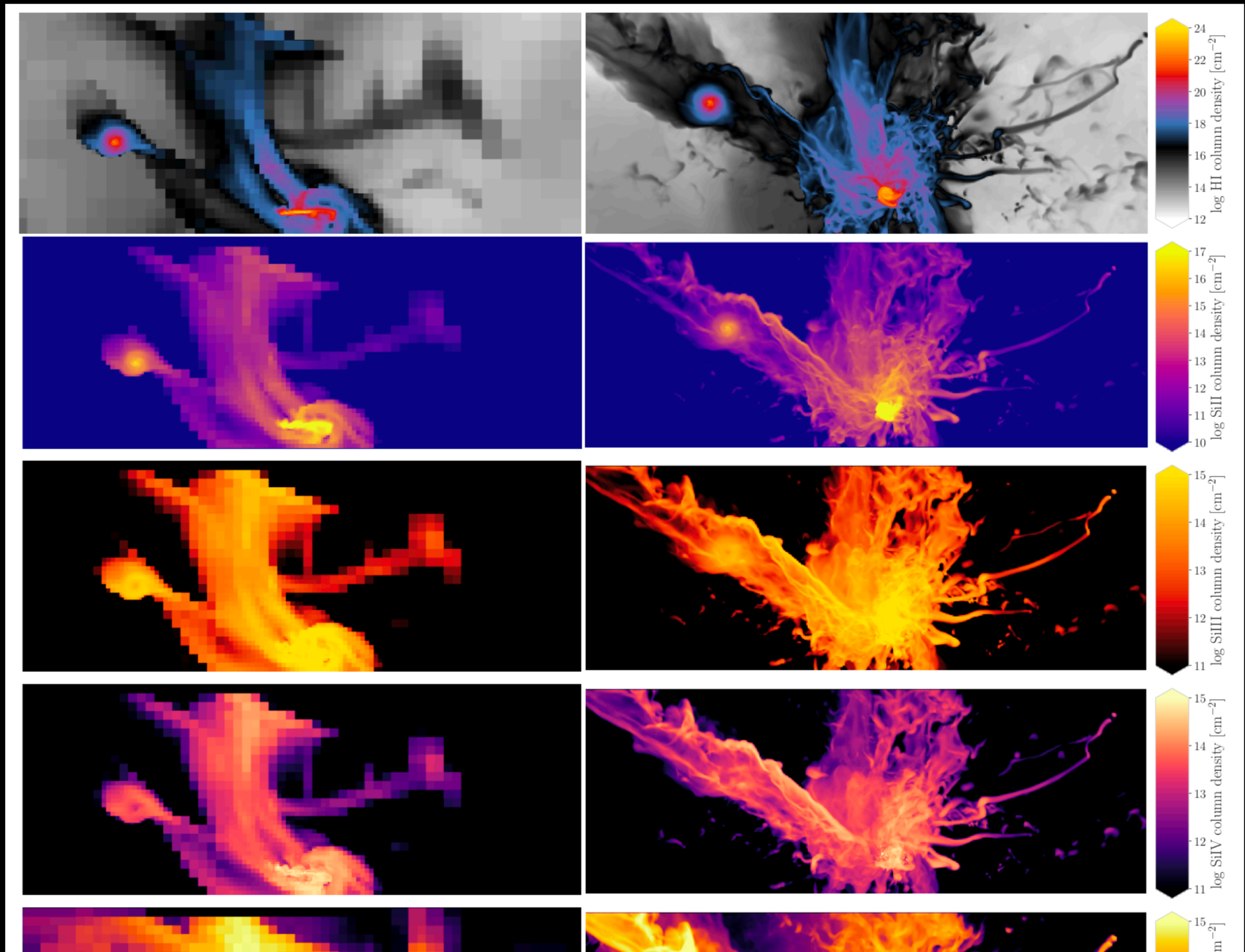
H I

Si II

Si III

Si IV

Peeples+



Si II

Si III

Si IV

C IV

O VI

Peeples+

Standard simulation

Refined everywhere

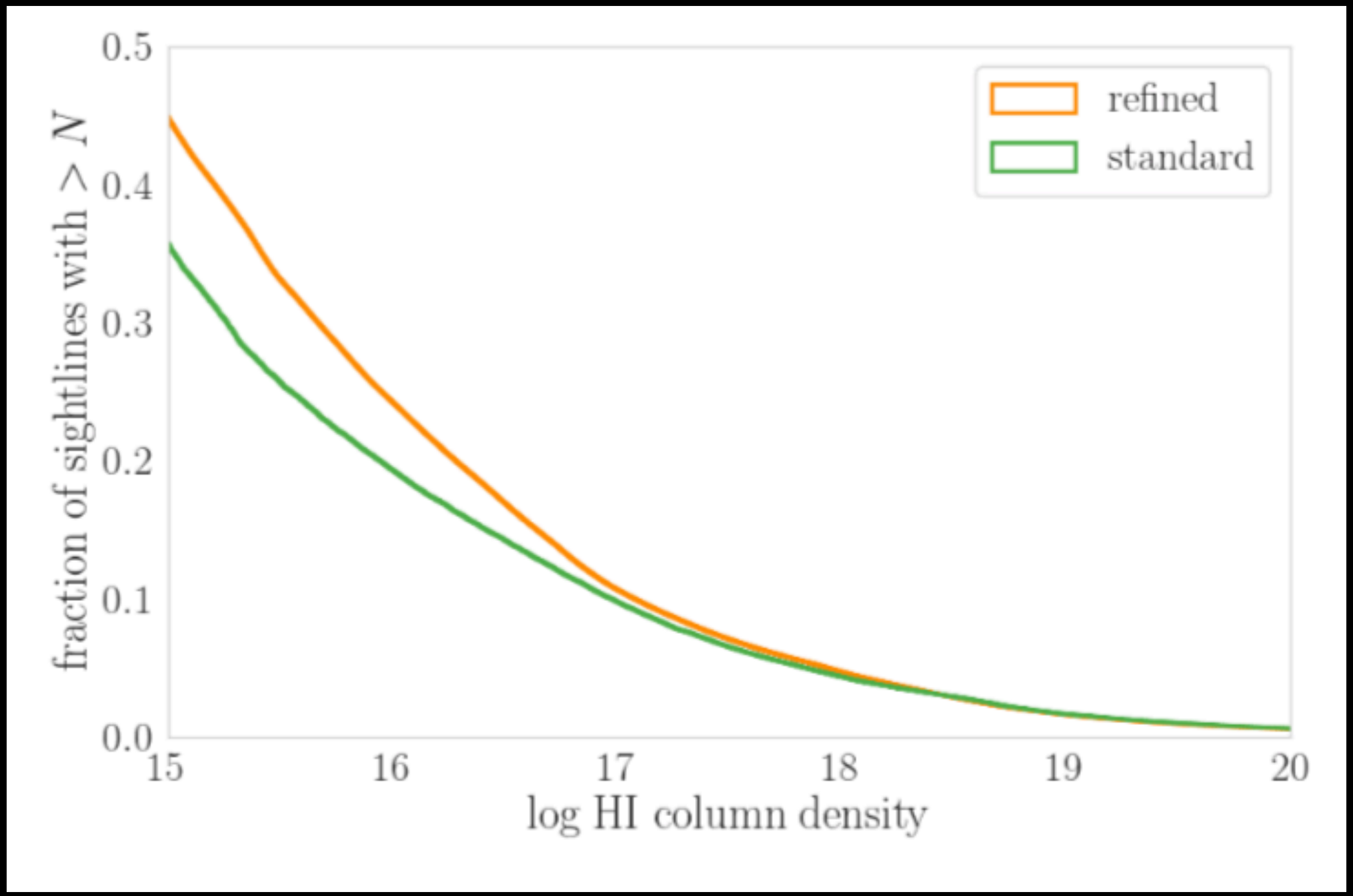
log SiII column density

log SiIII column density [cm^{-2}]

log SiIV column density [cm^{-2}]

log CIV column density [cm^{-2}]

log OVI column density [cm^{-2}]

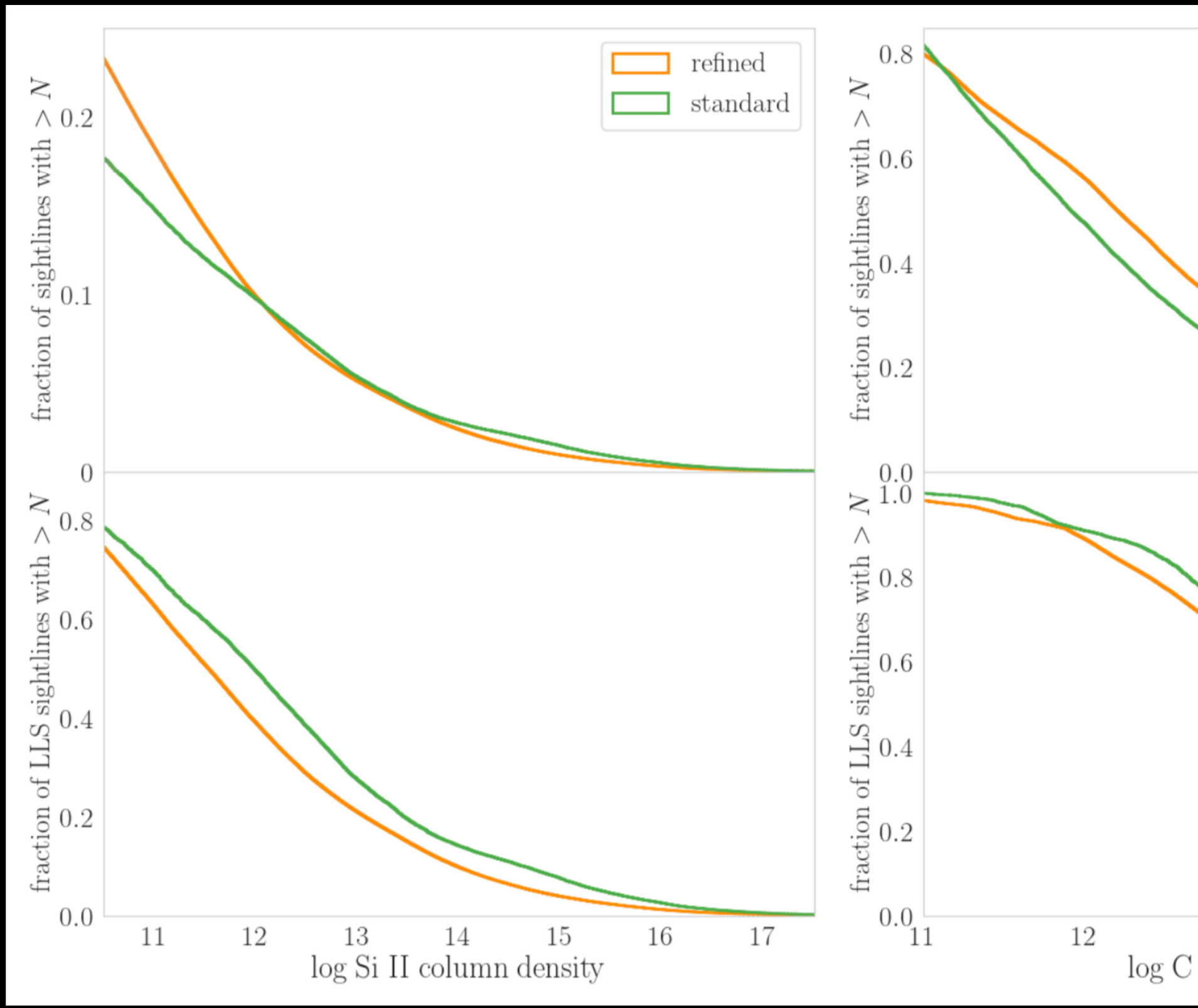

0.5
0.4
0.3
0.2
0.1
0.0
fraction of sightlines with > N
15
16
17
18
19
20
log HI column density
refined
standard

Peeples+

Si II

Covering fraction (all sightlines)

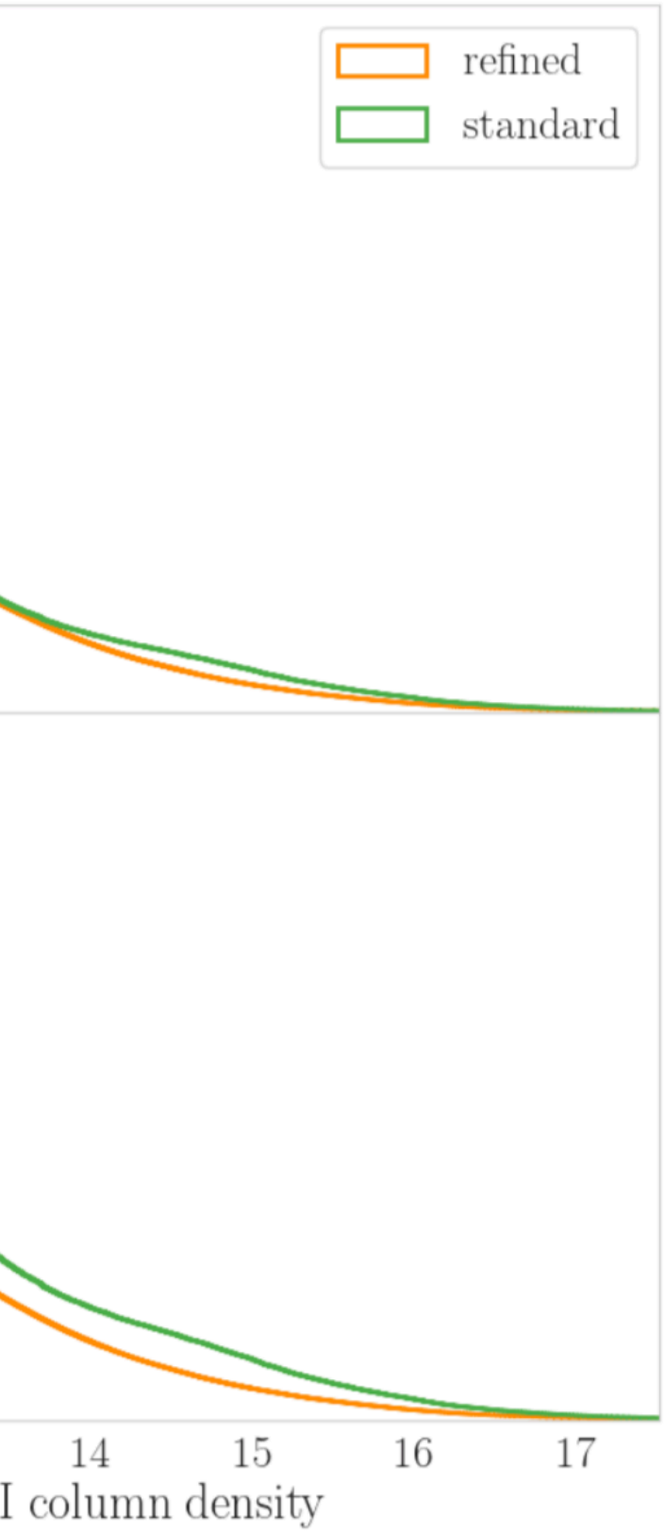
Covering fraction (logNHI > 16)

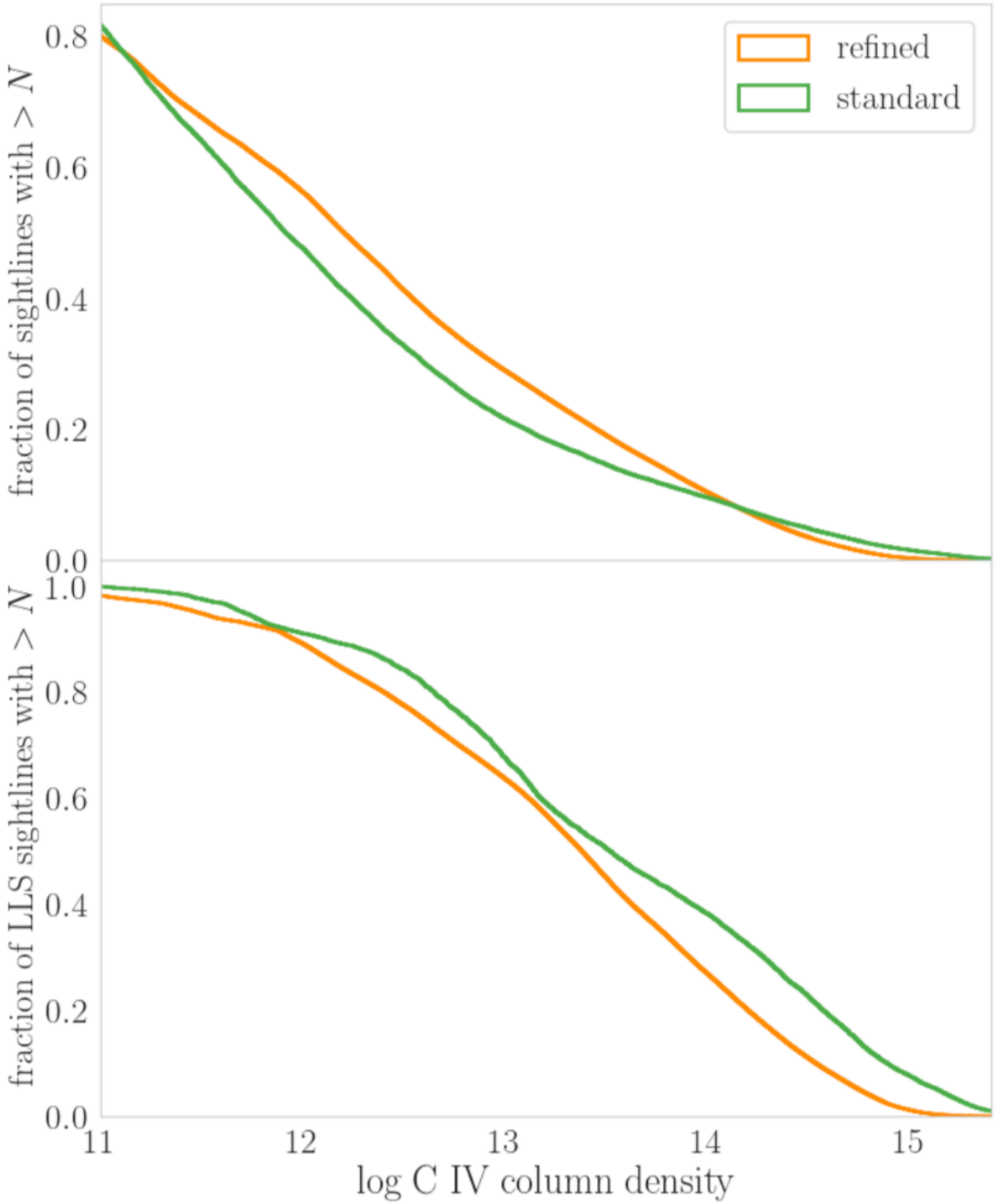


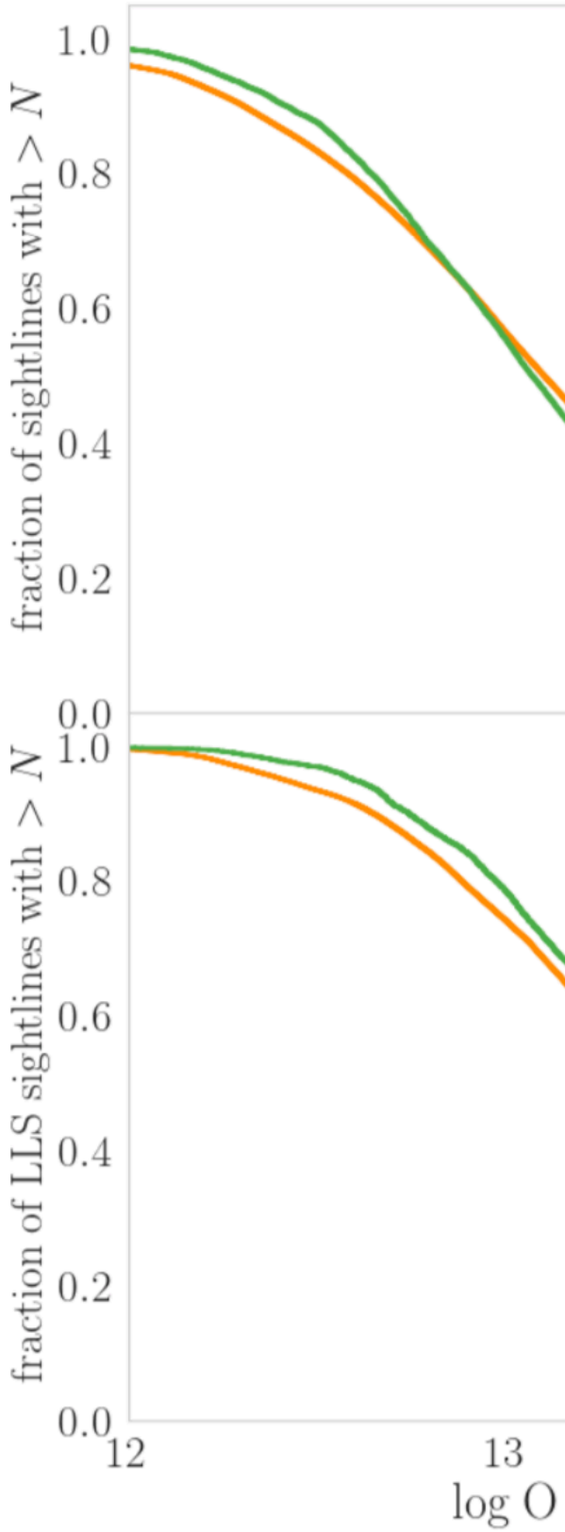
Peeples+

Si II

C IV



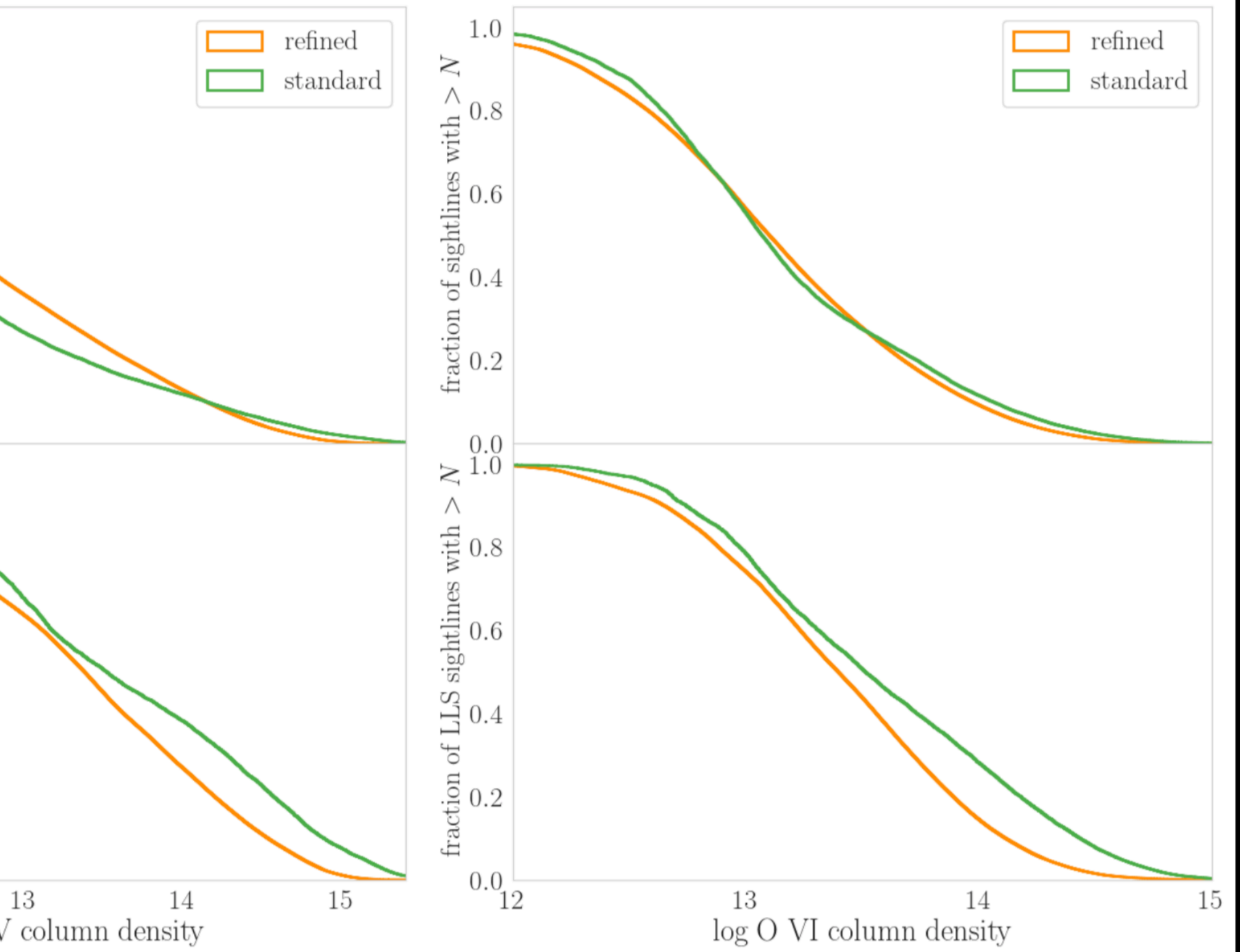




Peeples+

C IV

O VI

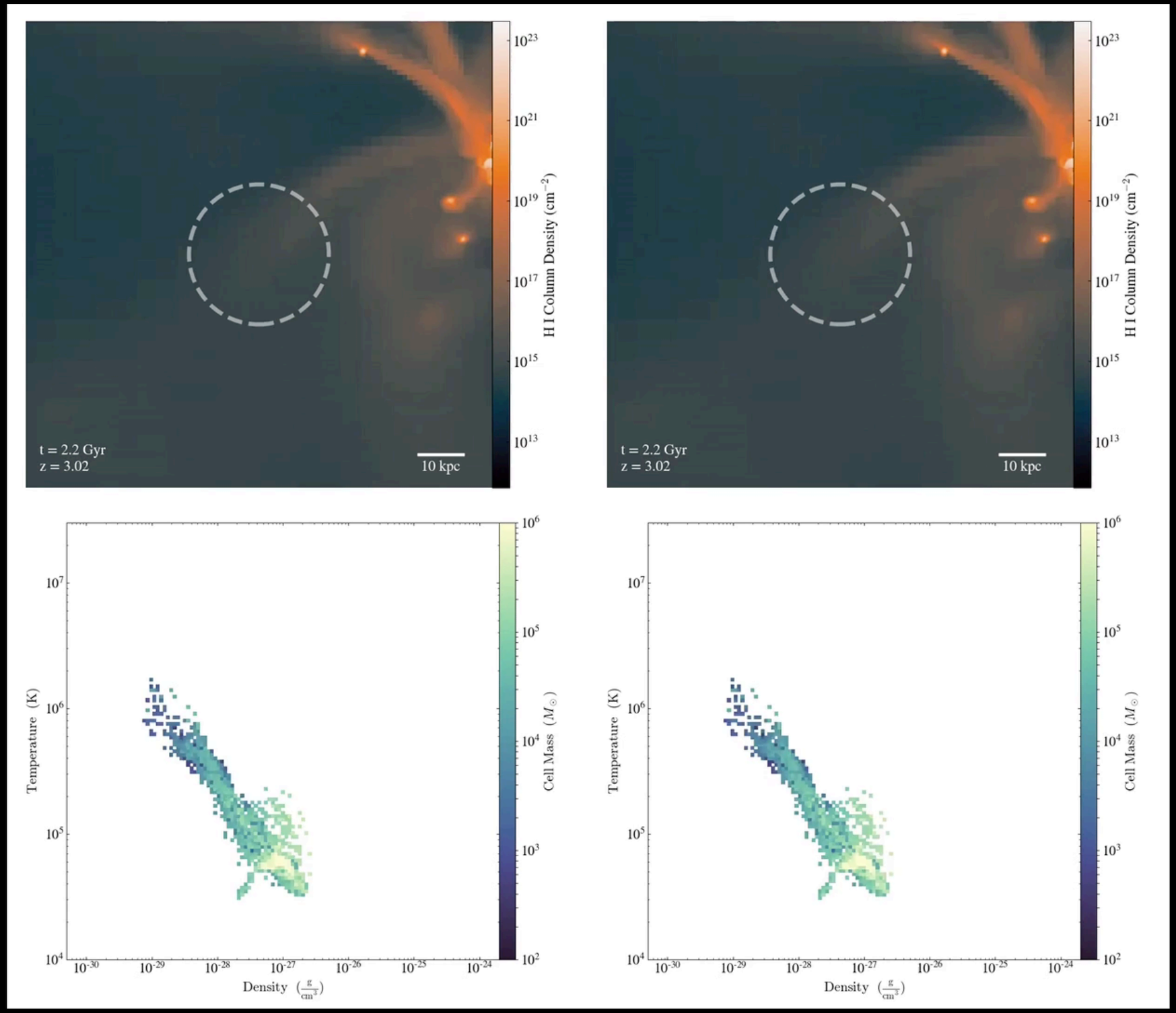


Peeples+

What causes the changes?

Better sampling of gas properties + seeding thermal instabilities

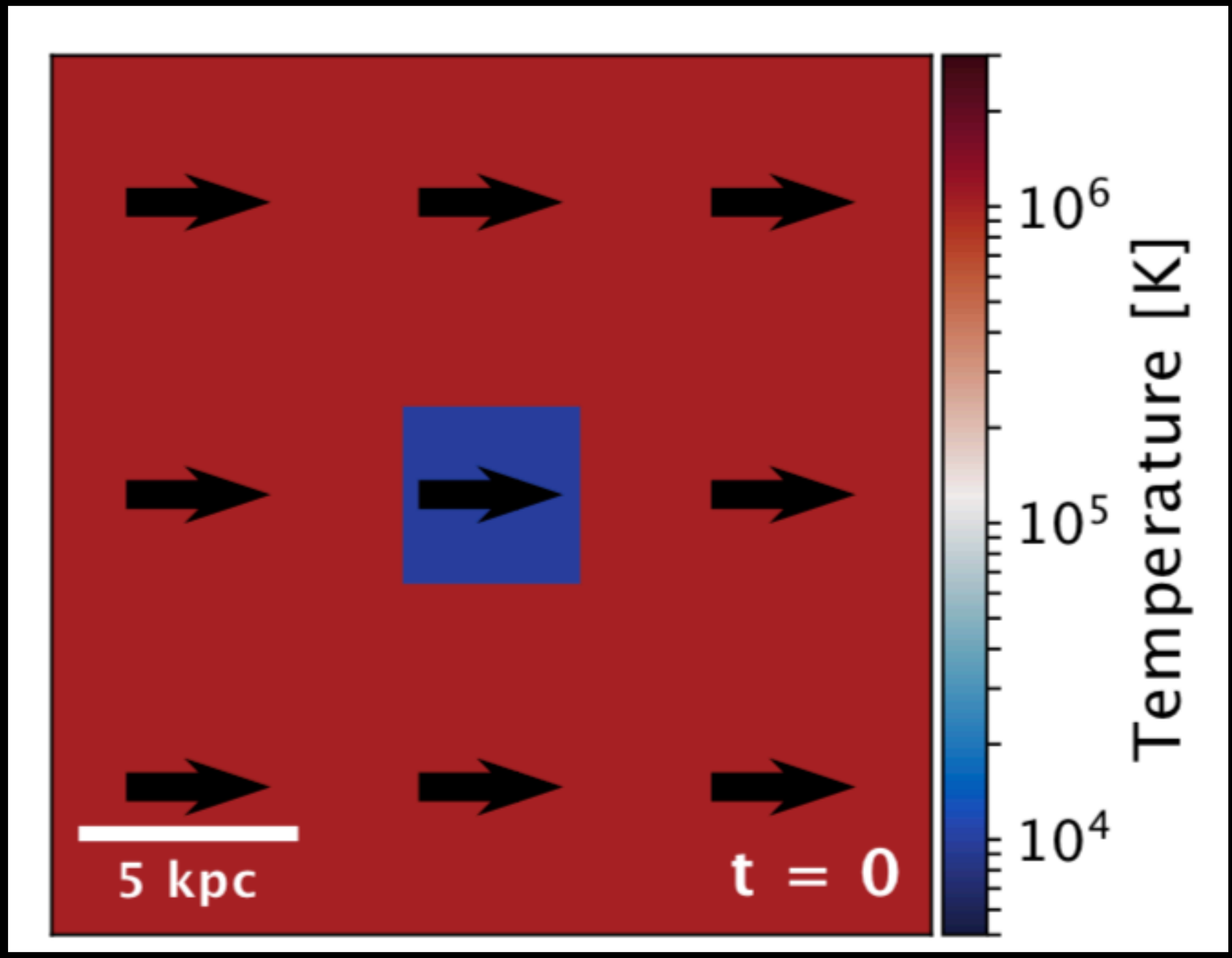
Standard refinement



Forced refinement

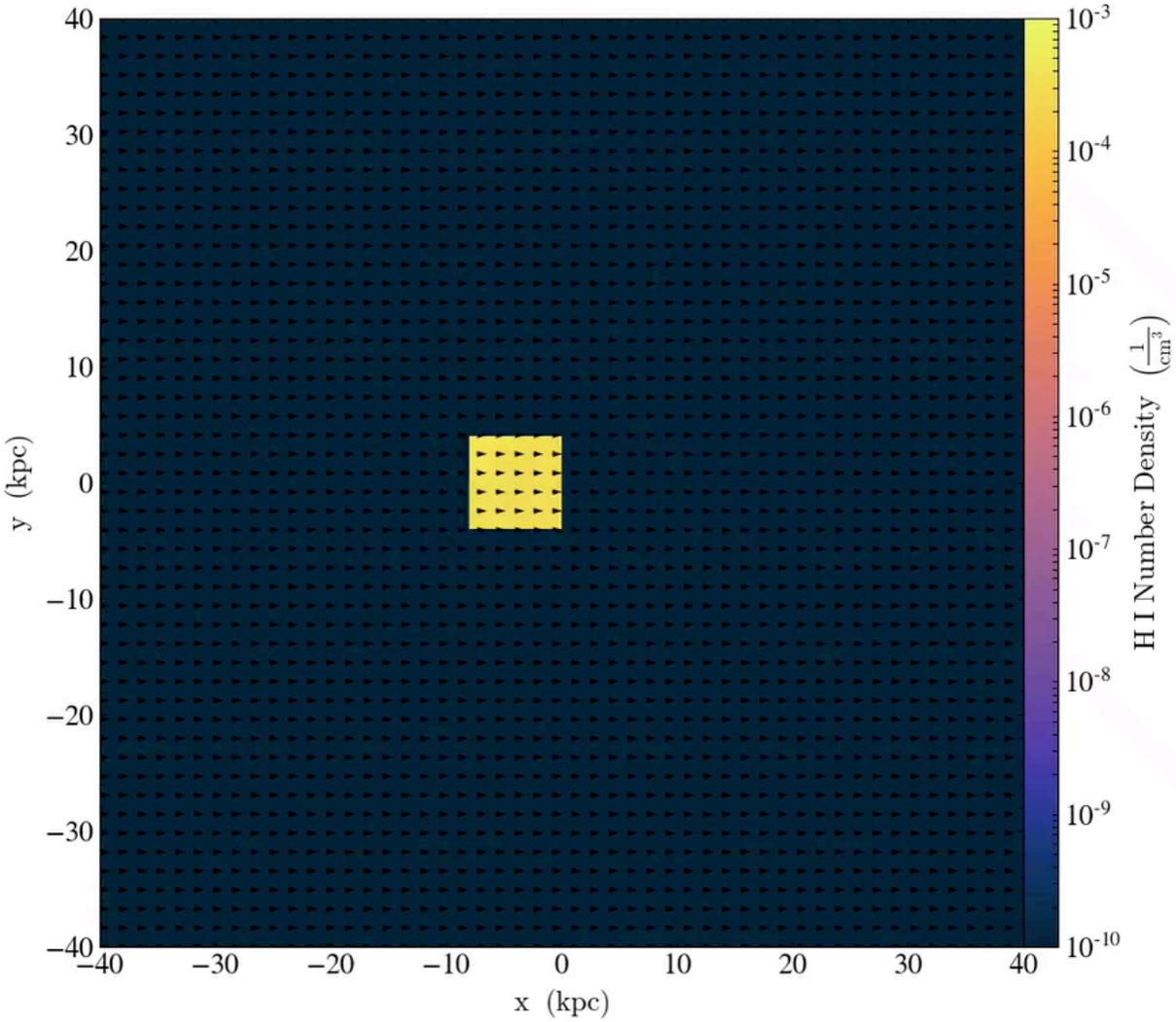
Hummels+ 2019

Preventing mixing of hot and cold gas

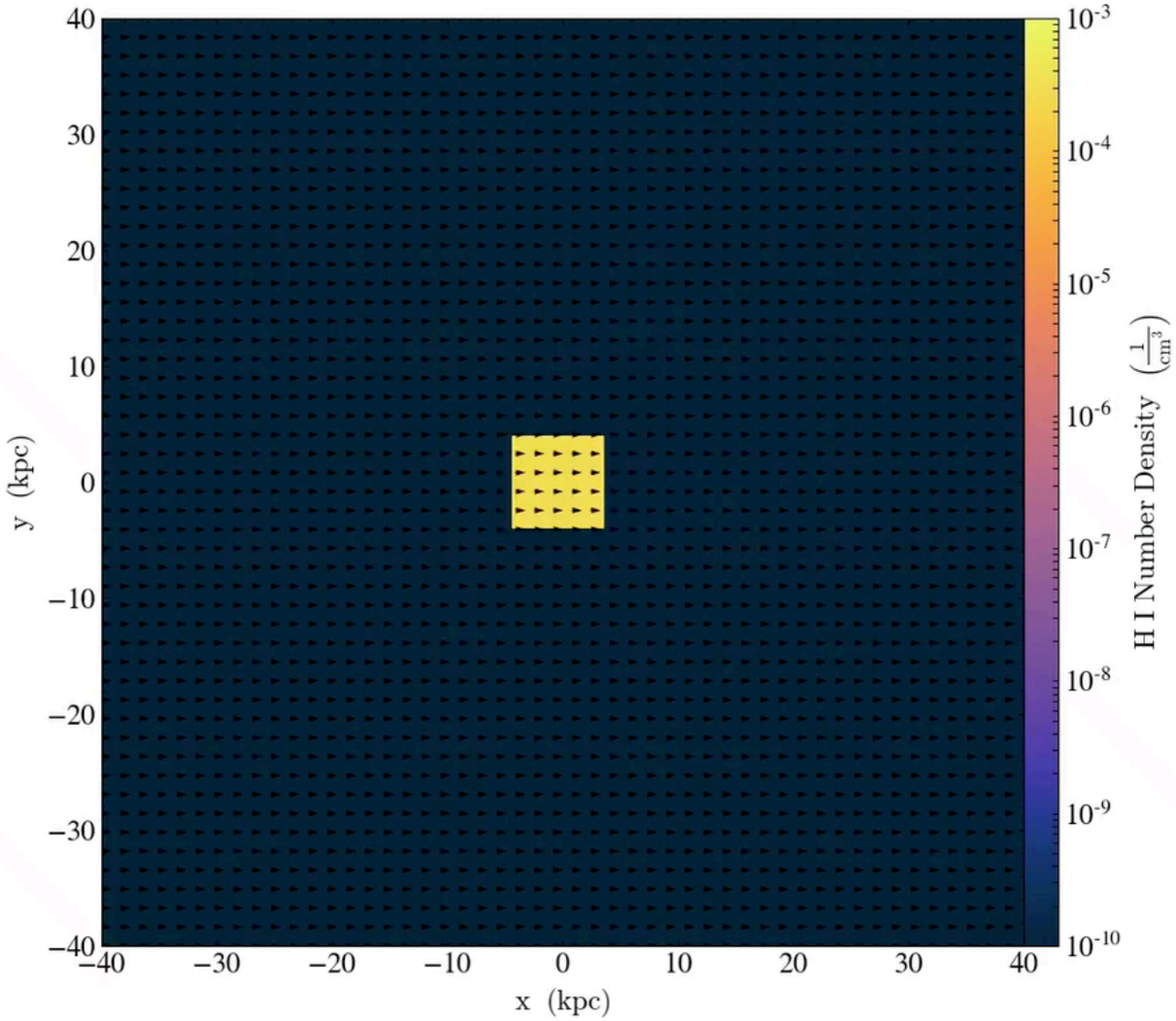


Hummels+ 2019

Preventing mixing of hot and cold gas



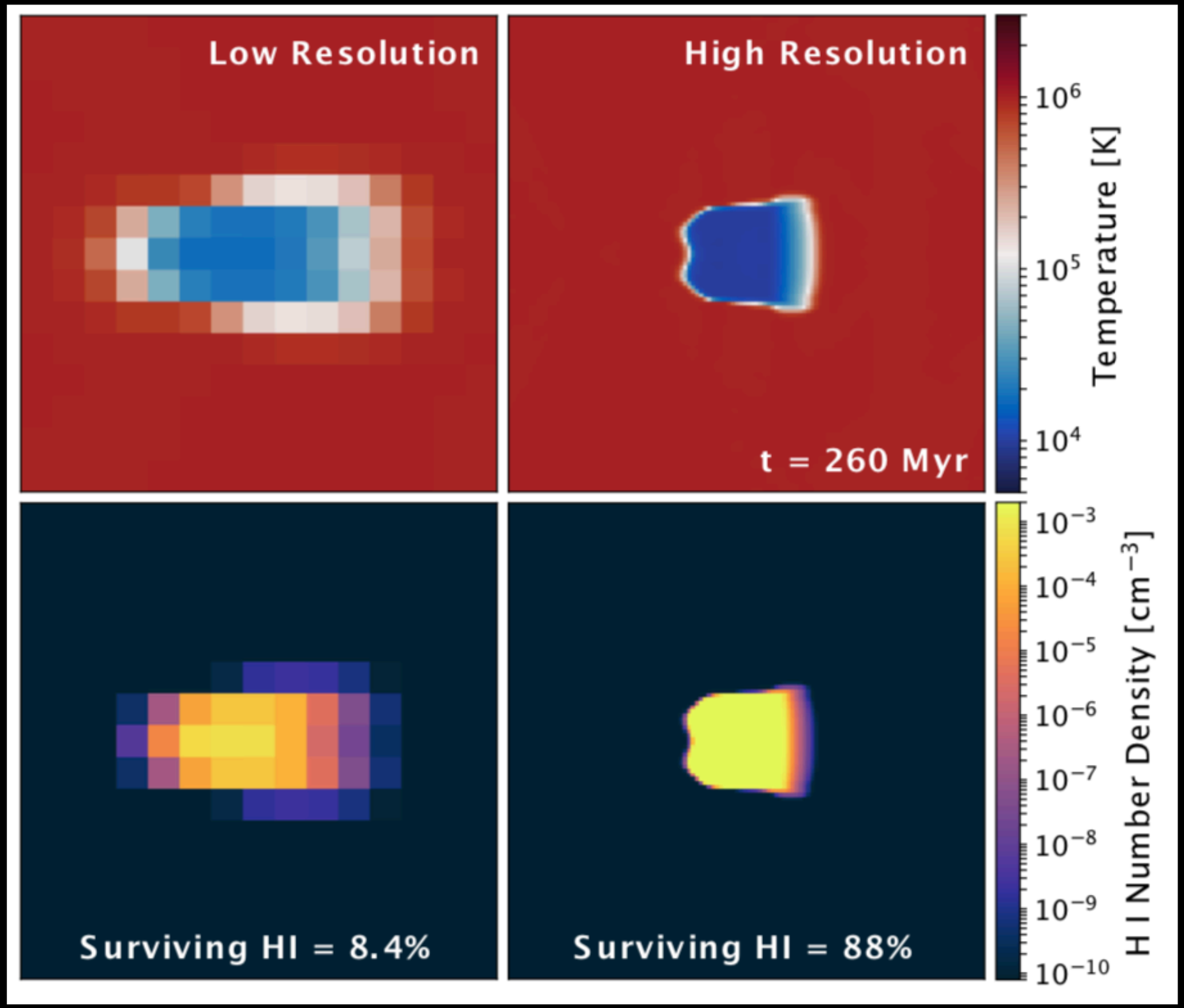
Low resolution (4 cells/blob)



High resolution (32 cells/blob)

Hummels+ 2019

Preventing mixing of hot and cold gas



Hummels+ 2019

Probing the CGM with next-generation codes

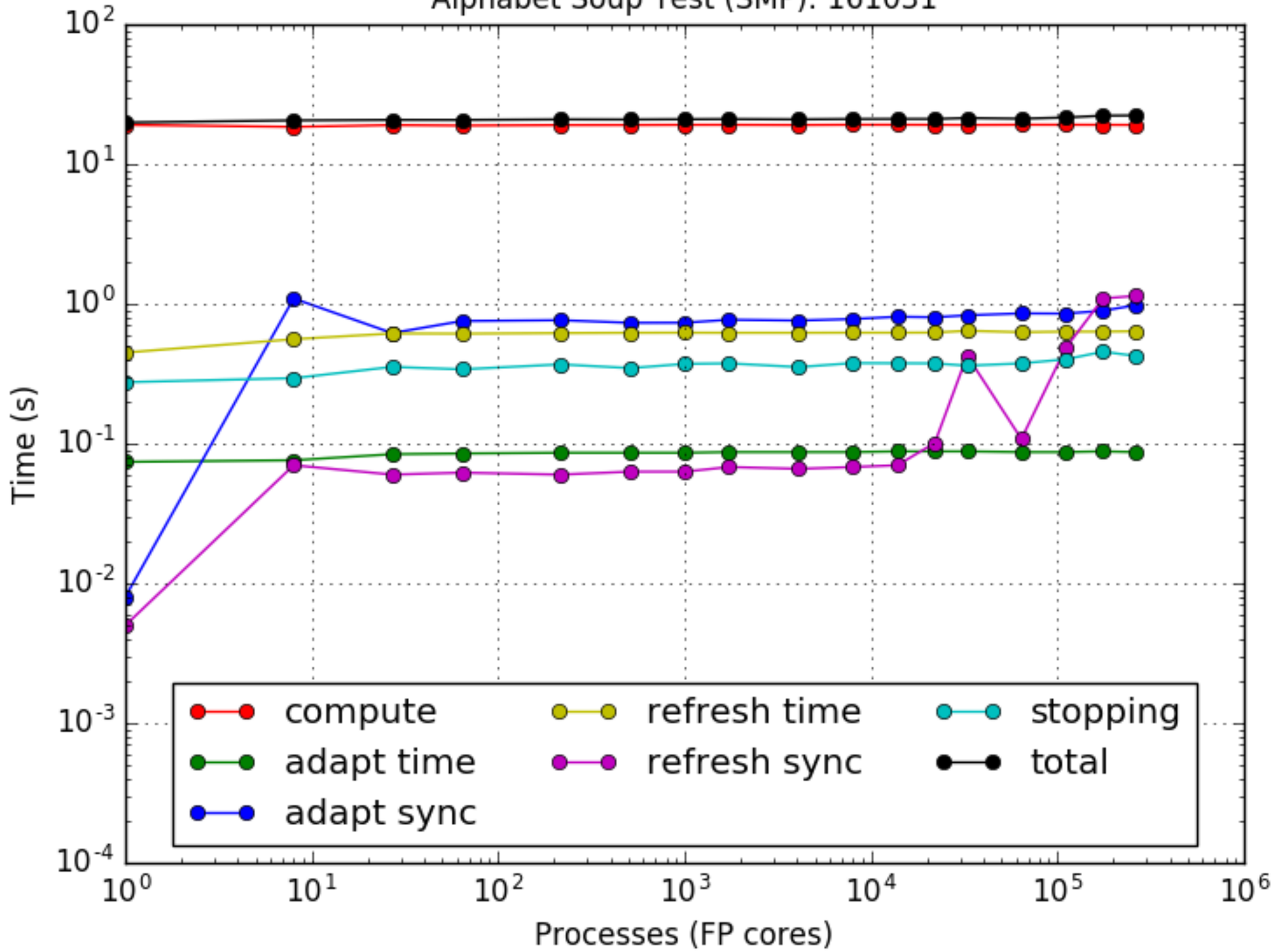
Enzo-E

- Charm++ parallel runtime system (task management, redundancy, etc.)
- “Forest of octtree” AMR with fully distributed data structures and local, causality-preserving time-stepping
- Scalable gravity solvers, modular fluid, chemistry, particle-pushing, etc. solvers

cello-project.org

Enzo-P Weak Scaling on Blue Waters: Time

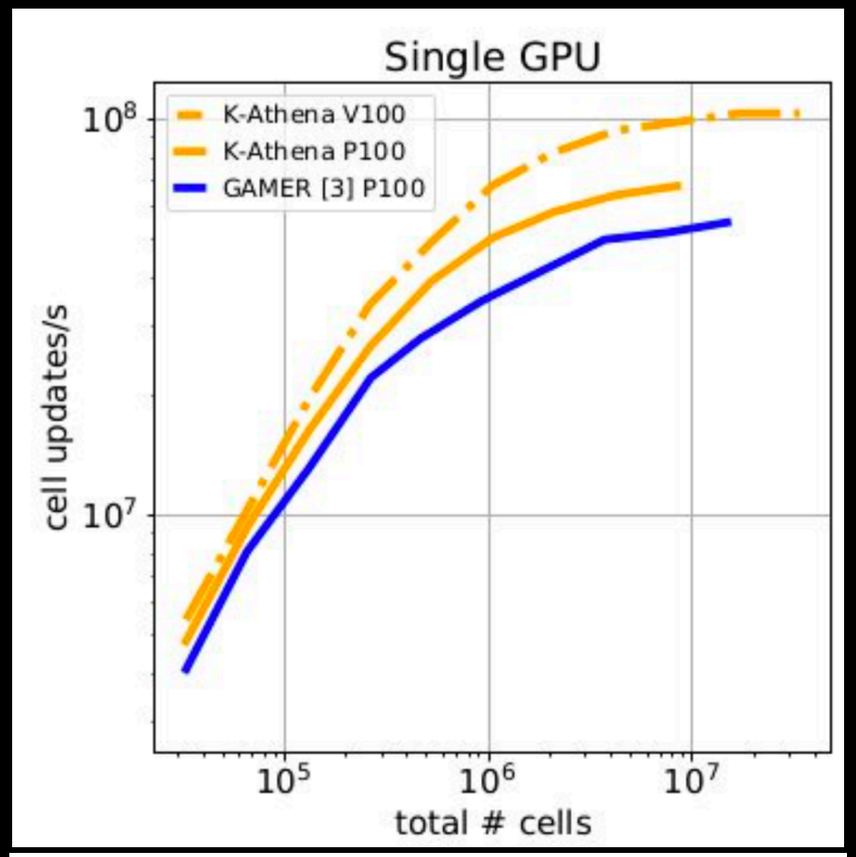
Alphabet Soup Test (SMP): 161031

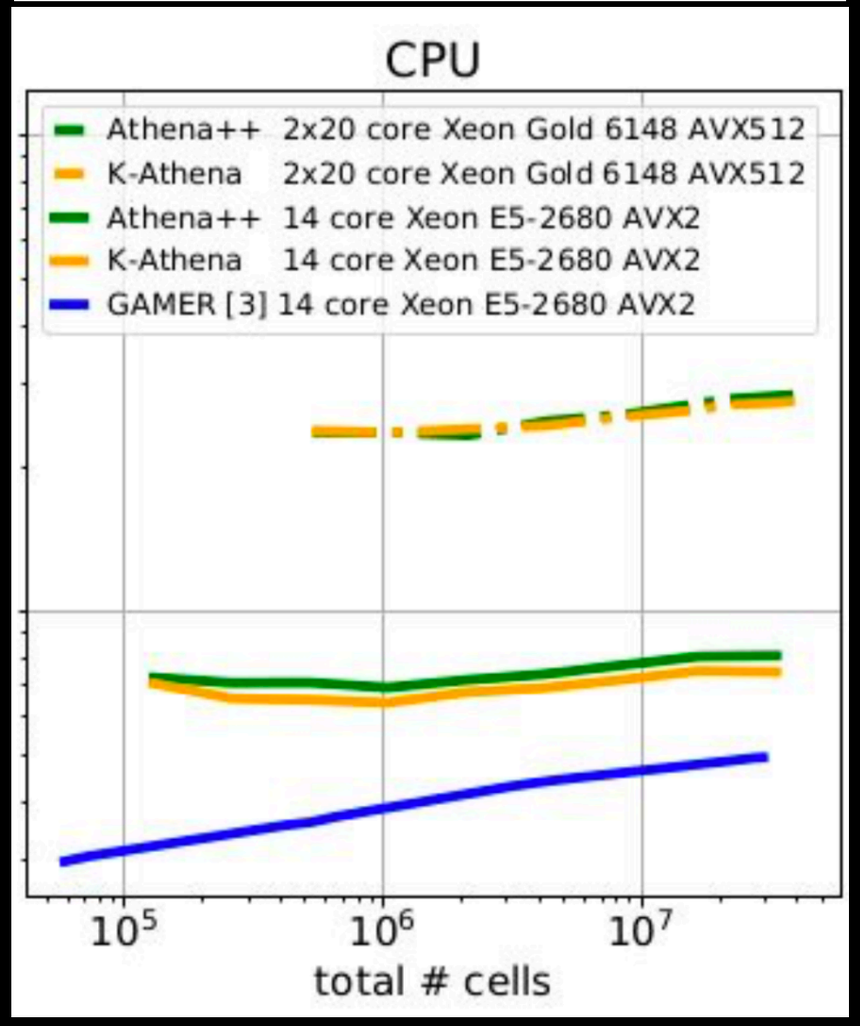


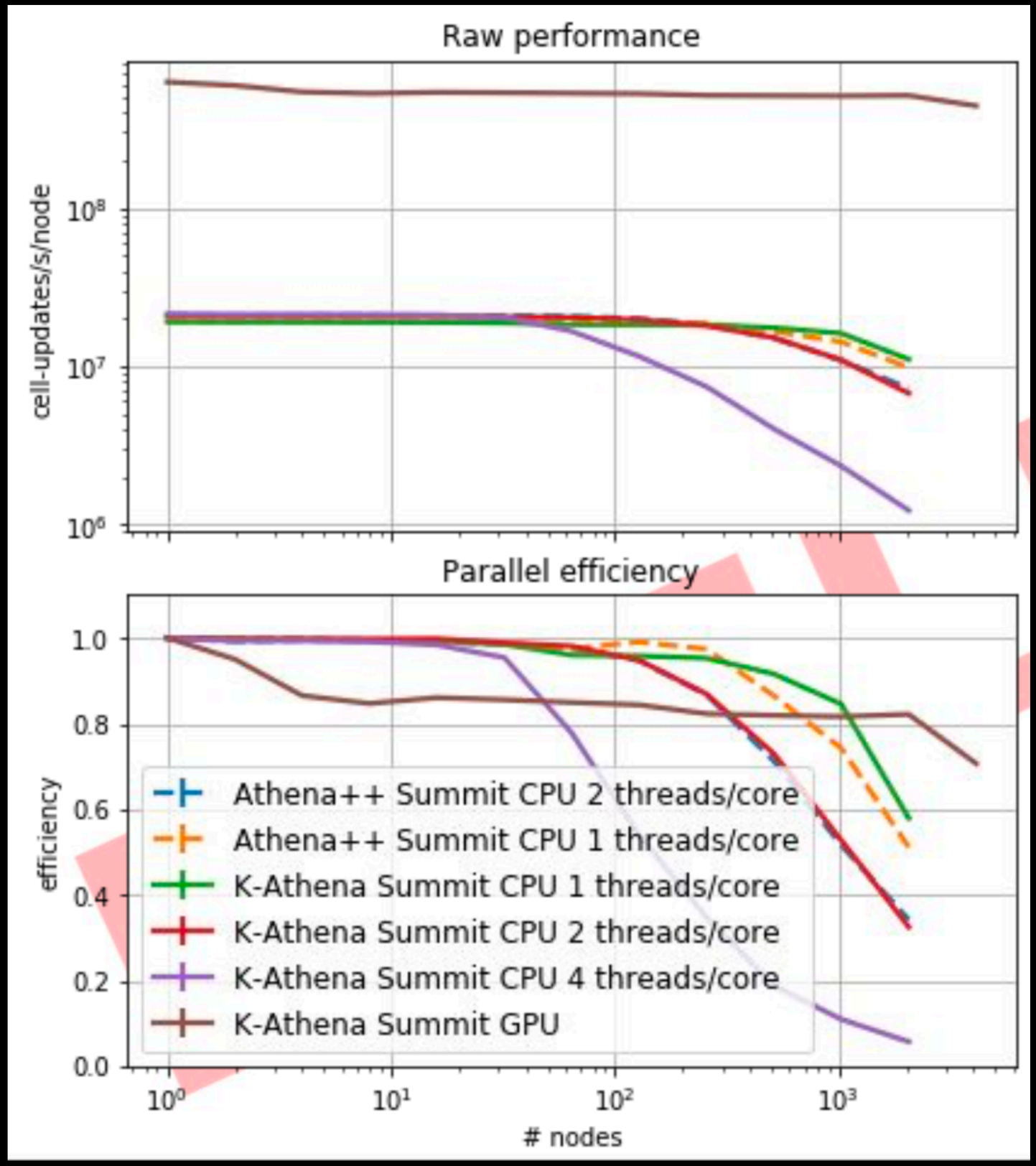
K-Athena++

- Started with Athena++ (Stone and collaborators)
- Kokkos for performance portability across architectures
- Aim: maintain CPU performance while achieving high level of GPU performance
- Primary code change: loop macros, memory management

Note: work primarily done by Philipp Grete and Forrest Glines!







1.8 x 10^{12} cell updates/s on 4,096 nodes of Summit!

16 petaflops sustained speed!

Key points

- The CGM is a critical for regulating the evolution of galaxies, and most simulations do a poor job of resolving it.
- Sometimes, we get some quantities “right” in poorly-resolved simulations, but not some corresponding observations.
- Significantly increased spatial resolution in the CGM resolves key physics and effects; the same is likely true in galaxy clusters.
- New codes are required in order to radically increase our simulation capabilities.