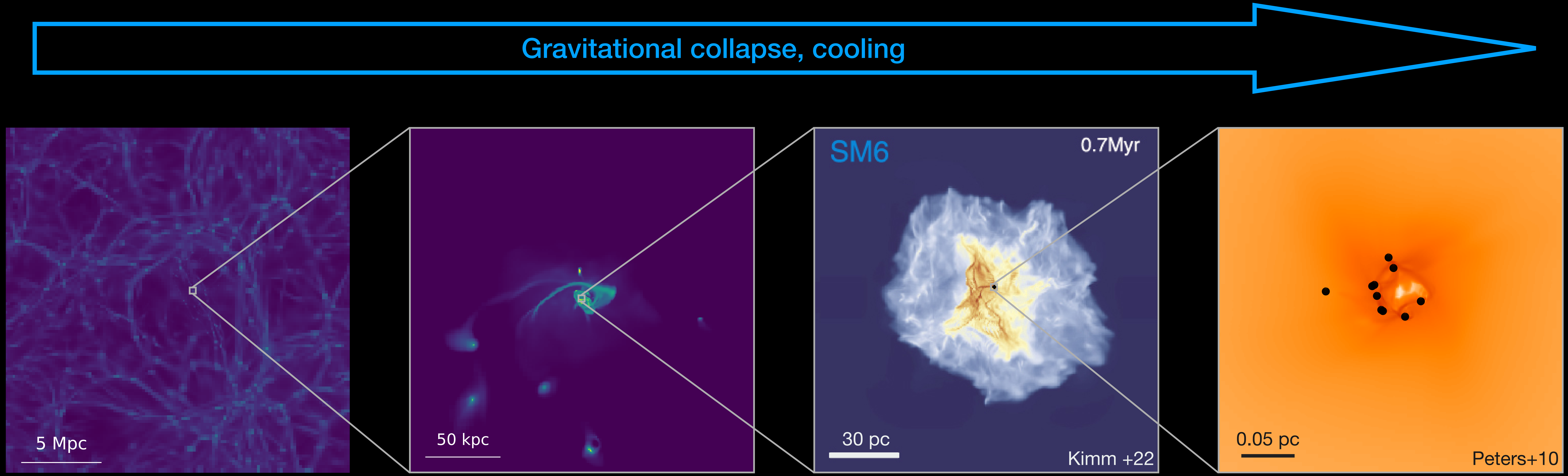
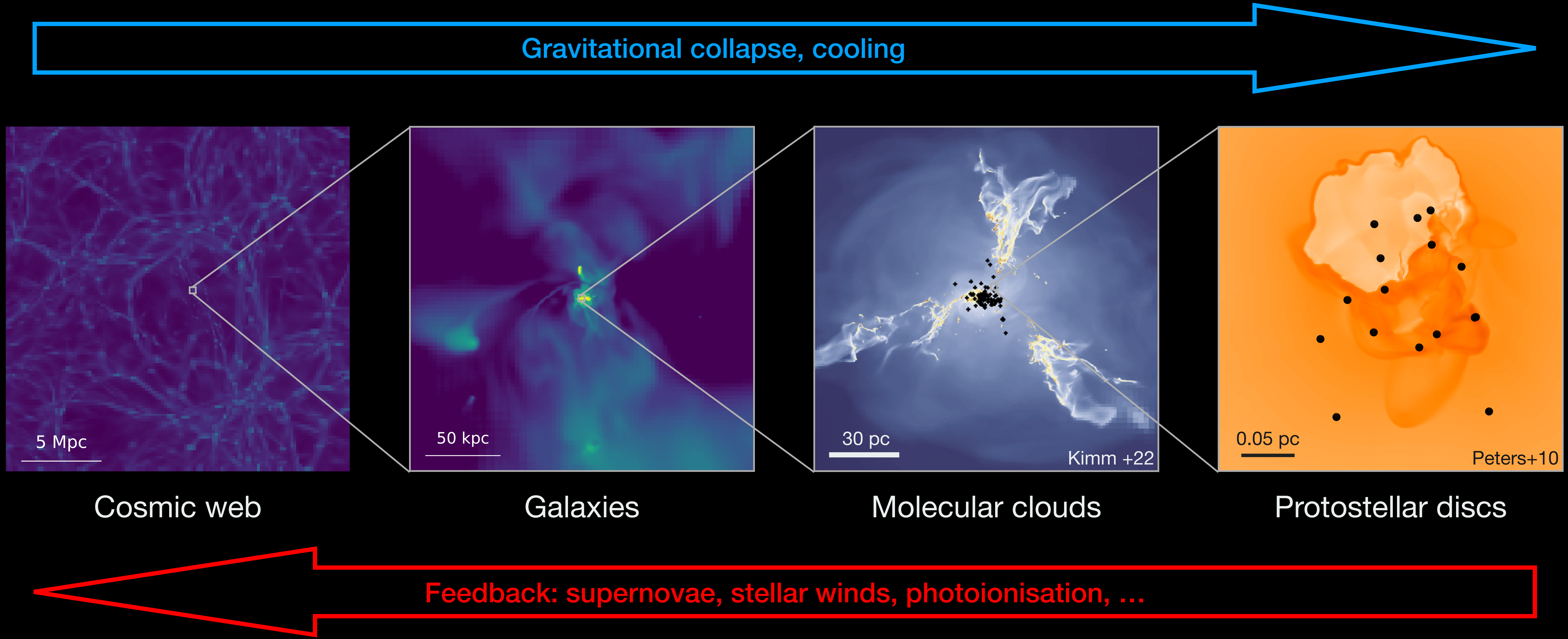
ARCHITECTS:
Resolving degeneracies from feedback processes with the circumgalactic medium.

The formation of galaxies

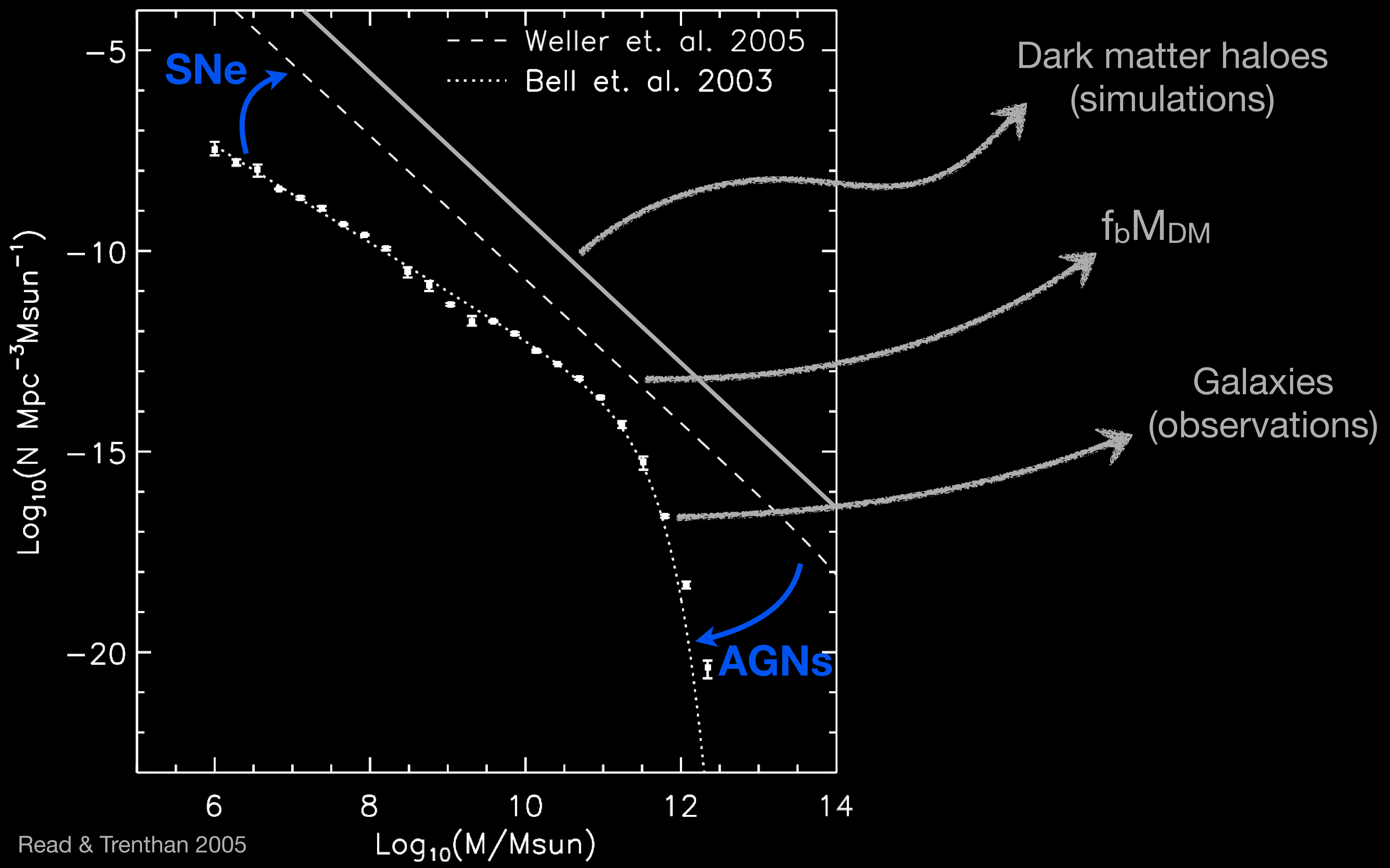


Cosmic web | Galaxies | Molecular clouds | Protostellar discs

The formation of galaxies



Galaxies stellar mass function



Read & Trenthan 2005

The circumgalactic medium (CGM)

NASA, ESA and the Hubble Heritage Team

The ARCHITECTS simulations

Rey+25

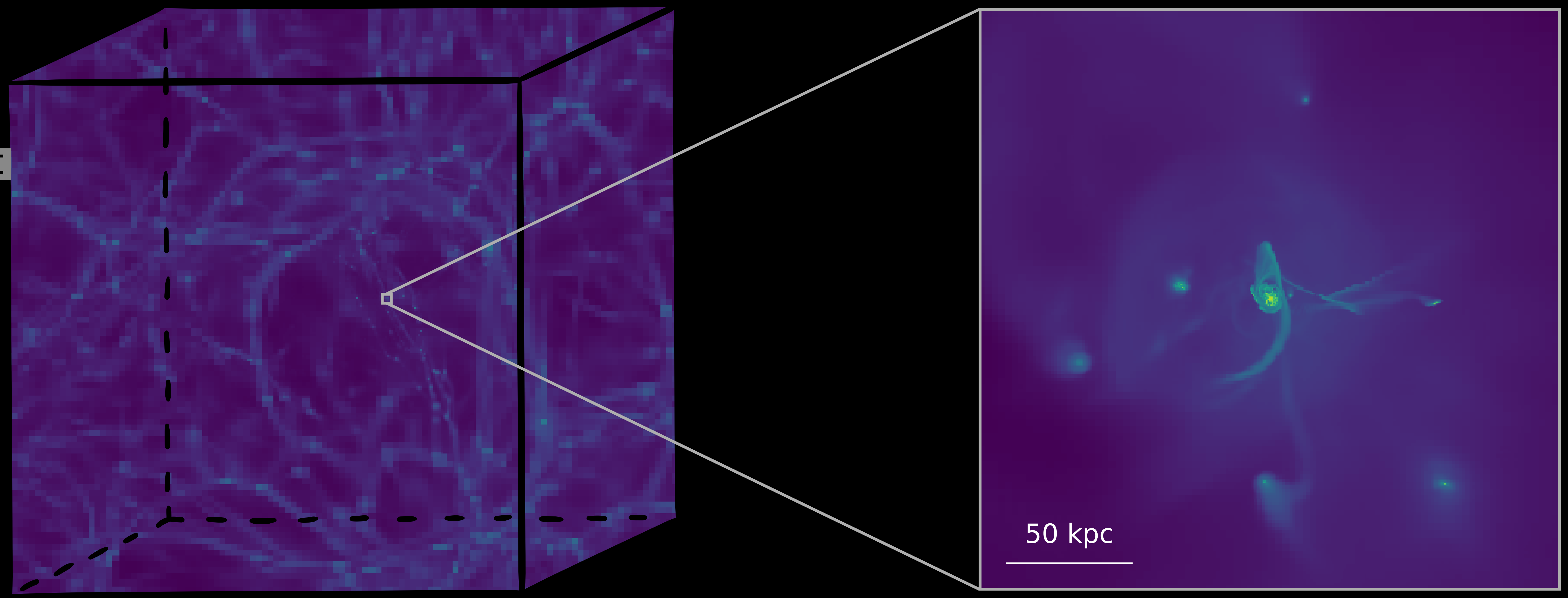
Sphinx / ramses_cral Developer

★ 0 Updated 2 days ago

RAMSES-RT.f90

```
# Gravity
if has_mass then
    call attract_others
endif
# Hydrodynamics
if things_move then
    call conserve_stuff
endif
# Radiation
if star_isalive then
    call let_there_be_light
endif
```

Teyssier+02, Rodahl+13,15



Simulation cube

Main galaxy

Box: $30\ \mathrm{cMpc\,h^{-1}}$

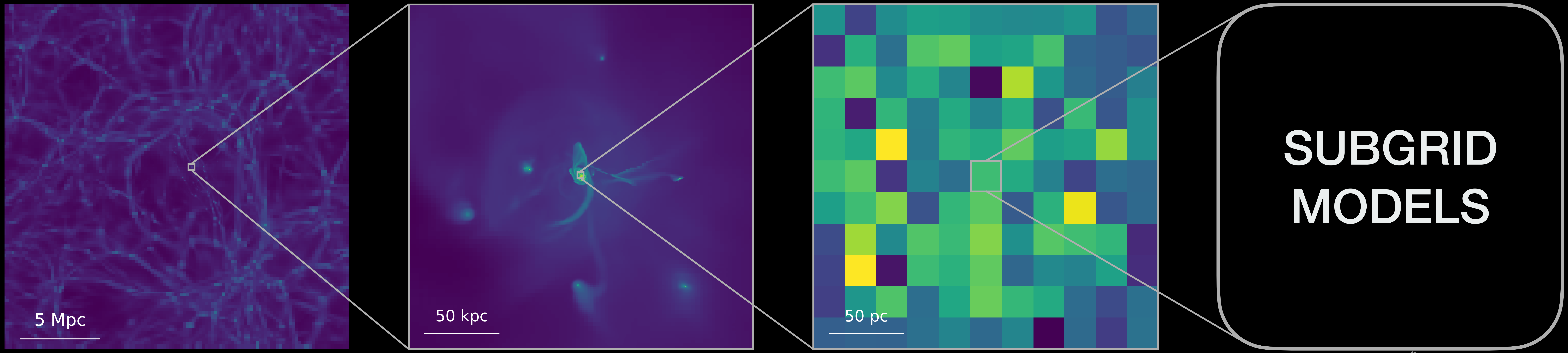
Resolution: $40\ \mathrm{pc}$

$M_{\mathrm{halo}} \sim 4 \times 10^{11}\ M_{\odot}$

$R_{200} \sim 100\ \mathrm{kpc}$

$z = 1\ (6\ \mathrm{Gyr})$

Subgrid models



Cosmic web

Galaxies

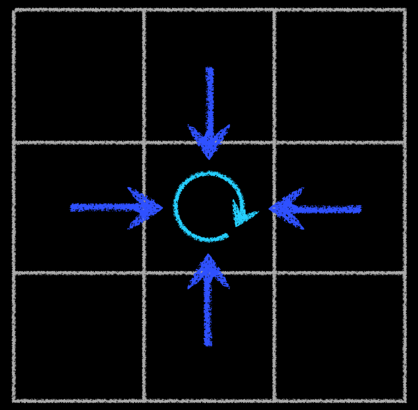
Molecular clouds

Models describing unresolved physics

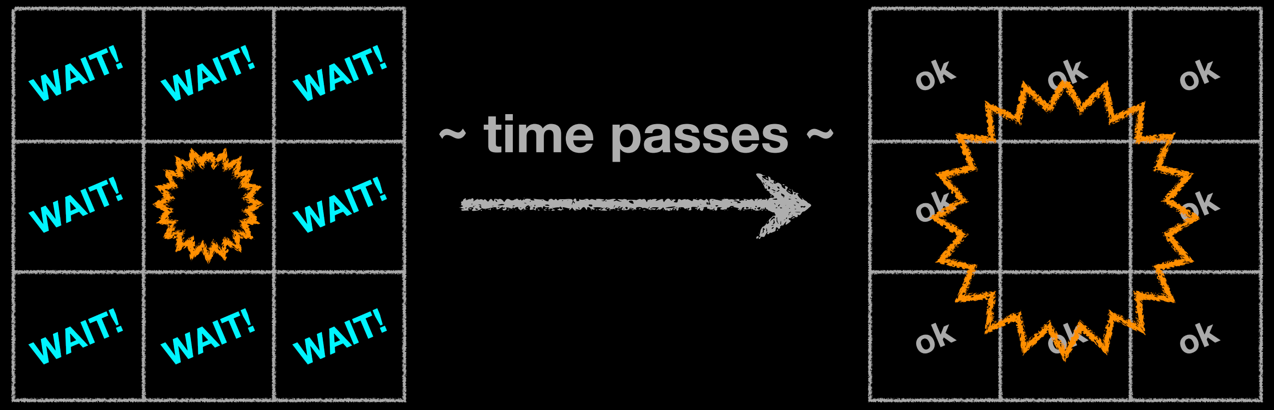
Subgrid models

Kimm et al. 2017 + Teyssier et al. 2013: “DC”

➢ Gravoturbulent star formation with local approximation

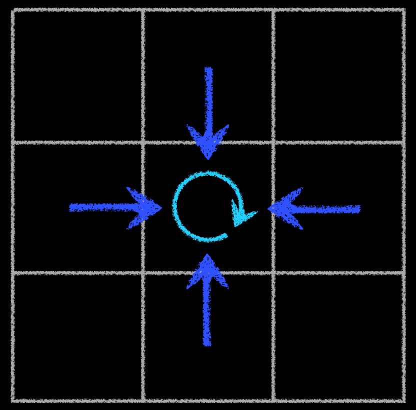


➢ Thermal injection with delayed cooling

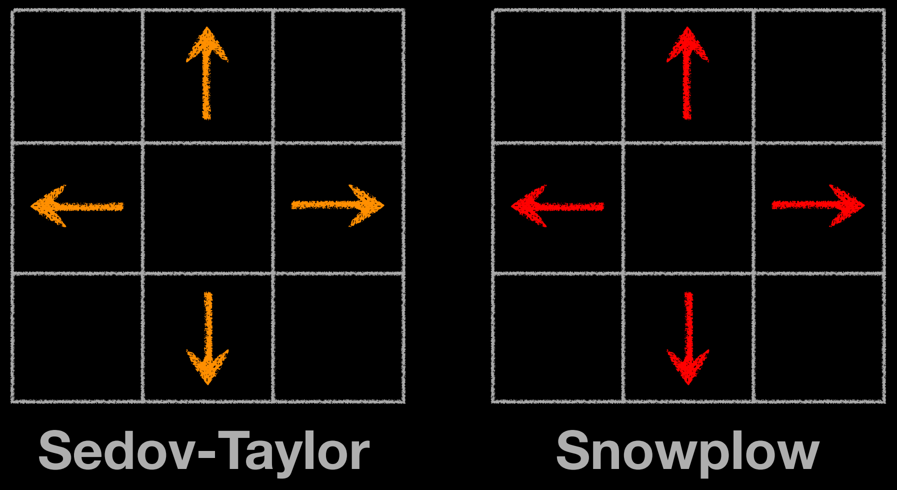


Kimm et al. 2015, 2017: “ME”

➢ Gravoturbulent star formation with local approximation

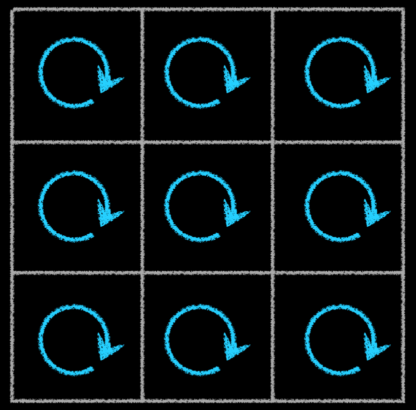


➢ Mechanical feedback

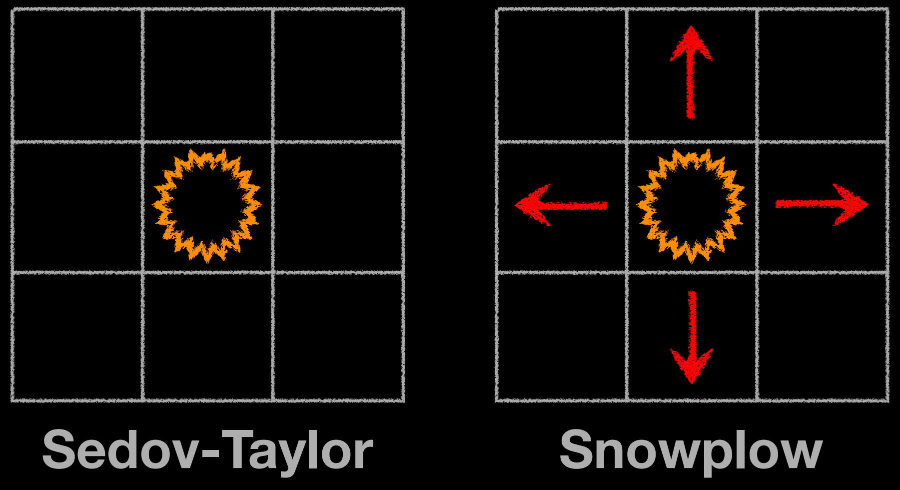


Kretschmer & Teyssier 2020: ”MT”

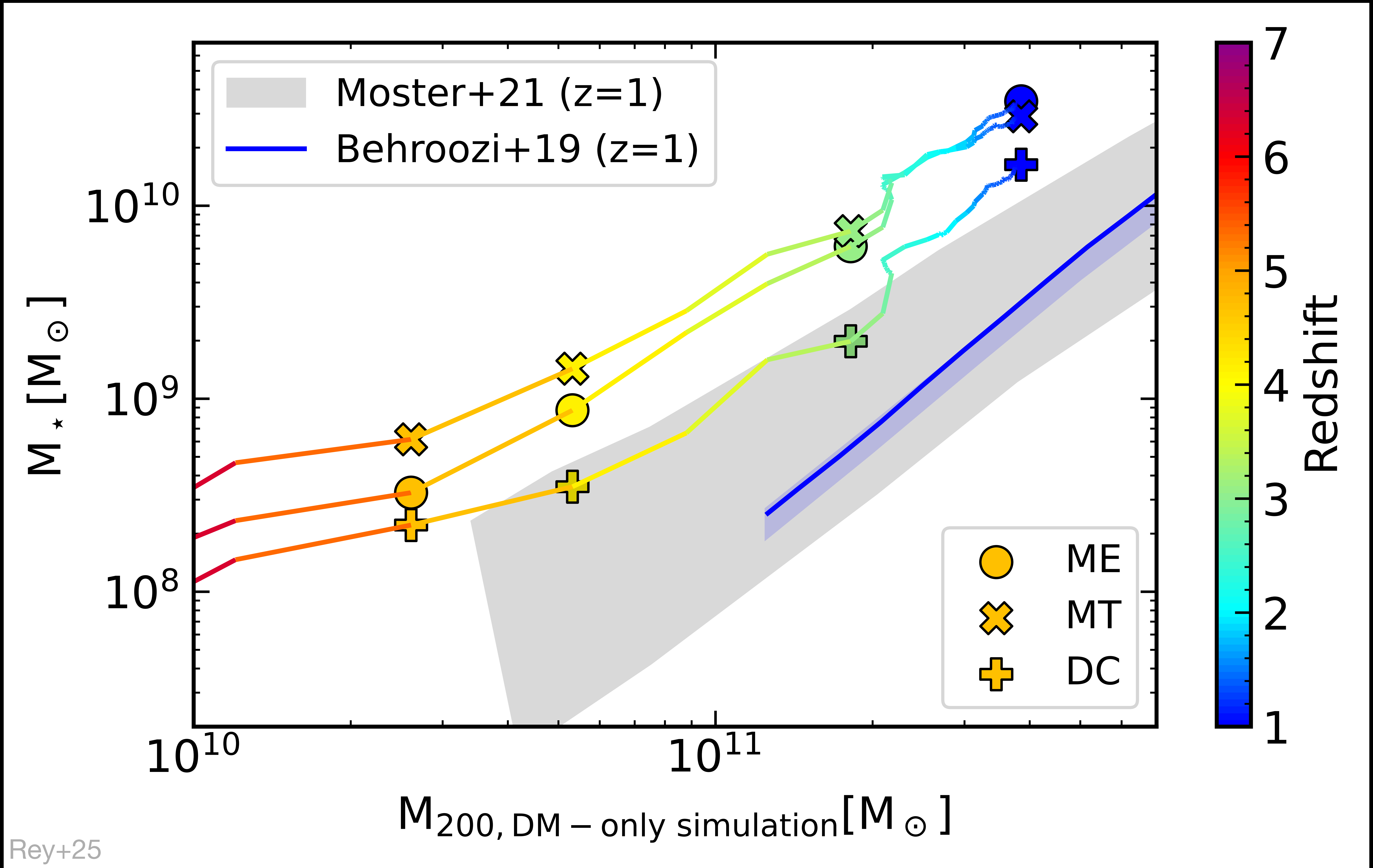
➢ Gravoturbulent star formation with subgrid turbulence



➢ Thermal injection + momentum injection



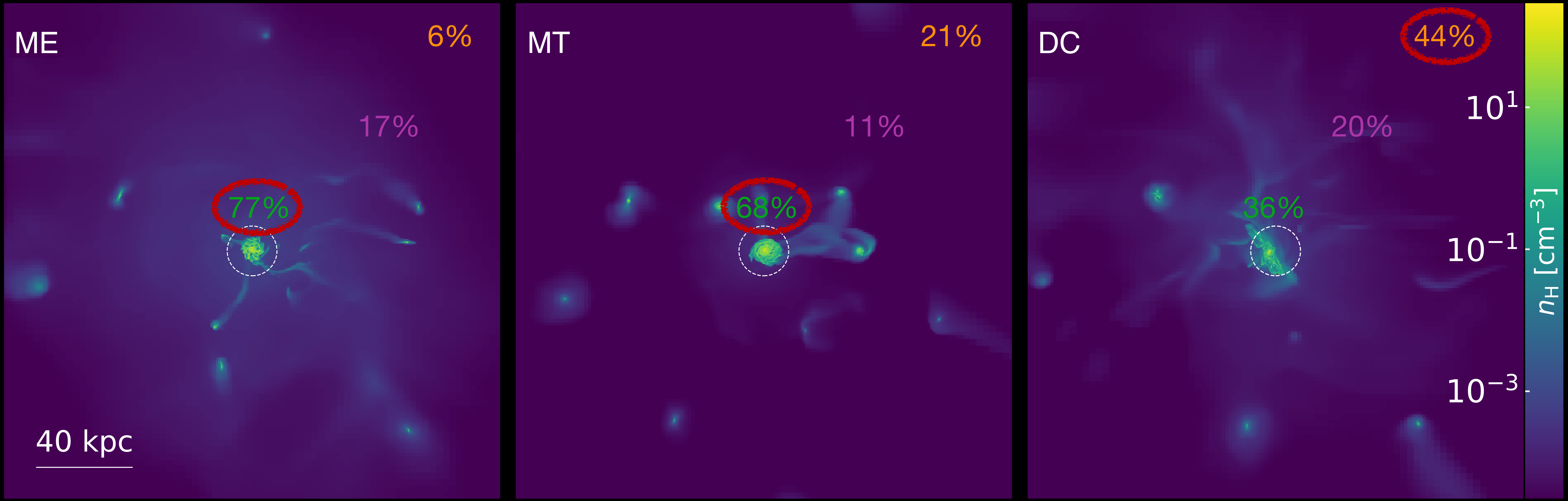
Stellar mass formed



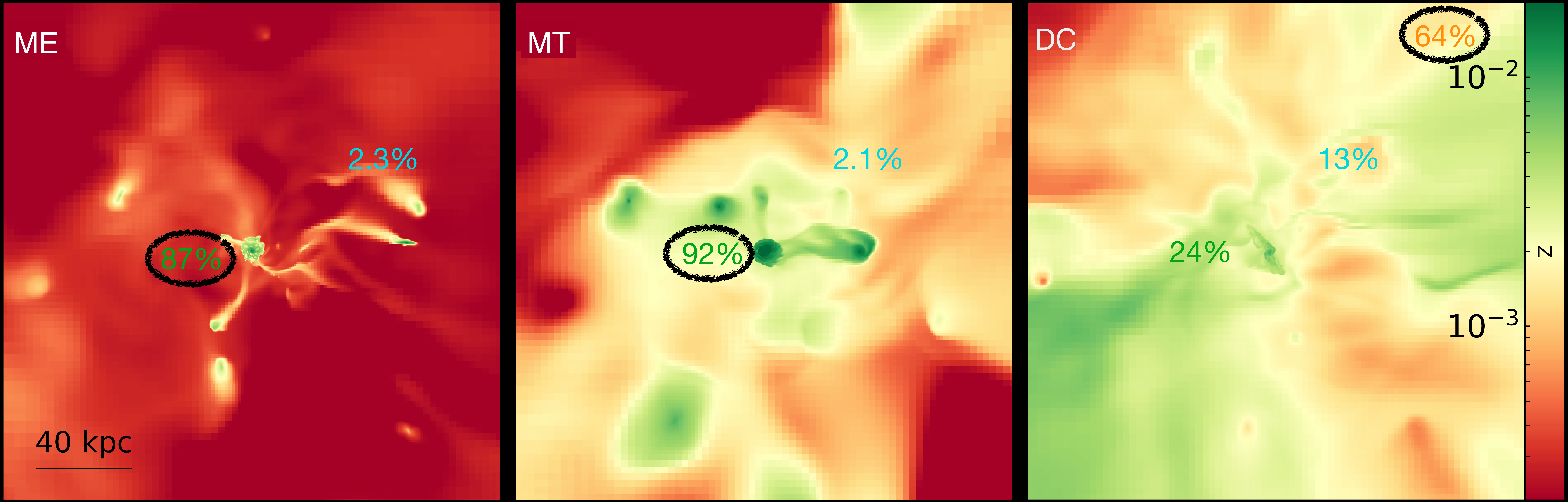
"Yay, they have the same mass."
—Me

What about the CGM?

Baryonic content of the halo



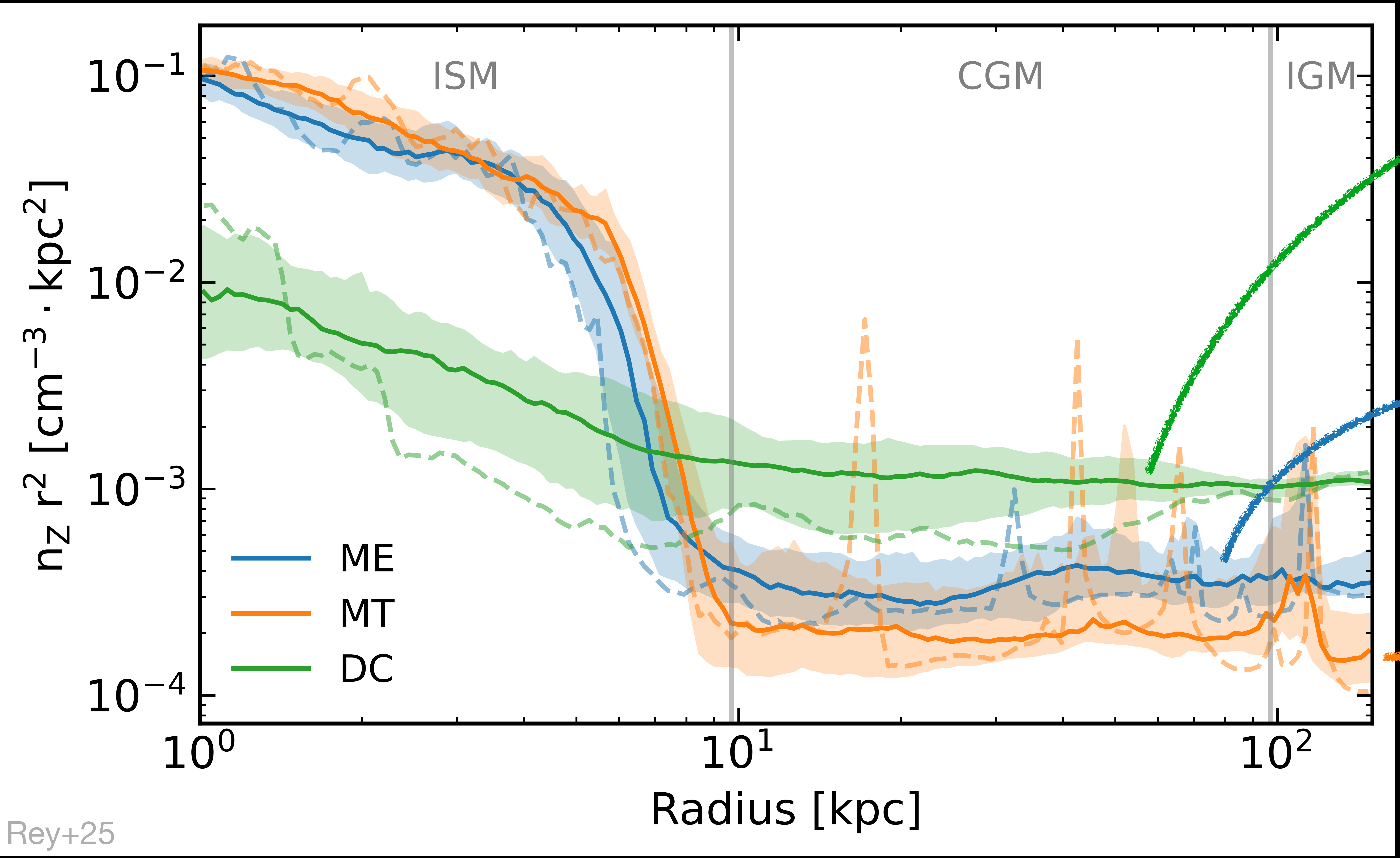
Baryonic content of the halo



- KI has a gas-rich CGM with low metallicity.
- KR has a gas-poor CGM with high metallicity.
- DC has a gas-rich CGM with high metallicity.

Metal content of the halo

ME (mechanical feedback)
MT (kinetic feedback)
DC (delayed cooling)



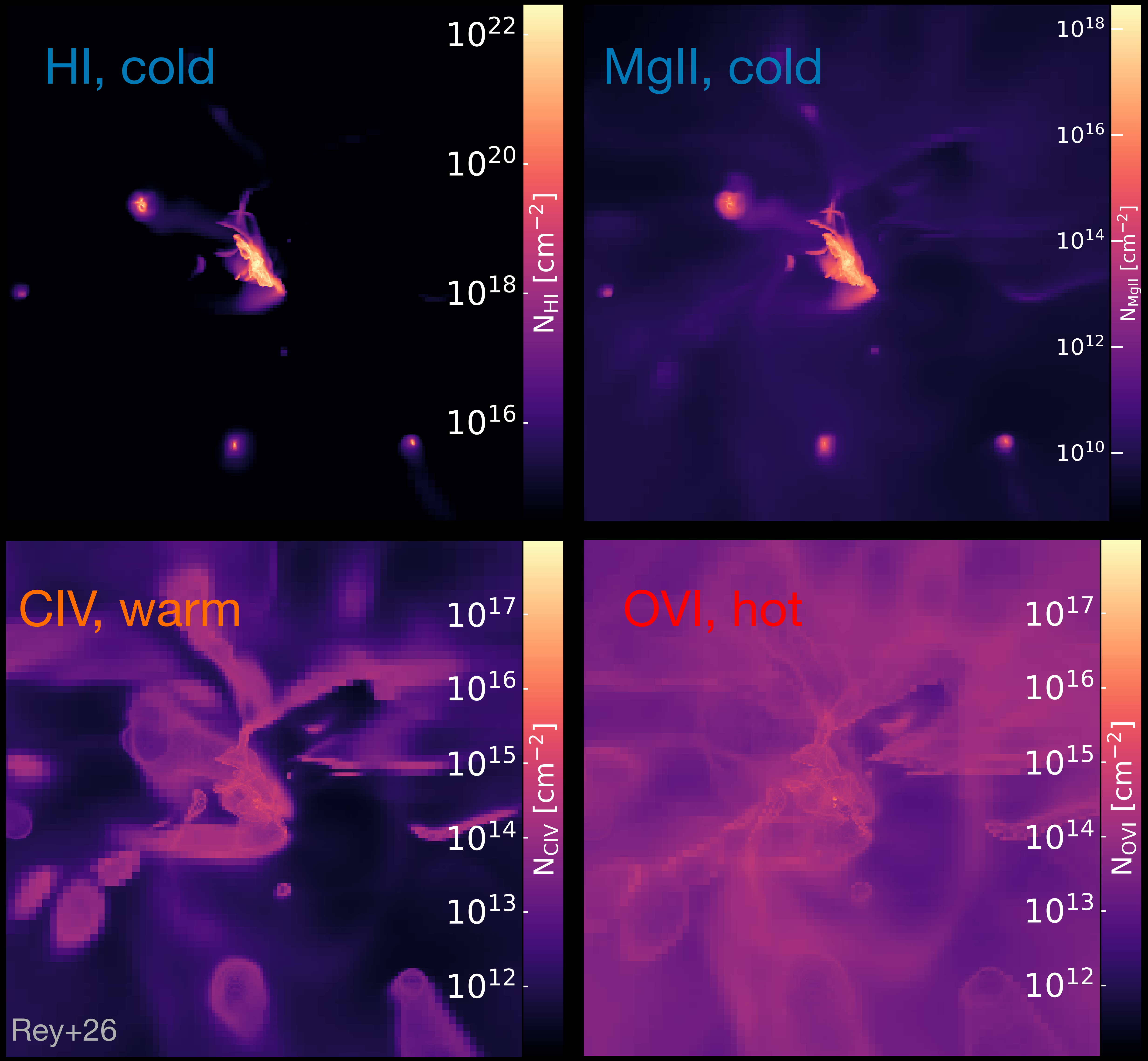
DC ejects metals more efficiently.

In ME and MT, metals are concentrated in the galaxy.

64% of metals ejected out of the halo
VS
75/72% in stars

The three models have very different feedback modes!

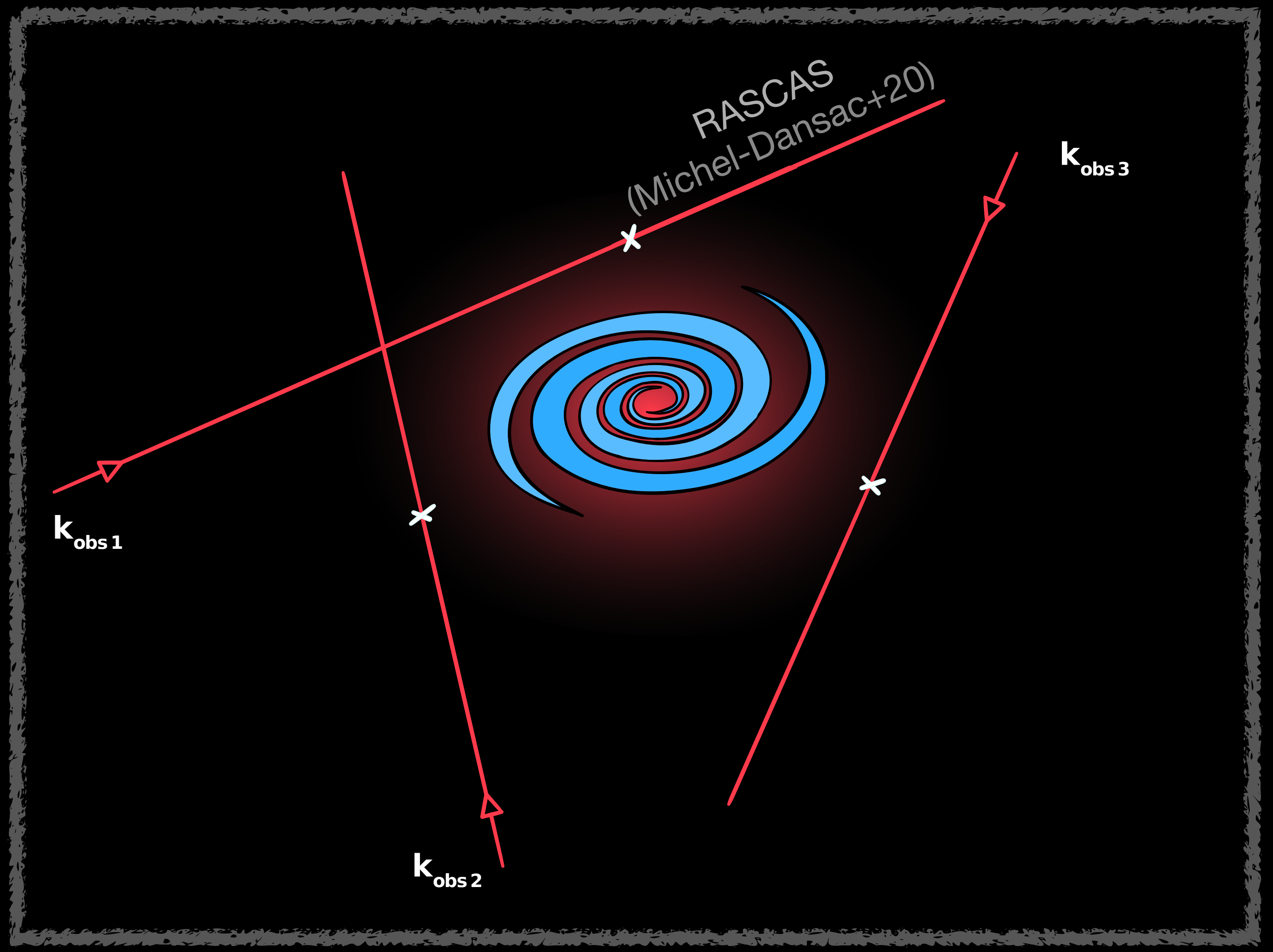
Simulating CGM observations



Simulations post-processing with KROME (Grassi+14)

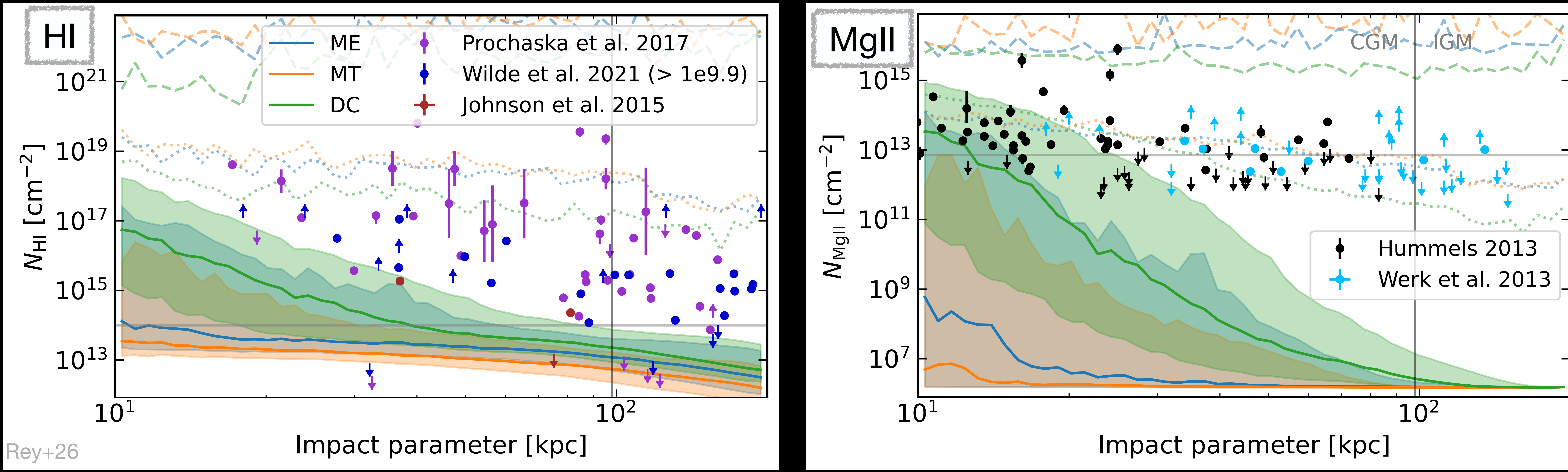
$$\rho, \mathrm{T}, \mathrm{Z}, \Gamma \rightarrow \mathrm{f}_{\mathrm{ion}}$$

Mauerhofer et al. 2021



The cold phase of the CGM

ME (mechanical feedback)
MT (kinetic feedback)
DC (delayed cooling)

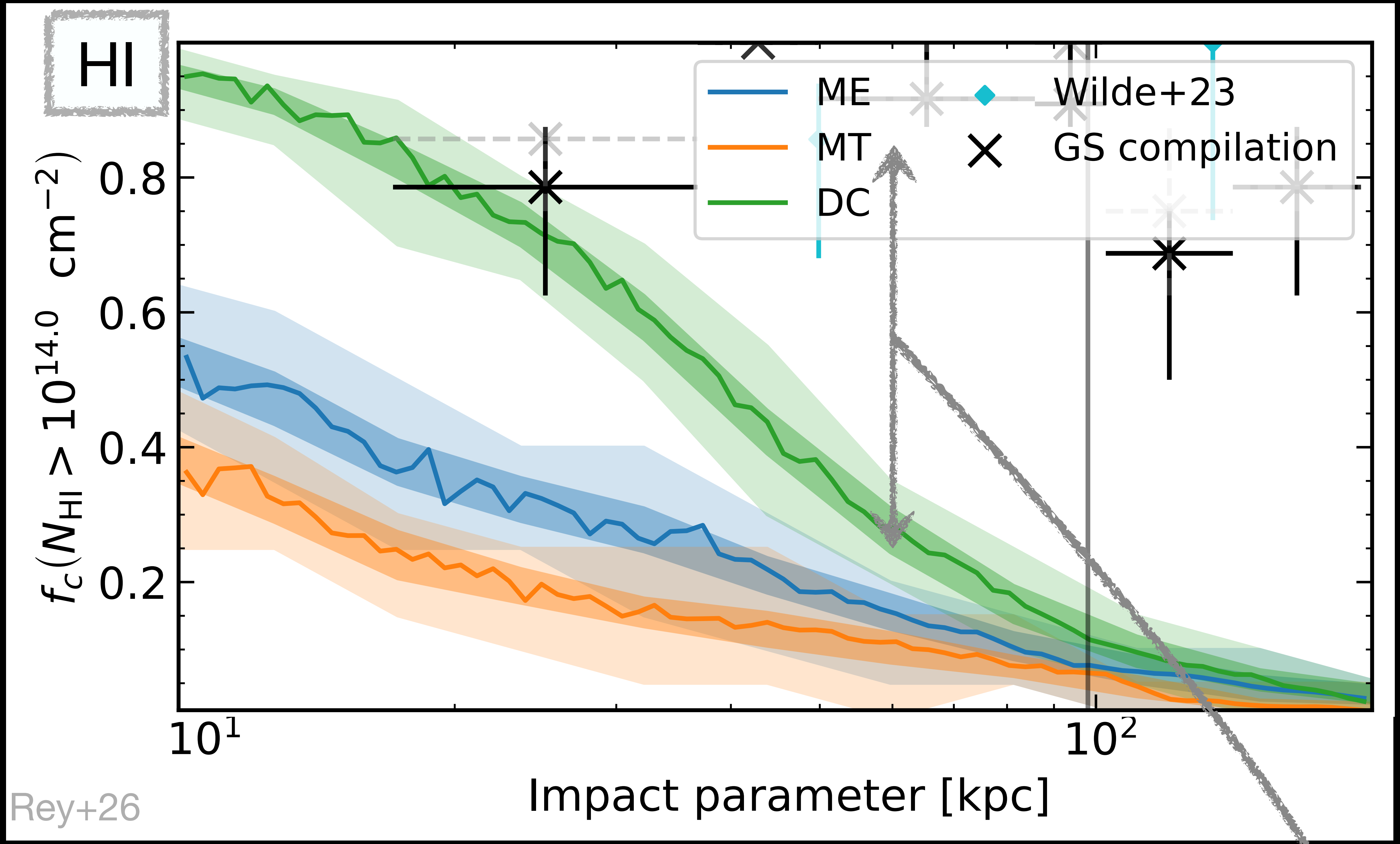


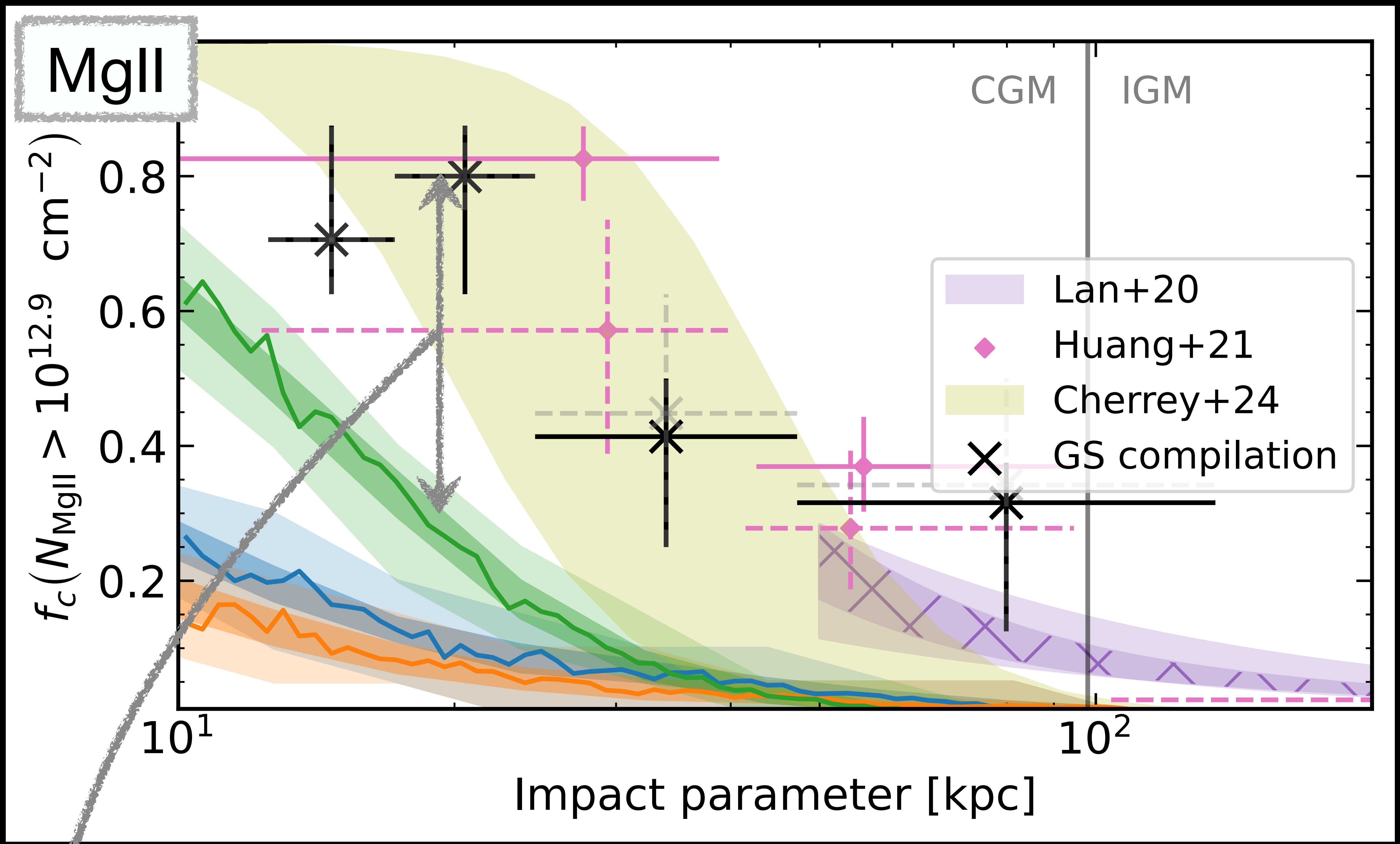
Which statistics?

max: above observations
average: agreement
median: below observations

→ covering fractions of weak absorbers

The cold phase of the CGM

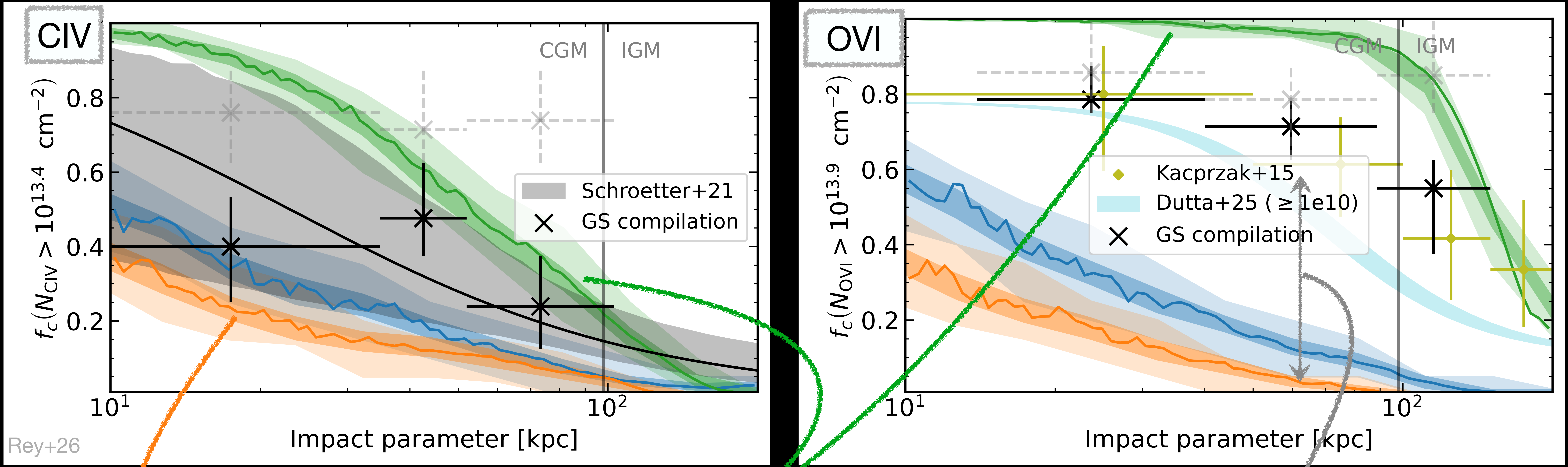




All models are well below observations

The warm and hot phases of the CGM

ME (mechanical feedback)
MT (kinetic feedback)
DC (delayed cooling)



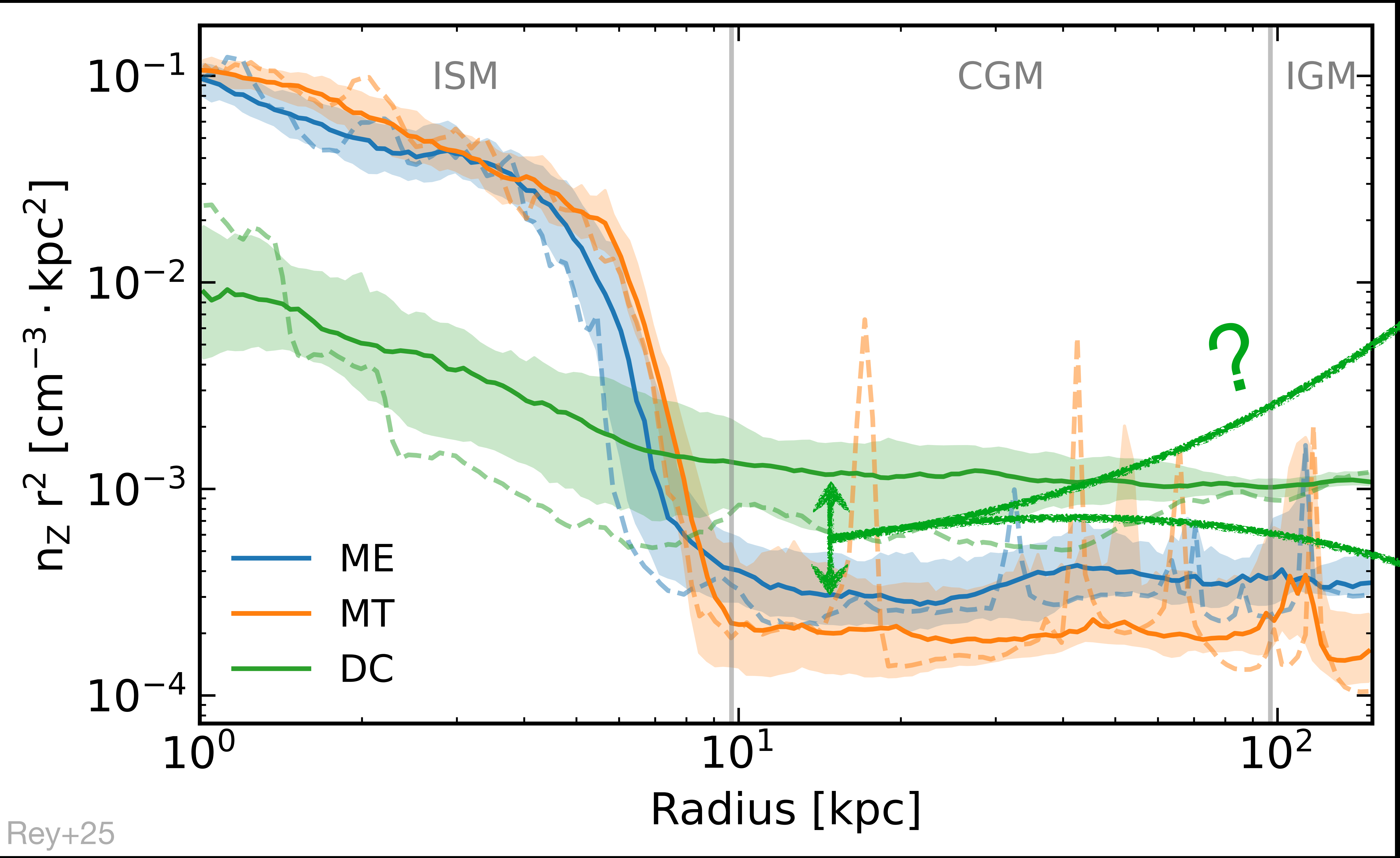
DC is higher than observations!

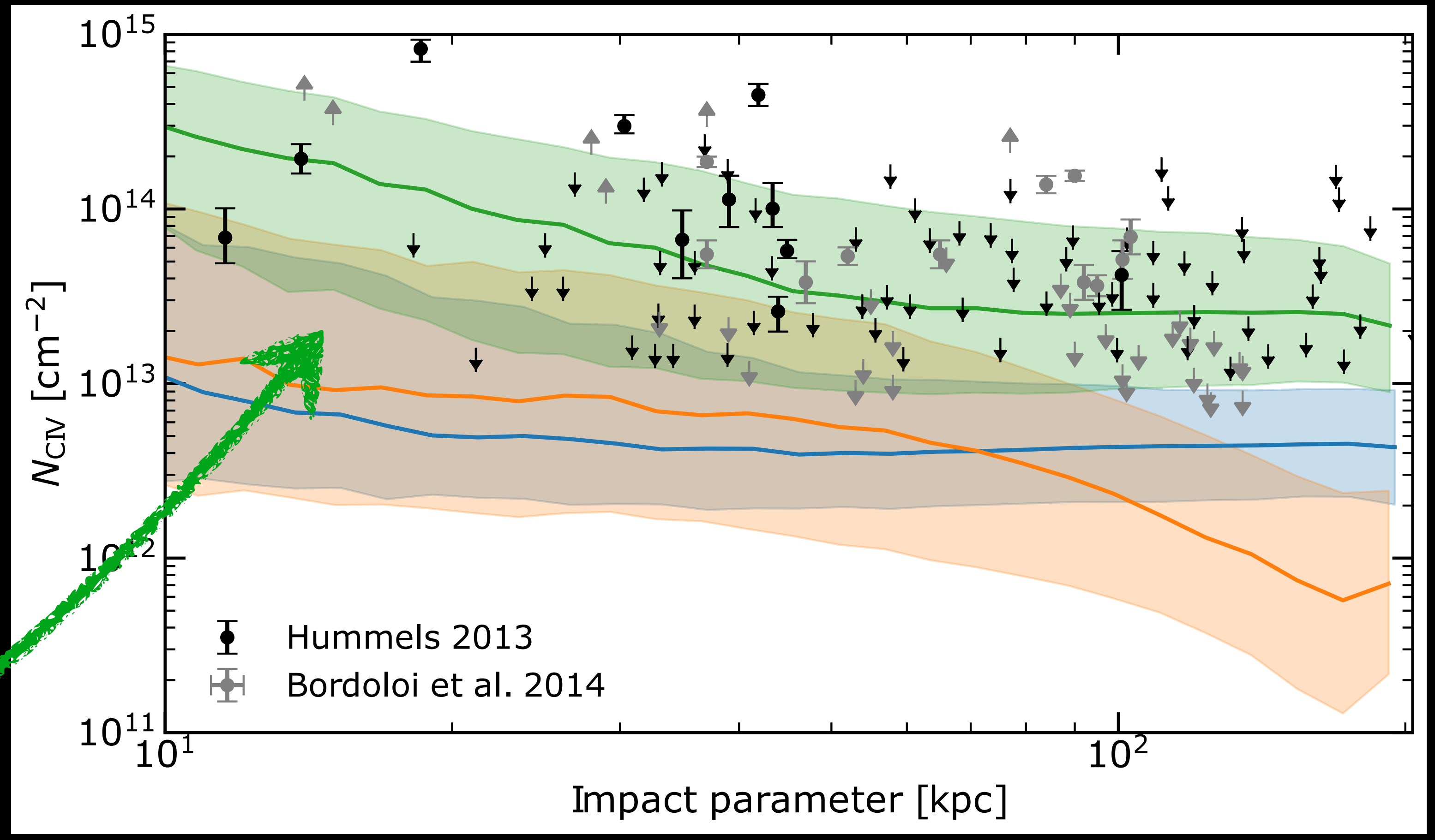
KR is almost in agreement with observations

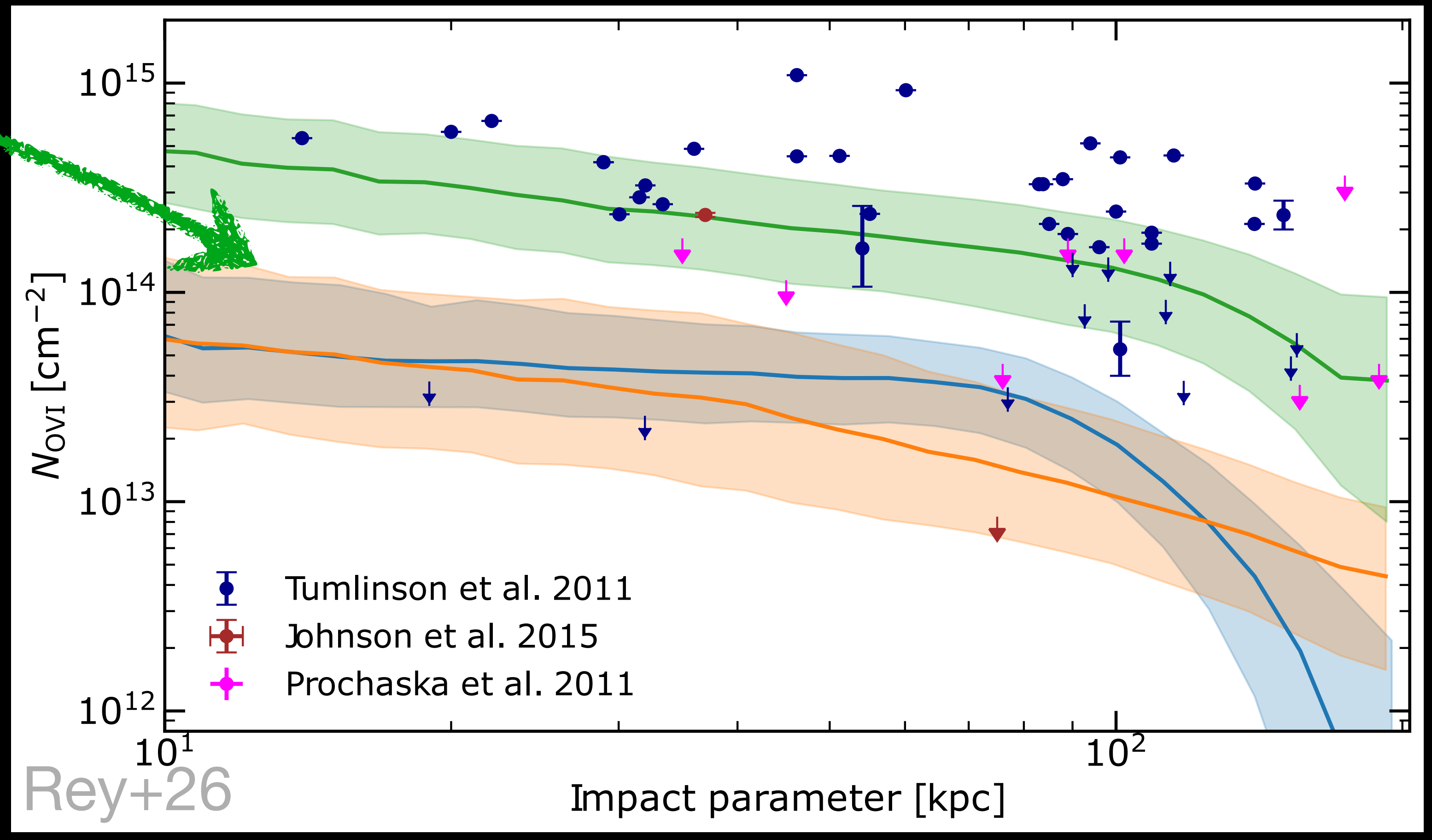
ME and MT are well below observations

ME (mechanical feedback)
MT (kinetic feedback)
DC (delayed cooling)

The role of metals







DC has more metals in the CGM.
Is it **driving** the difference in column densities?

What are we missing?

~ preliminary ~

What we want, column density!

~~column~~ density

$$N_{\mathrm{ion}} \propto \int_{\mathrm{l.o.s.}} \rho Z_{\mathrm{atom}} f_{\mathrm{ion}}(T, \Gamma/\rho) \mathrm{d}l$$

radiation field

atom abundance

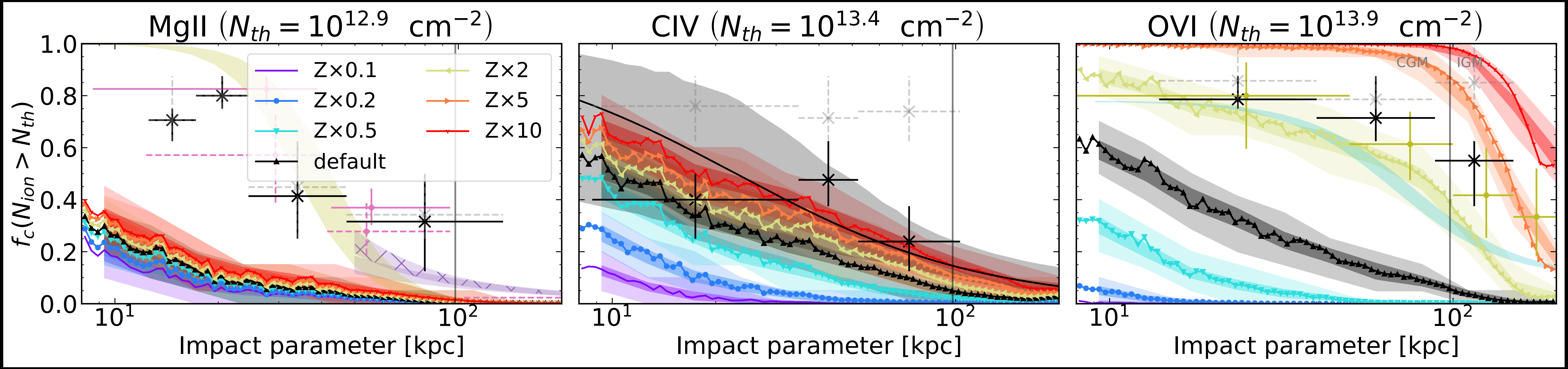
~ metallicity

ionisation fraction

temperature

Do we need more metals?

$$N_{\rm ion} \propto \int_{\rm l.o.s.} \rho Z_{\rm atom} f_{\rm ion}(T, \Gamma/\rho) {\rm d}l$$

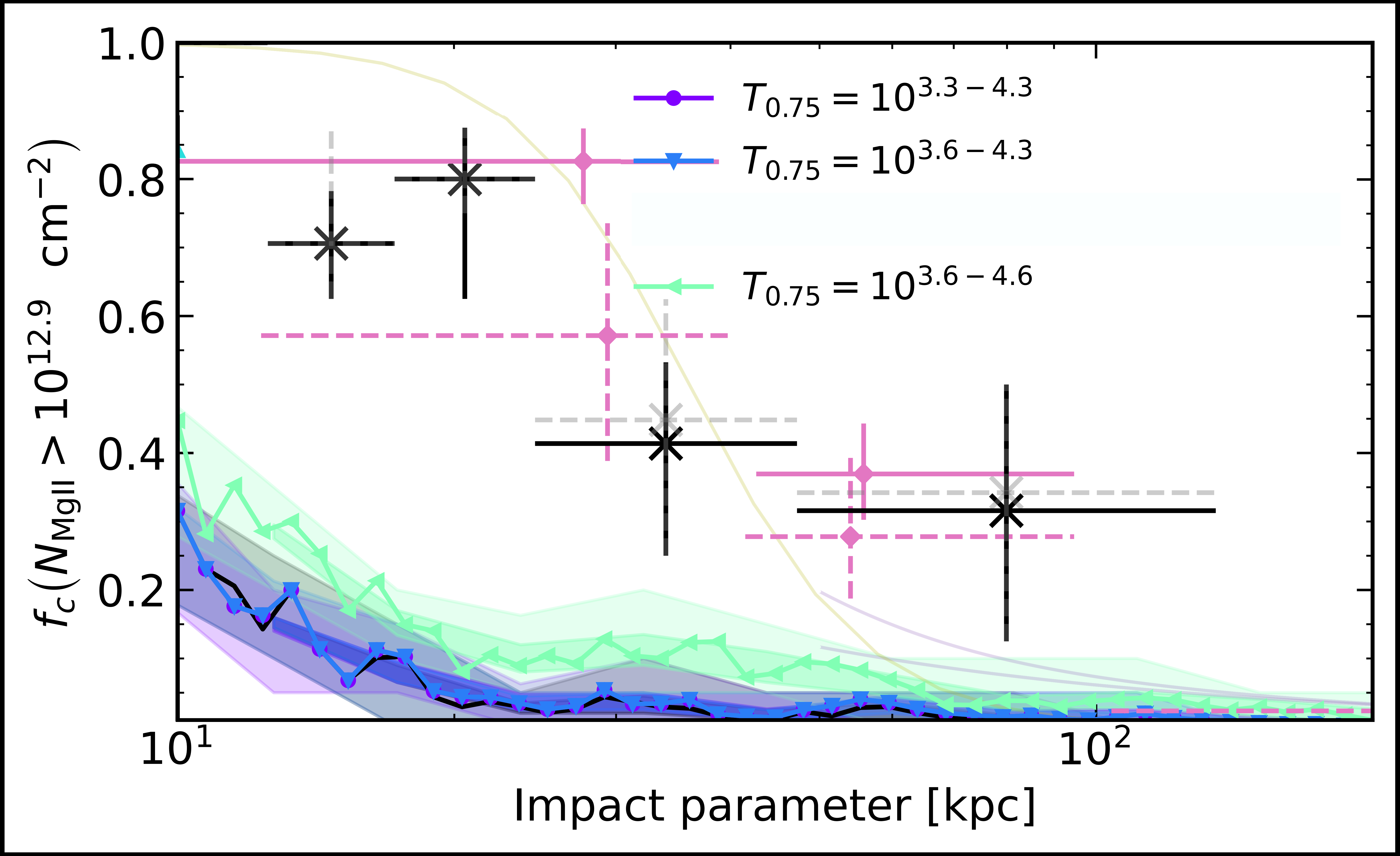


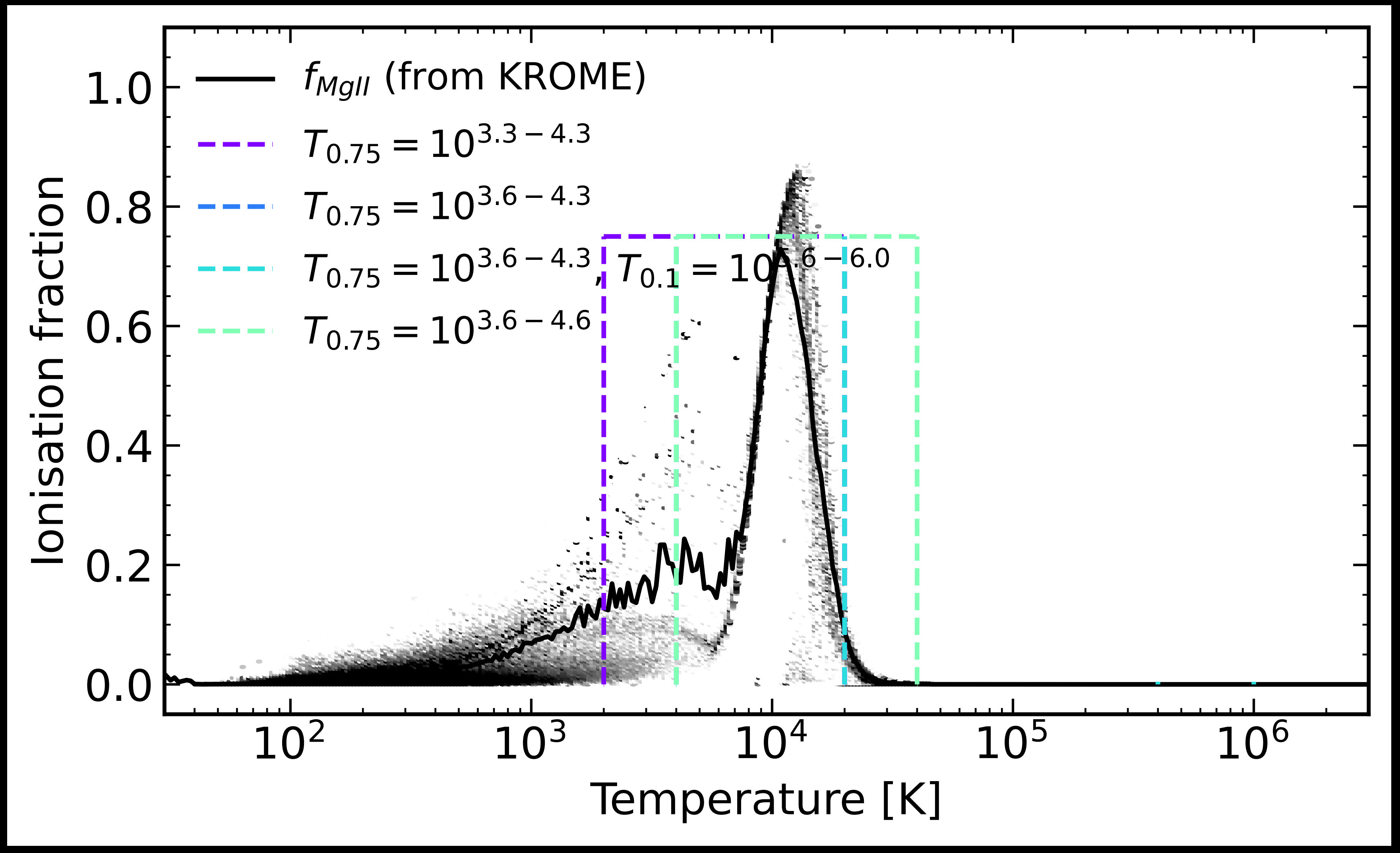
We would need an unrealistic amount of metals to match MgII.

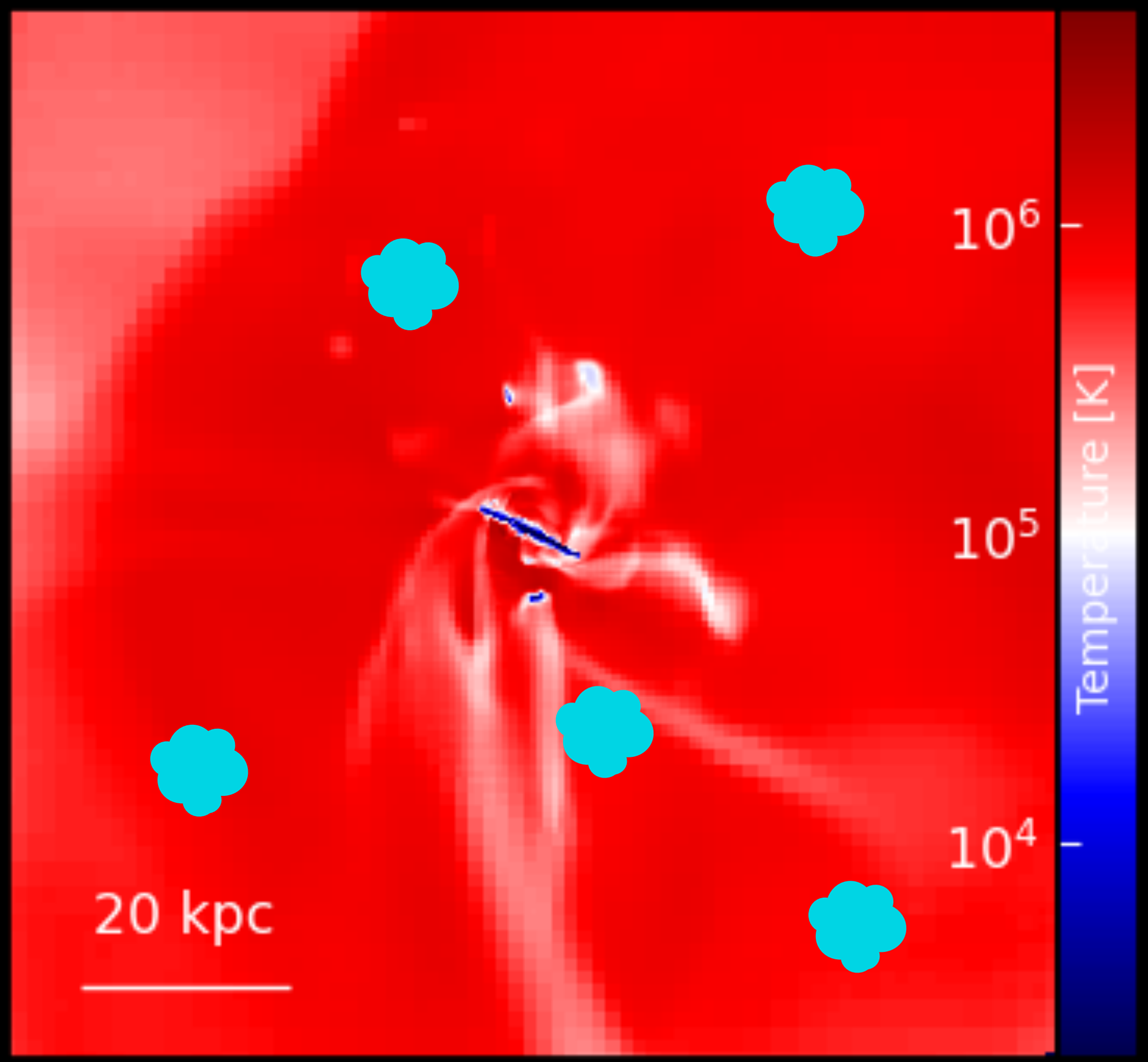
…but a twice higher metallicity is more than enough for CIV and OVI!

Is the ionisation fraction incorrect?

$$N_{\rm ion} \propto \int_{\rm l.o.s.} \rho Z_{\rm atom} f_{\rm ion}(T, \Gamma/\rho)\,{\rm d}l$$







Much more efficient than increasing metallicity!

What are we missing?

~~density~~

$$N_{\rm ion} \propto \int_{\rm l.o.s.} \rho Z_{\rm atom} f_{\rm ion}(T, \Gamma/\rho) {\rm d}l$$

~~radiation field~~

metallicity

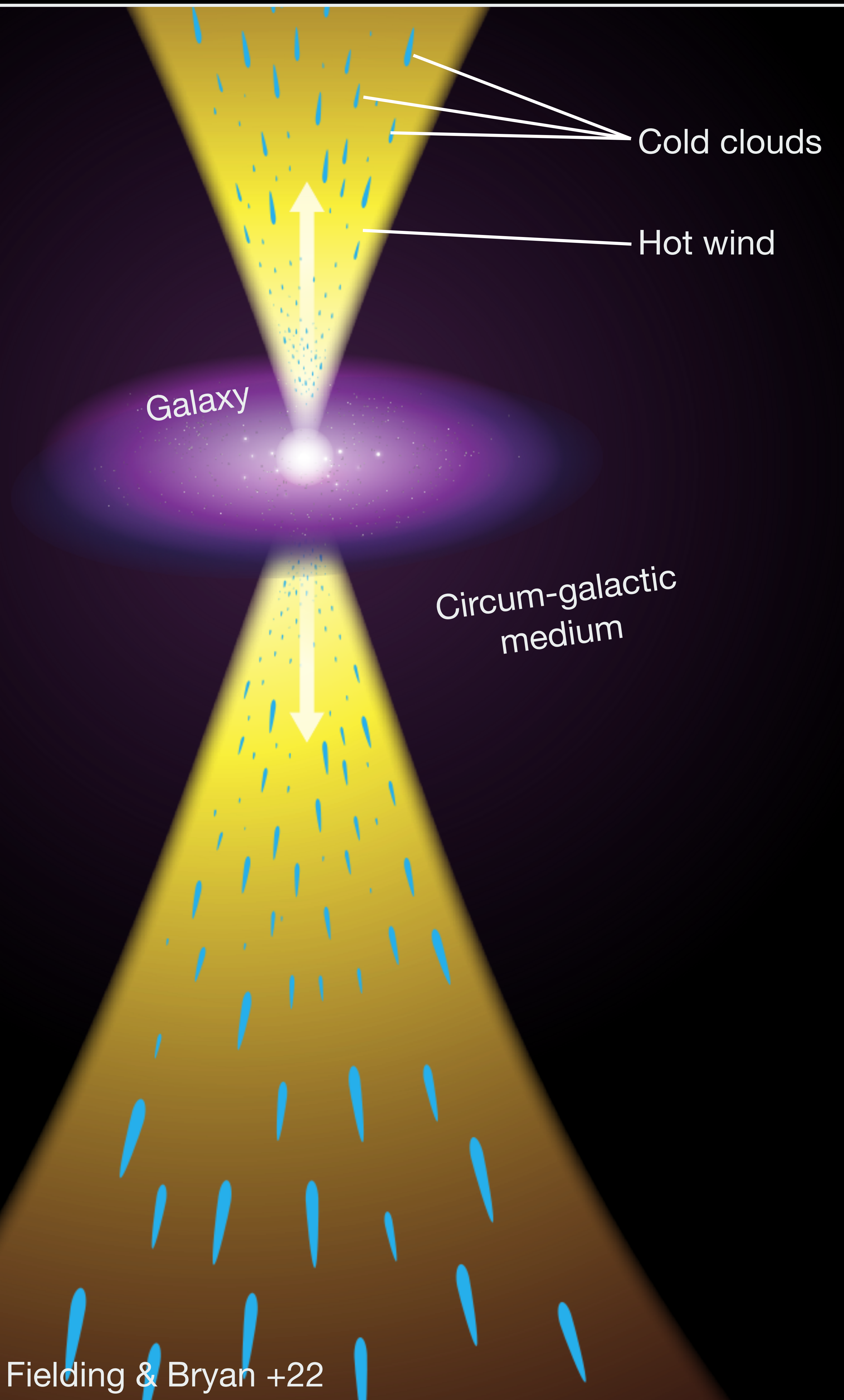
High ions 👍
Low ions 👎

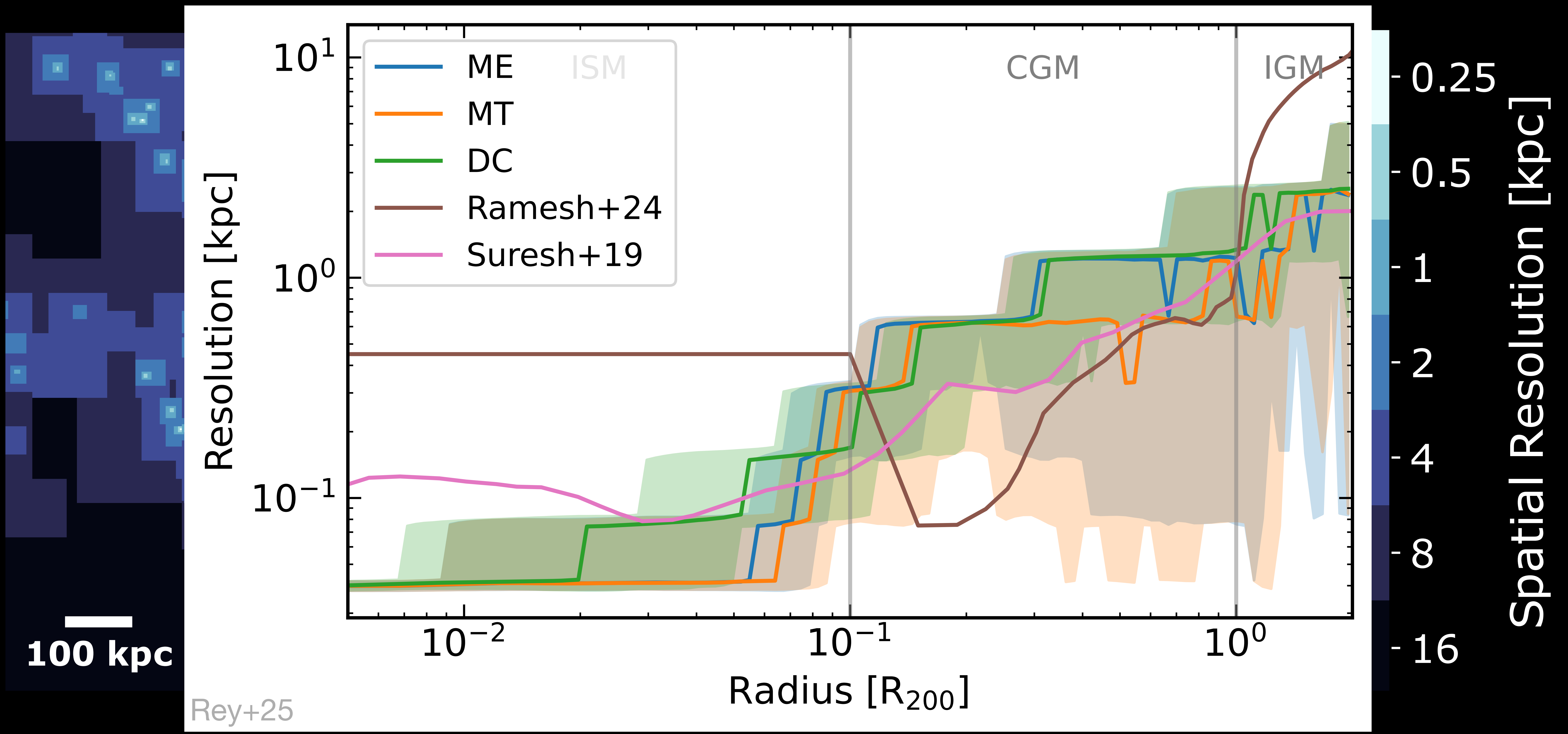
ionisation fraction

High ions 👎
Low ions 👍

temperature

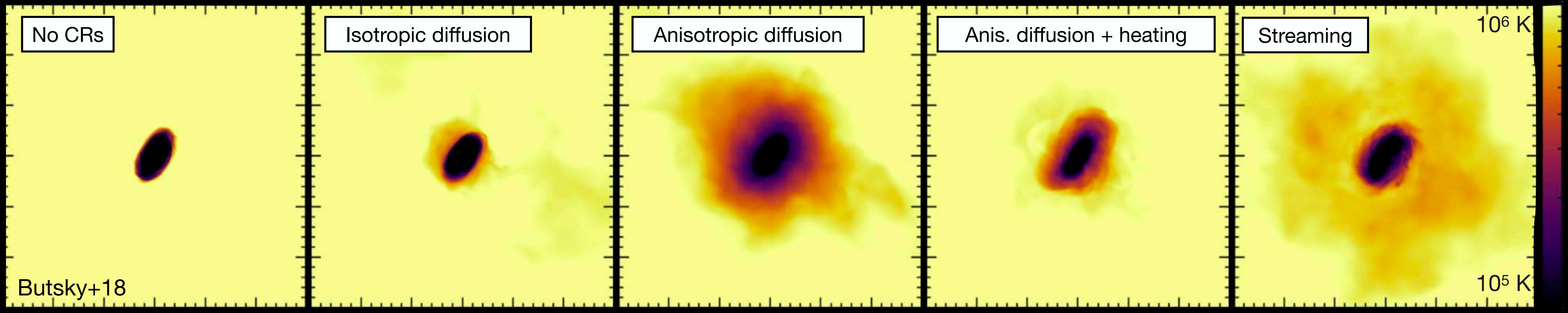
Prospects: do we lack resolution?

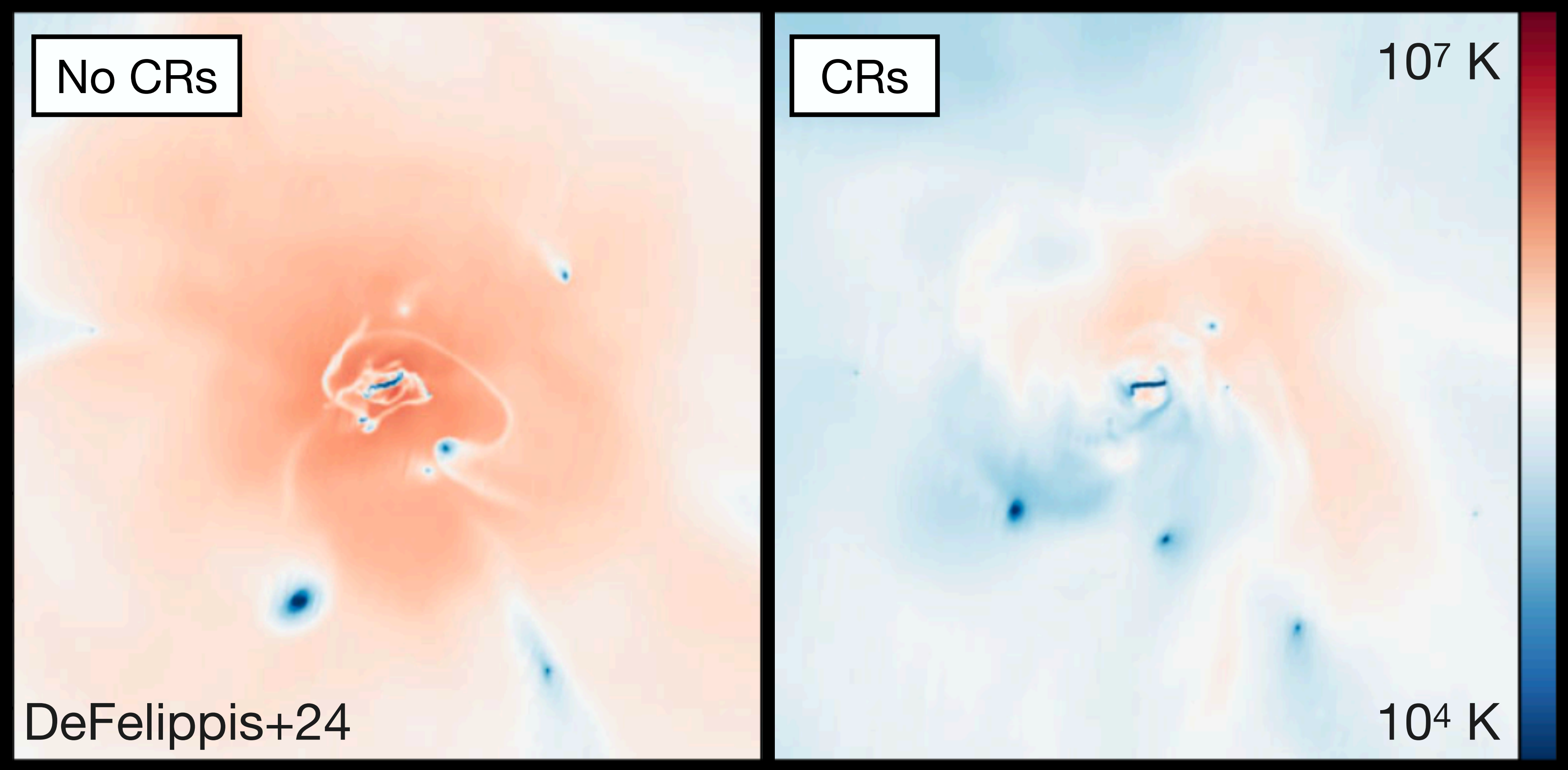




➢ Resolve the CGM

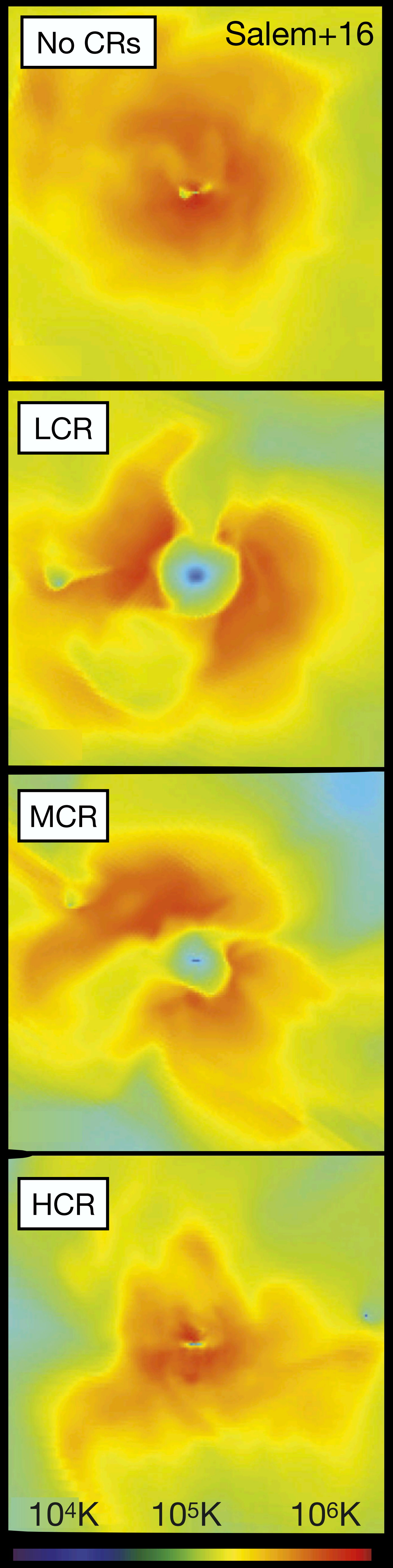
Prospects: do we lack cosmic rays?



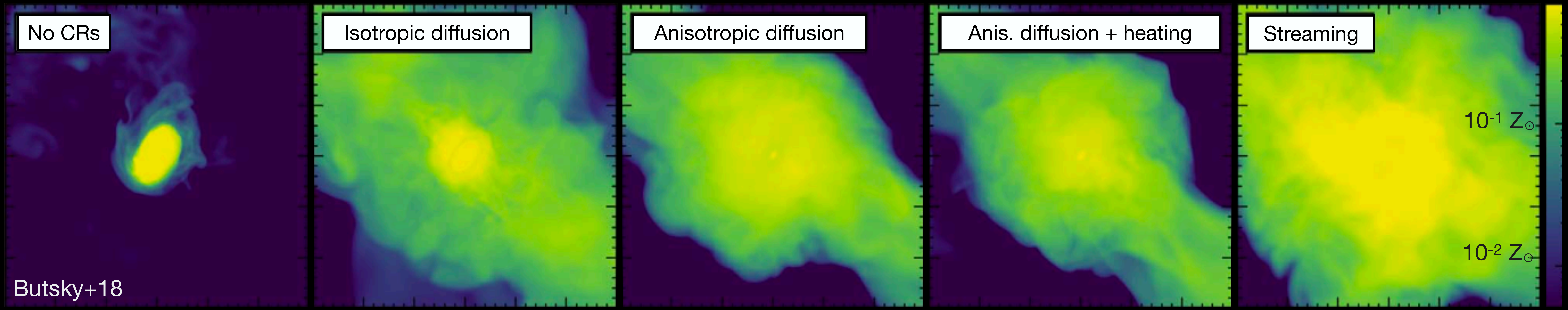


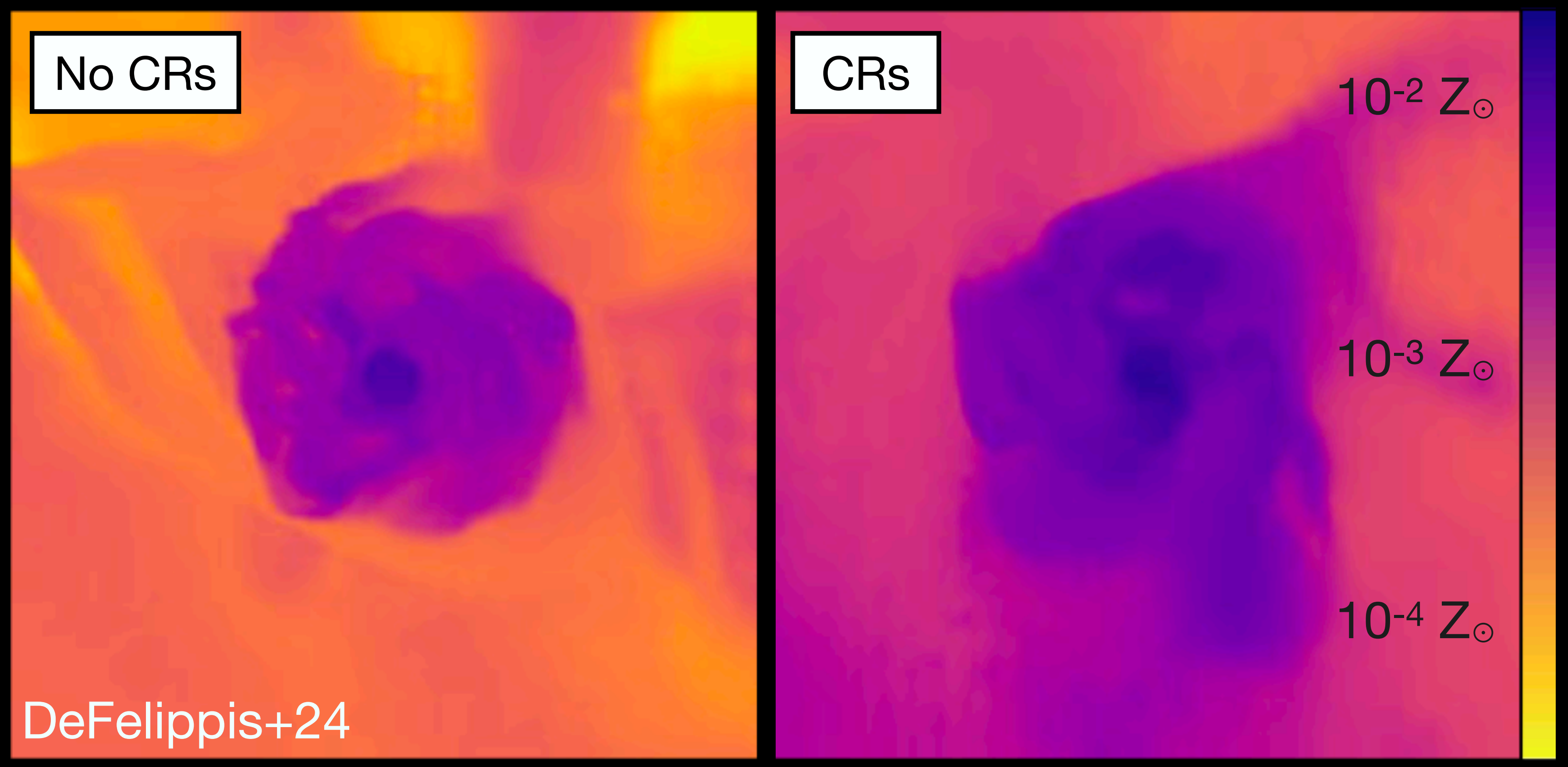
- Pushes cooler gas in the CGM.

➢ Modelling cosmic rays



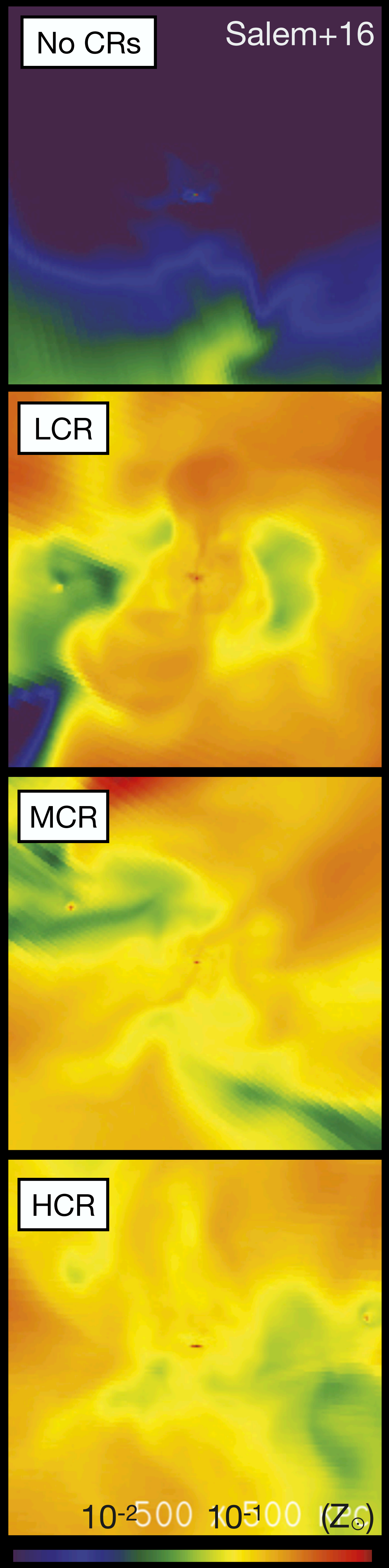
Prospects: do we lack cosmic rays?





- Pushes cooler gas in the CGM.
- Pushes more metals into the CGM.

➢ Modelling cosmic rays



Conclusions

The ARCHITECTS simulations

- 3 widely used models
- calibrated in M_{star}

ME (mechanical feedback)
MT (kinetic feedback)
DC (delayed cooling)

ARCHITECTS I

Different models lead to different feedback modes and distinct CGMs

ARCHITECTS II

Column densities can discriminate them ✓
(need both HI and metals to lift degeneracies)

Good to constrain degenerate models!
Best practice: covering fractions of low absorbers!

All struggle to reproduce CGM observations ✗
(to be fair, all simulations do)

We need…

(x2 = 😚👌)

Higher metallicity.
More powerful feedback: SINK

CIV
OVI

Low-temperature gas.
Hard: resolution? CRs?.

HI
MgII