On the relevance/importance of of better modelling the interface between CGM and cosmic web

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Why should we care?

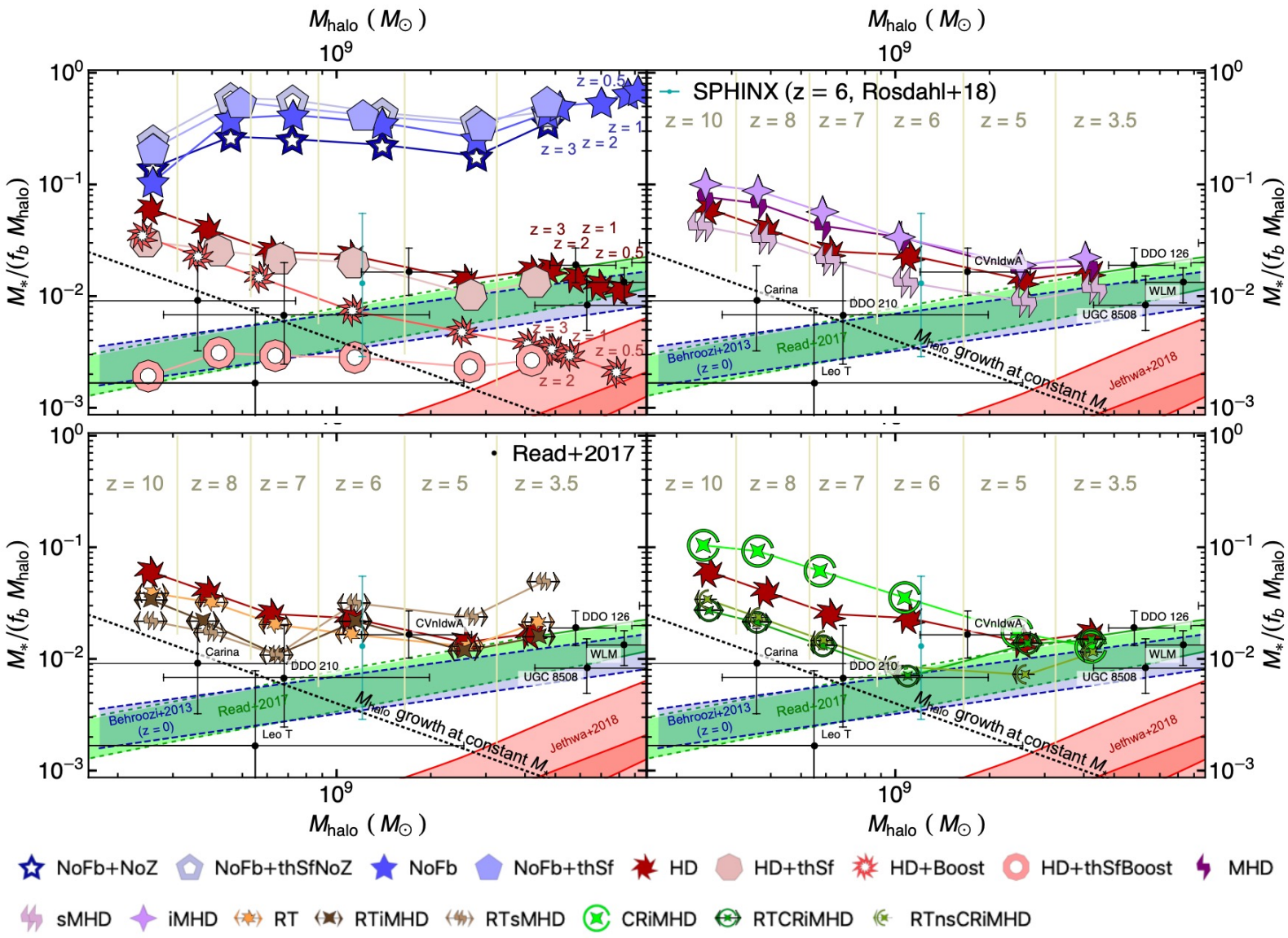
Plenty of reasons:

- **Charlotte's talk about multiphase filamentary flows**
- **Corentin's talk about AM … (also Tillson et al 2015) etc …**

But above and overall: constraining feedback models/physics!

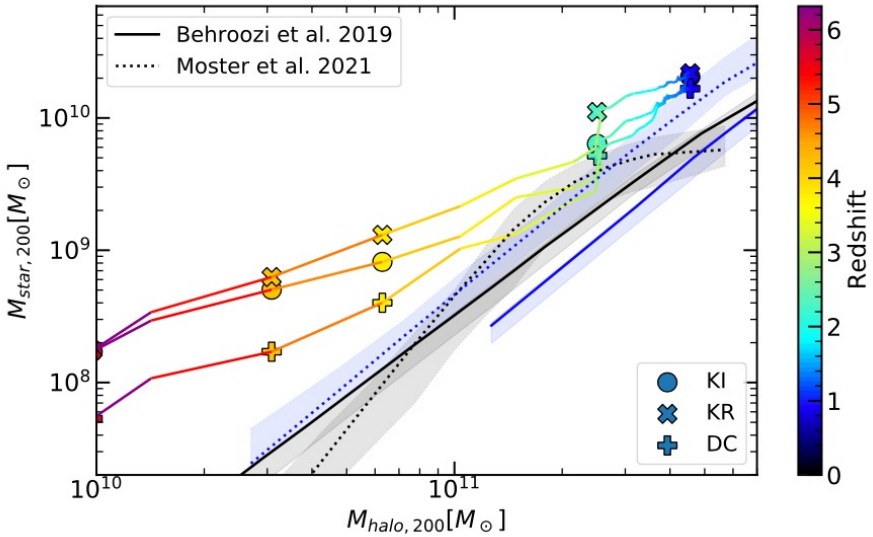
Pandora project:
Martin-Alvarez et al, arXiV:2211.09139

	Simulation	Solver	B_0 (G)	RT	CR	Stars	Stellar feedback
	NoFb+thSfNoZ	Hydro	✗	✗	✗	thres	✗
	NoFb+thSf	Hydro	✗	✗	✗	thres	No energy/mom injection
	NoFb+NoZ	Hydro	✗	✗	✗	MTT	✗
	NoFb	Hydro	✗	✗	✗	MTT	No energy/mom injection
	HD+thSf	Hydro	✗	✗	✗	thres	Mech
	HD+thSfBoost	Hydro	✗	✗	✗	thres	Boosted Mech
	HD	Hydro	✗	✗	✗	MTT	Mech
	HD+Boost	Hydro	✗	✗	✗	MTT	Boosted Mech
	MHD	MHD	$3 \cdot 10^{-13}$	✗	✗	MTT	Mech
	sMHD	MHD	$3 \cdot 10^{-11}$	✗	✗	MTT	Mech
	iMHD	MHD	$3 \cdot 10^{-20}$	✗	✗	MTT	MagMech
	RT	Hydro	✗	✓	✗	MTT	Radiation + Mech
	RTsMHD	MHD	$3 \cdot 10^{-11}$	✓	✗	MTT	Radiation + Mech
	RTiMHD	MHD	$3 \cdot 10^{-20}$	✓	✗	MTT	Radiation + MagMech
	CRiMHD	MHD	$3 \cdot 10^{-20}$	✗	✓	MTT	CRMagMech
	RTnsCRiMHD	MHD	$3 \cdot 10^{-20}$	✓	✓	MTT	Radiation + CRMagMech
	RTCRiMHD	MHD	$3 \cdot 10^{-20}$	✓	✓	MTT	Radiation + CRMagMech

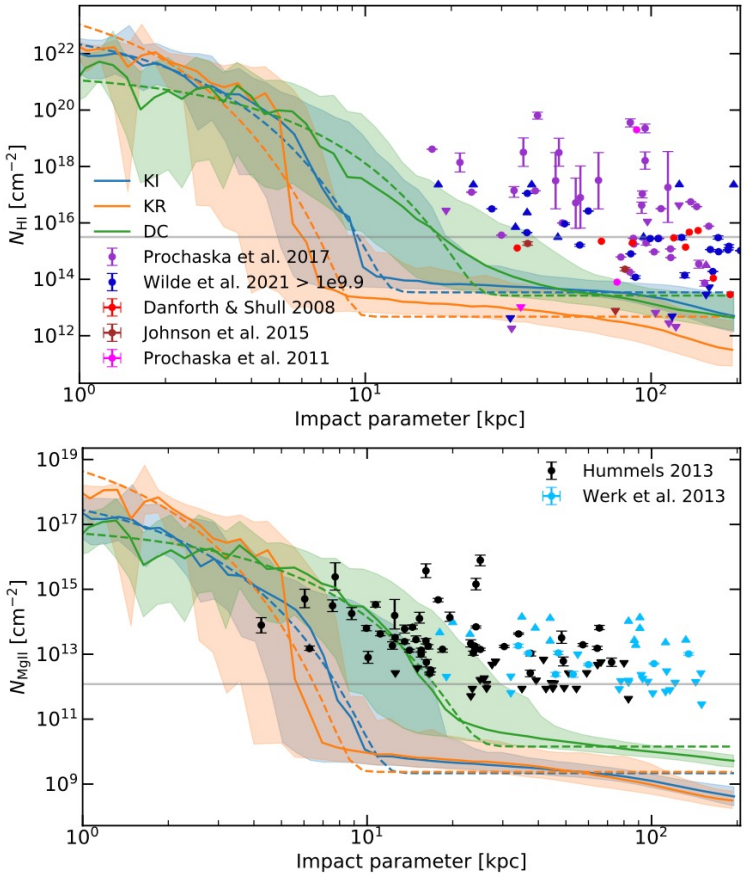


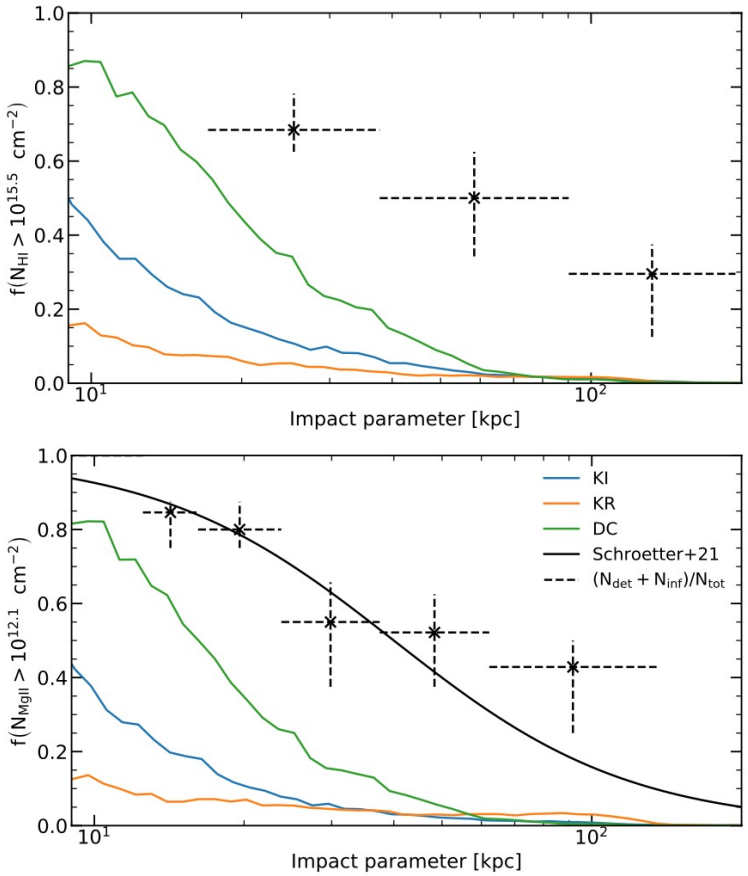
What is (are) the problem(s)?

Rey and Blaizot (in prep) … but also others



→ **Need to track metals and ionization states**

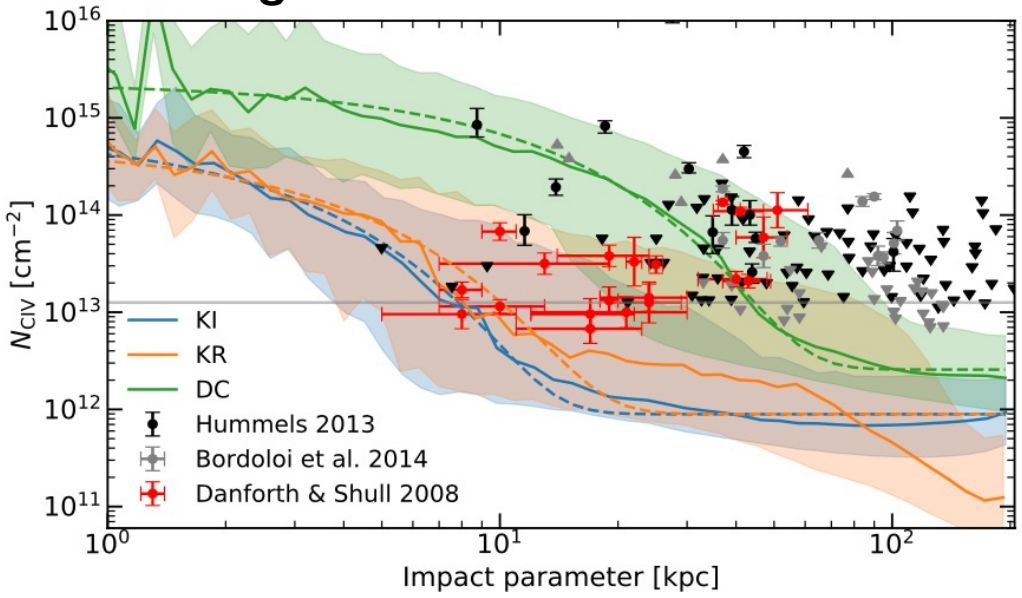


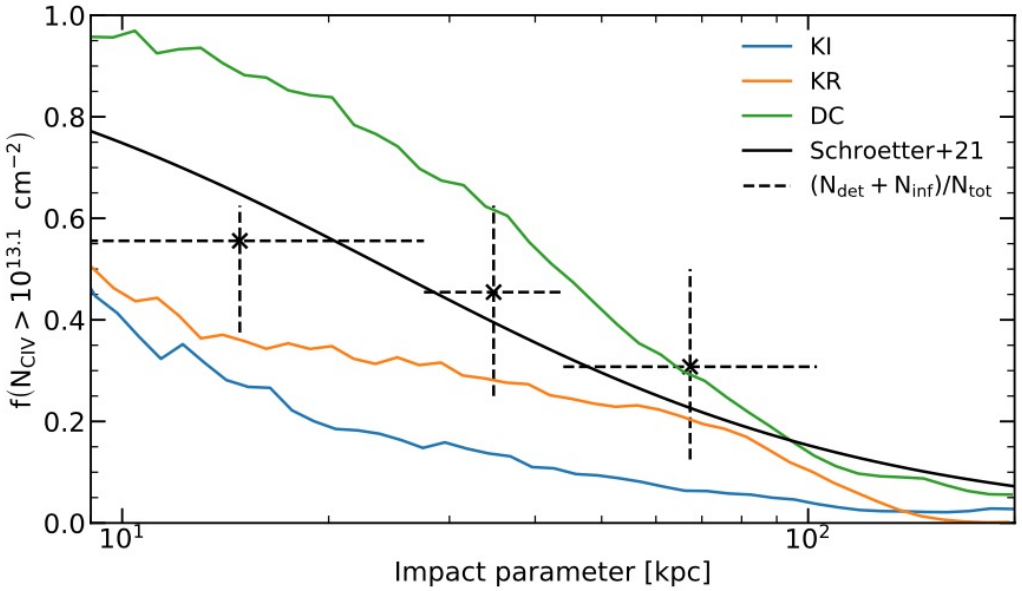


Cold CGM Gas

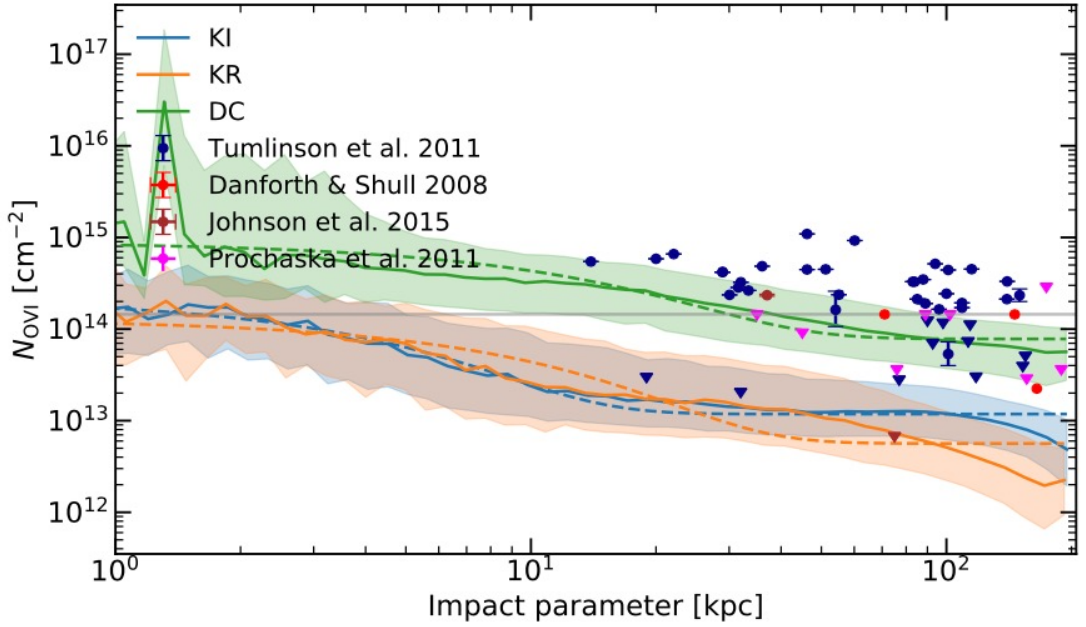
Rey, Maxime (PhD Thesis)

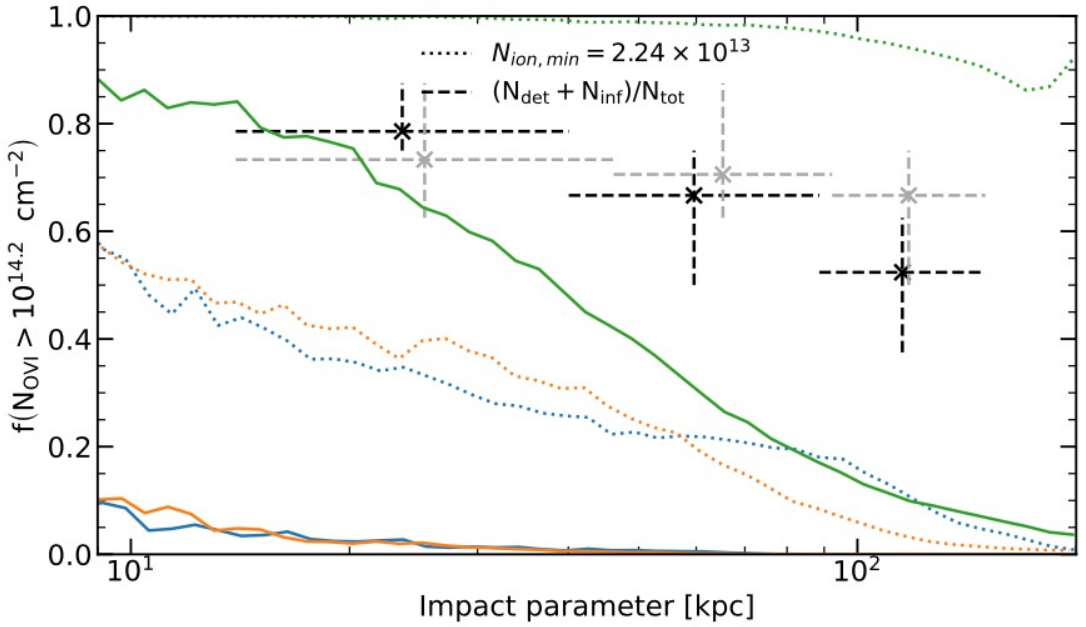
Warm CGM gas





→ **Need to have resolution in the CGM to properly capture its multiphase nature!**





Rey, Maxime (PhD Thesis)

Hot CGM gas

PRISM: Tracking the metals and atom ionization states

Katz et al, arXiV:2211.04626

NB: also applies to the CGM but metals produced in the ISM (although see movie later on)!

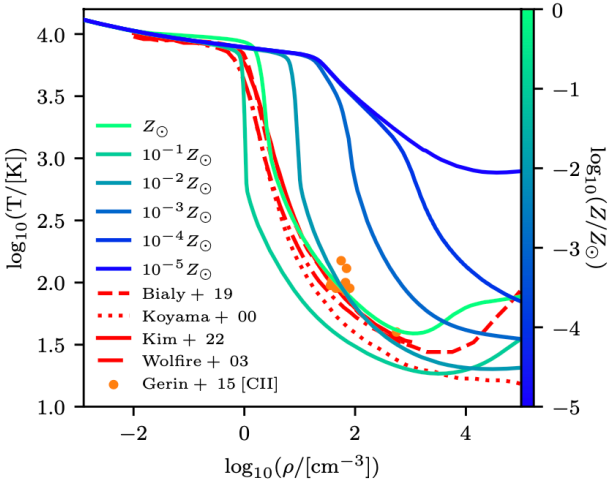
Group Name	E_{low} (eV)	E_{high} (eV)	Function
IR	0.1	1.0	Infrared radiation pressure
Opt.	1.0	5.6	Direct radiation pressure
FUV	5.6	11.2	Photoelectric heating, Mg I, Si I, S I, Fe I ionization
LW	11.2	13.6	H_2 dissociation, C I ionization
EUV_1	13.6	15.2	H I, N I, O I, Mg II ionization
EUV_2	15.2	24.59	H_2, C II, Si II, S II, Fe II, Ne I ionization
EUV_3	24.59	54.42	He I, O II, C III, N II, N III, Si III, Si IV, S III, S IV, Ne II, Fe III ionization
EUV_4	54.42	∞	He II, O III+, N IV+, C IV+, Mg III+, S V+, Si V+, Fe IV+, Ne III+ ionization

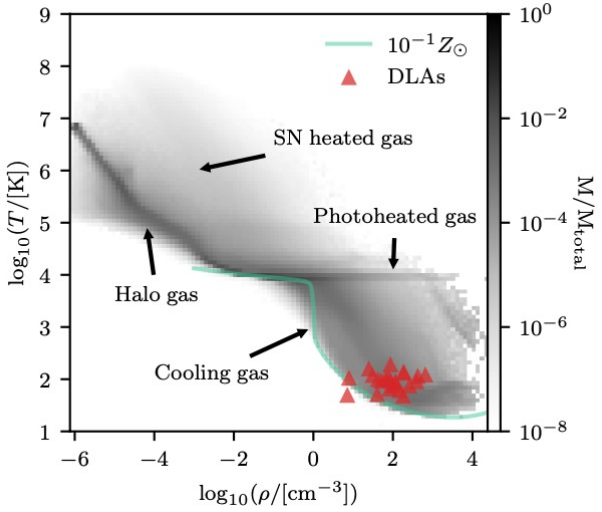
(> 60 ions)

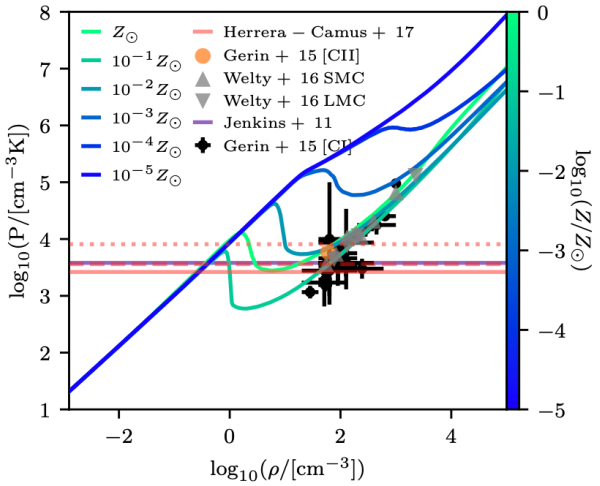
Caveats: no MHD, thermal conduction, non-self consistent dust model or CR treatment yet but coming soon … also only valid for optically thin regime (density limited)

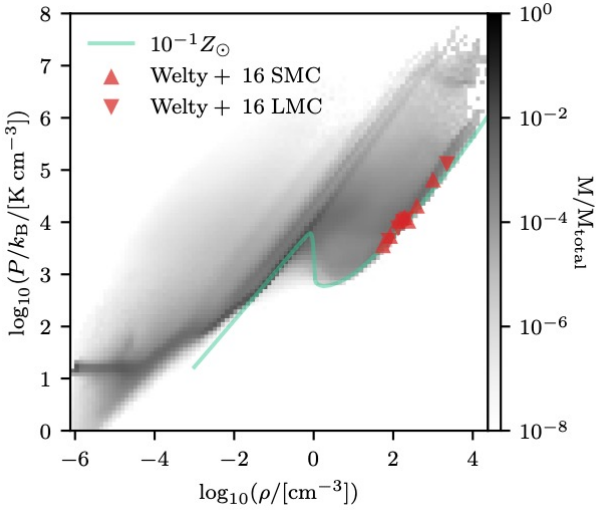
PRISM: chemistry … main atoms/ions and even a few molecules (H_2, CO)

Katz et al, arXiV:2211.04626



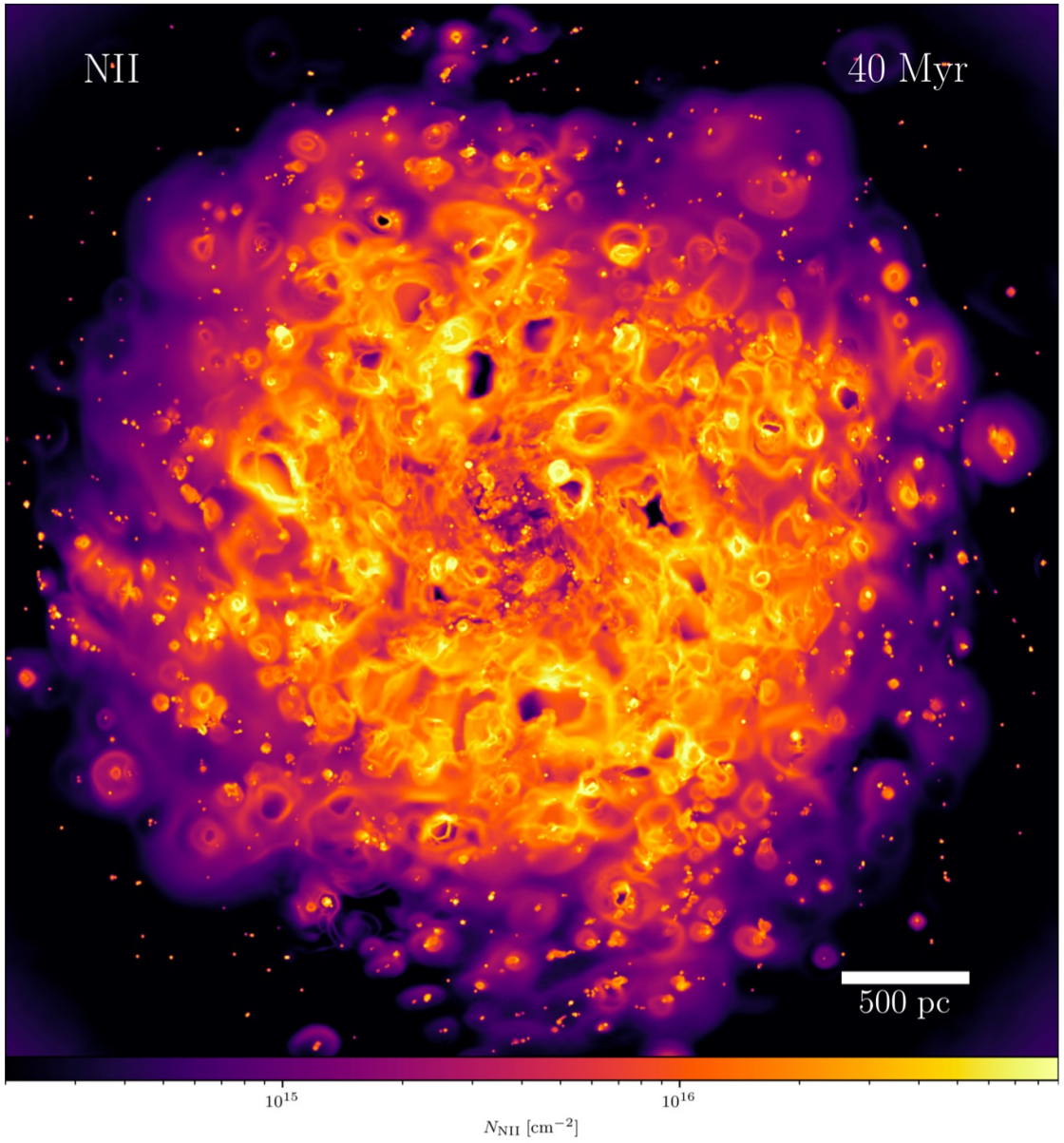




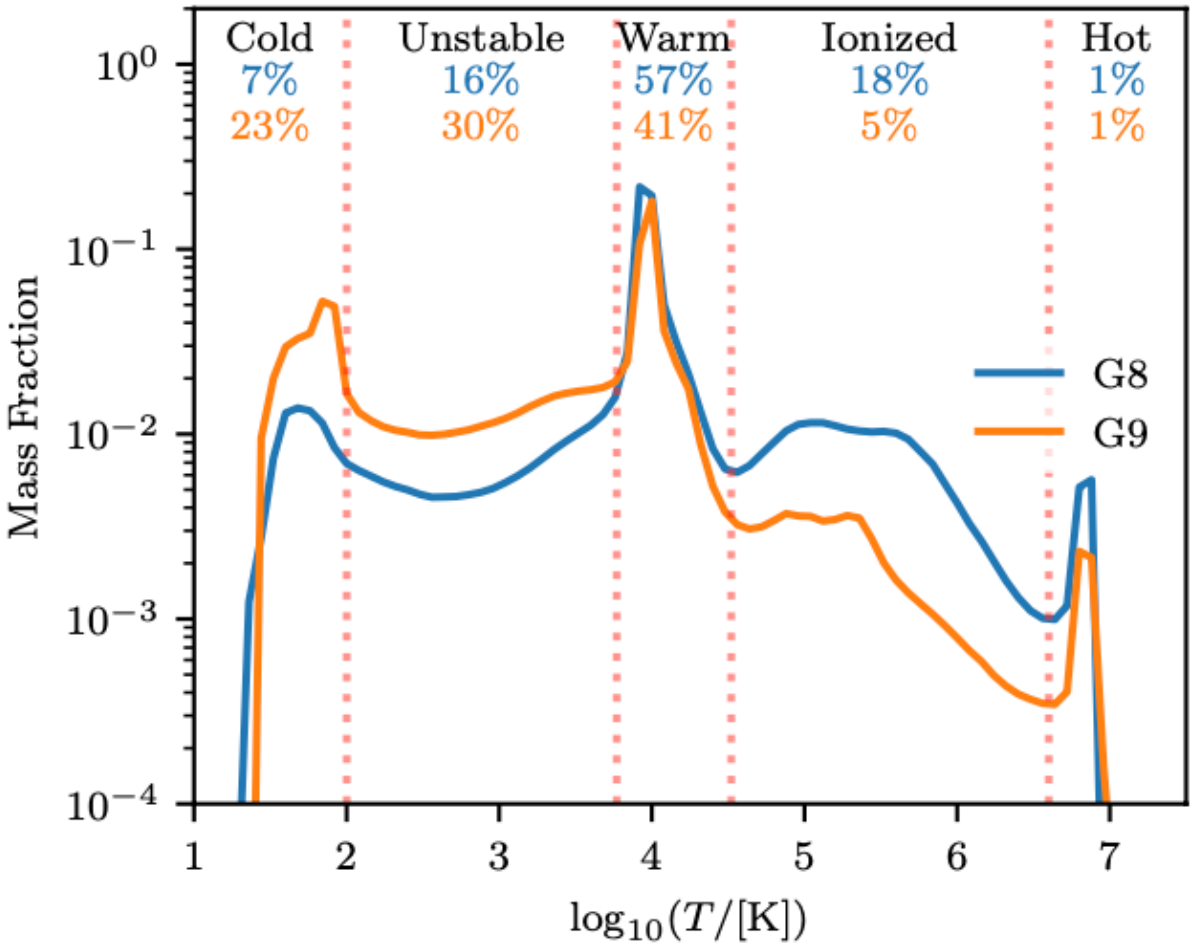


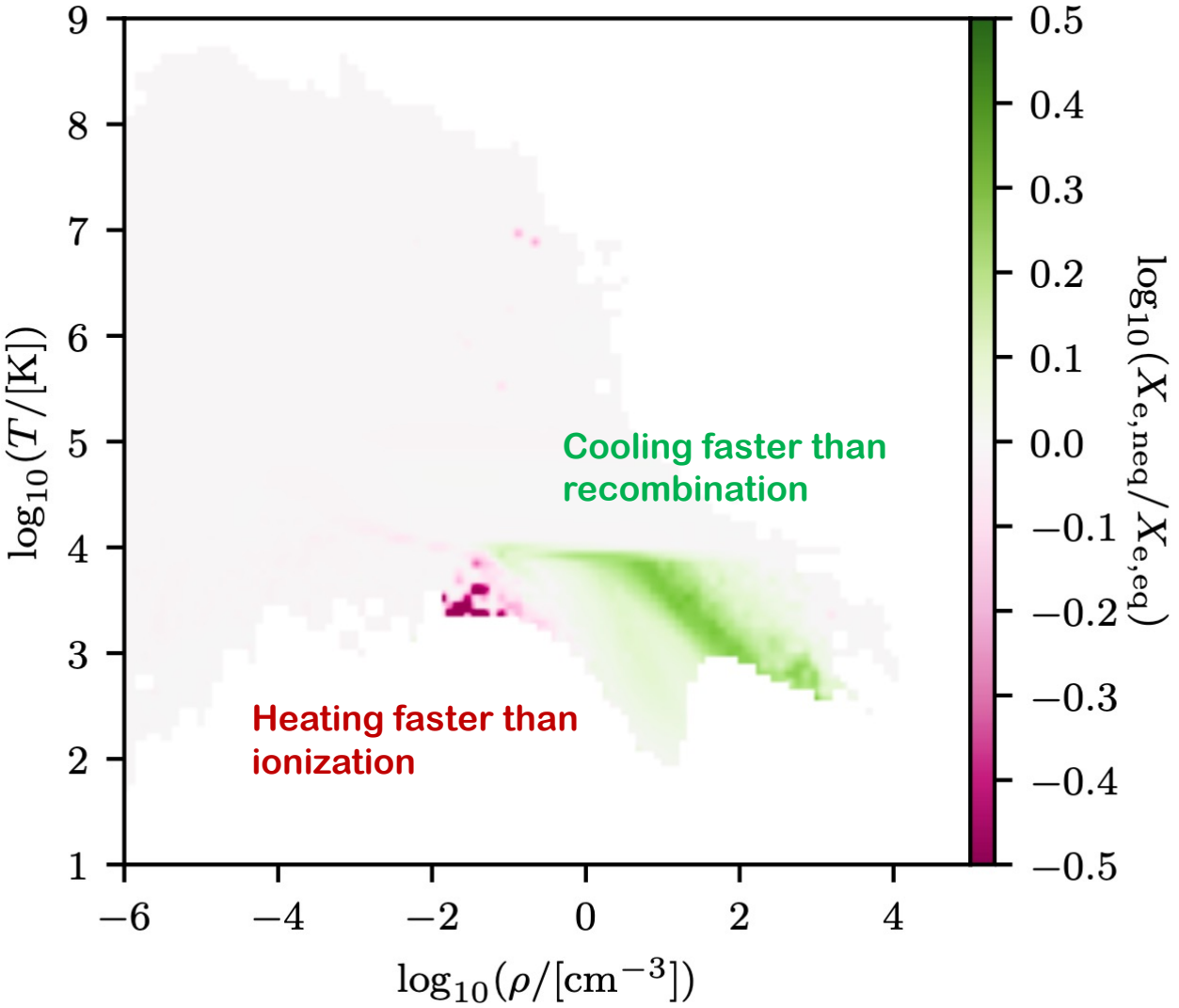
1D equilibrium model

Idealised galaxy simulation

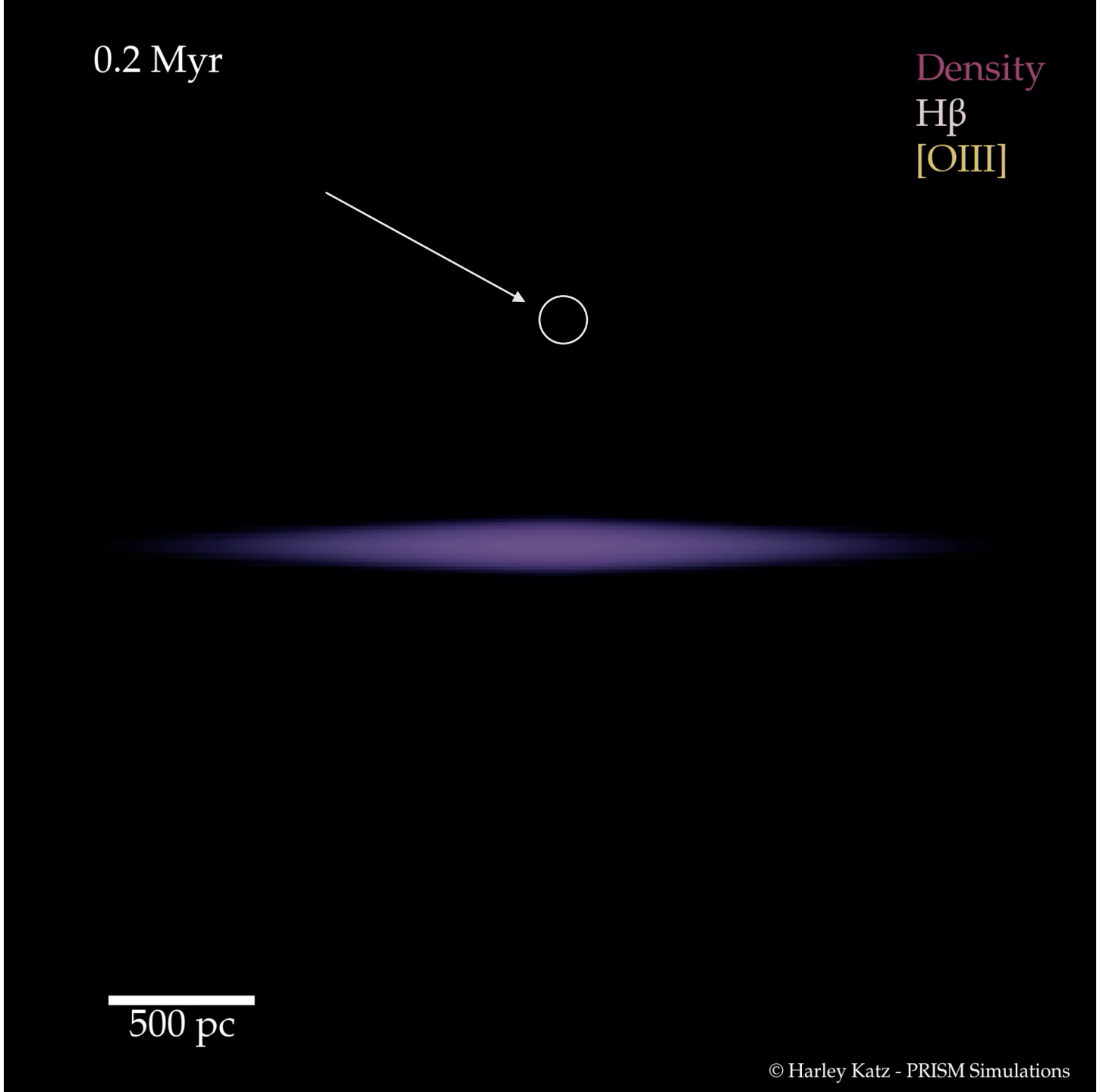


PRISM: multiphase ISM & non equilibrium effects





Katz et al, arXiV:2211.04626


0.2 Myr
Density
Hβ
[OIII]
500 pc
© Harley Katz - PRISM Simulations

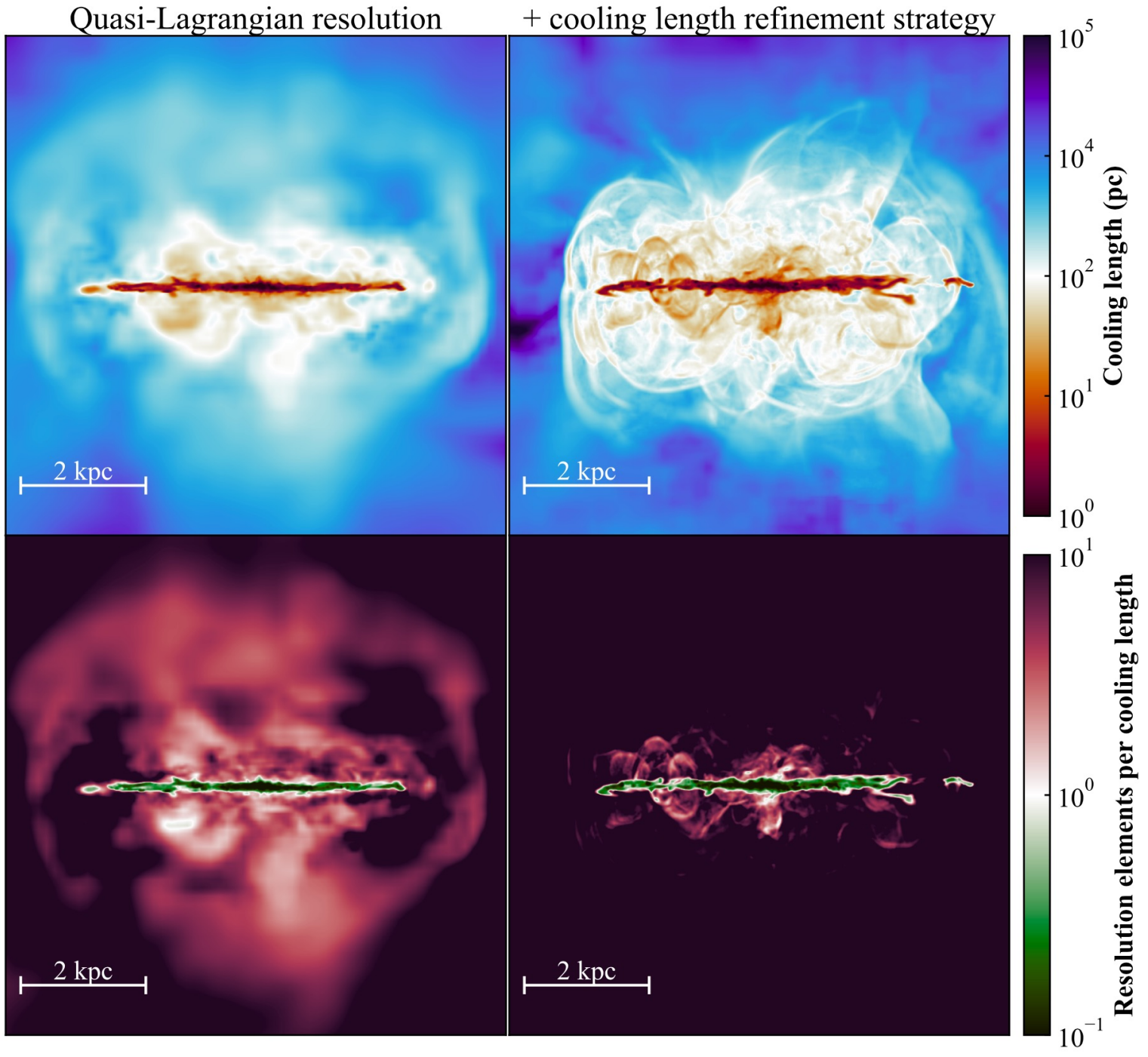
What about the resolution in the CGM problem?

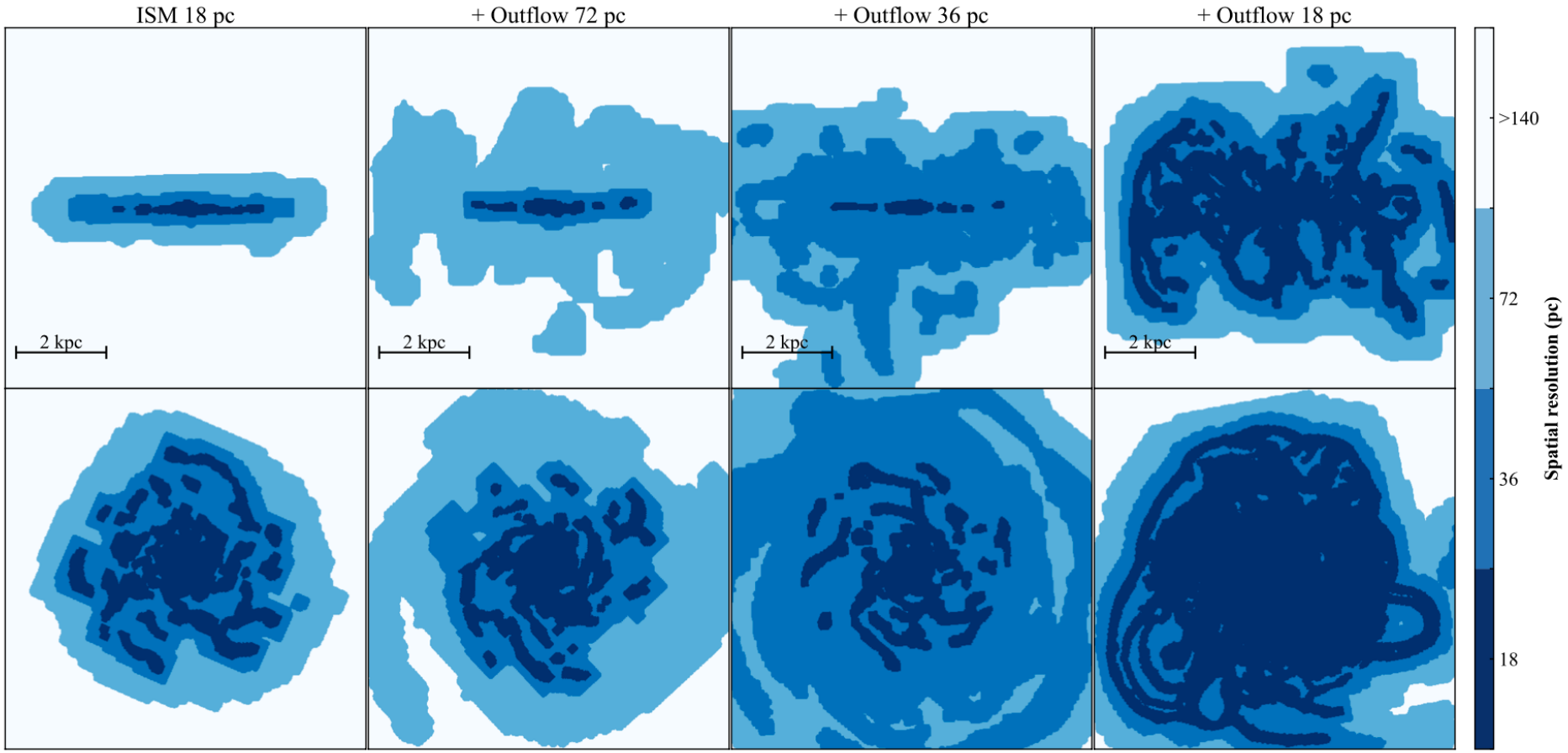
Rey et al, (in prep)

<u>Caveat:</u> all idealized simulations so far → no inflow/cosmic web yet but once again, coming soon!

$$l_{\rm cool} = \sqrt{\frac{P_{\rm th}}{\rho}} \times \frac{1}{\Lambda_{\rm net}}$$

for each gas cell → refine if $n\,dx > l_{\rm cool} > 0$





Rey et al, (in prep)

Simulation	Maximum cooling length target (pc)	Average timestep cost (CPU s / simulated Myr)
ISM 18pc (x3)	N/A	1965^{+144}_{-248}
+ Outflow 72pc	72	2093^{+144}_{-210}
+ Outflow 36pc (x3)	36	3537^{+326}_{-281}
+ Outflow 18pc	18	$10,389^{+945}_{-698}$

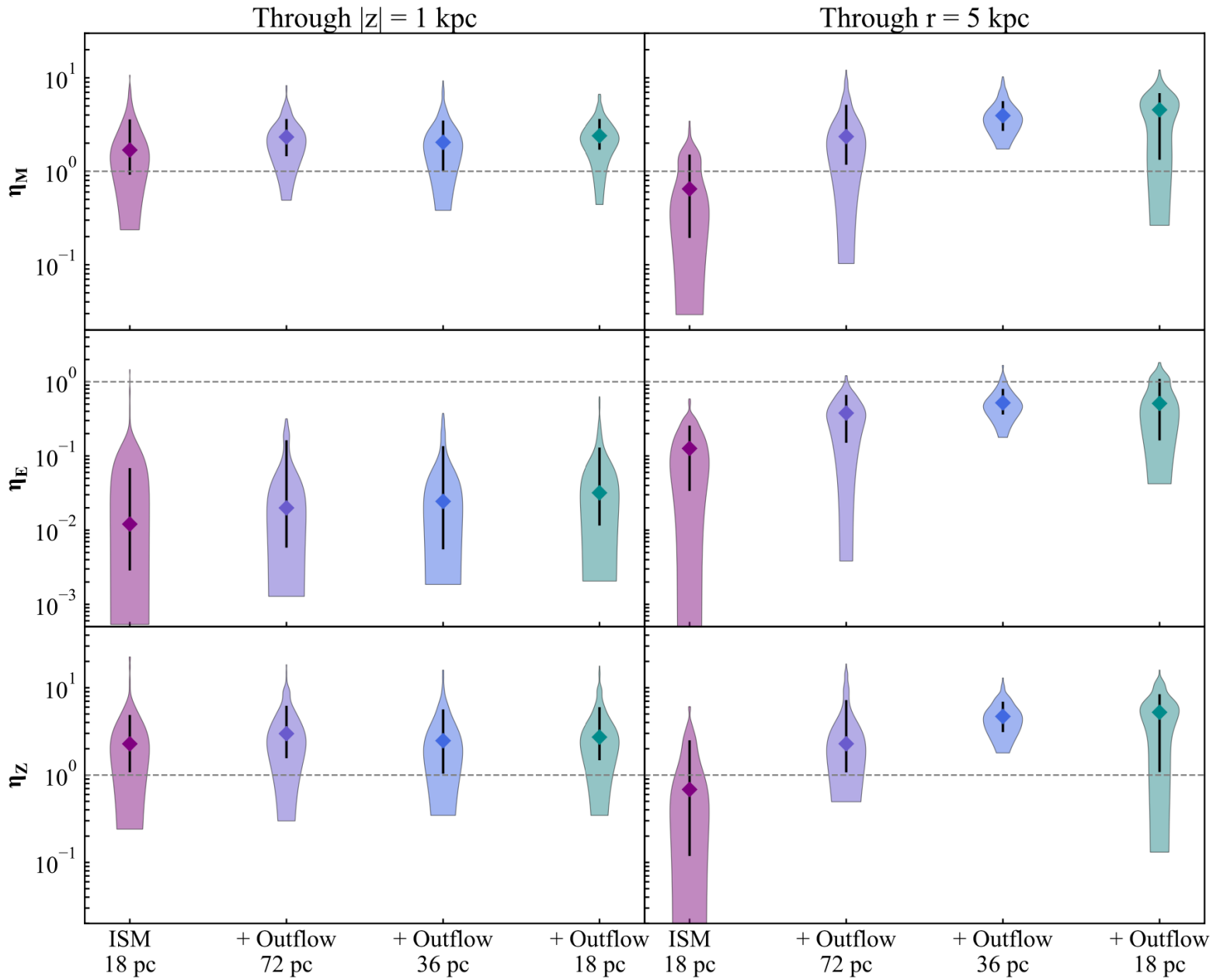
Mass loading factors

$$\eta_M = \frac{\dot{M}_{\rm out}}{\rm SFR_{10\,Myr}},$$

$$\eta_E = \frac{\dot{E}_{\rm out}}{\rm SFR_{10\,Myr}\, p_{SN}},$$

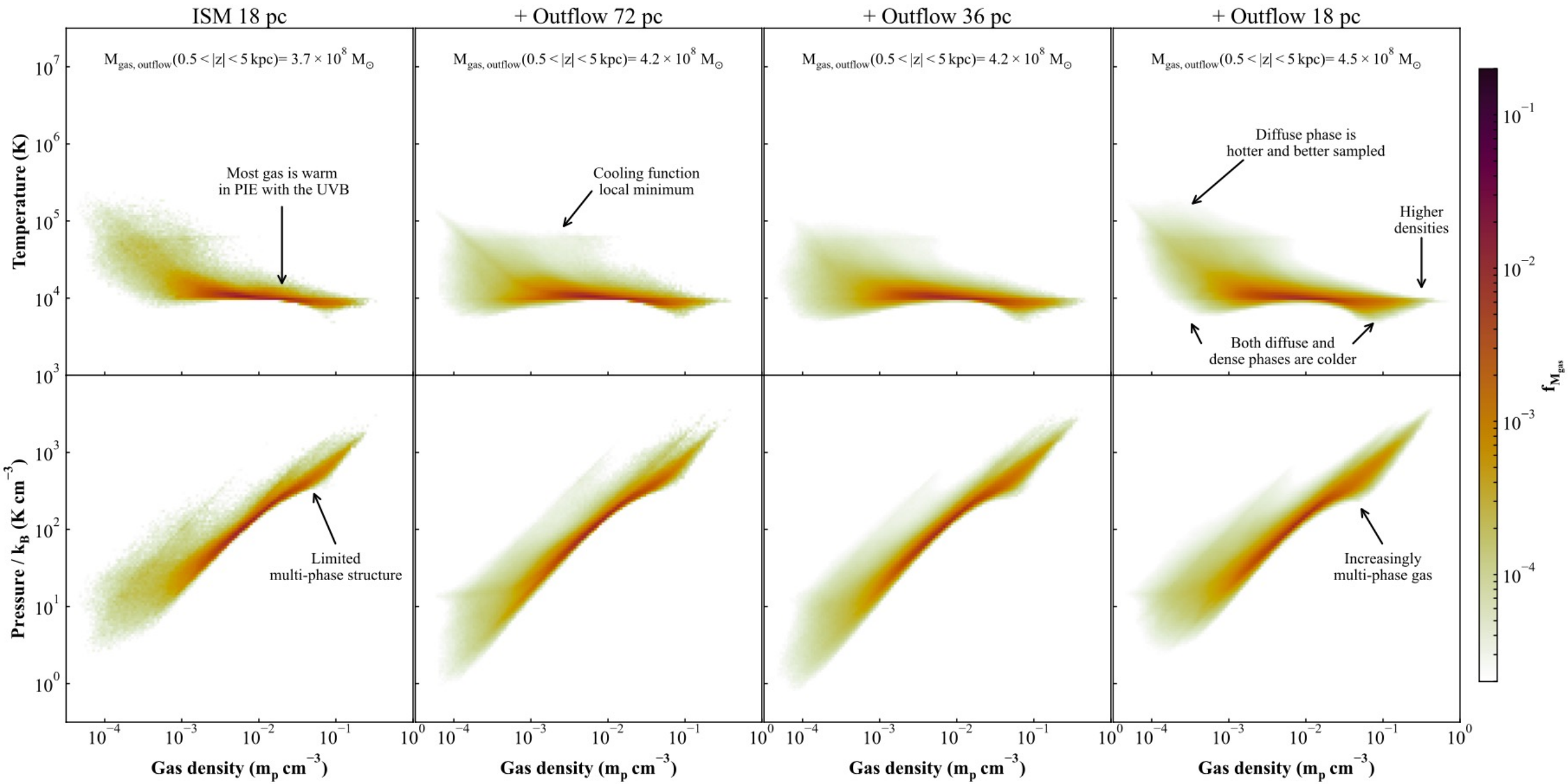
$$\eta_Z = \frac{\dot{Z}_{\rm out}}{\rm SFR_{10\,Myr}\, Z_{disc}},$$

Rey et al, (in prep)

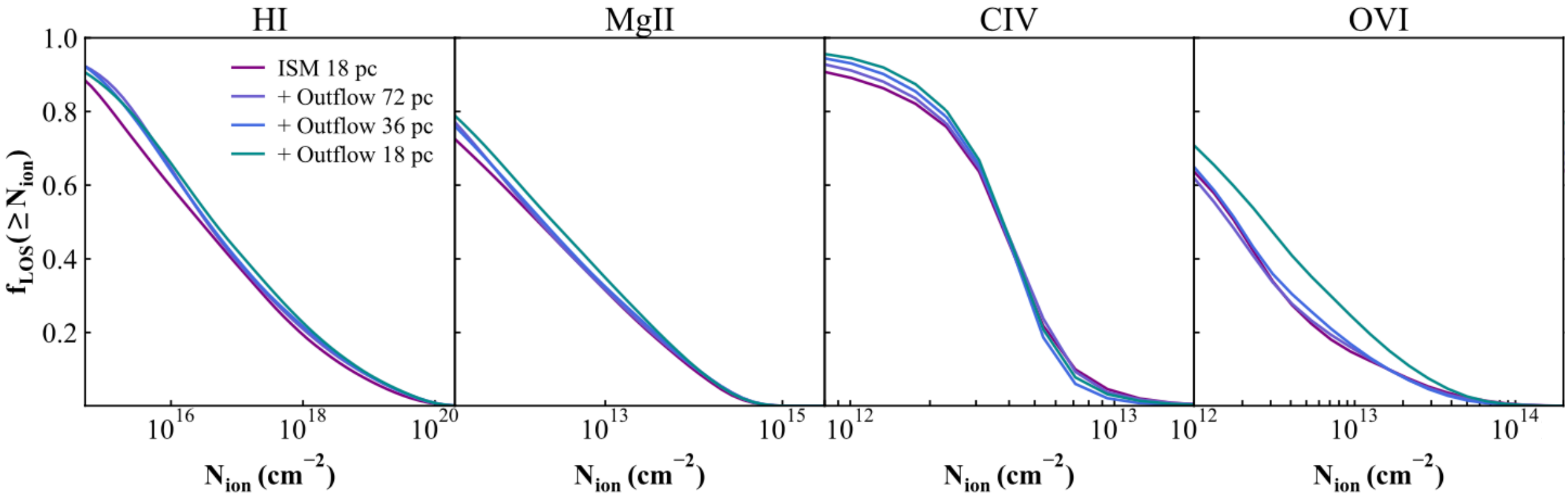


Rey et al, (in prep)

Towards multiphase outflows



Impact on covering fractions



Cold outflow gas **Warm outflow gas** **Hot outflow gas**

Rey et al, (in prep)