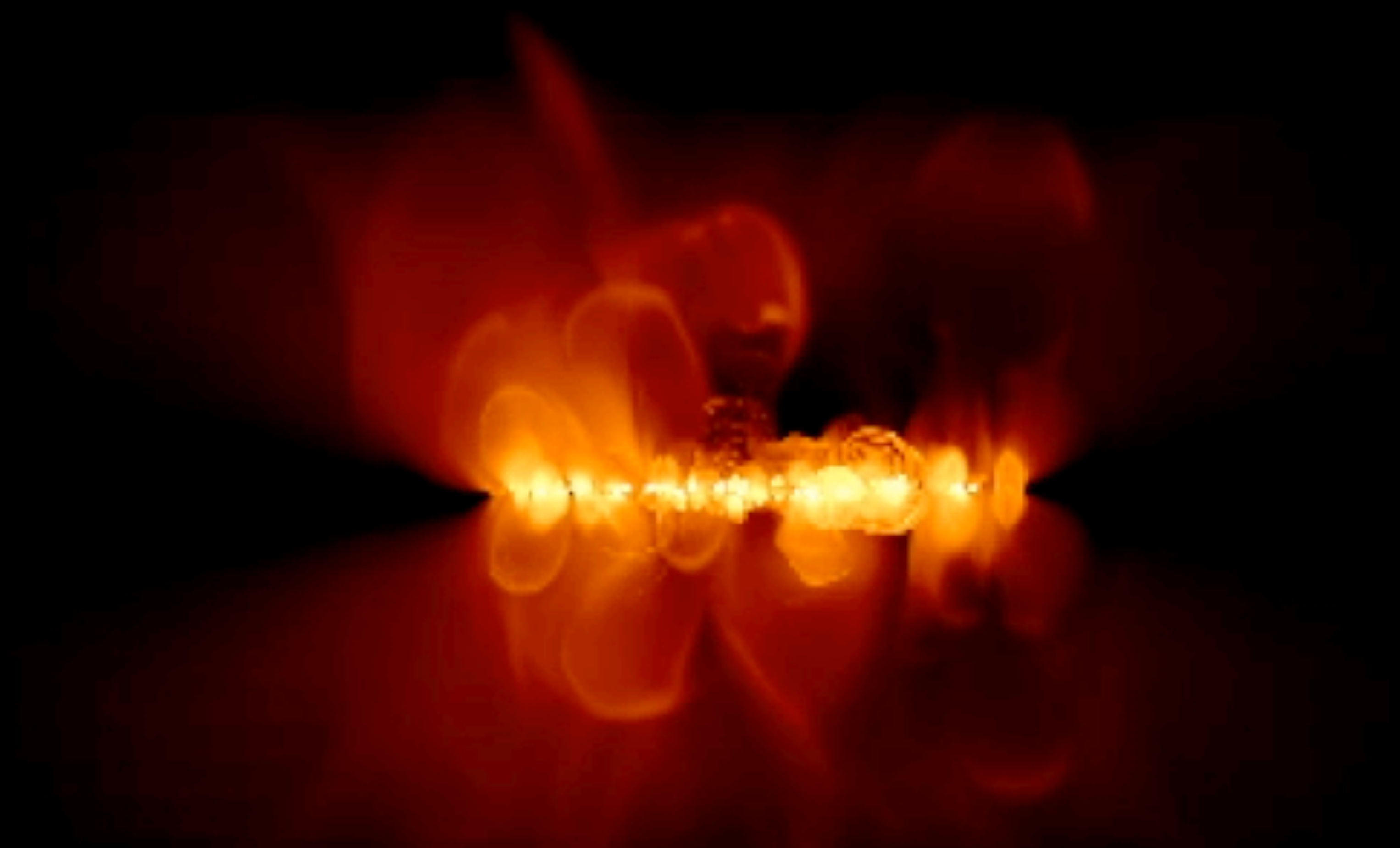
New models to unveil the properties of galactic outflows



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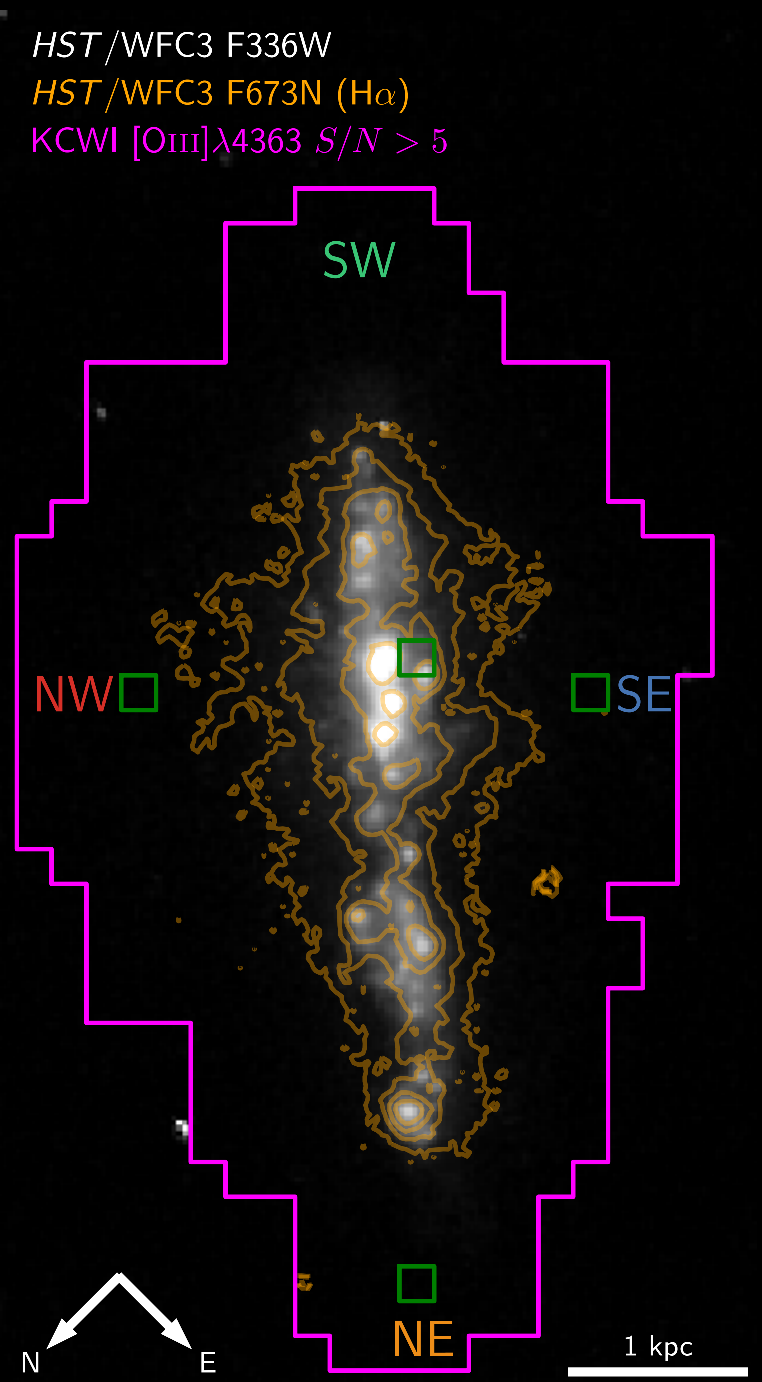
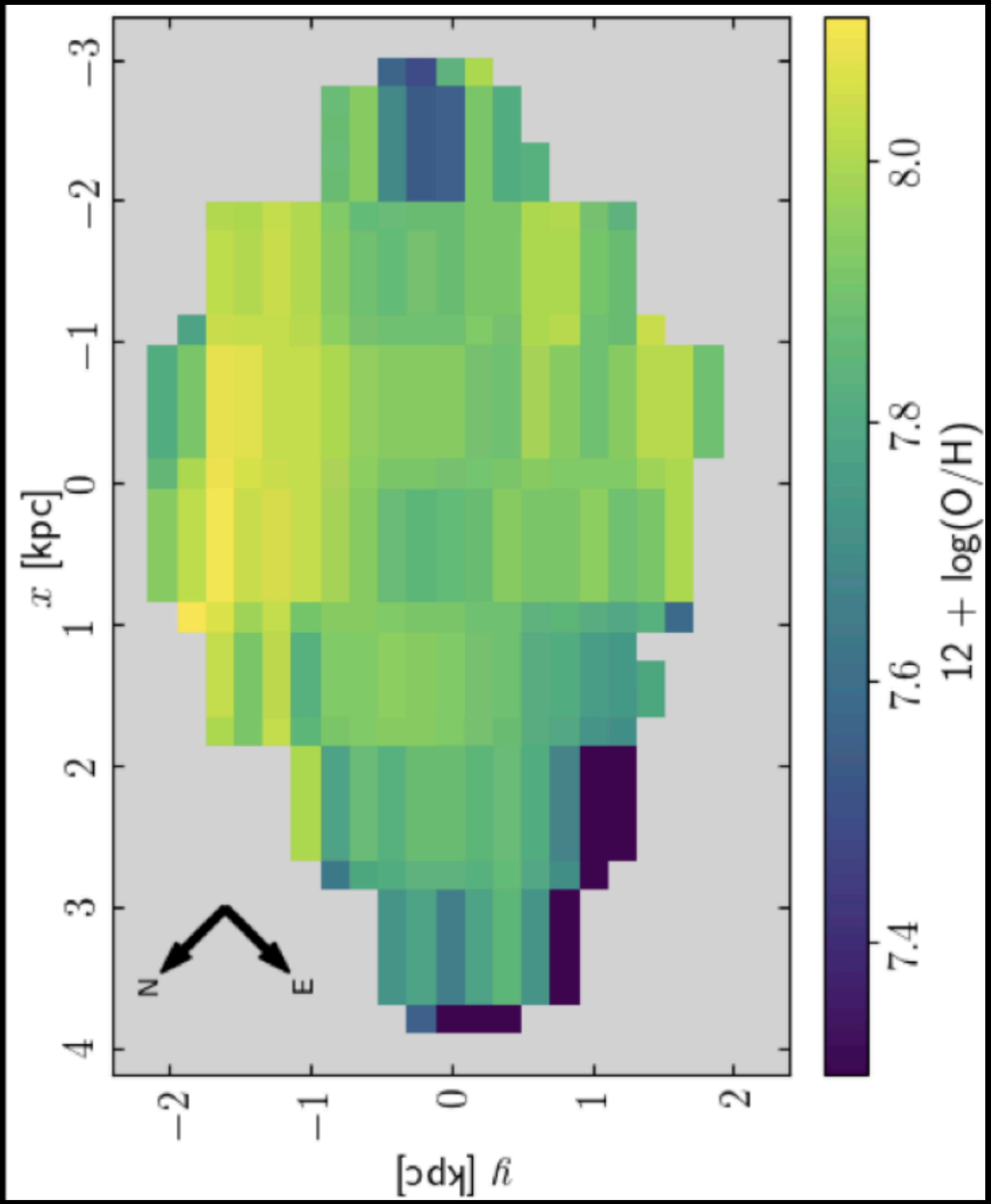
Rey et al 2024, 2302.08521

Cameron, Rey and Katz in prep.

With Alex Cameron and Harley Katz

Modern spectrographs now allow us to map and constrain outflows directly





Cameron et al. 2021

See also e.g. Marasco et al. 2023, Rupke et al. 2023, Reichardt Chu et al. 2024 …

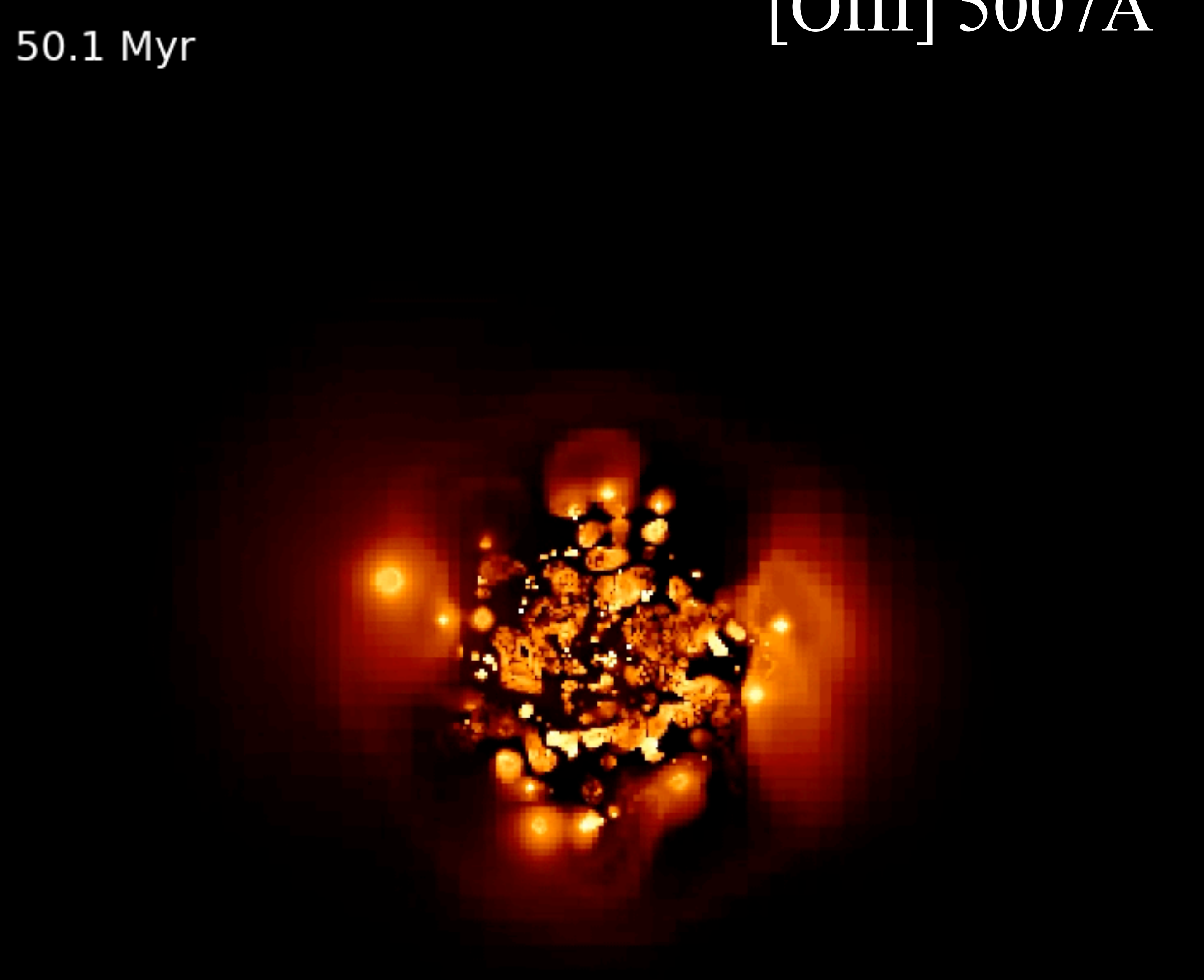
How to link emission lines to gas properties in outflows?

Non-equilibrium/RT effects matter in diffuse gas
(e.g. Richings et al. 2018, Sarkar et al. 2021, 2022)

Structure along the line-of-sight and outflow geometry is unknown
(Is a one-zone, one-source, Cloudy-like model good enough?)

Harley Katz

Simulations tailored to calibrate spectroscopic observations



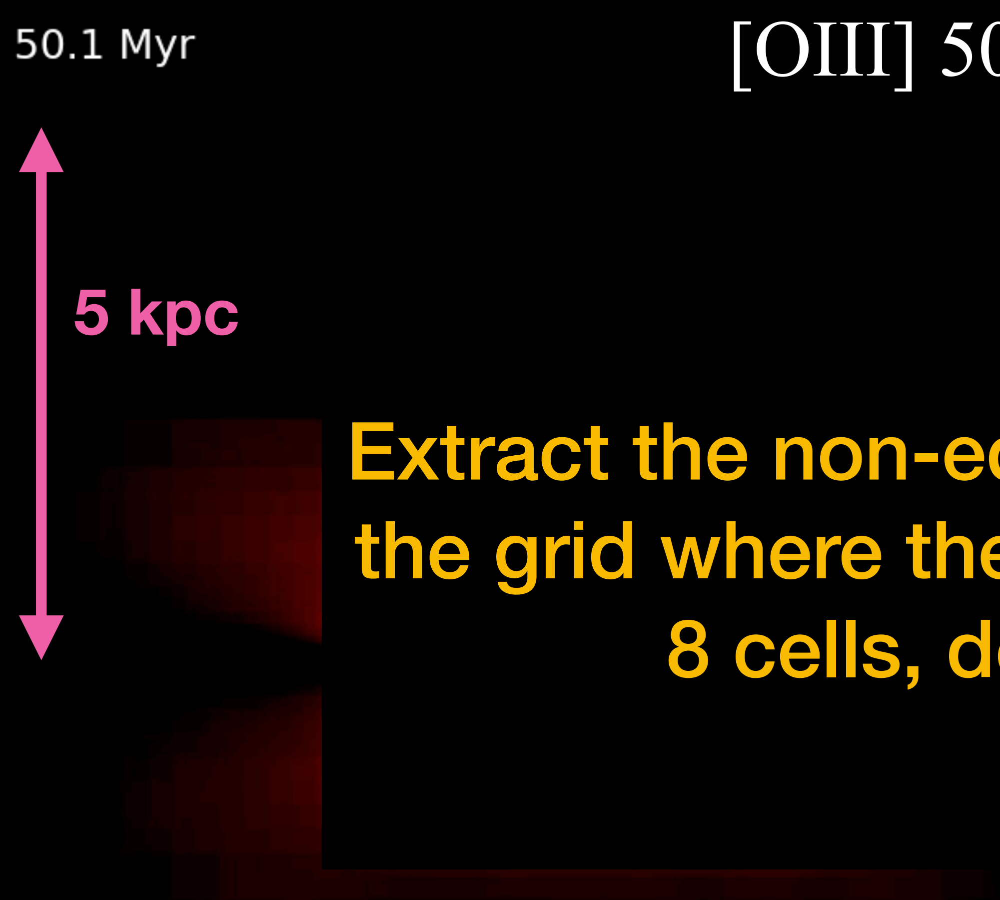
Idealised dwarf galaxy simulations with Ramses-RTZ (Katz 2022).
18 pc ISM

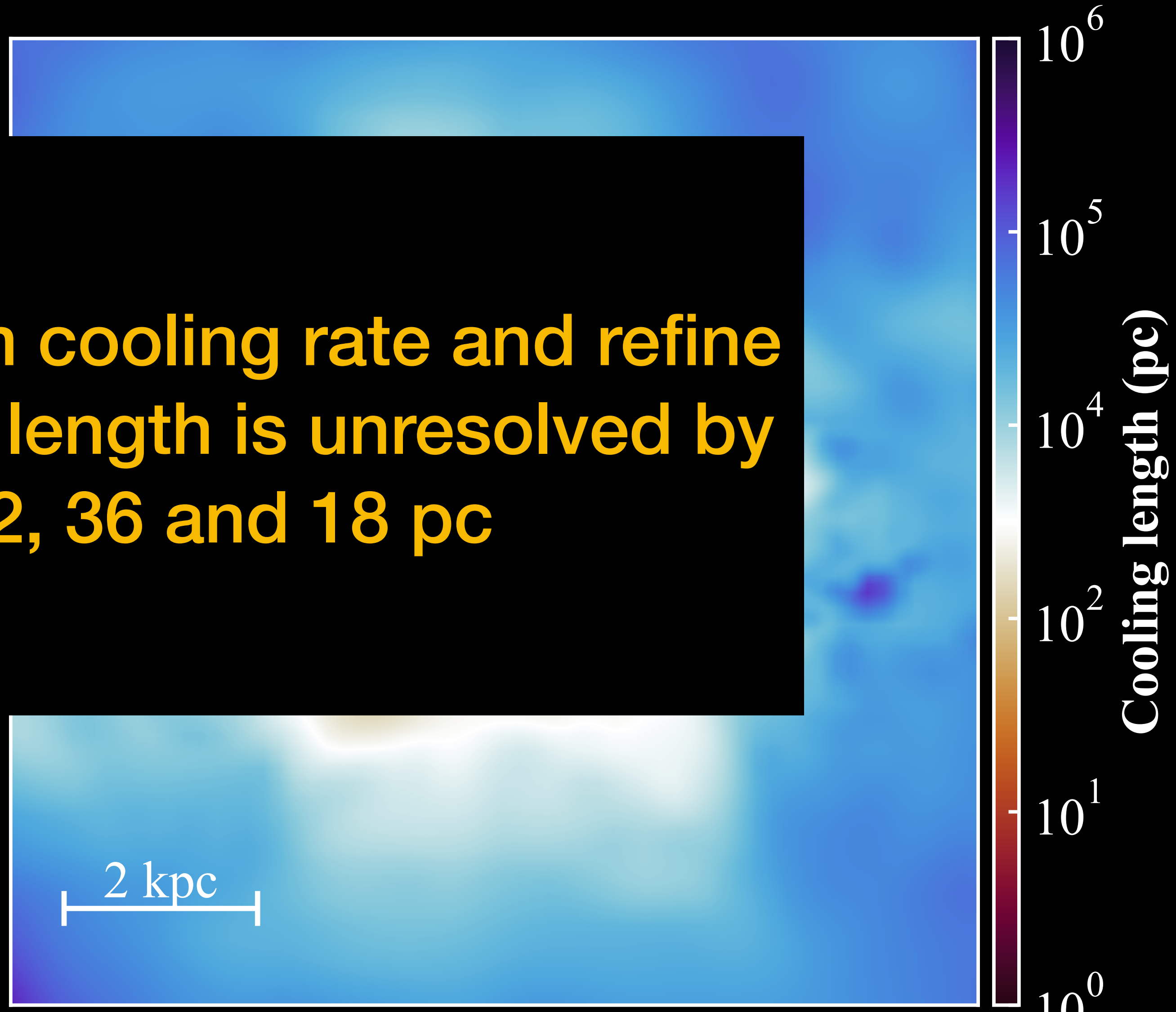
Model hydrodynamics of gas, star formation, stellar evolution and feedback, metal enrichment and radiation in 7 frequency bins

Self-consistent galactic-scale outflows from stellar feedback

70 ions, non-equilibrium chemistry directly coupled on-the-fly to the radiation from stars. Direct predictions of CELs.

Simulations tailored to interpret outflow emission lines?



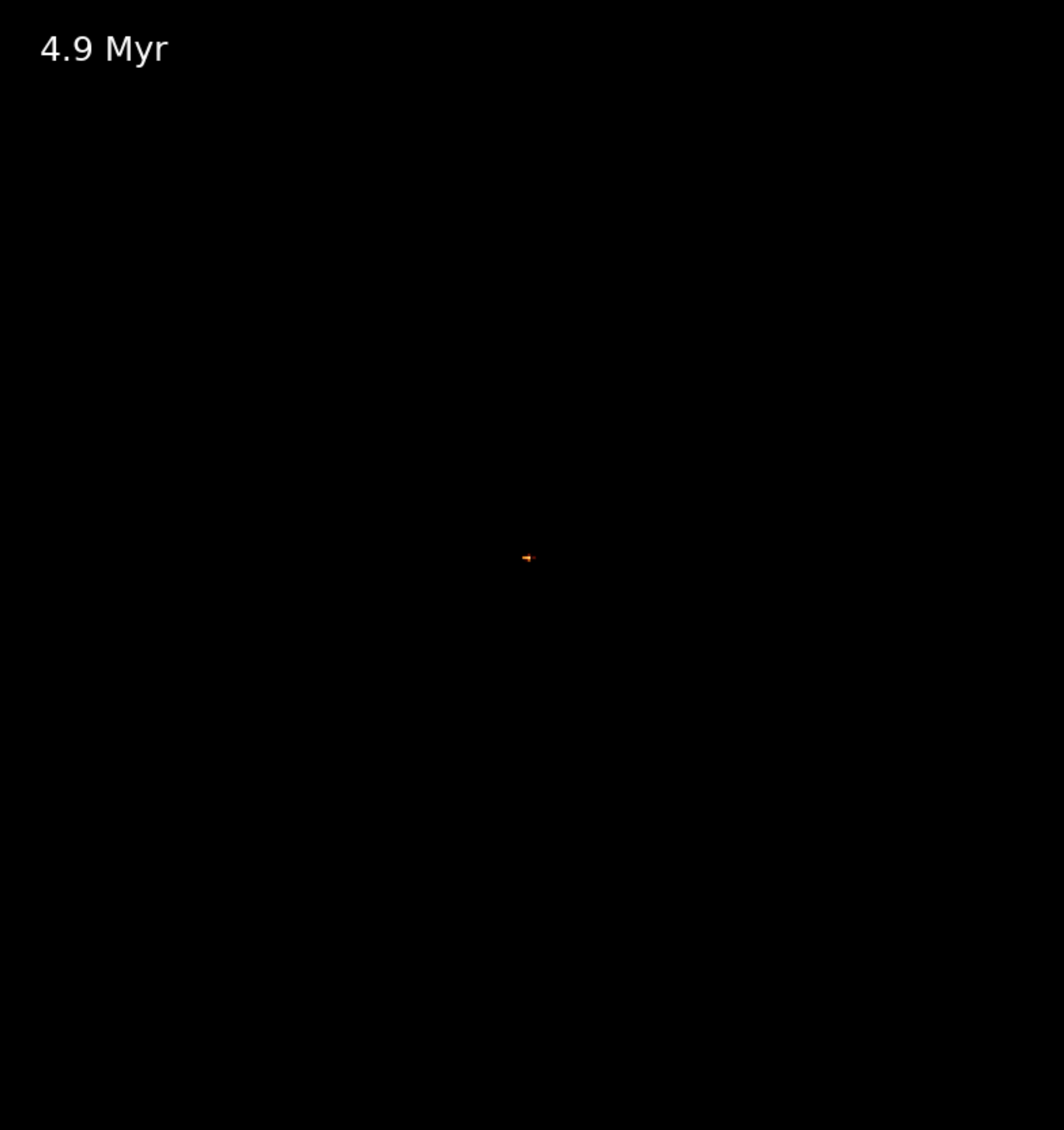


Extract the non-equilibrium cooling rate and refine the grid where the cooling length is unresolved by 8 cells, down to 72, 36 and 18 pc

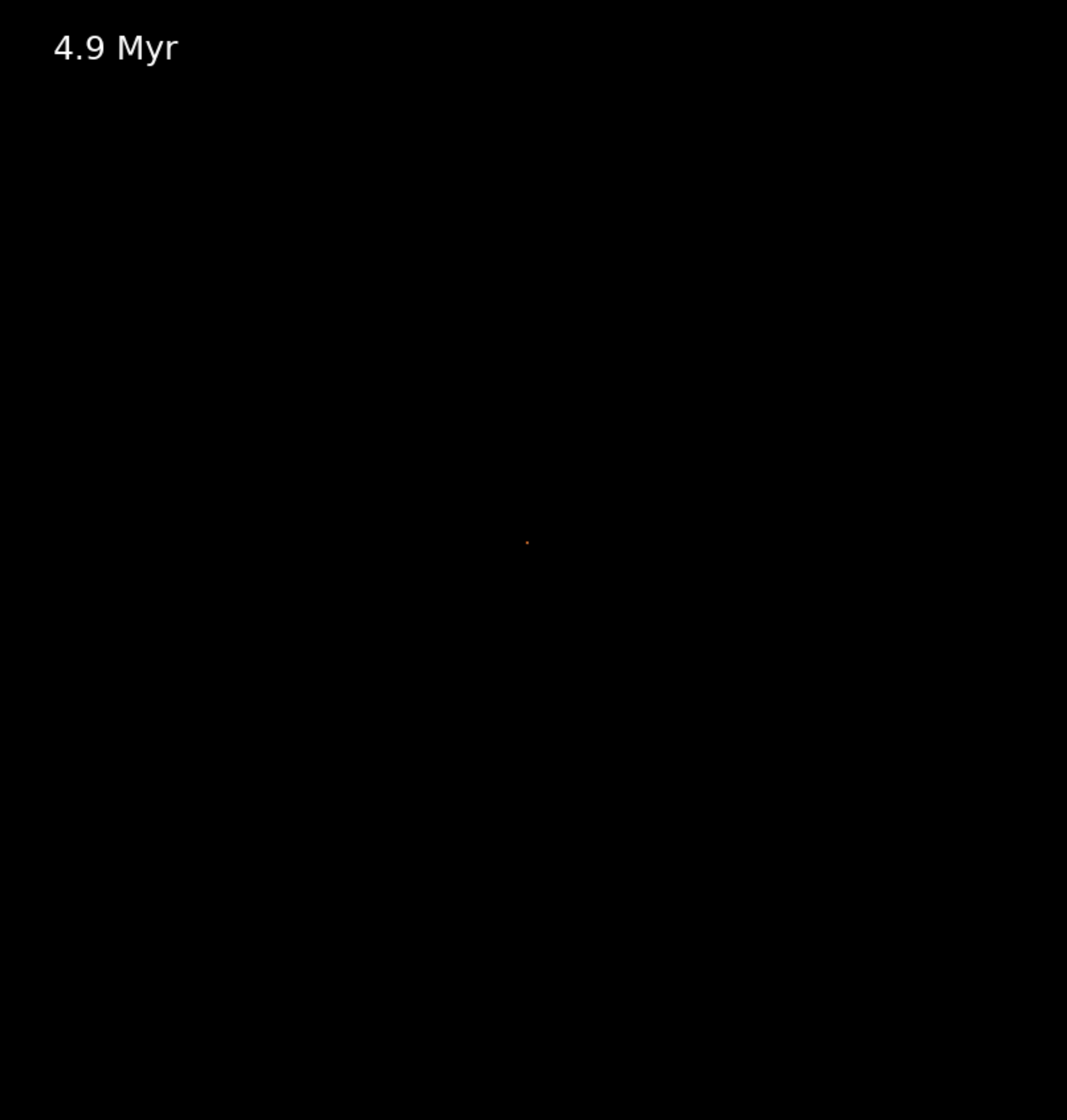
Resolution quickly degrades out of the disc and in the outflow

Over-mixing gas phases, unresolved shocks, etc, etc

Reference with traditional Lagrangian scheme

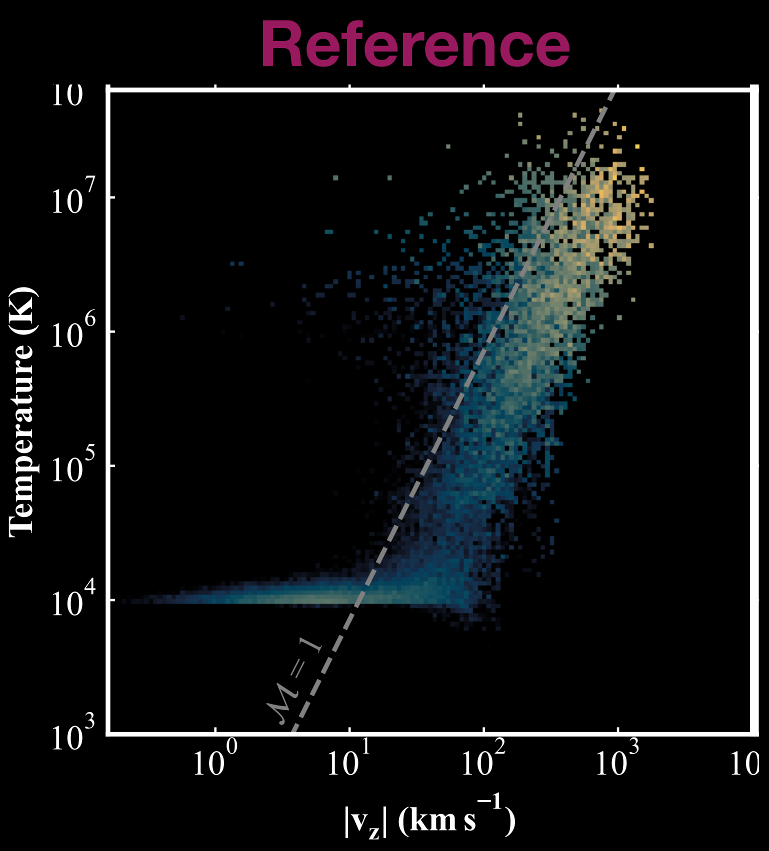


Cooling length refined down to ISM resolution (18 pc)

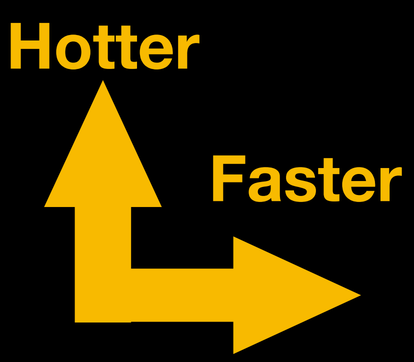


@Cosmic Rey on YT for movies

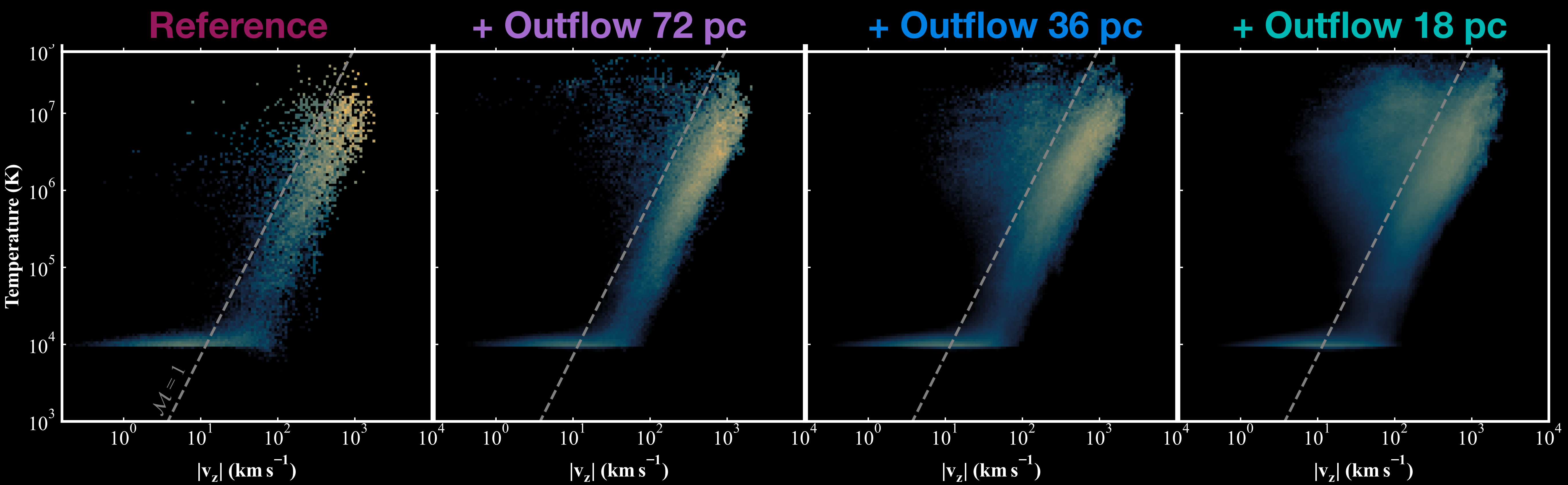
[OIII] 5007Å



Energy-weighted gas at |z| = 1 kpc, averaged over 500 Myr

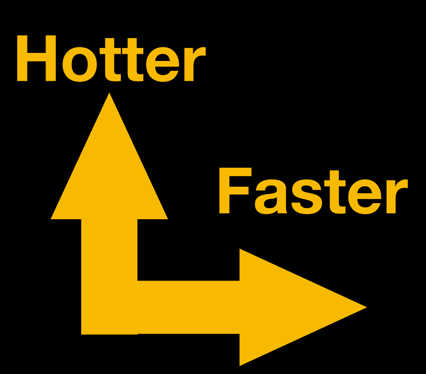


Rey et al. 2024



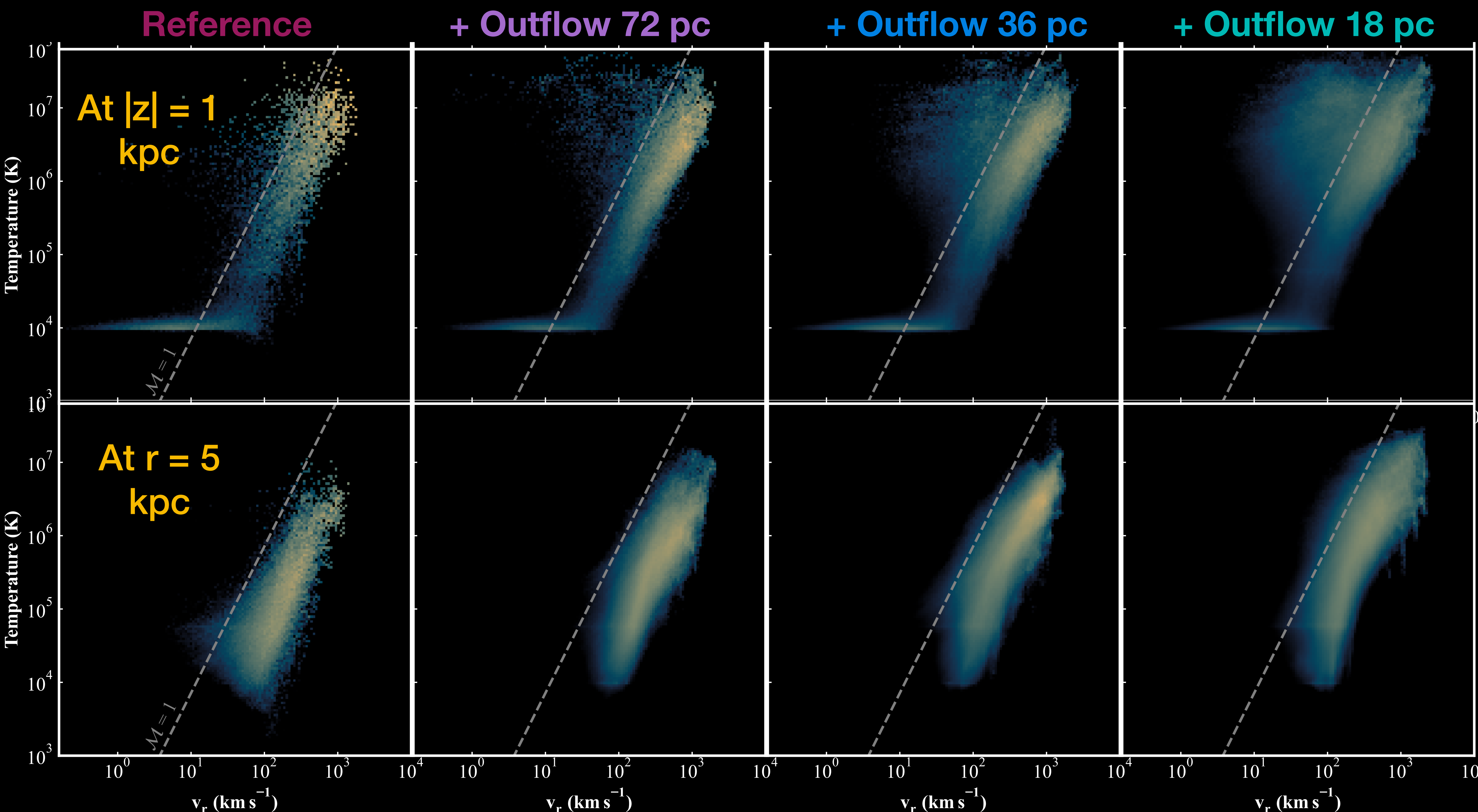
Energy-weighted gas at |z| = 1 kpc, averaged over 500 Myr

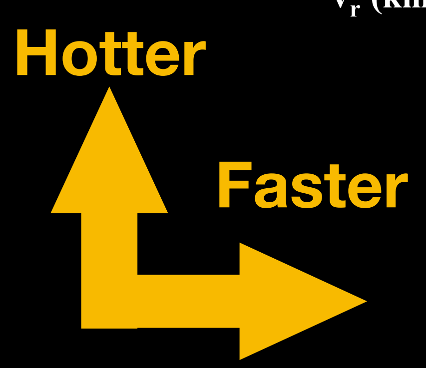
Close to the disc, more hot and subsonic gas. Post-shocked gas stays hot and pressurizes bubbles



Rey et al. 2024

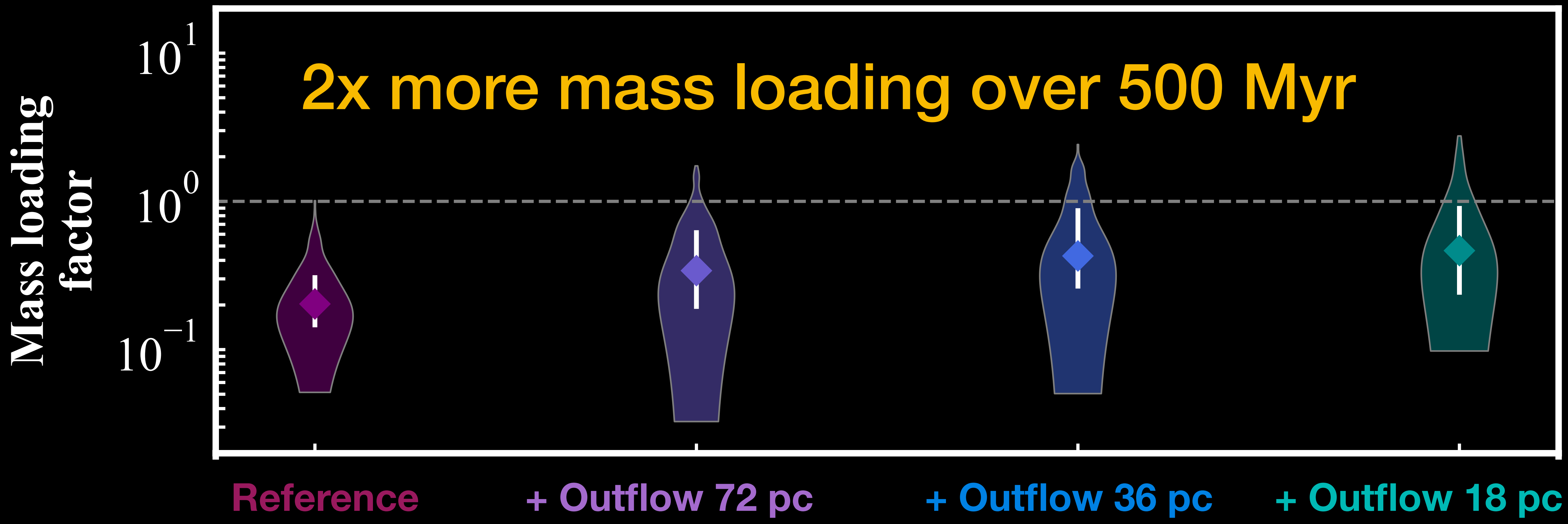
See also M. Smith et al. 2024



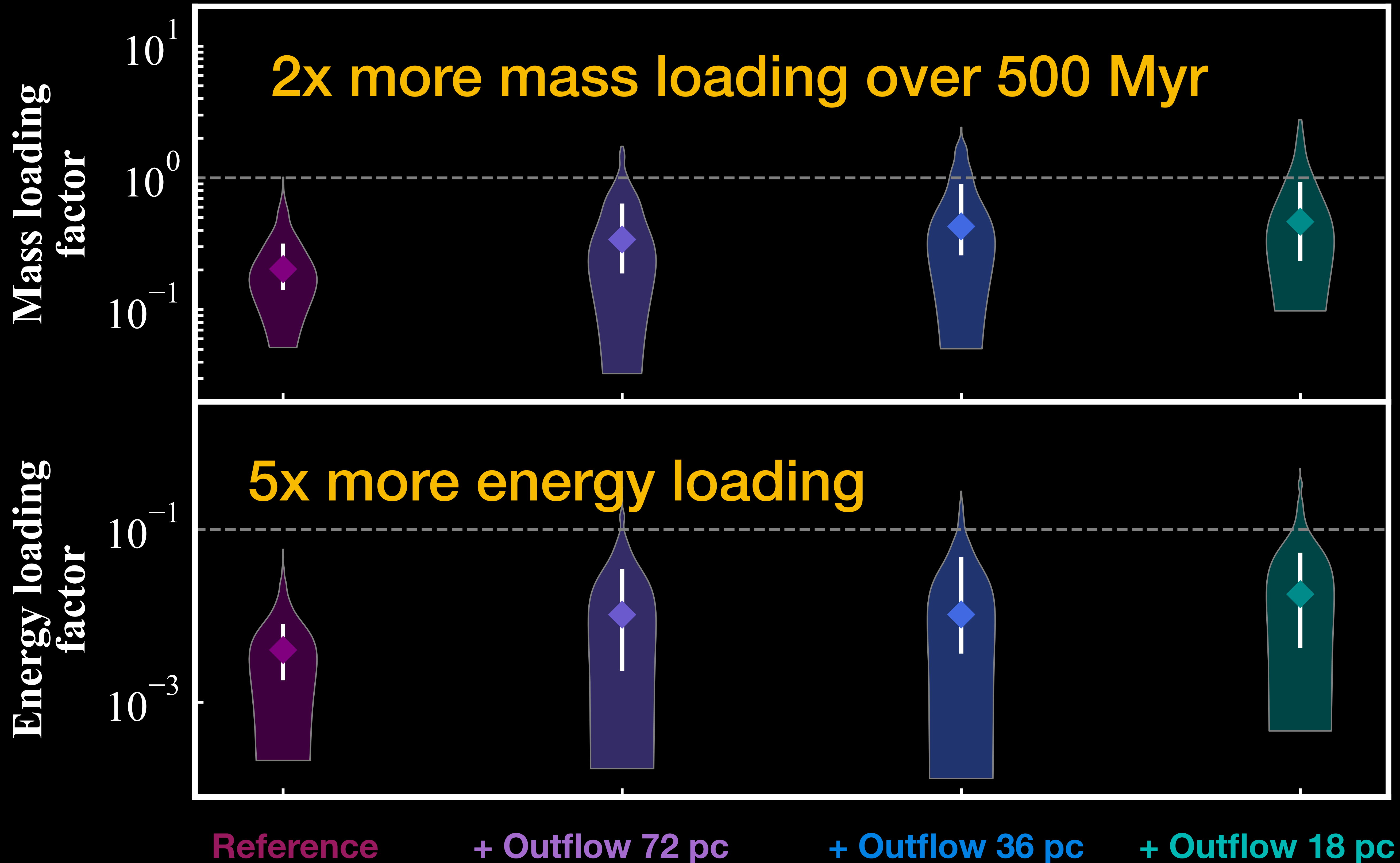


Gas stays hotter and faster for longer, as it propagates outwards

Rey et al. 2024

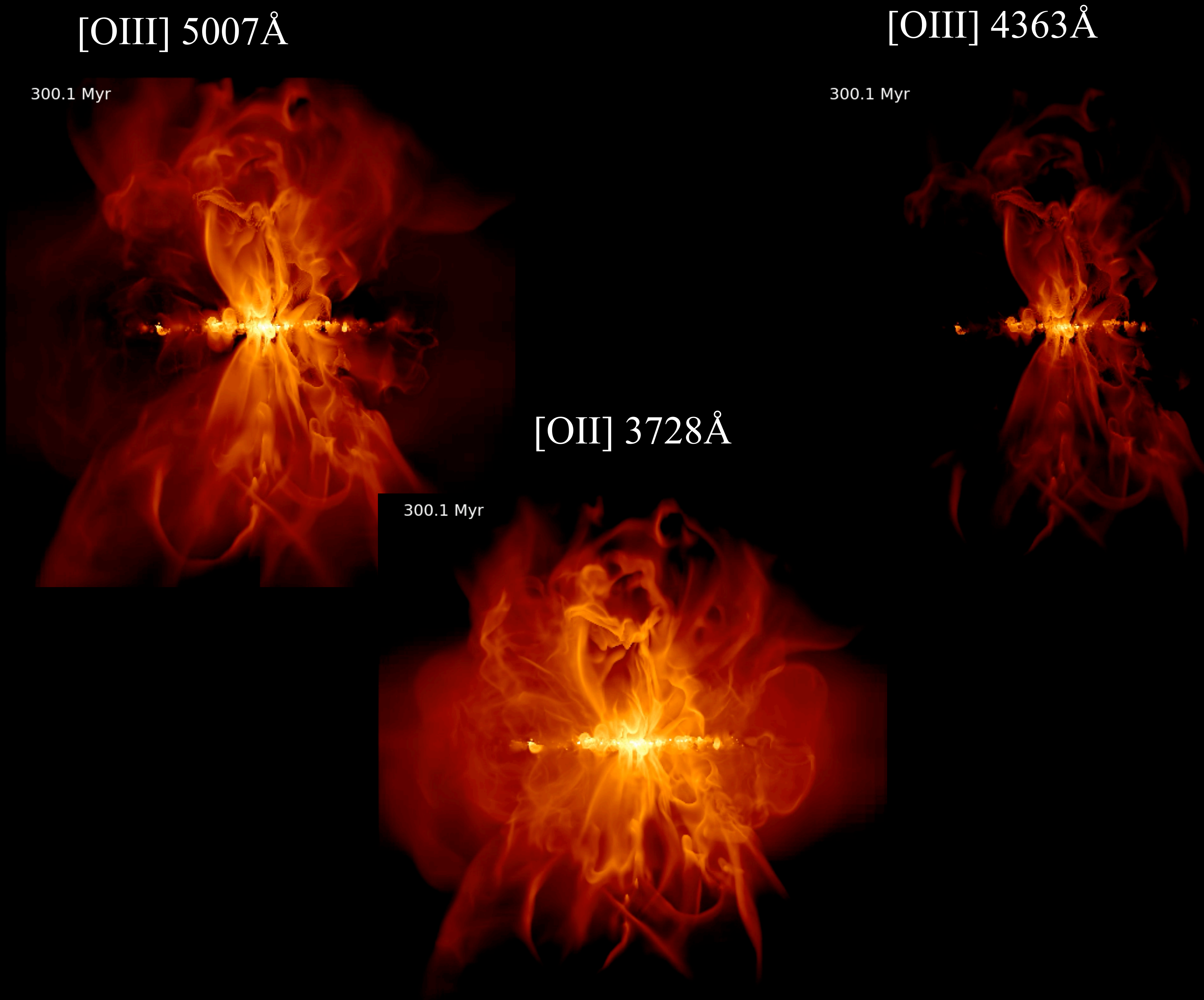


Rey et al. 2024



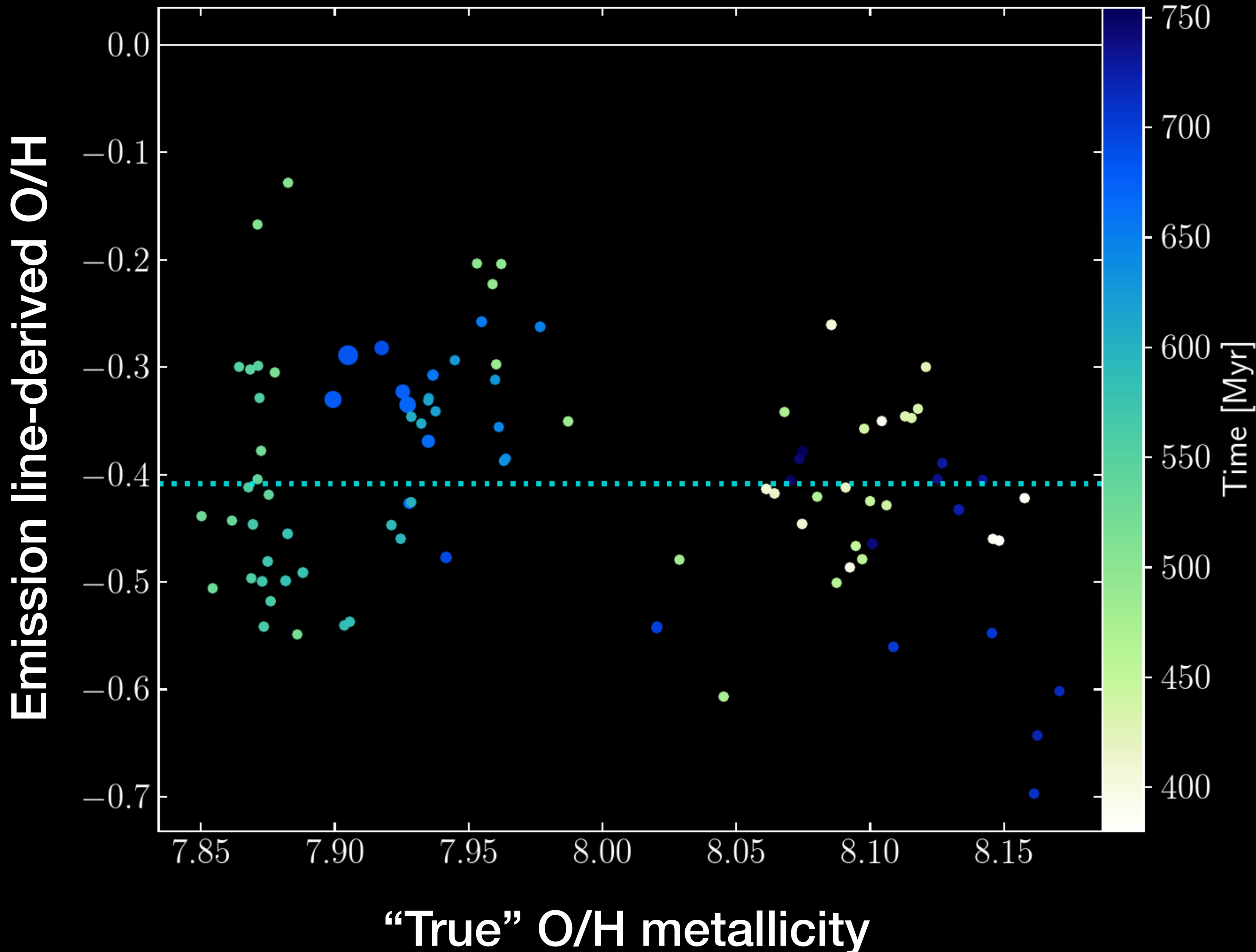
without modifying launching conditions in the disc, the feedback energetics, or the included physics

Rey et al. 2024


[OIII] 5007Å
300.1 Myr
[OIII] 4363Å
300.1 Myr
[OII] 3728Å
300.1 Myr

Alex Cameron

Implications on ionic structure of outflows



Metallicities derived from auroral lines (Te-method) are biased low in outflows, from 0.2 to 0.6 dex

Cameron, Rey et al. in prep

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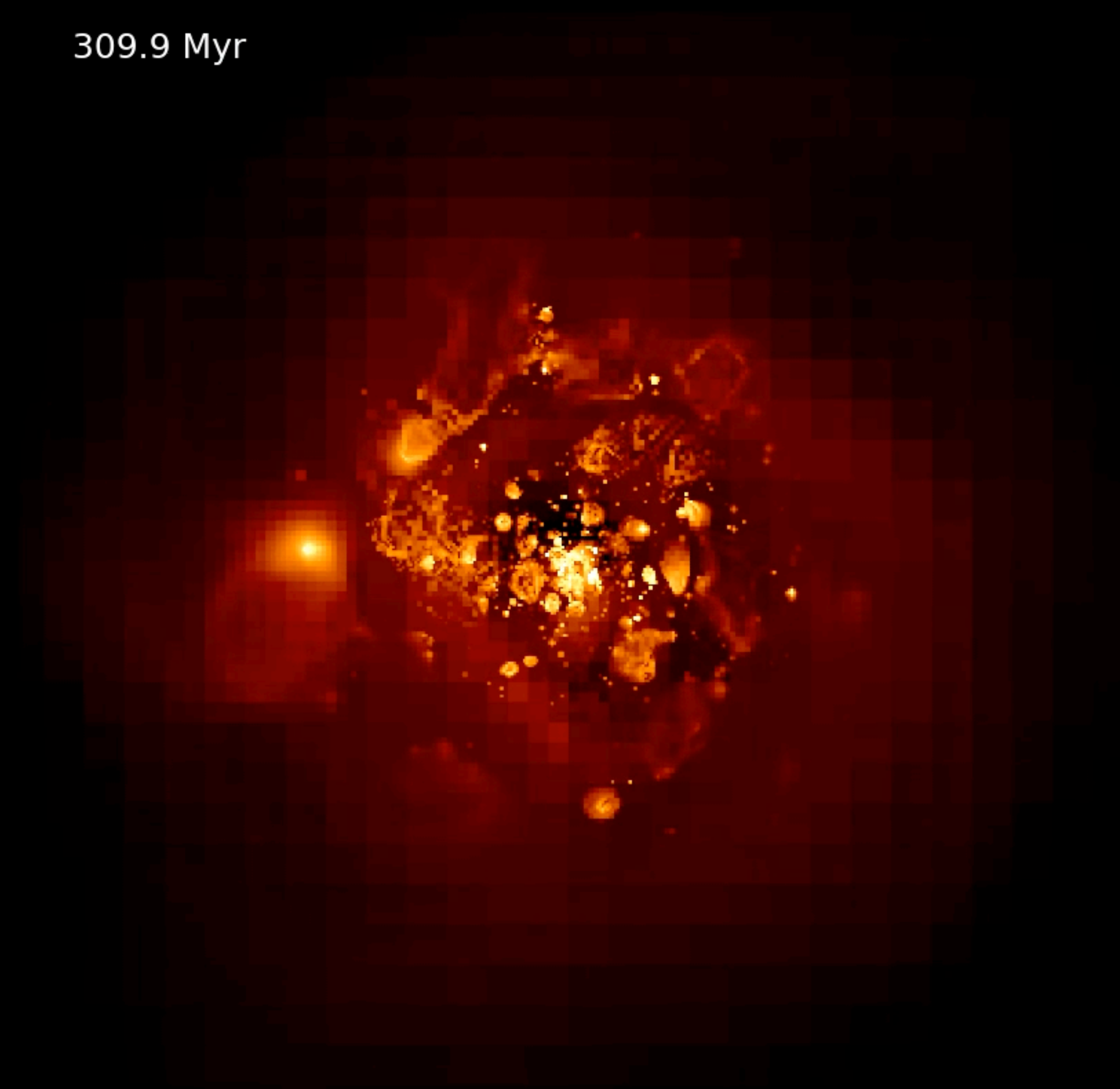
Conclusion

1. Galaxy formation models can now explicitly model non-equilibrium thermochemistry and radiative transfer to robustly link to spectroscopic observables



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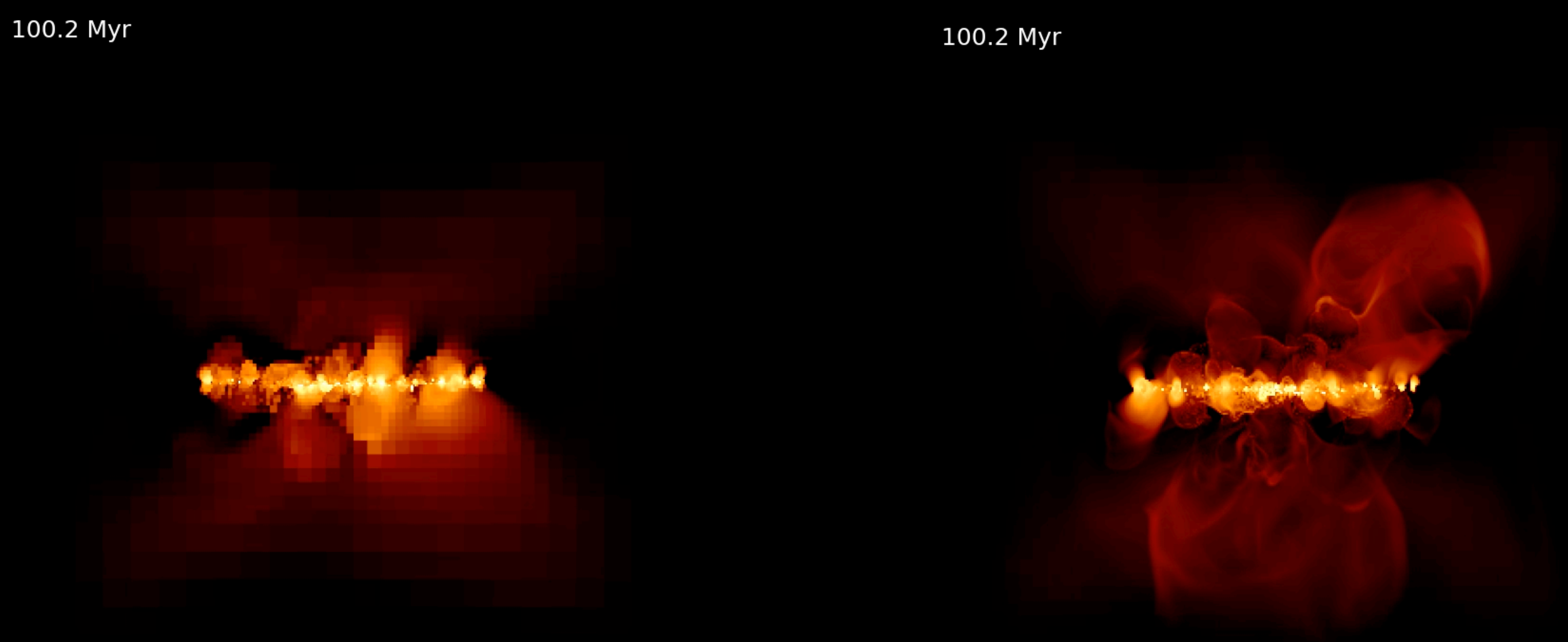
Conclusion

2. We are under-resolving the multiphase structure of outflows. Fixing this requires beyond-Lagrangian resolution schemes, e.g. refining on the cooling length.



O[III] 5007Å

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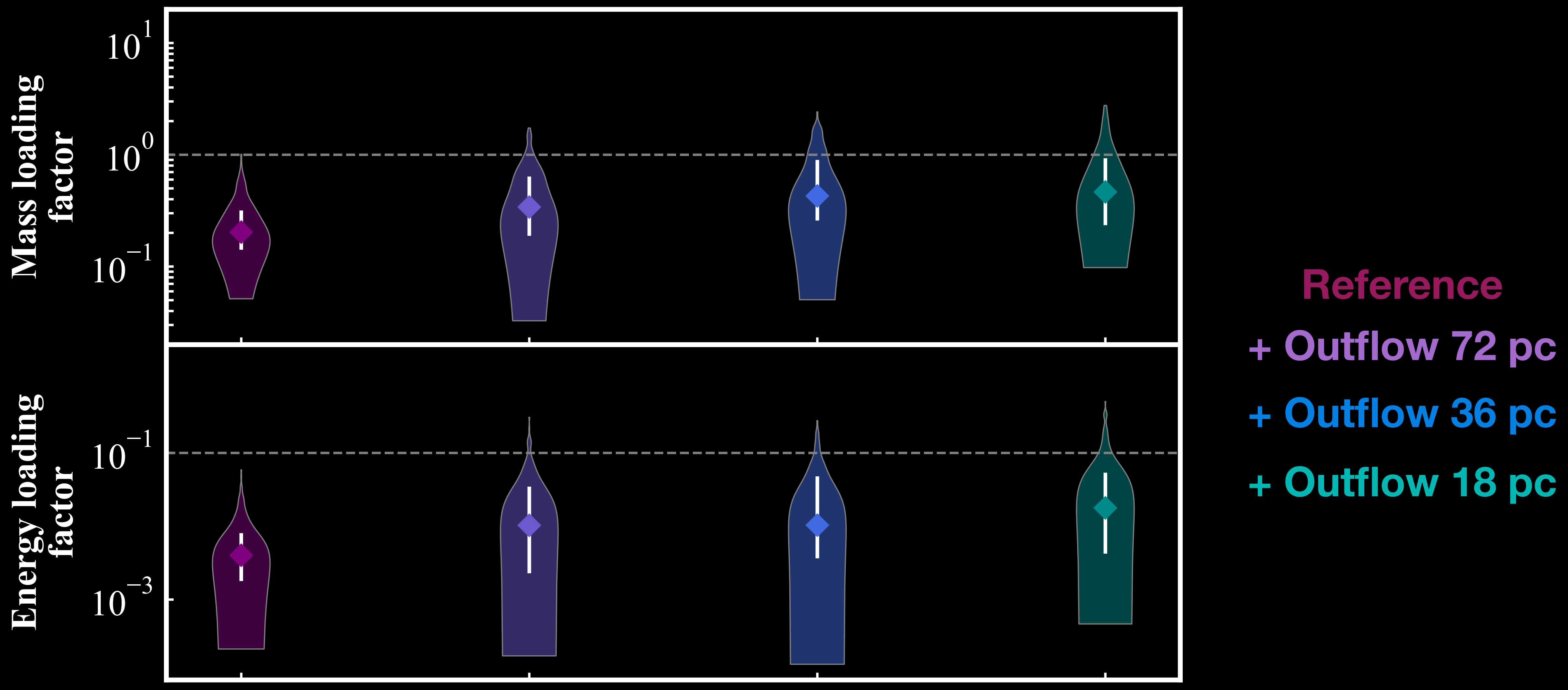
Conclusion

3. Better-resolved outflows are systematically more energetic, without modifying the central galaxy or the feedback model.



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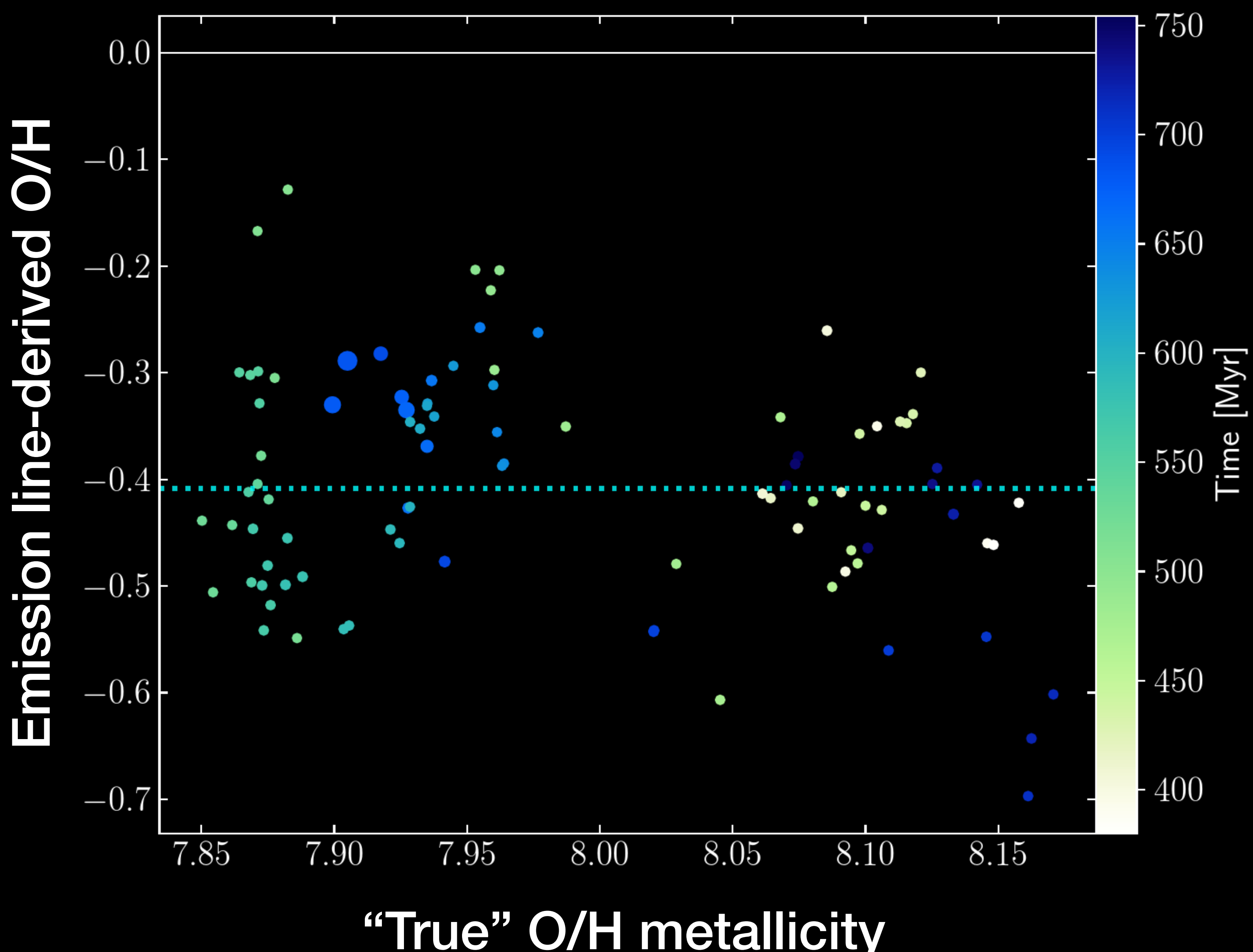
Conclusion

4. These new abilities can help us quantify observational biases when inferring outflow energetics, kinematics and chemistry from emission lines of distant galaxies.



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Conclusion

arXiv:2202.04083
arXiv:2211.04626
arXiv:2302.08521

1. Galaxy formation models can now explicitly model non-equilibrium thermochemistry and radiative transfer, robustly linking to spectroscopic observables

2. We are under-resolving the multiphase structure of outflows. Fixing this requires beyond-Lagrangian resolution schemes, e.g. refining on the cooling length.

3. Better-resolved outflows are systematically more energetic, without modifying the central galaxy or the feedback model.

4. These new abilities can quantify potential observational biases when inferring outflow energetics, kinematics and chemistry from emission lines of distant galaxies.