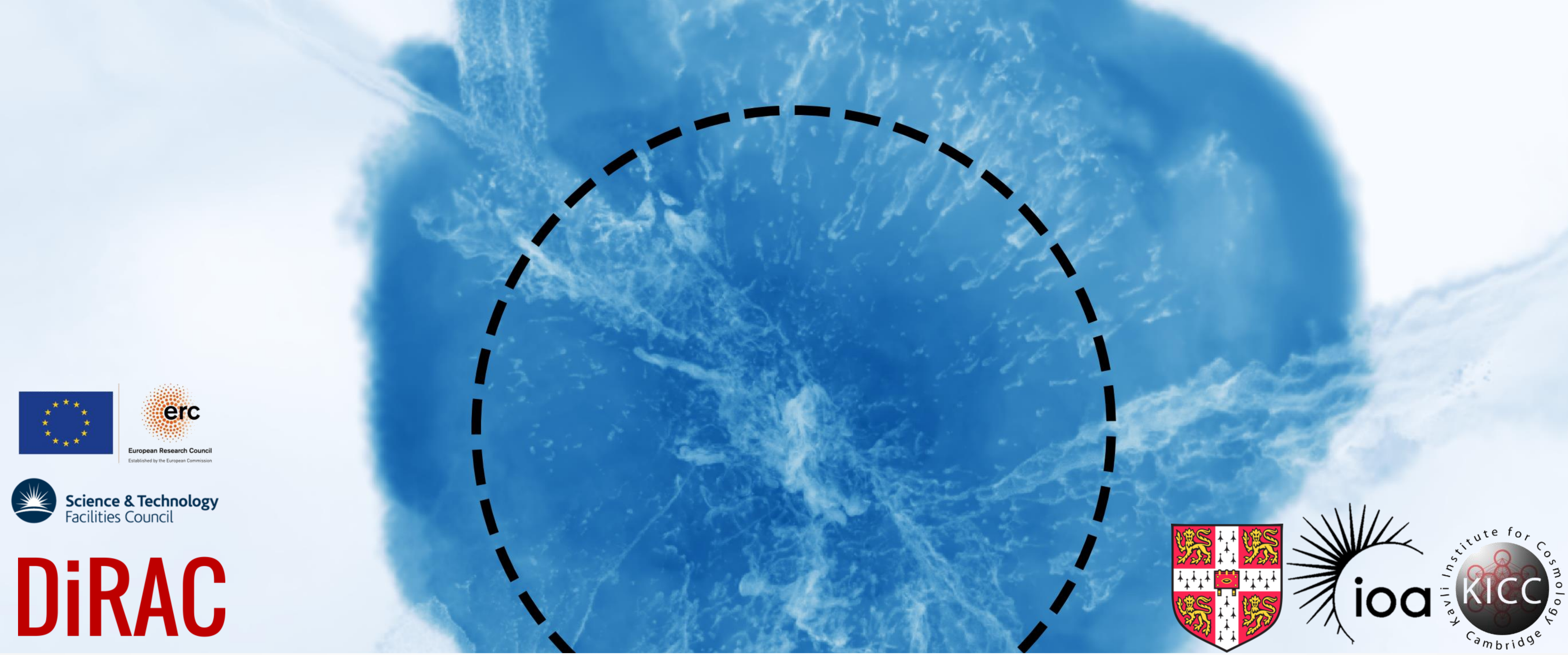

Resolving shocks and filaments at the boundary of the CGM and IGM: effects on gas properties and star formation

Jake Bennett & Debora Sijacki

Institute of Astronomy & KICC, University of Cambridge

Epoch of Galaxy Quenching

jake.bennett@ast.cam.ac.uk

Bennett & Sijacki (submitted to MNRAS), arXiv: 2006.10058

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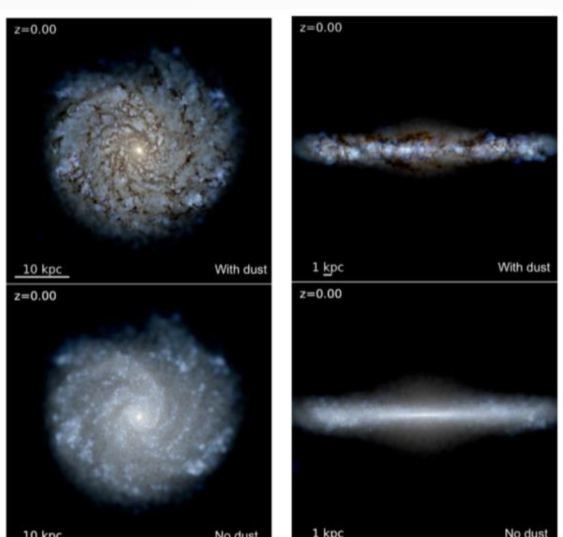
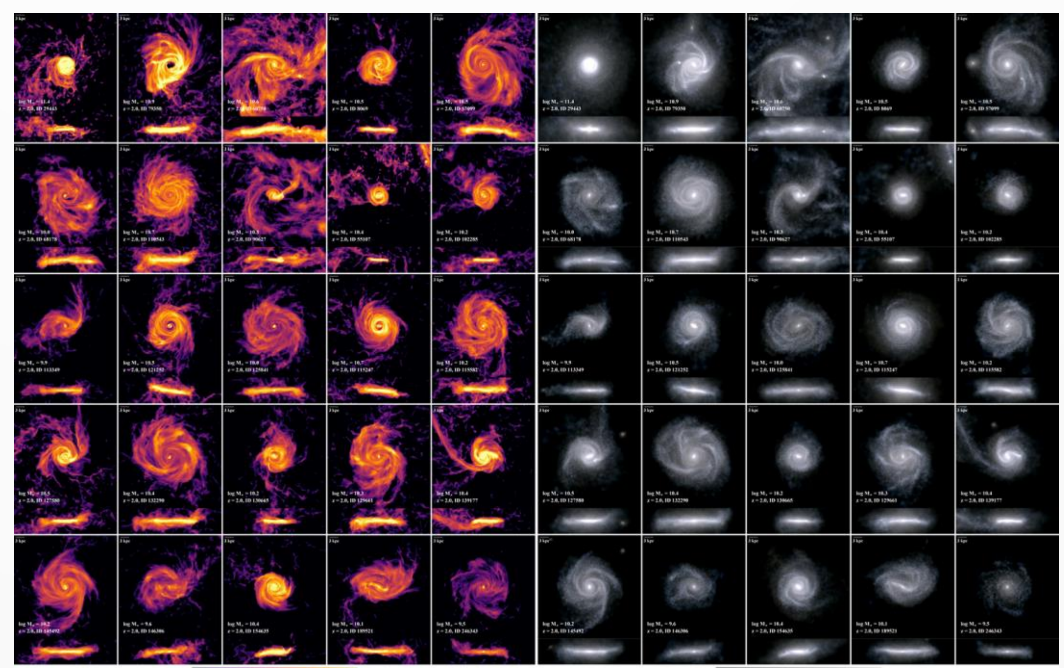
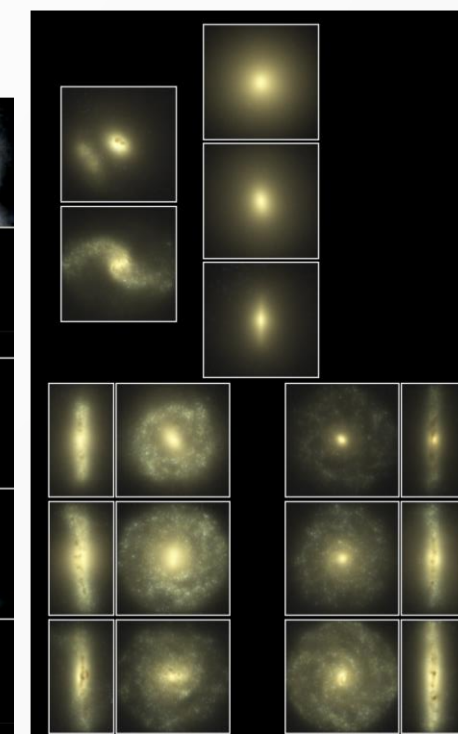
Introduction

- Cosmological, hydrodynamical simulations are powerful tools to follow physical processes across a wide range of scales.
- Applied to galaxy formation, there have been a number of recent successes, e.g. EAGLE (Schaye et al. 2015), IllustrisTNG (Nelson et al. 2018) and FIRE (Hopkins et al. 2013).

Left: MW-like galaxy with FIRE physics.
Centre: Galaxies in IllustrisTNG.
Right: Hubble diagram from EAGLE.

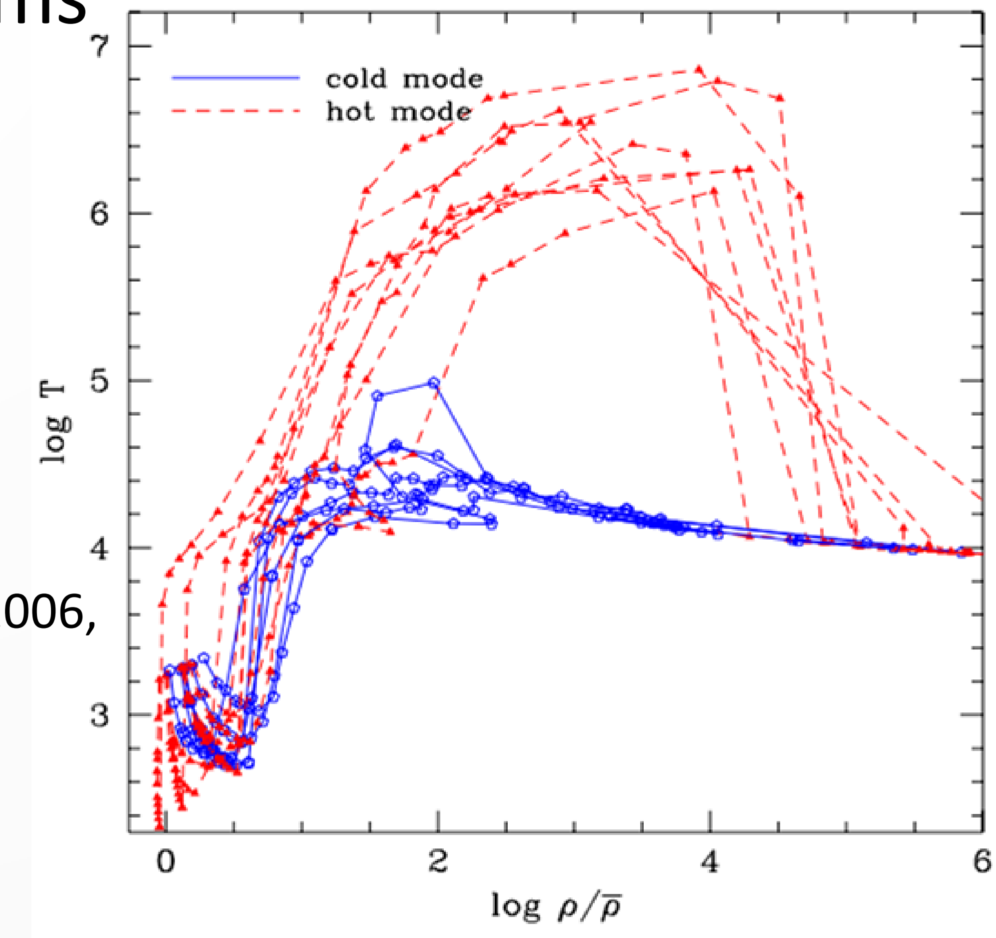






Introduction - Accretion onto Galaxies

- Hot mode – gas shock heats and forms a hot halo, which slowly cools.
- Cold mode - gas rapidly cools, delivering cold gas quickly (*e.g.* Silk 1977, White & Rees 1978, White & Frenk 1991).
- Simulations suggest filamentary accretion (*e.g.* Kereš et al. 2005, Dekel & Birnboim 2006, Ocvirk et al. 2008).
- Inflow rates can depend on codes used, feedback schemes and resolution. (*e.g.* Hummels et al.2019, Peeples et al. 2019, Suresh et al. 2019, van de Voort et al. 2019)

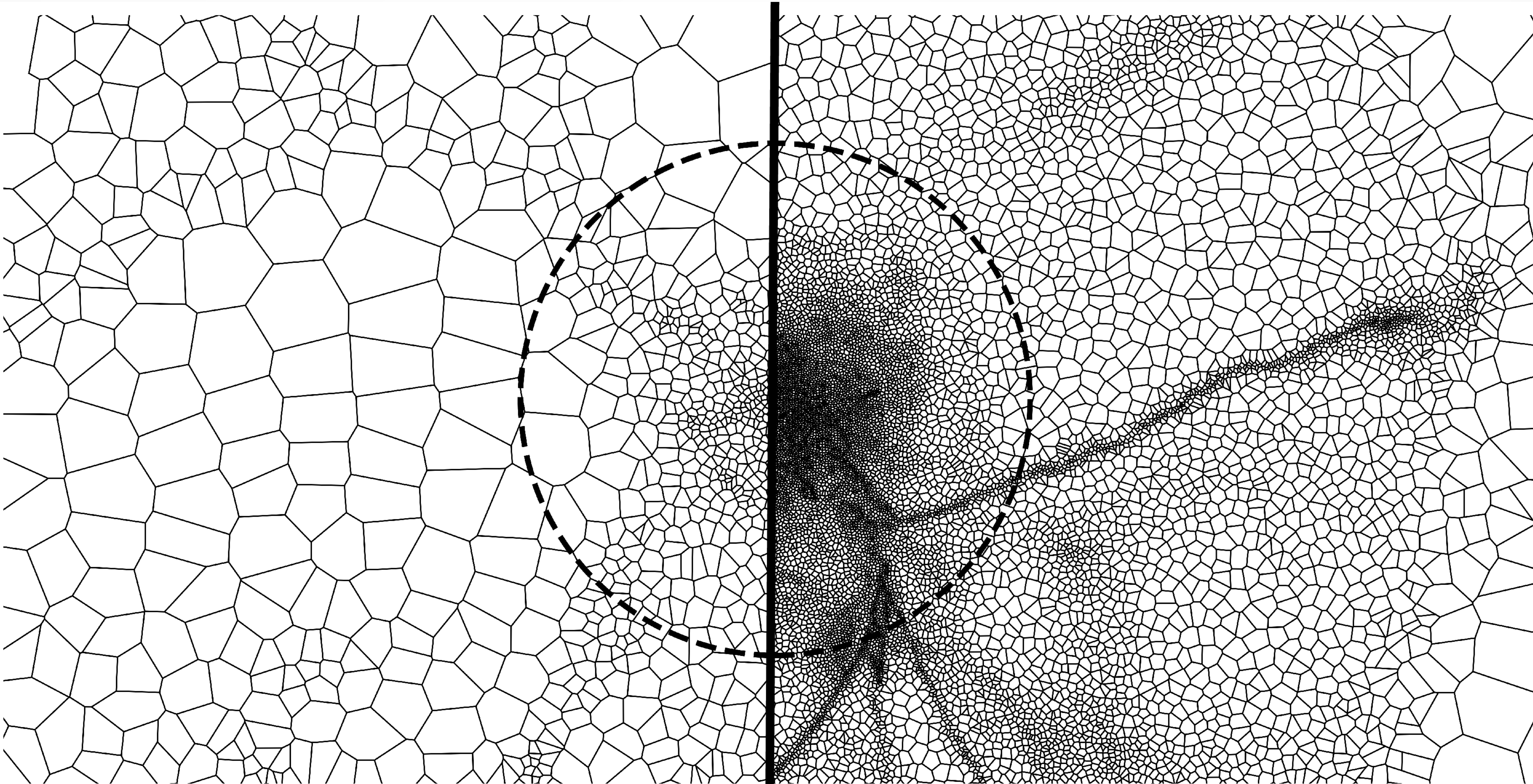


Kereš et al. 2005

Simulations

- Using AREPO (Springel 2010).
- Zoom-in of $\sim 10^{12}$ $M_\odot$ halo to z=6.
- Using successful feedback model from FABLE (Henden et al. 2018), itself based on Illustris (Vogelsberger et al. 2013; Genel et al. 2014, Sijacki et al. 2015).
- Introducing our new on-the-fly `shock refinement' scheme:
  - Cells identified as shocks are flagged for refinement (using Schaal & Springel (2015)).
  - Mass resolution is then boosted by a factor of up to 512 (with a target cell mass of 3.2×10^4 $M_\odot$).

Applying shock refinement to the halo



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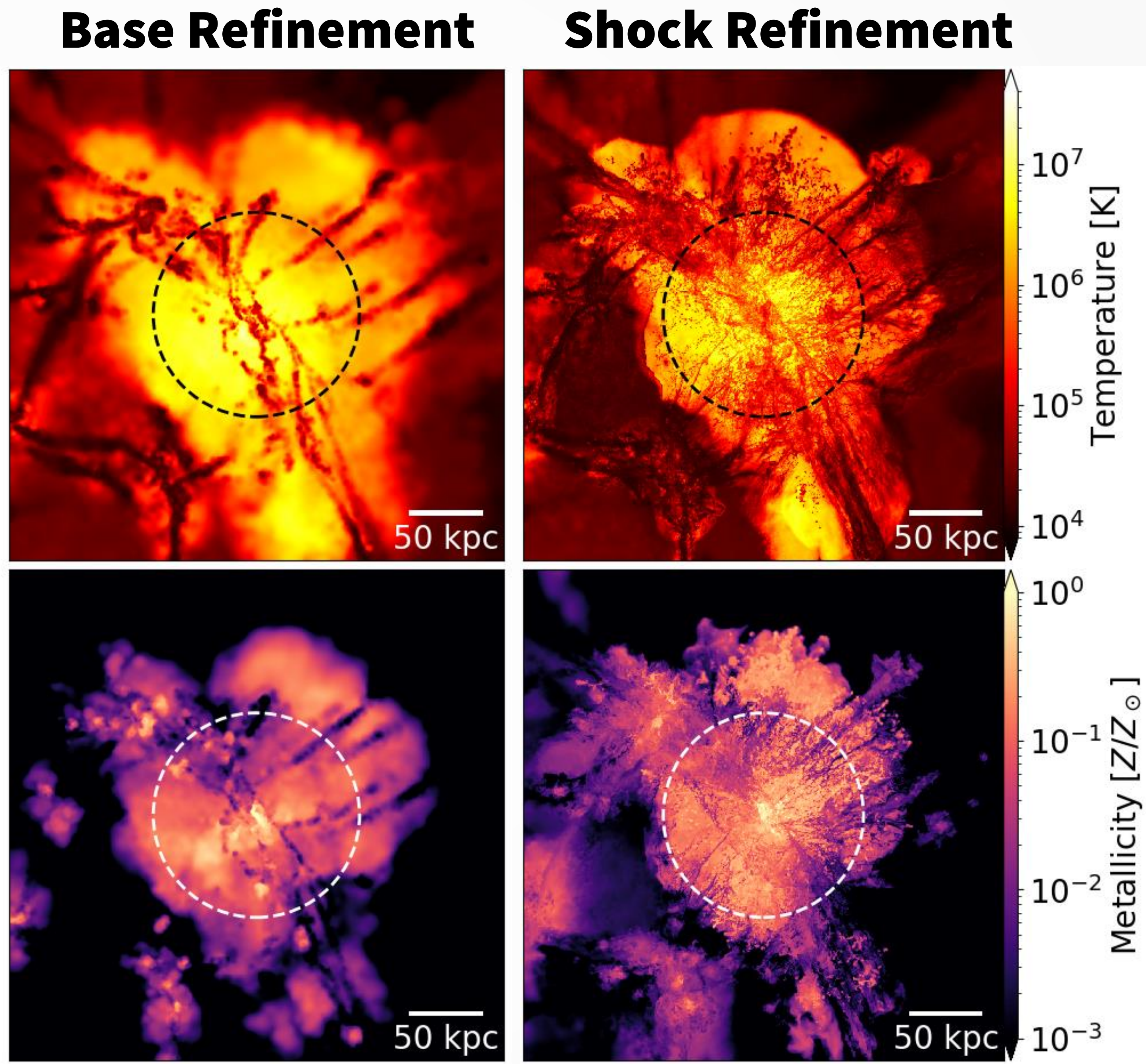
- Considerably more cool structures within the hot halo (50% increase by mass).
- Filaments penetrate deeper, delivering more gas.
- Structures mostly correspond to metal-poor primordial filaments.
- We develop a more multiphase CGM more in line with observations (*e.g.* Rudie et al. 2012, Werk et al. 2013, Rubin et al. 2015, Crighton et al. 2015).



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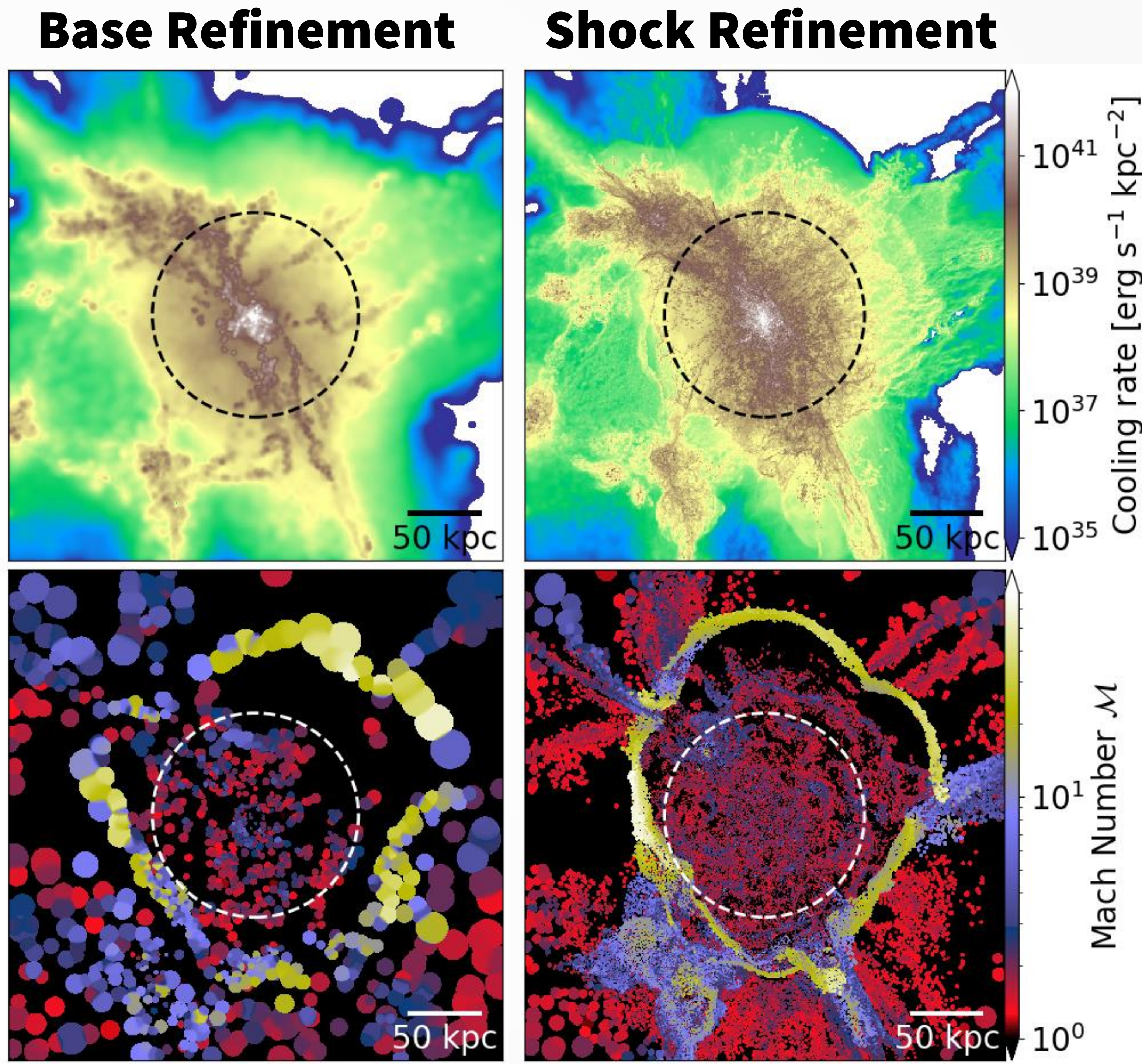
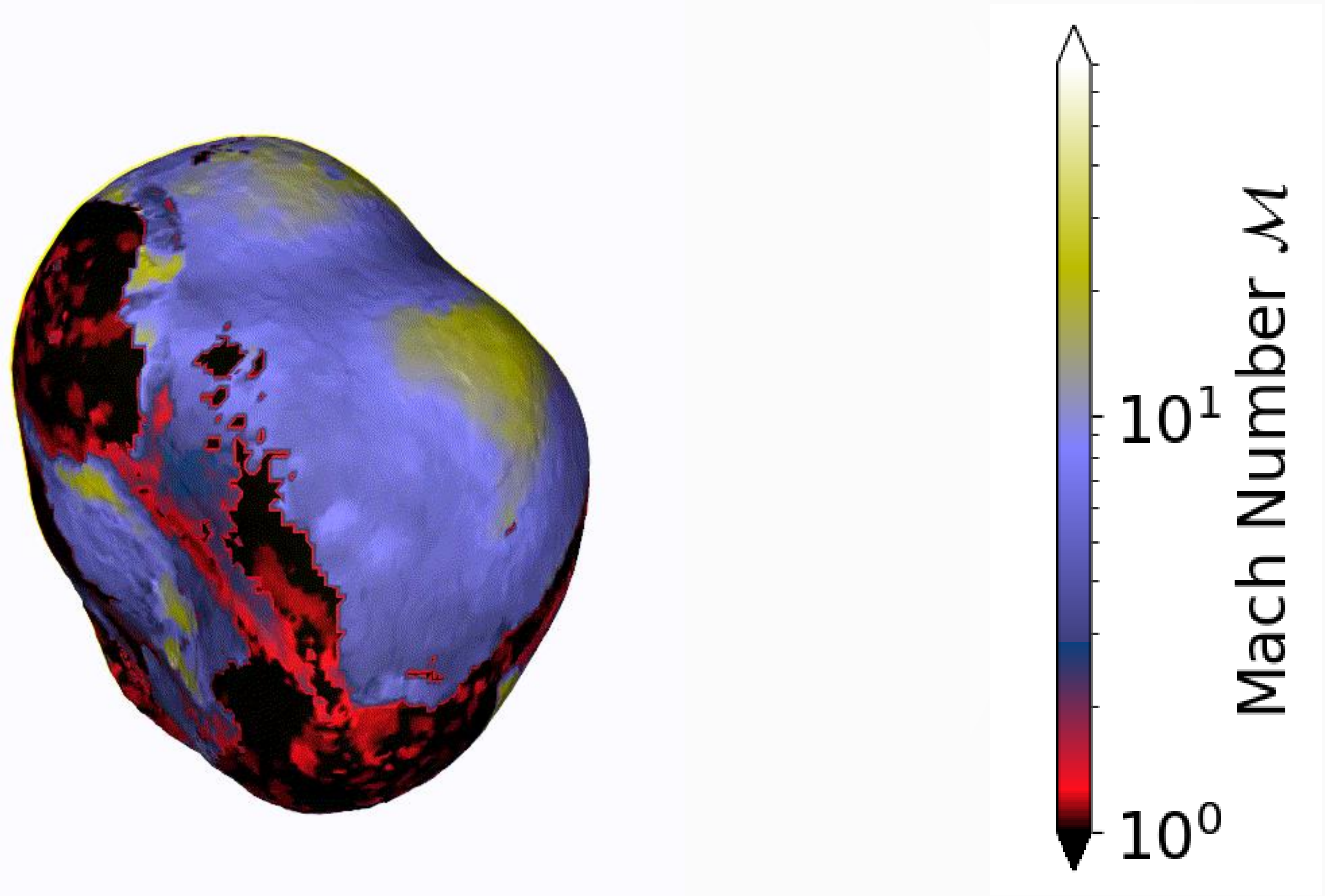
- Enhanced cooling rates throughout the halo.
- Denser inflowing filaments.
- More cold clumps.



- Shocks narrower and better defined.
- Higher energy dissipation at shocks.

3D Mesh of the accretion shock, coloured by local Mach number



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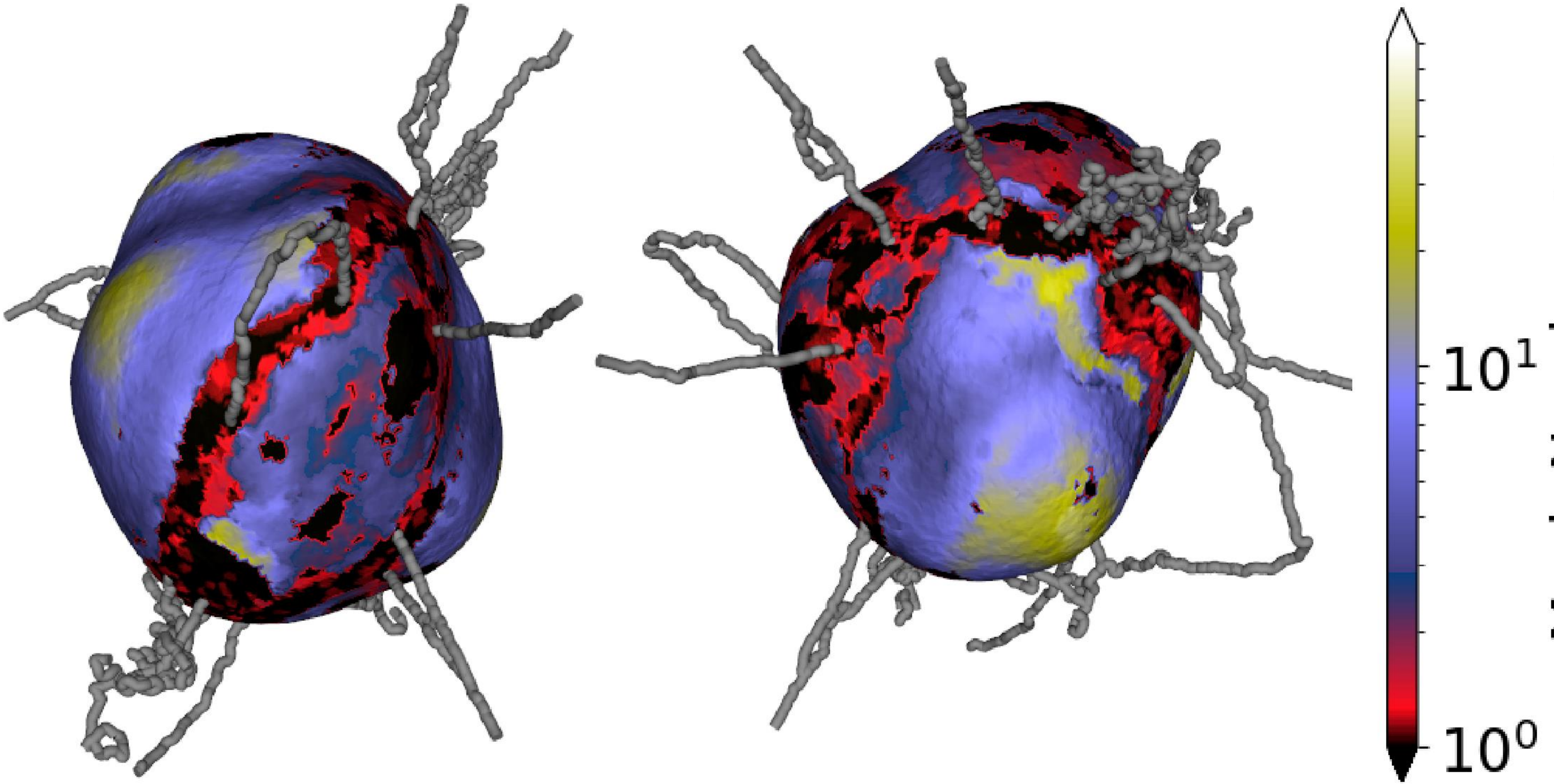
3D Mesh of the accretion shock (same halo, 2 viewpoints) (with filaments found with DisPerSE (Sousbie 2011))



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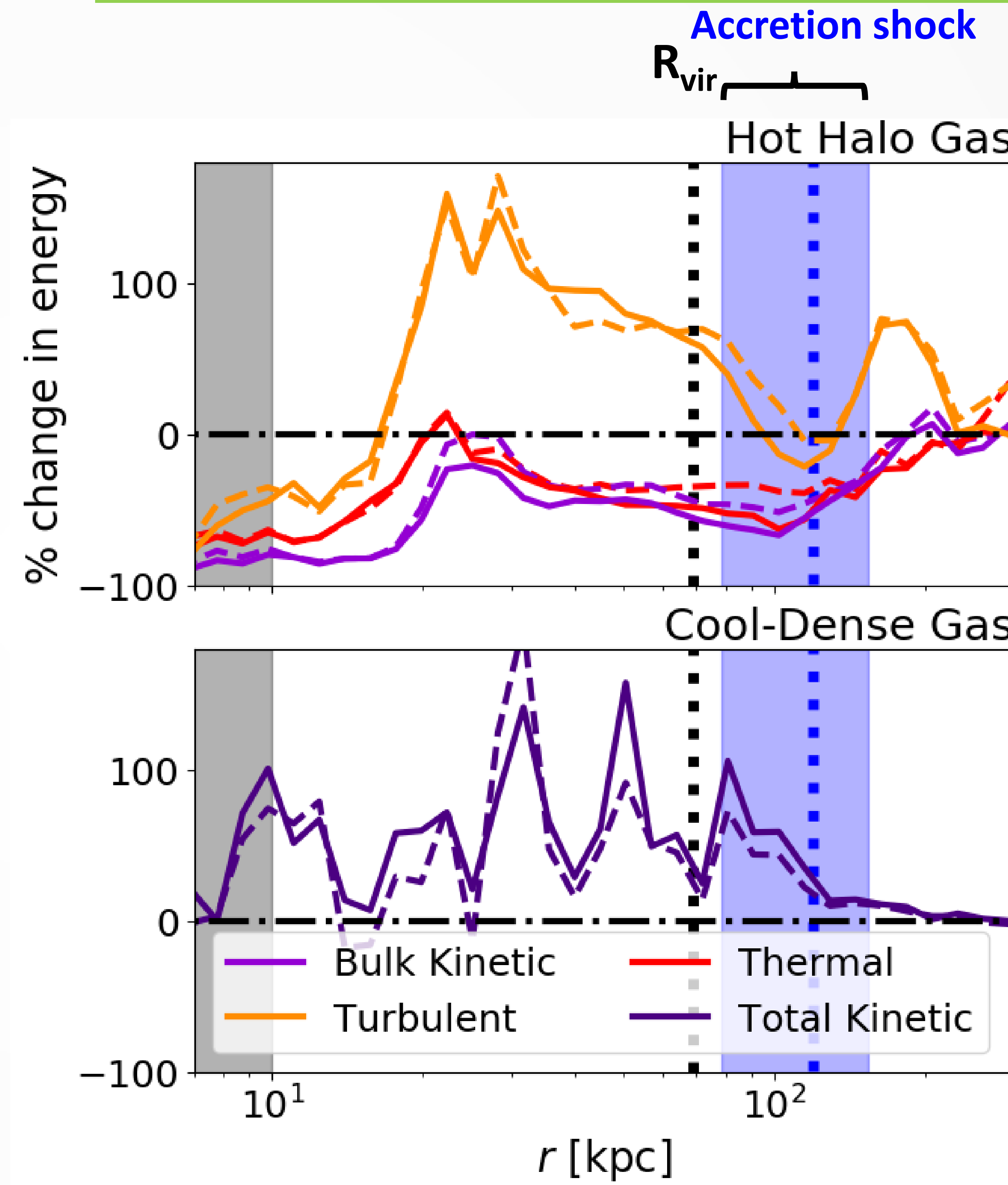
- Boosted turbulence and velocity dispersion in the hot phase.
- Suppression of thermal energy.



- Increased mass flux leads to higher kinetic energy in the cool phase.

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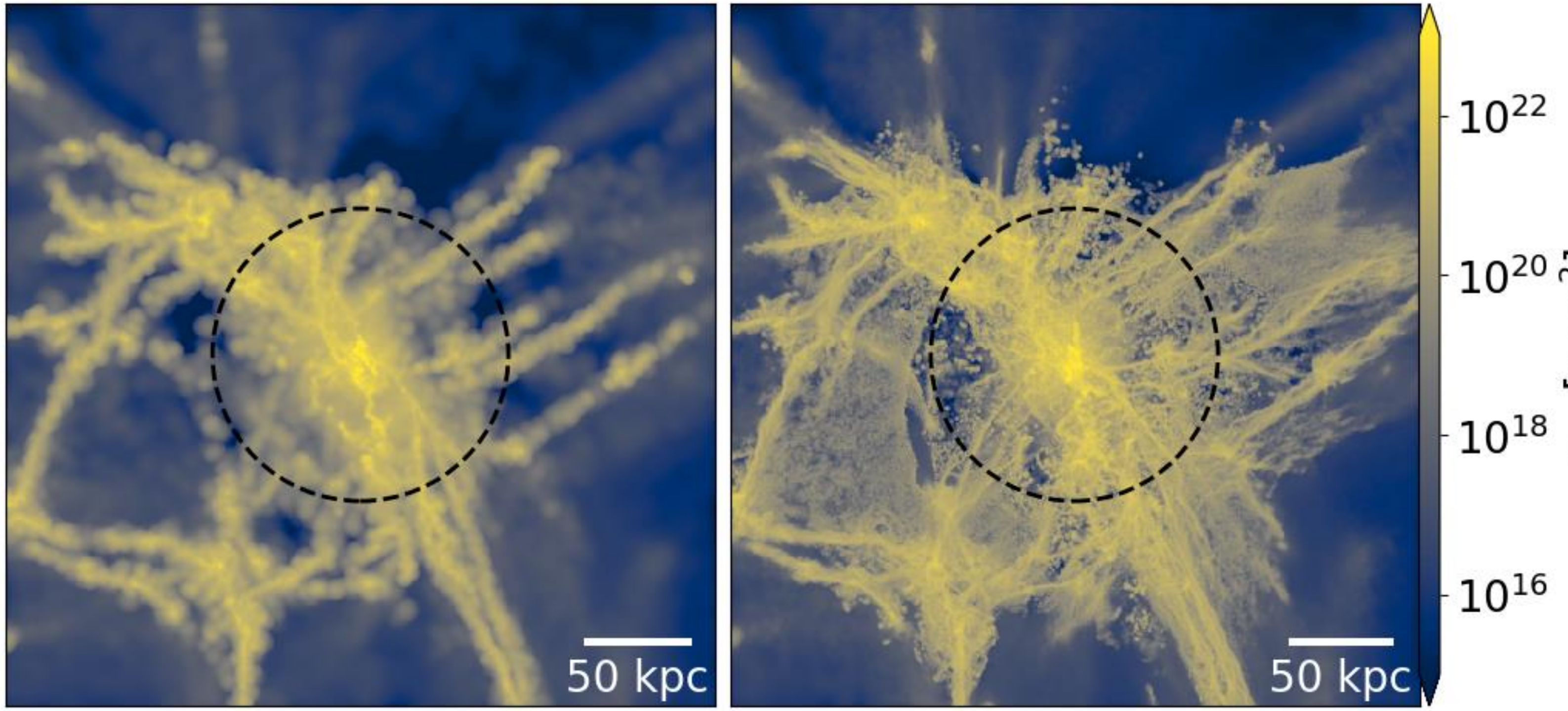
HI Prevalence

- HI covering fractions increased in the CGM.
- Interesting at lower redshifts for distribution of Damped Ly-α and Lyman Limit systems.

Base Refinement **Shock Refinement**



Threshold	Refinement	$R_{\rm vir}$	$2R_{\rm vir}$
$\log(n_{\rm HI}/{\rm cm}^{-2}) < 17$	Base Shock	0.133 0.027	0.490 0.347
$\log(n_{\rm HI}/{\rm cm}^{-2}) > 17$	Base Shock	0.867 0.973	0.510 0.653
$\log(n_{\rm HI}/{\rm cm}^{-2}) > 18$	Base Shock	0.760 0.929	0.281 0.460
$\log(n_{\rm HI}/{\rm cm}^{-2}) > 19$	Base Shock	0.585 0.849	0.217 0.353
$\log(n_{\rm HI}/{\rm cm}^{-2}) > 20$	Base Shock	0.365 0.592	0.135 0.190

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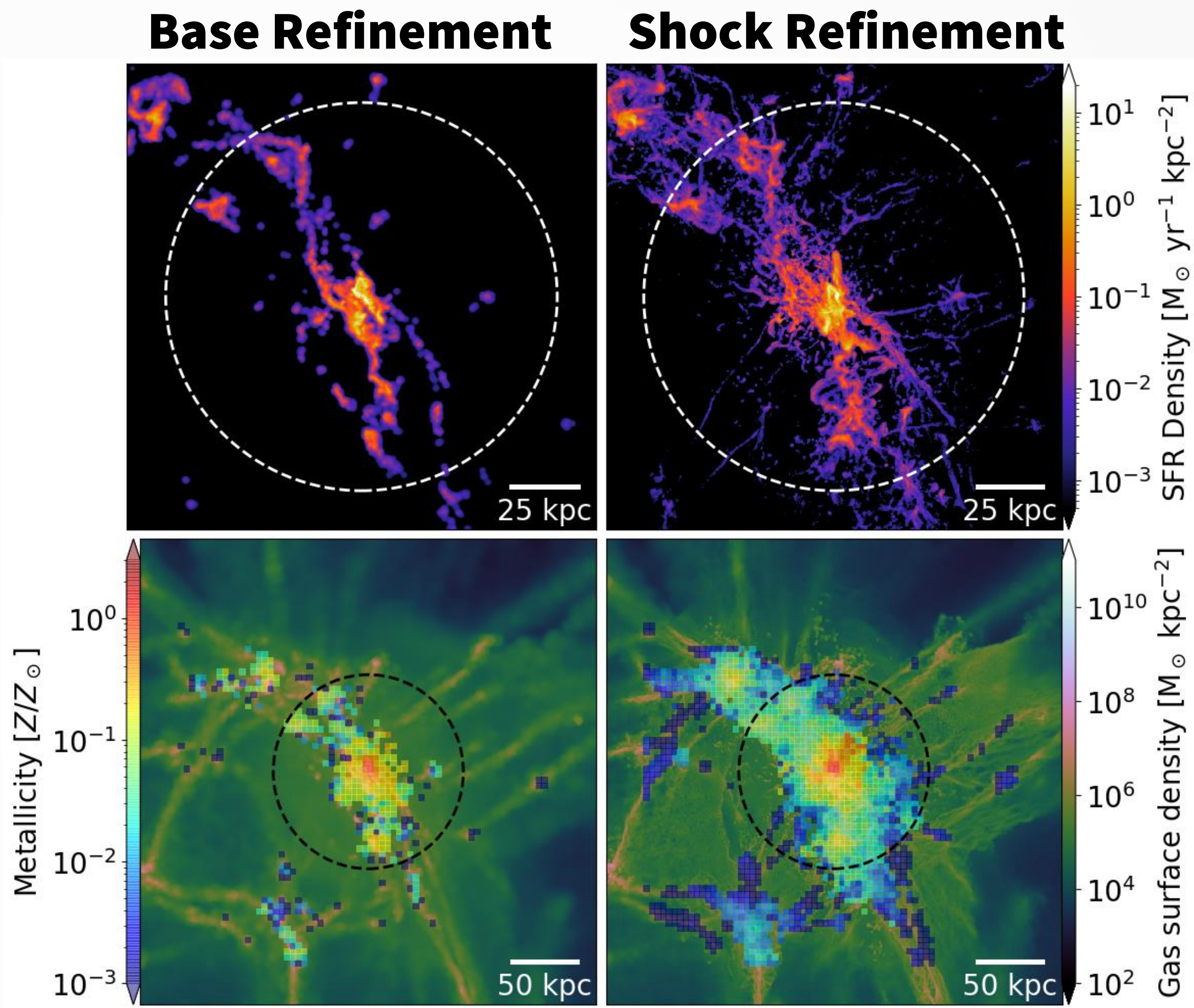
- Star formation higher.
- Also much spread out within the halo.

- Broader stellar distribution.
- Formation of metal-poor stars in primordial filaments.



Contact: jake.bennett@ast.cam.ac.uk

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Conclusions

- We’ve developed a novel scheme to boost resolution on-the-fly around shocks in cosmological simulations, leading to:
  - More cold structures within the hot halo, creating a more multiphase CGM.
  - Visualised in 3D the link between filamentary accretion and accretion shocks.
  - Neutral hydrogen covering fractions significantly increased in the CGM.
  - Star formation is increased and is more spread out throughout the halo.