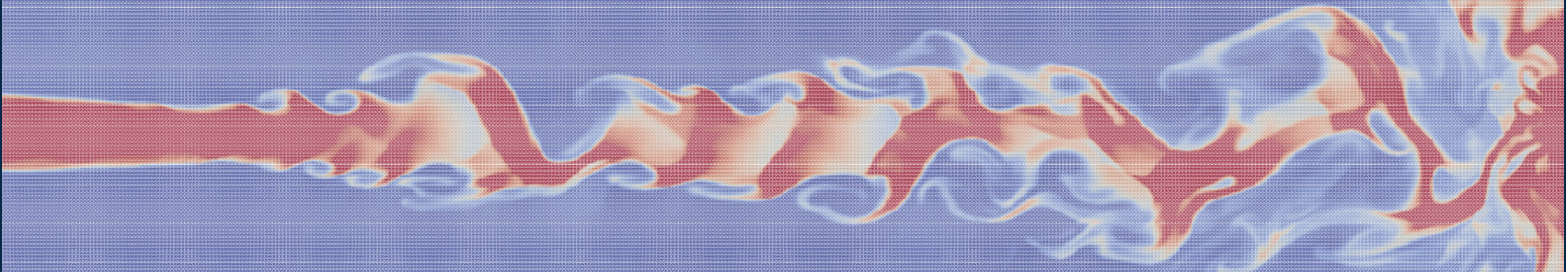
Cold stream accretion:
Effect of heat conduction on stream accretion.



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Content

(Part – 1) Theoretical Background:

Galaxy growth and Cold Stream accretion

(Part - 2) Methods:

Implementation and initial conditions of an idealized model

(Part - 3) Results:

Effect of heat conduction cold stream accretion

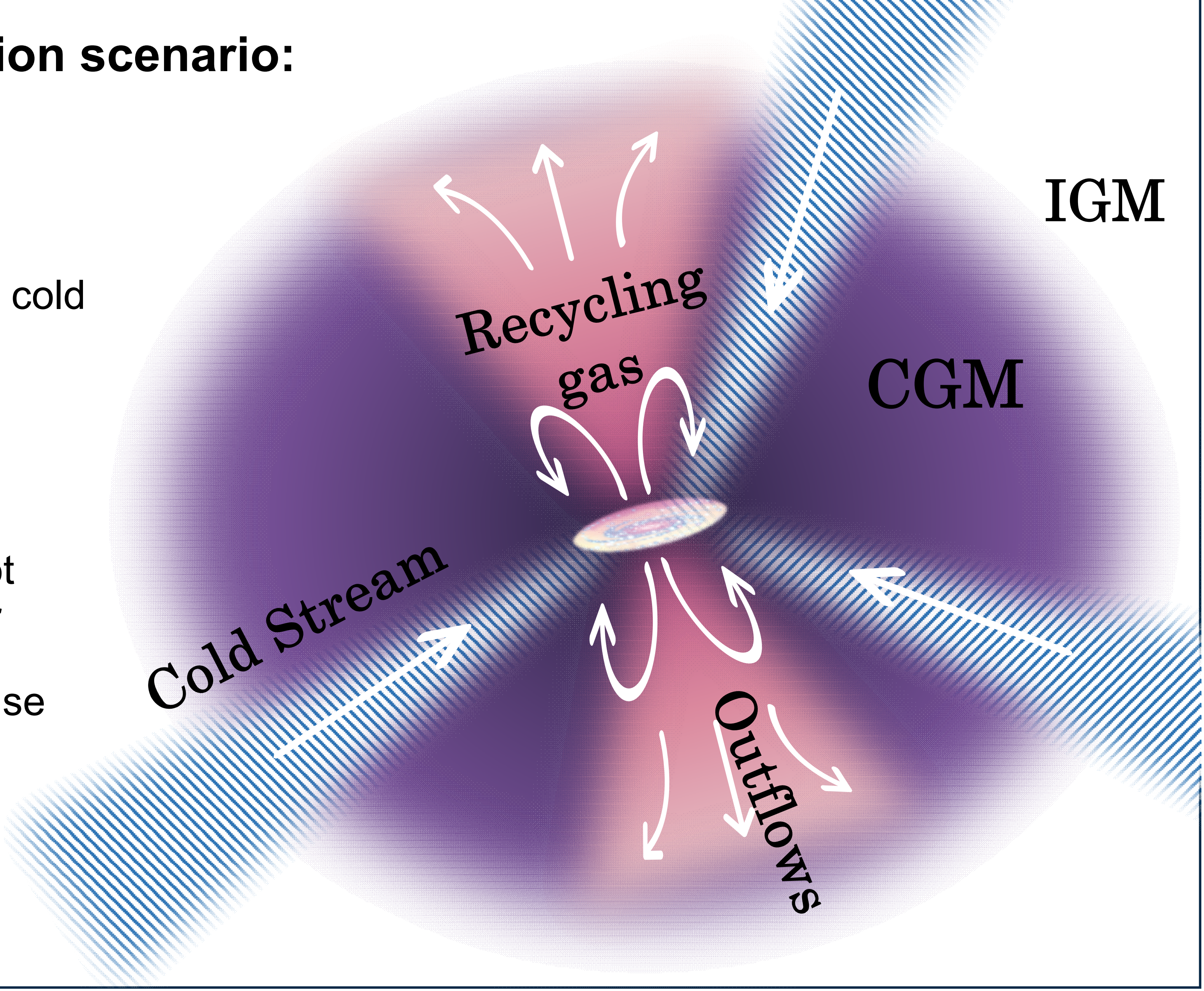
Part – 1/3 : Theoretical background

Galaxy Growth and gas accretion scenario:

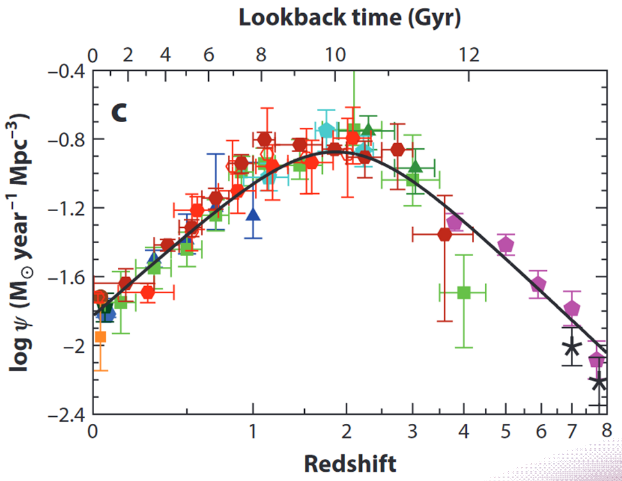
- **Two-modes of accretion:** hot and cold (*D. Keres et al, 2005*).
- **Cold streams** (*A. Dekel et al, 2006*).

For typical $\mathrm{M_h} \sim 10^{12} M_{\odot}$ at z~2

- CGM: circum-galactic-medium, hot ($10^6 K$) and diffuse gas ($n_H \sim 10^{-4} cm^{-3}$),
- Cold Stream: cold ($10^4 K$) and dense pristine gas ($n_H \sim 10^{-2} cm^{-3}$)
- IGM: Inter-galactic-medium.



Importance and issue of cold streams:



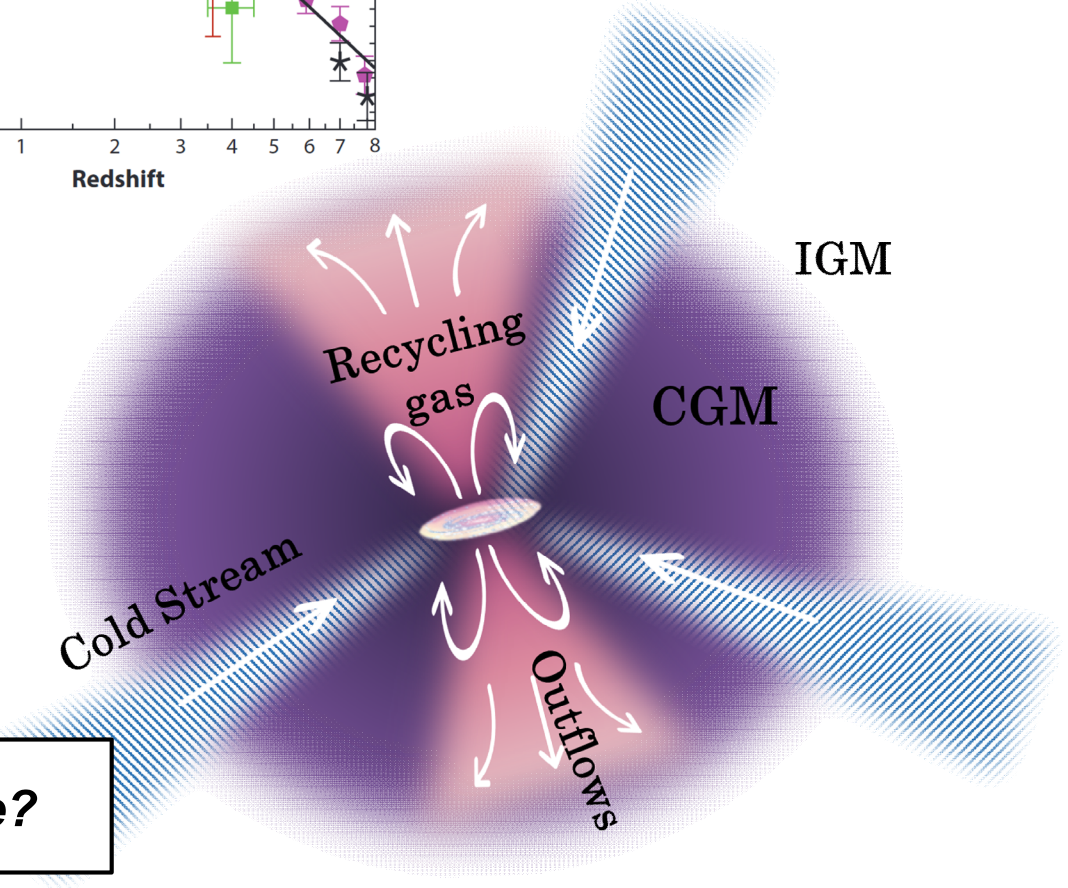
P. Madau, M. Dickinson (2014)

Importance:

- Cosmic star formation history peak,
- Gas accretion > Mergers (*E. Romano-Diaz et al, 2014*)
- Other: Gal. morphology (spin, etc…).

Issues:

- Few observations despite being common in simulations (*A. Faucher-Giguere, 2011*),
- Kelvin Helmholtz instabilities (KHI) -> but the **resolution is too low** in cosmological simul ations (*N. Mandelker et al, 2016*).
  $(R_{cold\ stream} \sim 1kpc \approx finest\ resolution)$



=> Question: How long does cold stream survive?

Part – 1/3 : Theoretical background

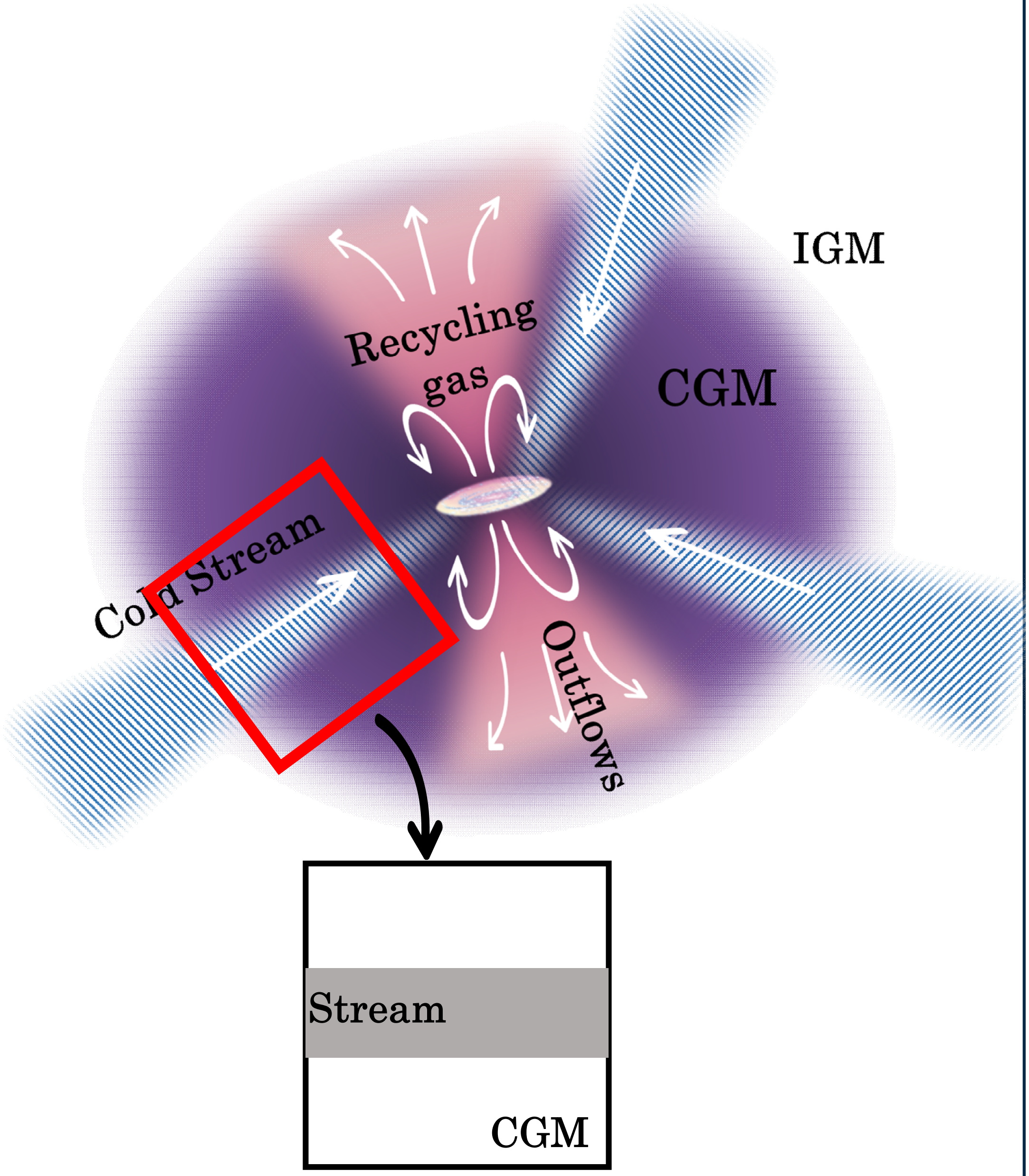
=> Question: How long does cold stream survive?

-> Leading work from N. Mandelker *(2016, 2019a, 2019b, …)*

Linear pertubation theory + idealised simulation:
Investigated:
- self-gravity (*H. Aung et al, 2019*),
- MHD (*T. Berlok et al, 2019*),
- Radiative cooling (*N. Mandelker et al, 2020a*).

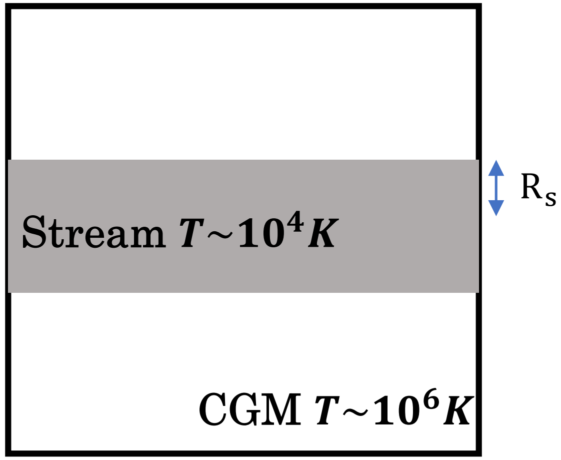
=> Resulting Lyα emission (*N. Mandelker et al, 2020b*).

… but other impactful physics/mechanism remains:
- Heat conduction,
- Dark matter potential,
- Global Multiphysics simulation,
- …



Part – 2/3 : Methods

Heat conduction: why and how?



Why:

→ strong temperature gradient at the interface of the stream and the CGM,

→ Field length $\lambda_F = \sqrt{\frac{\kappa_{hot} T_{hot}}{n_{cold}^2 \Lambda(T_{cold})}} \sim 0.2kpc$, with $\mathrm{R_s} \sim 1kpc, l_{KHI} \sim 0 - 100pc$.

→ (*may enhanced condensation from cooling due to difference of timescale*)

$$t_{diff,s} = 10^4 \times t_{diff,CGM}$$

How:

→ Implementation of an anisotropic heat conduction solver in the code Athena++ (*J. Stone et al, 2020*).

Part – 2/3 : Methods

Initial conditions

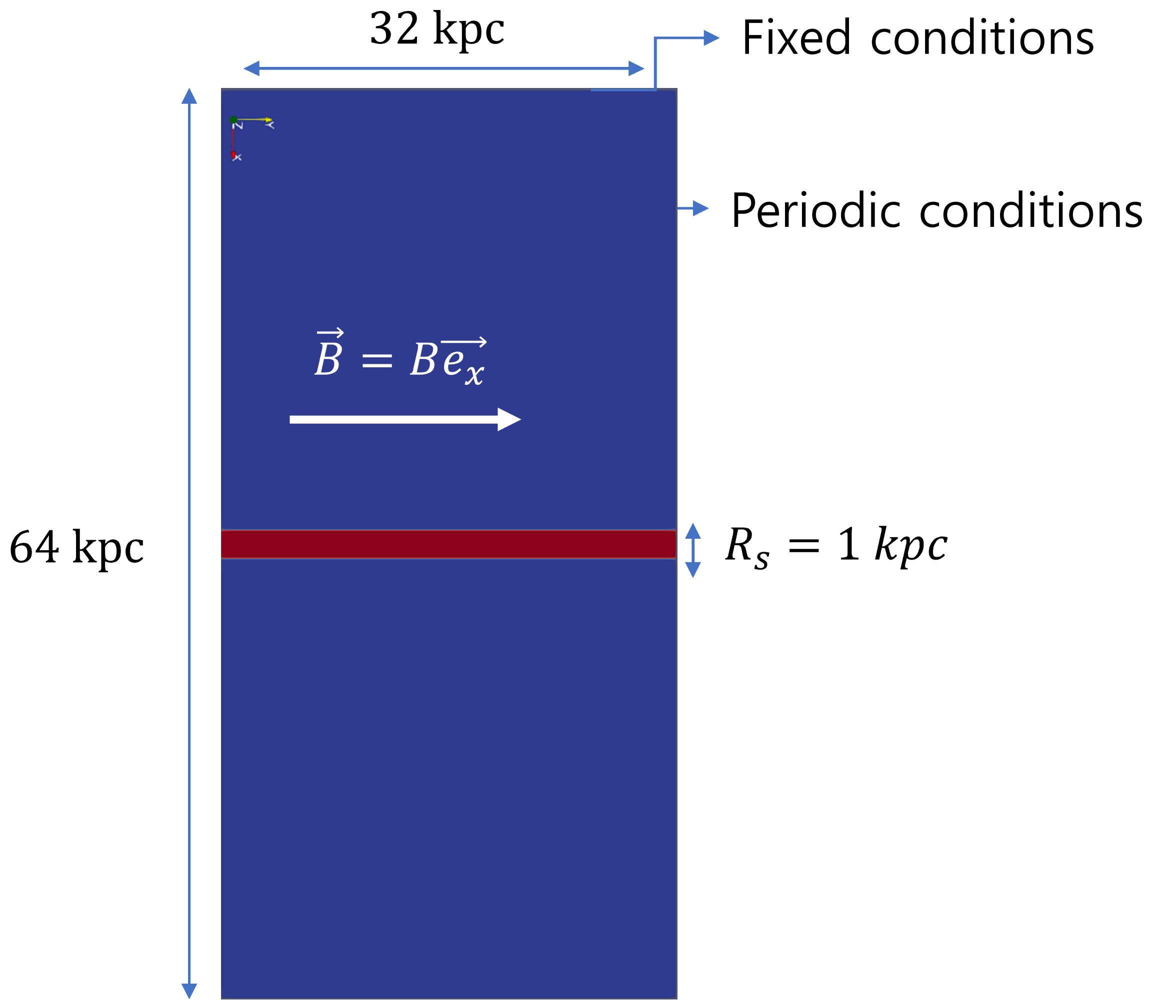
	Stream	CGM
Density:	$m_p \times 10^{-2} cm^{-3}$	$m_p \times 10^{-4} cm^{-3}$
Temperature:	$10^4 K$	$10^6 K$
Sound speed:	$\sim 12\ km.s^{-1}$	$\sim 120\ km.s^{-1}$

Initial Mach num.: $\{0.5 , 1.0 , 2.0\}$

Magnetic field: $\beta = \frac{P}{B^2/2} = 10^5$

Smooth transition stream/CGM $\sim 0.1\ \mathrm{R_s}$

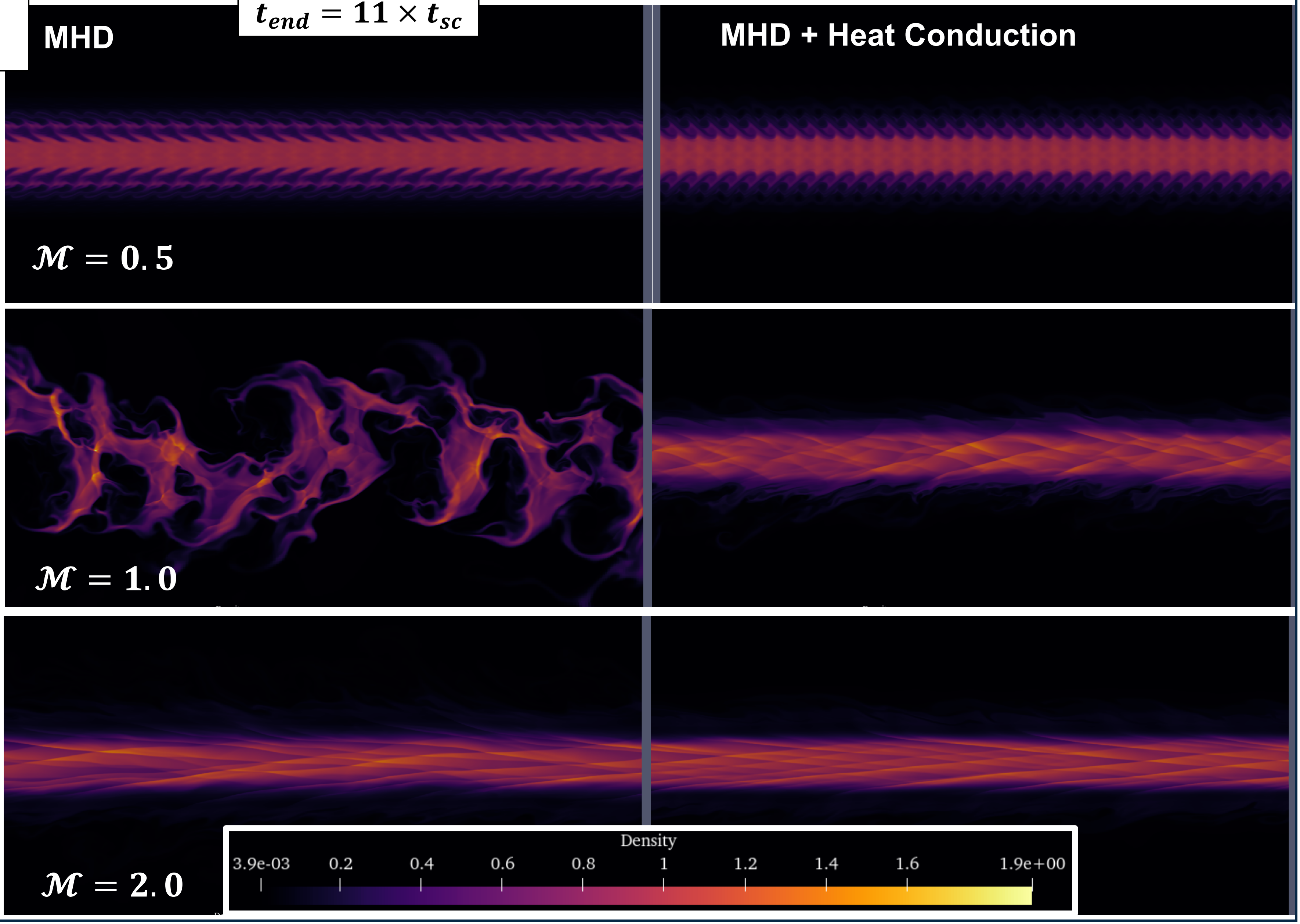
Computational configuration:
MHD with/without heat conduction + Static Mesh Ref.
Finest resolution $\sim \mathbf{15pc}$
+Super-Time-Stepping
Simulation time: $\mathrm{t_{end}} = 11 \times t_{sc} = 11 \frac{2R_s}{c_s} \sim \boldsymbol{2Gyr}$



Part – 3/3 : Results – Qualitative analysis

$$\mathcal{M} = \frac{v_{stream}}{c_{cgm}}$$

$$t_{end} = 11 \times t_{sc}$$



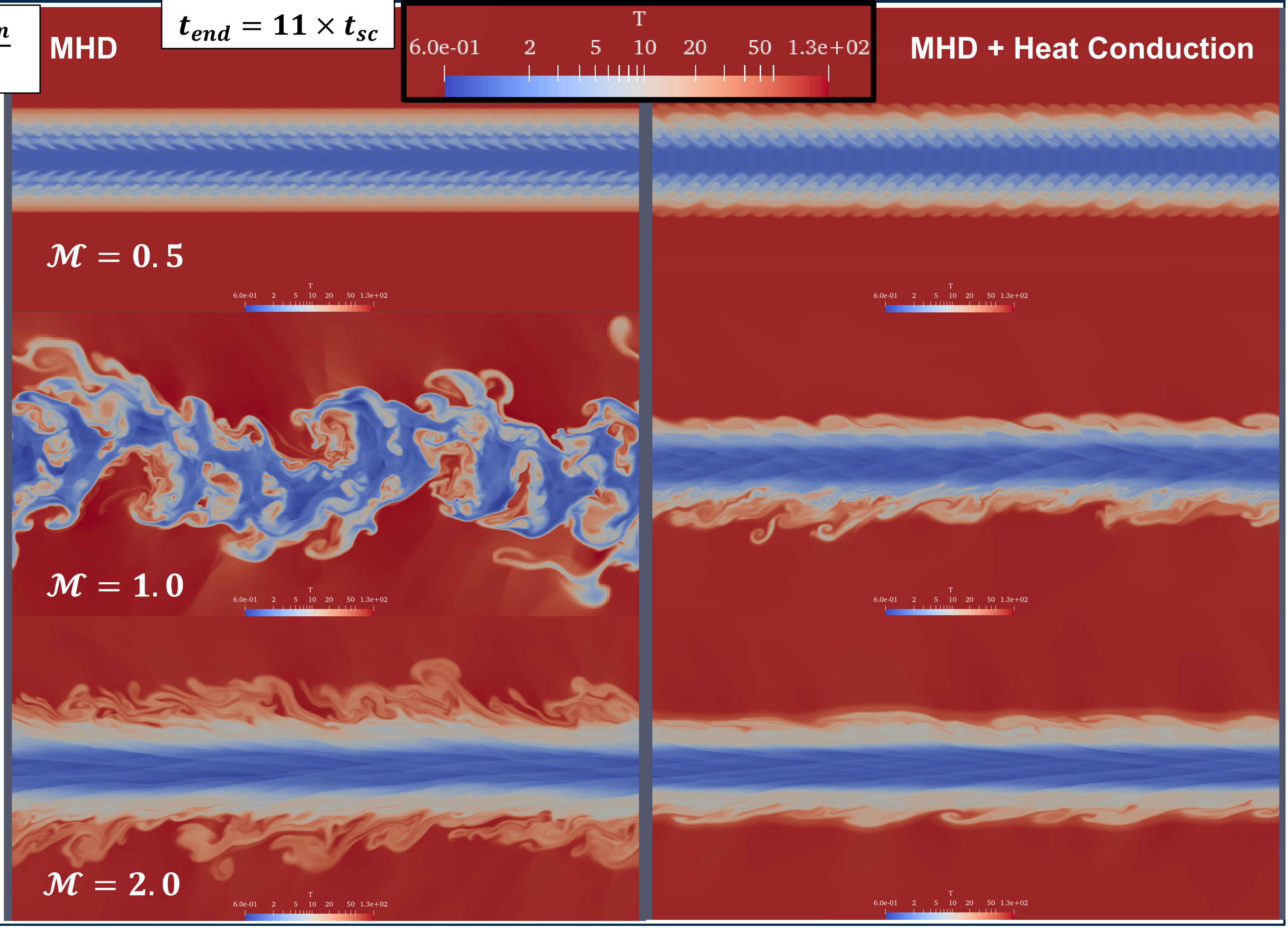
- ☐ Heat conduction stabilize the stream for $\mathcal{M} = 1$,
  → perturbations smoothed out by diffusion,

- ☐ Weak mixing of stream and CGM gas,
  → due to smooth transition,

Part – 3/3 : Results – Qualitative analysis

$$\mathcal{M} = \frac{v_{stream}}{c_{cgm}}$$

$$t_{end} = 11 \times t_{sc}$$

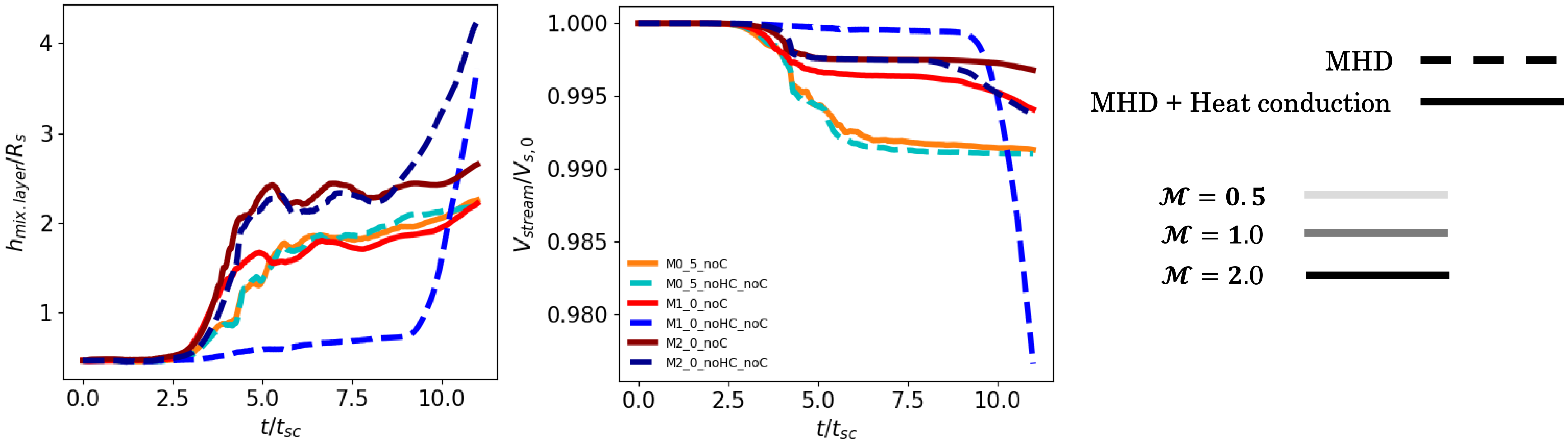


- No clear heating of the stream,

→ magnetic field line are bent in the mixing layer preventing heat diffusion in the stream,

- Heat conduction slightly reduces mixing $\mathcal{M} = 2$,

Mixing layer and stream deceleration:

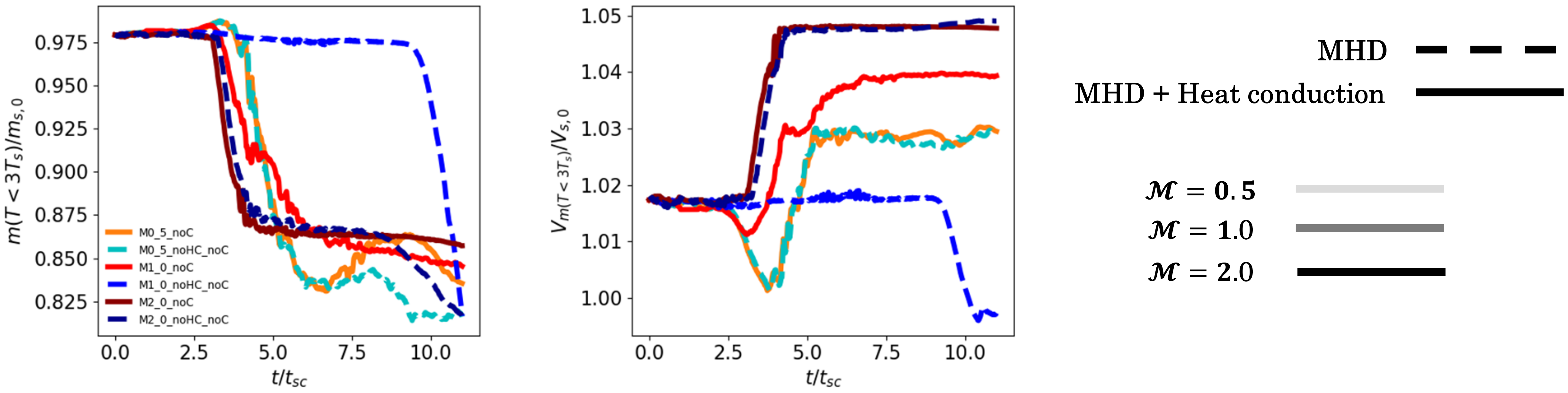


- Growth of the mixing layer is also reduced for $\mathcal{M} = 2$,
- Similar growth with heat conduction for $\mathcal{M} = 0.5$,

- Deceleration of the stream is linked to the growth rate of the mixing layer.

  => less deceleration = smaller/no Lyα emissions

Mass accretion, and effective stream velocity:



- ☐ As expected without cooling -> no growth of the cold stream (no condensation),
- ☐ Degrowth of the stream ~ growth of mixing layer,

- ☐ No real change in the velocity of the remaining stream.

=> Heat conduction alone leads to higher gas mass accretion in super- and sonic case.

Conclusion

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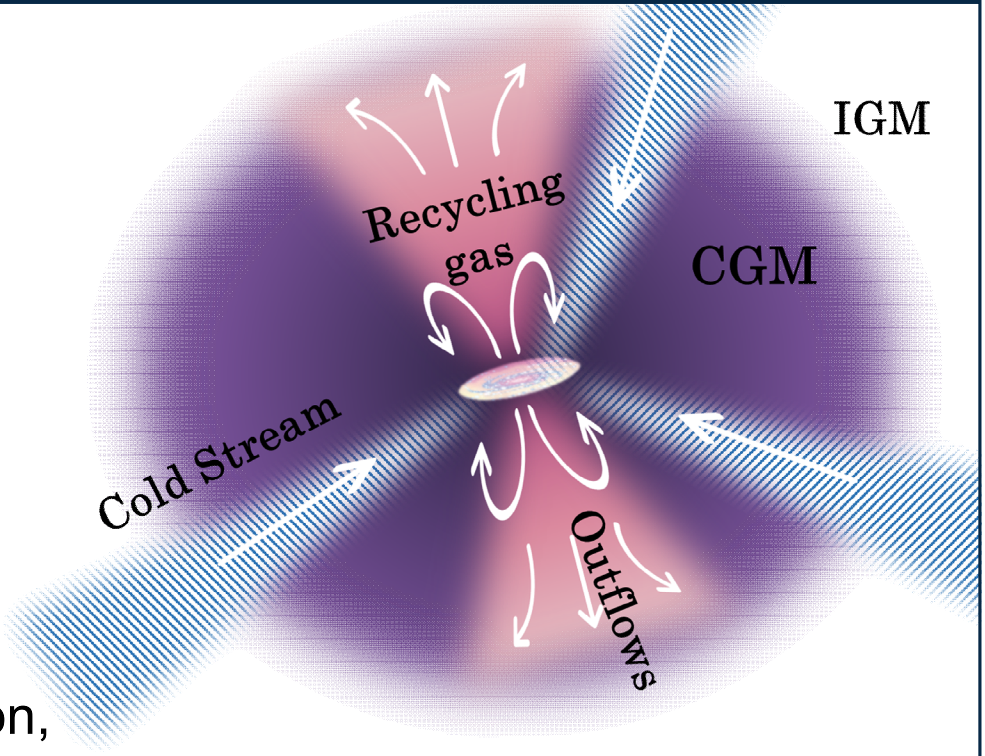

- No clear heating of the stream,
- Growth of the mixing layer leading stream deceleration,
  => Heat conduction reduces mixing for supersonic case.
  => less deceleration = smaller/no emissions
- Sonic stream is stabilize (do not disrupt) by heat conduction,
- No clear change in the mass accretion for sub- and supersonic cases,
- No real deceleration of the remaining cold stream.

=> Heat conduction alone leads to higher gas mass accretion in super- and sonic case.