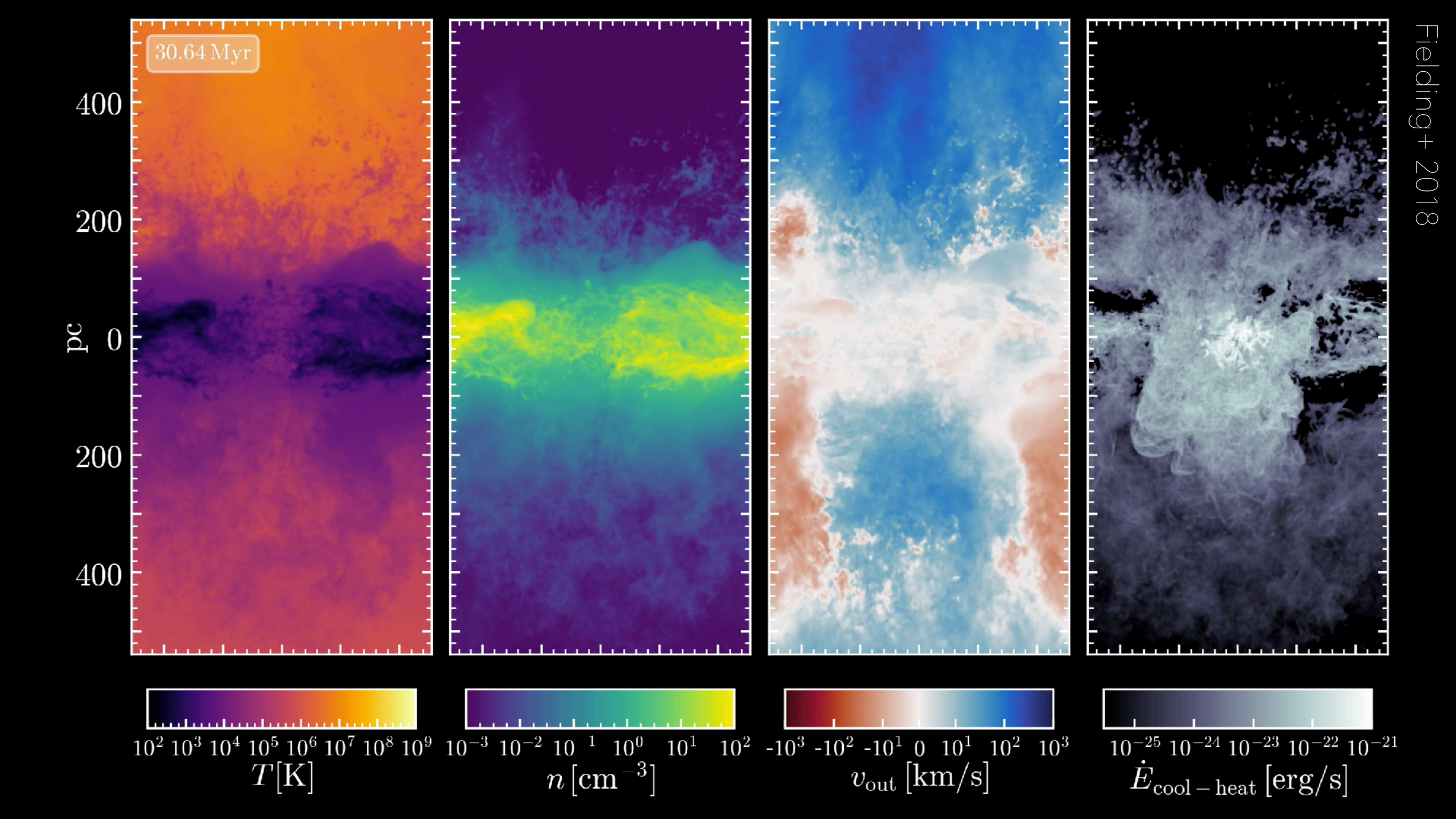
What does it mean to *resolve* multiphase gas?

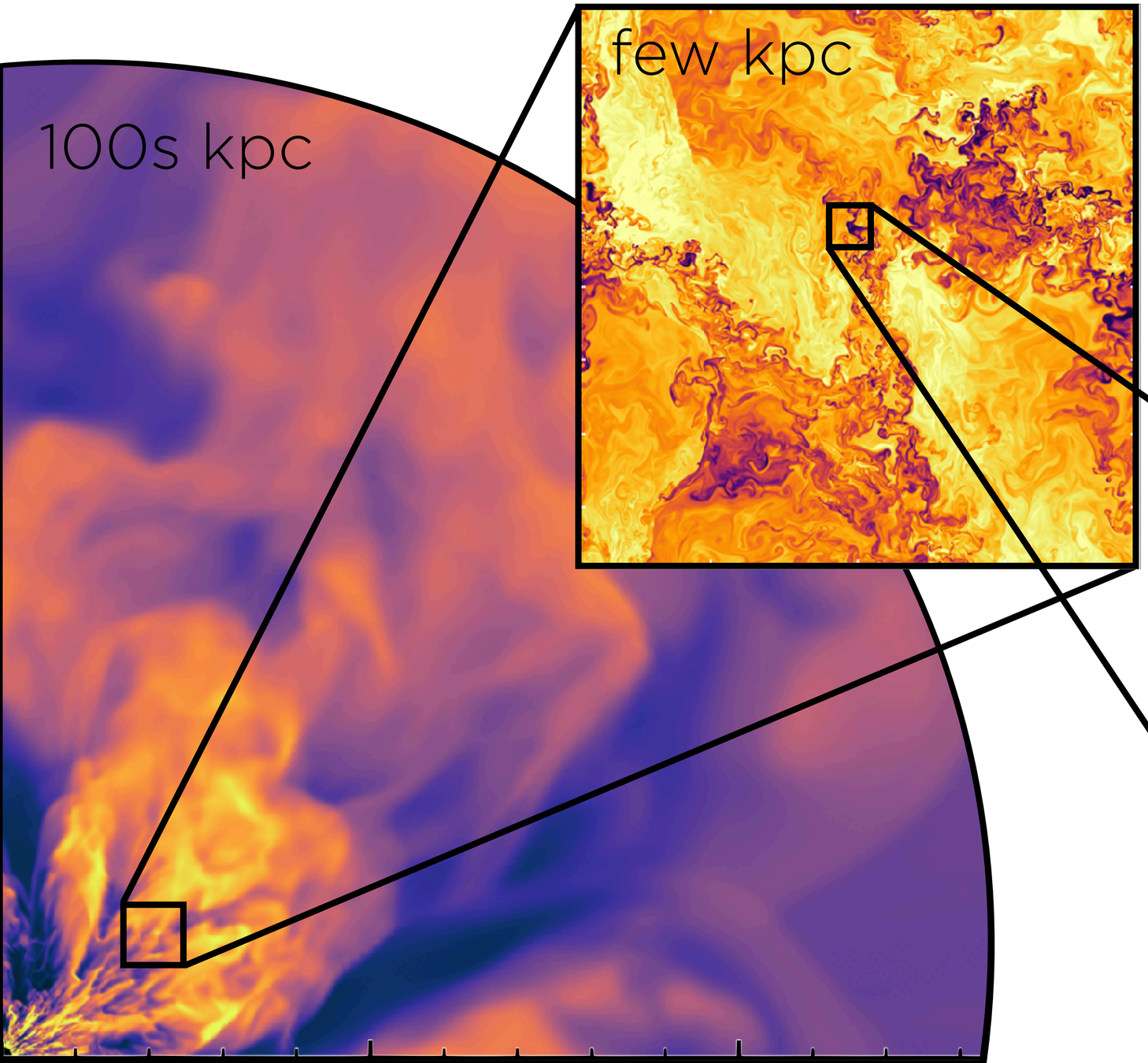
Drummond Fielding 15 Oct 2020

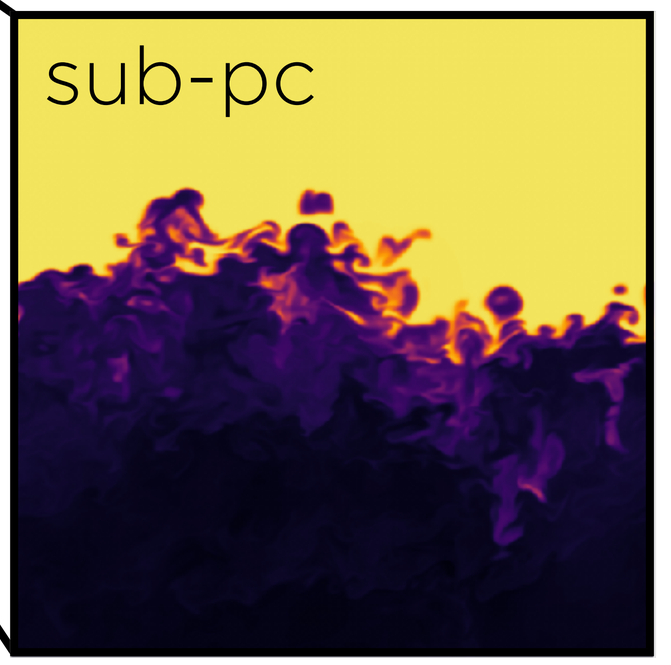
Greg Bryan + Eve Ostriker + Adam Jermyn + Matthew Abruzzo + Miao Li + Stephanie Tonnesen


30.64 Myr
400
200
pc 0
200
400
10^2 10^3 10^4 10^5 10^6 10^7 10^8 10^9
T[K]
10^{-3} 10^{-2} 10 1 10^0 10^1 10^2
n [cm^{-3}]
-10^3 -10^2 -10^1 0 10^1 10^2 10^3
$v_{\rm out}$ [km/s]
10^{-25} 10^{-24} 10^{-23} 10^{-22} 10^{-21}
$\dot{E}_{\rm cool-heat}$ [erg/s]
Fielding+ 2018

Resolve what?

- Hot ⇄ cold mass, energy, momentum transfer
- Structure of the hot-cold interface





Fielding, Ostriker, Bryan, Jermyn (2020)

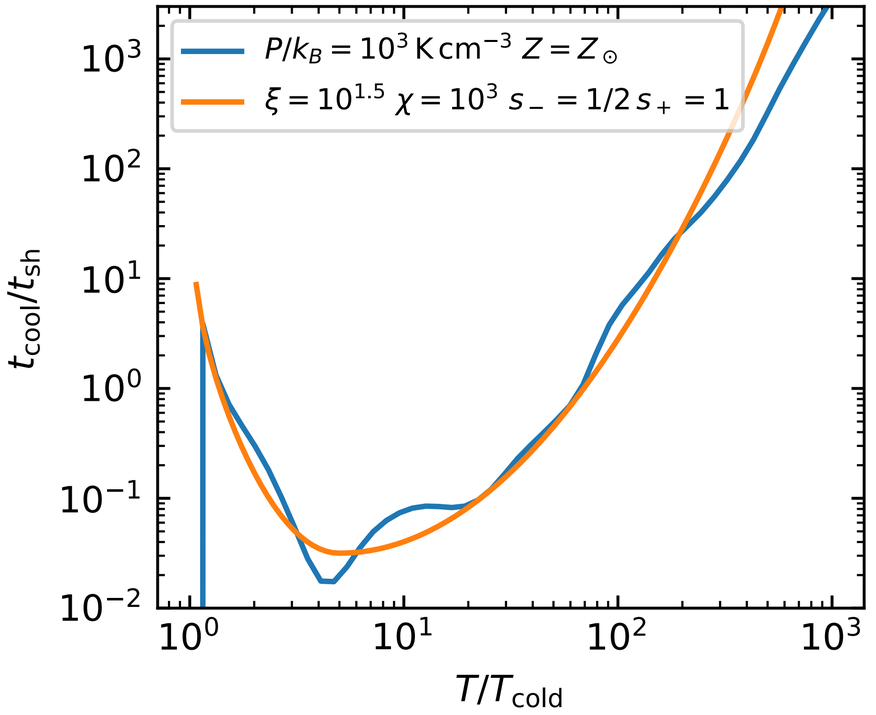
Numerical Experiment

$$\chi = \frac{\rho_{\rm cold}}{\rho_{\rm hot}}$$

$$\mathcal{M} = \frac{v_{\rm rel}}{c_{\rm s,hot}}$$

$$\xi = \frac{t_{\rm sh}}{t_{\rm cool,min}}$$

$$t_{\rm sh} = \frac{L}{v_{\rm rel}}$$



Cooling dominated by intermediate T material

Numerical Experiment

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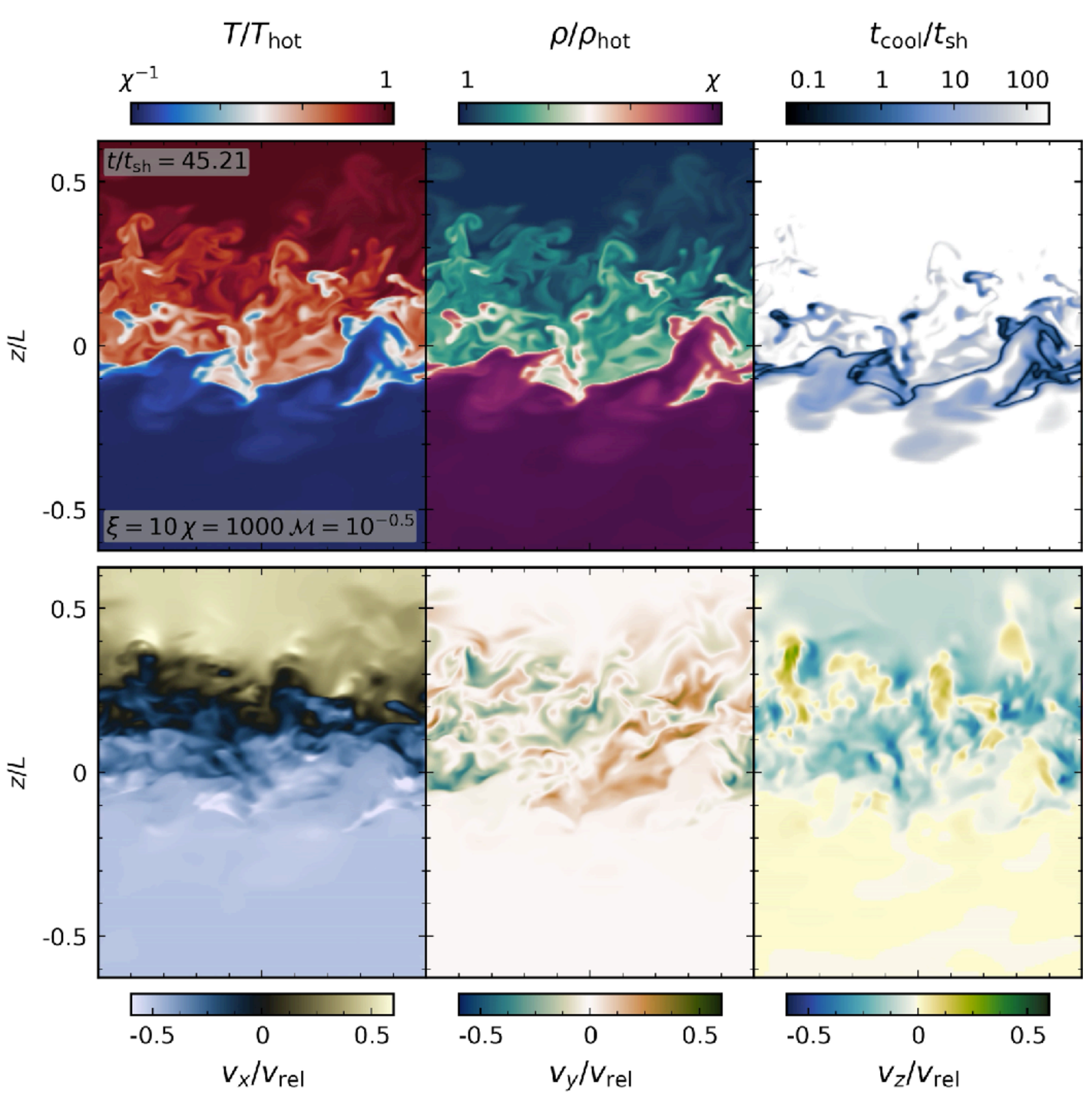
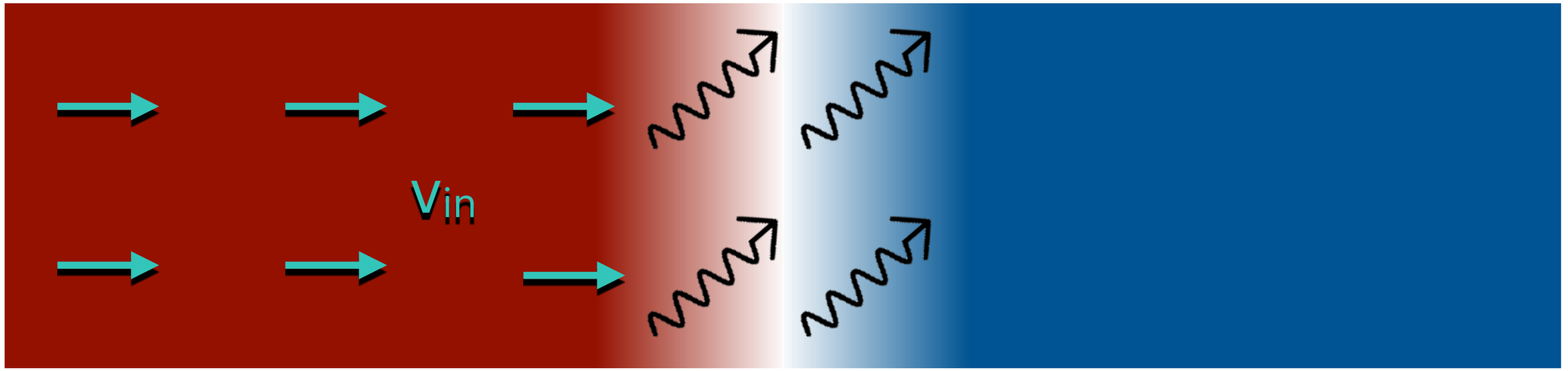
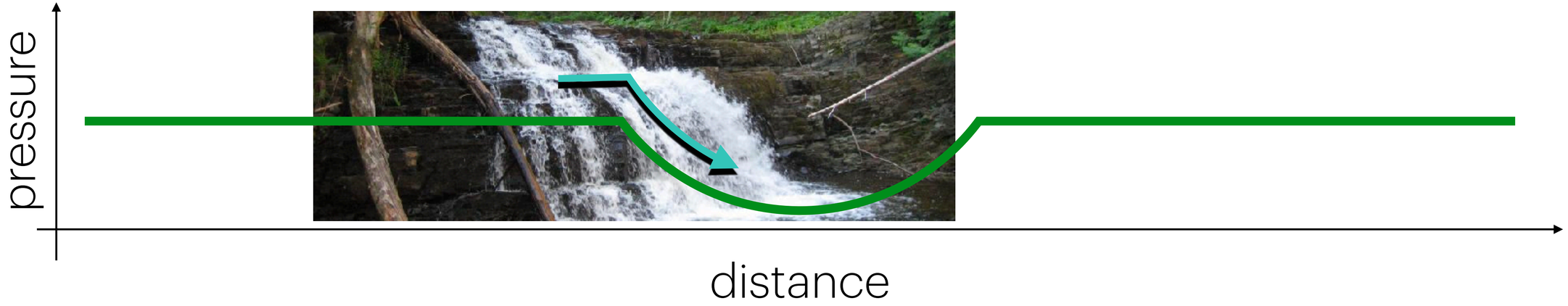


What draws fresh hot gas into the layer?

Could it be that cooling leads to a pressure dip that accelerates the material?





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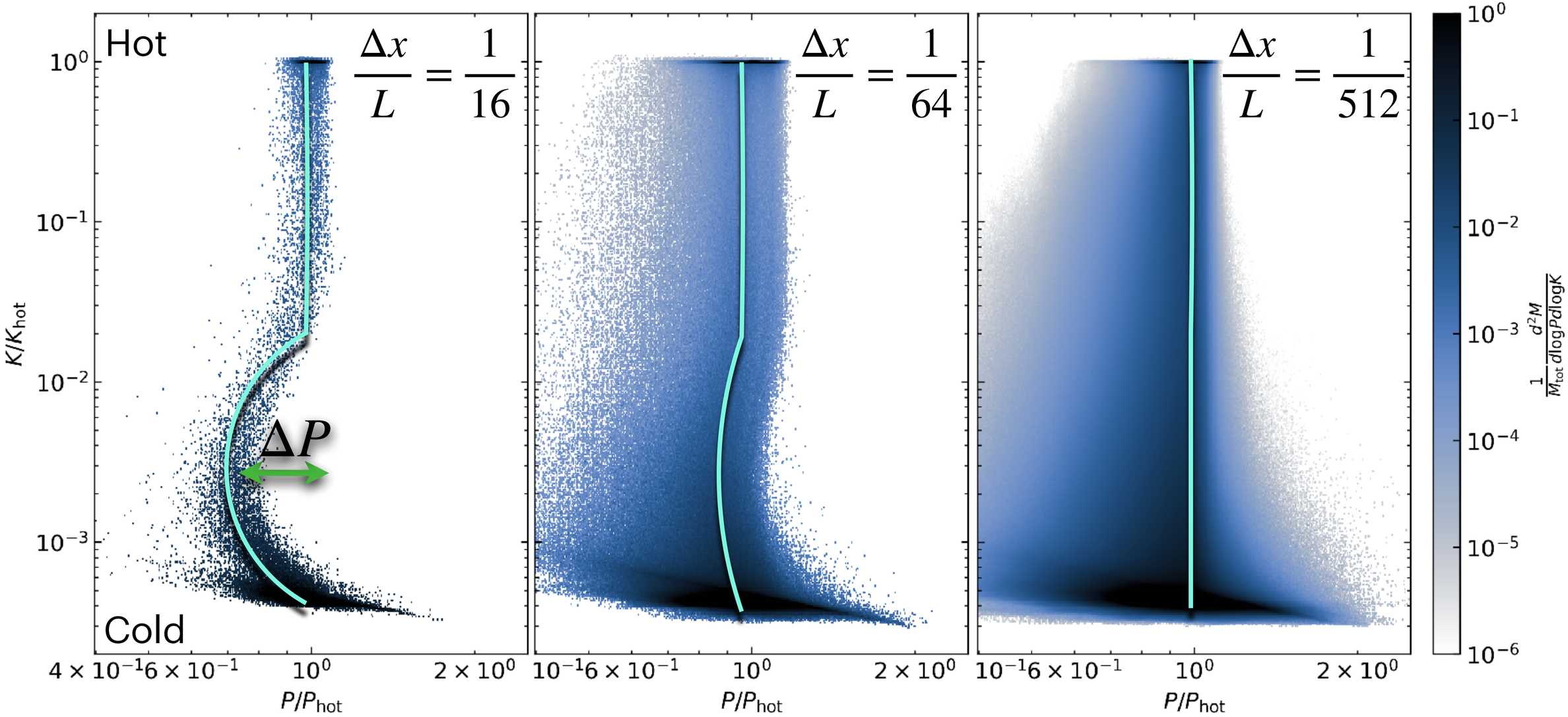
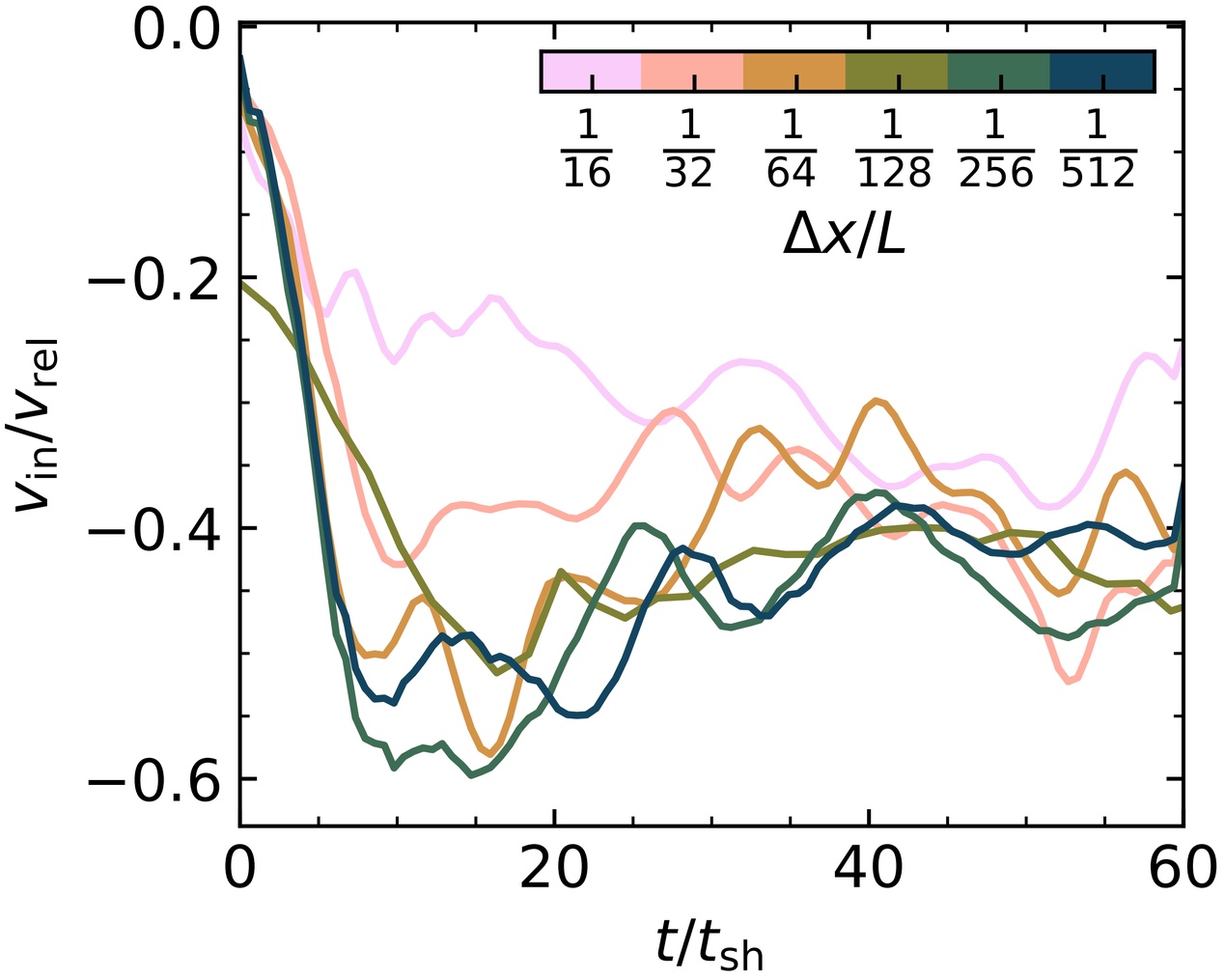
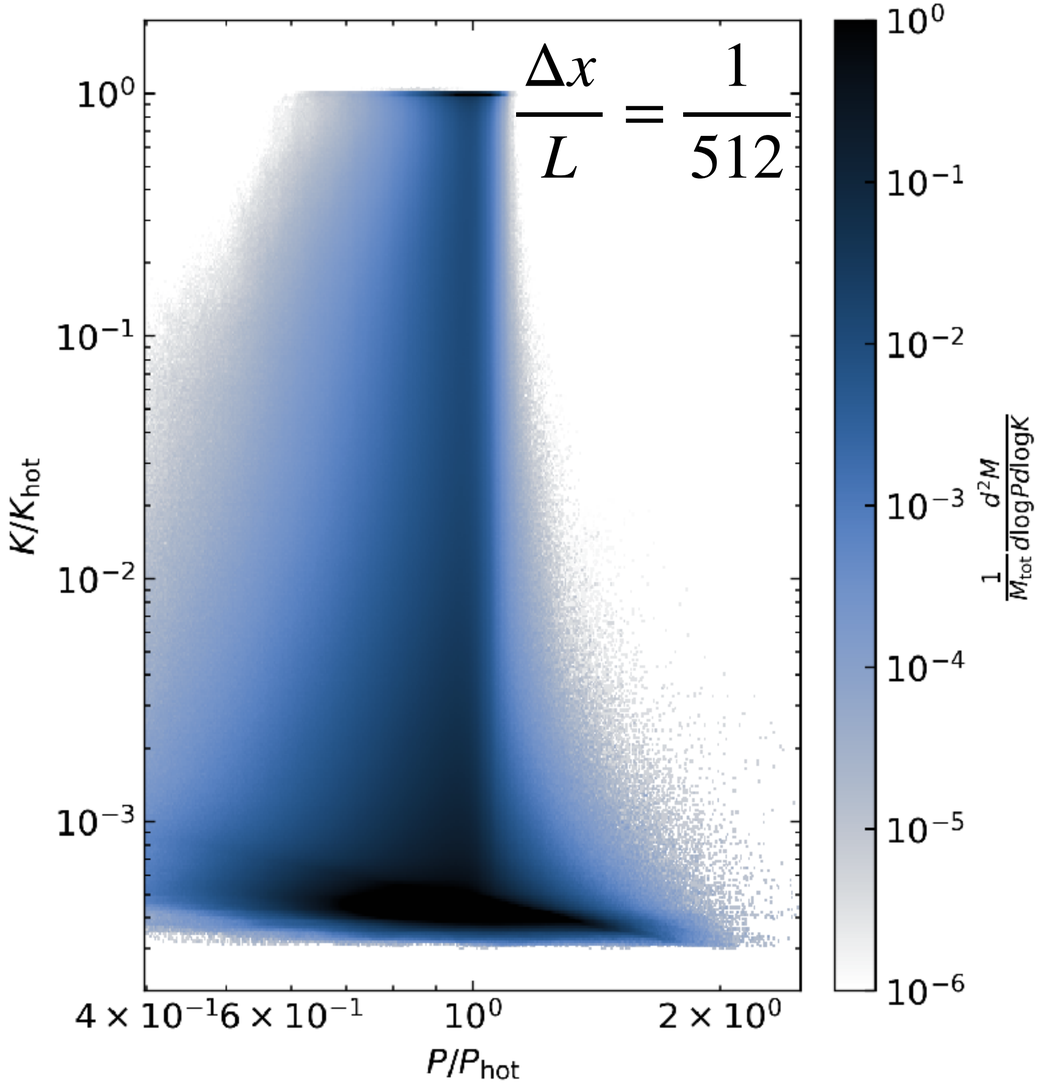


What draws fresh hot gas into the layer?

Pressure dip disappears at high resolution but inflow does not!





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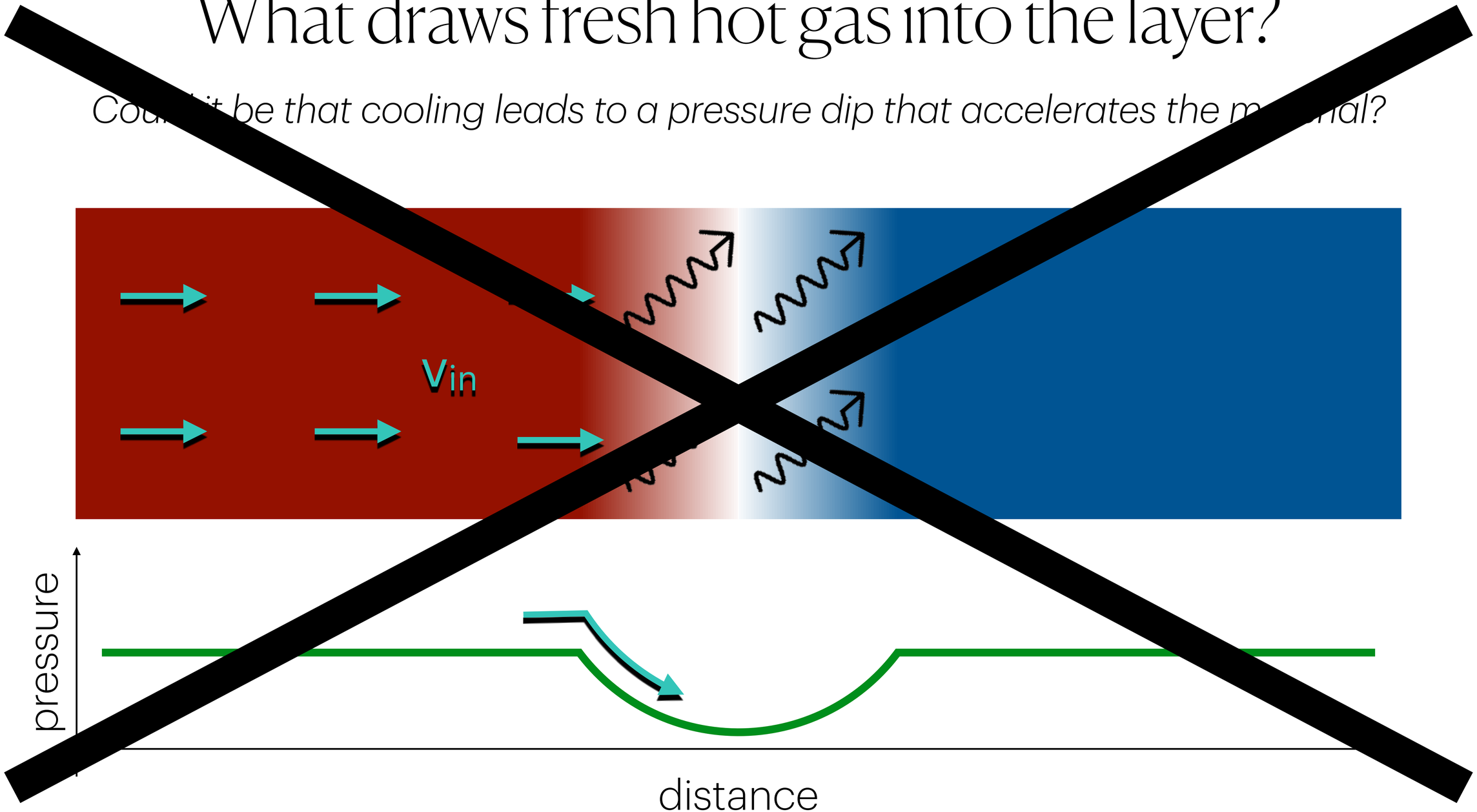
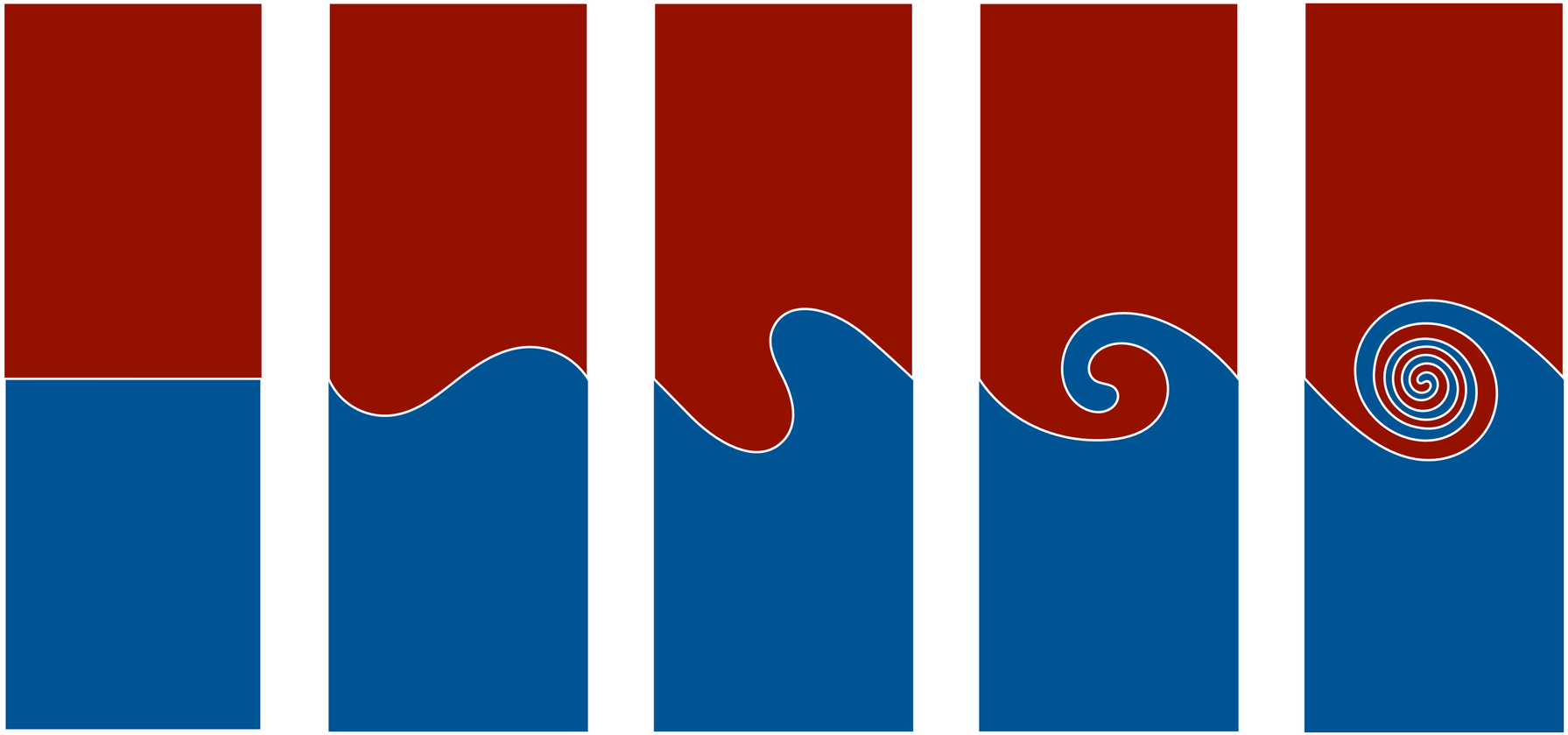
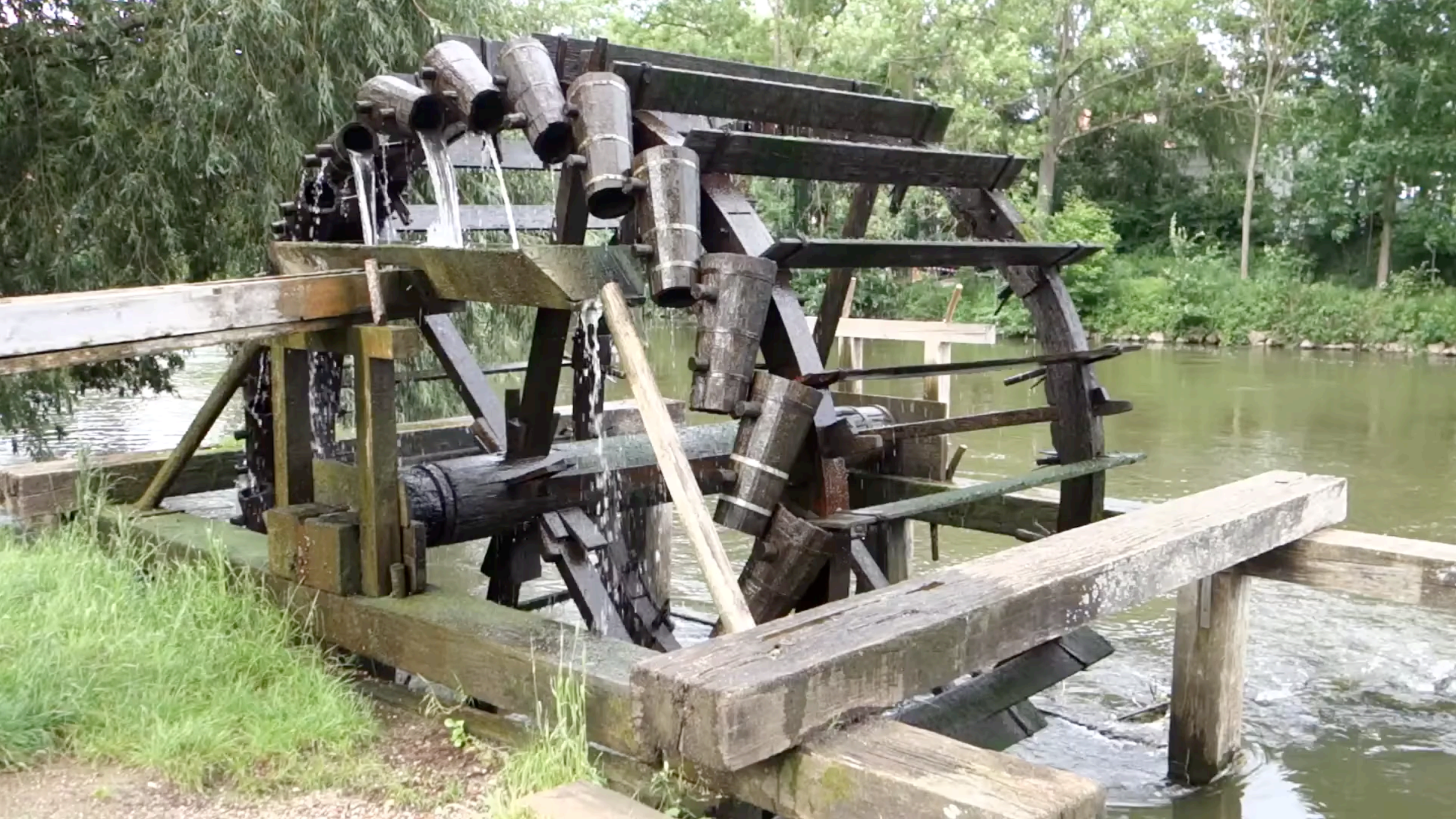


What draws fresh hot gas into the layer?

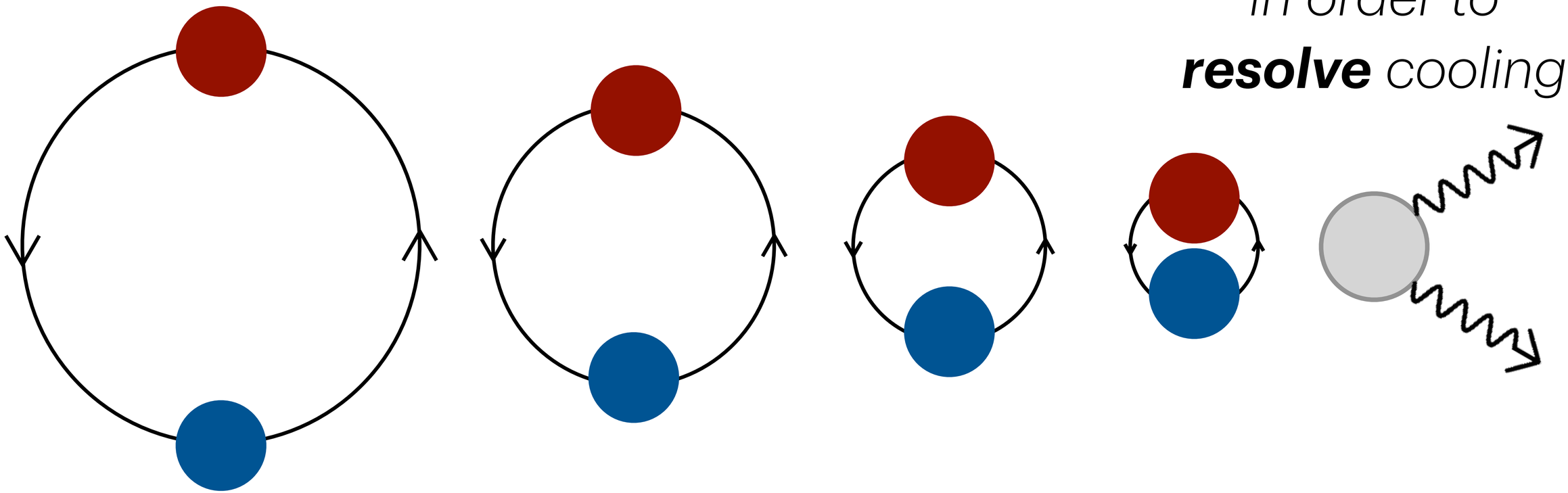
Turbulent mixing rate determines the radiative cooling rate



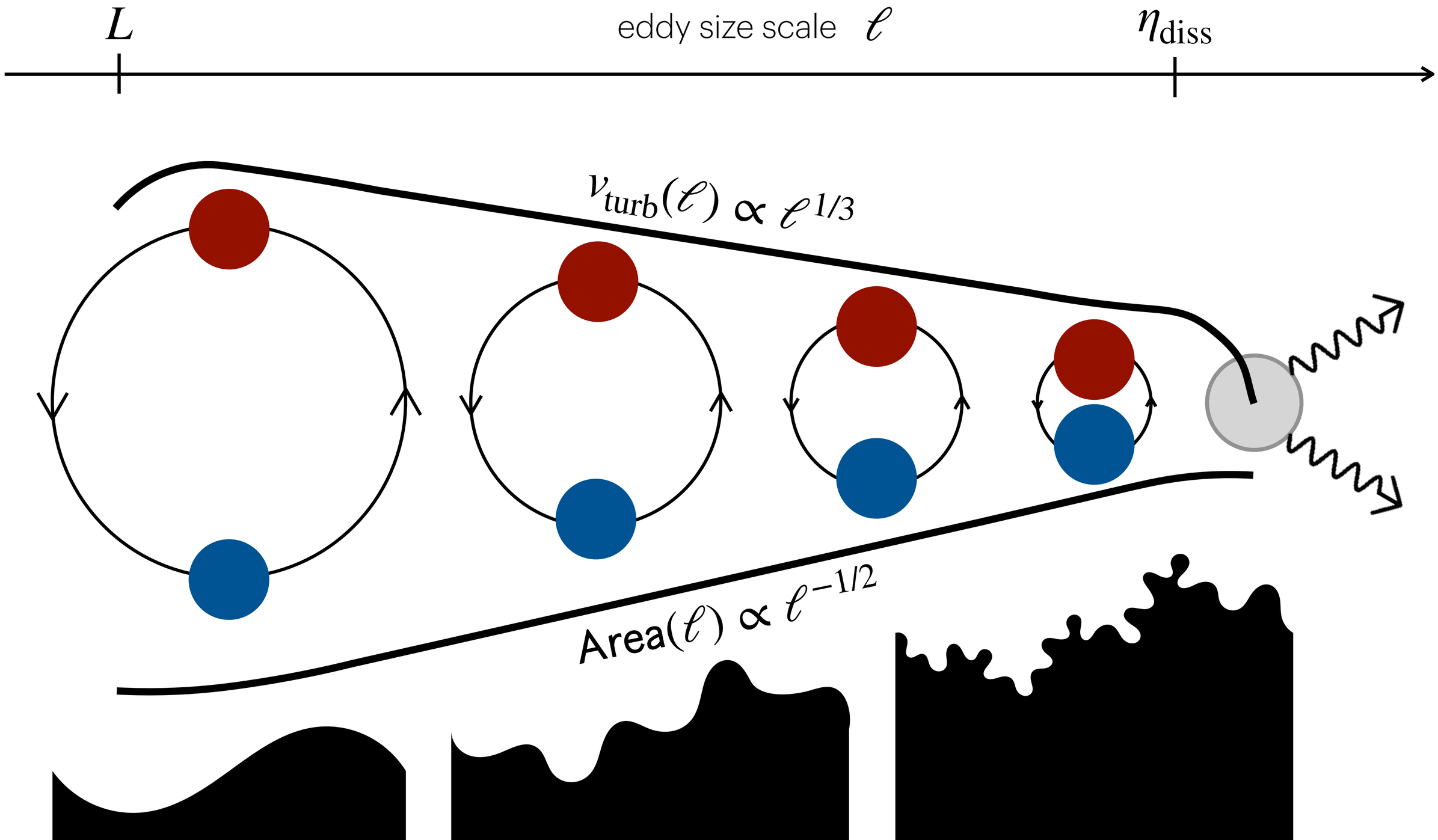


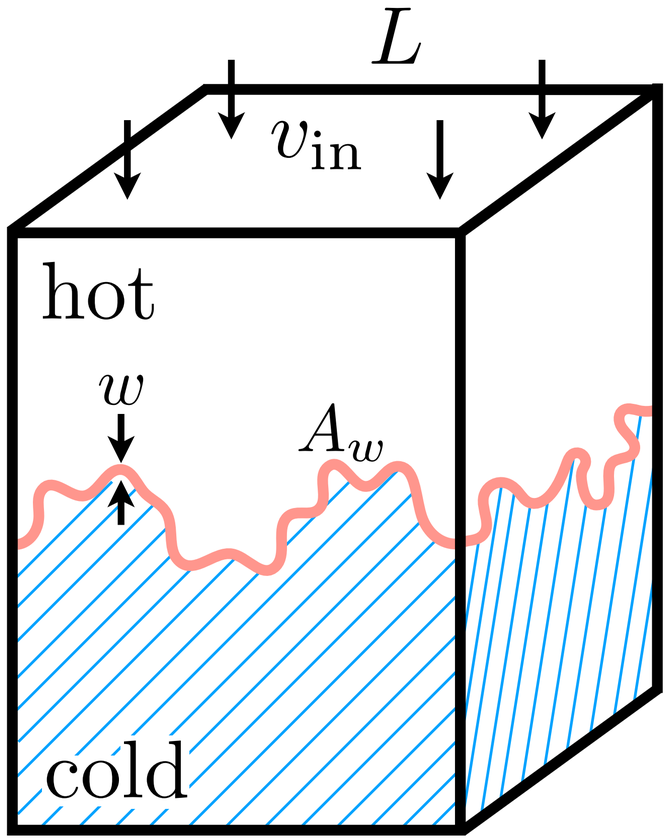
*need to **resolve** turbulent mixing*

*in order to **resolve** cooling*



** *and thereby capture the correct mass, momentum & energy transfer since cooling sets the inflow rate*


L
eddy size scale ℓ
η_{diss}
$v_{\mathrm{turb}}(\ell) \propto \ell^{1/3}$
$\mathrm{Area}(\ell) \propto \ell^{-1/2}$



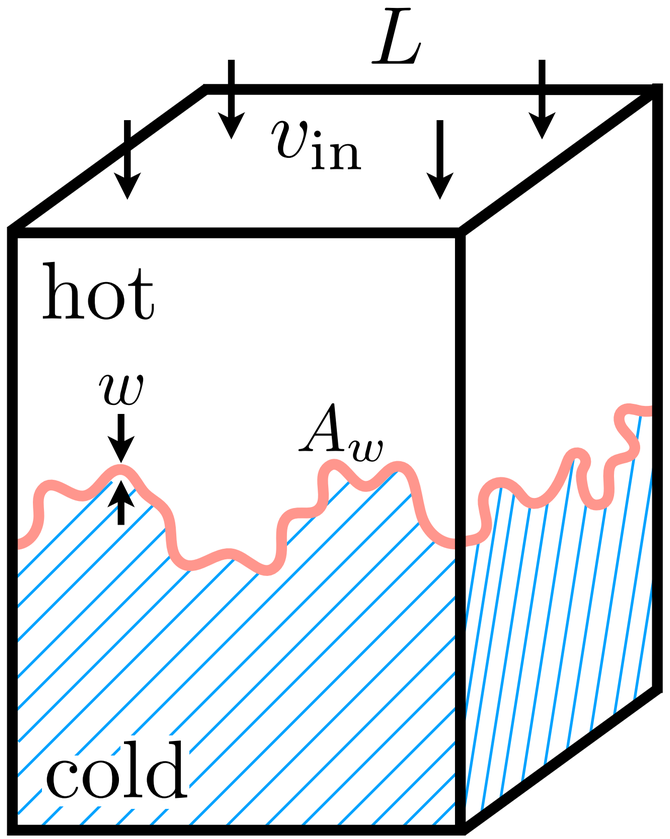
enthalpy flux

$$P v_{\mathrm{in}} L^2$$

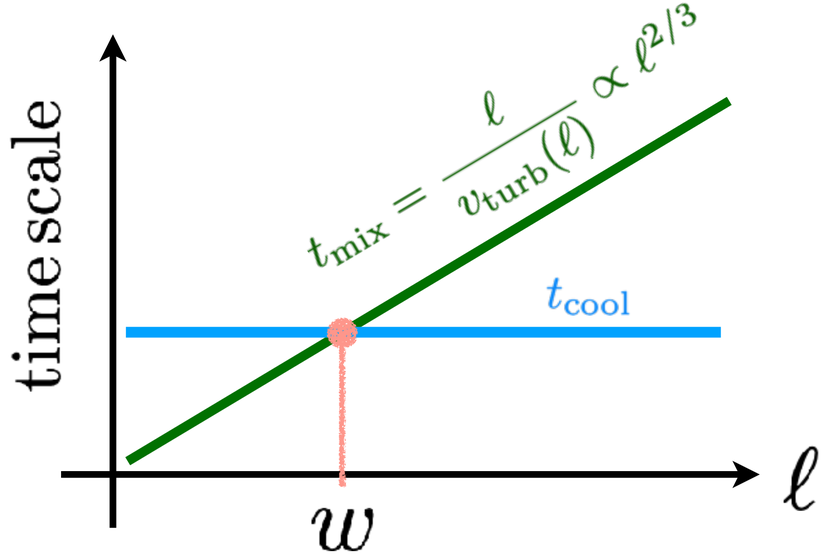
$$v_{\mathrm{in}} = \frac{w}{t_{\mathrm{cool}}} \frac{A_w}{L^2}$$

total cooling

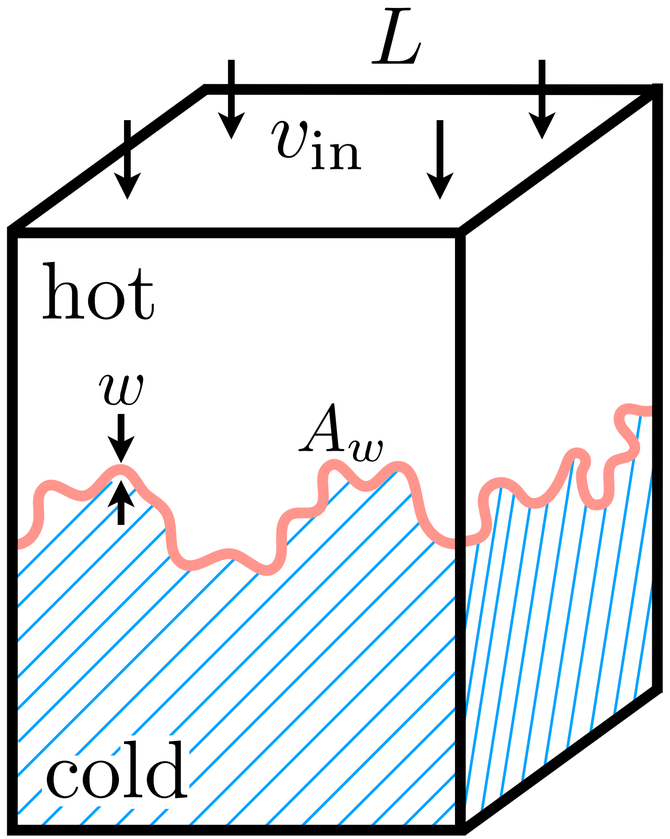
$$\frac{P}{t_{\mathrm{cool}}} w A_w$$



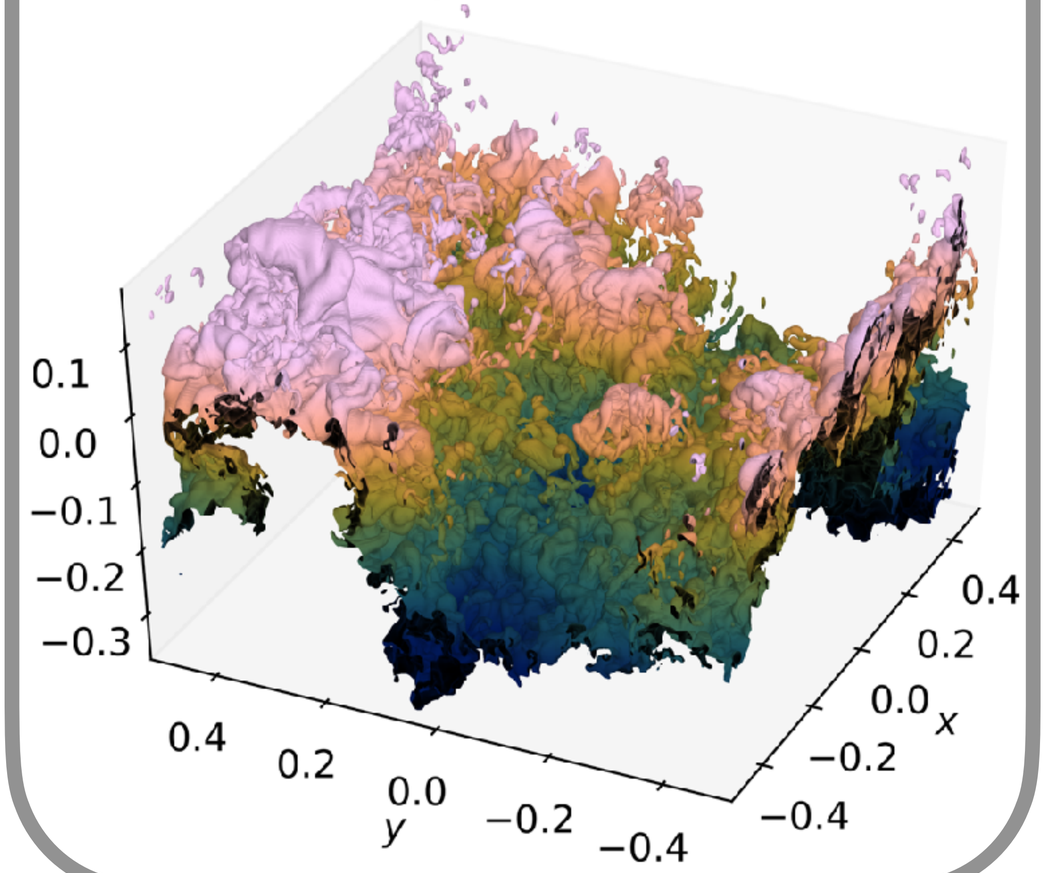
w | **hot gas is mixed in at the same rate that it cools**

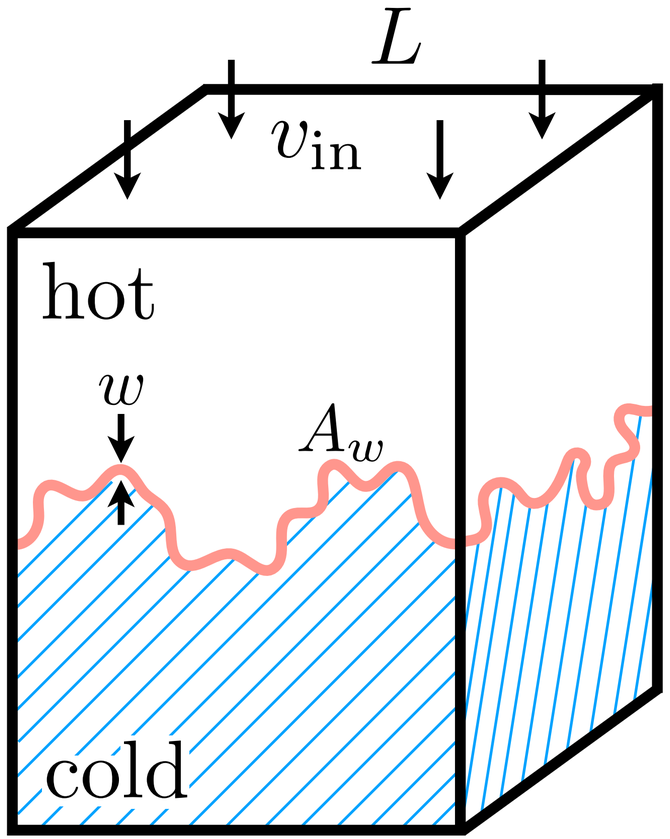


$$\frac{w}{L} = \left(\frac{v_{\rm turb,L} t_{\rm cool}}{L} \right)^{3/2}$$



A_w | surface area of the cooling volume





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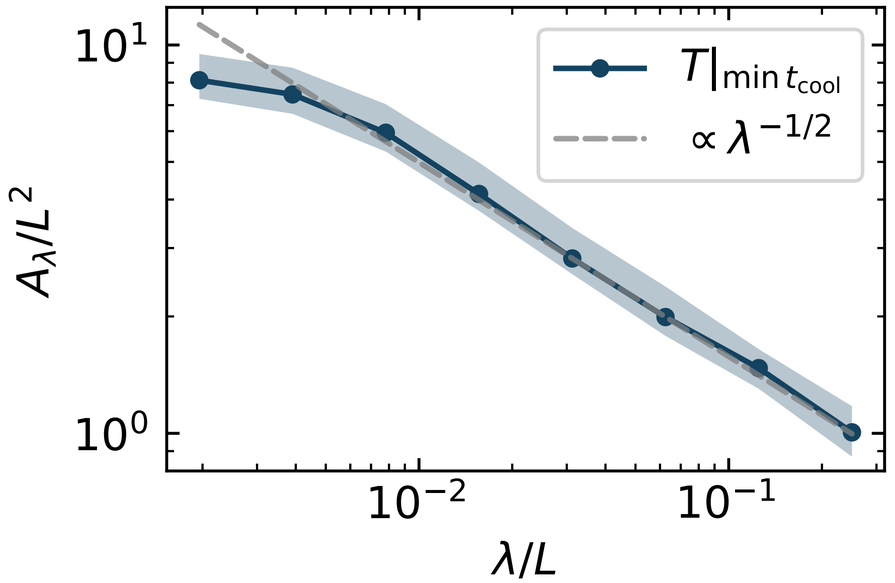
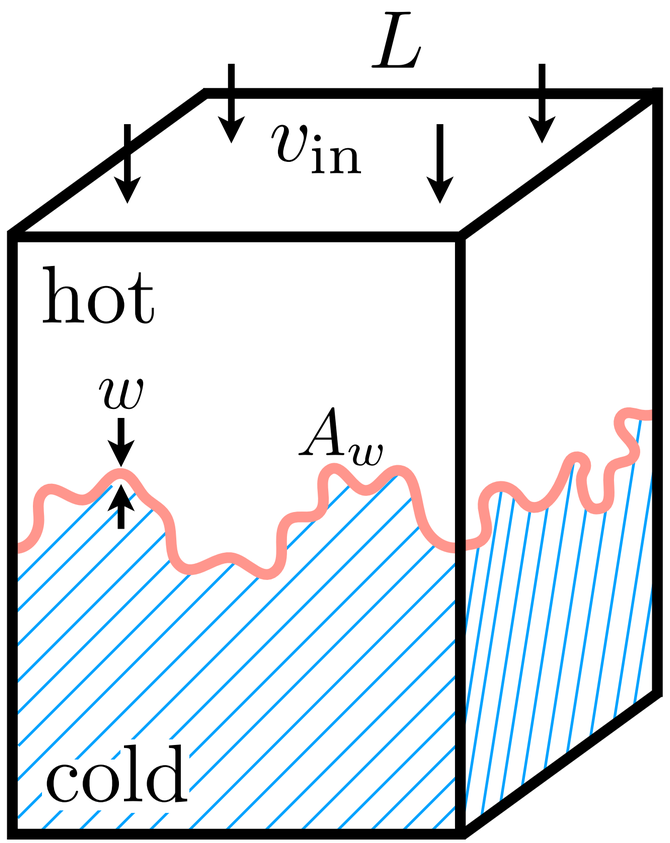
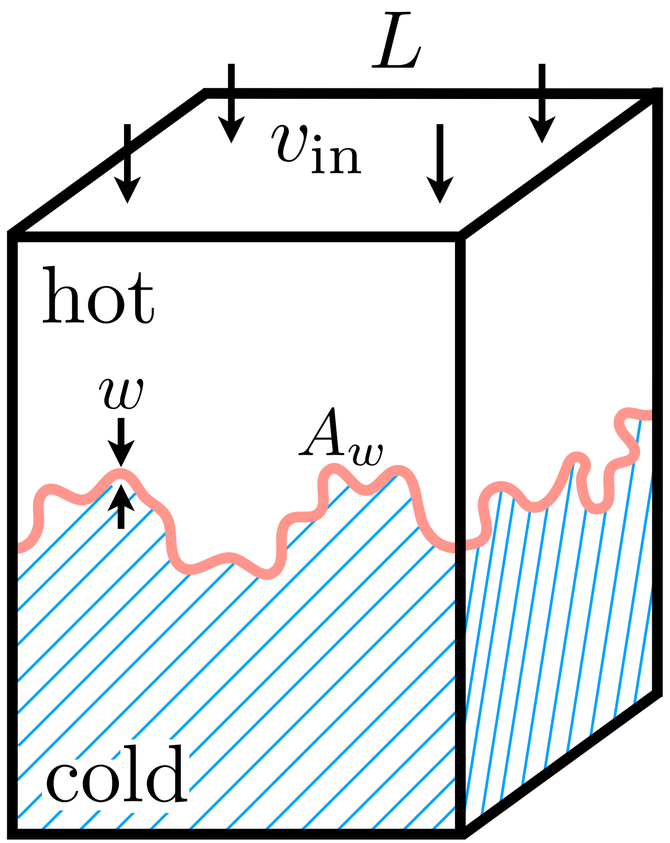


$$\frac{A_w}{L^2} = \left(\frac{w}{L}\right)^{-1/2}$$



v_{in} | **inflow rate of fresh hot material into mixing layer**

$$v_{\text{in}} = \frac{w}{t_{\text{cool}}} \frac{A_w}{L^2}$$



$v_{\rm in}$ | **inflow rate of fresh hot material into mixing layer**

$$\frac{v_{\rm in}}{v_{\rm turb,L}} = \left(\frac{L}{v_{\rm turb,L} t_{\rm cool}} \right)^{\frac{1}{4}}$$

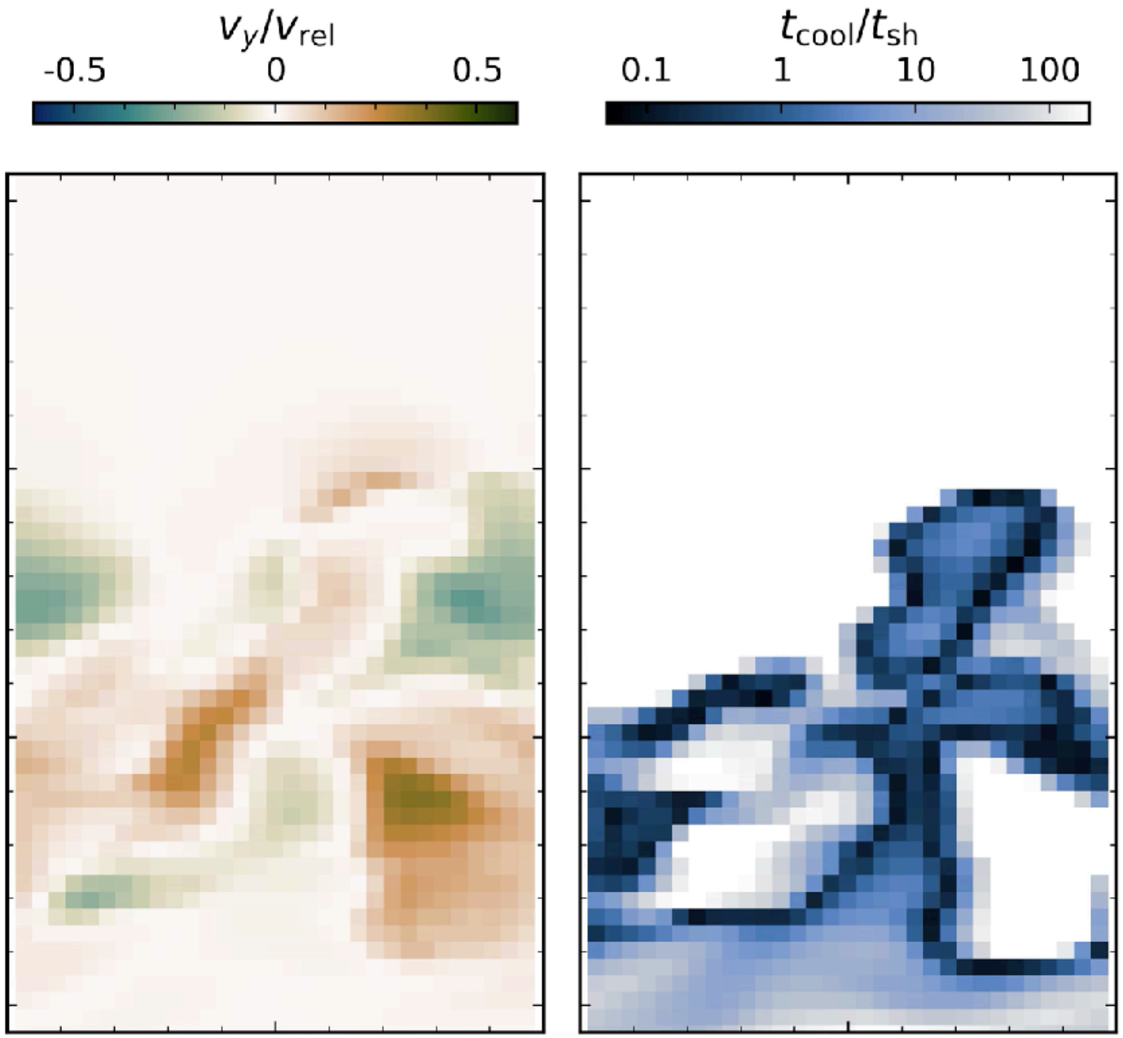
$$\dot{M} \approx \rho L^2 v_{\rm in}$$

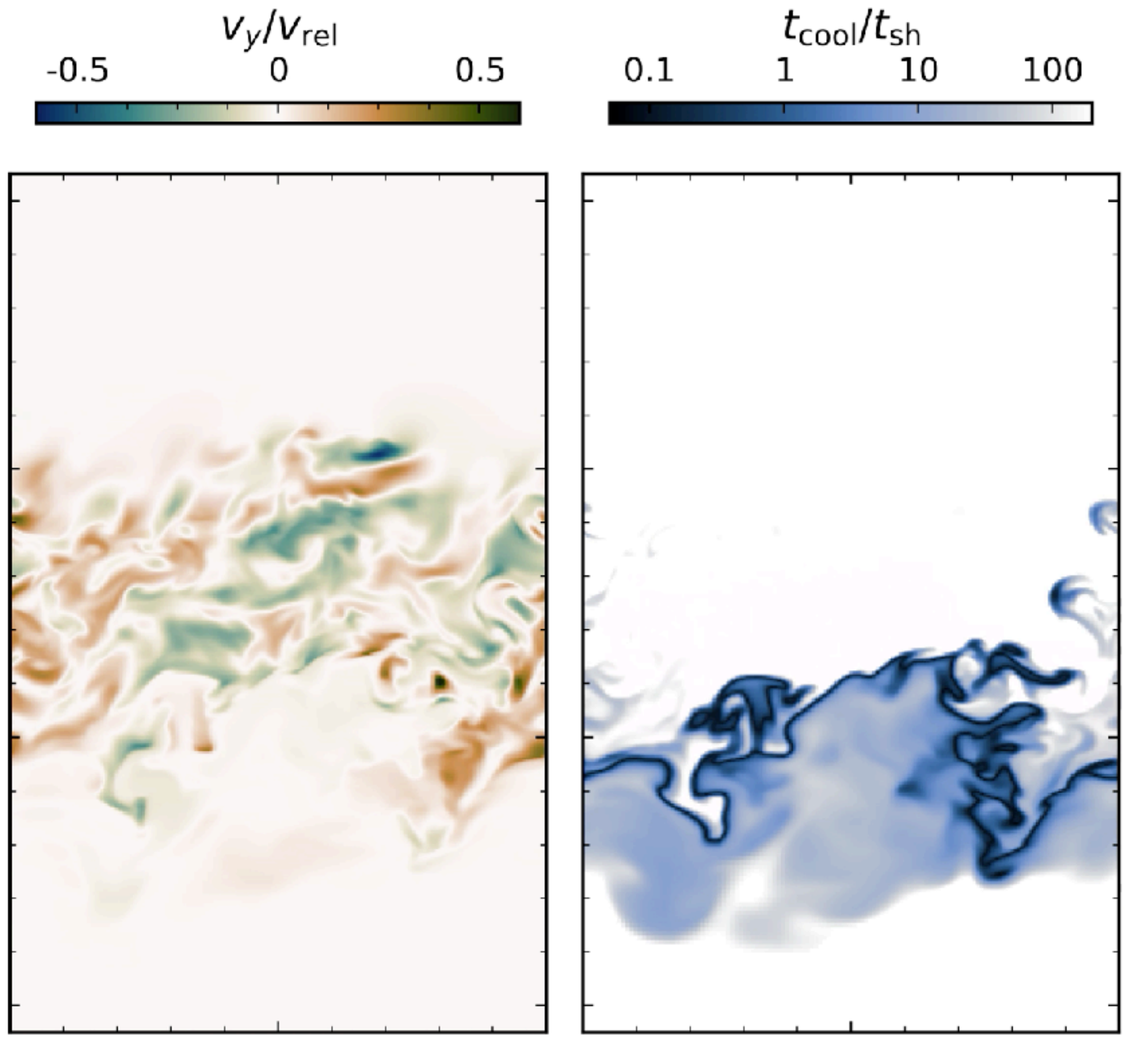
$$\dot{p} \approx \rho v_{\rm rel} L^2 v_{\rm in}$$

$$\dot{E} \approx P L^2 v_{\rm in}$$

What does it mean to *resolve* multiphase gas?

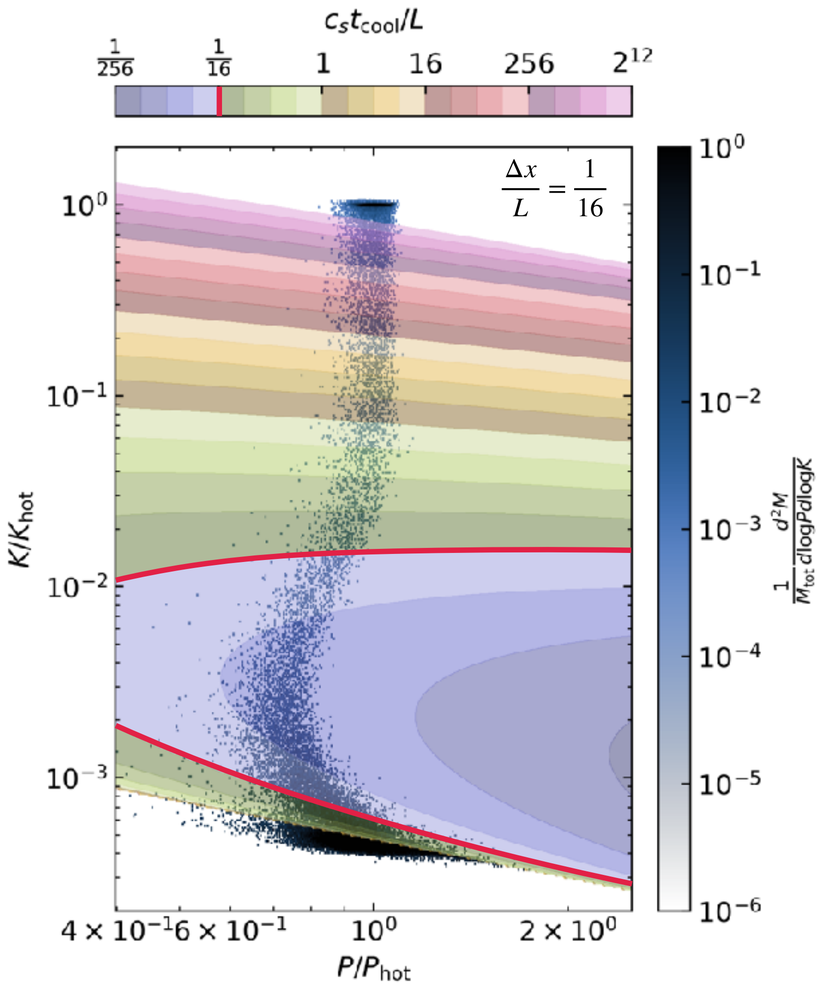
To get accurate cooling, growth, and acceleration ***resolve*** beginning of turbulent cascade

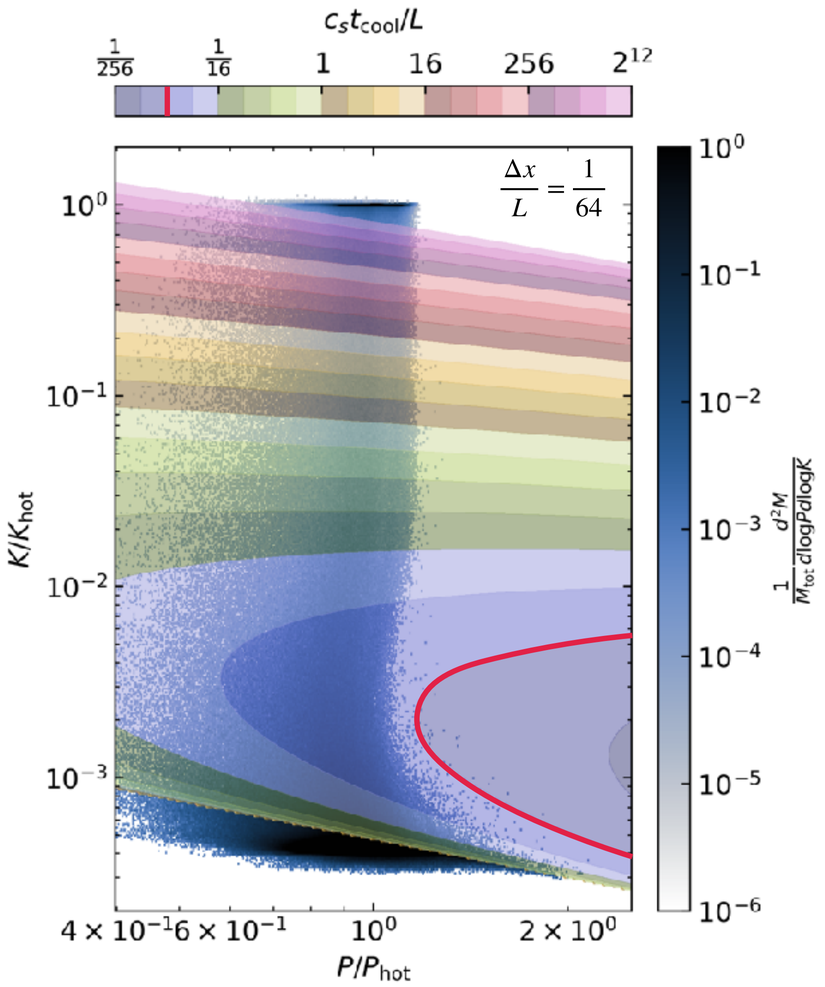


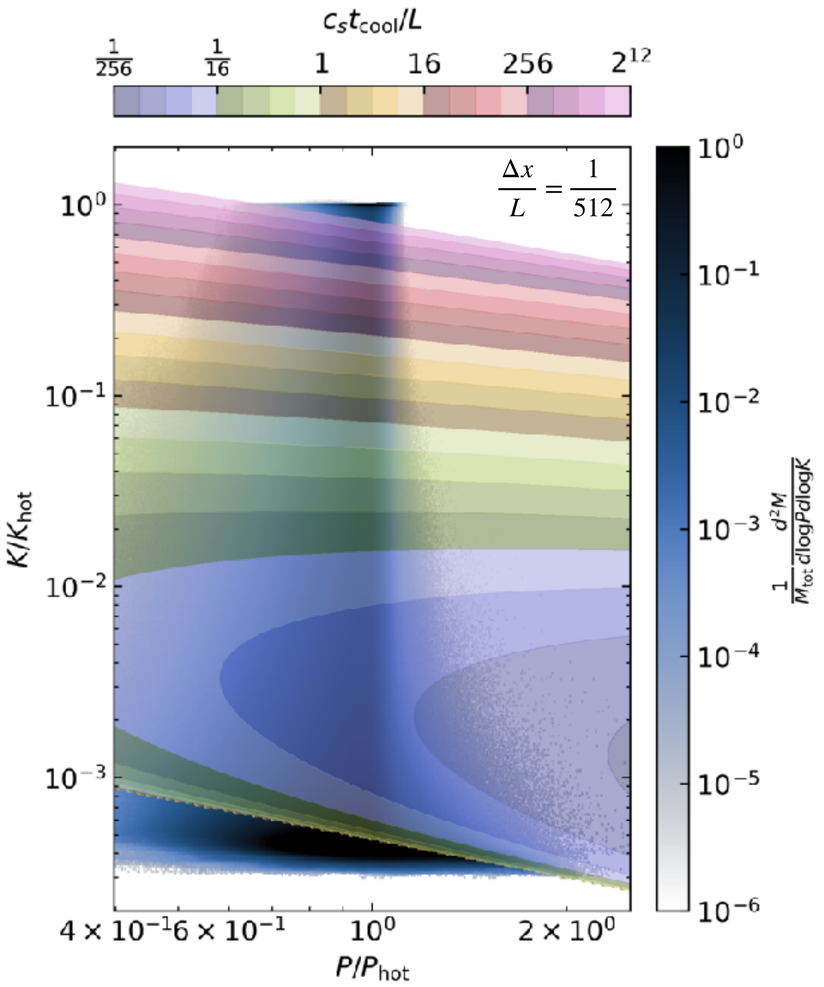


What does it mean to *resolve* multiphase gas?

To get accurate phase structure ***resolve*** cooling length







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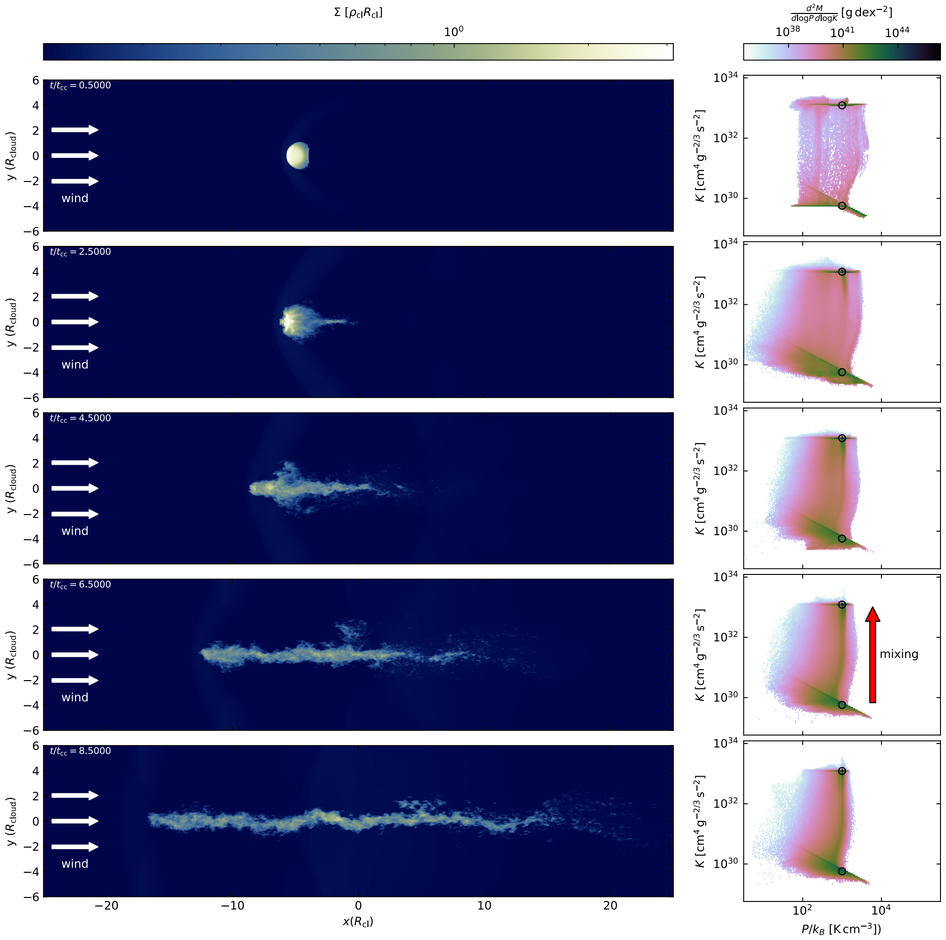
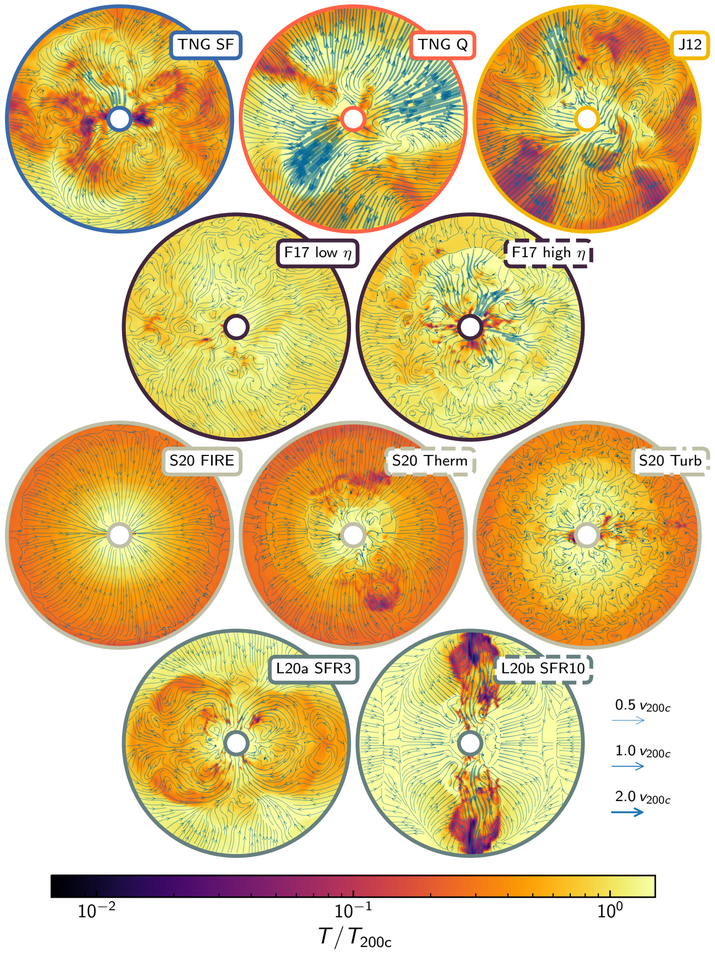
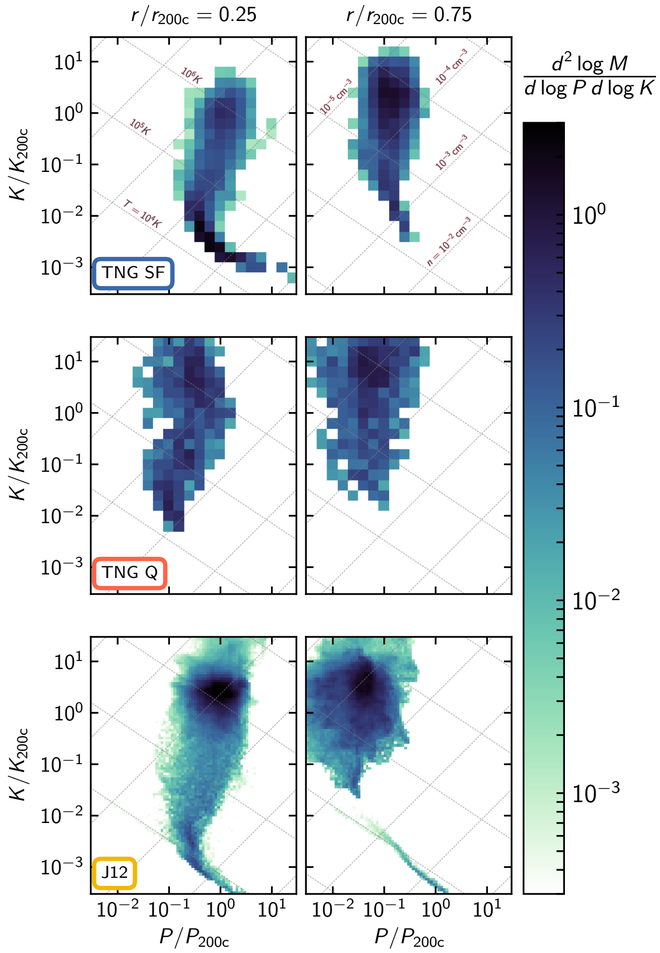


Abruzzo, Bryan, Fielding 2020





Fielding, Tonnesen, Li+ 2020b