Star Formation and Galactic Winds Regulated by Supernovae

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Computational Galaxy Formation @ Ringberg

Fundamental Question

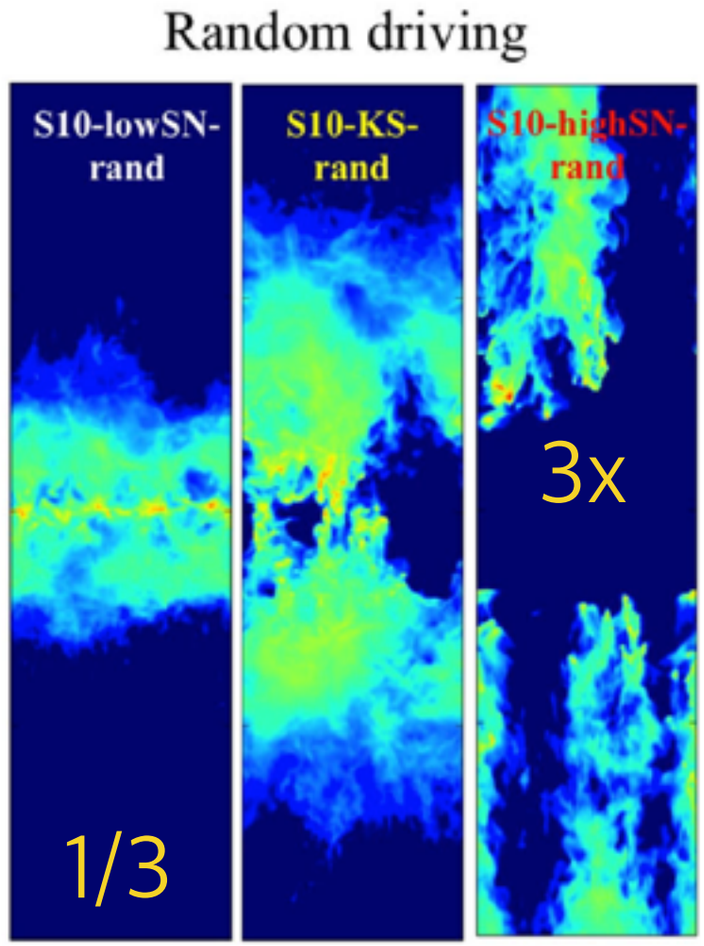
- Why do we need galactic winds?
  - blow out gas
  - quench star formation
  - because it is there
- Can SN (stellar) feedback drive galactic winds?
  - What is the mass loading factor?
  - Can it drive multiphase winds?

What is the current status?

- Large scale simulations begin to resolve individual SN (or better calibrated models for collective SN feedback)
  - Morning Talks!
  - Note: condition for convergence of SN feedback (Kim & Ostriker 15a)
- **Local box simulations for resolved individual SN with thermal energy feedback**
  - This session!
  - Importance of spatial distribution is emphasized
  - SFR (SN rate) was fixed, and ran for a short time (~100Myr)
  - CRs+MHD
- What can we learn from local box simulations?

How do SN details affect outflows?

- We now know the importance of spatial distribution of SNe (Gatto+14;Walch+15;Girichidis+16)

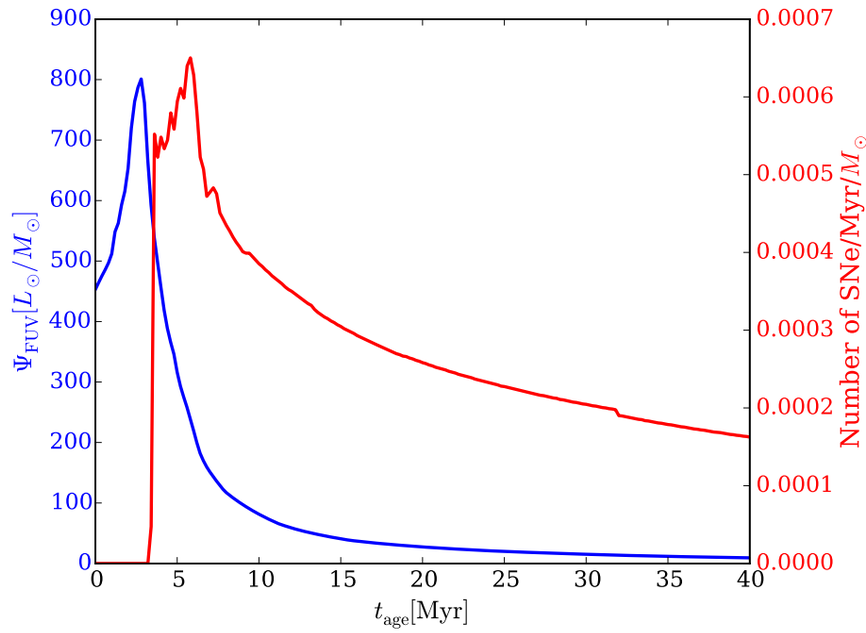


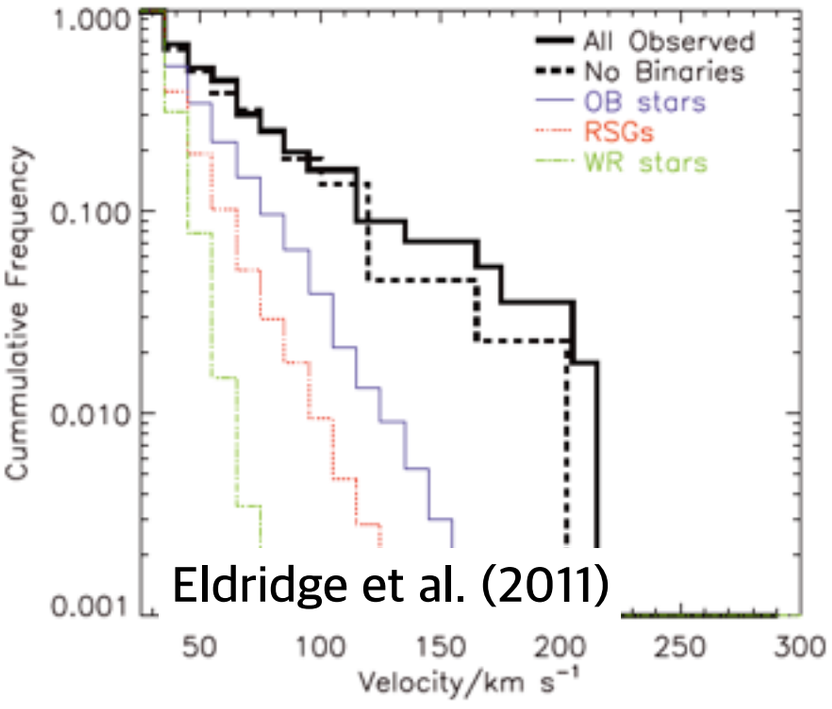
Walch+15

- Self-consistent temporal correlation of SNe does matter too!

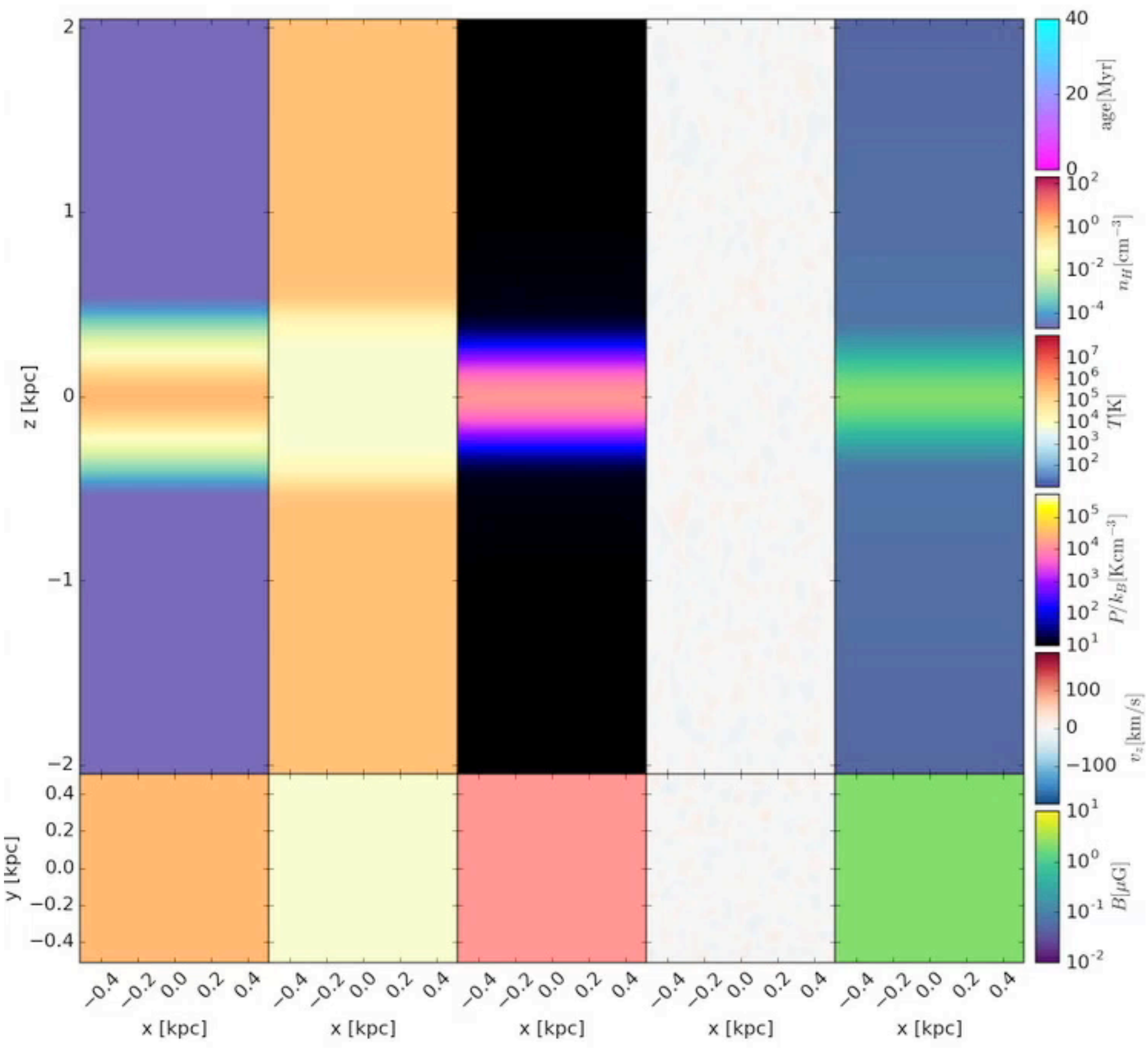
What are “the goods” of our simulations?

- **Self-consistent feedback from time-varying SFR**
  - Clusters: STARBURST99, fully sampled IMF, lifetime of 40Myr
  - Runaways: binary runaways, 1/3 of SNe
  - Resolved SN Feedback events (~90% in thermal energy; ~10% in momentum)
  - FUV heating (no radiative transfer)
- Magnetic fields with galactic differential rotation (Kim & Ostriker 15b)
- Long term evolution to reach self-regulated state (~$2t_{orb}$~450Myr)





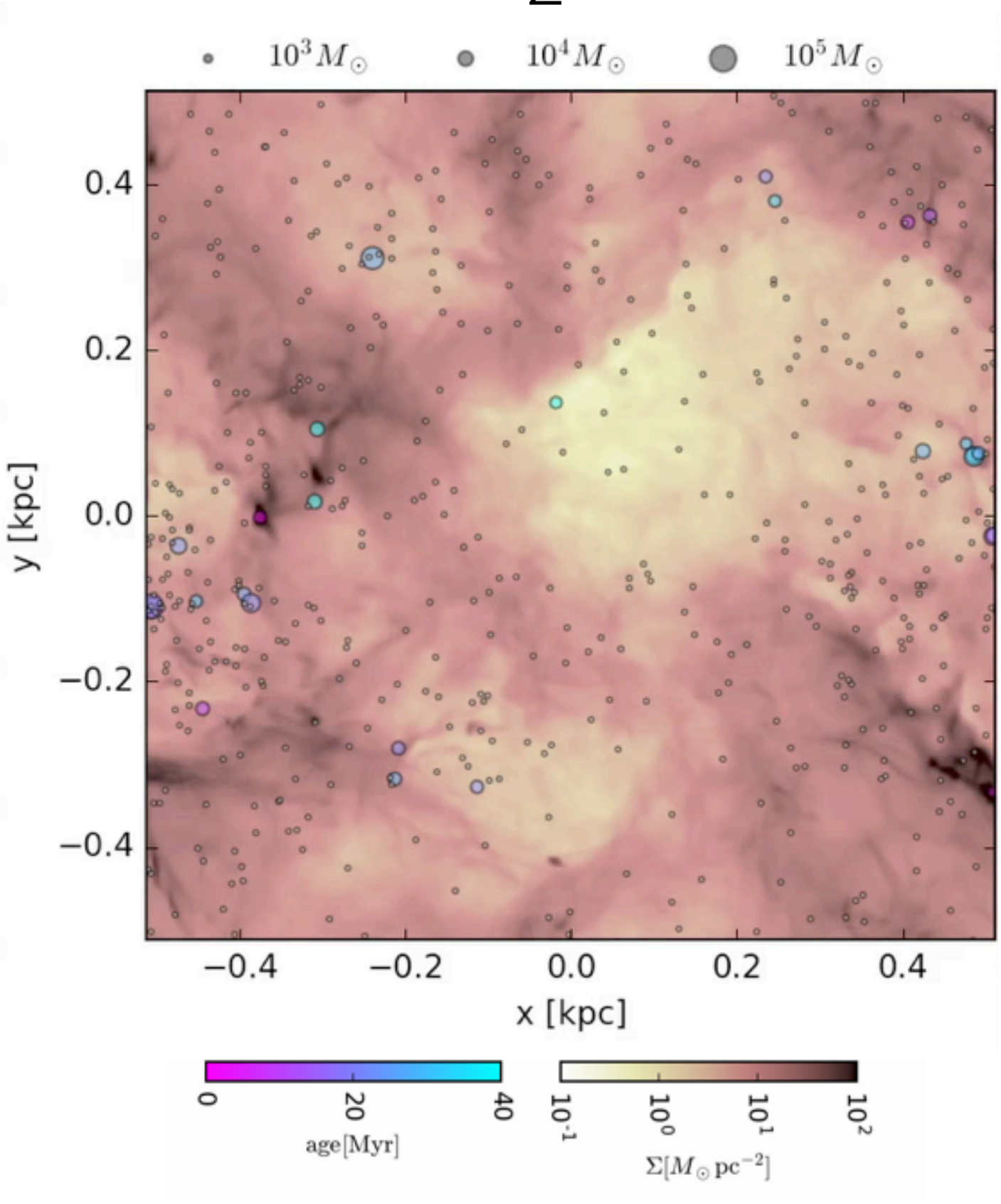
n_H T P/k_B v_z B



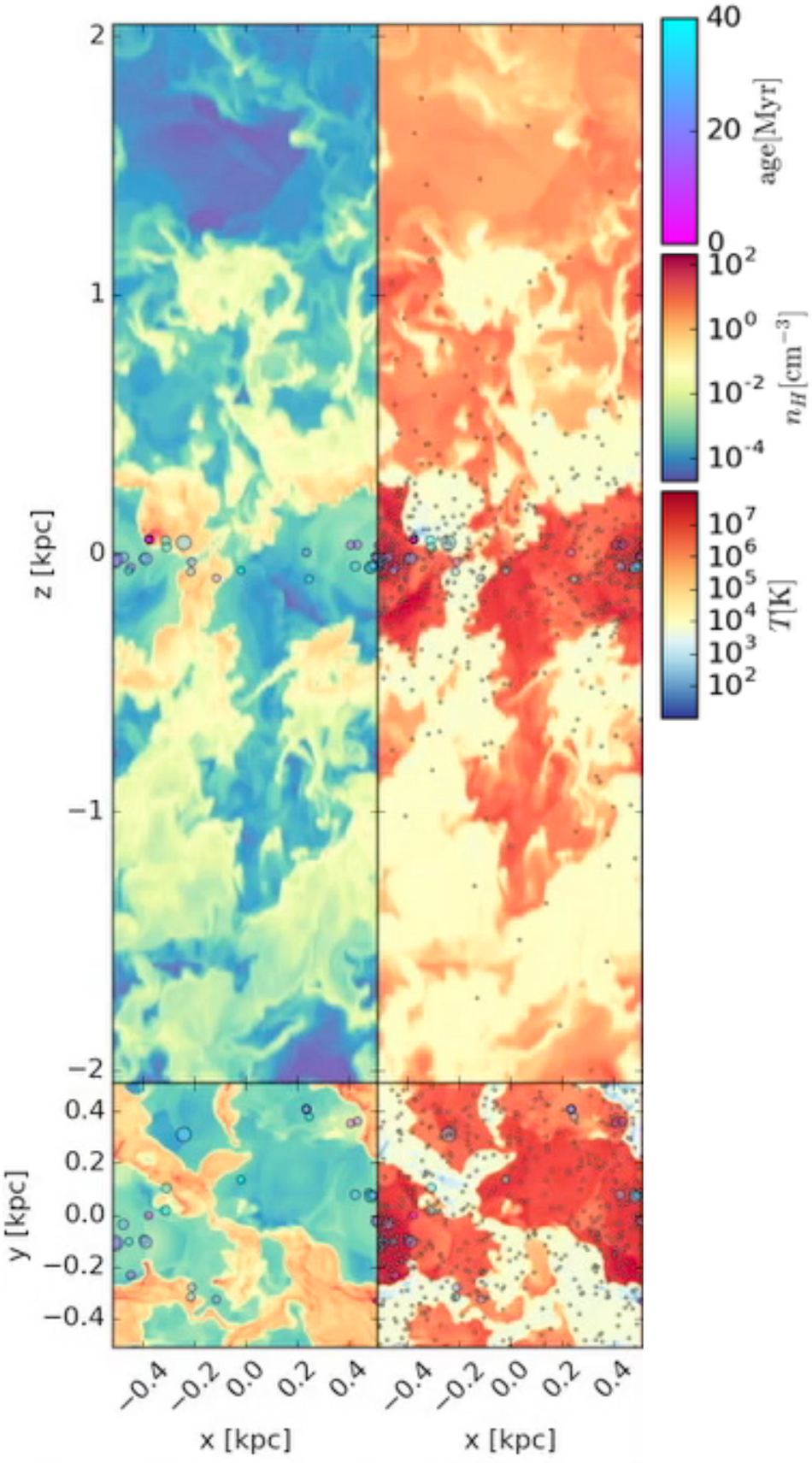
Solar nbhd.
Σ~10M_{sun}/pc^2
L_x=L_y~1kpc
L_z~4kpc
dx=4pc

Athena MHD
uniform grid

Σ

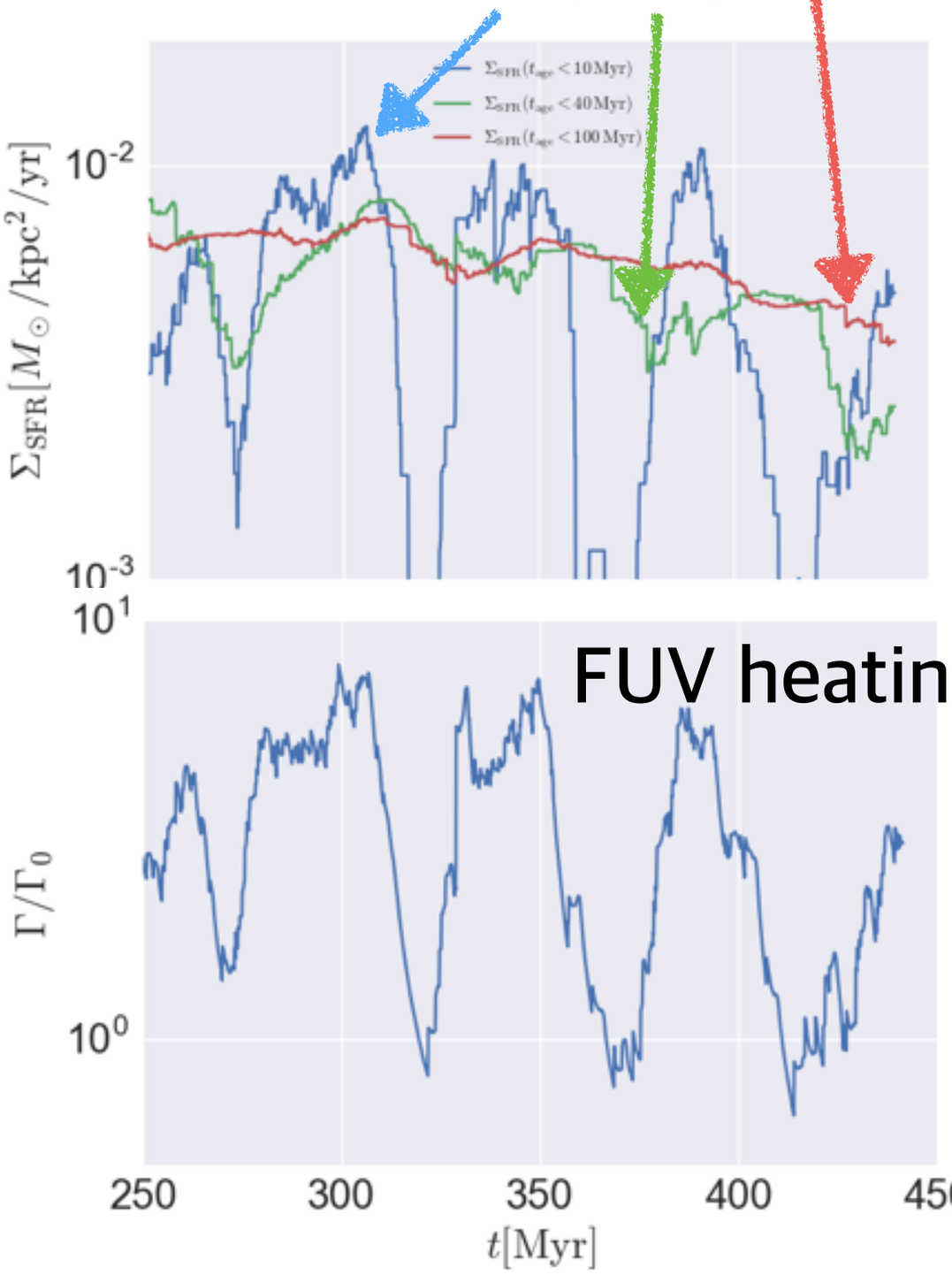

$10^3 M_\odot$
$10^4 M_\odot$
$10^5 M_\odot$
y [kpc]
x [kpc]
age[Myr]
$\Sigma[M_\odot\,\mathrm{pc}^{-2}]$

n_H T

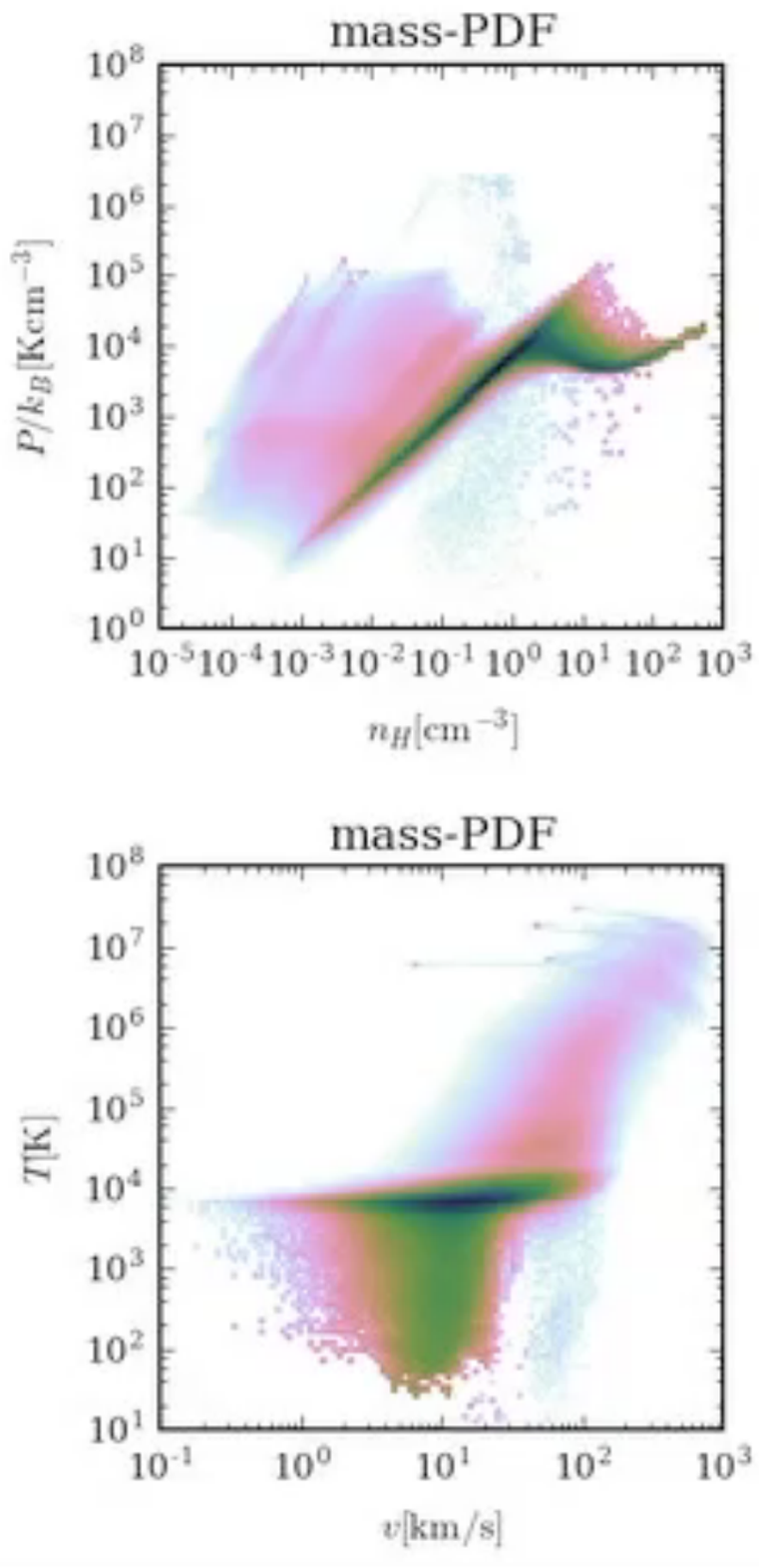

z [kpc]
y [kpc]
x [kpc]
x [kpc]
age[Myr]
$n_H[\mathrm{cm}^{-3}]$
T[K]

SFR is self-regulated!

SFR for last 10, 40, 100 Myr



FUV heating

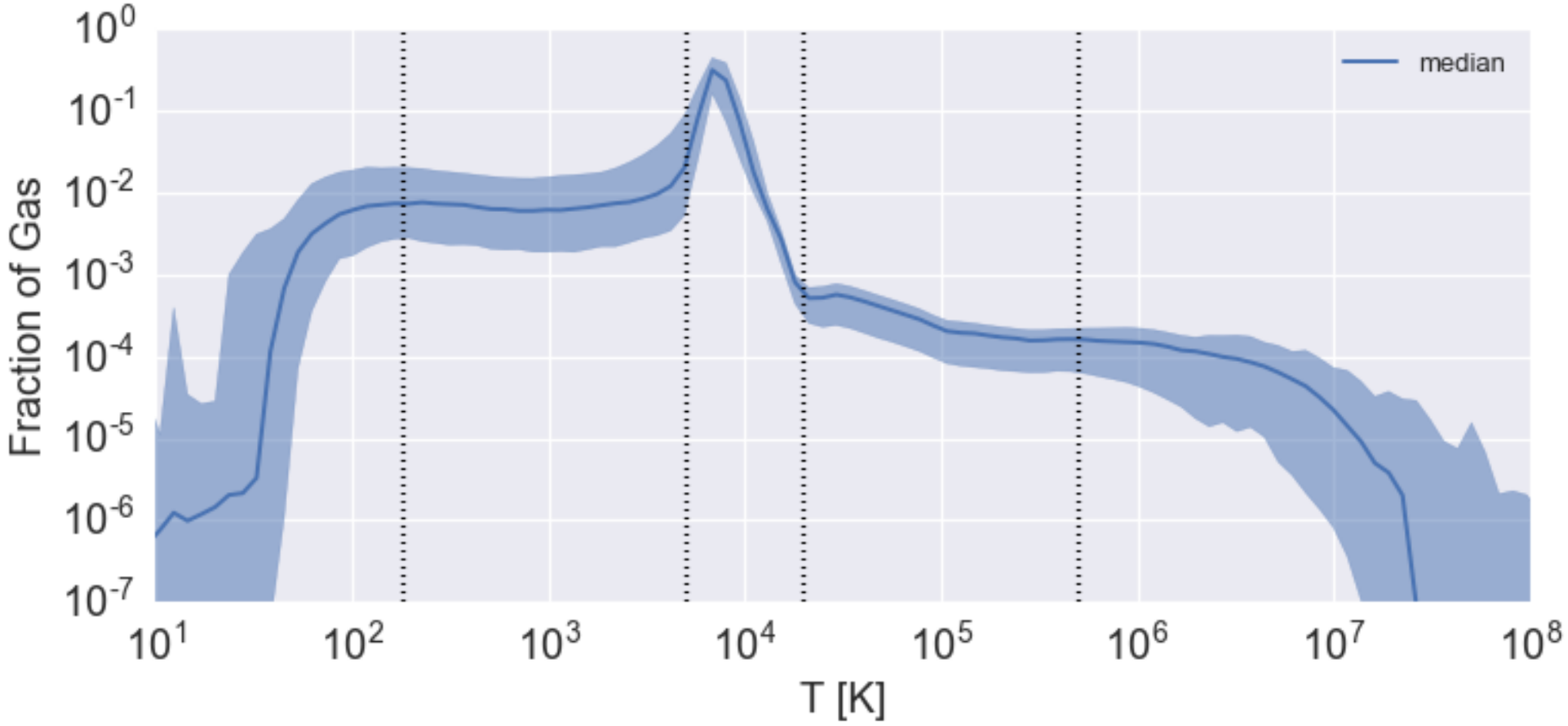


Multi-Phase ISM

two-phase
warm/cold
cool

WHIM

hot



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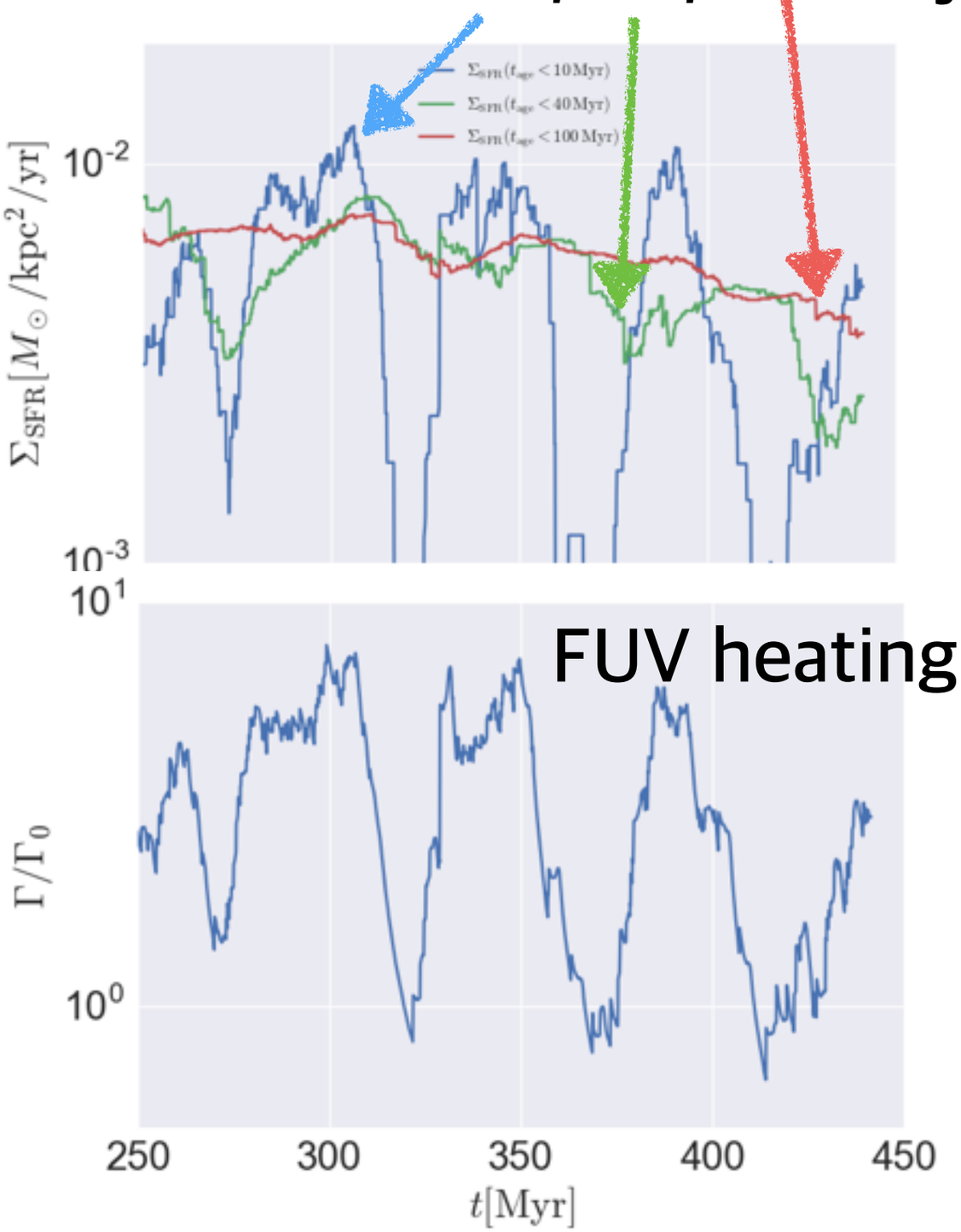
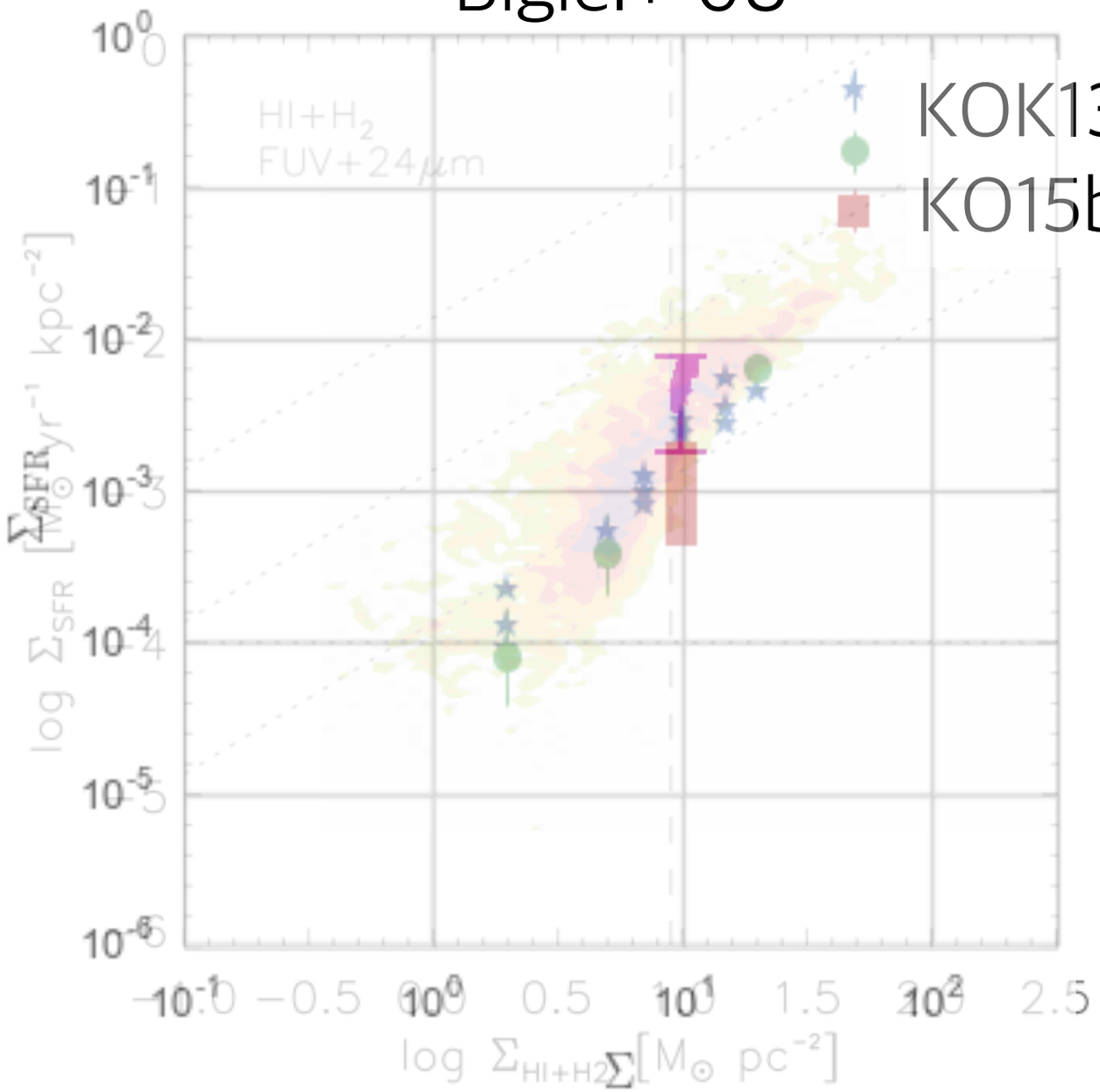


Bigiel+ 08



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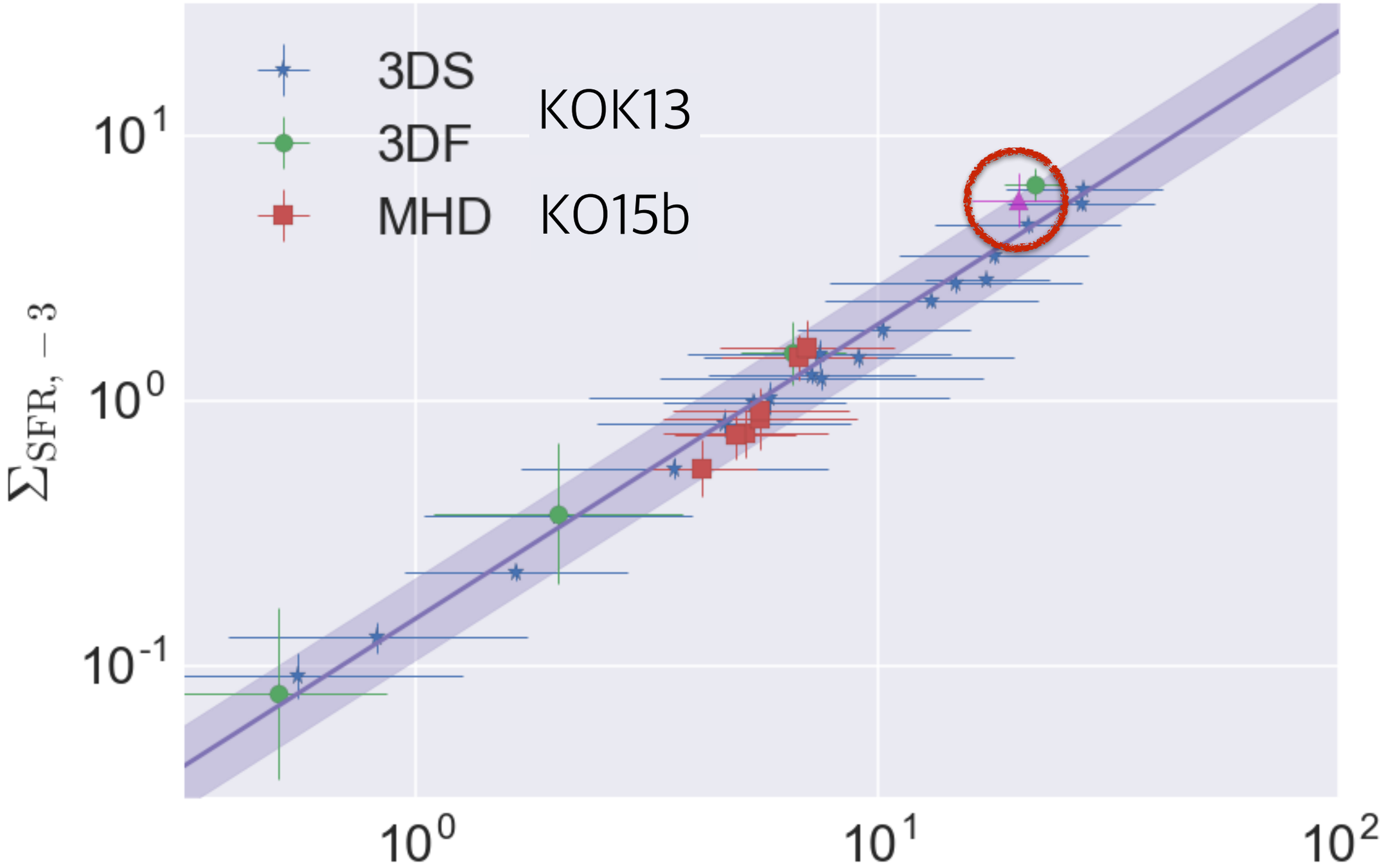
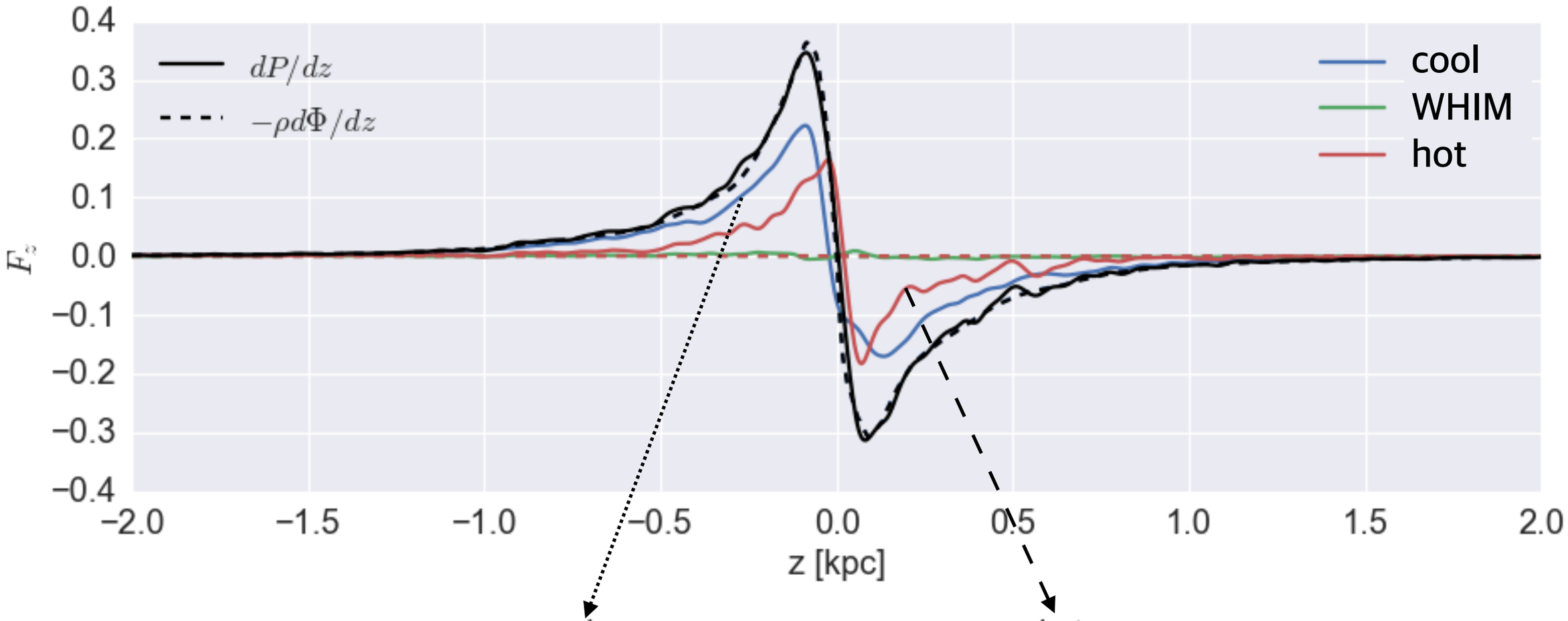
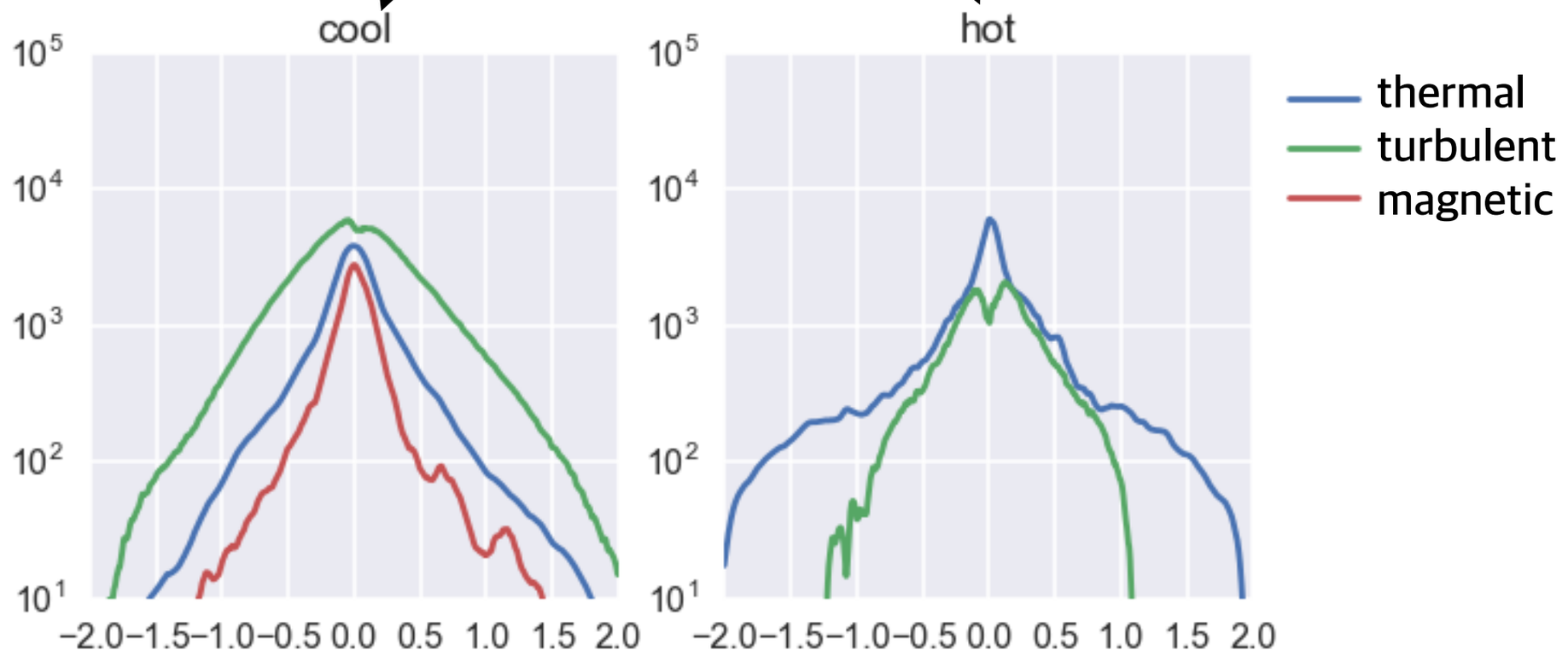


Vertical Dynamical Equilibrium: Force Balance



Pressure/k_B

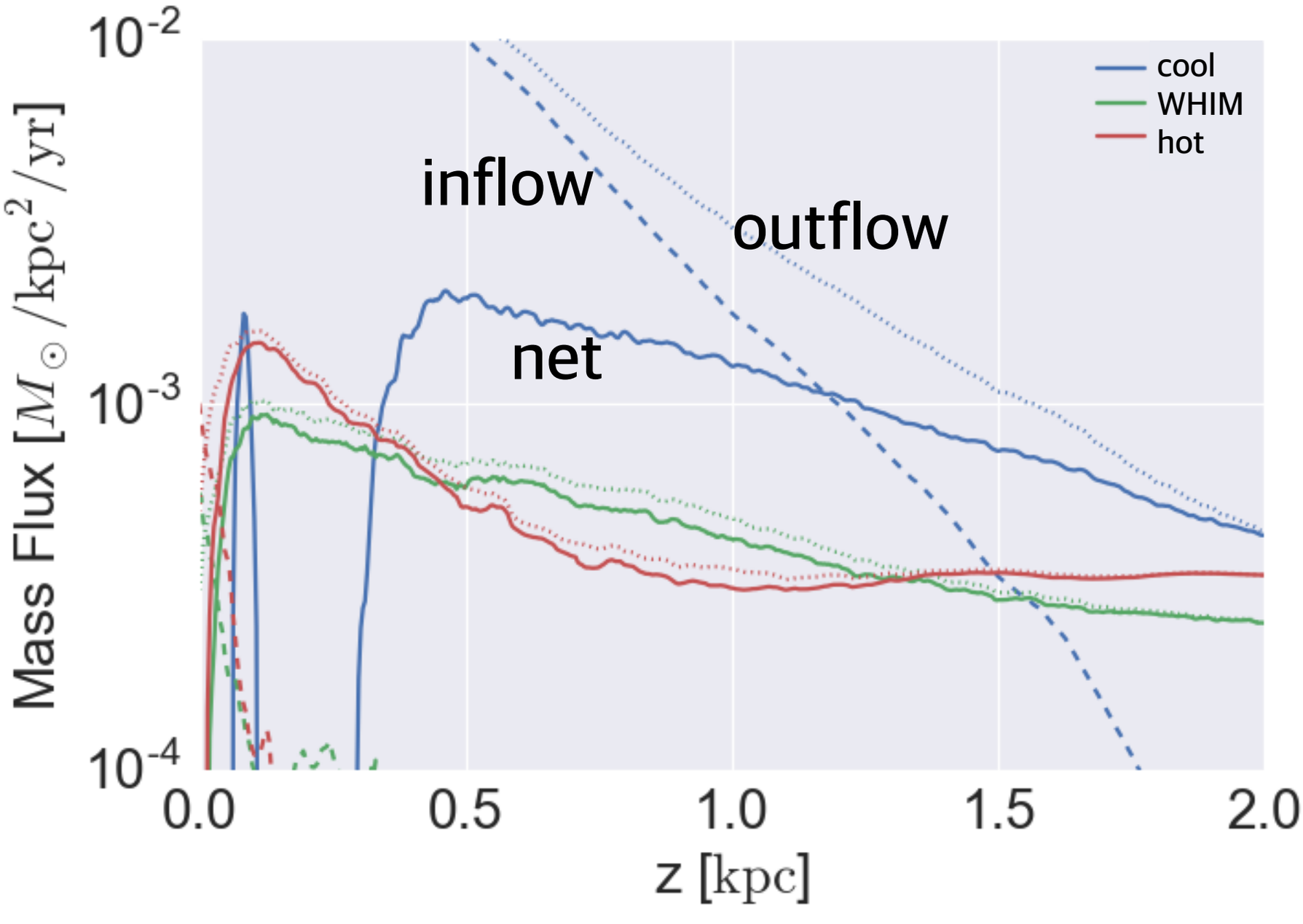


SNe drive Hot Winds!

steady, adiabatic **hot winds** launched at |z|~1kpc

—> $\langle \rho v_z \rangle$ is nearly constant in z

cool gas (+WHIM) fountain —> inflow/outflow



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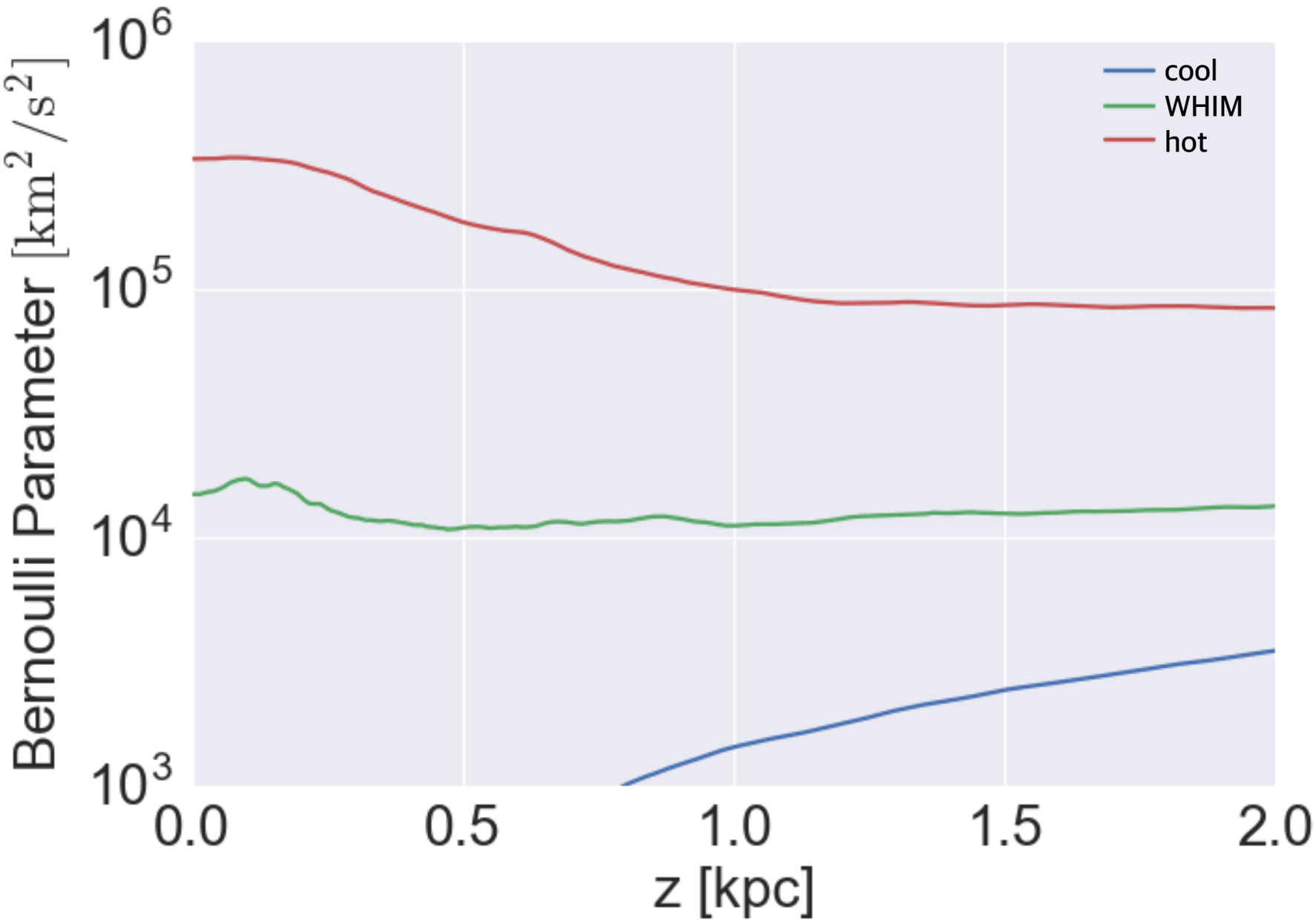
steady, adiabatic **hot winds** launched at |z|~1kpc

$\langle \mathcal{B} \rangle \sim \langle v^2/2 + \gamma P/(\gamma-1)\rho + \Phi \rangle$ is nearly constant in z

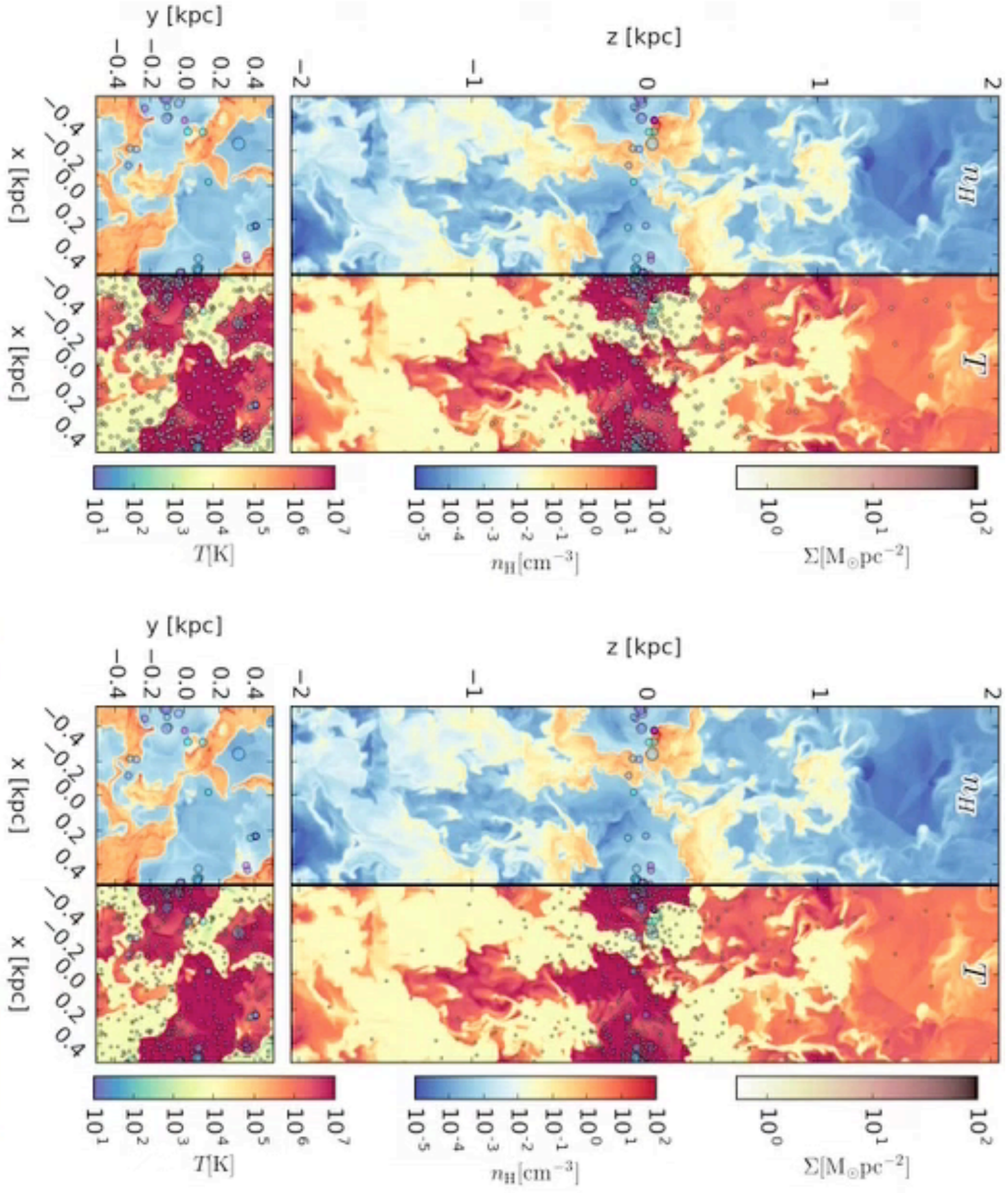
(or along streamlines in global geometry)



SNe drive Hot Winds!

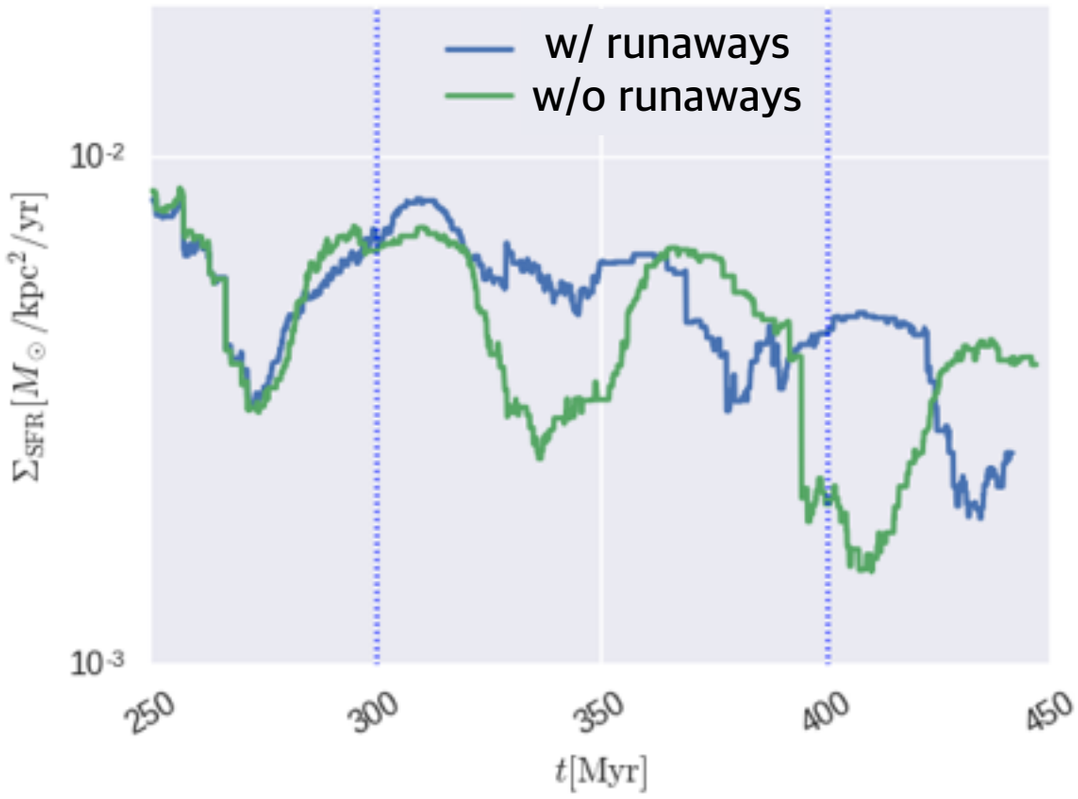
- Hot Winds launched at around ~1kpc
  - mass loading factor = (hot gas outflow rate)/(star formation rate) ~ 0.1 – 1
  - still subsonic, but can be further accelerated as in classical winds (CC85) or differently based on geometry (morphology of streamlines)
- Cool gas (and WHIM) can go up to a few kpc, but fall back (fountain) in a MW-like gravitational potential
  - cool phase outflows may be produced by cooling of hot outflows (Thompson+, Bustard+ 2016)
  - CRs?
- SN feedback regulates SFR and galactic winds!

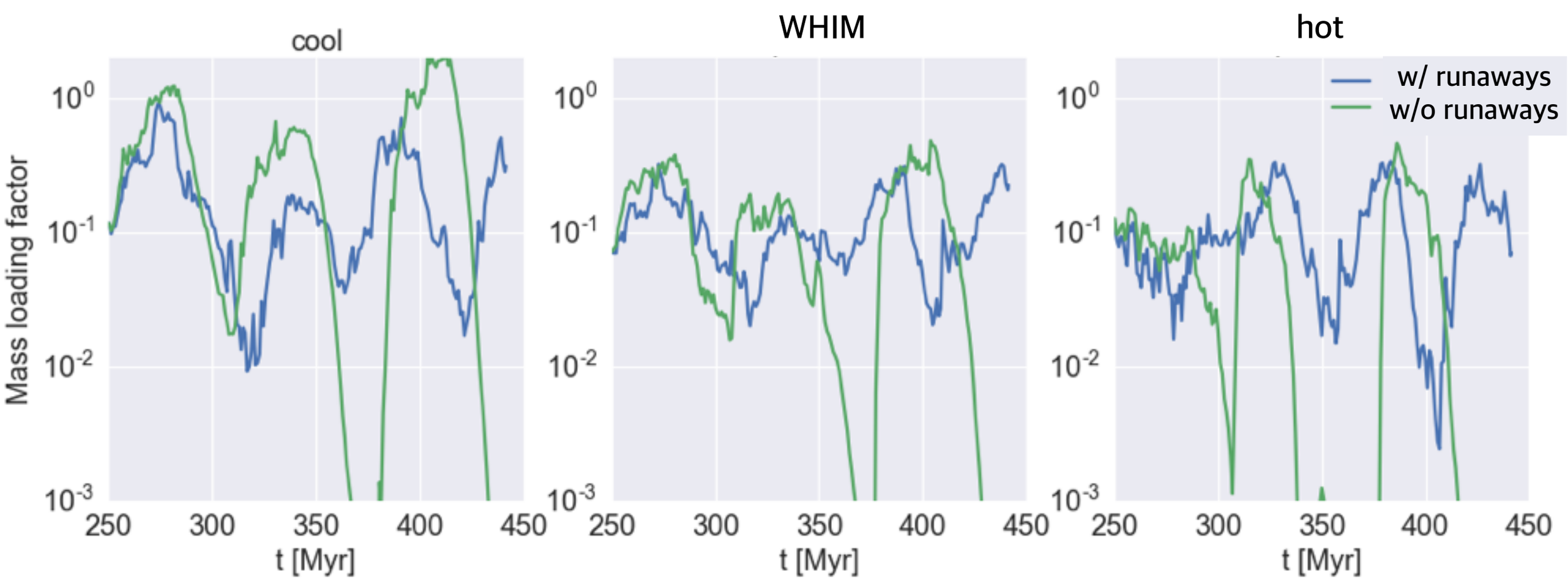
One more thing…


n_H
T
z [kpc]
y [kpc]
x [kpc]
x [kpc]
$\Sigma[\mathrm{M}_\odot\mathrm{pc}^{-2}]$
$n_\mathrm{H}[\mathrm{cm}^{-3}]$
$T[\mathrm{K}]$

What do runaways do?

- w/o runaways, winds are more bursty, pushing more/less cool/ hot gas to outflow (still, cool winds are not fast enough)





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  - cool phase outflows may be produced by cooling of hot outflows (Thompson+, Bustard+ 2016)
  - CRs?
- SN feedback regulates SFR and galactic winds!
- Runaways (SNe at high-|z|) are key for continuous Hot Winds