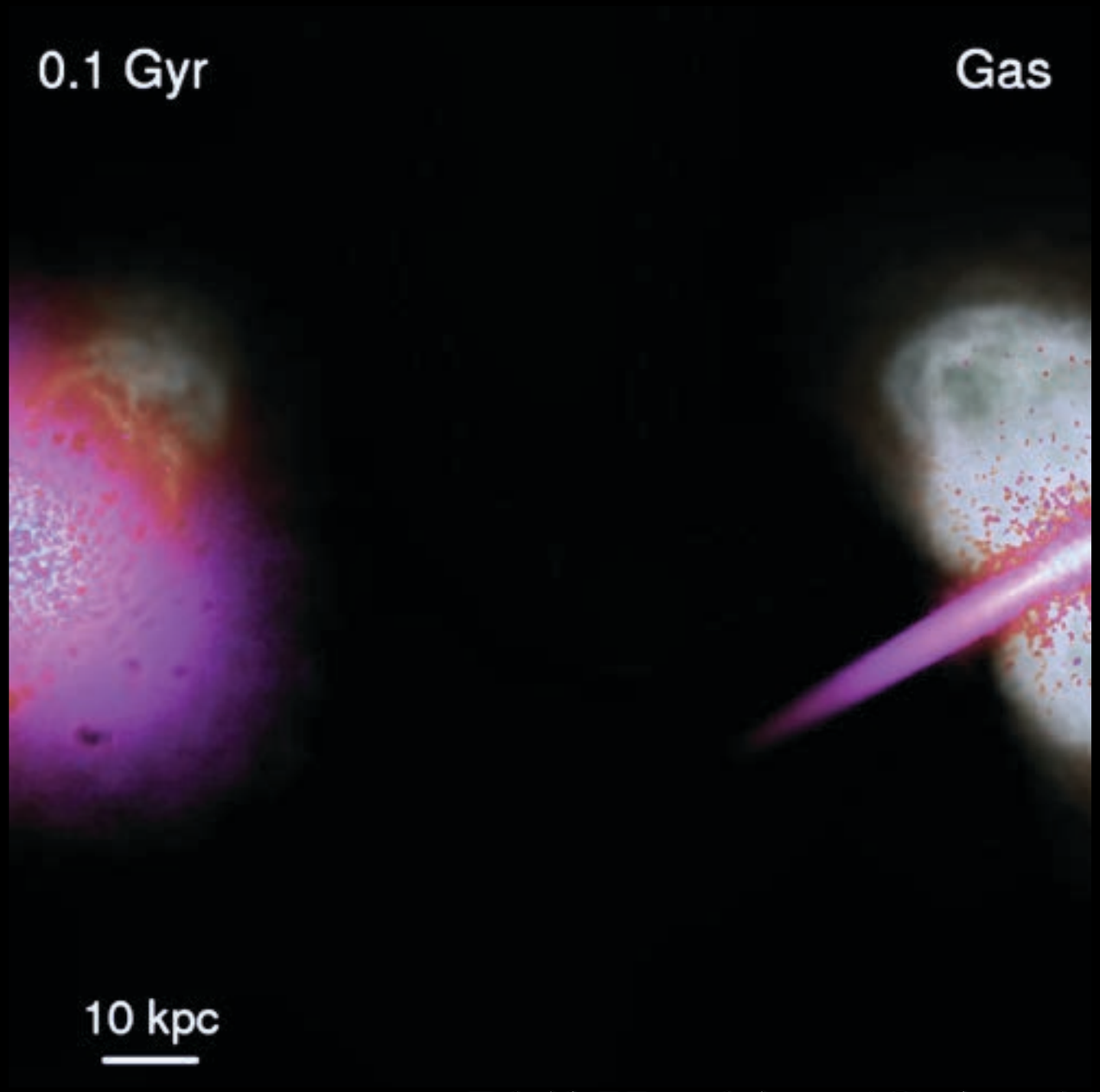
Updates on FIRE:
Feedback In Realistic Environments



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Stellar Feedback: How Can We Do Better?

- High-resolution (~1-10 pc), molecular/metal cooling (~10 K), SF at $n_H > 100$ cm^{-3}

- Energy/Mass/Metal Injection:
  - SNe (II & Ia)
  - Stellar Winds (O & AGB)
  - Photoionization (HII) & Photoelectric

- Momentum Flux:
  - Radiation Pressure

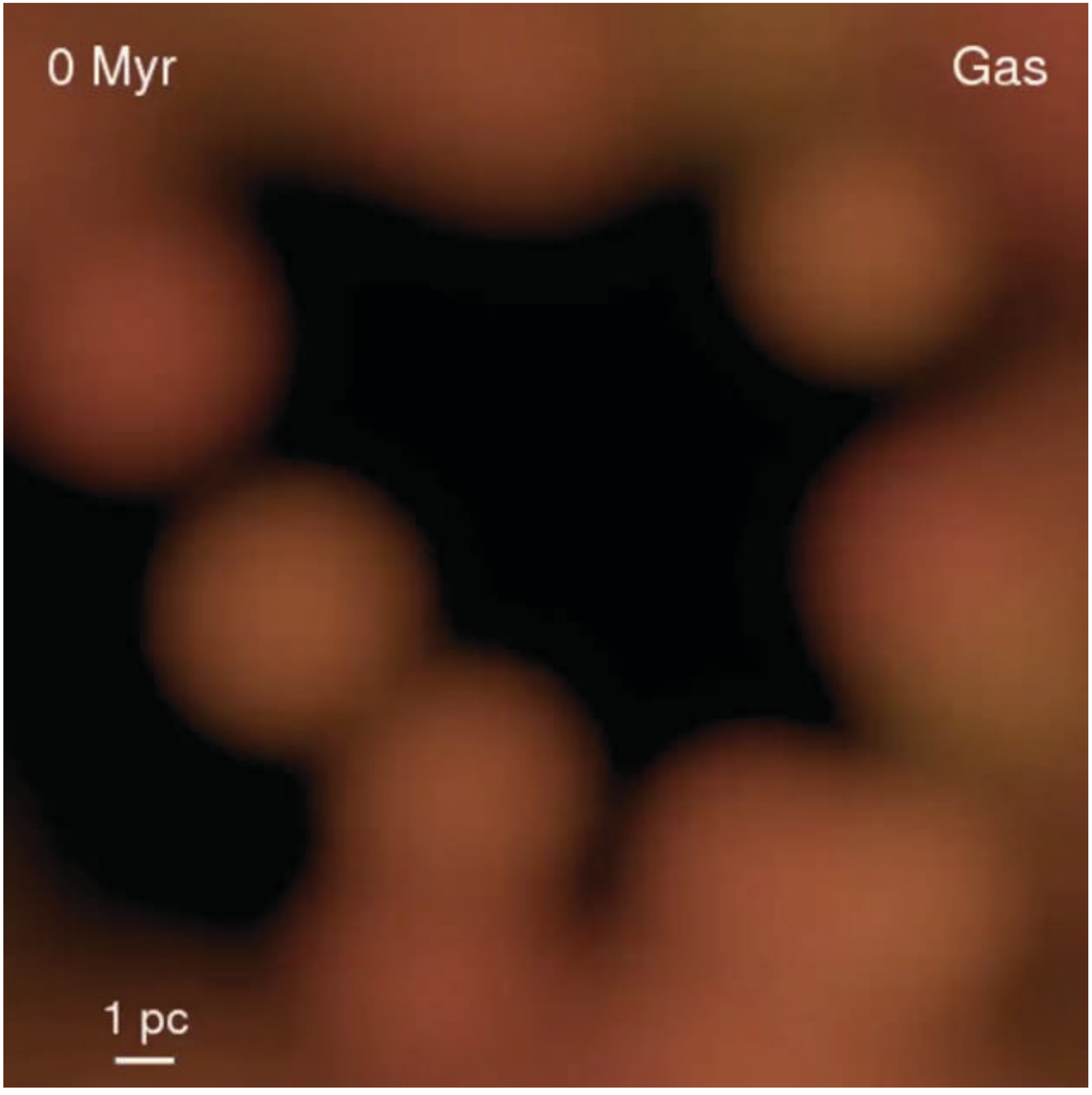
$$\dot{P}_{\rm rad} \sim \frac{L}{c}\,(1+\tau_{\rm IR})$$

  - SNe

$$\dot{P}_{\rm SNe} \sim \dot{E}_{\rm SNe}\, v_{\rm ejecta}^{-1}$$

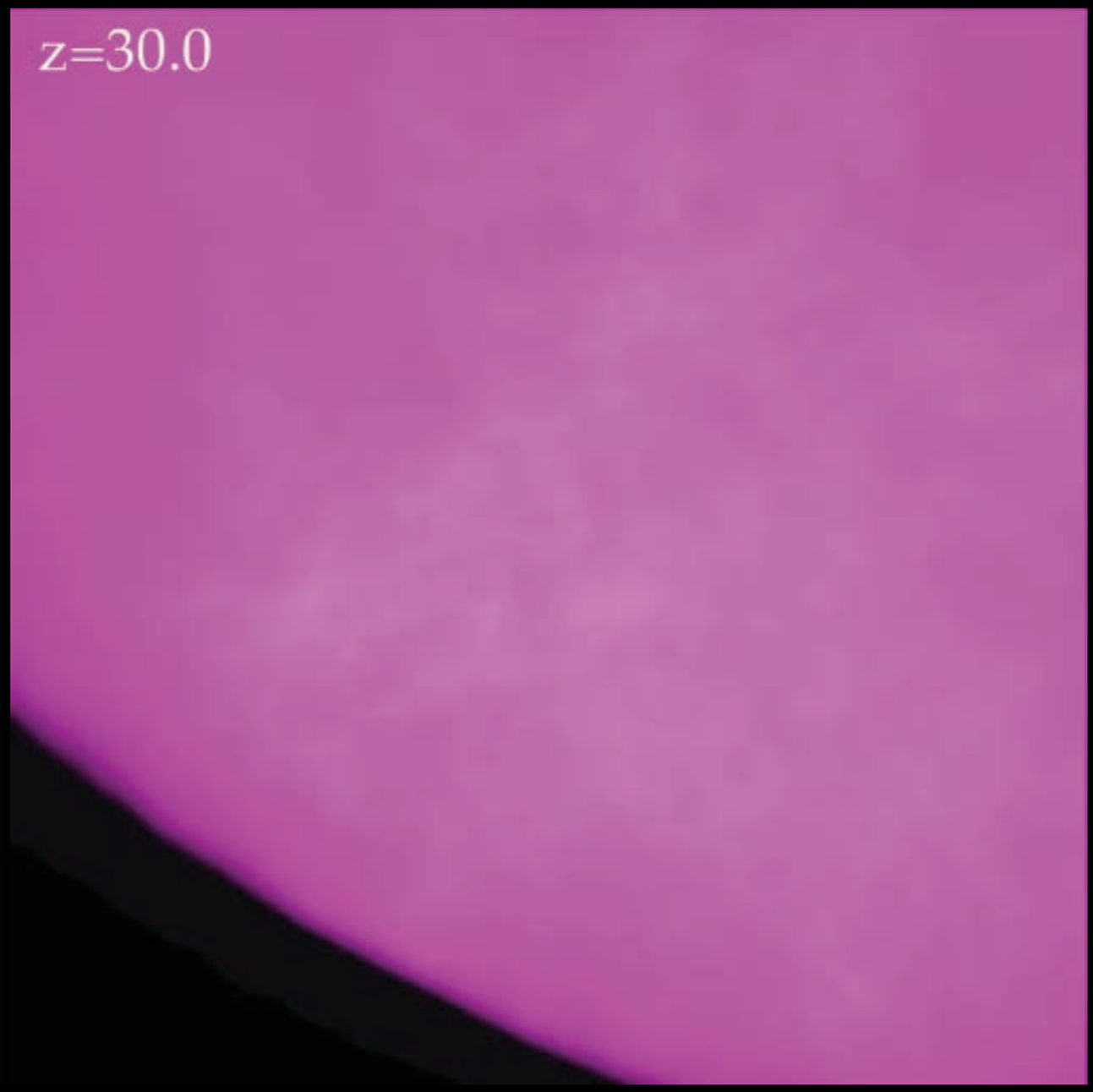
  - Stellar Winds

$$\dot{P}_{\rm W} \sim \dot{M}\, v_{\rm wind}$$



- (also MHD, anisotropic conduction, diffusion)

z=30.0



Stars (Hubble image):

Blue: Young star clusters
Red: Dust exinction

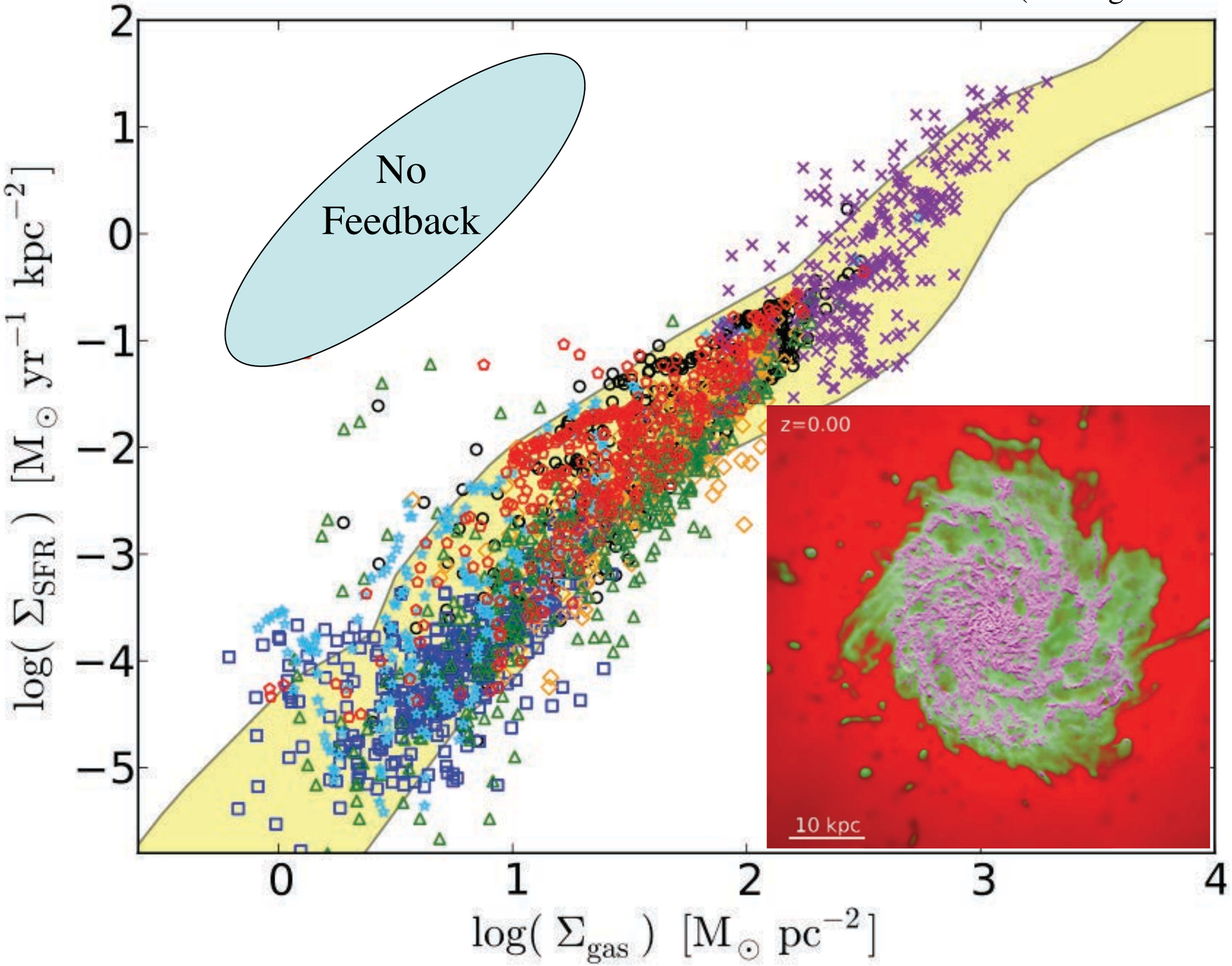
Gas: Magenta: cold $(< 10^4\,K)$
Green: warm (ionized)
Red: hot $(> 10^6\,K)$

The Kennicutt Law Emerges

INDEPENDENT OF SMALL-SCALE SF LAW

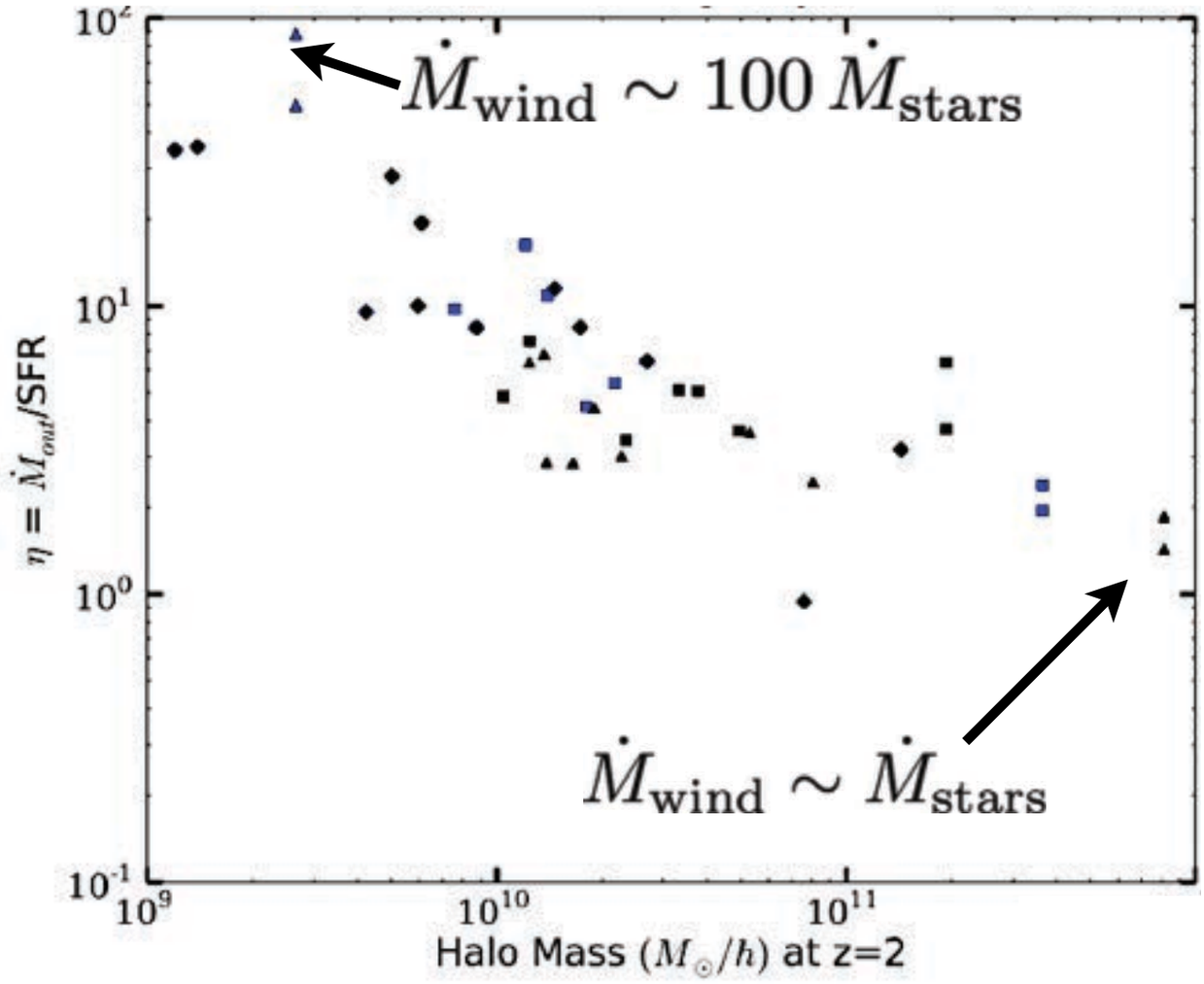
PFH et al. (arXiv:1311.2073)

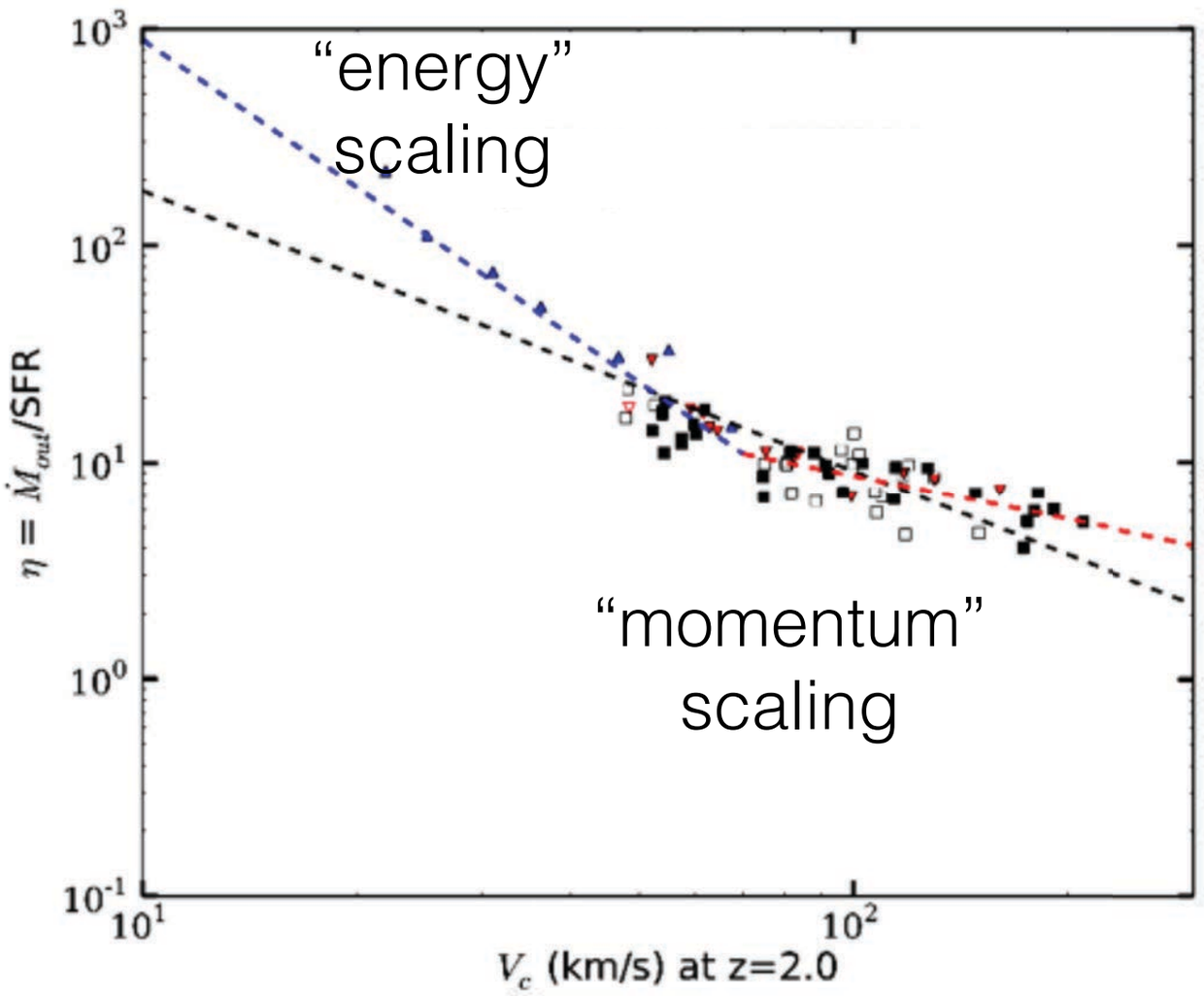
(also Agertz+ 1404.2613)



How Efficient Are Galactic Super-Winds?
WHAT MECHANISMS DRIVE THEM?

S. Muratov





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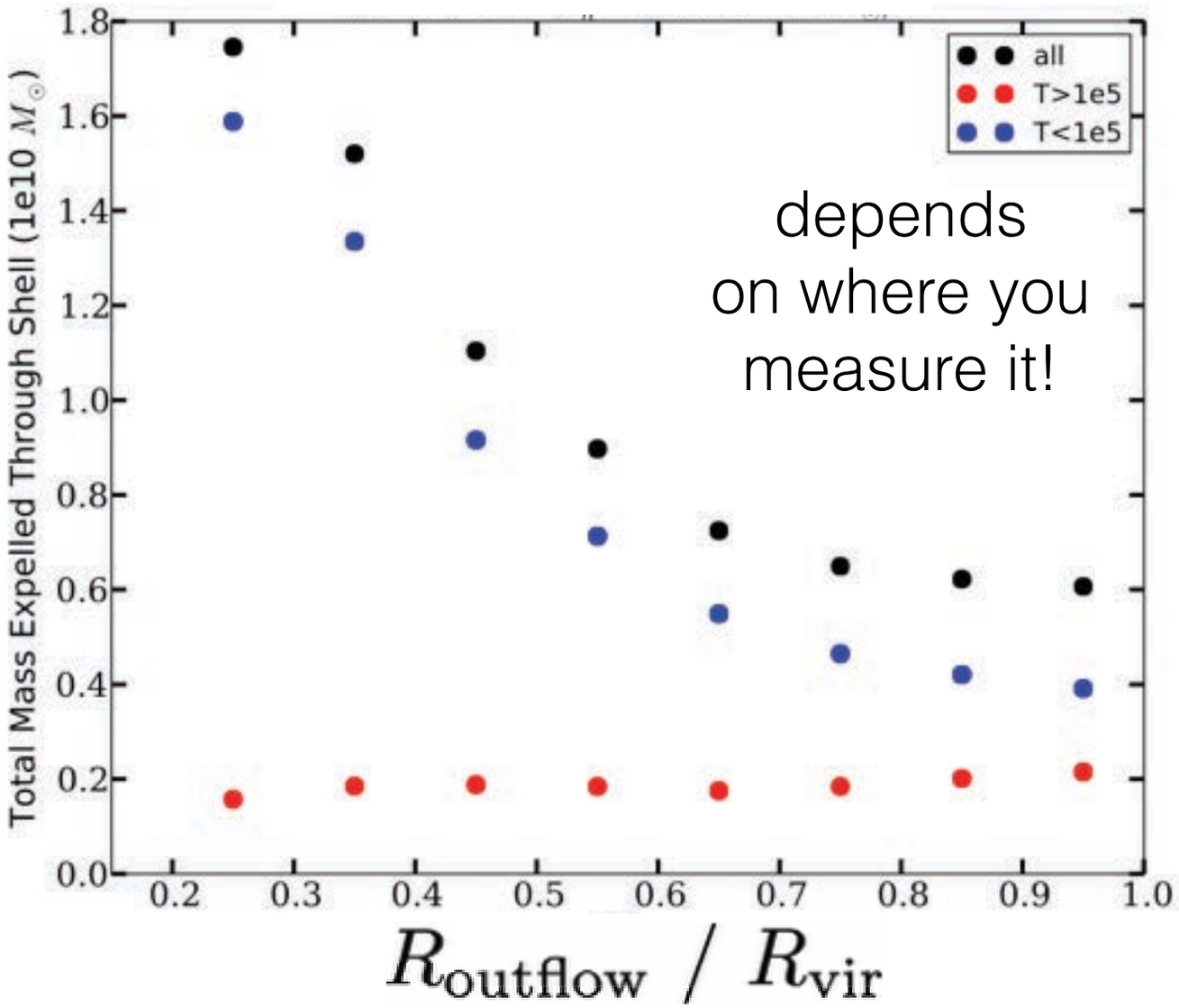
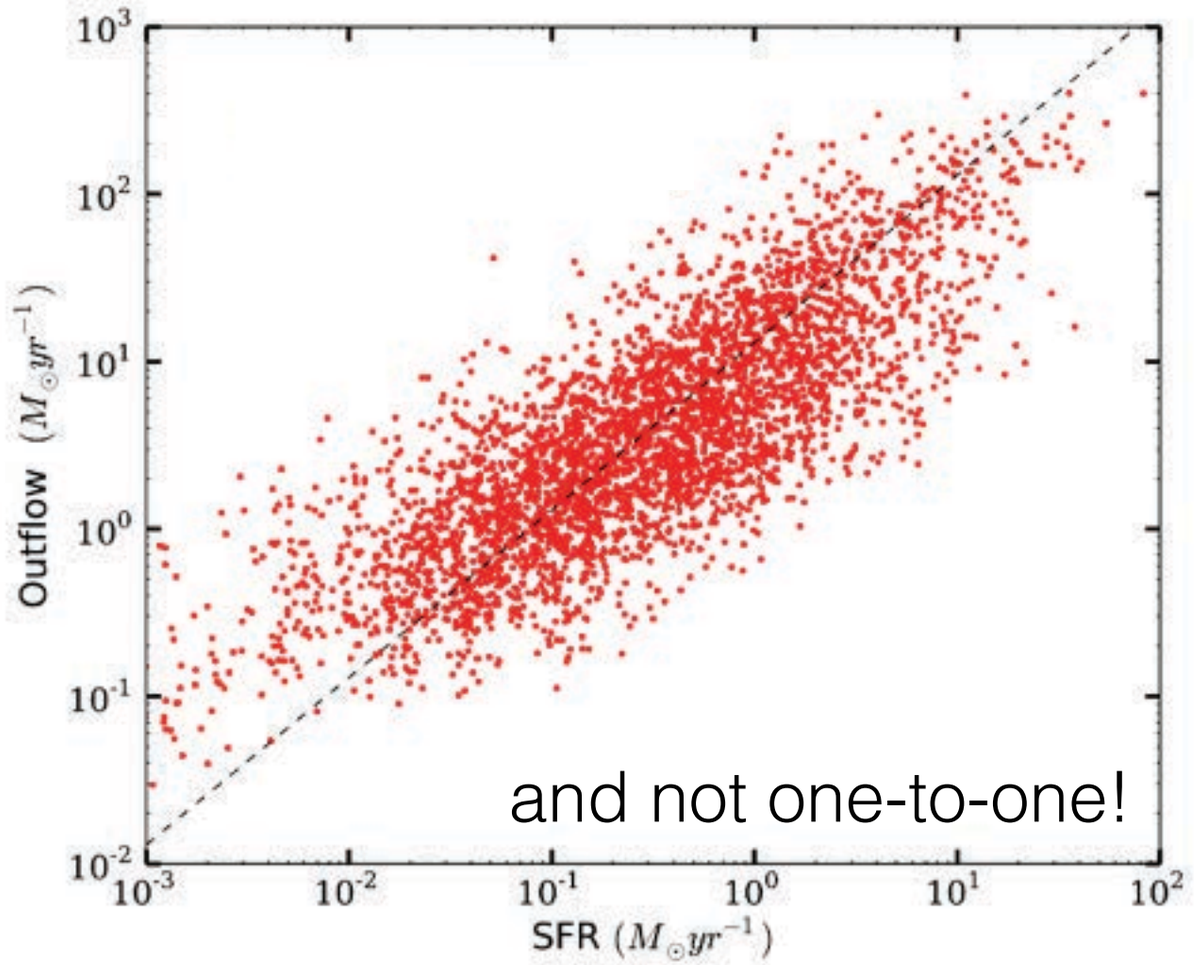
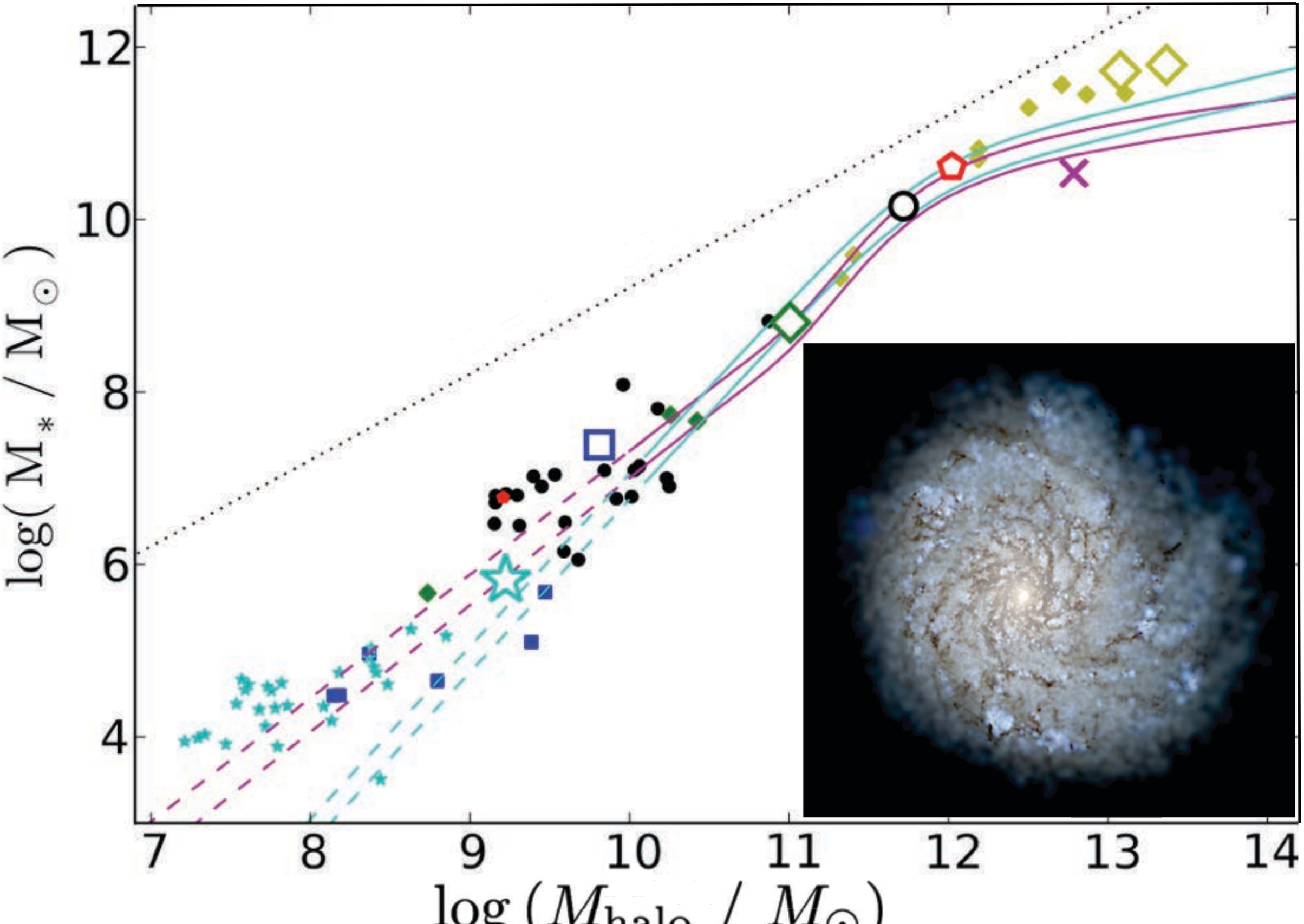




Does Stellar Feedback Explain the Mass Function?

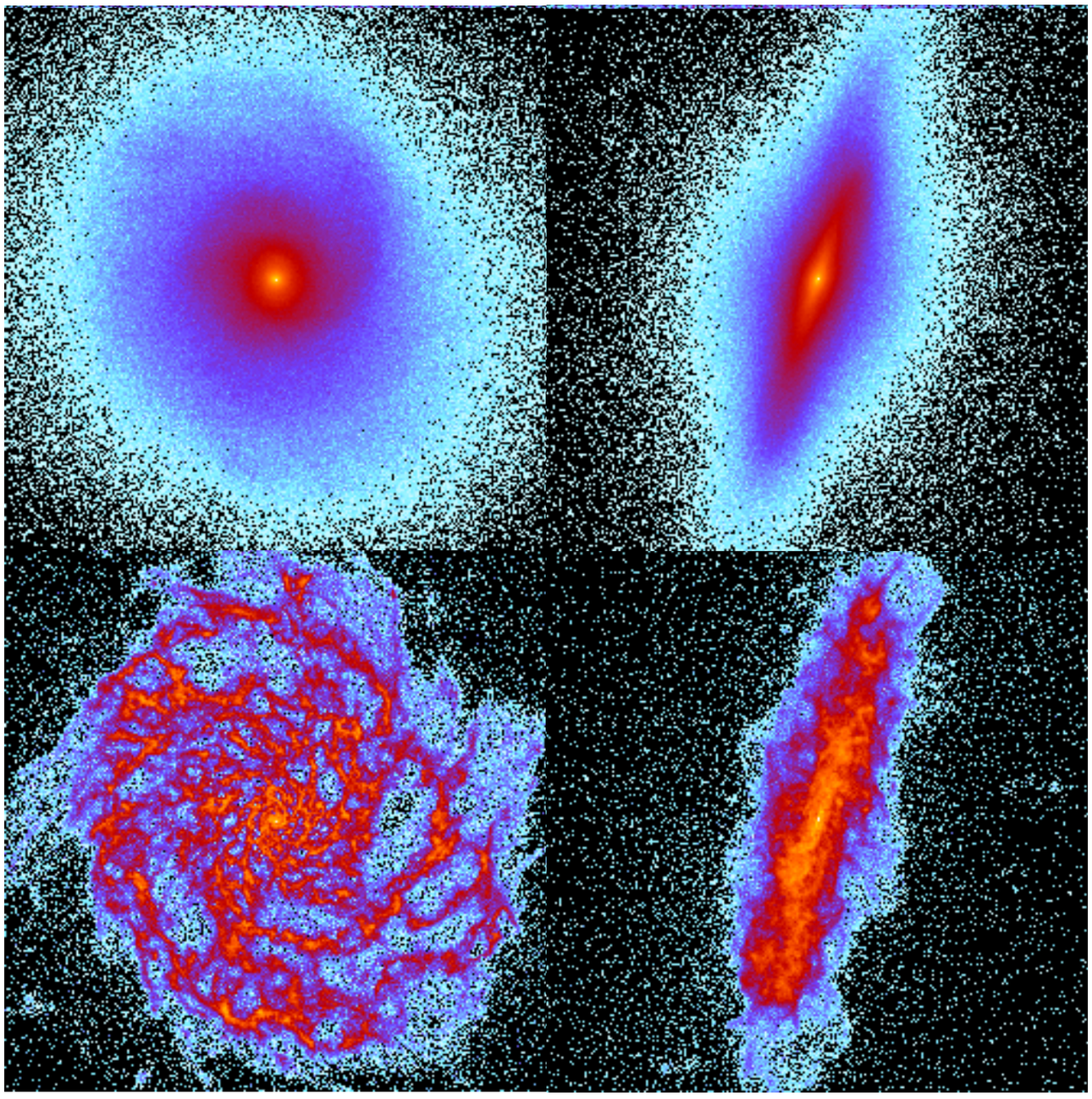
PFH et al. (arXiv:1311.2073)

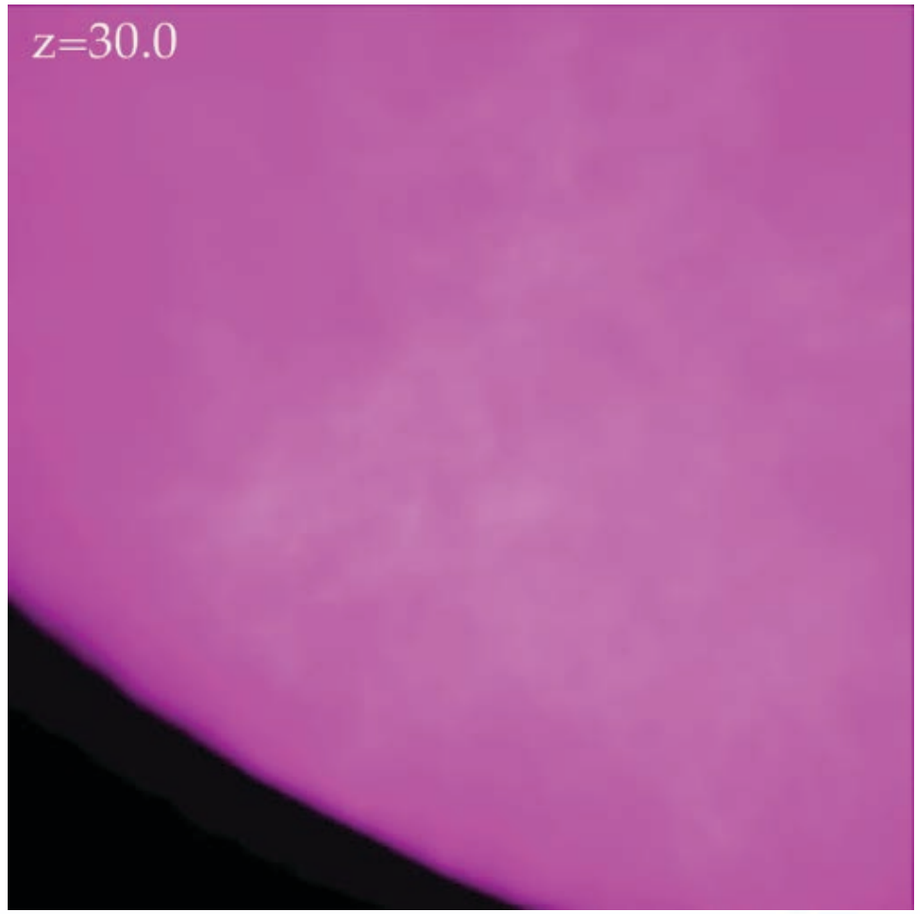
HOW EFFICIENT ARE GALACTIC WINDS?



You Can Have Feedback & Thin Disks

RESOLVED MULTI-PHASE PHYSICS KEY



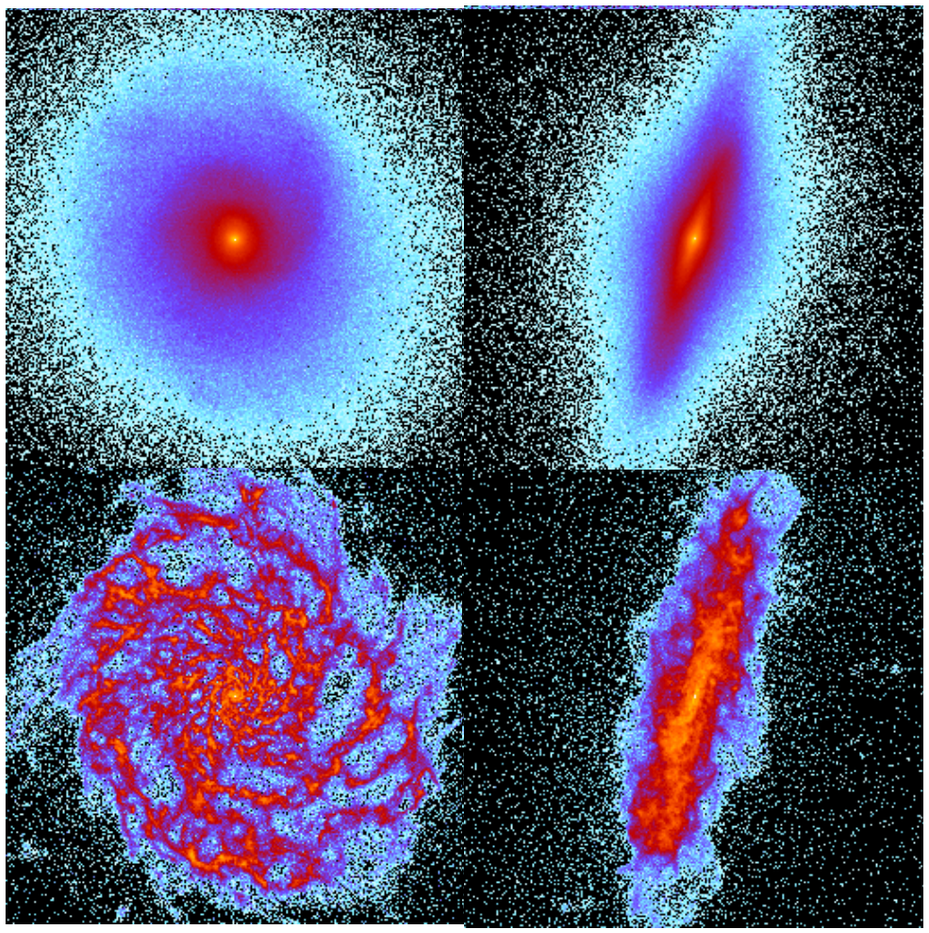


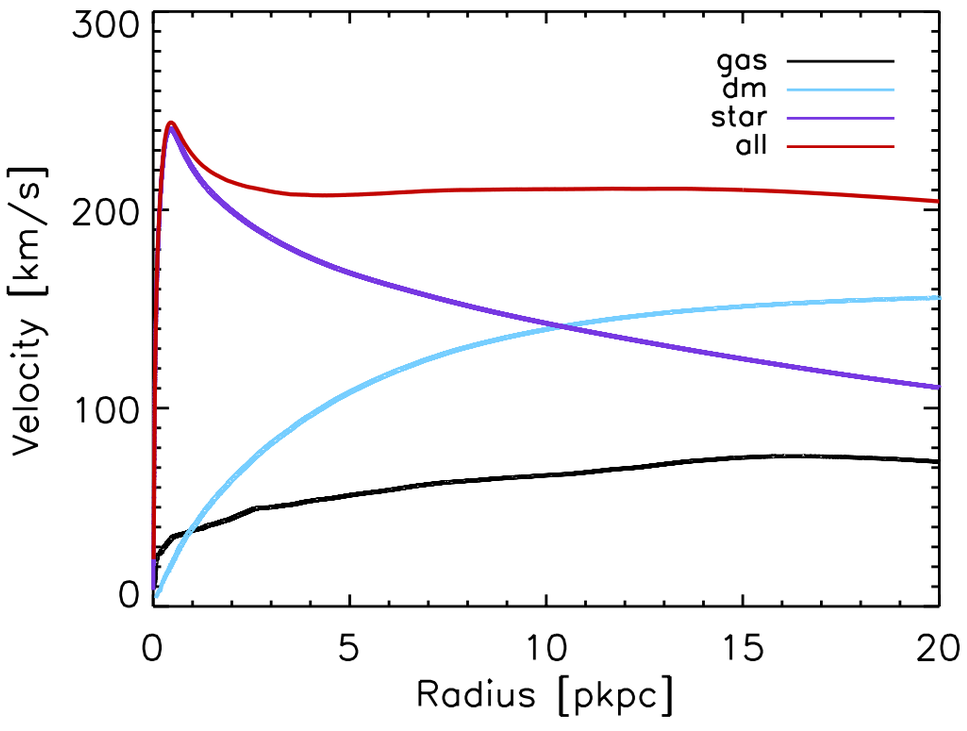
But Feedback *Does* Matter

DETAILS & MULTIPLE MECHANISMS IMPORTANT

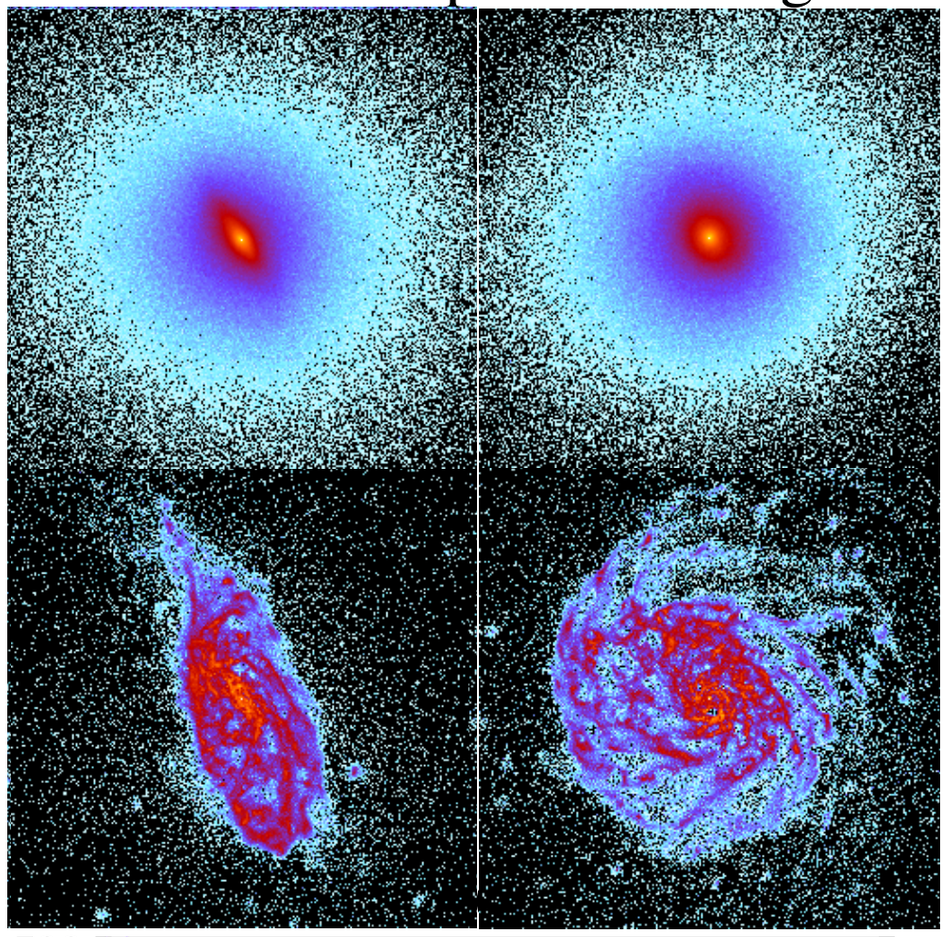
Denise Schmitz, van de Voort+

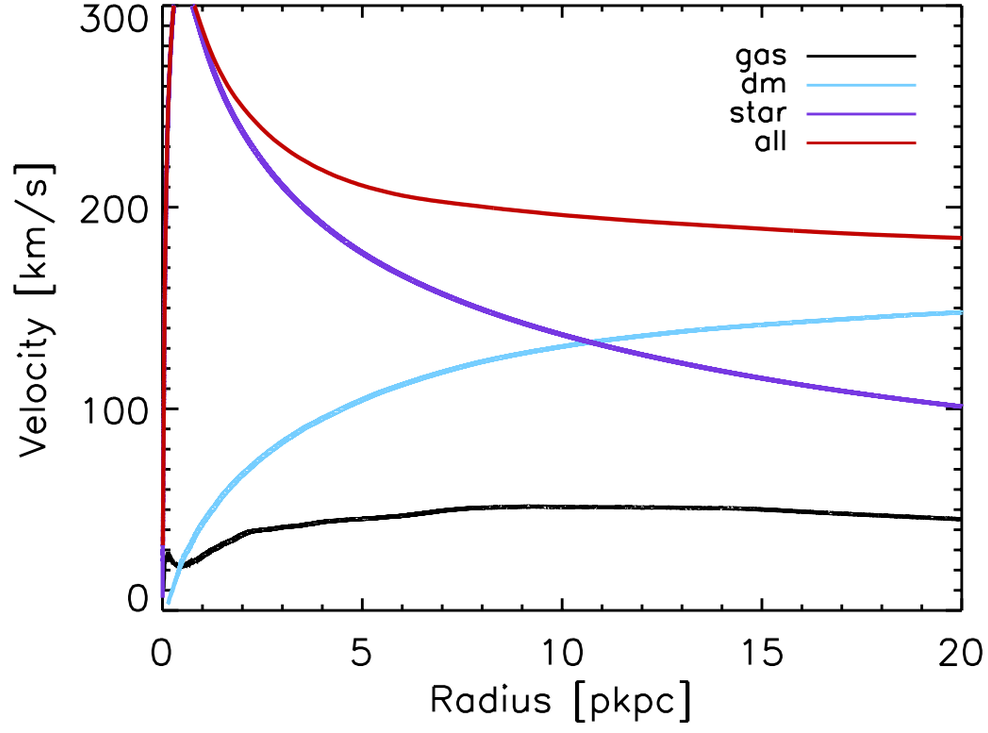
standard





no multiple-scattering

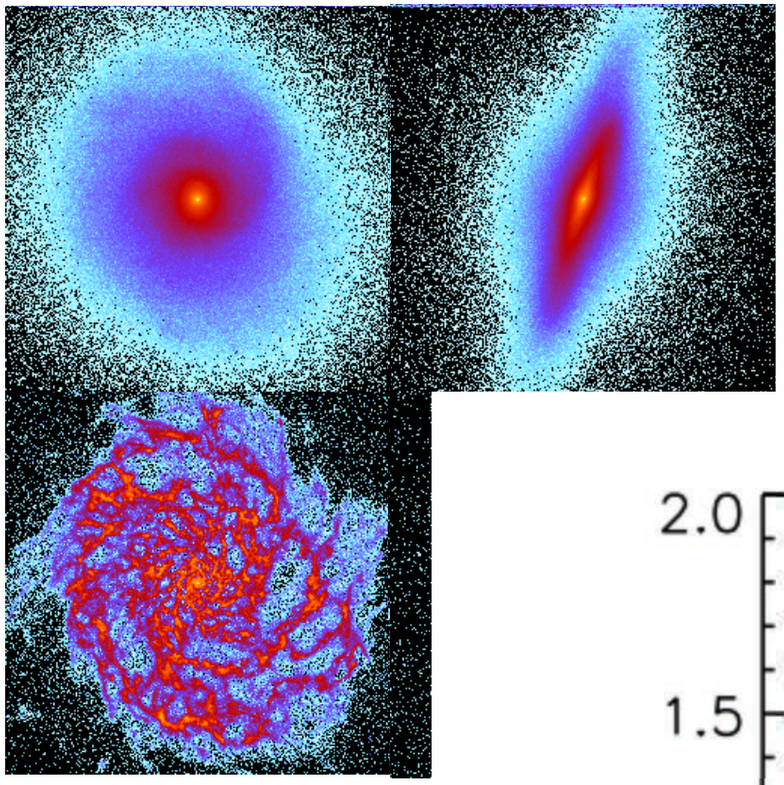




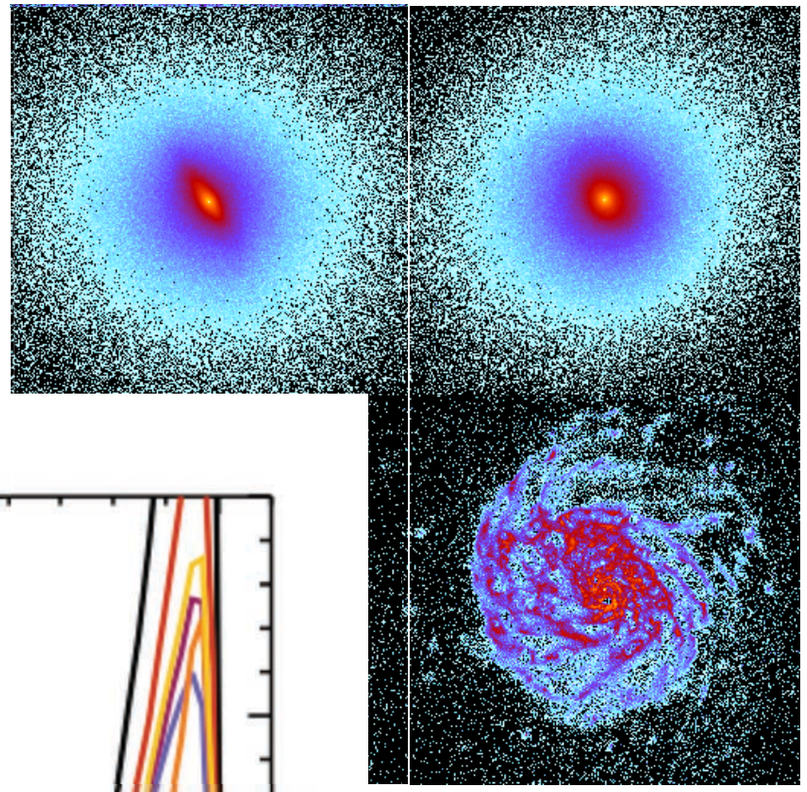
But Feedback *Does* Matter

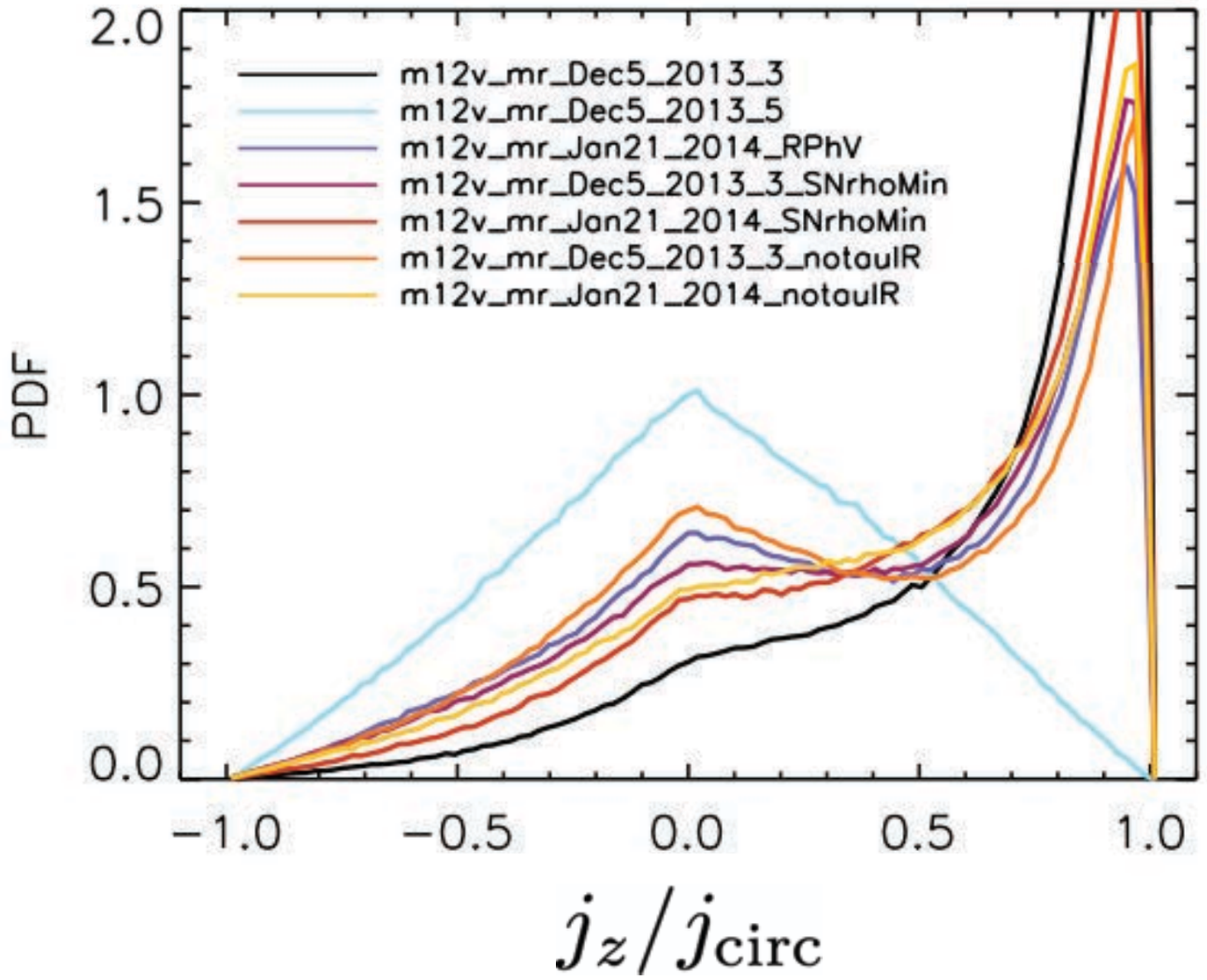
DETAILS & MULTIPLE MECHANISMS IMPORTANT

standard



no multiple-scattering





Denise Schmitz, van de Voort+

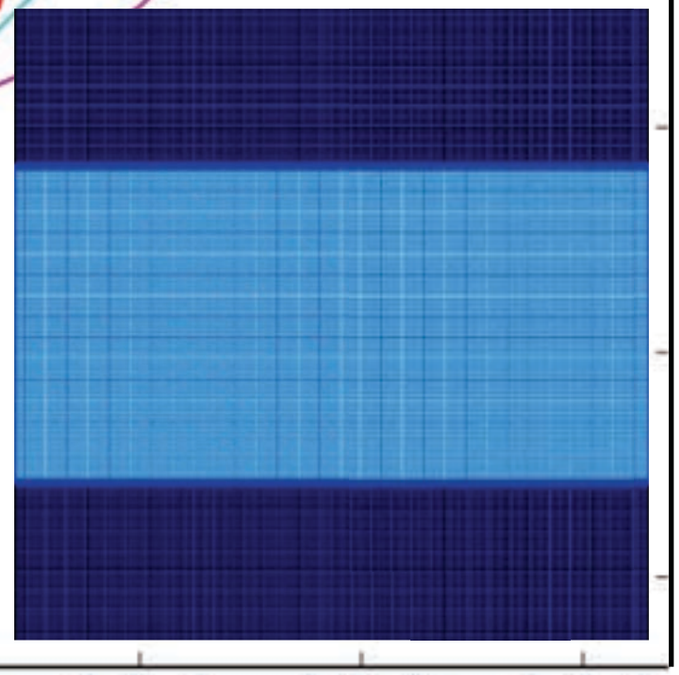
Weak Numerical Dependence

"ALGORITHMIC" CHOICES NOT DOMINANT

Keres et al., in prep

m09 (n_{crit}=10)
m09 (n_{crit}=1000)
m09 (n_{crit}=1000, low-res)
m09 (n_{crit}=10, low-res)
m09 (comoving softening)
m12v (traditional SPH)
m11 (low-res)
m12 (low-res)
m13 (low-res)
m12v (mod. Art. Visc.)

old-fashioned SPH



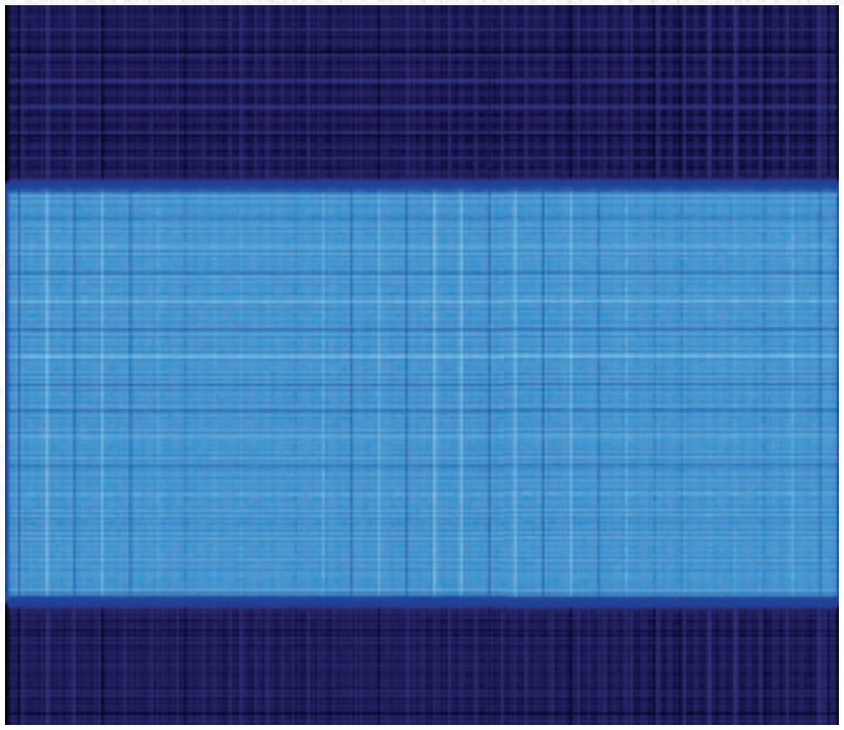
$\log(M_* / f_b M_{halo})$

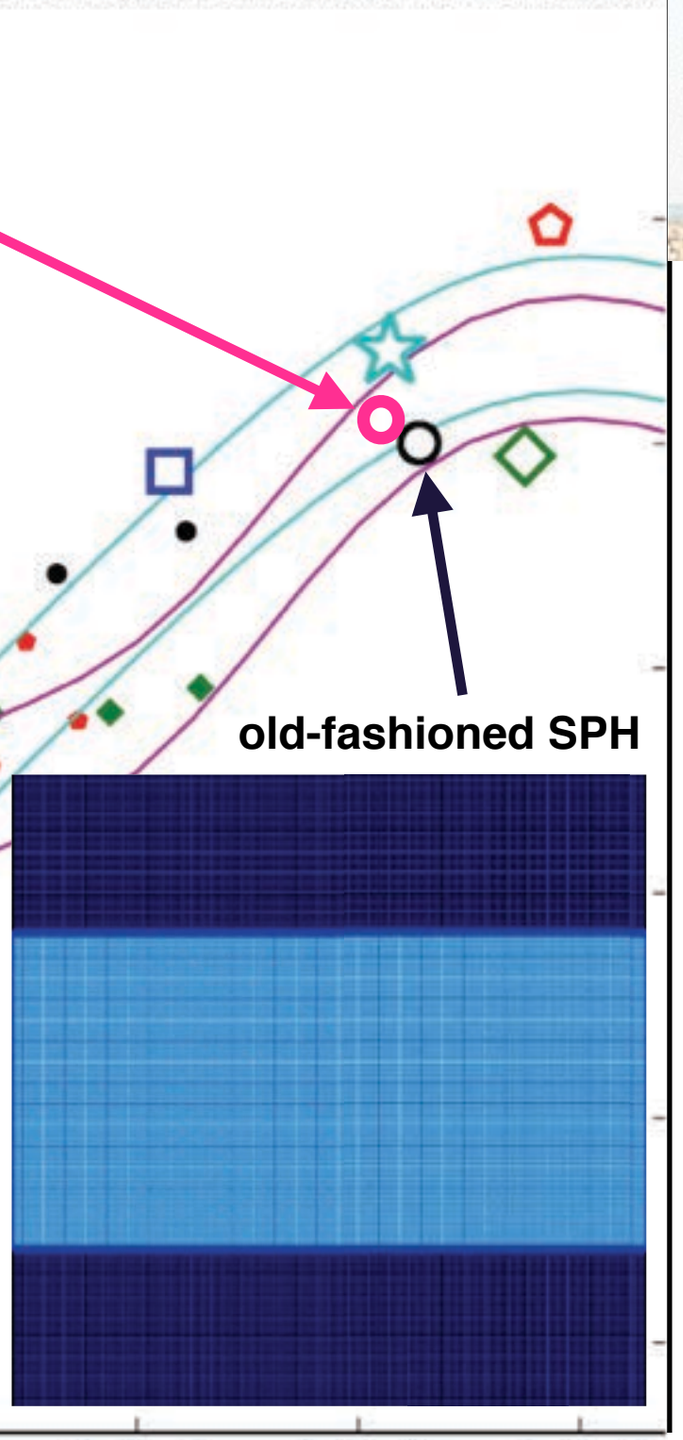
$\log(M_{halo} / M_\odot)$

Weak Numerical Dependence

"ALGORITHMIC" CHOICES NOT DOMINANT

Keres et al., in prep

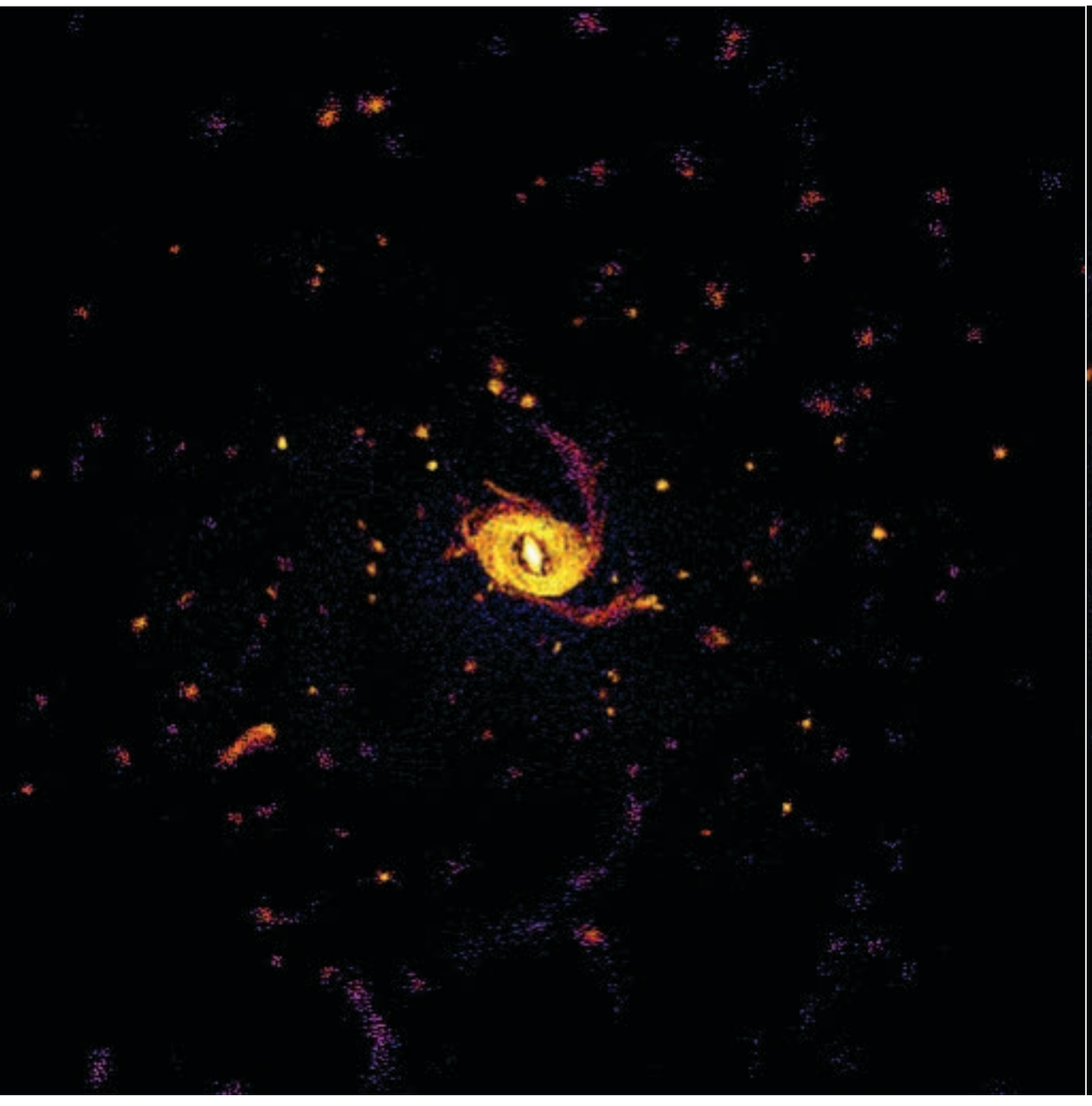




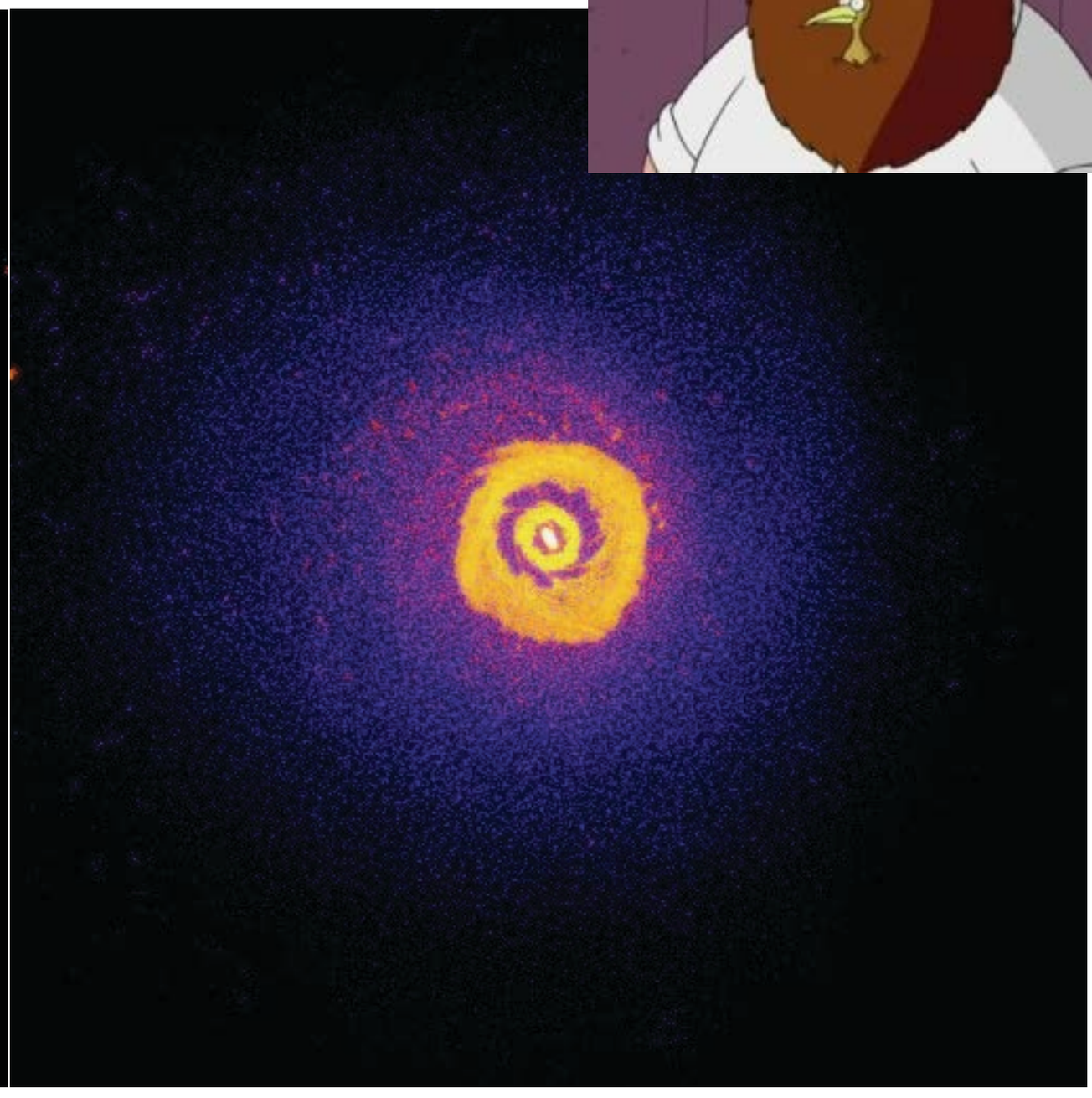
Gravitational Heating & Mixing

NOT AS MANY CLUMPS THESE DAYS!

Keres et al.,
(newer picture)



Density Formulation
("Old" GADGET)



Pressure-Entropy Formulation
(GIZMO)

Cooling from hot halo *is* sensitive to numerics

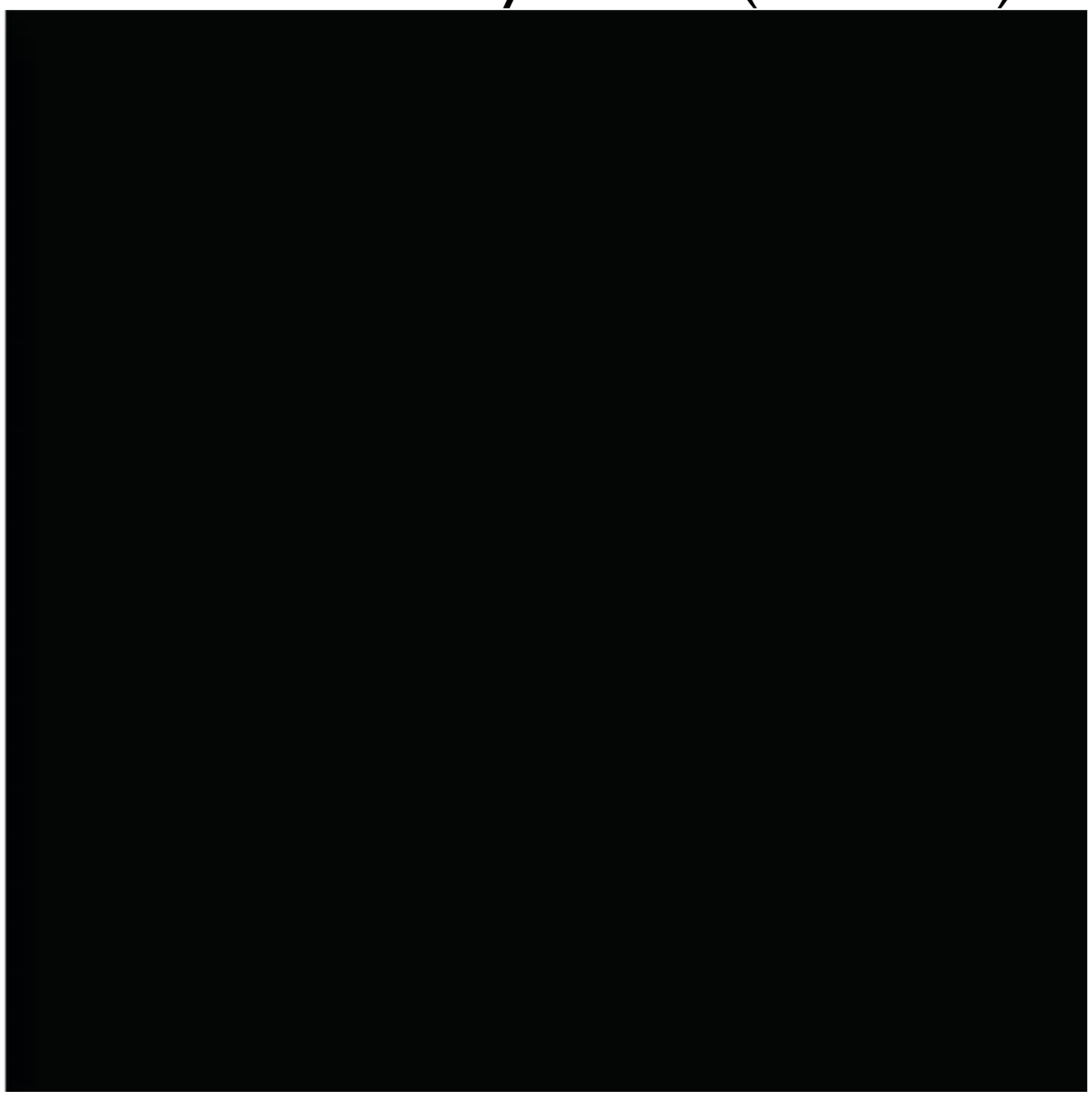
Sub-Grid Is Not Enough

WE NEED TO DO BETTER!

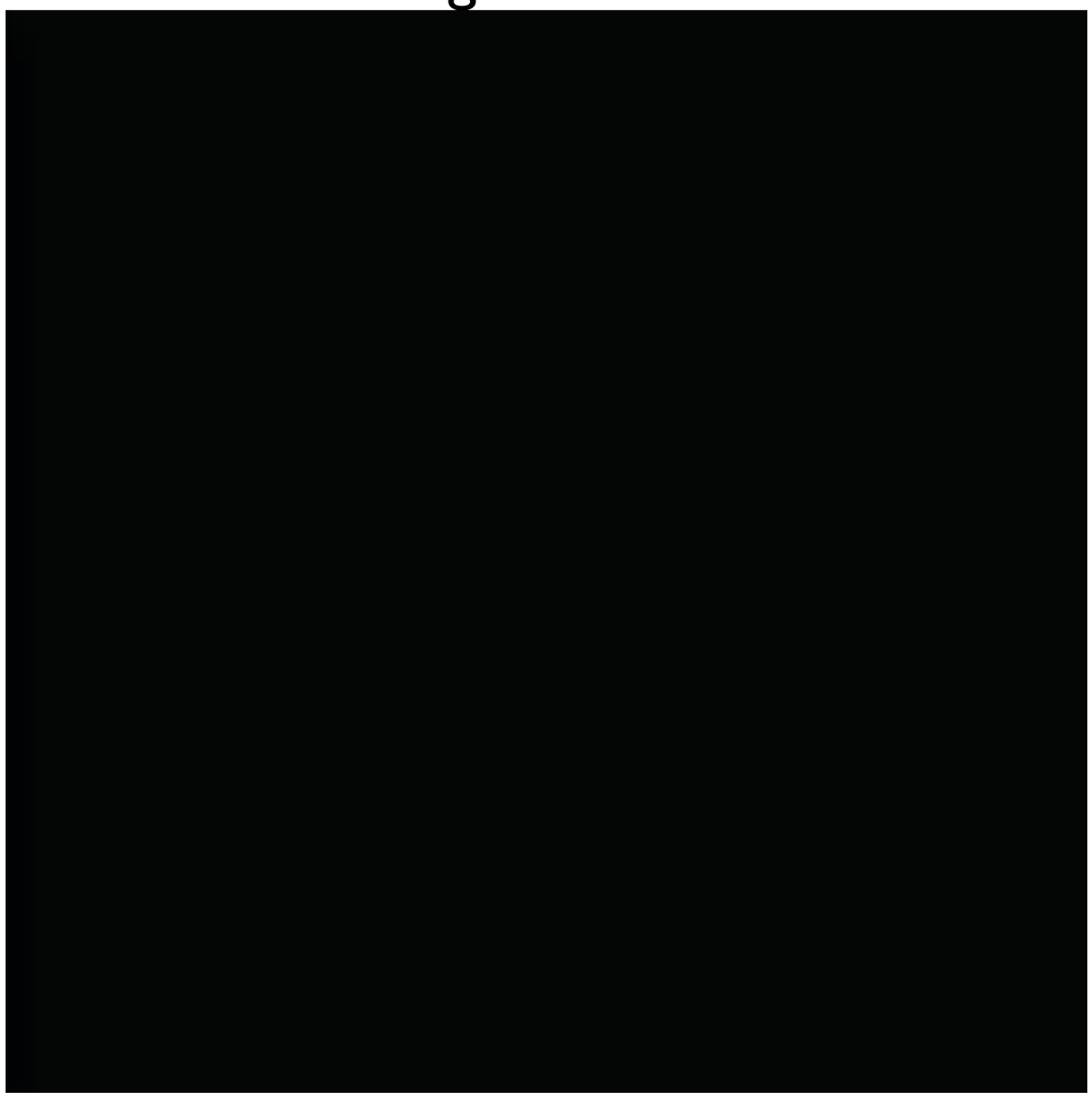
Faucher-Giguere, in prep

Proto-MW: Gas Temperature:

Insert Winds "By Hand" (Sub-Grid)



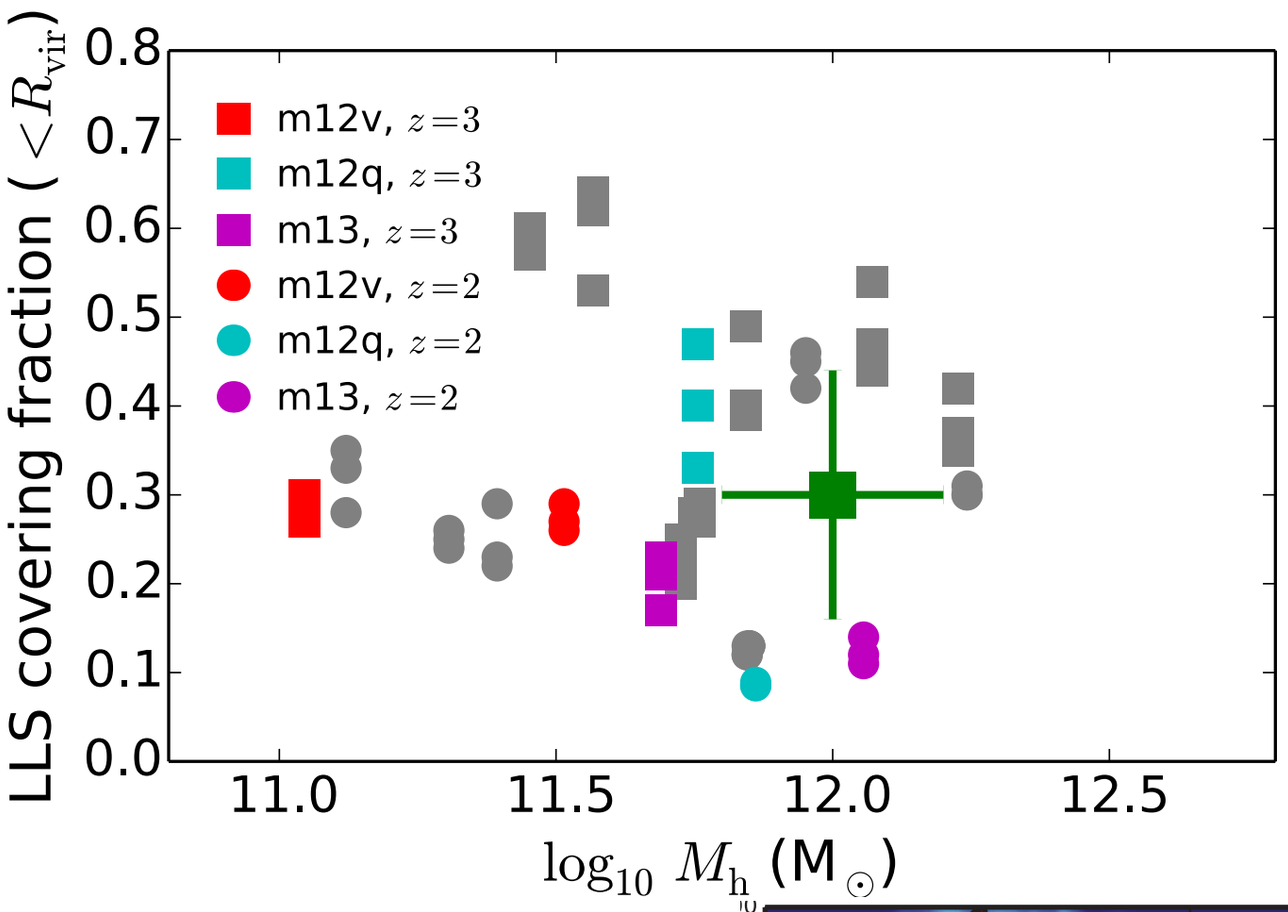
Following Full Feedback

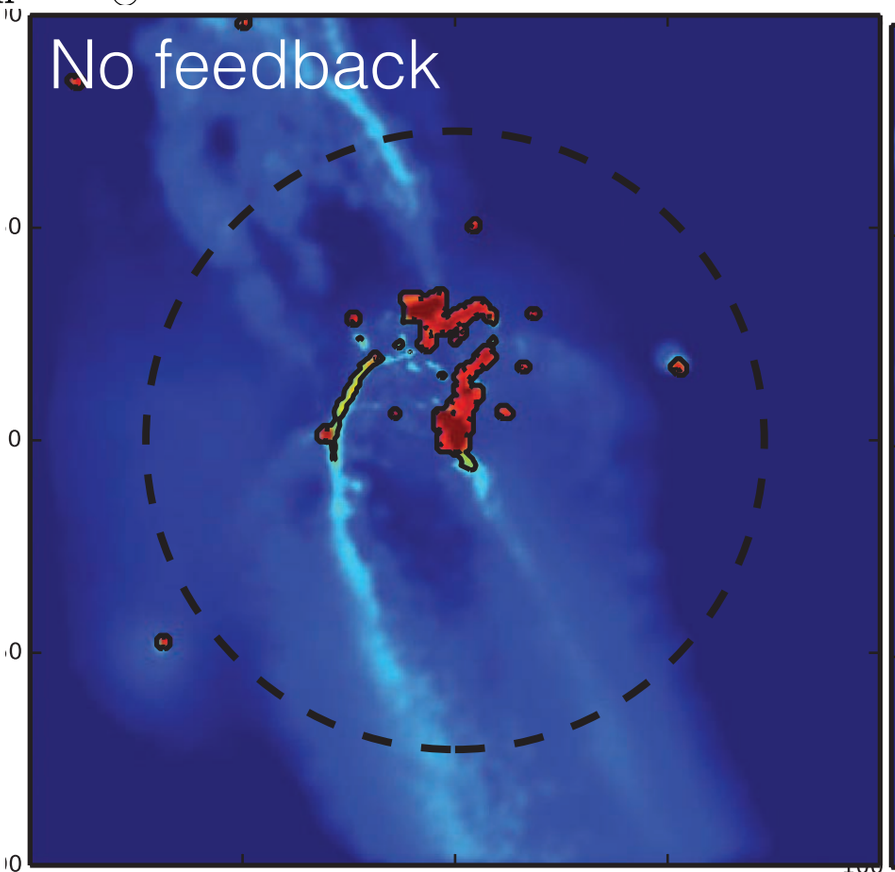


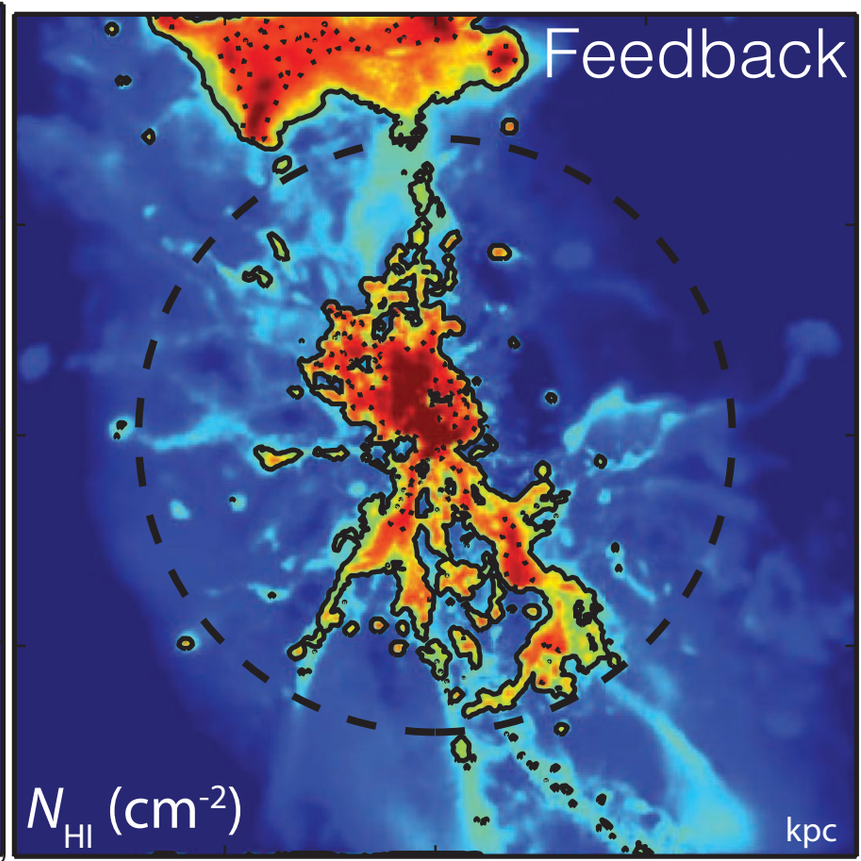
Feedback Determines the Halo Gas Properties

ABSORBERS FALL OUT NATURALLY… EXCEPT

Faucher-Giguere, in prep



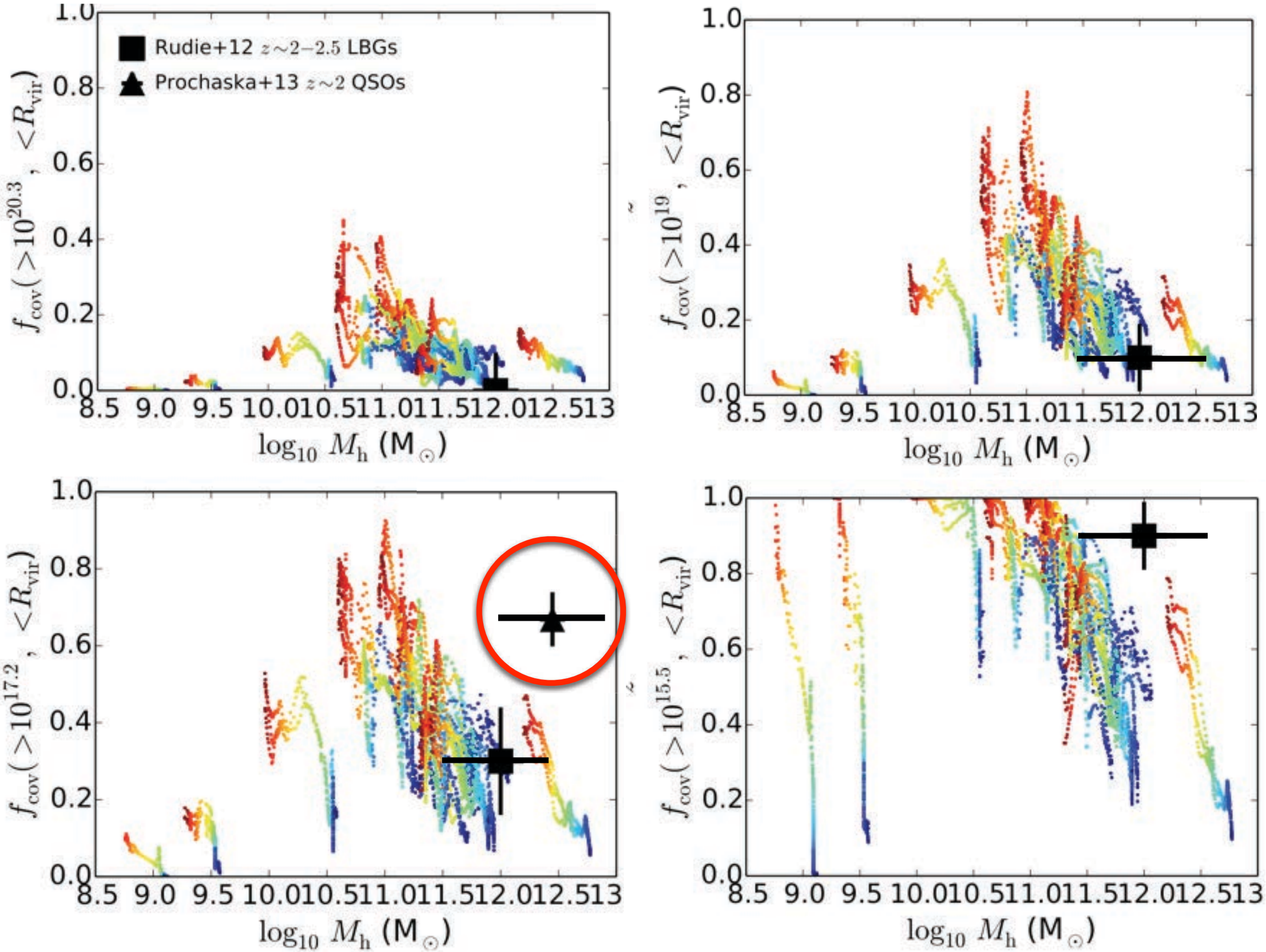




Feedback Determines the Halo Gas Properties

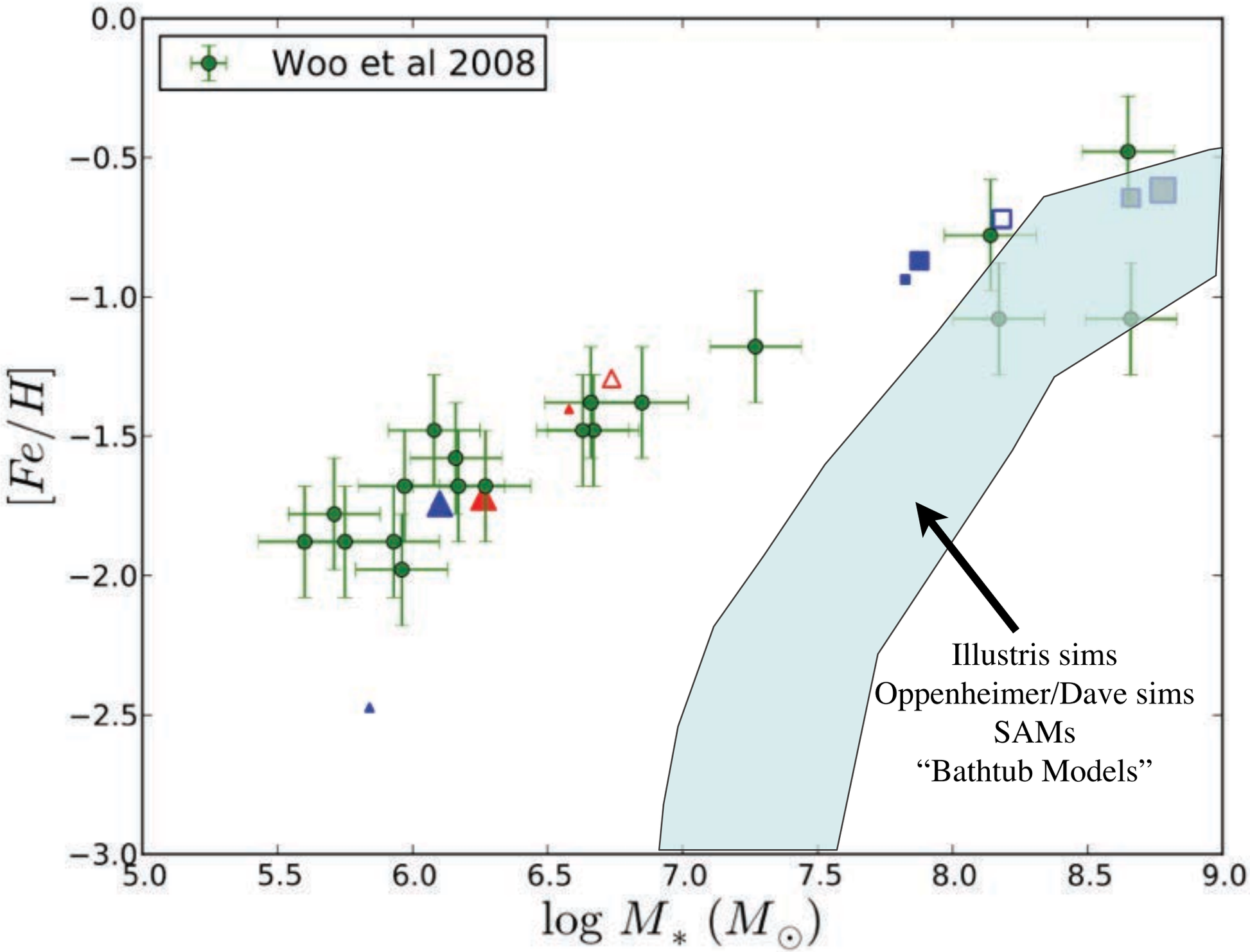
ABSORBERS FALL OUT NATURALLY… EXCEPT QUASAR SYSTEMS

Faucher-Giguere, in prep



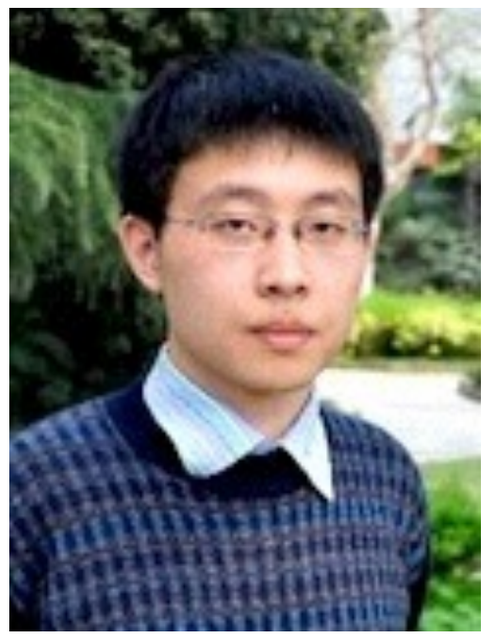
Mass-Metallicity Relation is Sensitive to Feedback

DETAILS MATTER



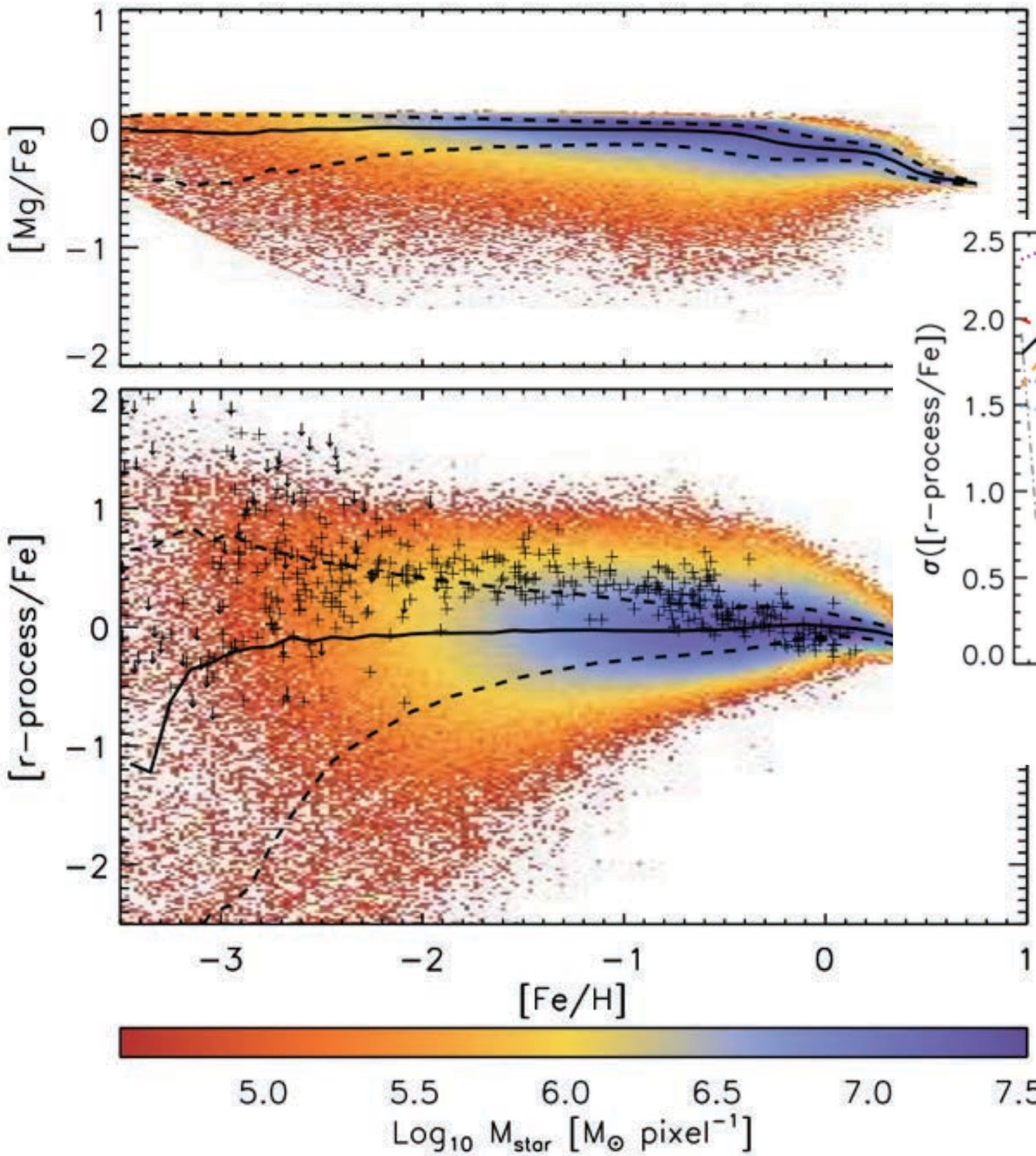
- Outflows suppress "new" infall of pristine material?
- Metal-rich gas preferentially re-accretes in fountains?

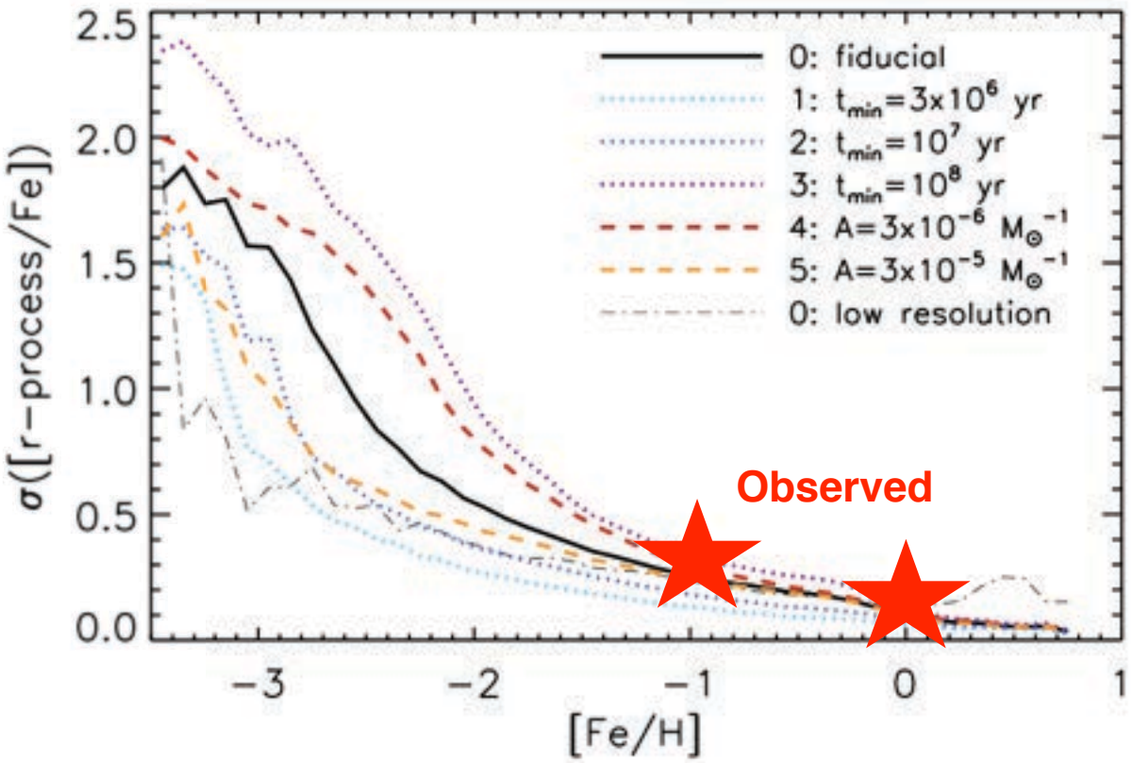
Xiancheng Ma



Constraints on the Origins of R-Process Elements?

CAN THEY COME FROM NEUTRON-STAR MERGERS?



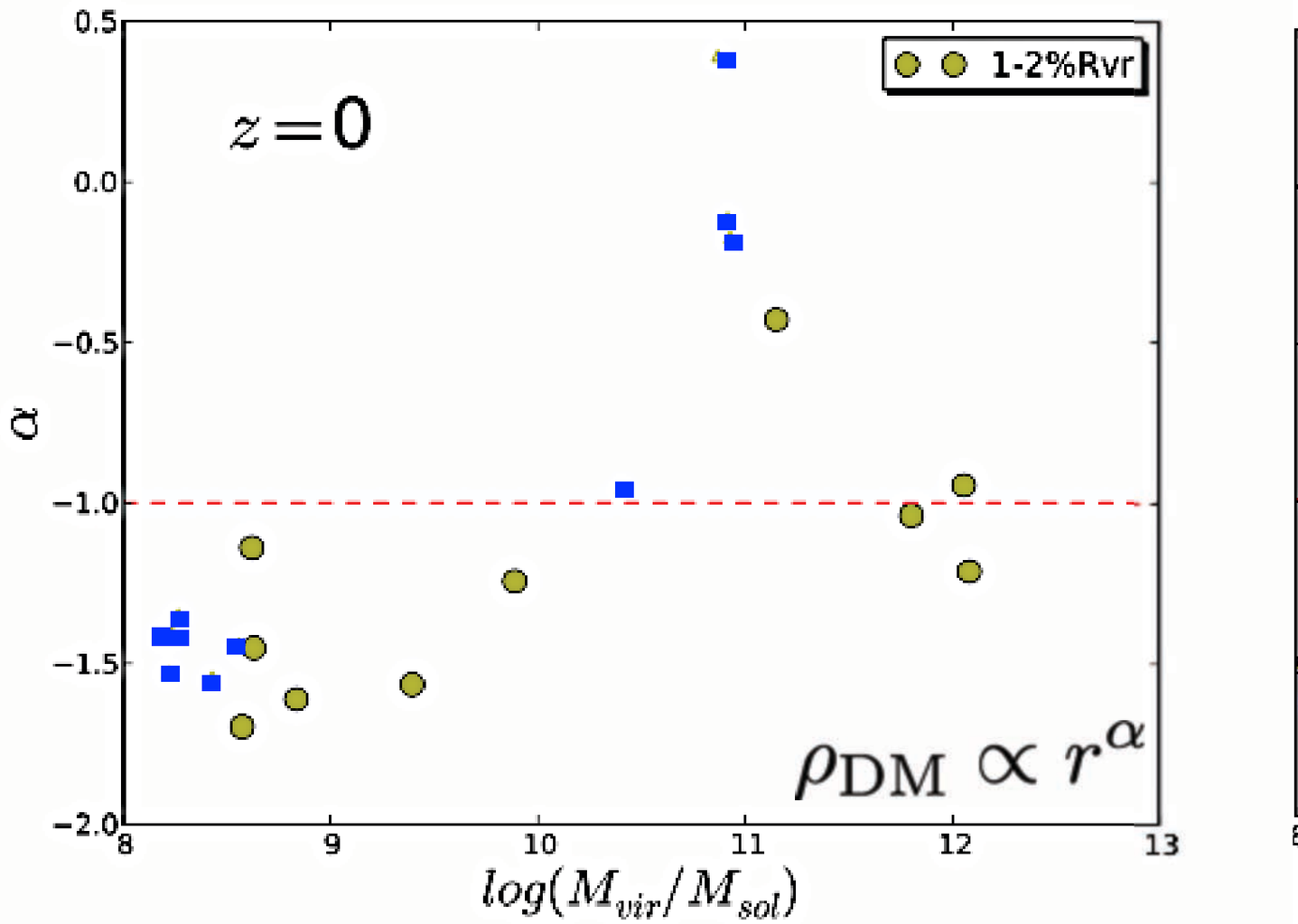


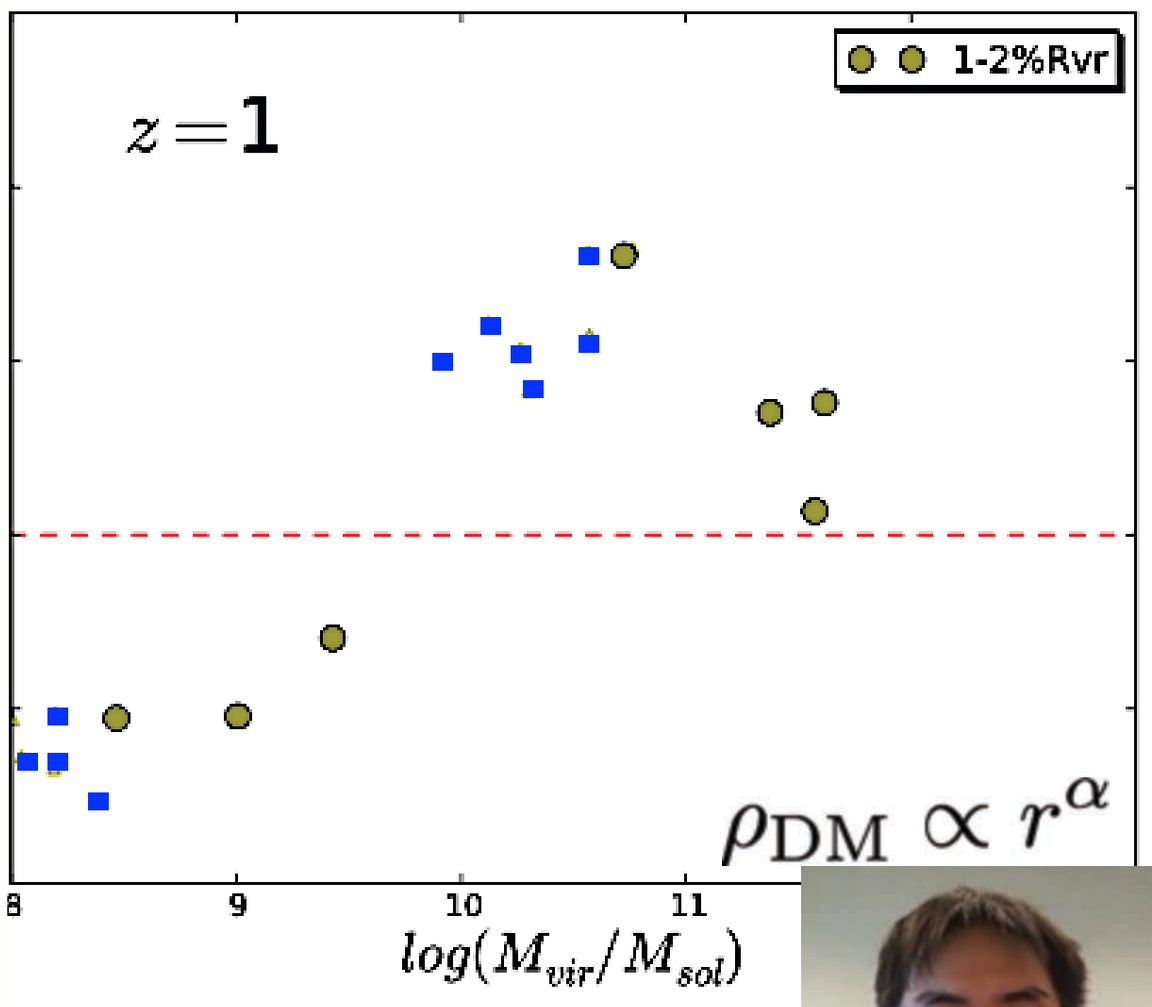
Freeke van de Voort

Cusp or core?

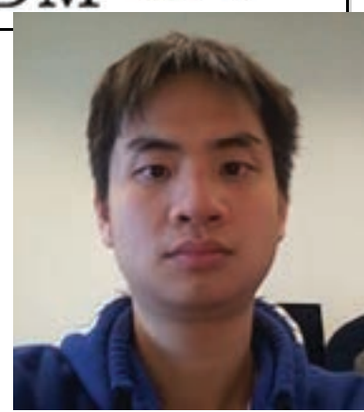
Overall in FIRE, cores form only in a limited range of halos masses: ~10^{10}-10^{11}Msun (halos hosting galaxies with M_*~10^6-10^9 Msun).

~MW mass halos are also affected: very little or no adiabatic contraction!





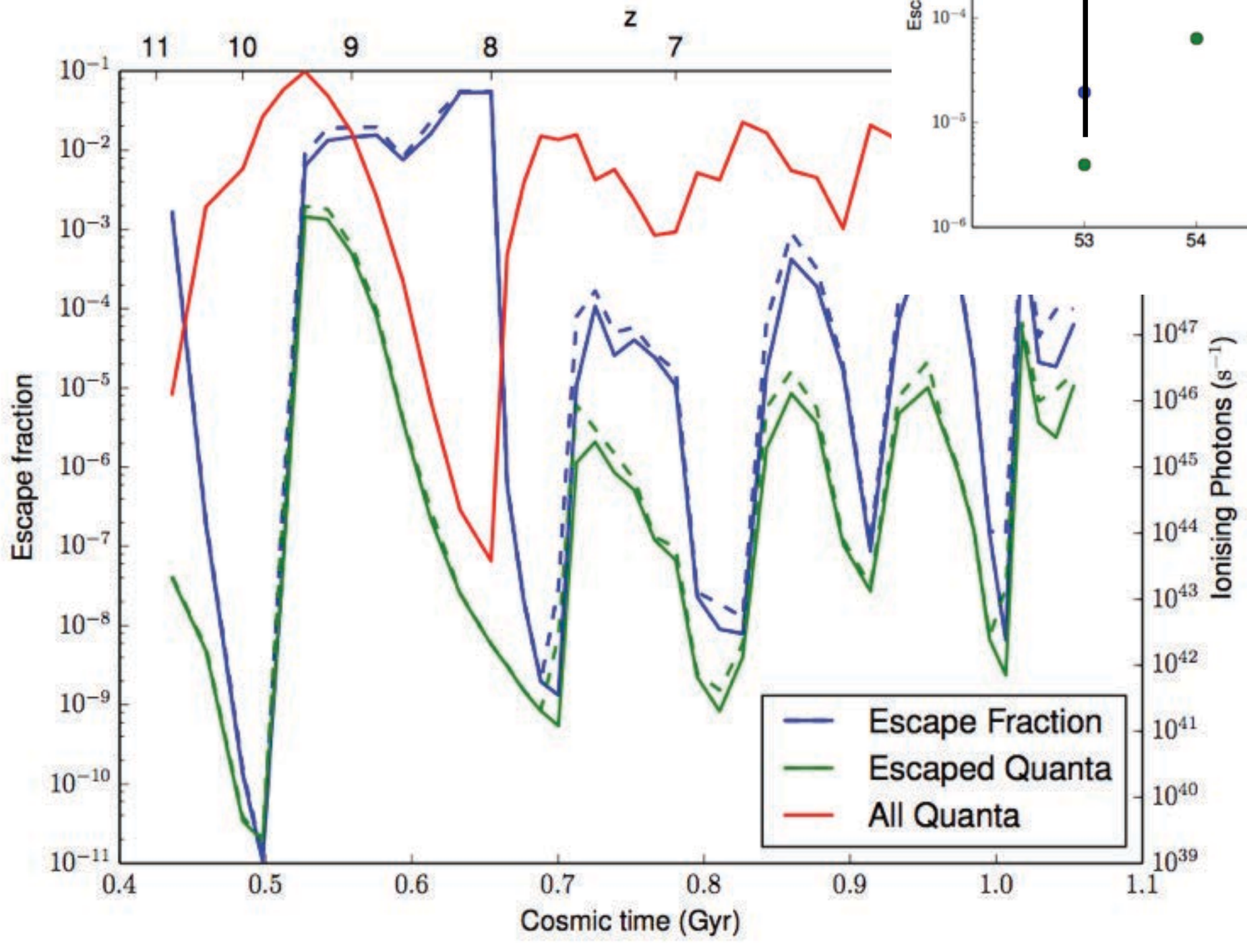
T.-K. Chan et al., in preparation

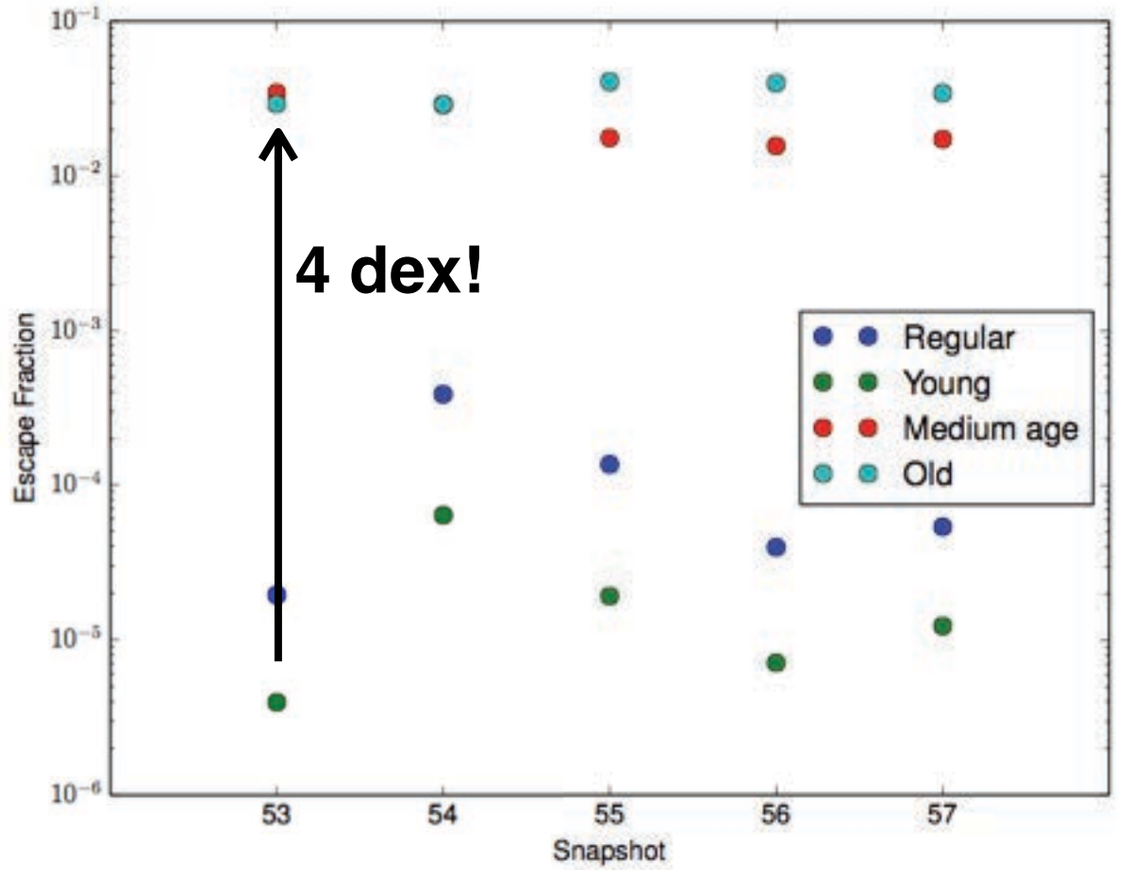


Escape fractions of ionizing photons

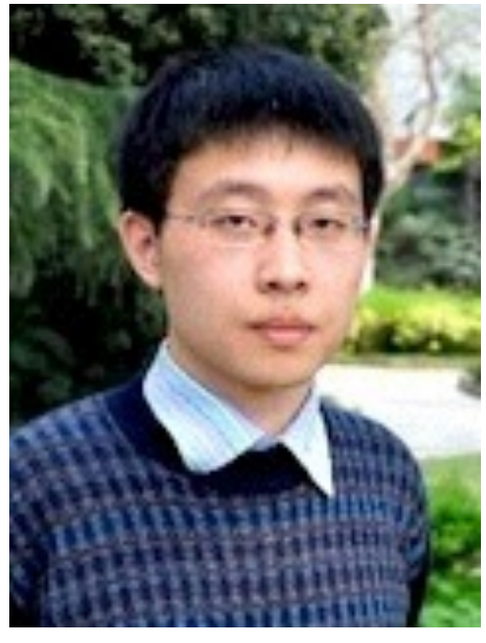
ISM PHASE STRUCTURE MATTERS

resolution ~ 0.1 pc, ~$20\,M_\odot$





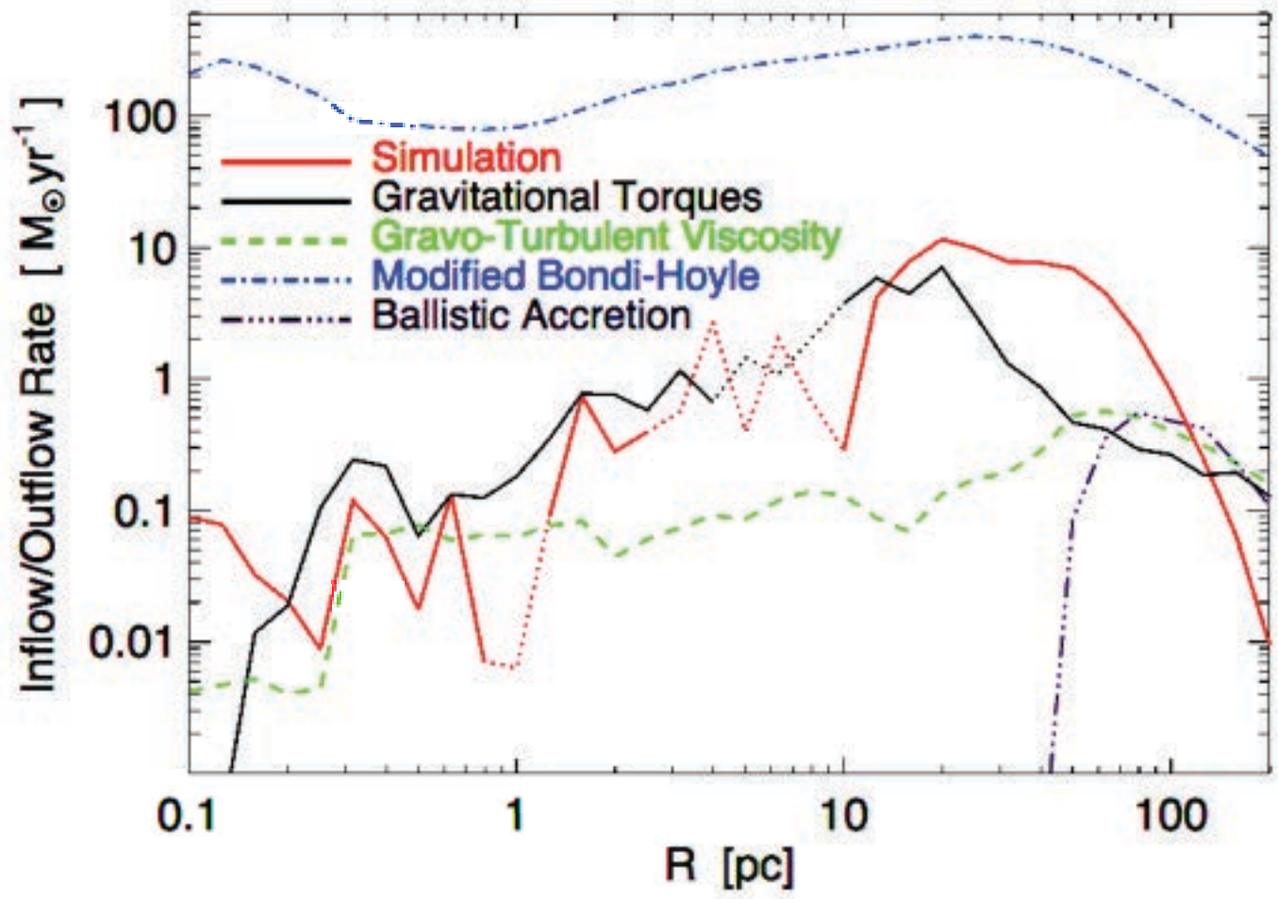
Xiancheng Ma

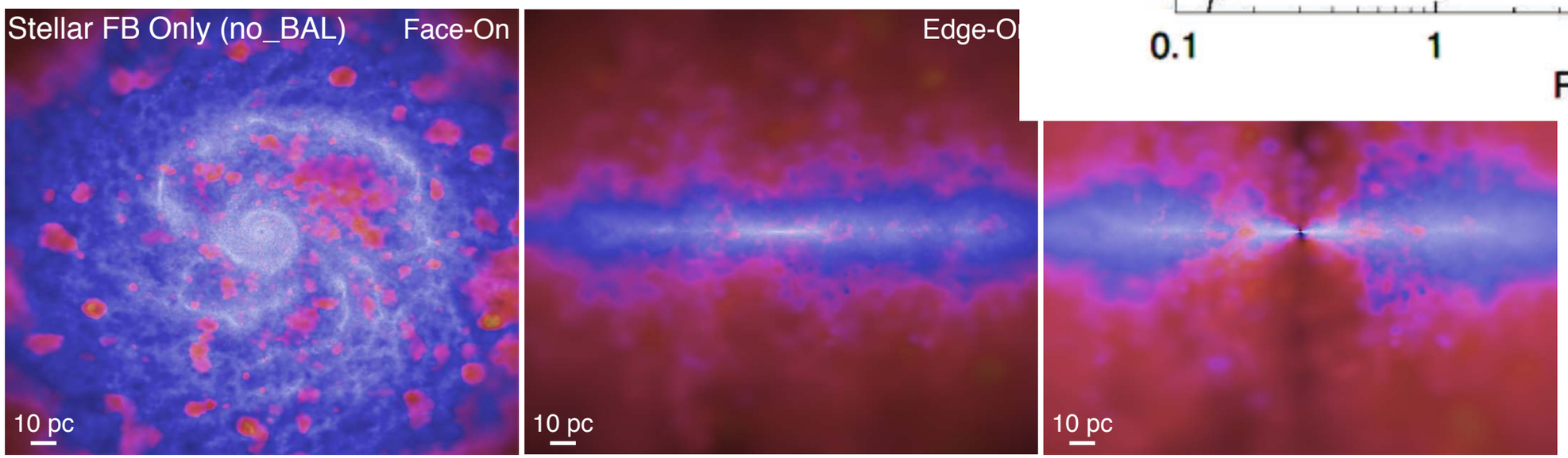


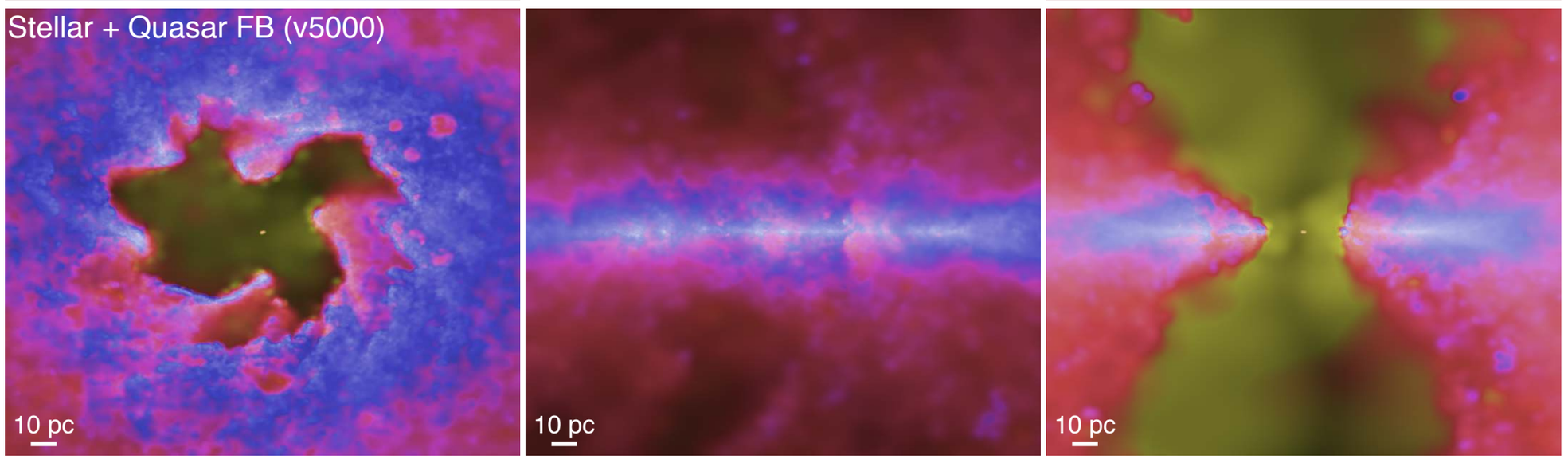
Revisiting Accretion

INCLUDING:

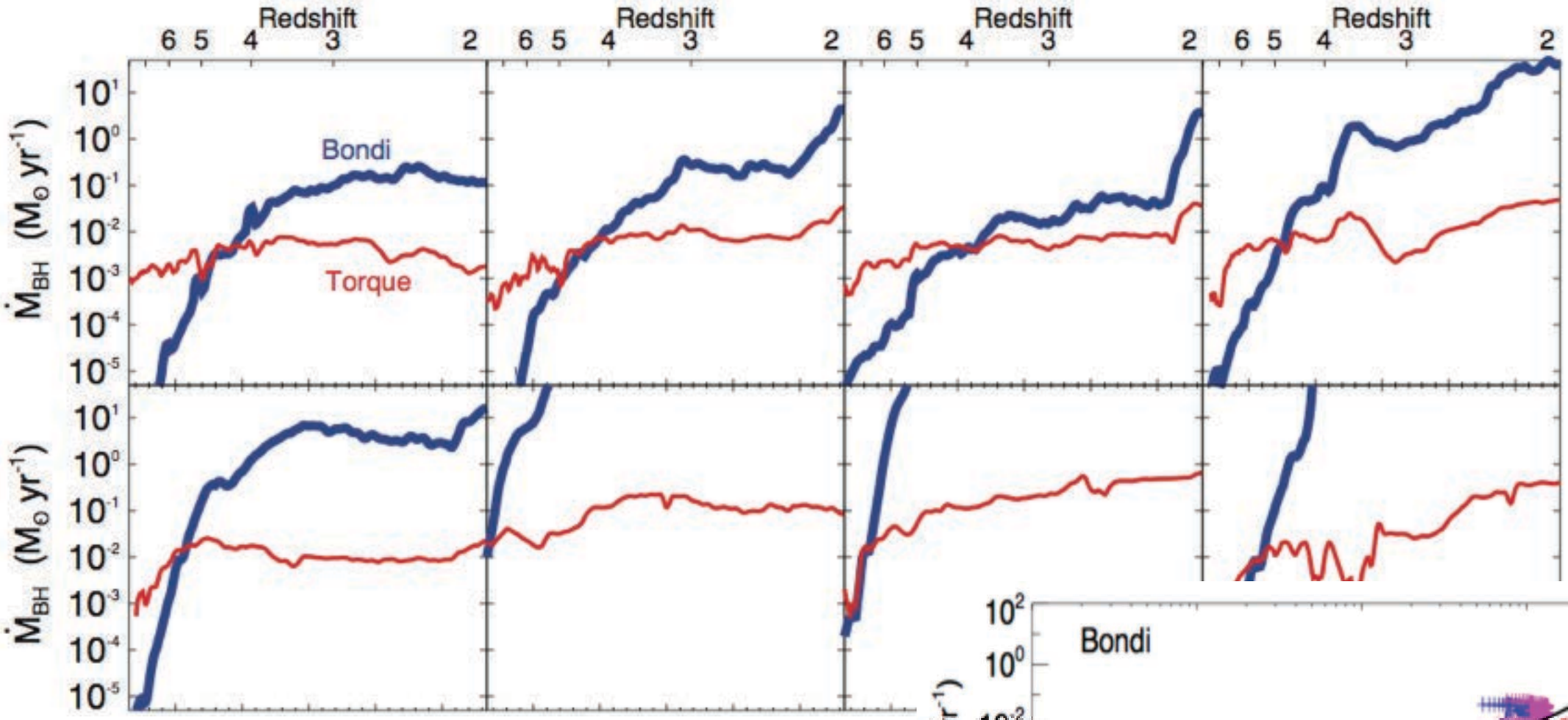
- *RESOLUTION = 0.01 pc, 10 Msun*
- *STELLAR FEEDBACK*
- *COOLING (10K - 1e10 K)*
- *COMPTON HEATING*
- *PHOTOIONIZATION FROM BH+STARS*
- *RADIATION PRESSURE*
- *ACCRETION DISK WINDS*







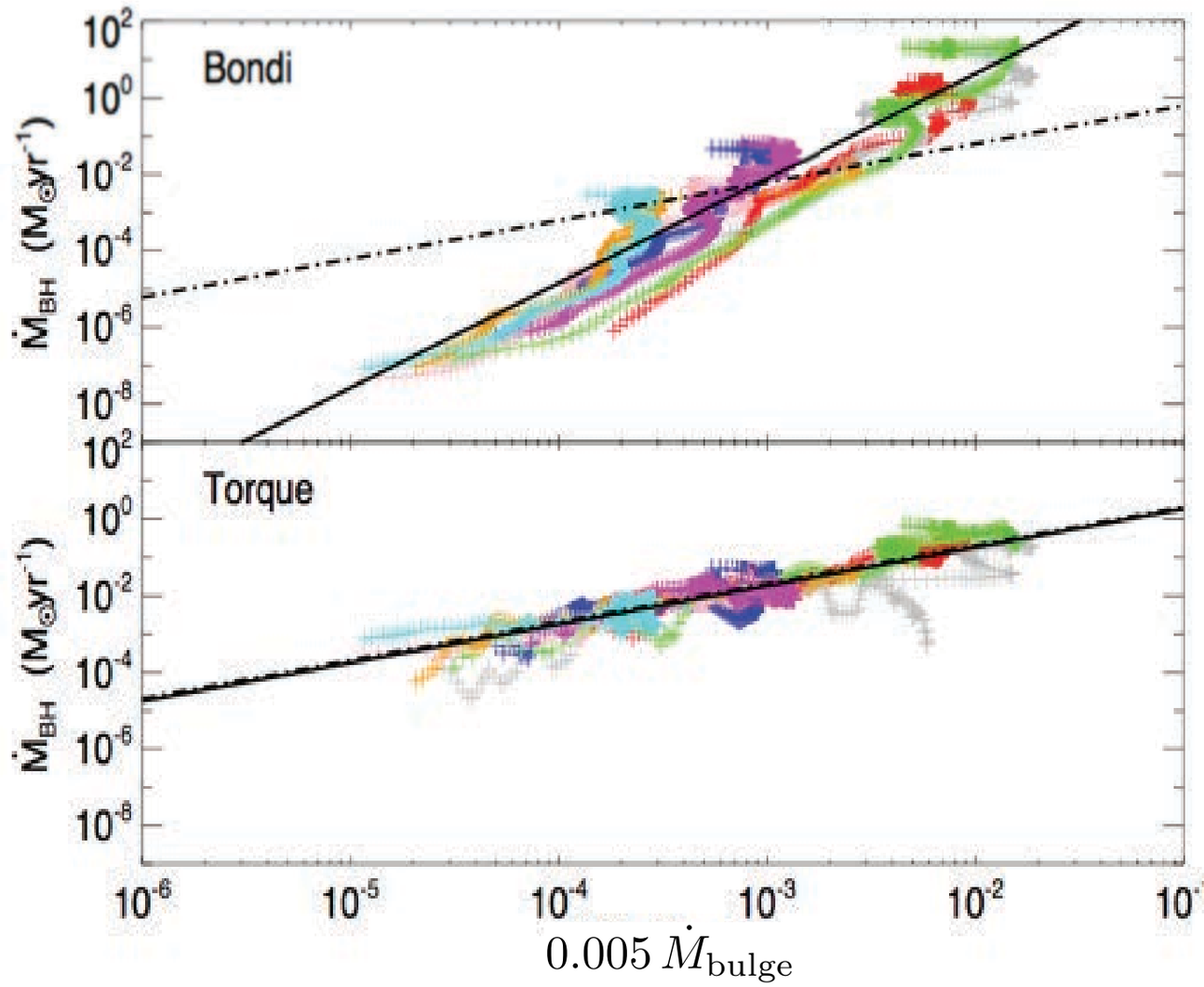
Paul Torrey



Gravitational Torques
vs.
Bondi

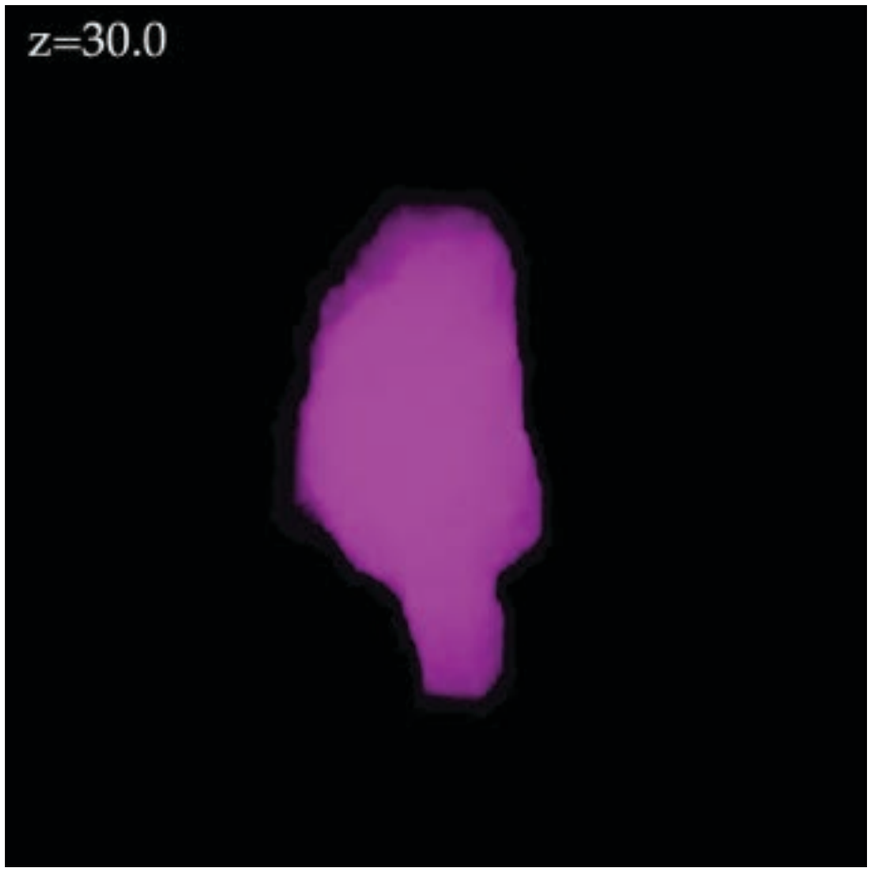
in cosmological sims

Angles-Alcazar et al. 2013

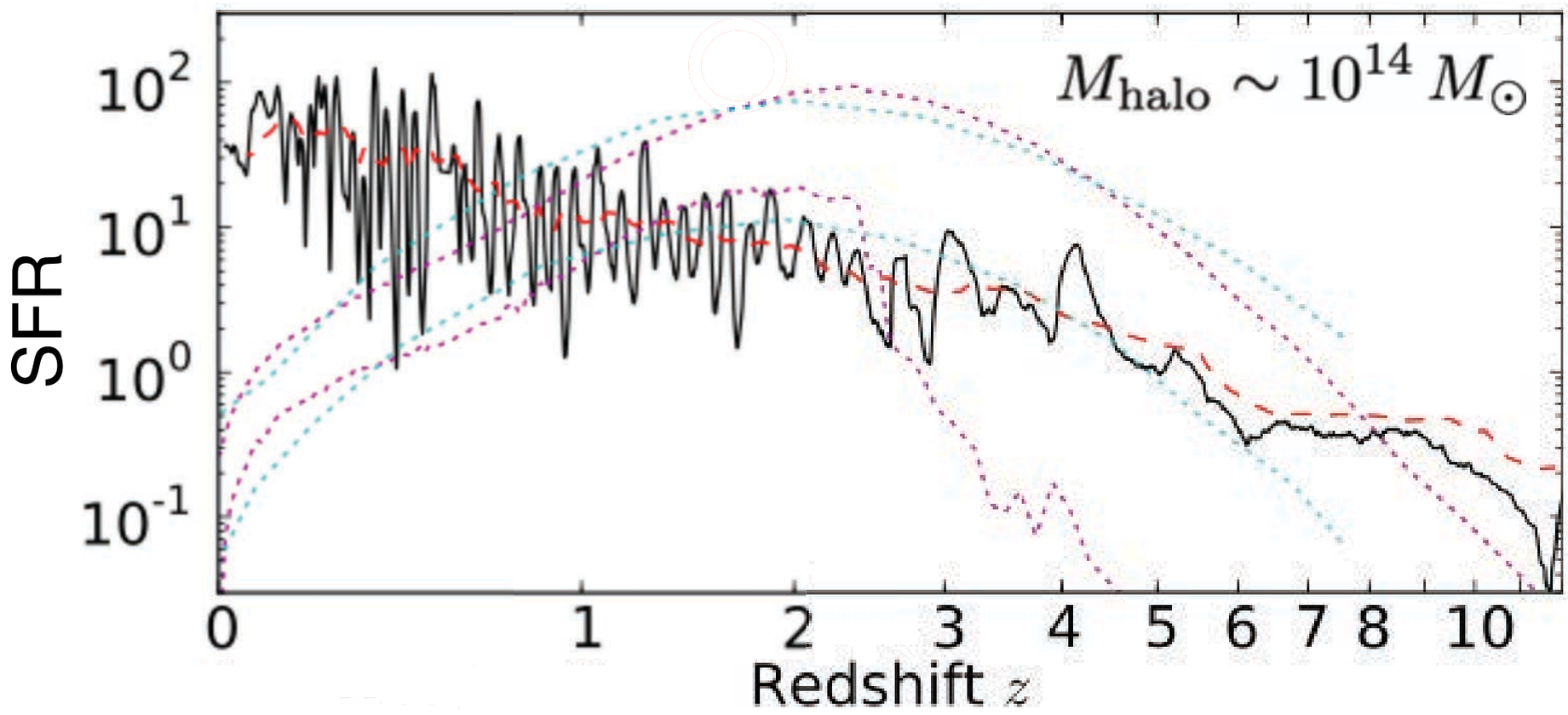


Quenching: Non-AGN Mechanisms *FAIL*

MORE THAN GRAVITY, COOLING, STARS, & MHD



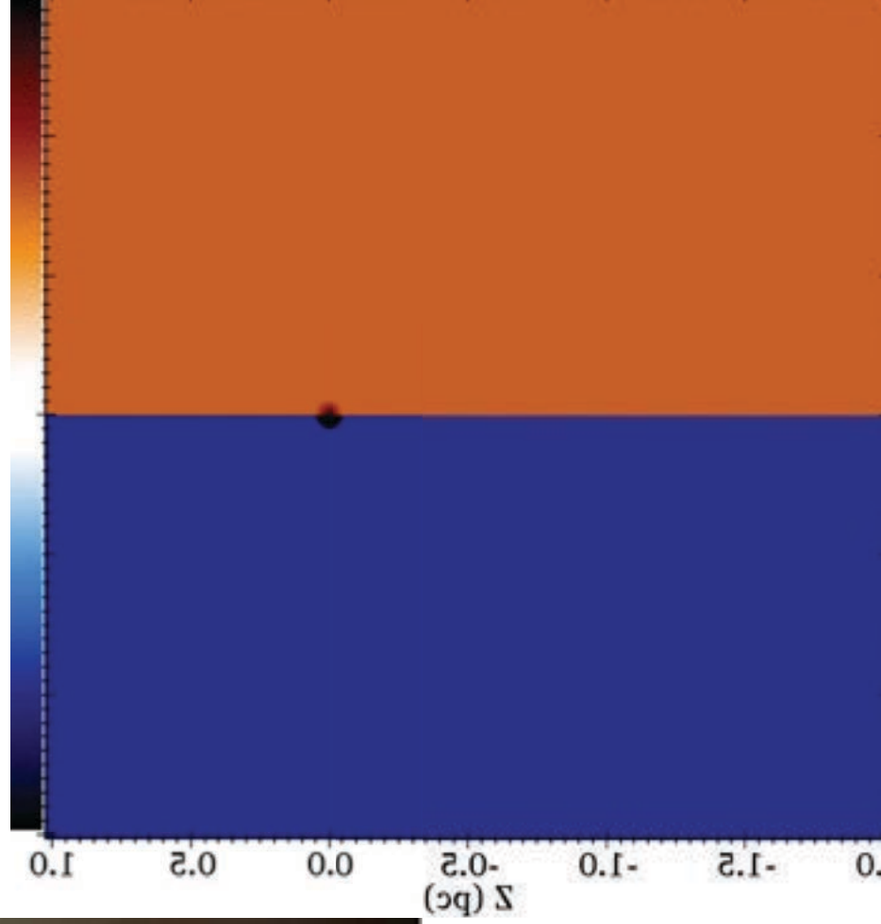
- **Morphology?** (**are** bulge-dominated)
- **Clumps/Gravity?** (resolution ~10^4 M_{sun})
- **MHD/Conduction?** (new runs included)
- **Stars?** (late-time AGB/SNIa included)

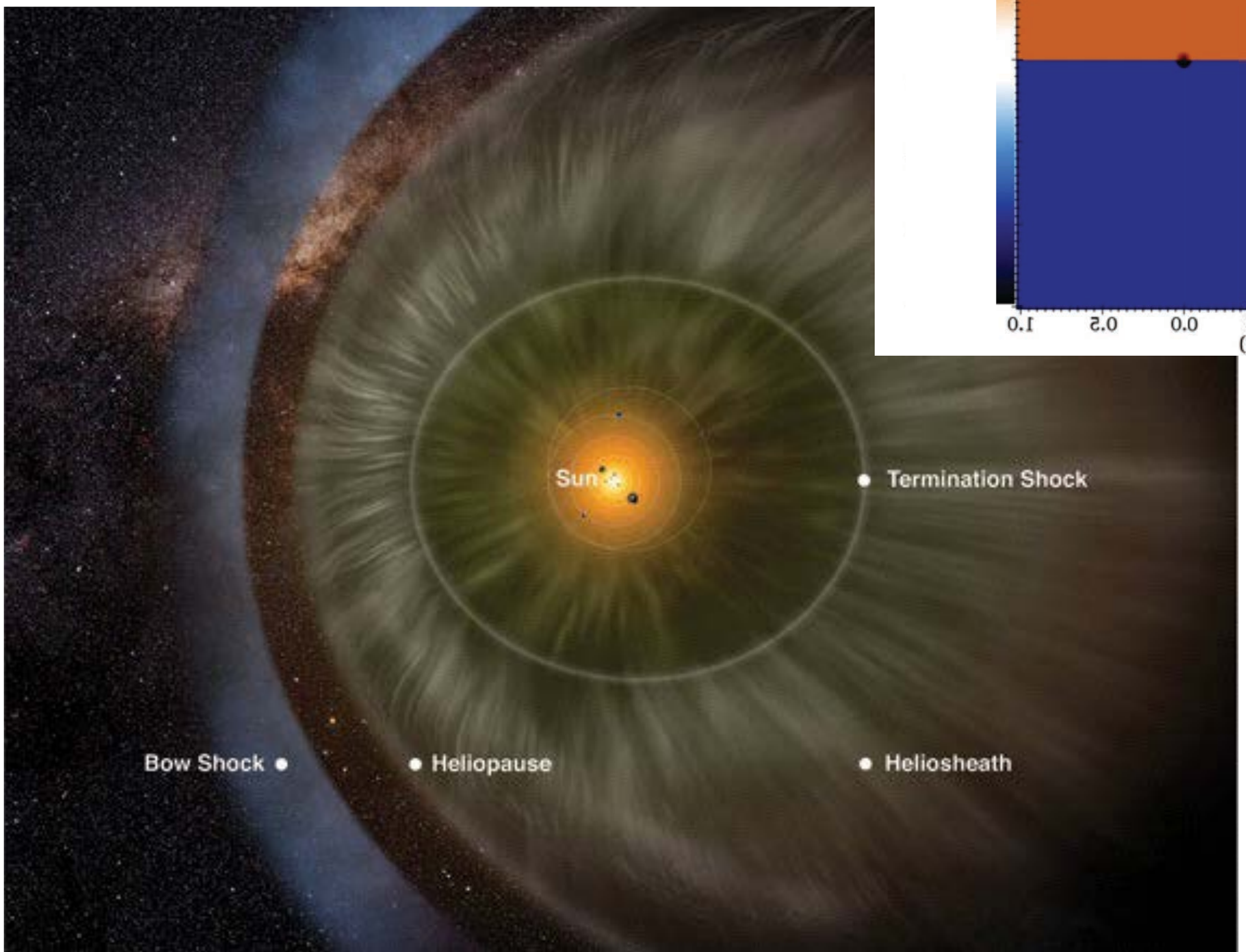


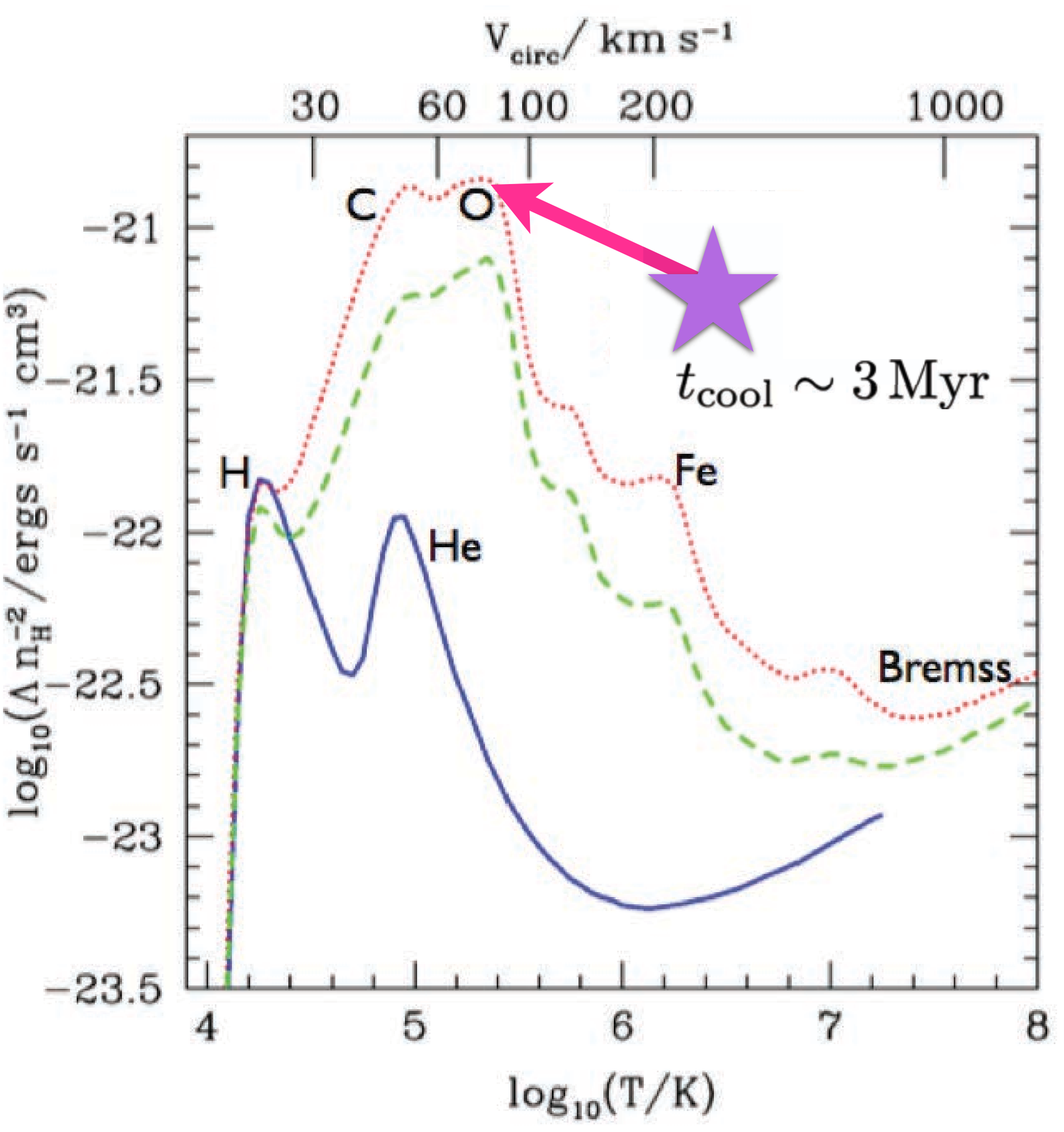
(more to come, Robert Feldmann)

Can Stars Do It?

SNIa, AGB (Conroy+, Ostriker, Novak)





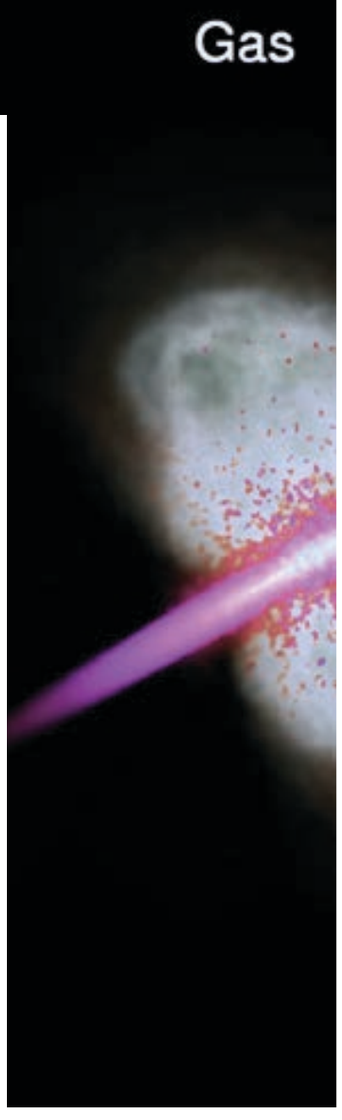

V_{circ}/ km s^{-1}
30
60
100
200
1000
C
O
Fe
H
He
Bremss
$t_{cool} \sim 3\,\mathrm{Myr}$
−21
−21.5
−22
−22.5
−23
−23.5
$\log_{10}(\Lambda\, n_H^{-2}$ /ergs s^{-1} cm^3)
4
5
6
7
8
$\log_{10}$(T/K)

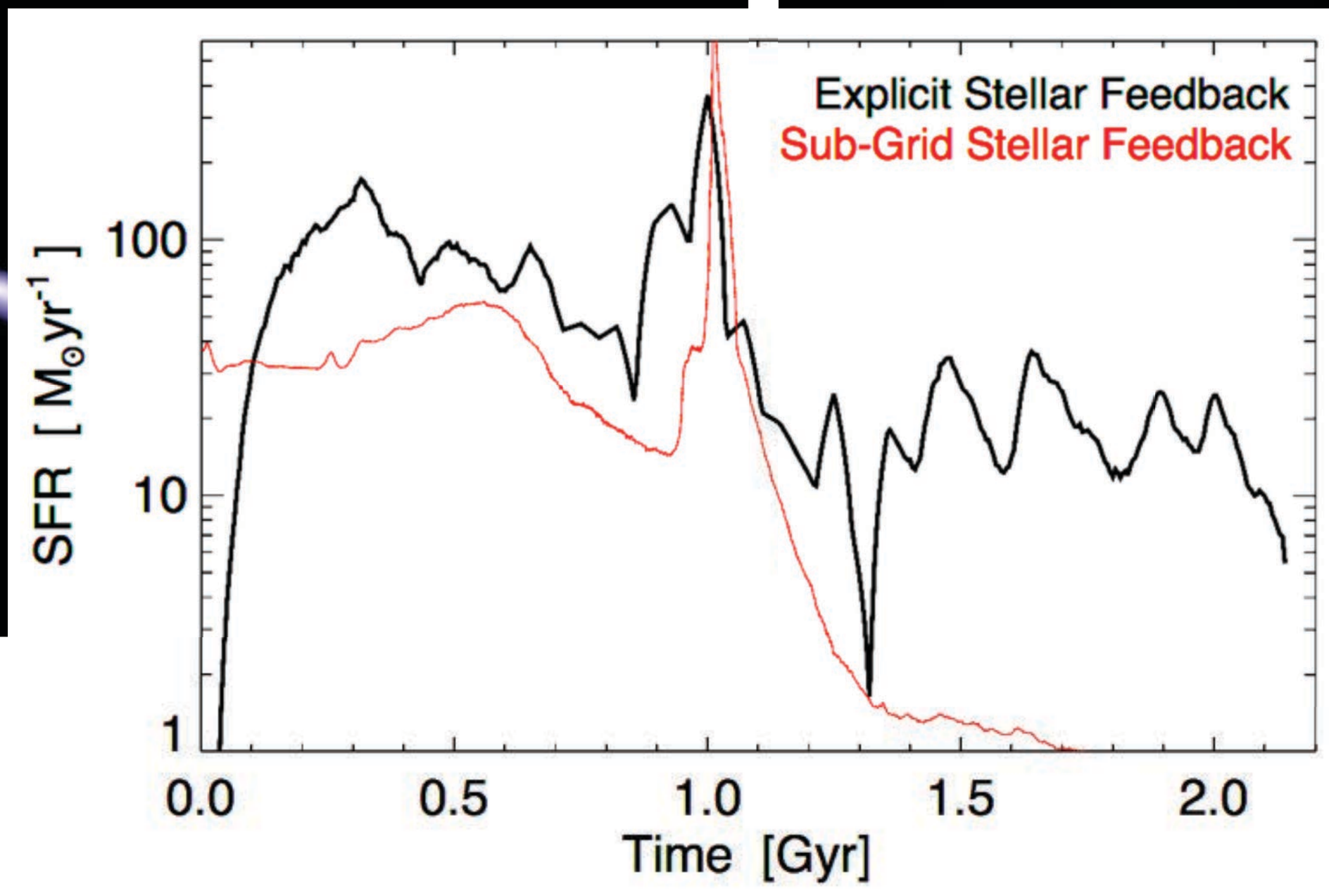
Quenching: Don't Trust Models that Don't Do Stars Right

SMALL GALAXIES BECOME BIG GALAXIES

"Decoupled Winds" (Sub-Grid)

Following Explicit Feedback

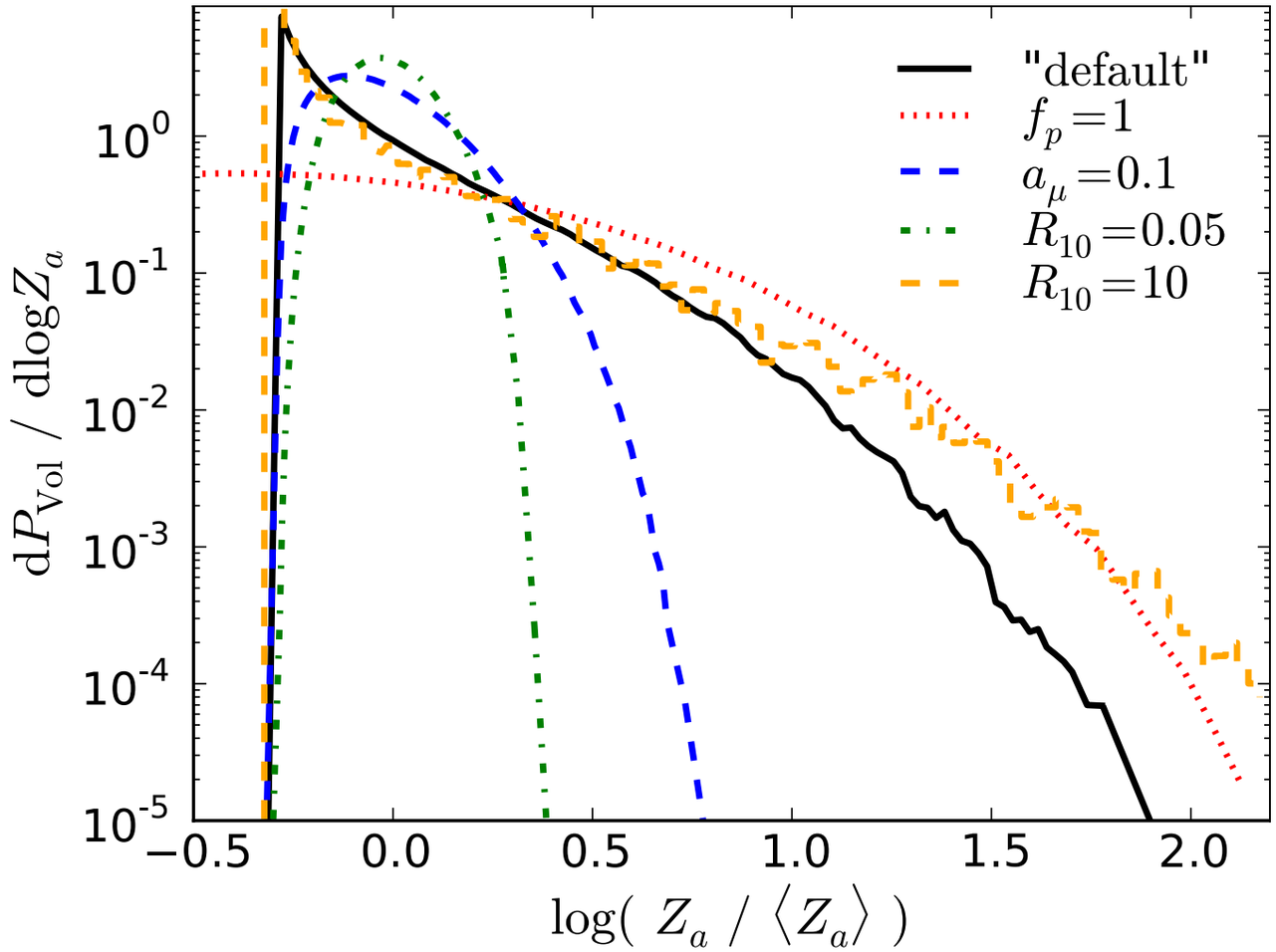


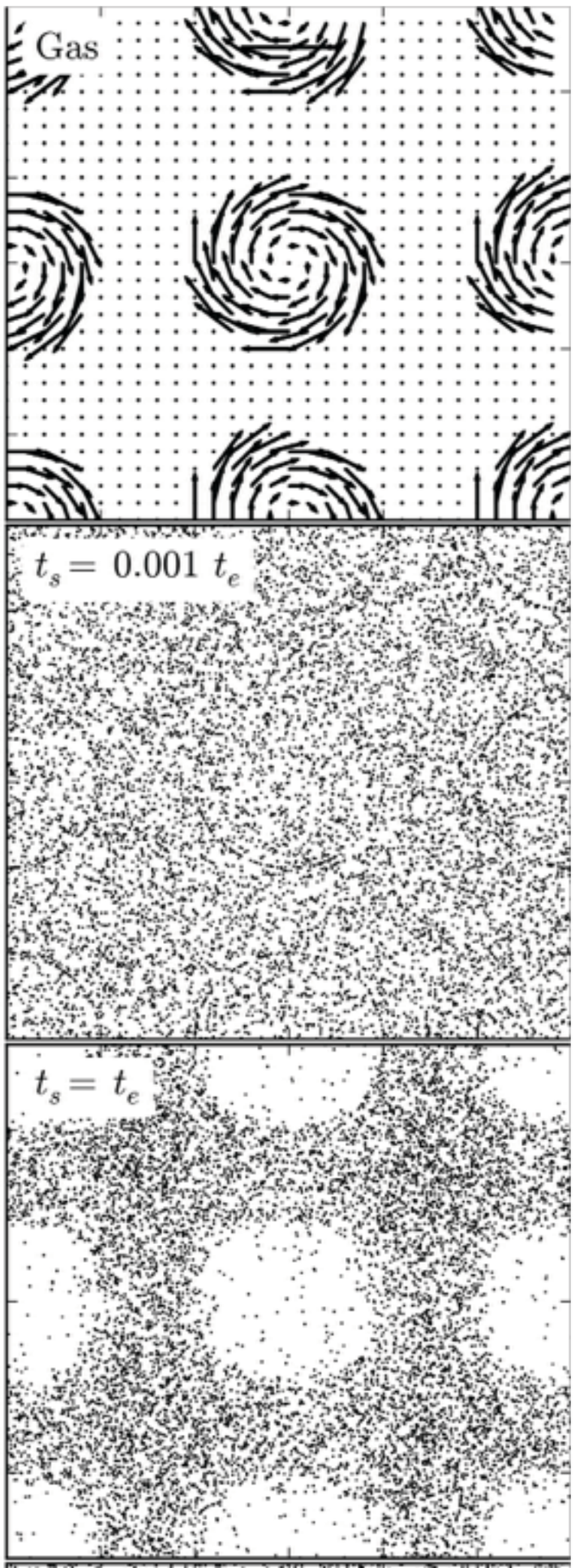


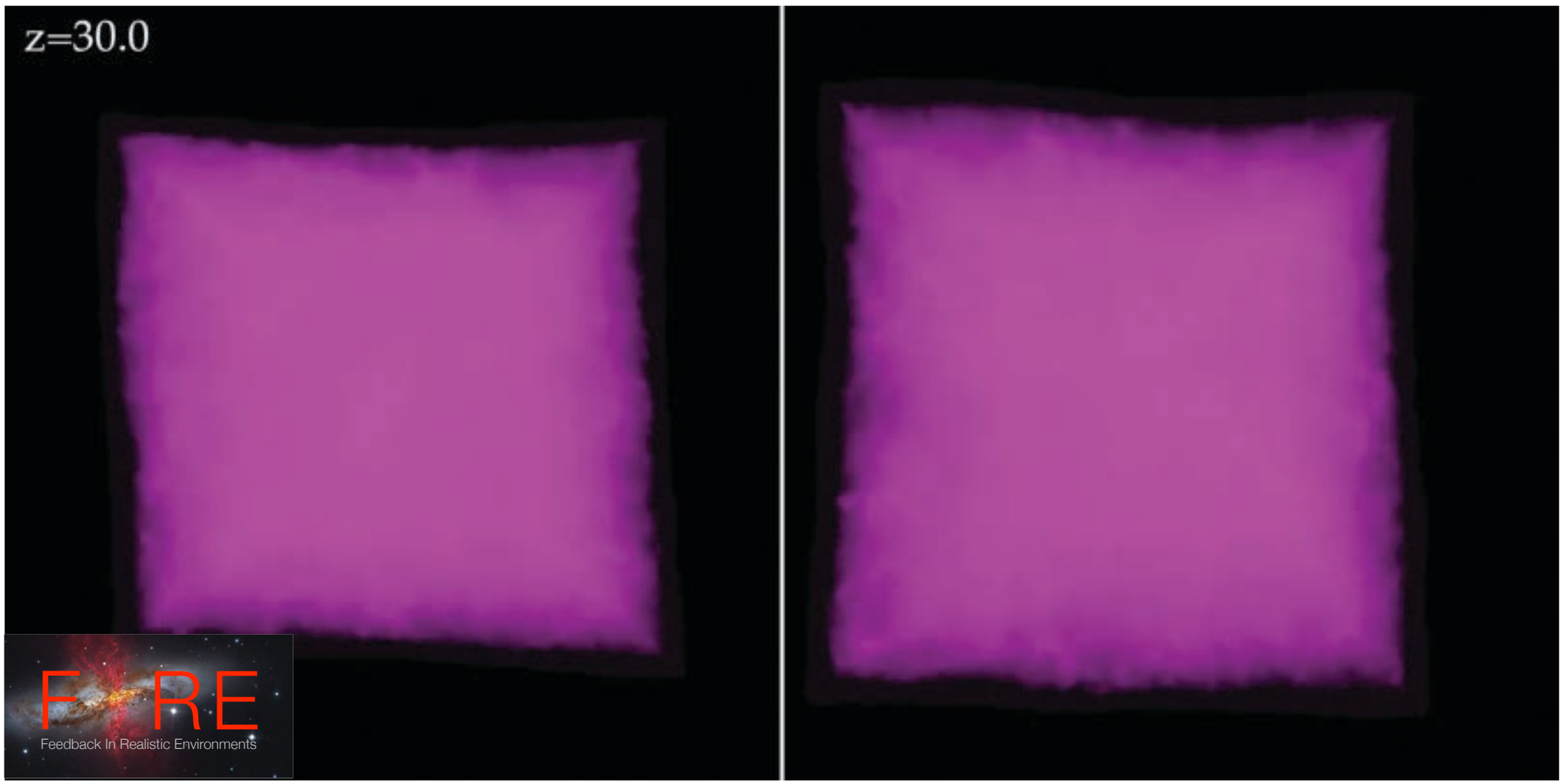
Totally Metal Stars?

(PFH, arXiv:1406.5509)

- **Dust is not Gas**
  - Instabilities segregate gas and dust
  - Large core-to-core fluctuations in species in big grains (C,O)







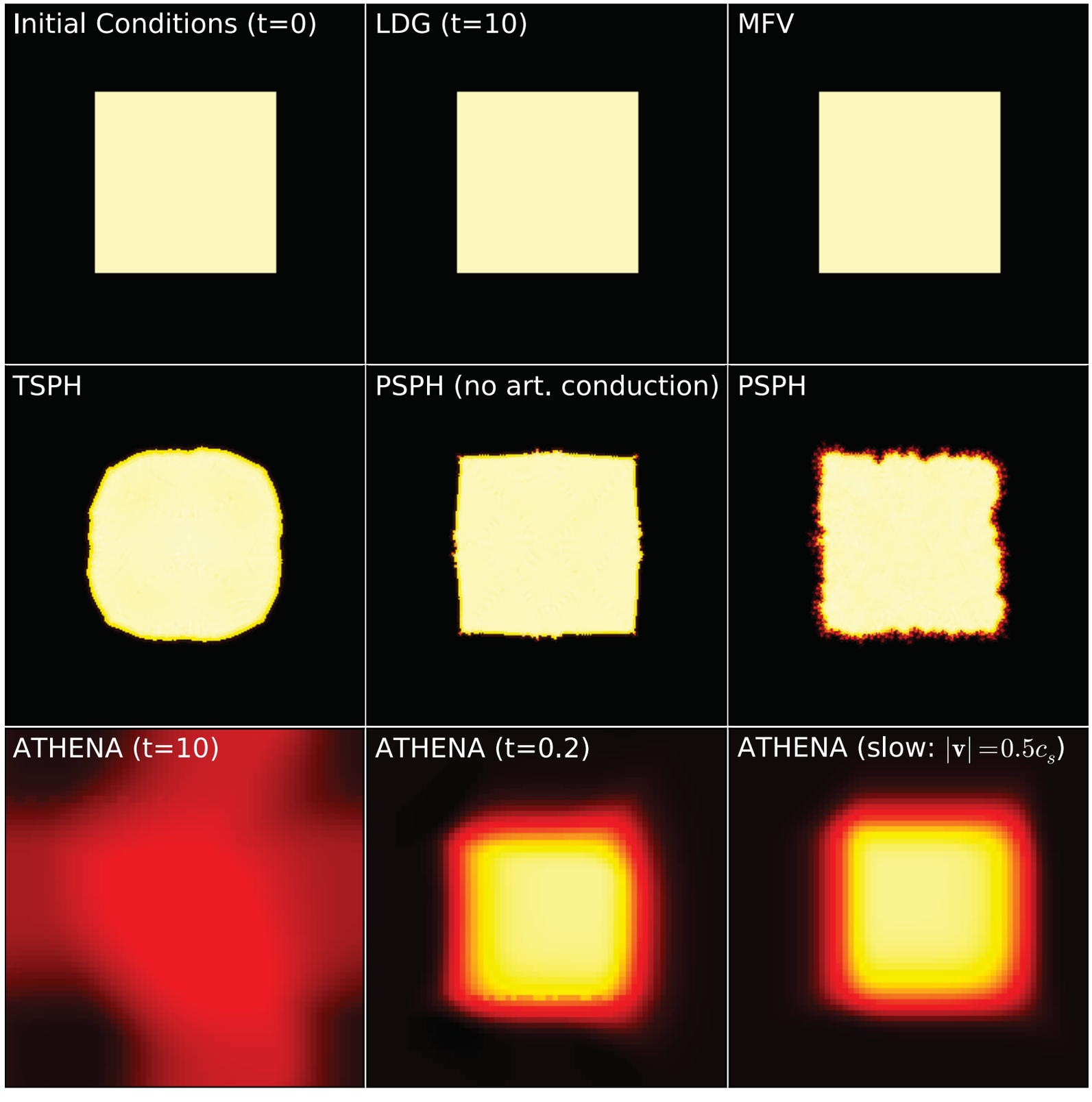
- **Star formation is Feedback-Regulated**: *independent* of small-scale SF
- Cosmologically: ***Accretion does not regulate star formation***
  - **Winds** determine **IGM enrichment, temperature, & subsequent inflow**
  - **Resolved feedback ≠ sub-grid feedback**!
    - Mass-metallicity, SFHs, morphology *not the same*
- **New Physics (AGN?)** needed to "quench": **Stars *enhance* overcooling**
- **Lots of work in progress!** (stay tuned)

GIZMO: A New, Public Gravity+Hydro Code

(to appear very soon)

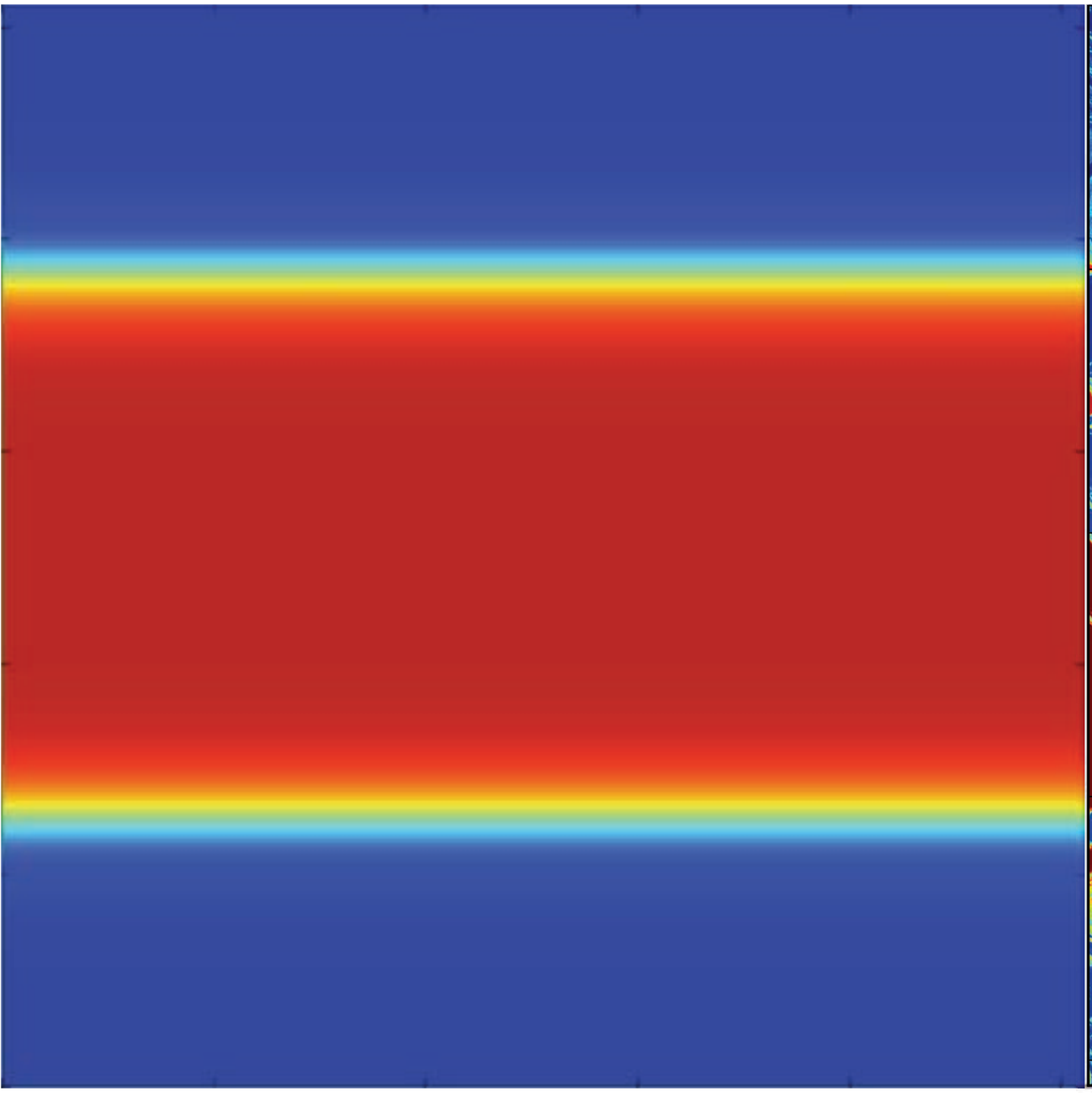
- **You choose:**
  - 'Traditional' SPH
  - 'Modern' P-SPH
  - Meshless Finite Volume
  - Finite-Mass Galerkin
  - Moving-Mesh (ongoing)

- **100% compatible**
  with GADGET ICs/snaps

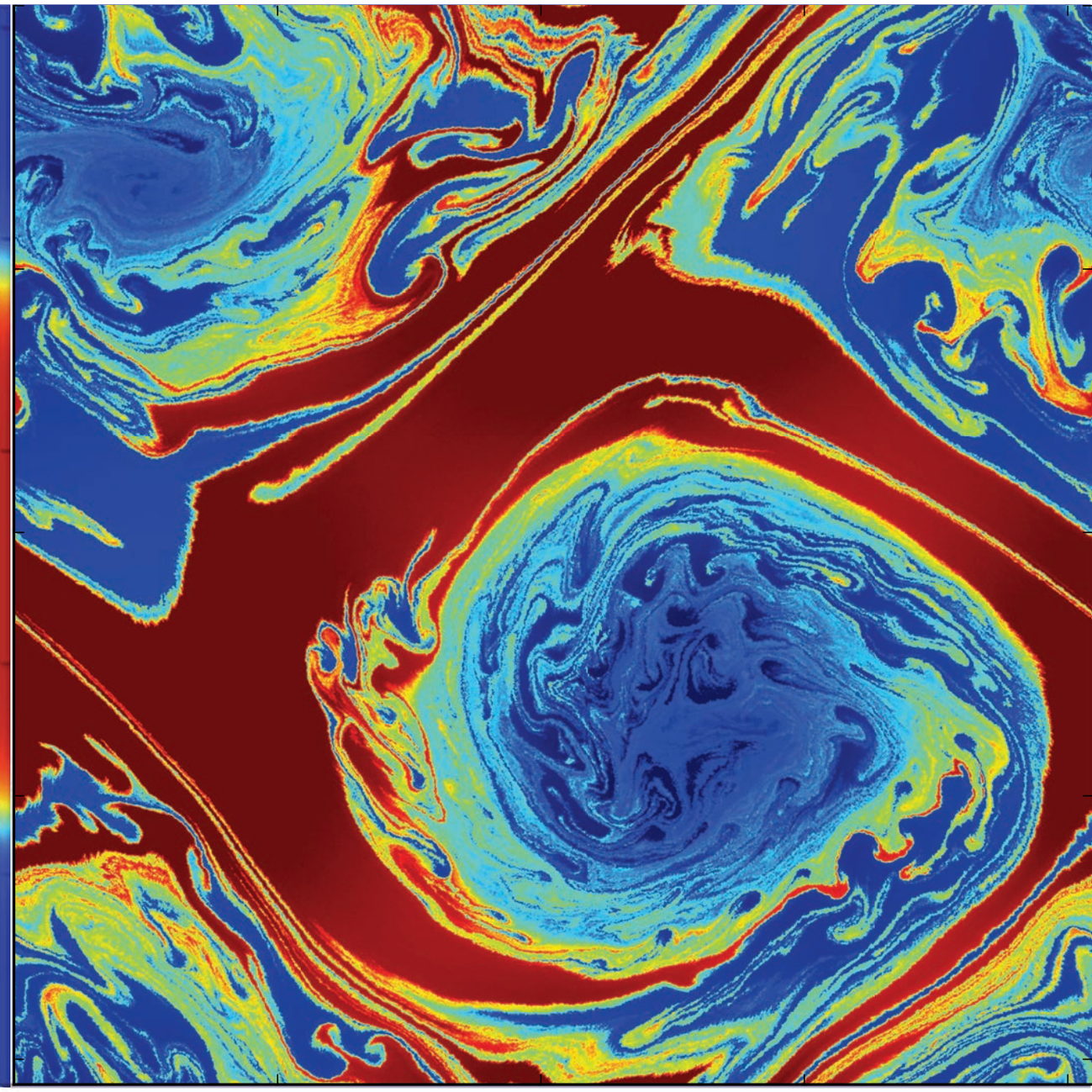


GIZMO: A New, Public Gravity+Hydro Code

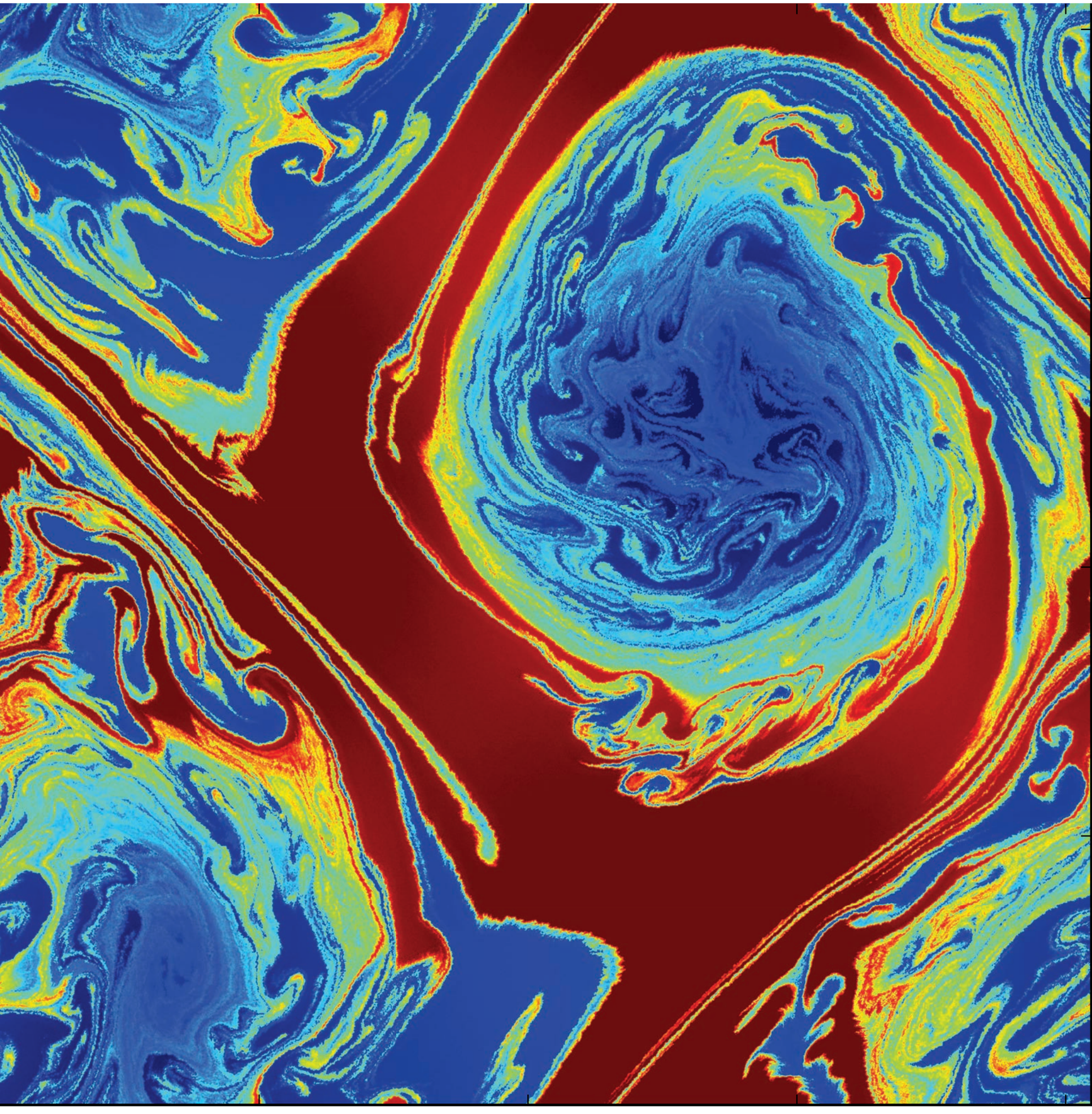
(to appear very soon)

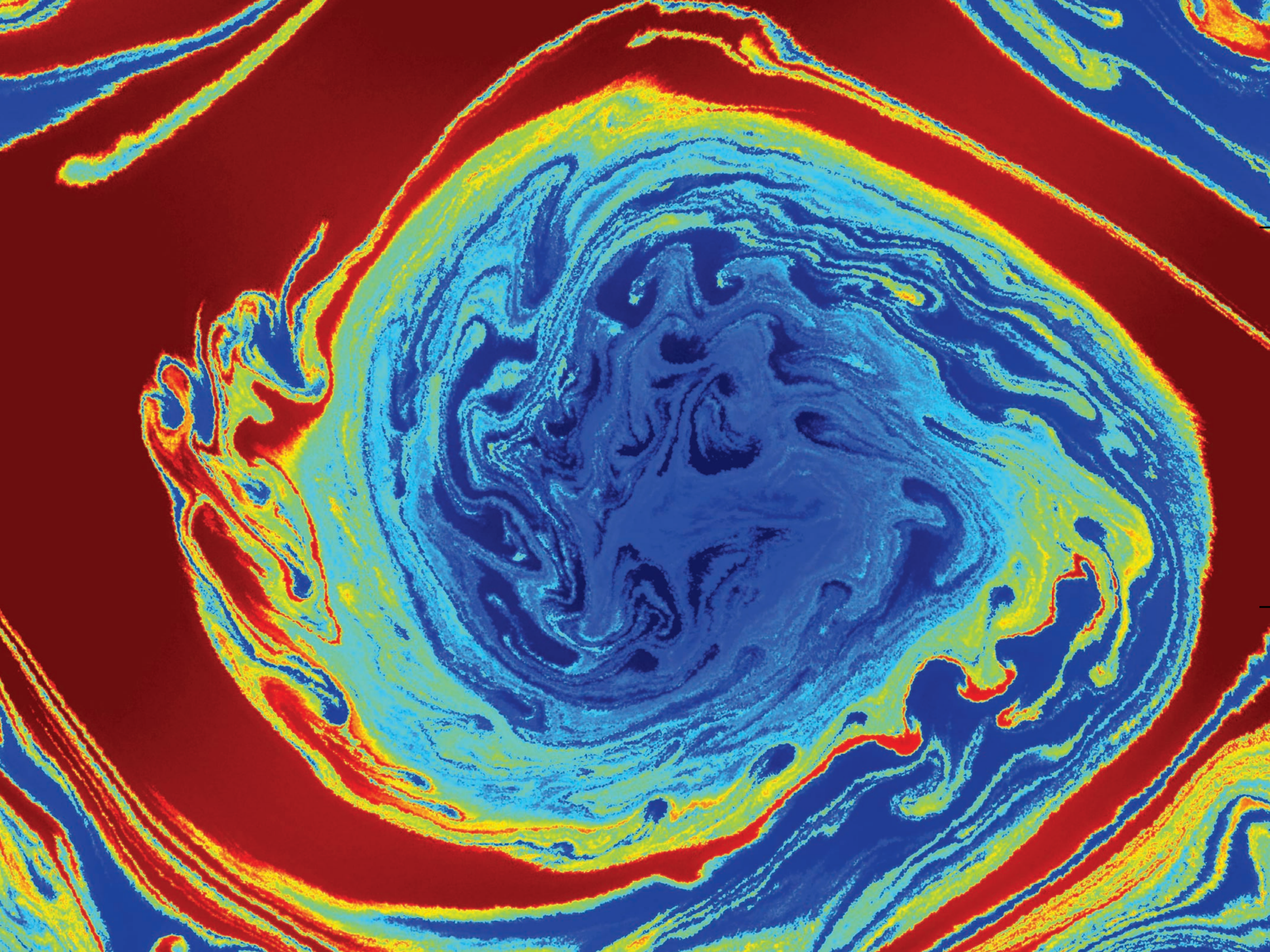


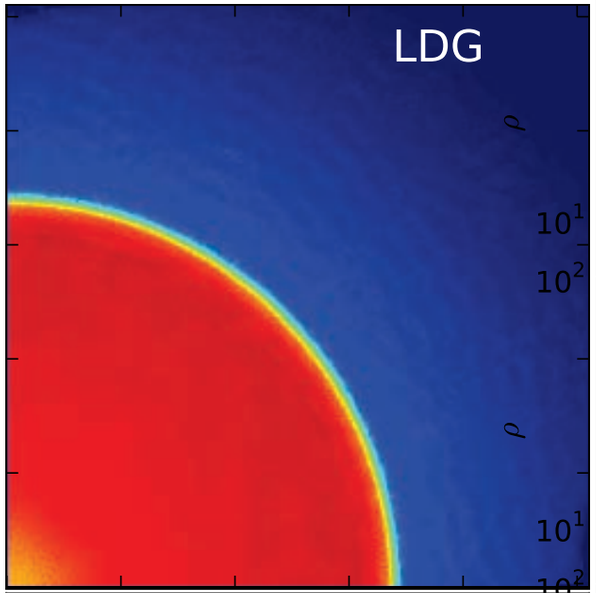
Cartesian Grid

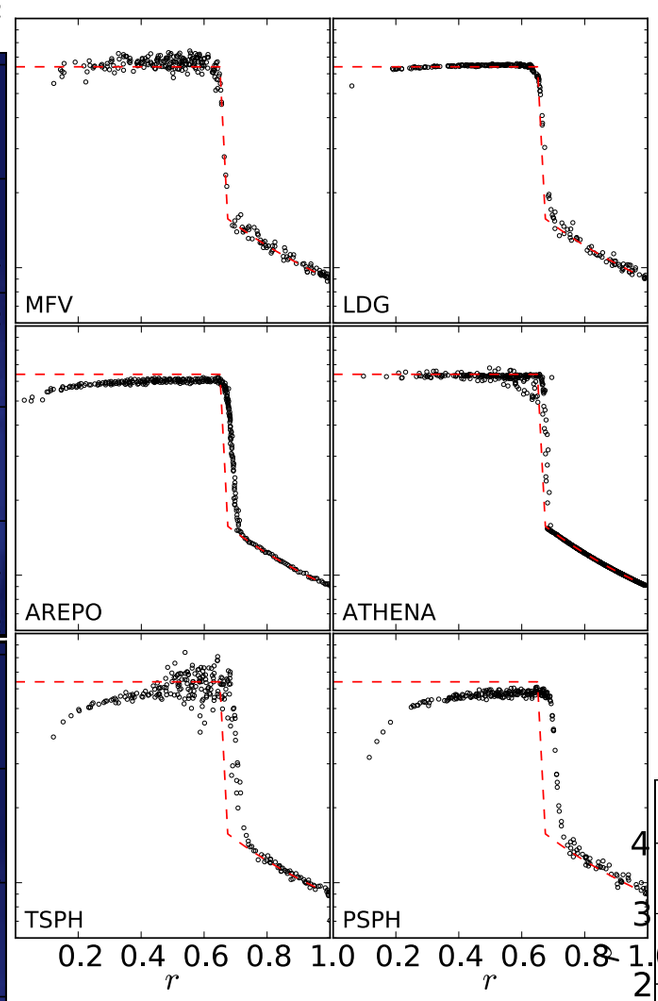


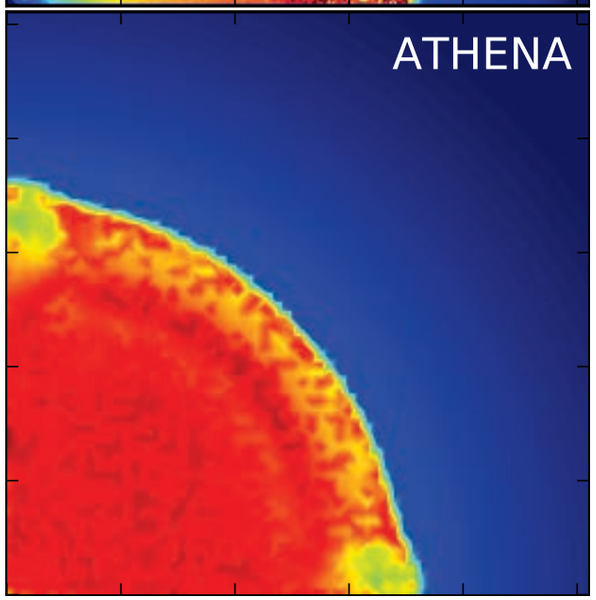
Meshless Finite Volume





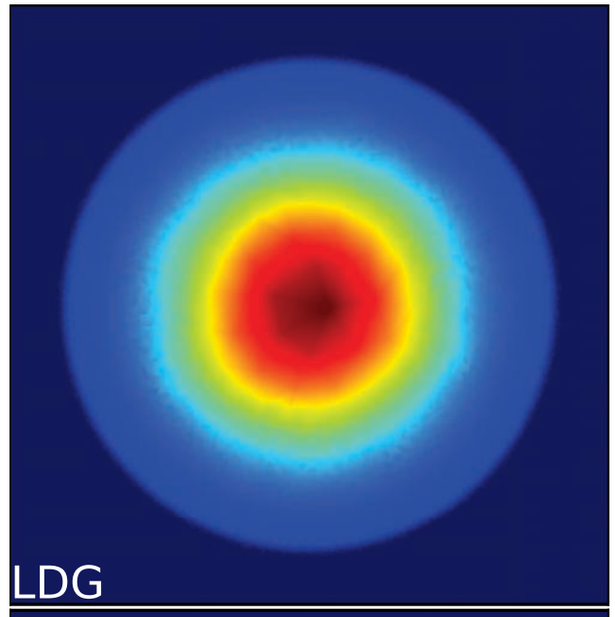


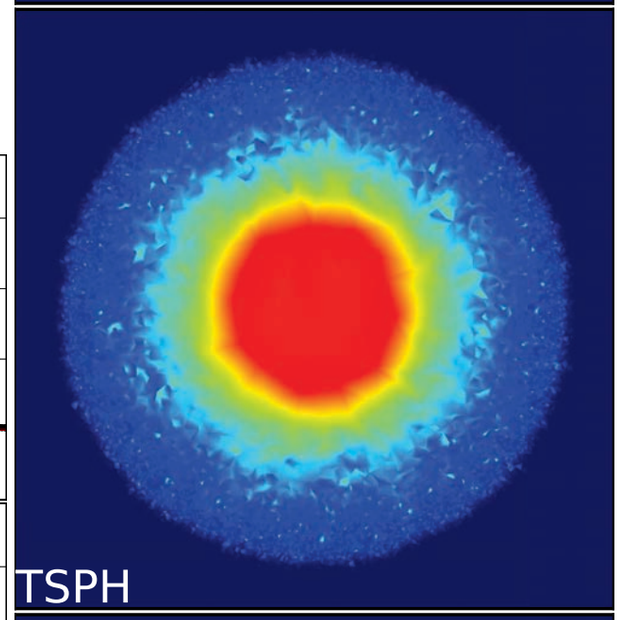


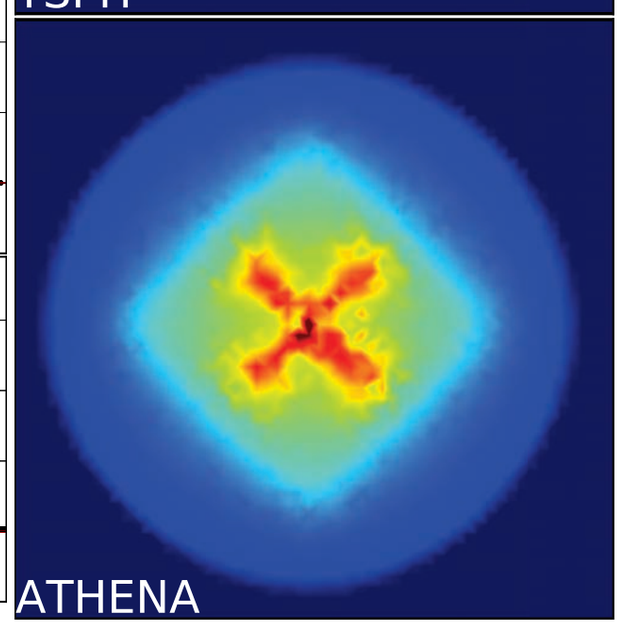


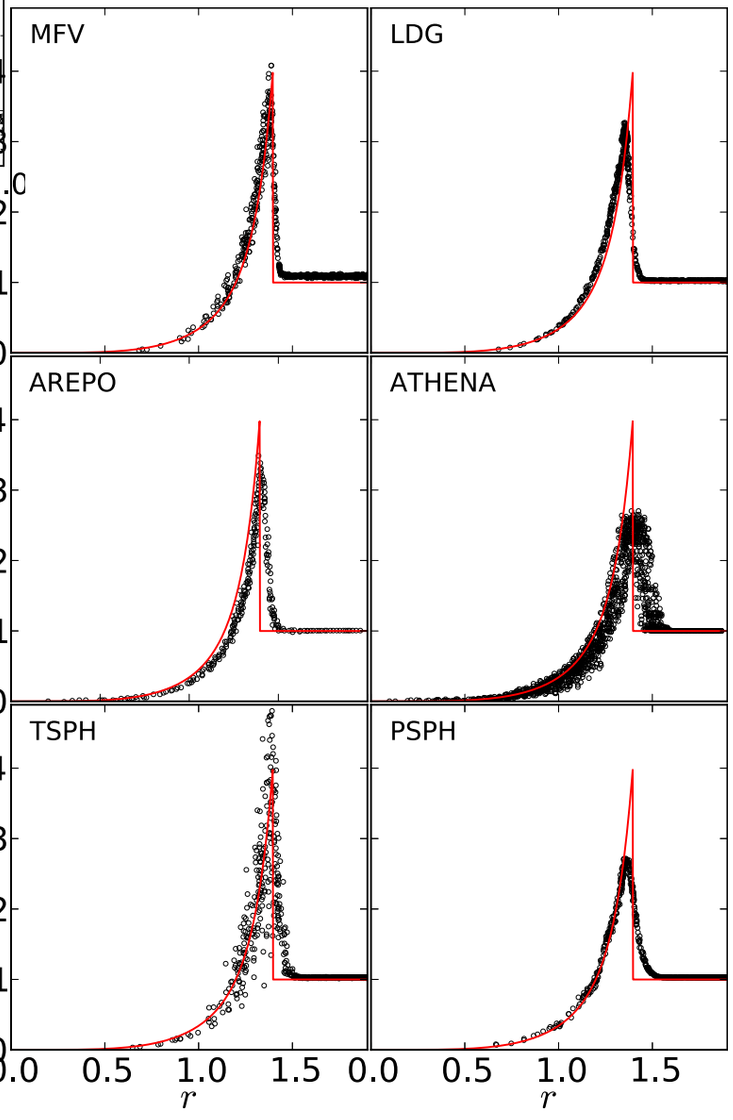
Sedov Explosion

Noh Implosion









Comparing methods in GIZMO: Angular Momentum