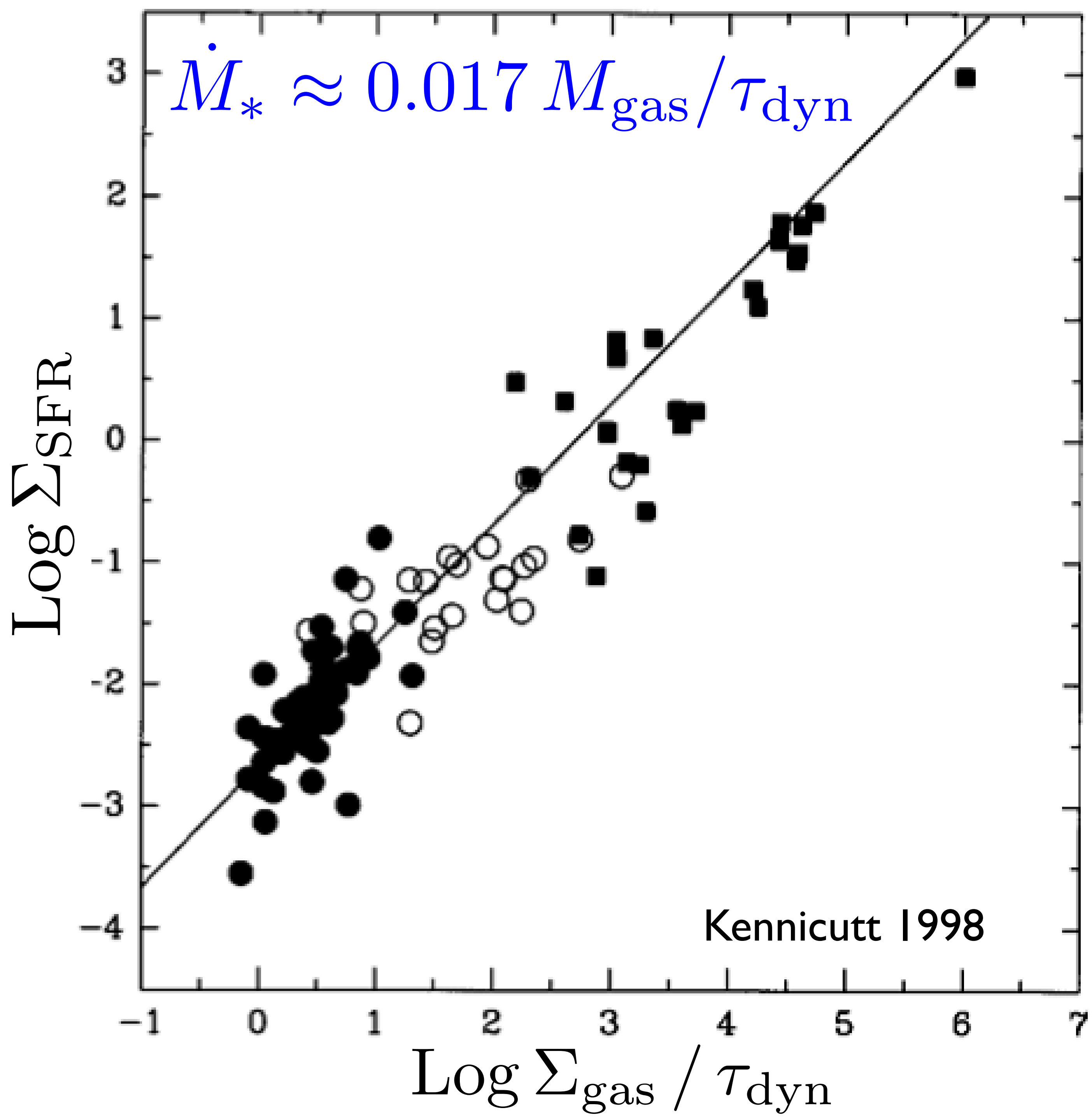
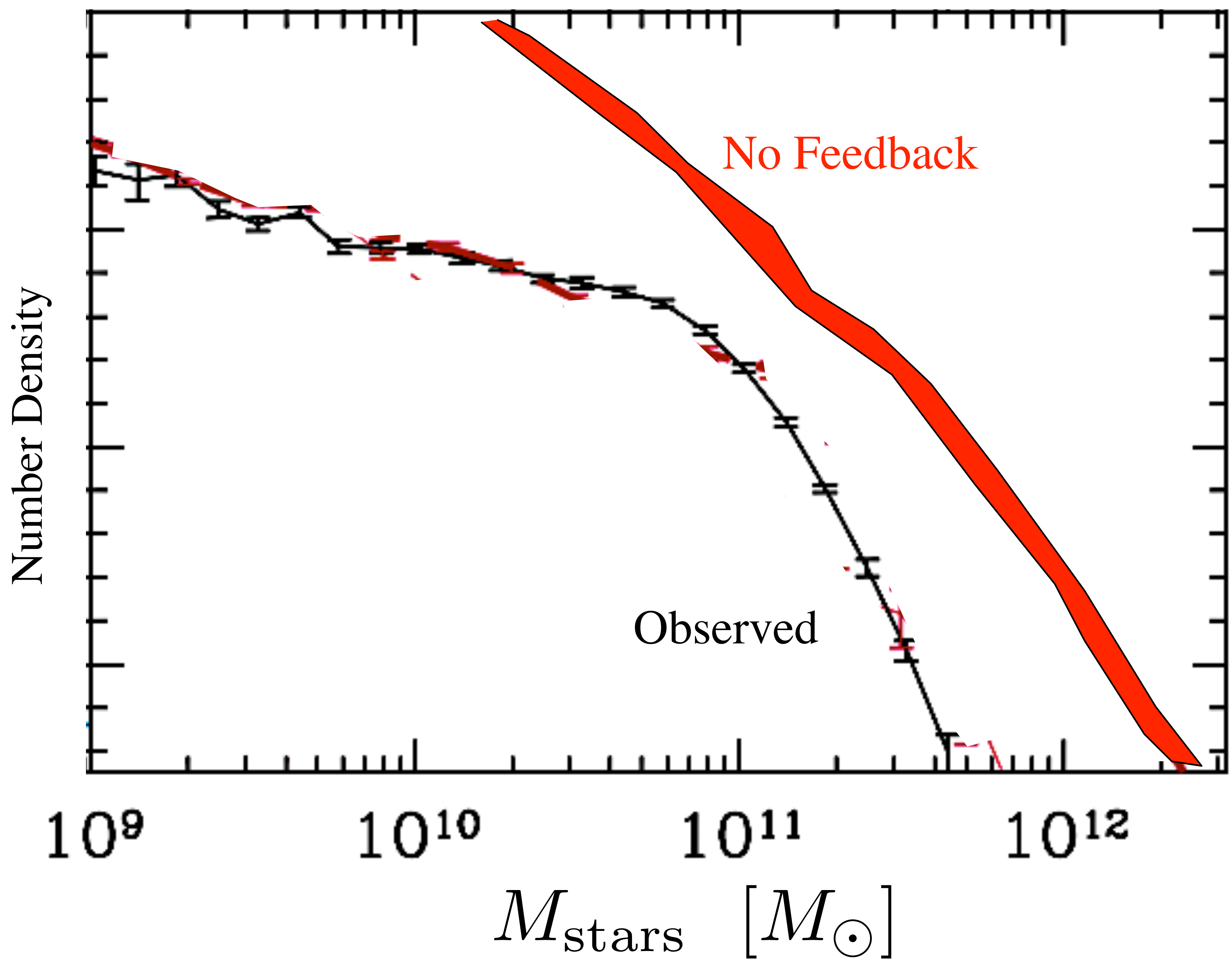
Motivation

Q: WHY IS STAR FORMATION SO INEFFICIENT?



Motivation

Q: WHY IS STAR FORMATION SO INEFFICIENT?



Feedback is the Key!
SO WHAT'S THE PROBLEM?

- Gravity — Good!
- Hydro + Ideal MHD — Yes!
- Chemistry / cooling physics — Not bad
- "Feedback" — Huh?

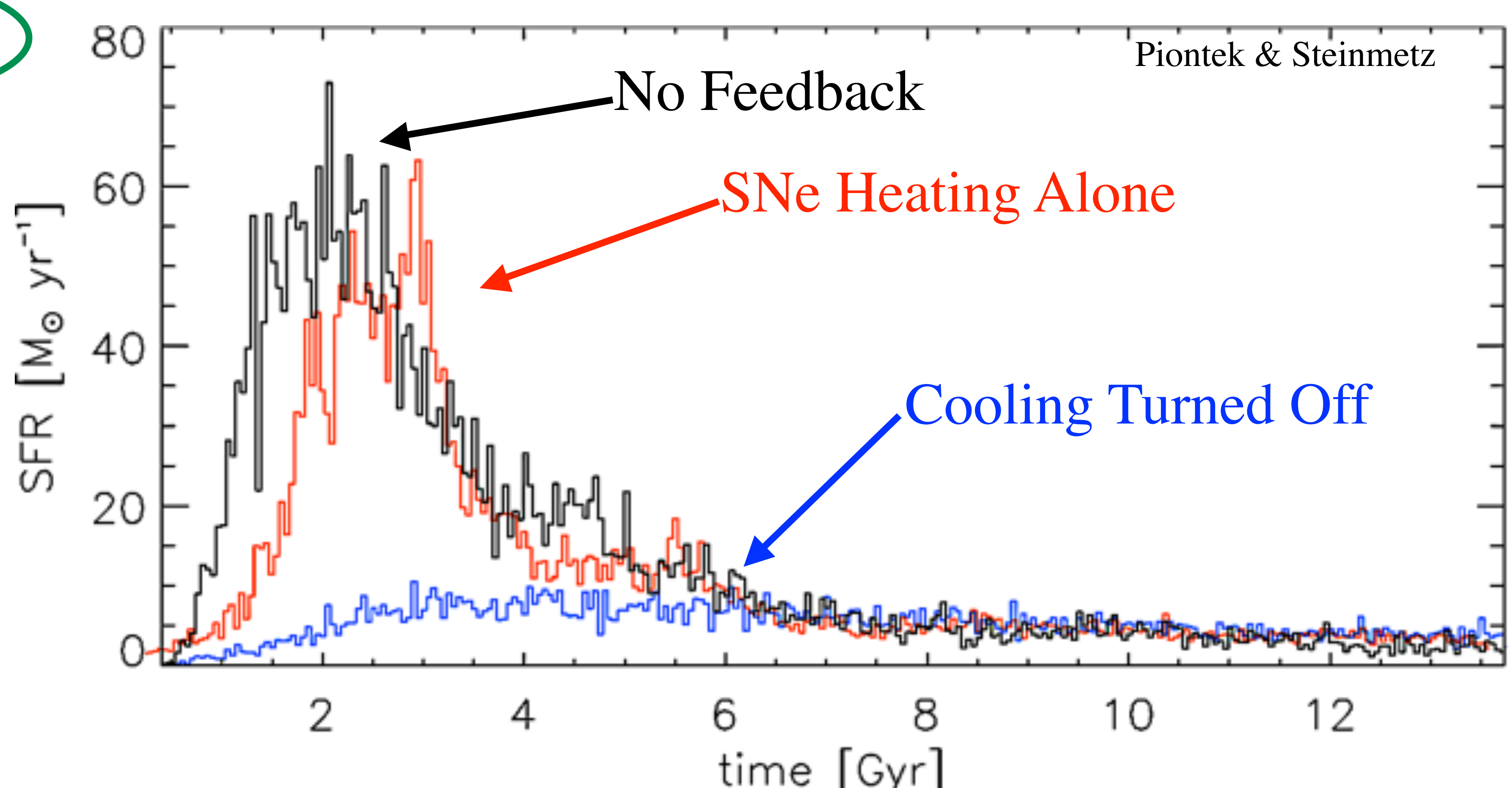
- Standard (in Galaxy Formation): Couple SNe (~1e51 erg/SN) as "heating"/thermal energy

...

...

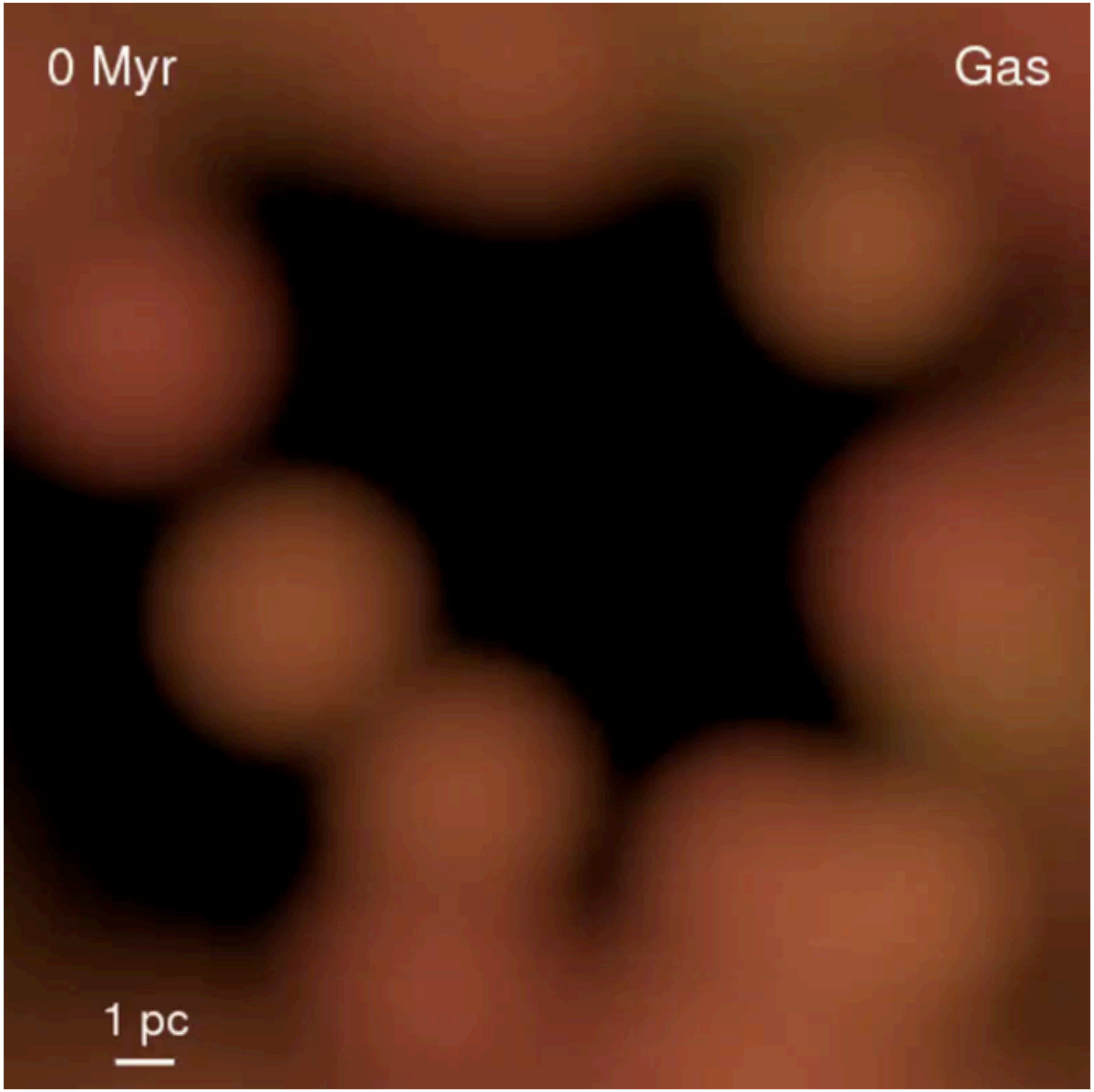
and then "cheat":

- Turn off cooling
- Force wind by hand ('kick' out of galaxy)



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/Momentum/Metal Injection:
  - SNe (II & Ia)
  - Stellar Winds (O & AGB)
  - Photoionization (HII) & Photoelectric
  - Cosmic Rays?



- (also MHD, anisotropic conduction, diffusion)

(Stellar) Feedback Does:

- generate galactic outflows (sets galaxy stellar masses)
- disrupt GMCs (sets GMC lifetimes/integrated SF ‘efficiency’; difference between bound cluster+association)
- self-regulate ISM/galaxy-scale collapse (sets KS law on >kpc scales)
- enrich ISM (metals, dust?)
- alter *low-mass* end of the IMF (preventing fragmentation), and (more indirectly) high-mass end (limiting runaway accretion)
- determine phase structure of ISM (hot/cold balance, not necessarily morphology)
- reionize the Universe (H, He from QSOs)
- power ISM turbulence

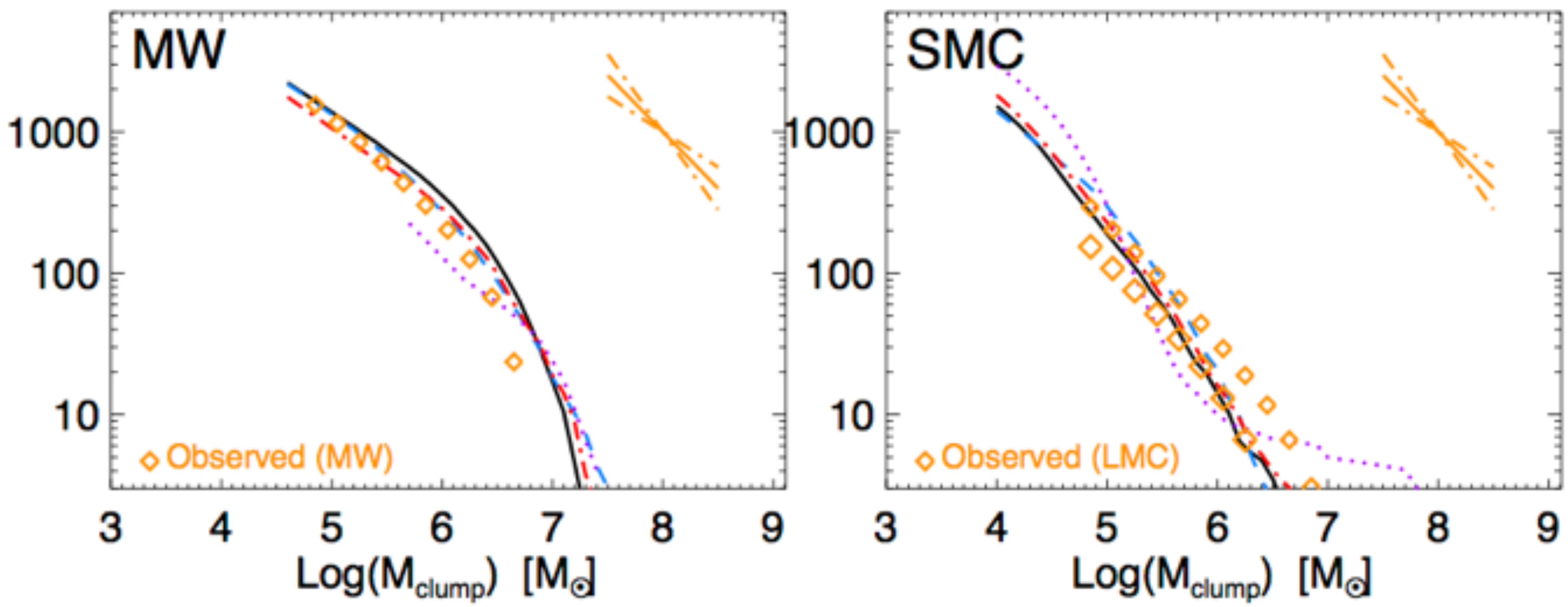
Feedback Does Not:

- regulate instantaneous collapse/SF ‘efficiency’ in GMCs/cores/dense gas (KS law on <<kpc scales)
- power turbulence in contracting clouds
- alter the GMC/cloud IMF (number you see affected by lifetimes)
- alter the *high-mass* end (Salpeter slope) of the IMF (except to *stop* runaway accretion)
- power *all* of the ISM-scale turbulence (gravity!)
- determine (most) morphology of the ISM (gravity+supersonic turbulence)
- affect galaxy or core/young star *clustering* (gravity alone; independent of SF efficiency)

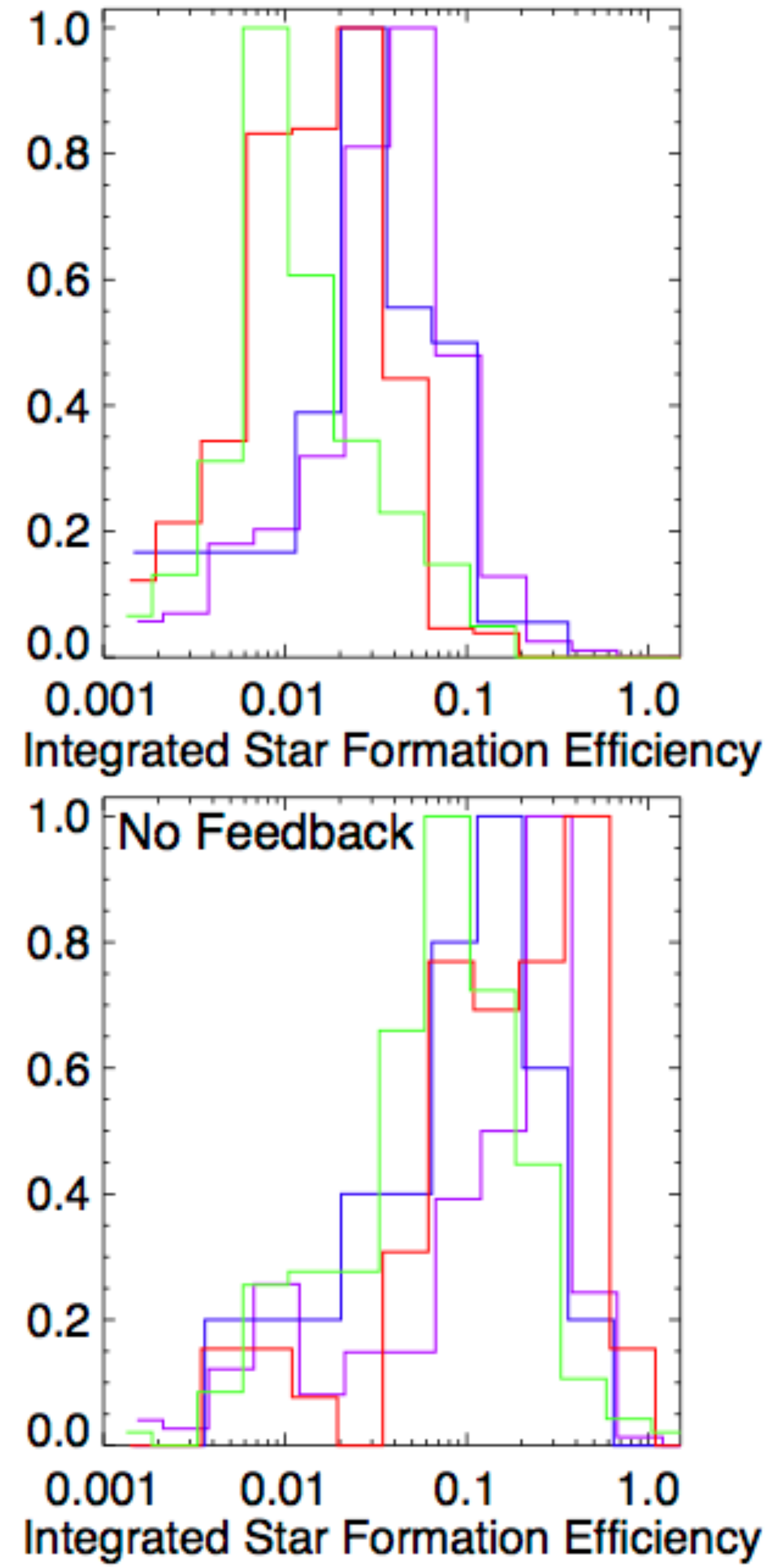
Cloud Properties

WHERE FEEDBACK MATTERS

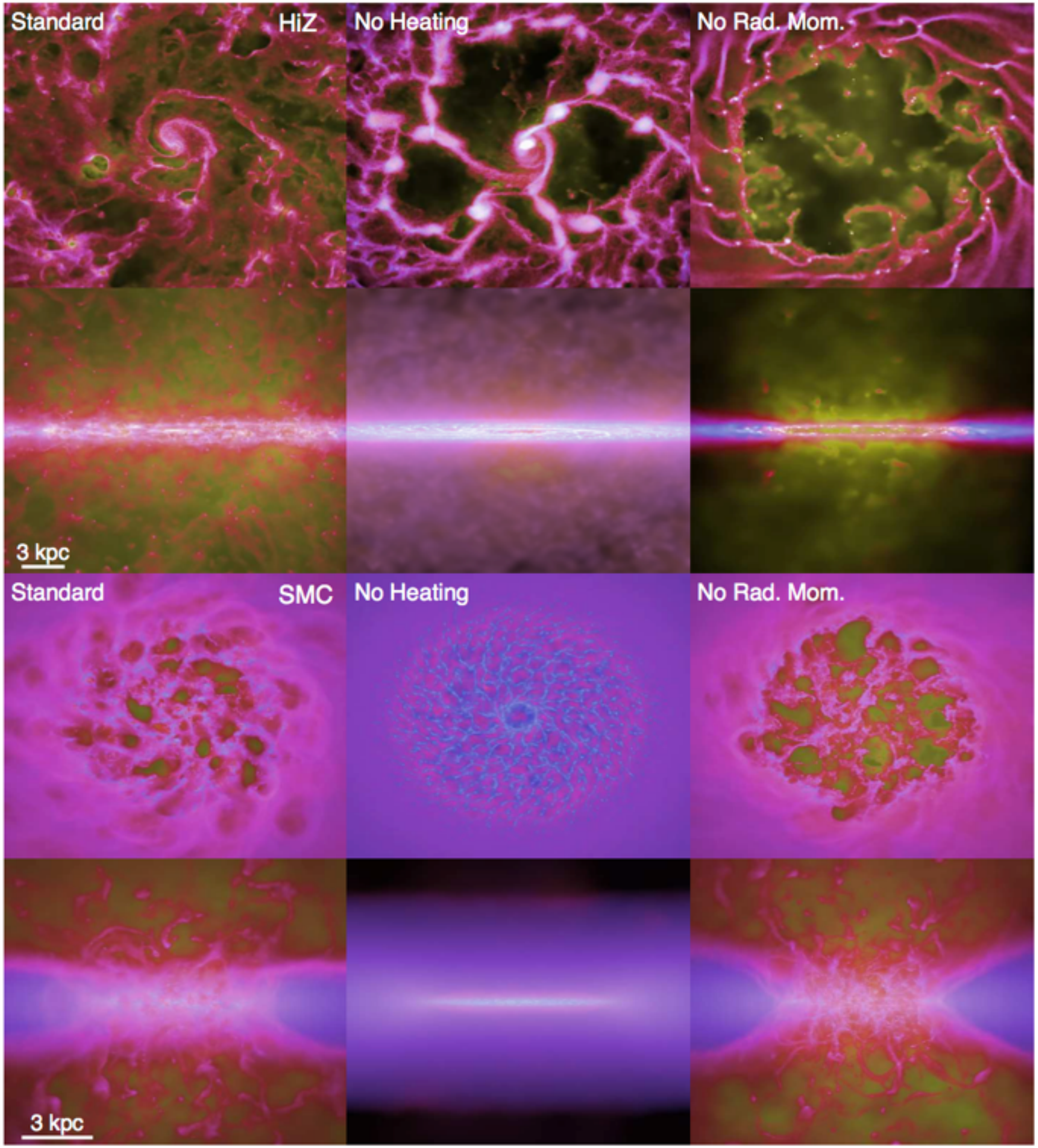
GMC MF



GMC SF Efficiencies

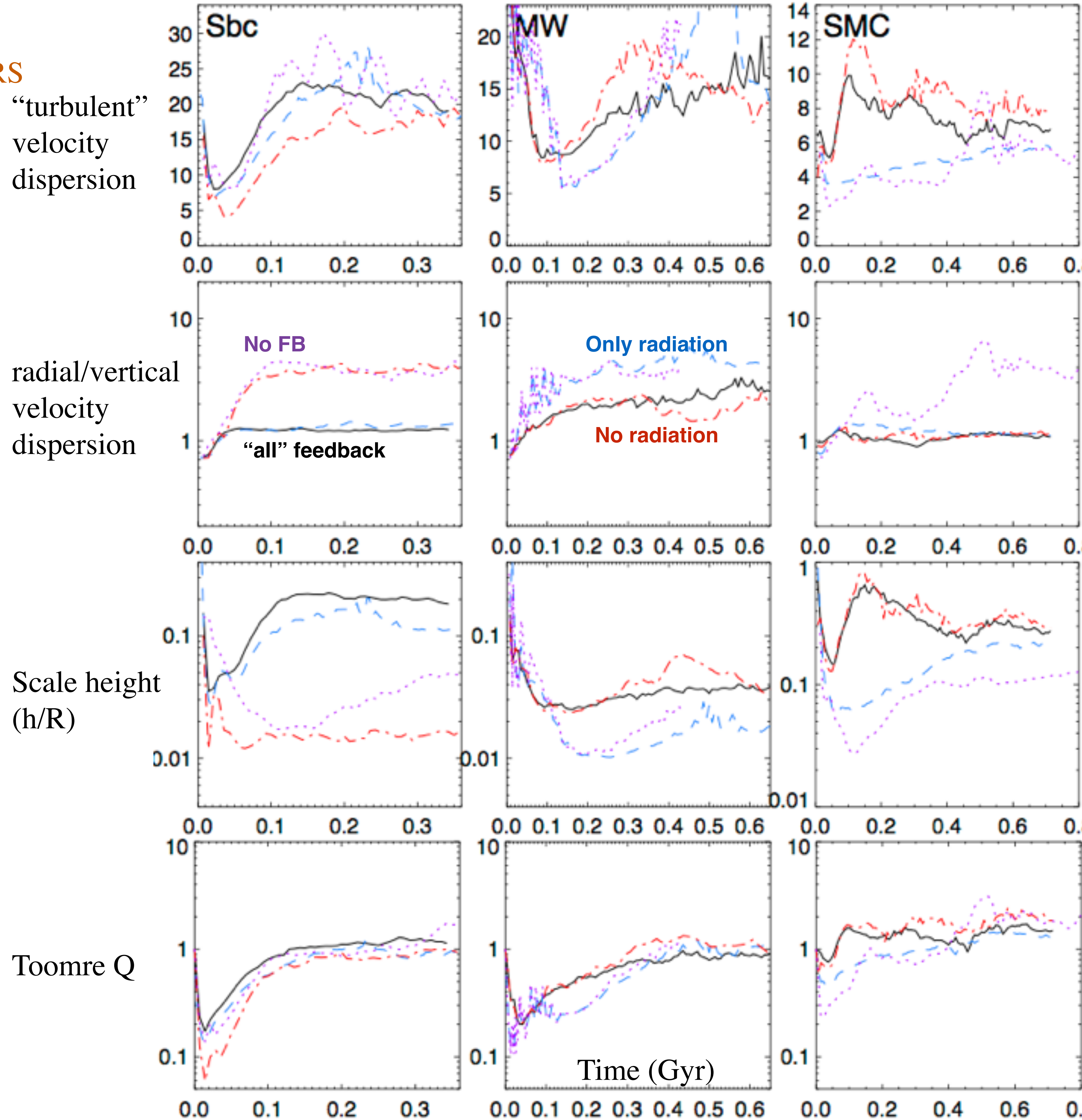


ISM Properties
WHERE FEEDBACK MATTERS



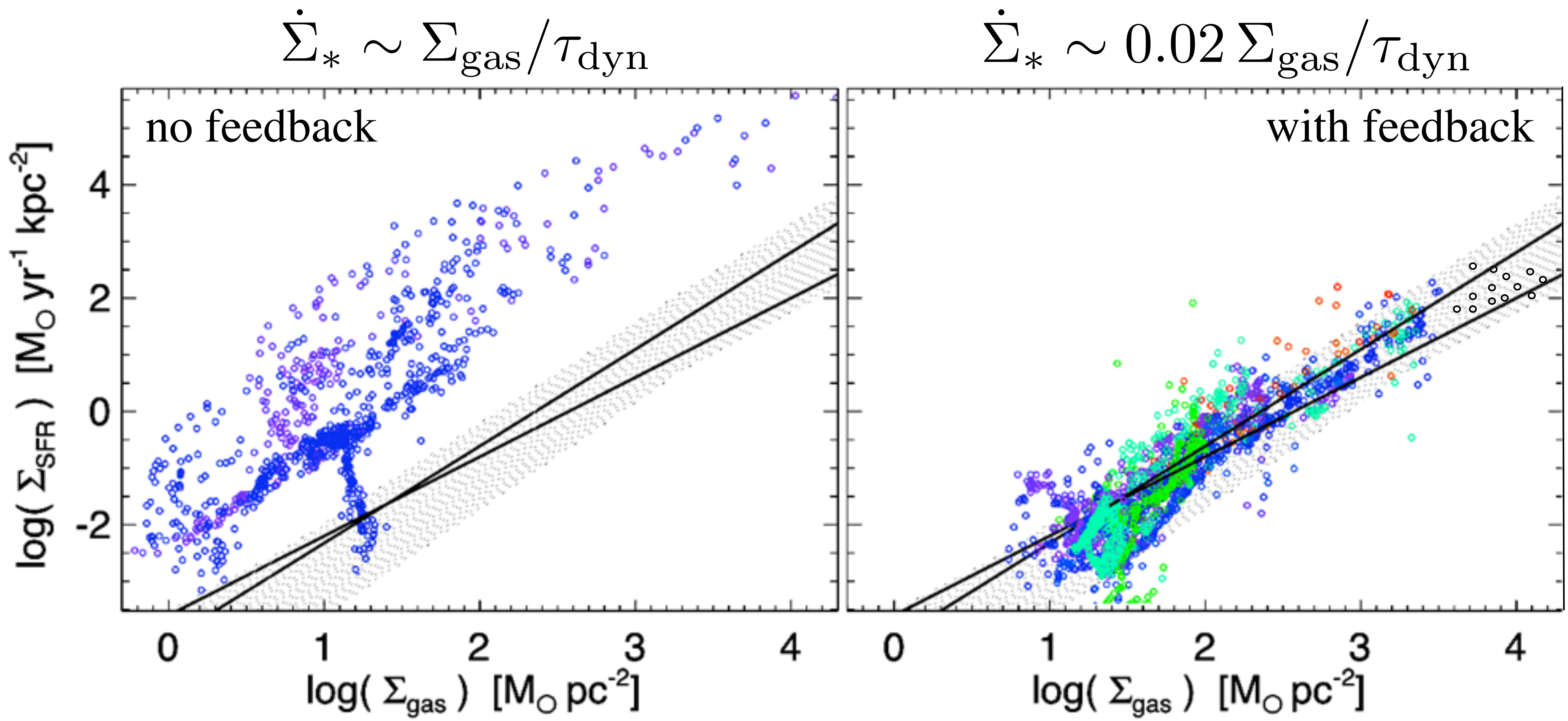
ISM Properties

WHERE FEEDBACK MATTERS



Kennicutt-Schmidt relation emerges naturally

ISOLATED GALAXIES

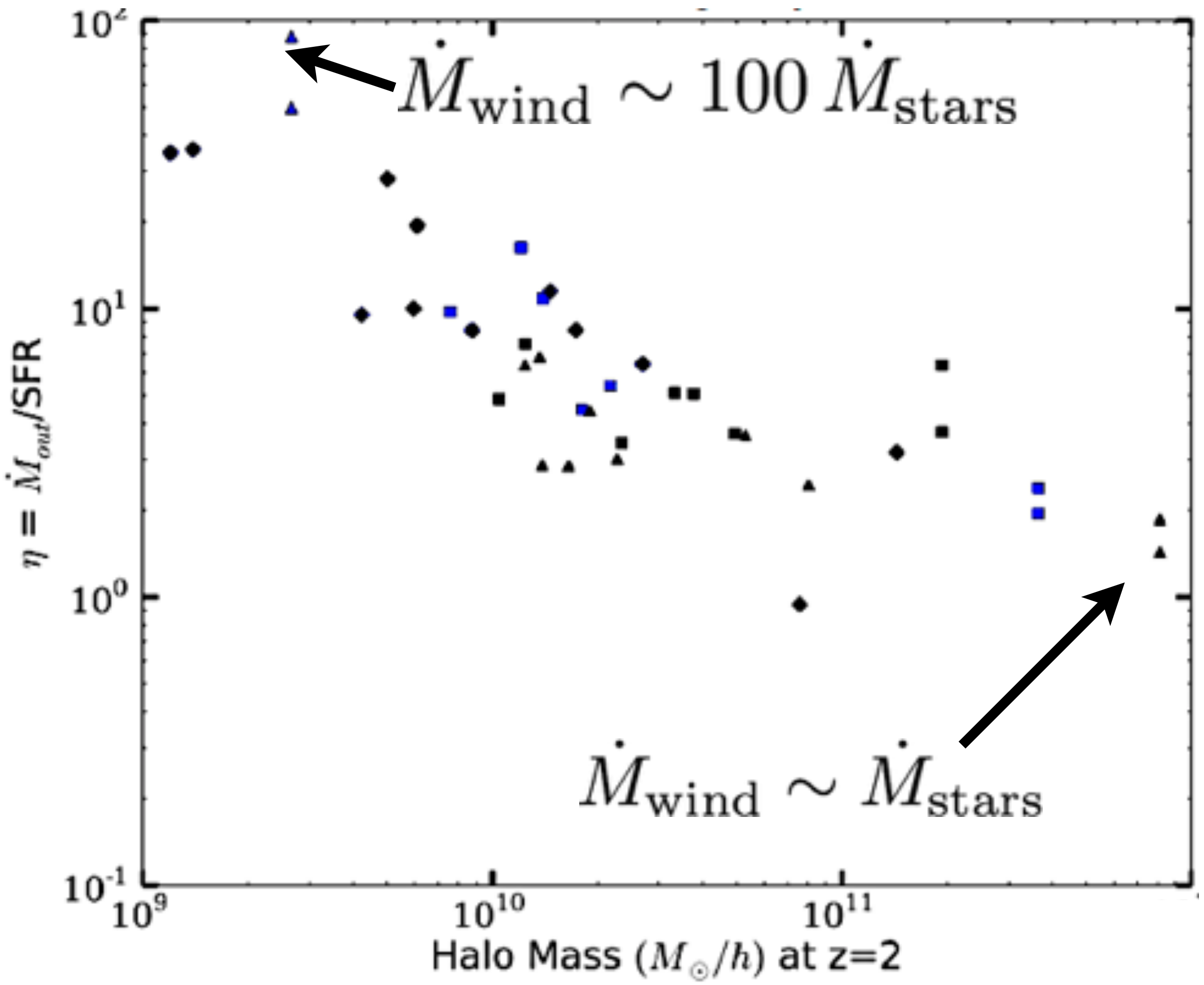


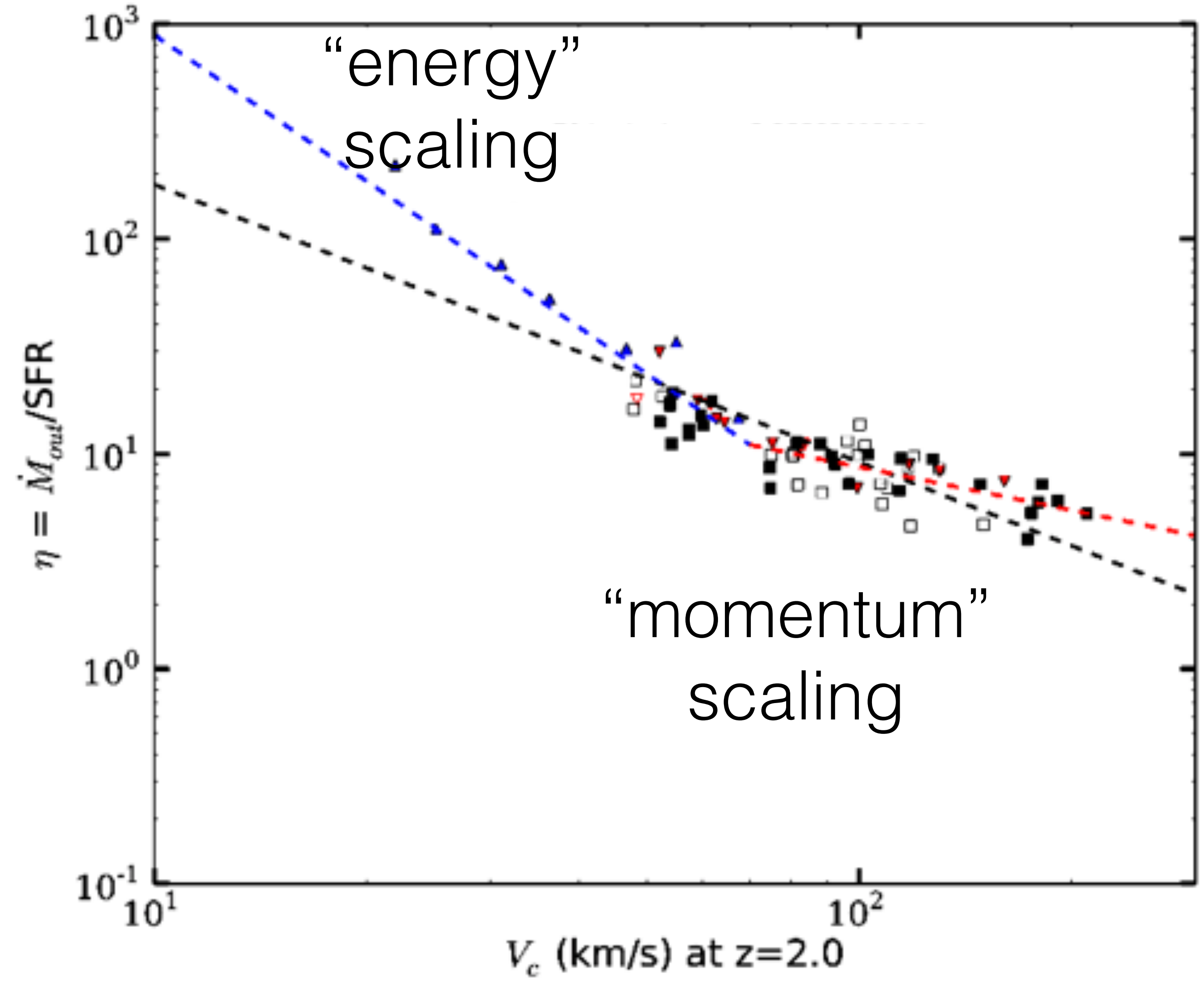
PFH, Quataert, & Murray, 2011a

How Efficient Are Galactic Super-Winds?

WHAT MECHANISMS DRIVE THEM?

S. Muratov

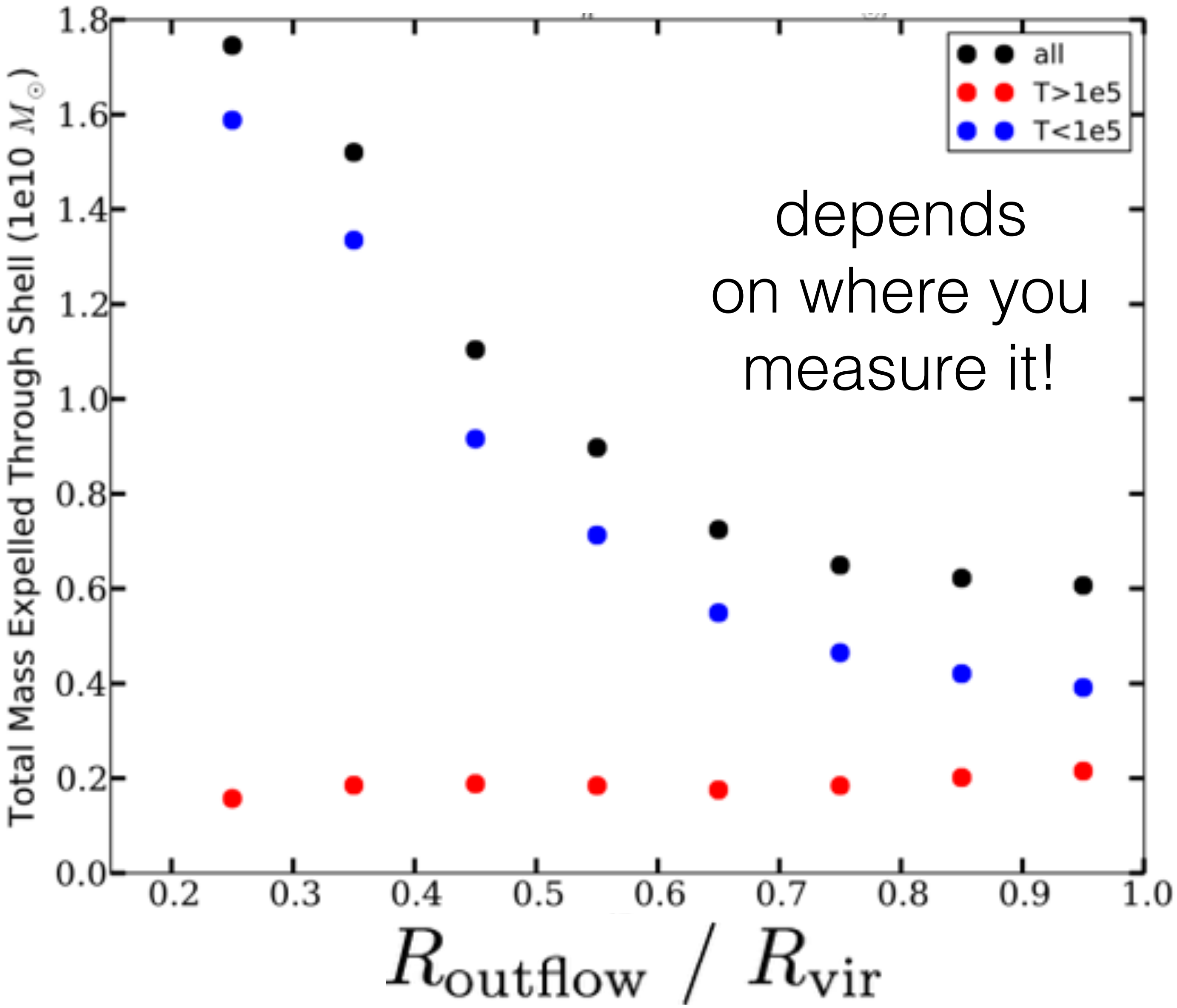


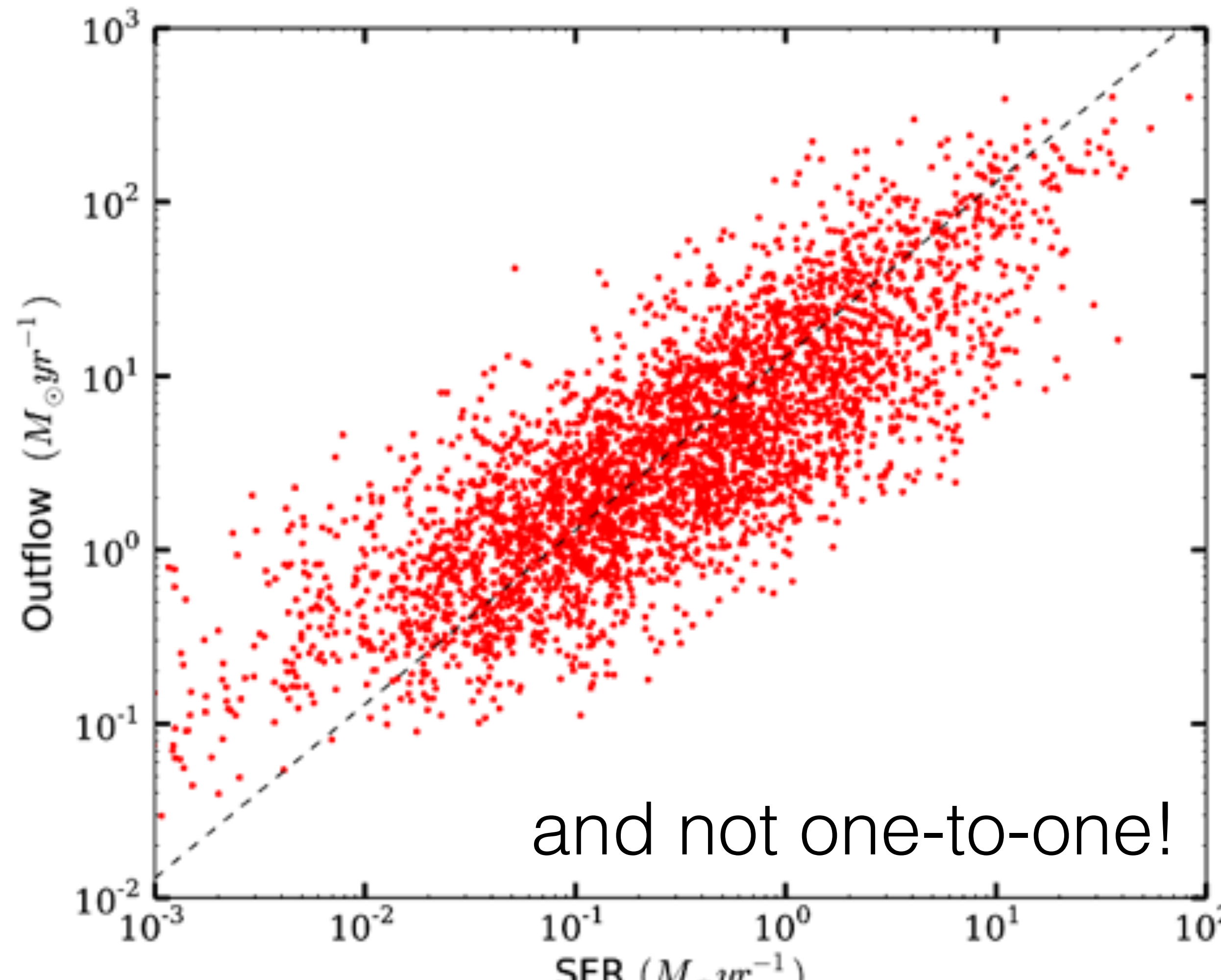


How Efficient Are Galactic Super-Winds?

WHAT MECHANISMS DRIVE THEM?

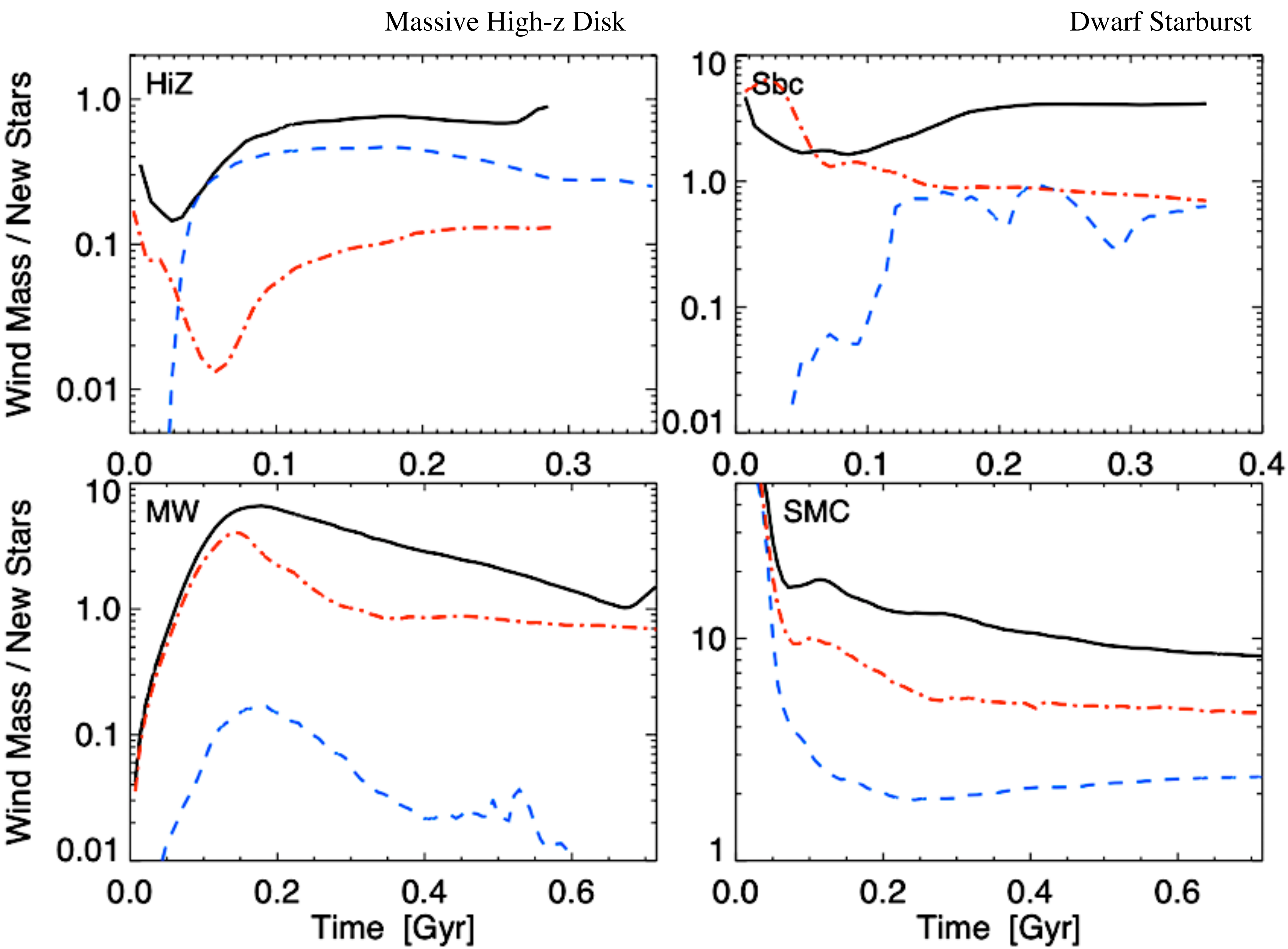
S. Muratov





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

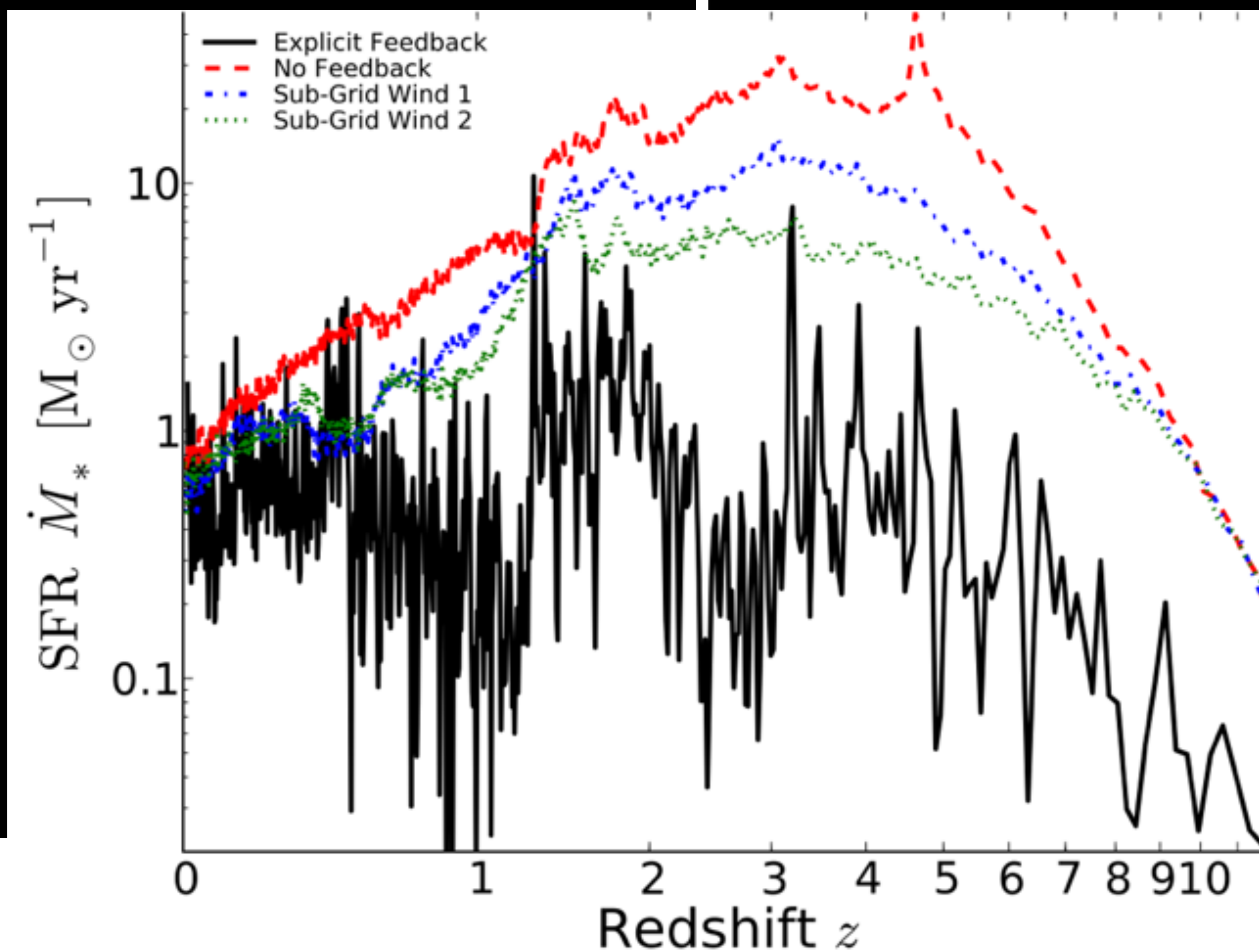
PFH, Quataert, & Murray, 2011c



Proto-MW: Gas Temperature:

Insert Winds "By Hand" (Sub-Grid)

Following Full Feedback



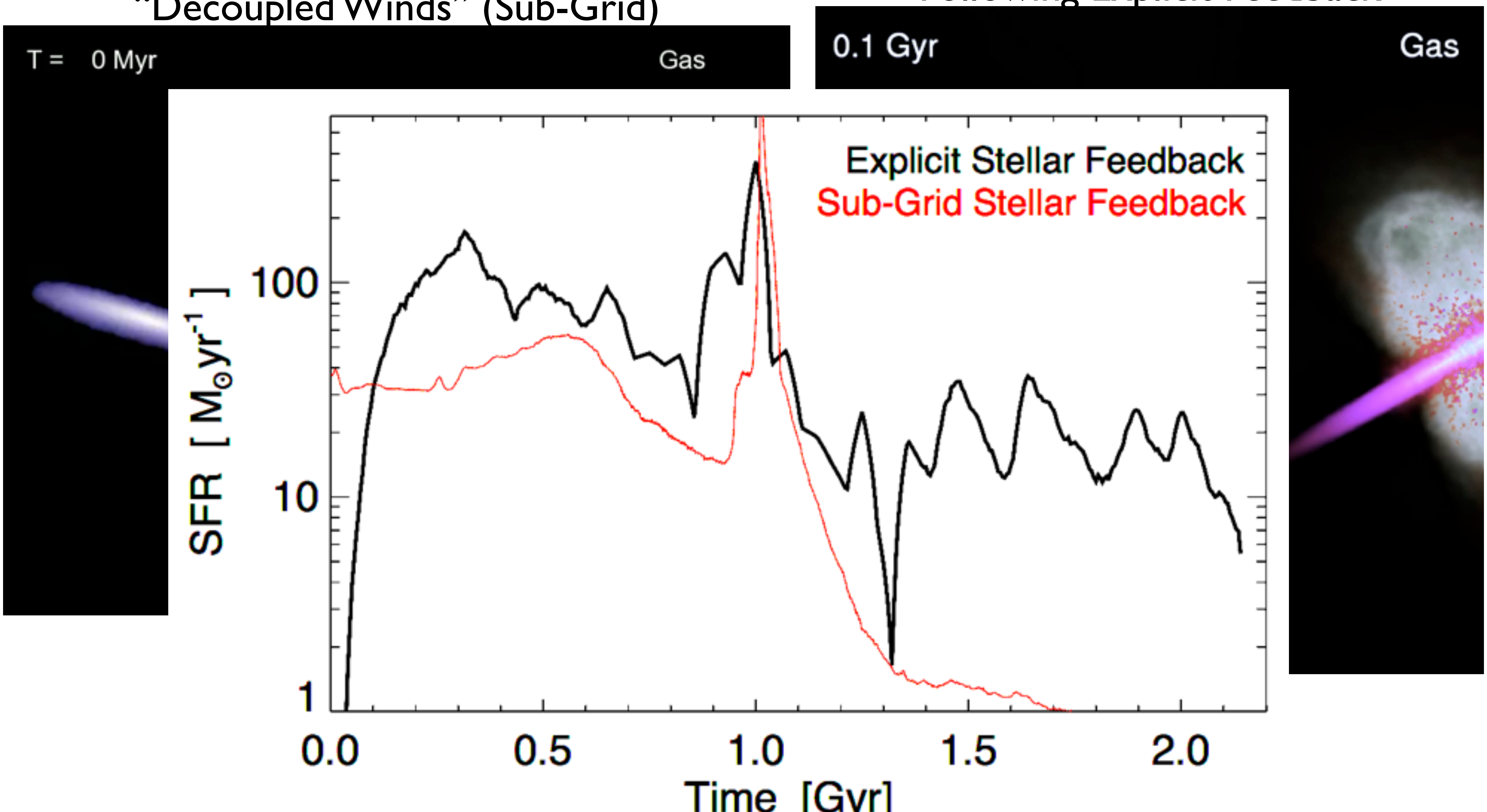
PFH, Keres, et al. (arXiv:1311.2073)

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

SMALL GALAXIES BECOME BIG GALAXIES

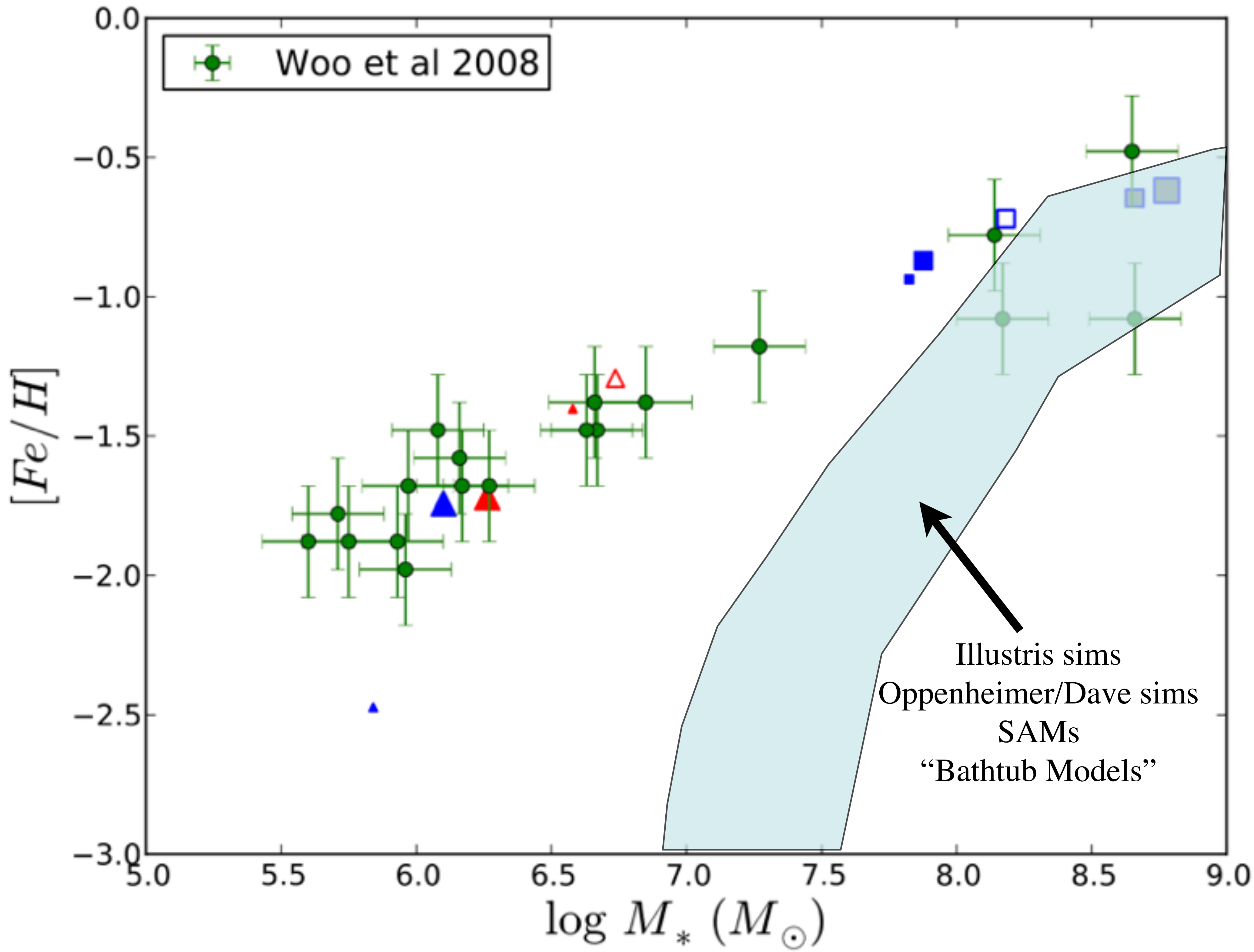
“Decoupled Winds” (Sub-Grid)

Following Explicit Feedback



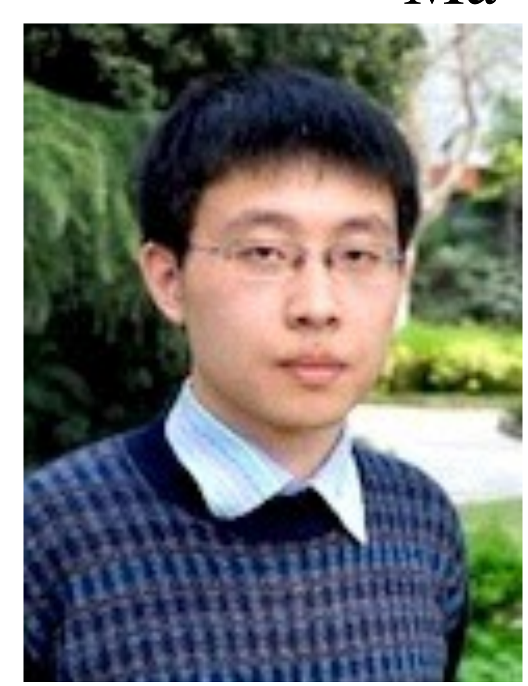
Dwarf Metallicities are Also Surprising

DEPENDS ON DETAILS OF INFLOW-OUTFLOW INTERACTIONS



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

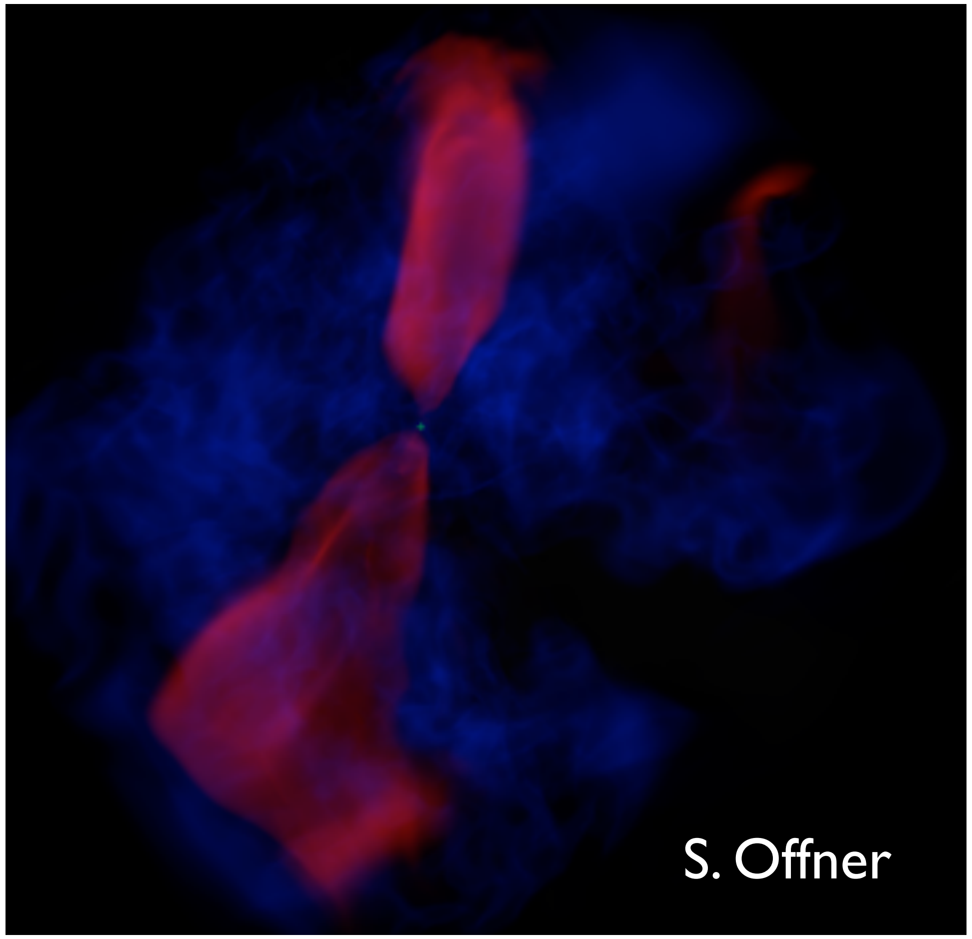
Xiancheng Ma



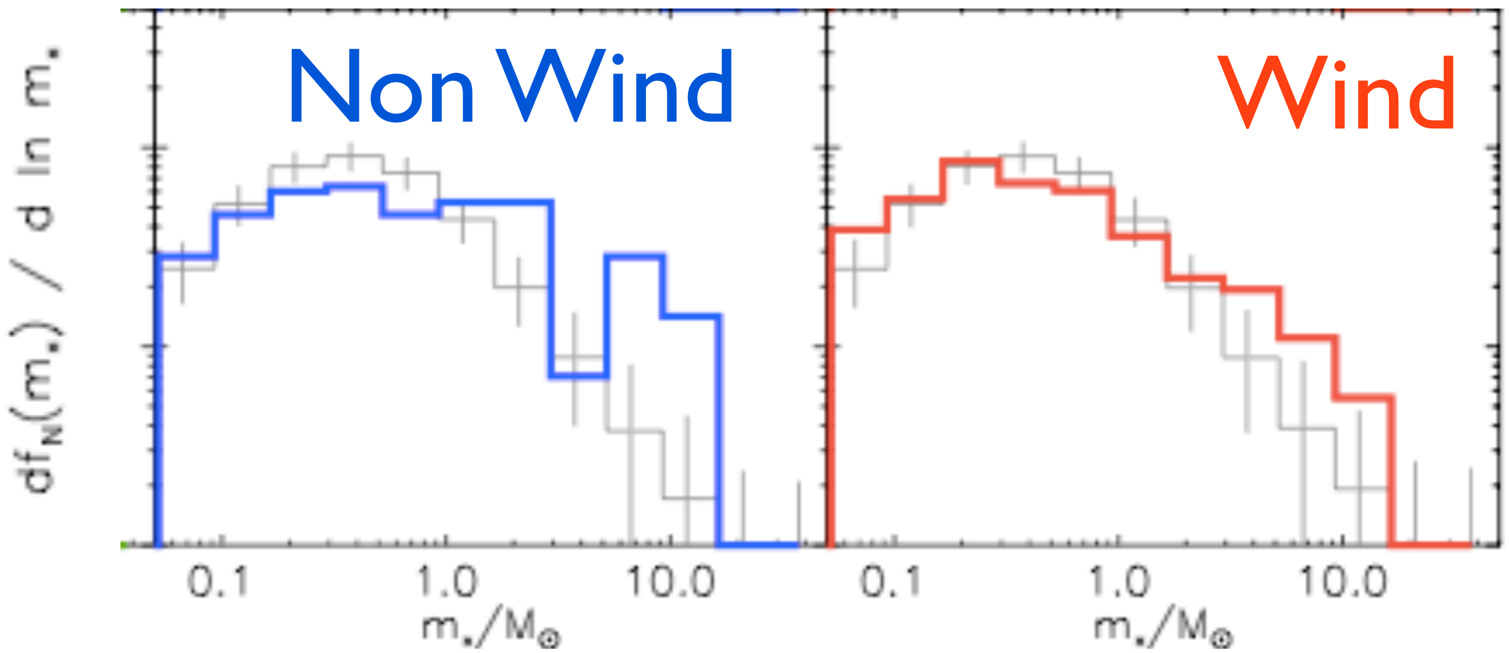
Winds ("Kinematic Feedback")

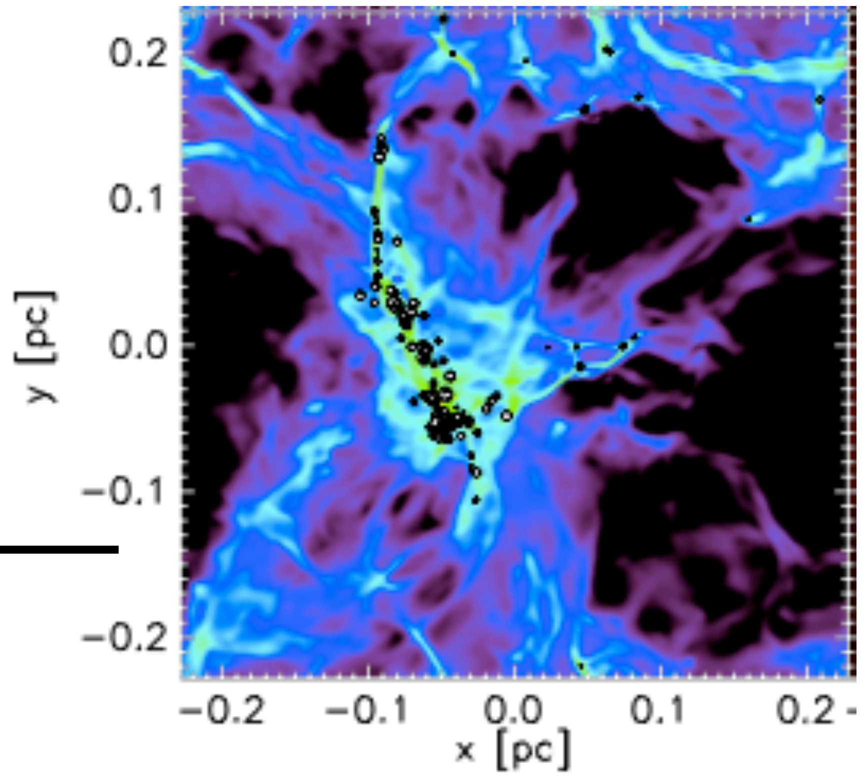
Clark+ 2013

BLOW OUT SOME CORE MASS (AND POWER TURBULENCE)



- Can we just multiply the CMF by ~0.3?



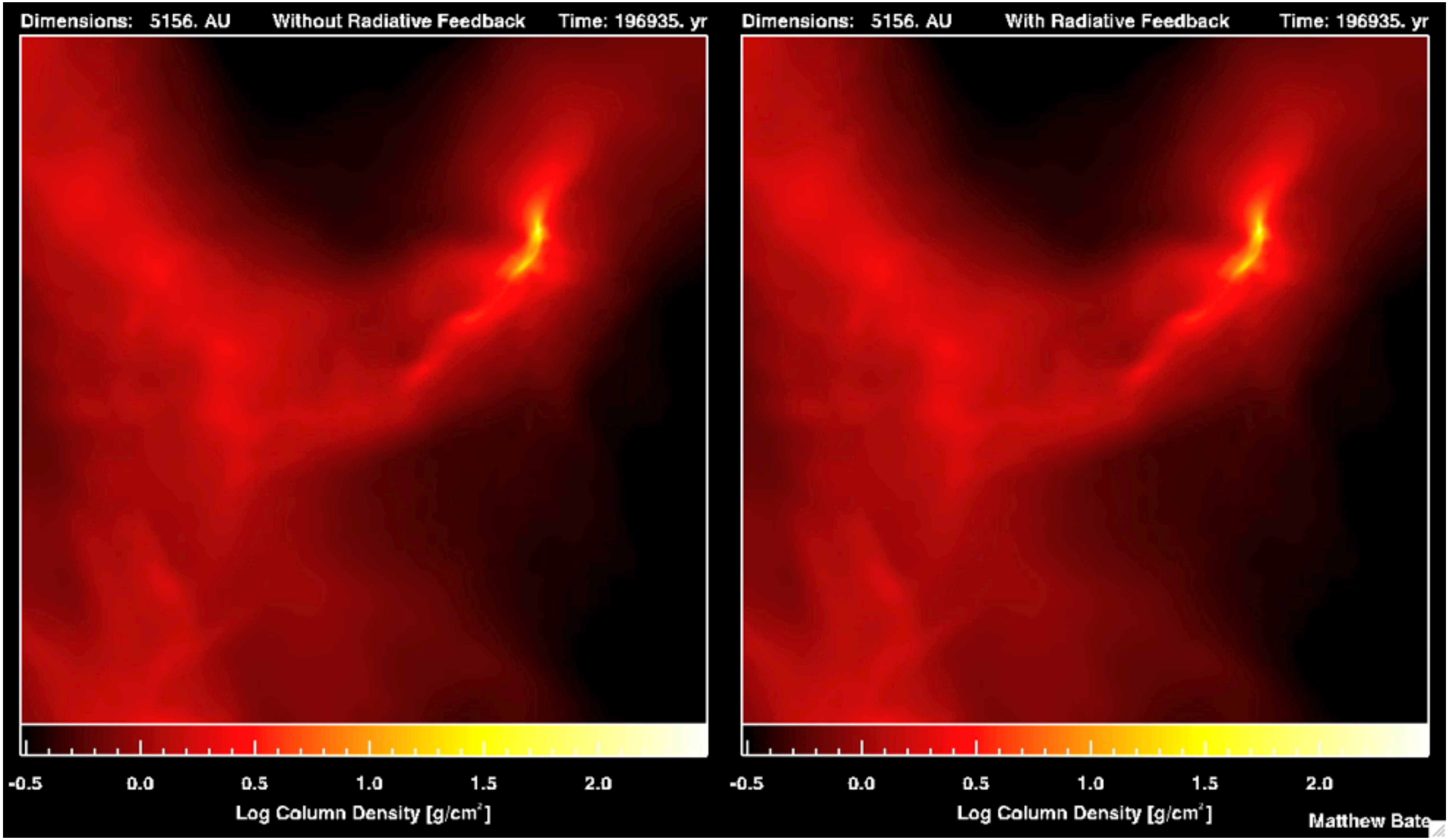


See also Li ea 2010, Hansen ea 2011

Krumholz ea 2012, ApJ, 545, 46

"Feedback" from Radiation

WITHOUT RADIATIVE TRANSFER THERE ARE TOO MANY BDs



My Wish List

- “onion structure” of massive GMCs (mapping ionization fronts, X-ray regions, breakout, different shells) for ~1e3 GMCs with different ages, masses

- “onion” for galaxies: fountain/CGM (outflow/inflow) *phases*+*kinematics* (Mdot, v) as function of radius, for ~1e4 galaxies with z~0-6, M*~1e4-1e12

- census of mechanisms: stellar winds (young+agb), SNe (I & II, hypernovae?), radiation pressure (‘trapping factors’ for IR/lines?), photo-heating, cosmic rays (???)

- inflow rates, not just outflow