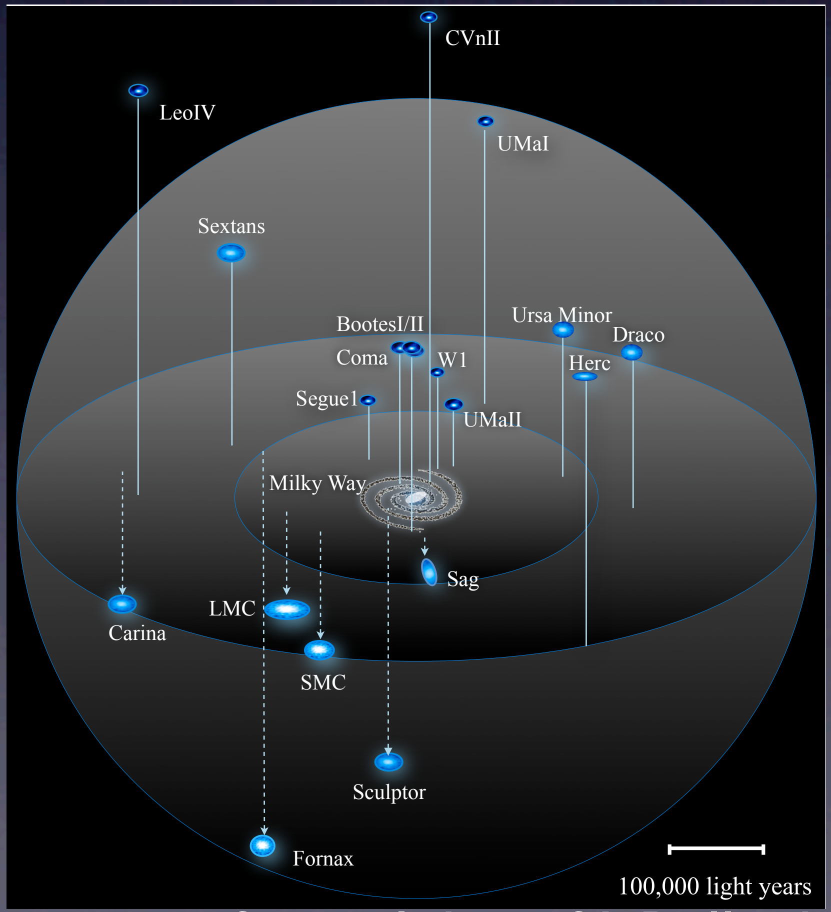
Momentum feedback in dwarf galaxy simulations

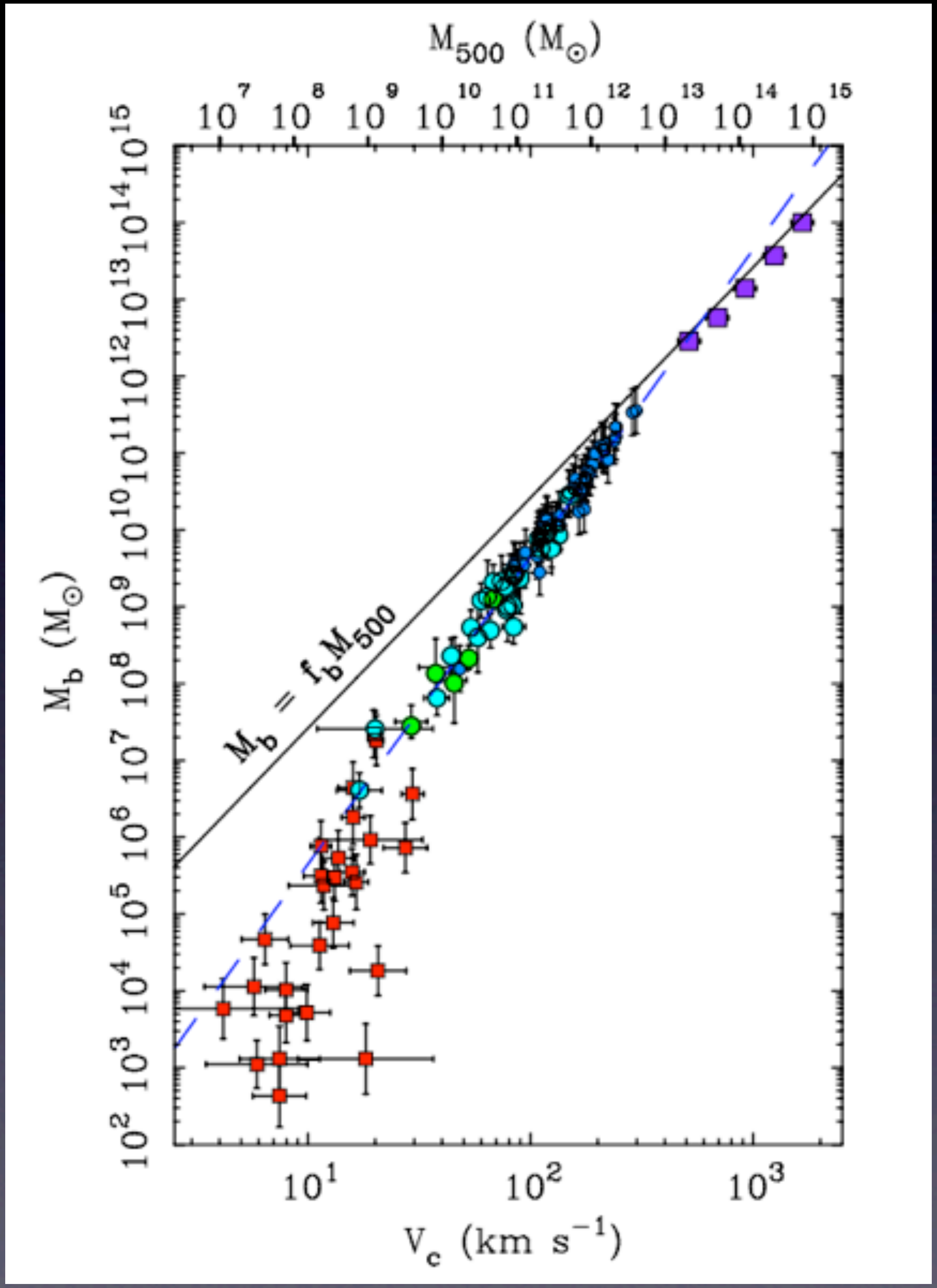
Christine Simpson
Columbia University (soon to be HITS)
AGORA Workshop
Aug. 16, 2013

Advisor: Greg Bryan
Collaborators: Kathryn Johnston (Columbia), Mordecai-Mark Mac Low (AMNH), Britton Smith (Michigan State), Sanjib Sharma (Sydney), Jason Tumlinson (STSI), Cameron Hummels (Arizona), Jerry Ostriker (Columbia)

Low baryon fractions in MW Dwarfs



from slides of J. Bullock



McGaugh et al. 2010

Zoom-in Simulation of Low Mass Dwarf Halo

Halo Properties

M_{200} = 1.55 x 10^9 $M_\odot$ at z = 0

Isolated Environment

Resolution

Δx_{min} = 11 comoving pc

m_* = 100 $M_\odot$

m_{dm} = 5353 $M_\odot$

Simpson et al. 2013

Physics

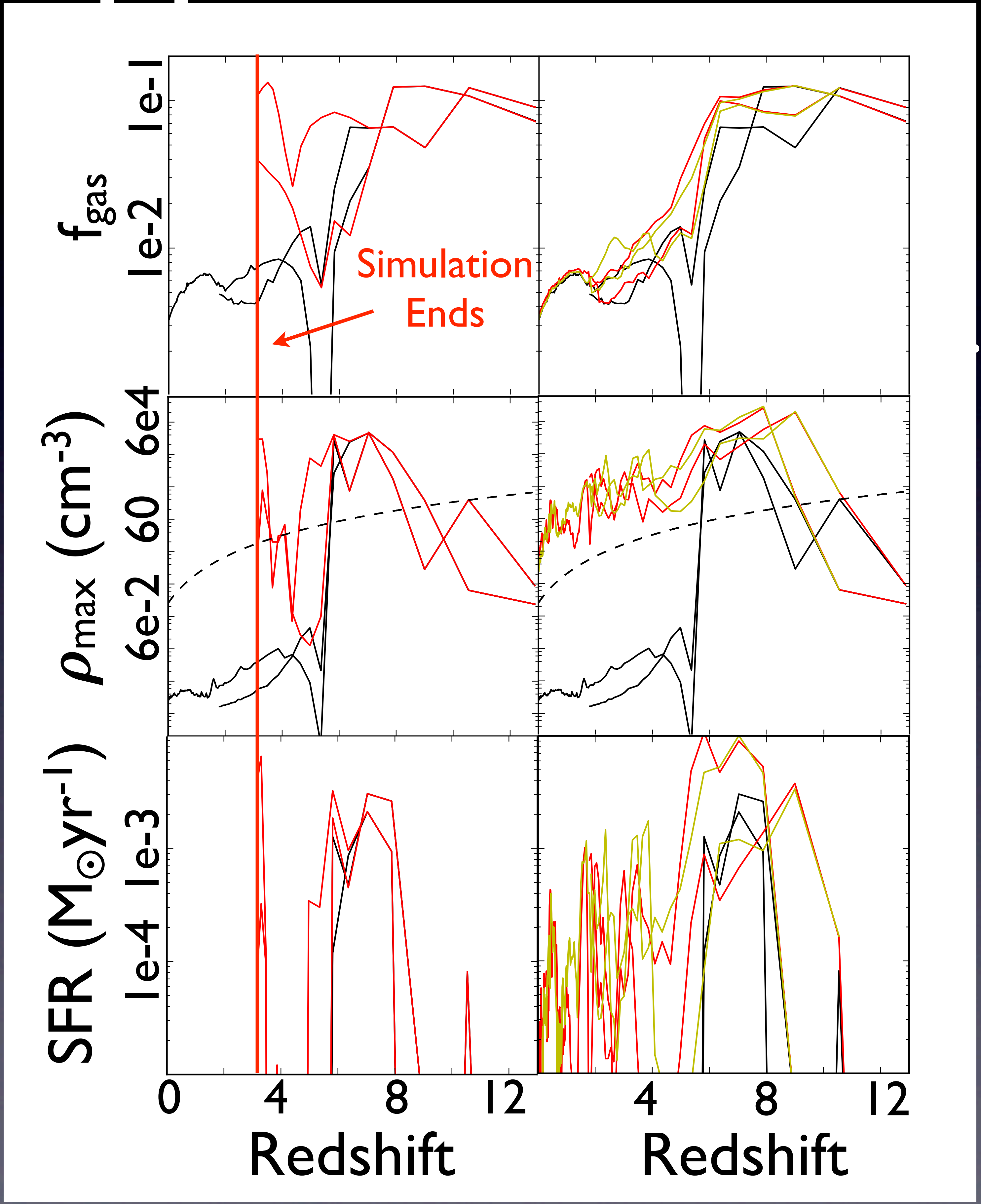
- Enzo - Adaptive Mesh Refinement code
- Non-equilibrium H_2 cooling
  (Anninos et al. 1997, Abel et al. 1997)
- Metal line cooling & heating rates
  (Smith et al. 2008)
- Cosmic UV backgrounds (photoionizing & photodissociating)
  (Haardt & Madau 2001, 2011)
- Photoionization & photodissociation self-shielding
  (Simpson et al. 2012, Shang, Bryan & Haiman 2010)
- Thermal supernova feedback
  150 $M_\odot$ stars → 10^{51} ergs injected over 10 Myrs (Cen & Ostriker 1992)

Suppression of SF

Remove UV background…

… gas reaccretes

black: full physics
red: No UV bg



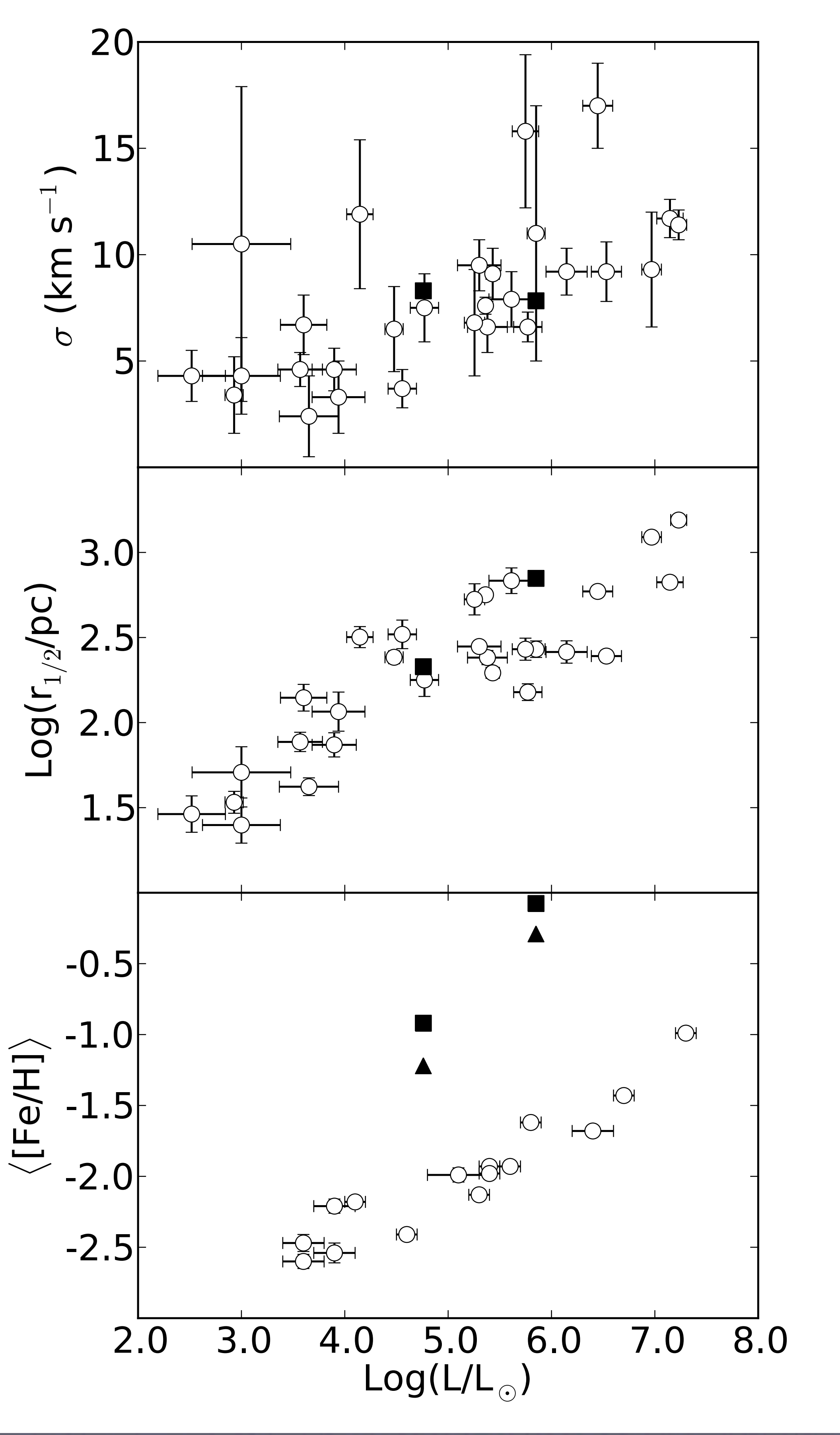
Remove SN feedback…

… self-shielded clumps survive

black: full physics
red, yellow:
No SN feedback

Simpson et al. 2013

Comparison to MW dSphs



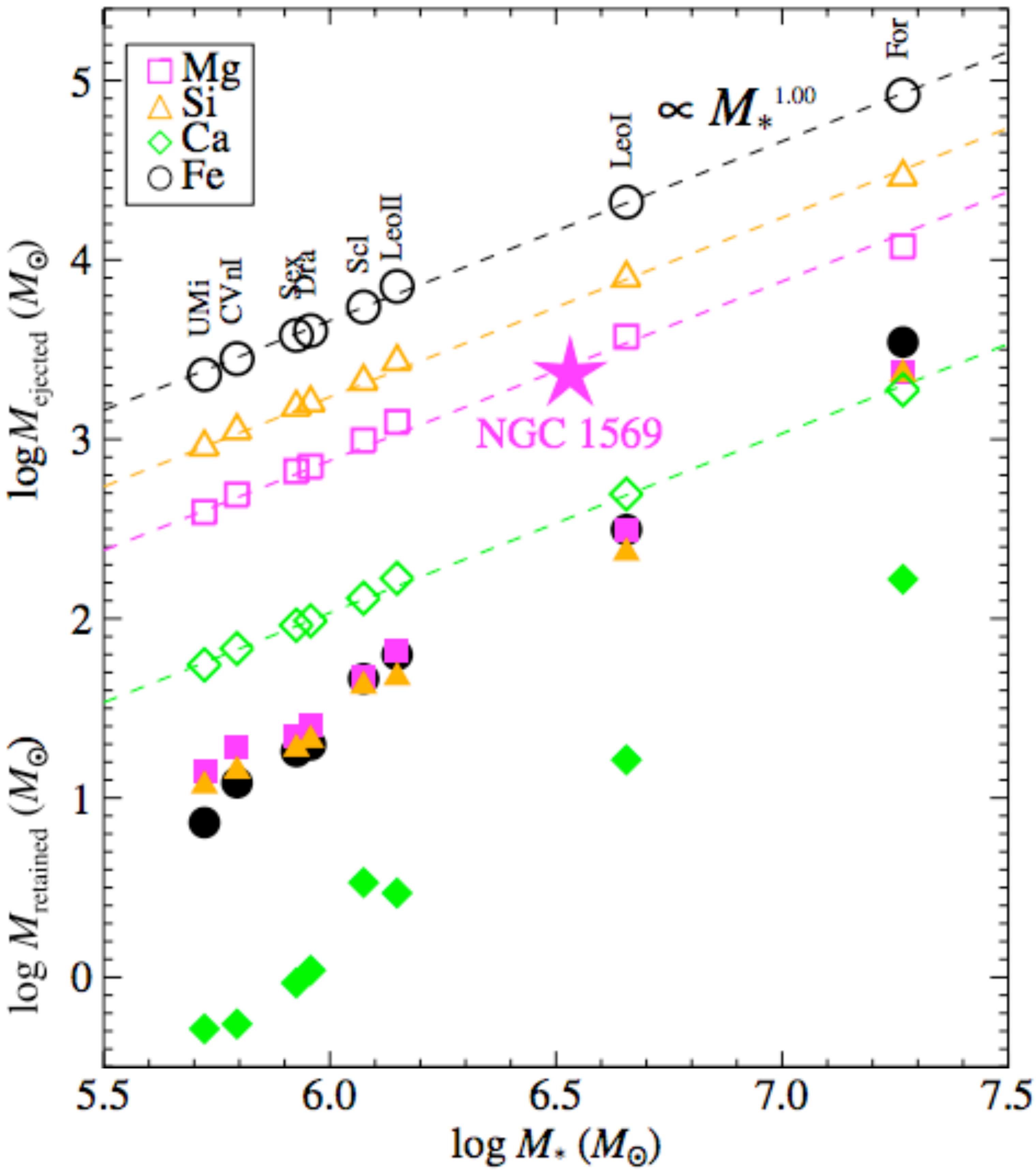
Reionization z=6-7 | Reionization z=8-8.9

	R10	R10-earlyUV
$M_{tot}/M_{\odot}$	1.55×10^9	1.55×10^9
$M_*/M_{\odot}$	1.43×10^6	1.16×10^5
r_{200} (kpc)	23.7	23.9
$r_{1/2}$ (pc)	704	213
$M_{1/2}/M_{\odot}$	3.05×10^7	3.86×10^6
$M_{300}/M_{\odot}$	7.53×10^6	7.41×10^6
$\sigma_{1/2}$ (km/s)	7.83	8.30
$\langle Z/Z_{\odot}\rangle$ (median)	0.51	0.06

Data from Walker et al. 2009, Kirby et al. 2008 & Kirby et al. 2011

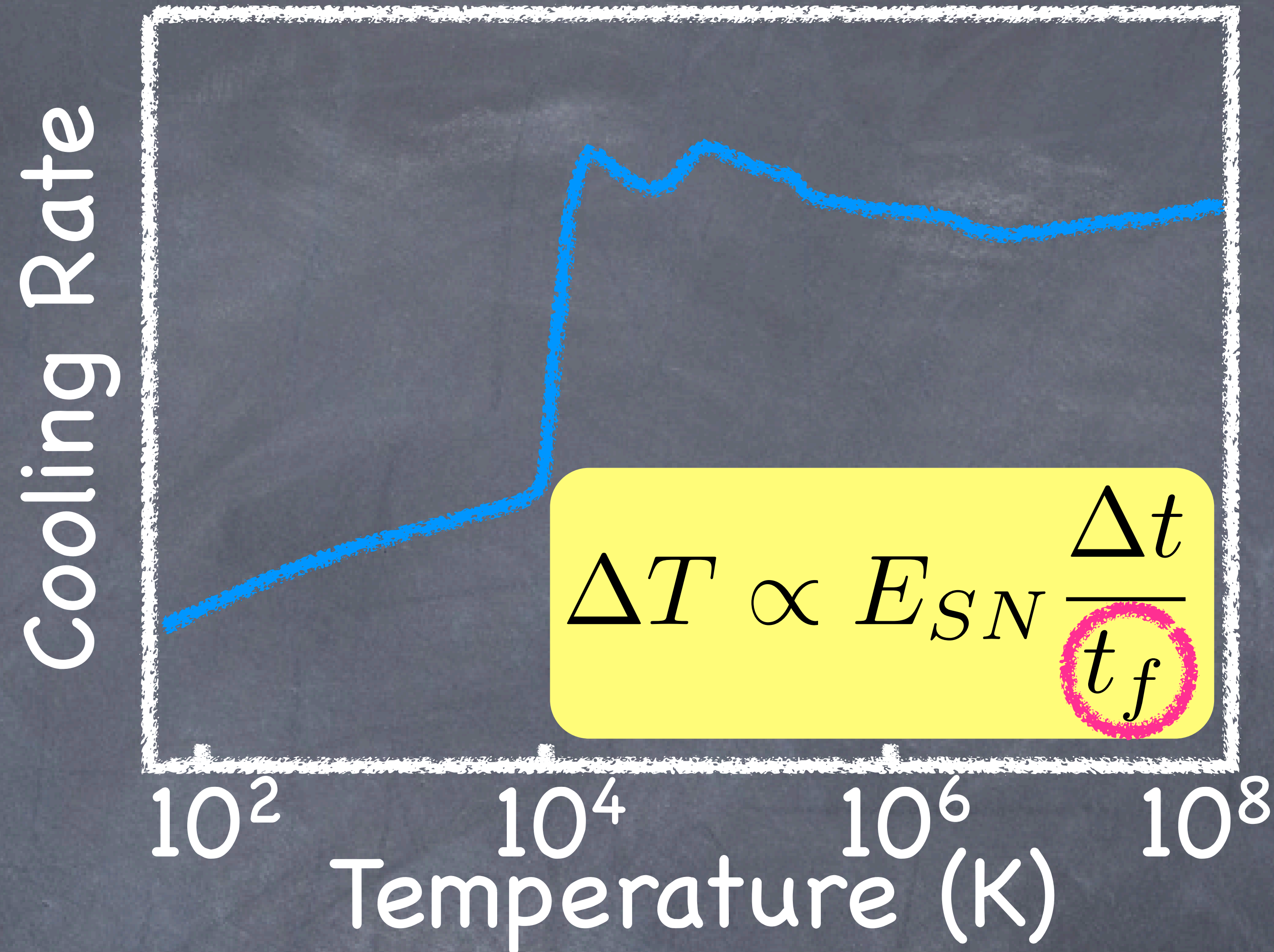
Simpson et al. 2013

Metal Loss in dSphs

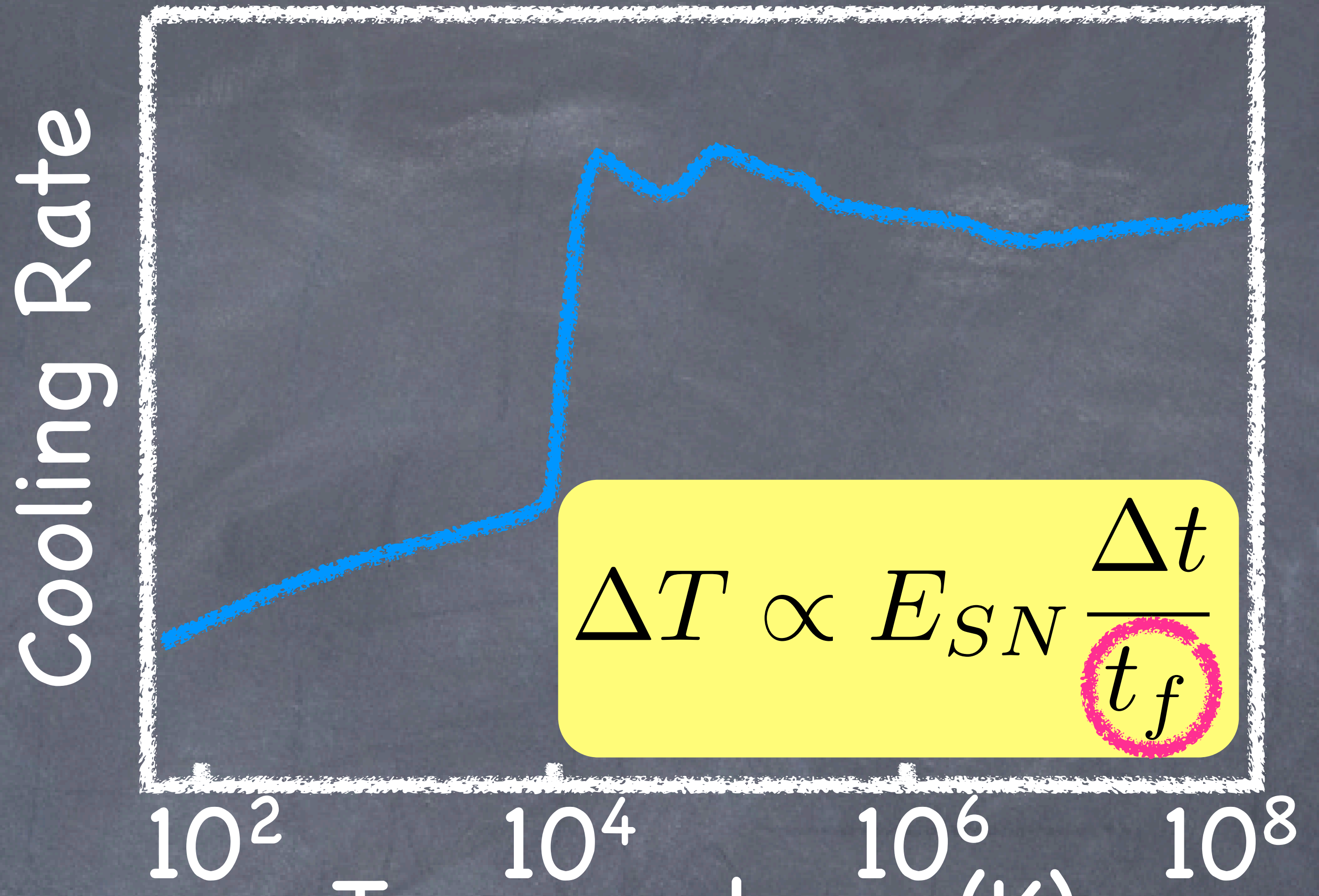


Kirby+ 2011

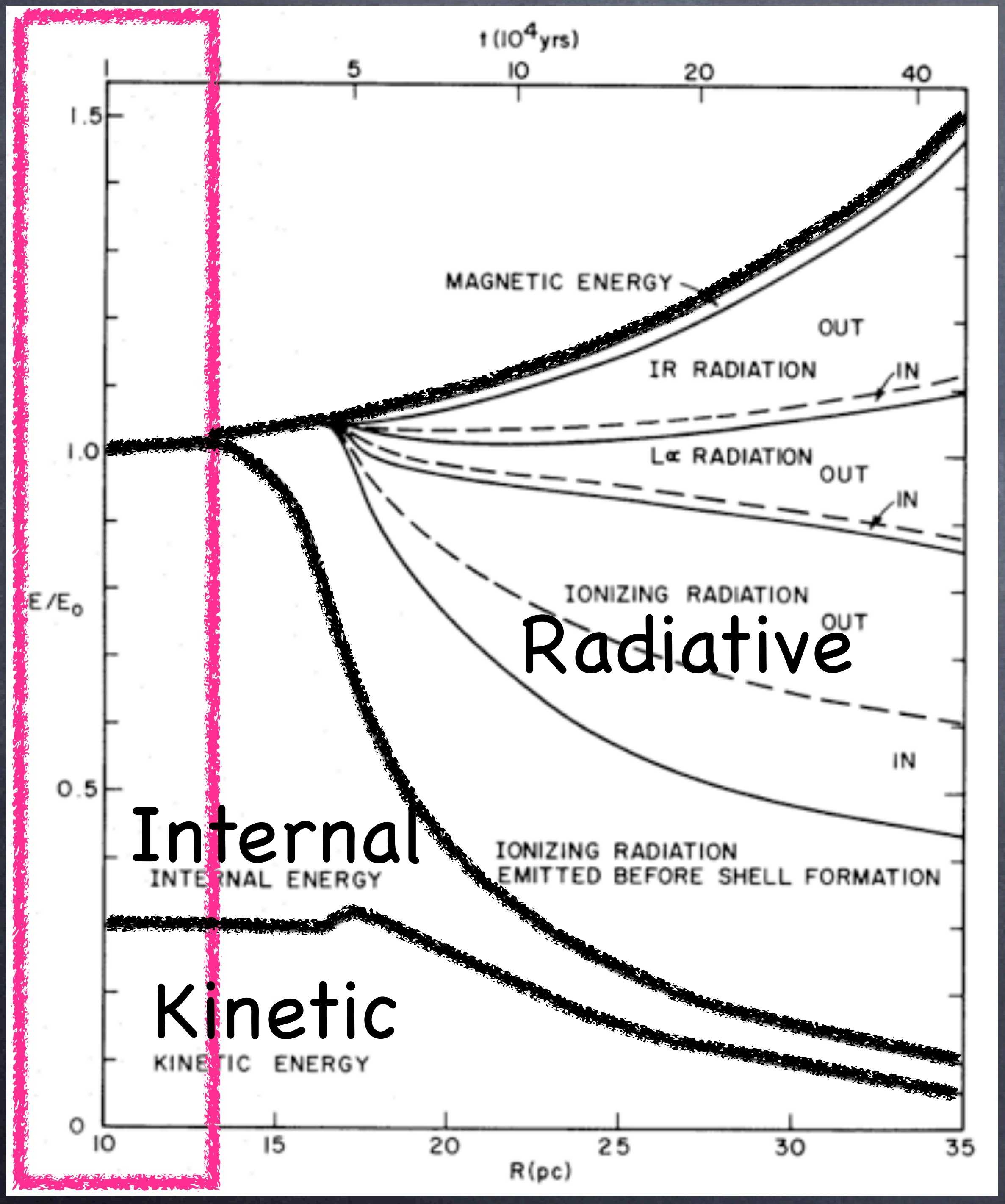
We want to inject energy on shorter timescales...



We want to inject energy on shorter timescales...



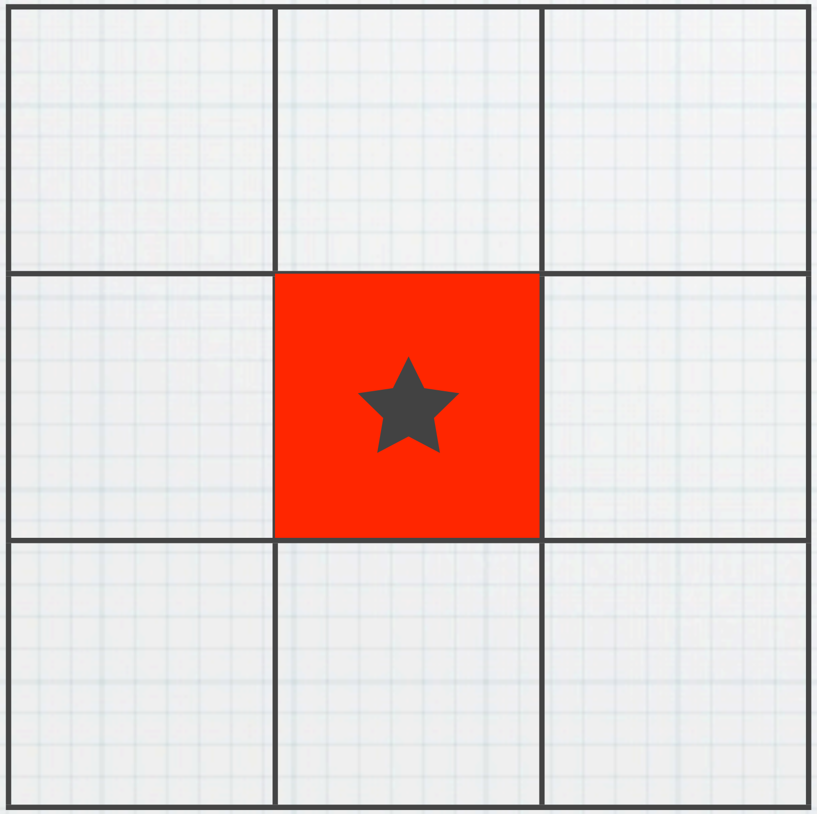
...and we want a method that injects energy of the proper type



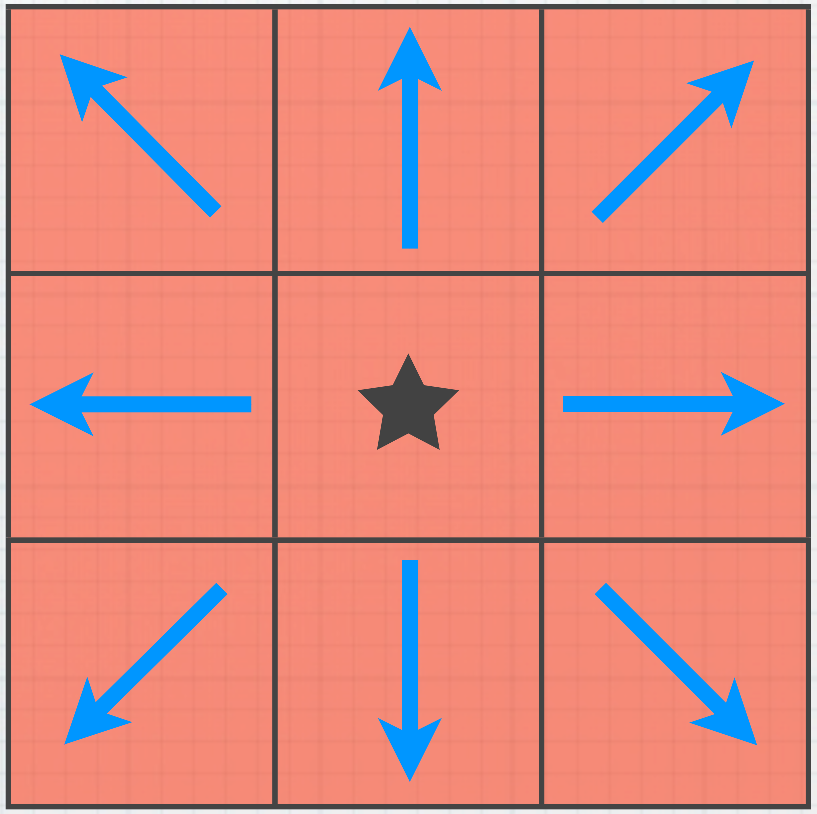
Chevalier 1974

Distributed Thermal *and Kinetic* Feedback

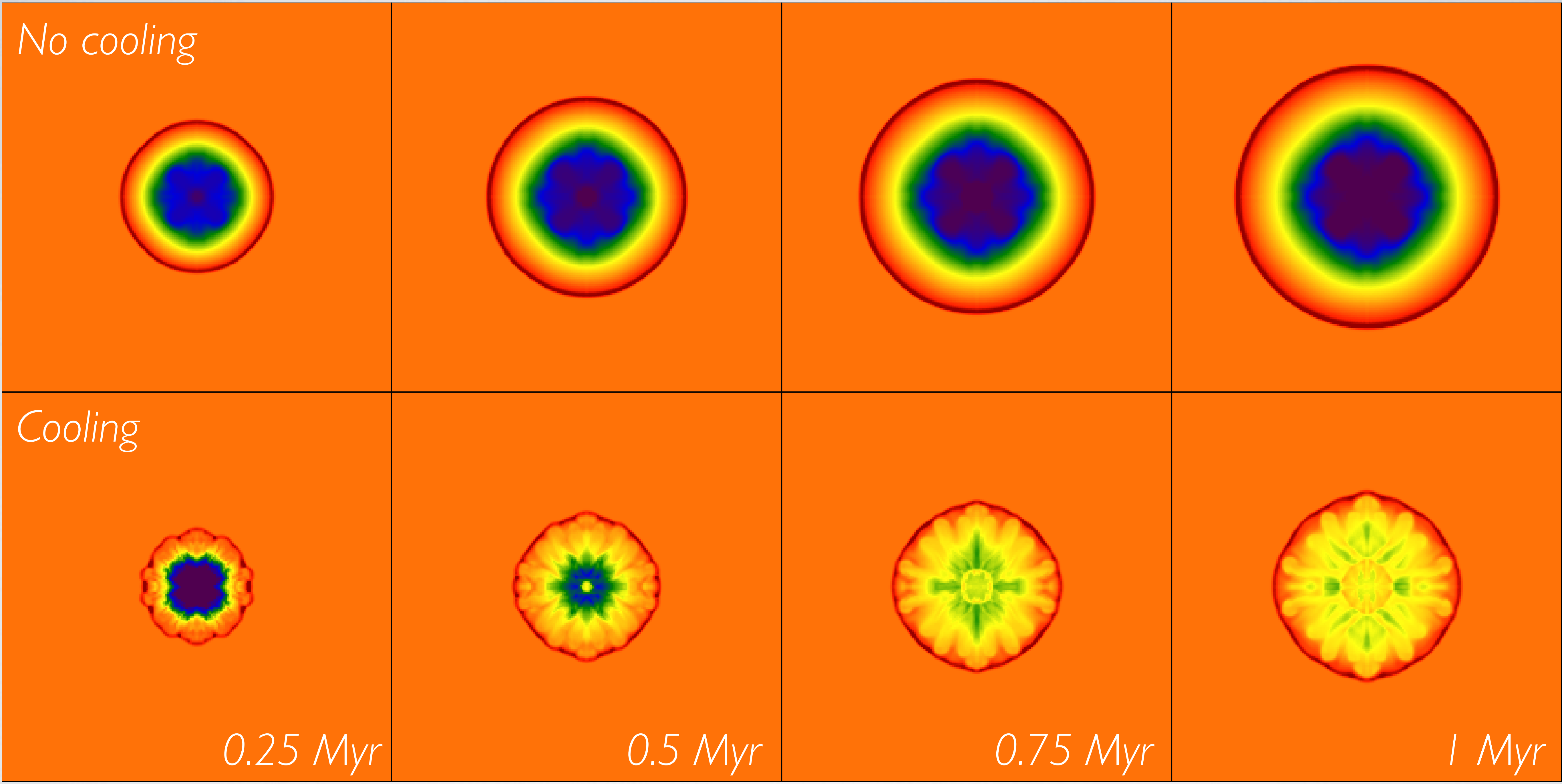
Cen & Ostriker Model
(single cell)
$E_{SN} = E_{therm}$



New Model
$E_{SN} = \sum E_{therm,i} + E_{kin,i}$



High Resolution Tests

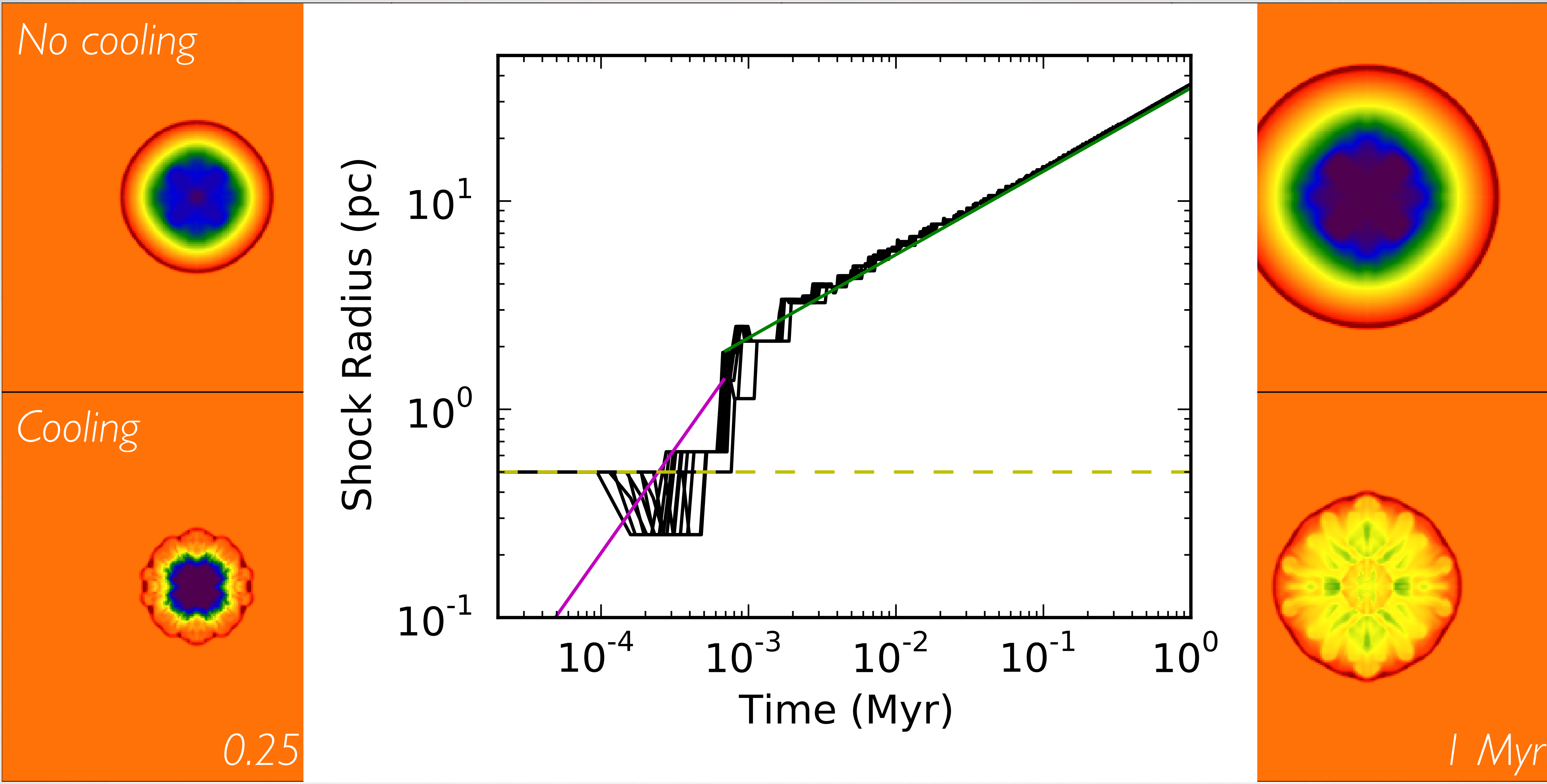


$dx = 0.5$ pc $\quad f_{kin} = 0.3$

$\rho_0 = 100$ cm^{-3} $\quad E_{SN} = 10^{51}$ ergs

Simpson et al. in prep

High Resolution Tests

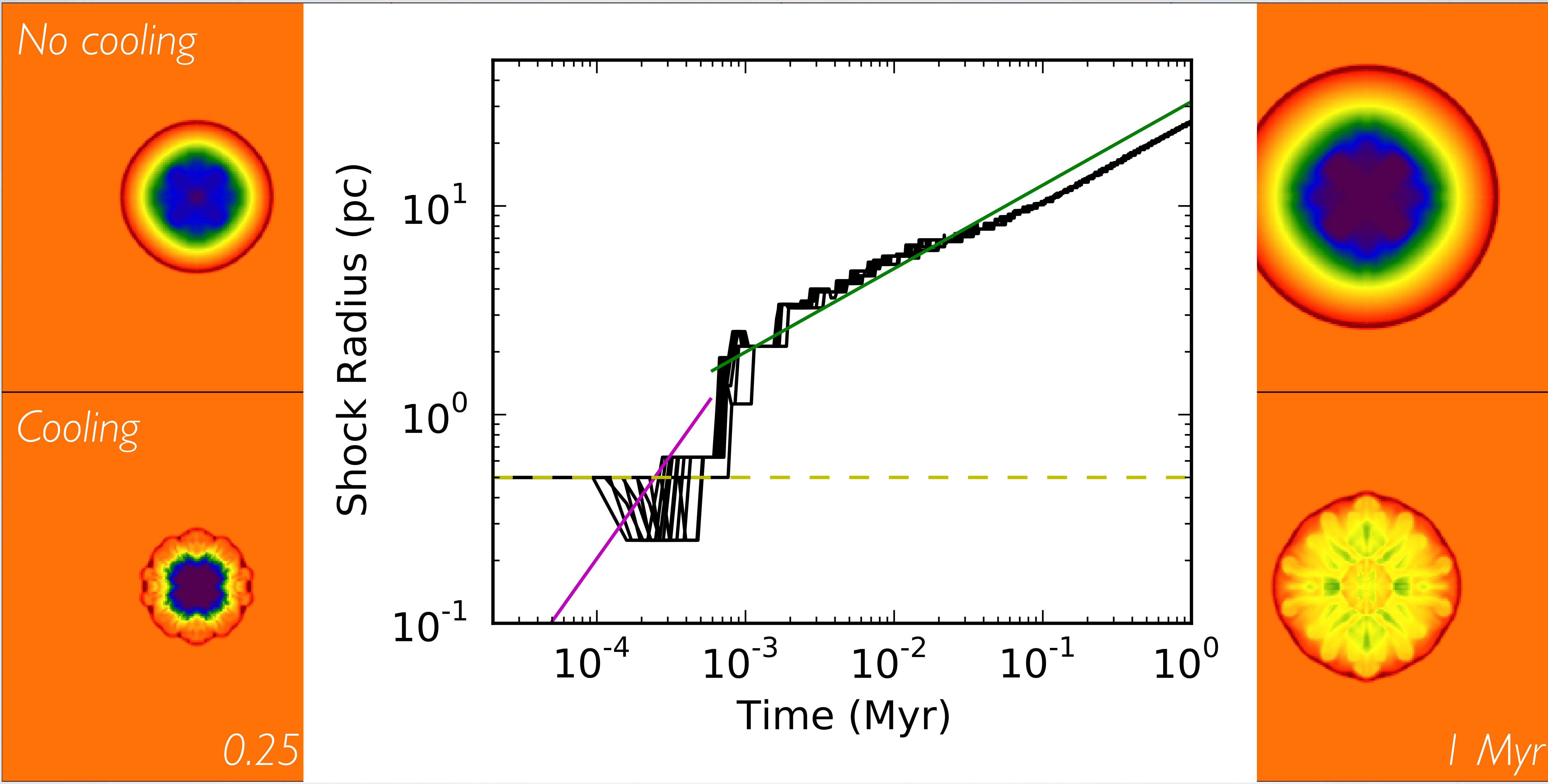


$dx = 0.5$ pc $\quad f_{kin} = 0.3$

$\rho_0 = 100\ cm^{-3}$ $\quad E_{SN} = 10^{51}$ ergs

Simpson et al. in prep

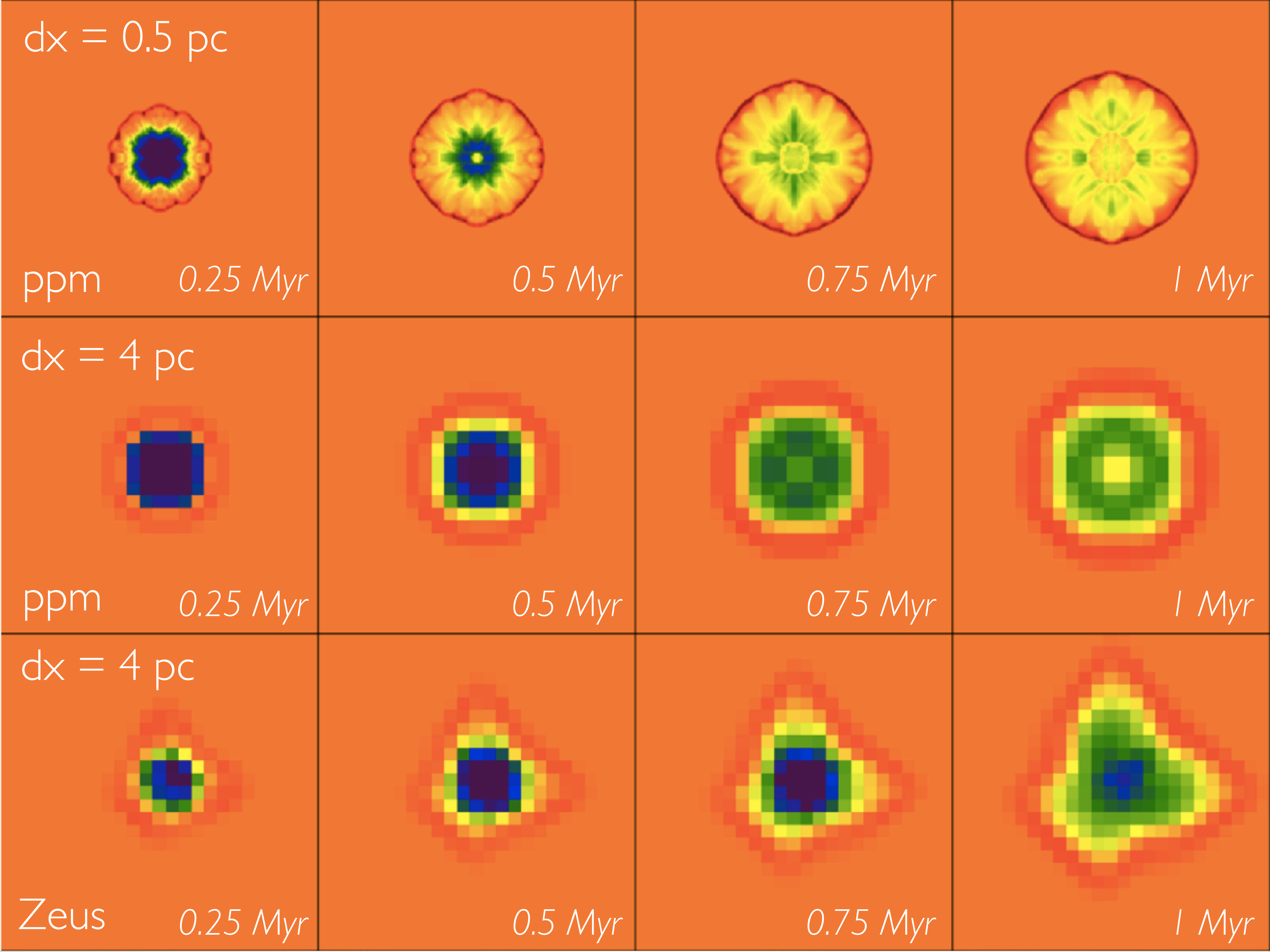
High Resolution Tests



$dx = 0.5$ pc $\quad f_{kin} = 0.3$

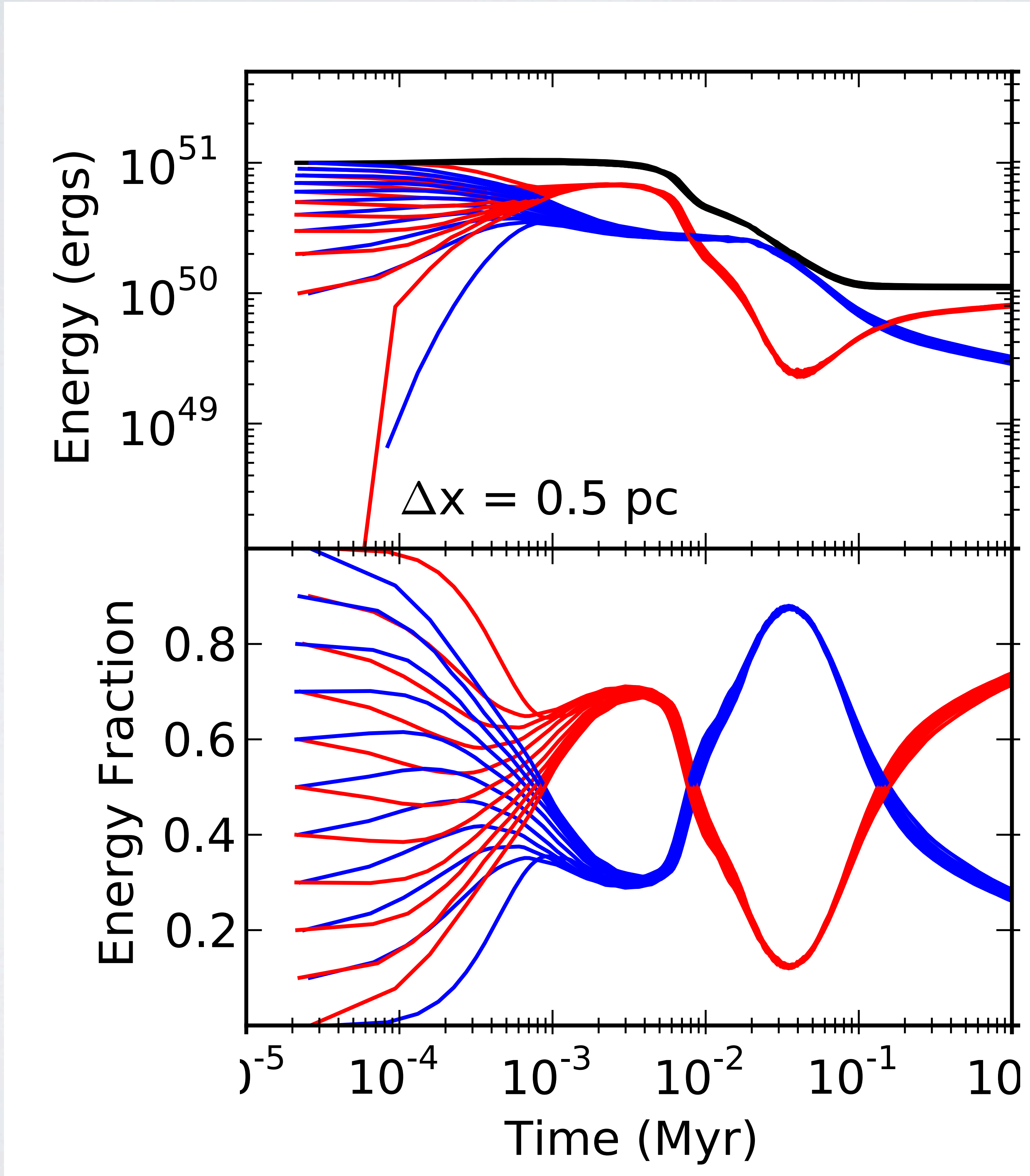
$\boldsymbol{\rho}_0 = 100$ cm^{-3} $\quad E_{SN} = 10^{51}$ ergs

Simpson et al. in prep



dx = 0.5 pc
ppm
0.25 Myr
0.5 Myr
0.75 Myr
1 Myr
dx = 4 pc
ppm
0.25 Myr
0.5 Myr
0.75 Myr
1 Myr
dx = 4 pc
Zeus
0.25 Myr
0.5 Myr
0.75 Myr
1 Myr

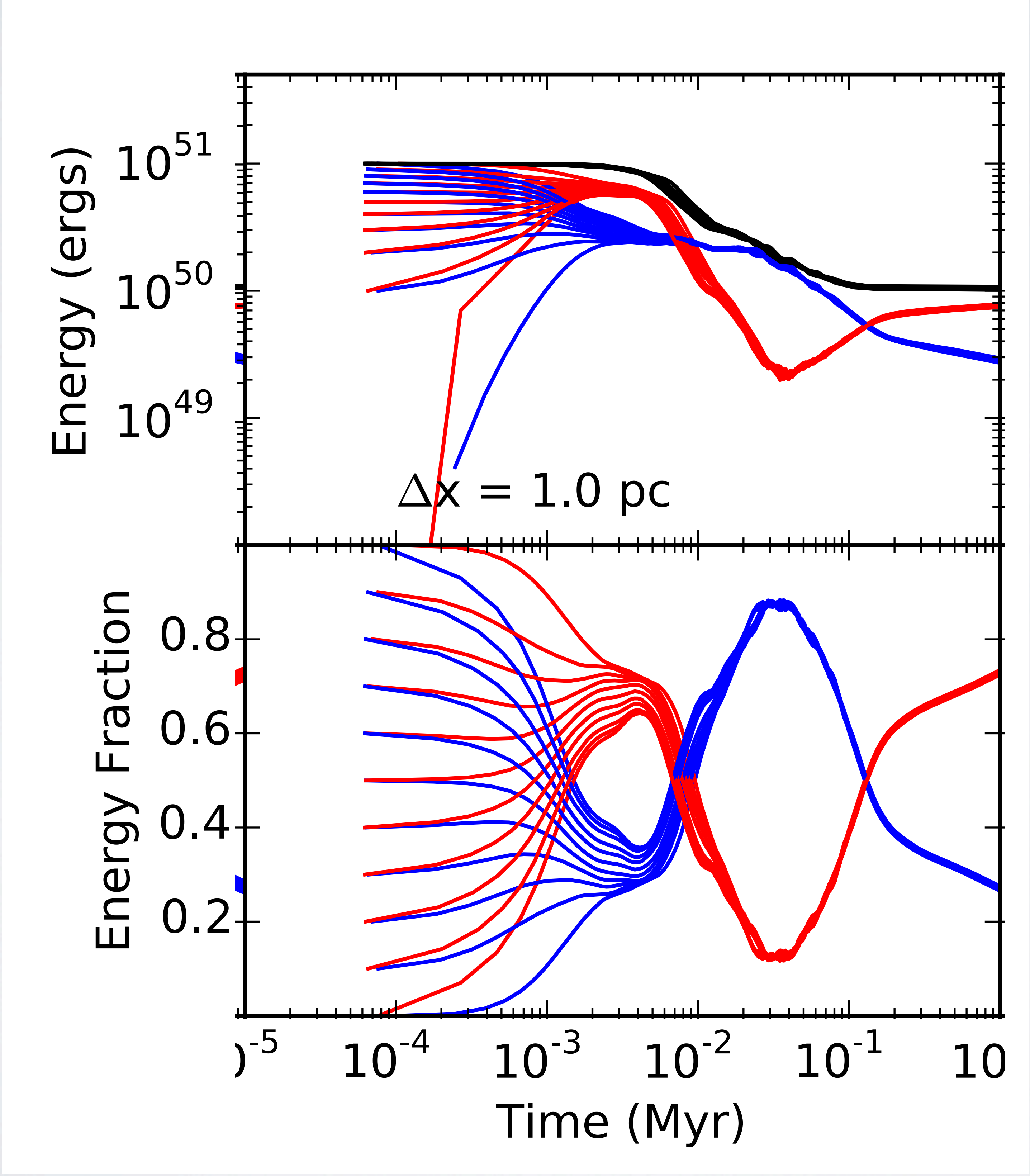
Kinetic Injection Fraction Matters in High Densities and at Low Resolution



100 cm^{-3} background density

Simpson et al. in prep

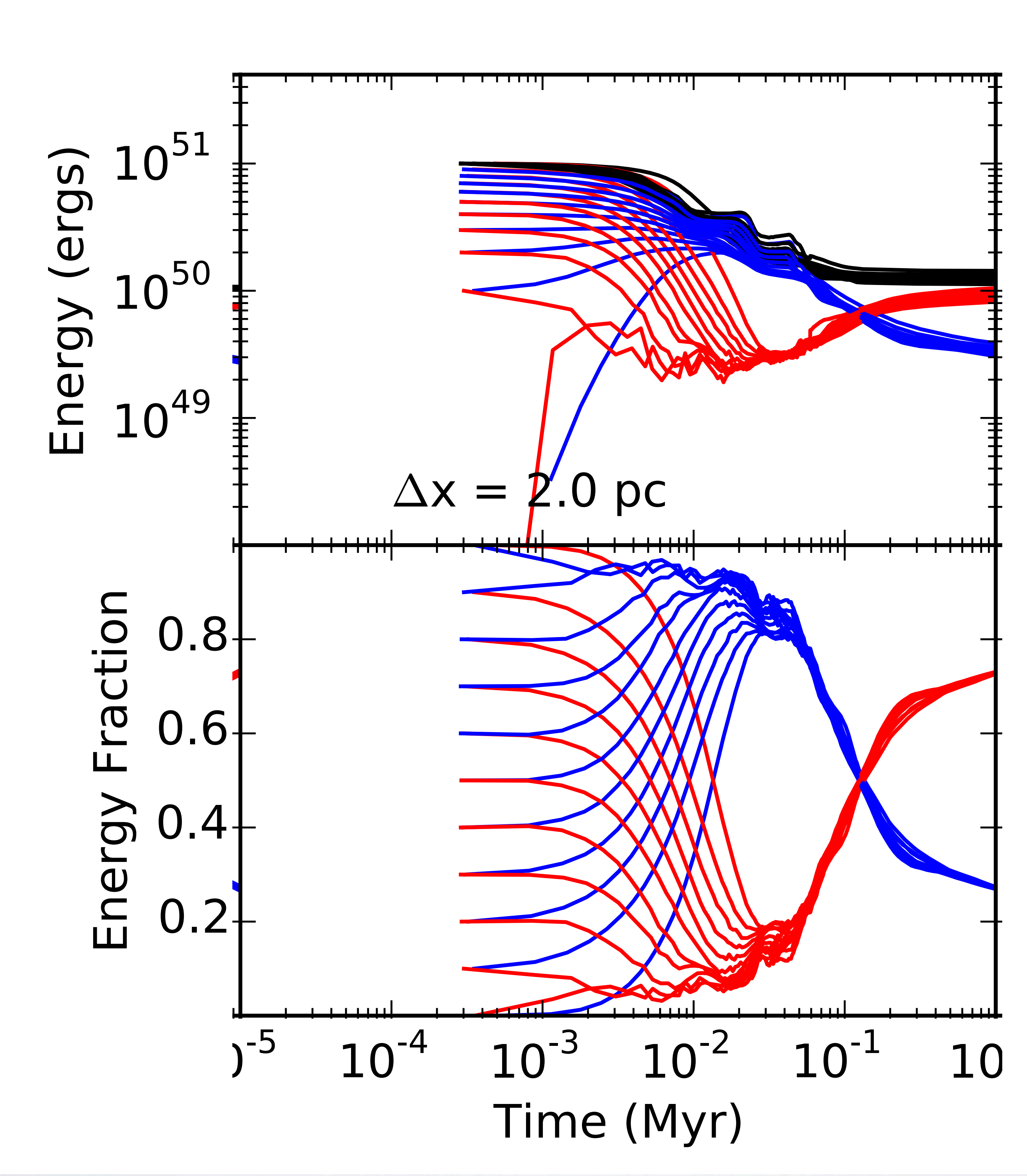
Kinetic Injection Fraction Matters in High Densities and at Low Resolution



100 cm^{-3} background density

Simpson et al. in prep

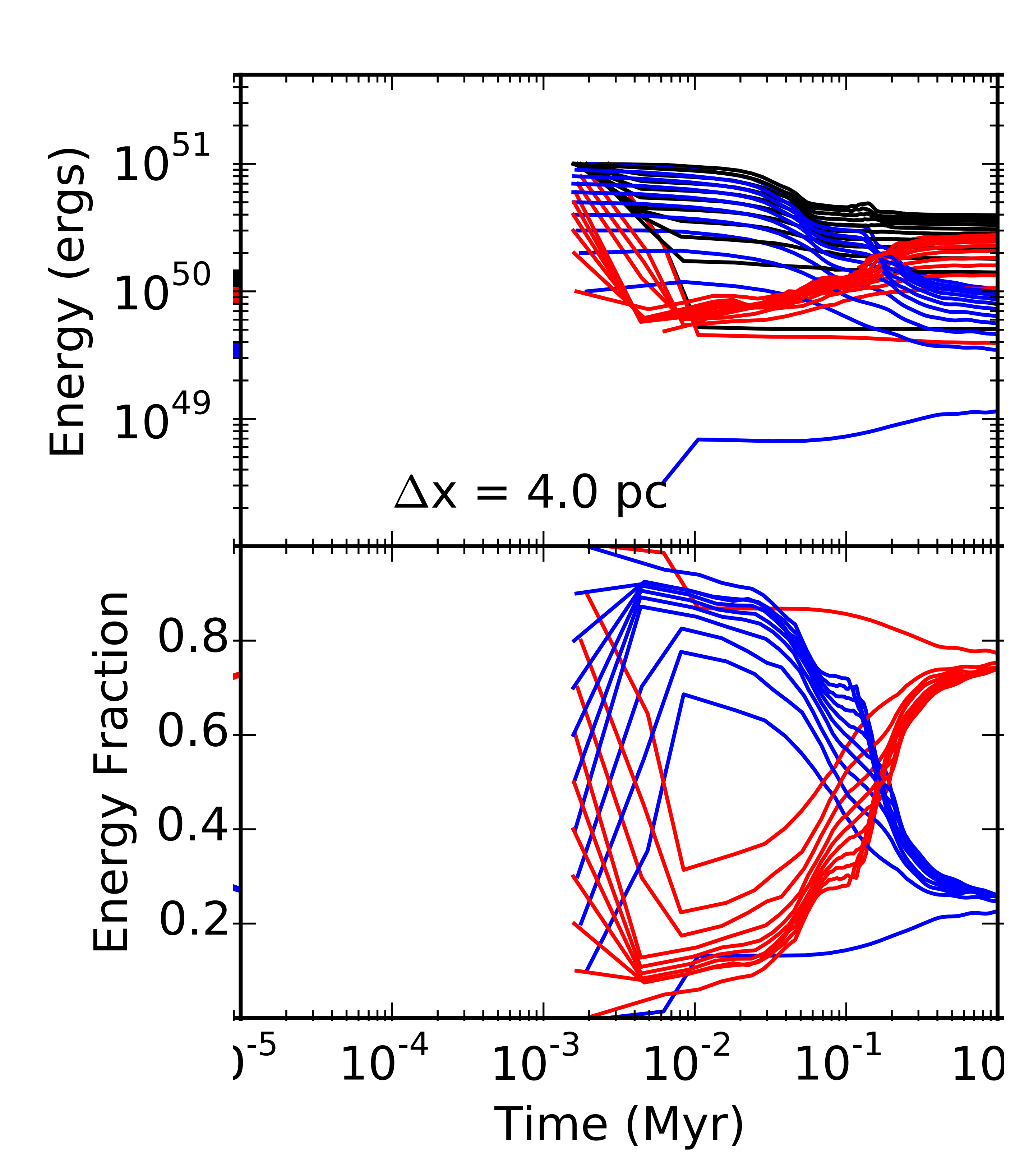
Kinetic Injection Fraction Matters in High Densities and at Low Resolution



100 cm^{-3} background density

Simpson et al. in prep

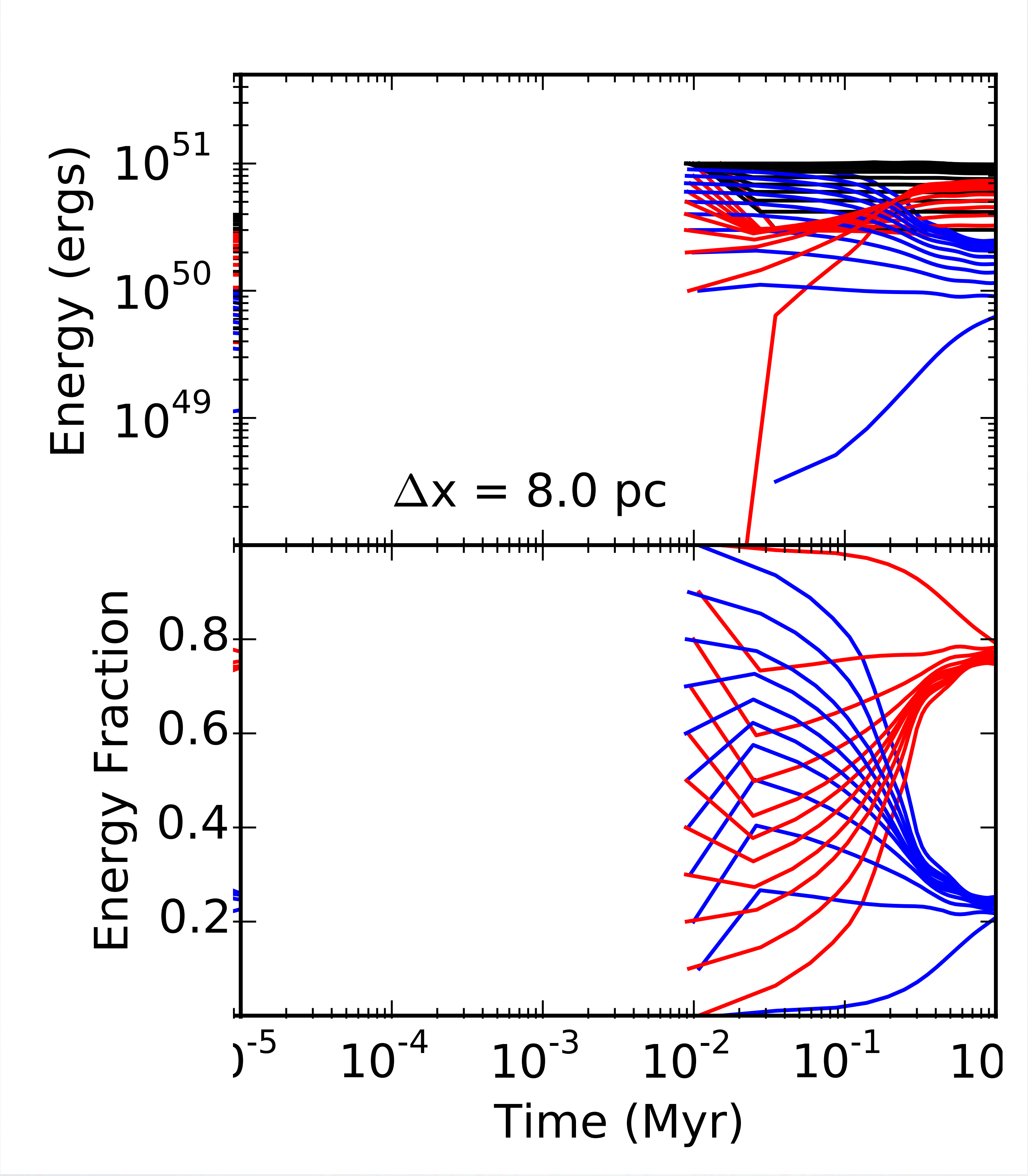
Kinetic Injection Fraction Matters in High Densities and at Low Resolution



100 cm^{-3} background density

Simpson et al. in prep

Kinetic Injection Fraction Matters in High Densities and at Low Resolution



100 cm^{-3} background density

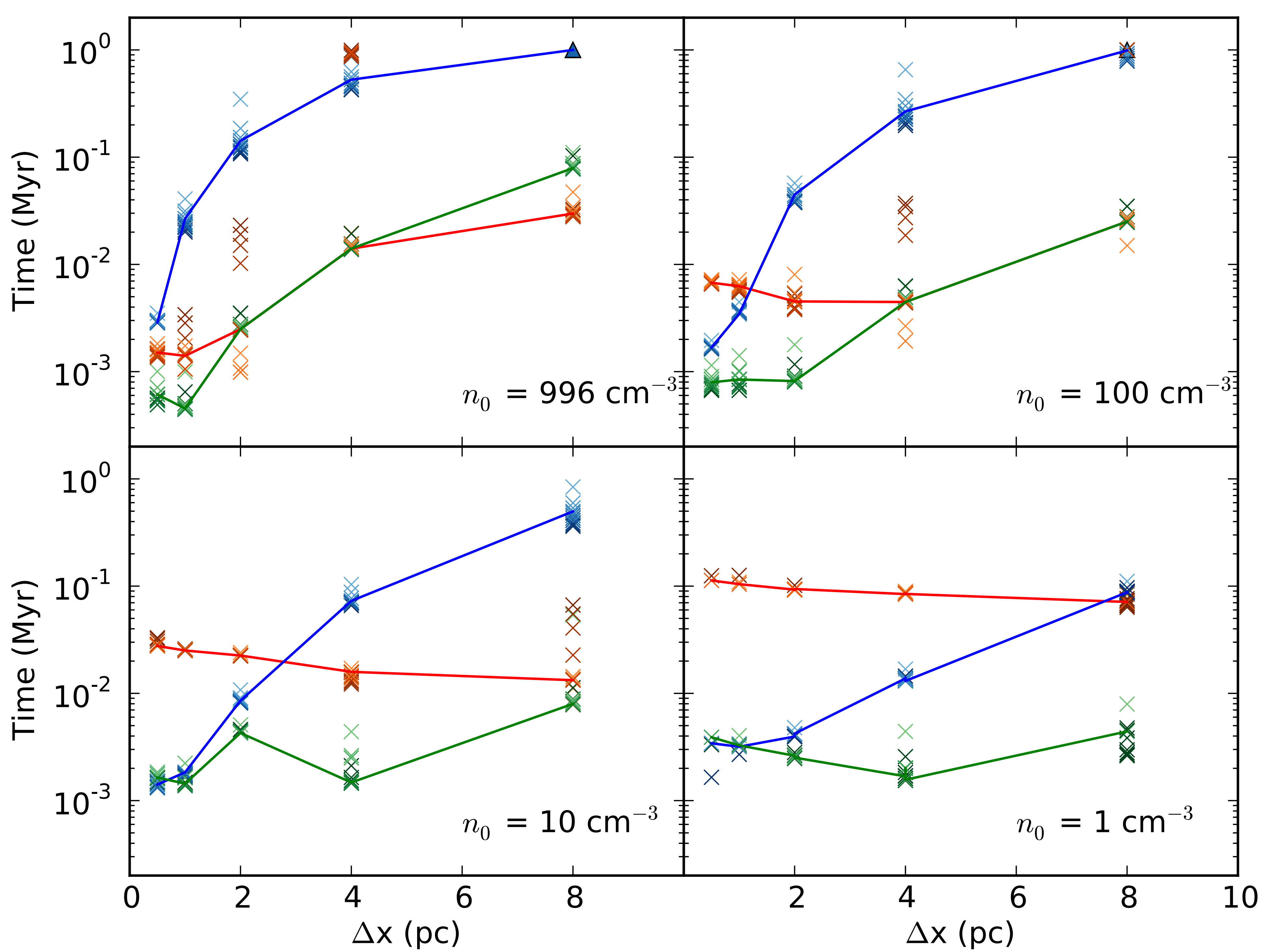
Simpson et al. in prep

Evolutionary Timescales of Feedback

Equilibrium Timescale
$M_{sweep} > 2(M_{inj} + M_{fbr})$

Snow-plow Timescale
$\Delta E = -{}^{1}/_{3} E_0$

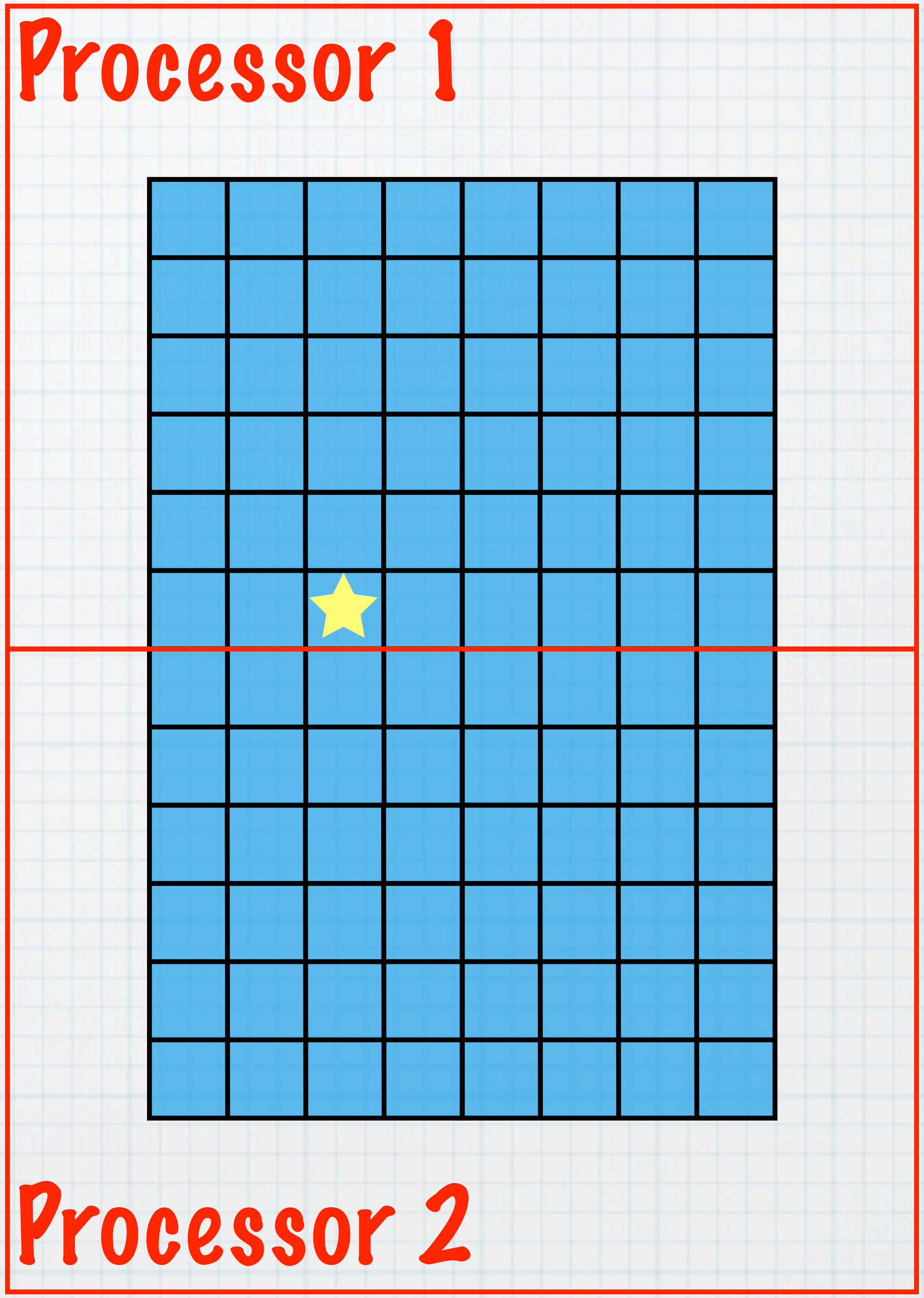
Resolution Timescale
$R_s > 4.5\ \Delta x$



Simpson et al. in prep

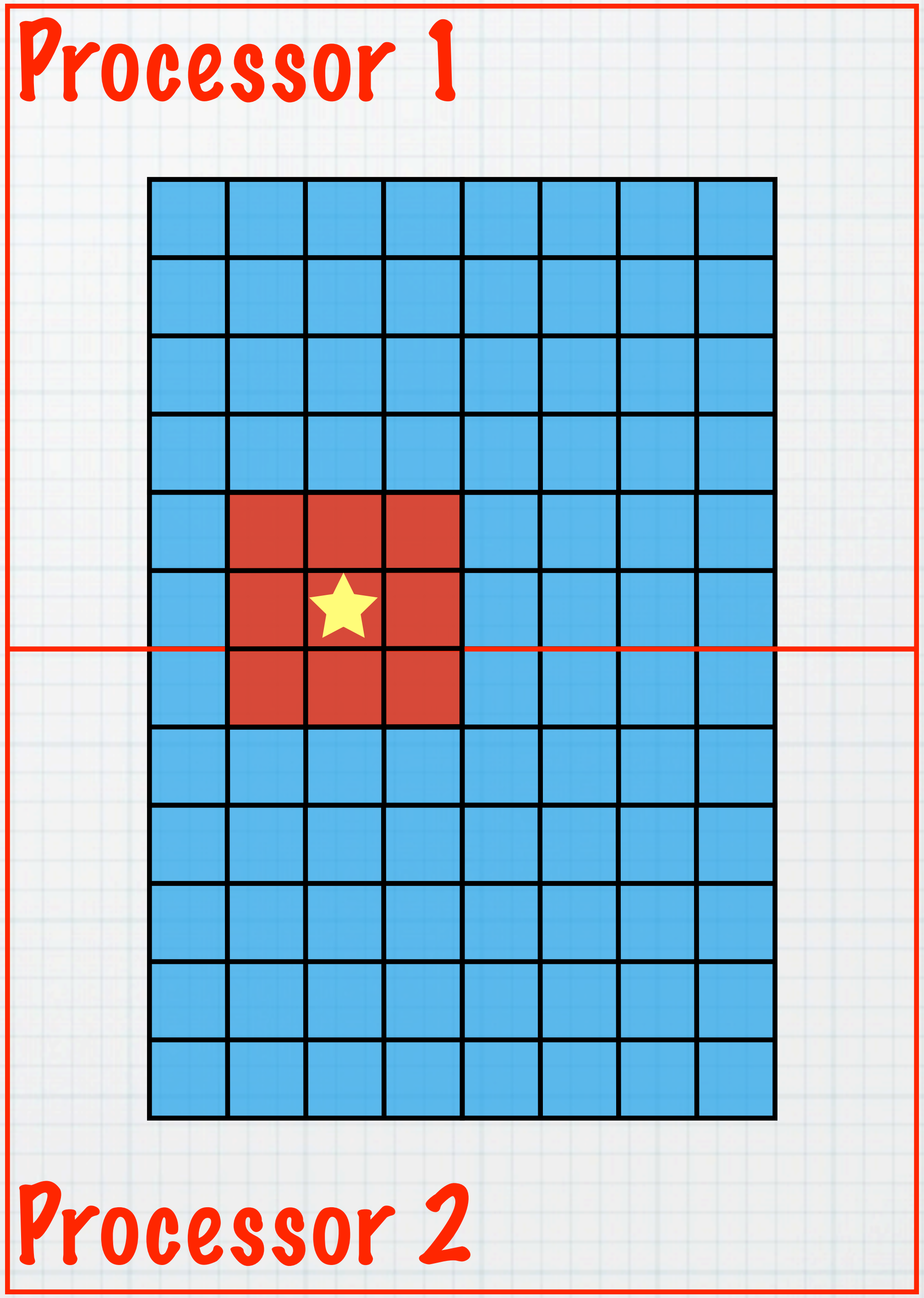
Preliminary Galaxy Models

* Includes physical prescriptions from previous models
* Star particles produce a single SN event with same total energy and mass loading as used previously
* SN event occurs promptly
* Due to current numerical constraints, feedback injection zones near 'grid' edges must be shifted (this will be corrected in future work!)



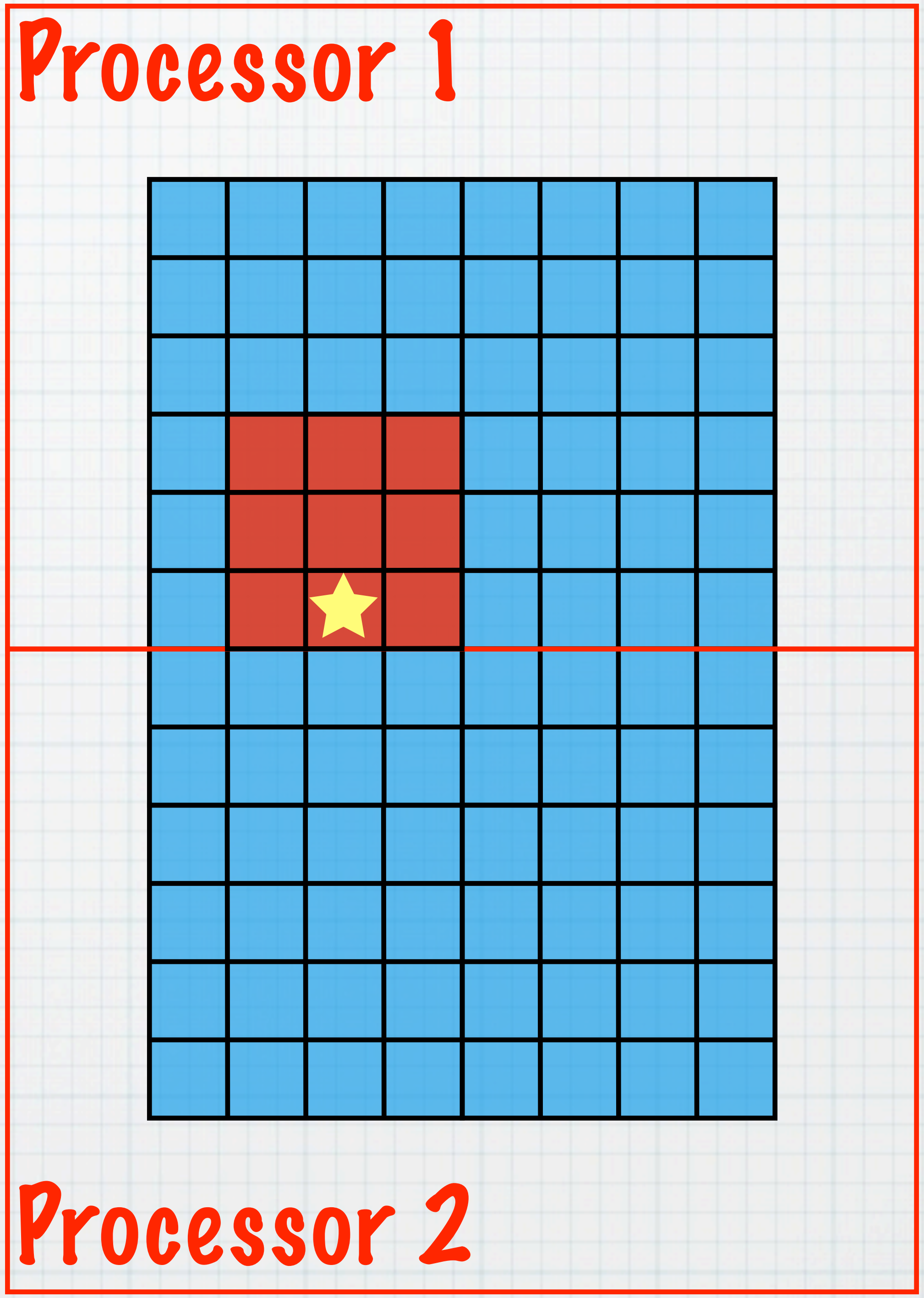
Preliminary Galaxy Models

* Includes physical prescriptions from previous models
* Star particles produce a single SN event with same total energy and mass loading as used previously
* SN event occurs promptly
* Due to current numerical constraints, feedback injection zones near 'grid' edges must be shifted (this will be corrected in future work!)

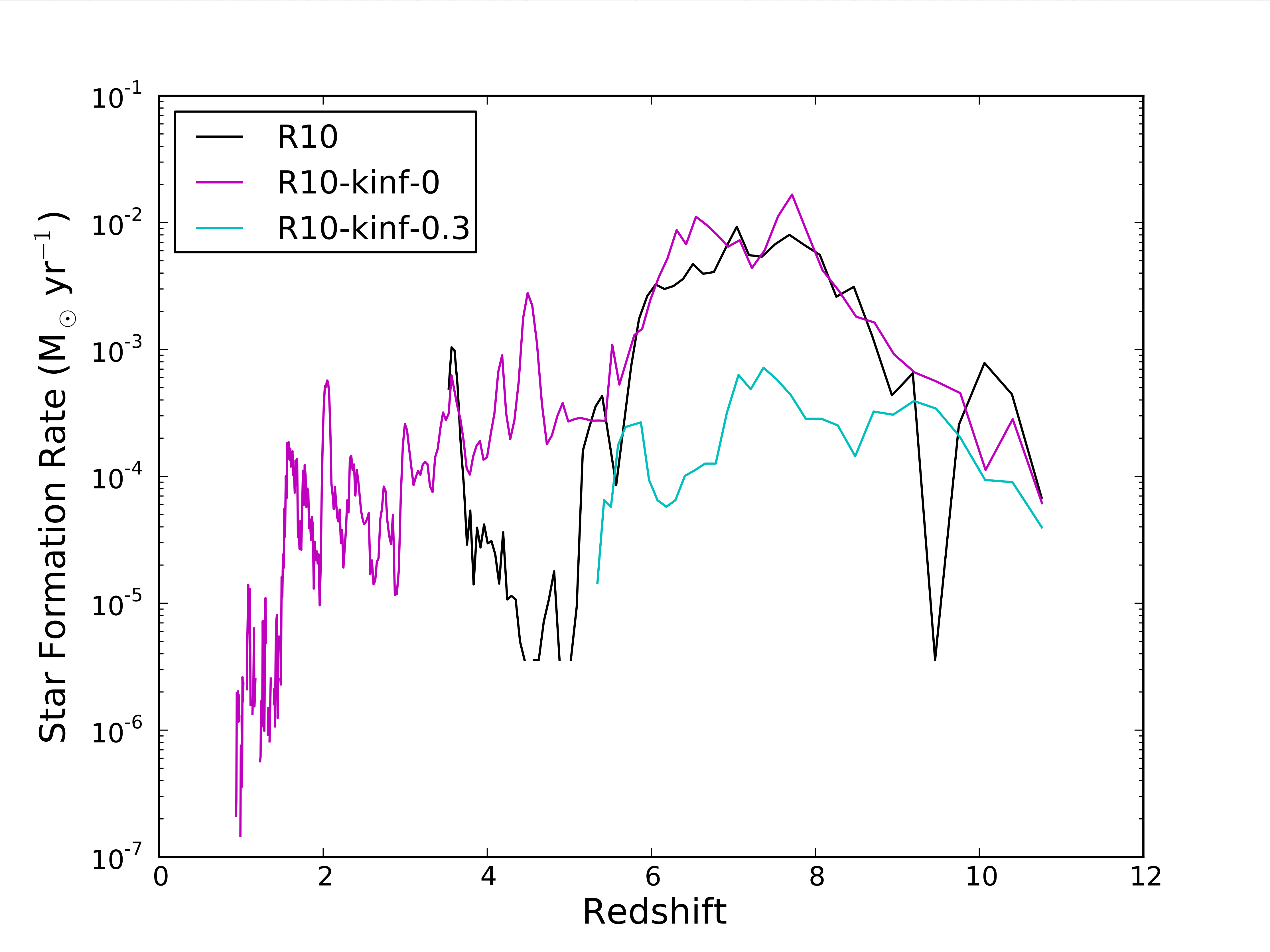


Preliminary Galaxy Models

* Includes physical prescriptions from previous models
* Star particles produce a single SN event with same total energy and mass loading as used previously
* SN event occurs promptly
* Due to current numerical constraints, feedback injection zones near 'grid' edges must be shifted (this will be corrected in future work!)

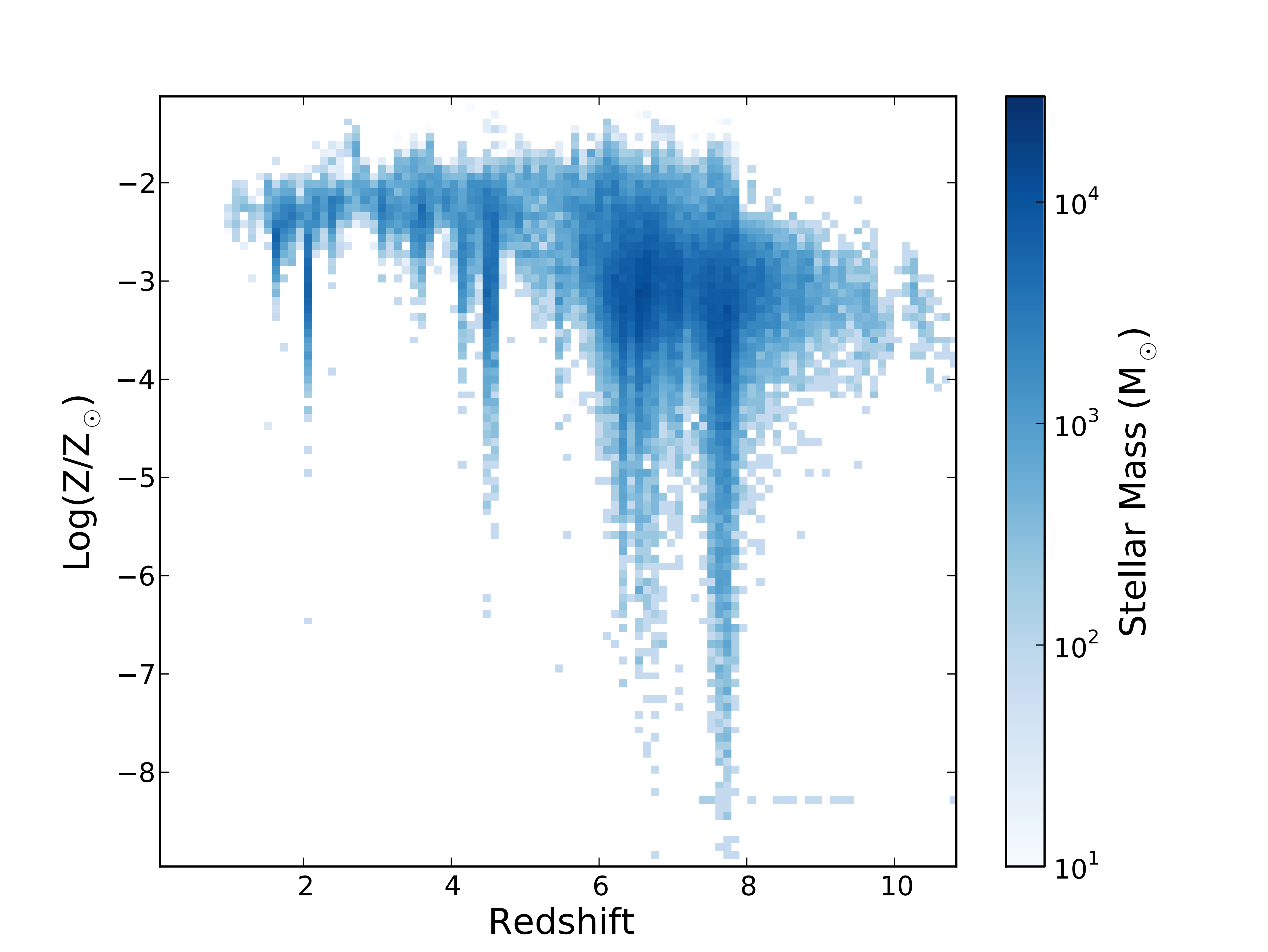


SFR



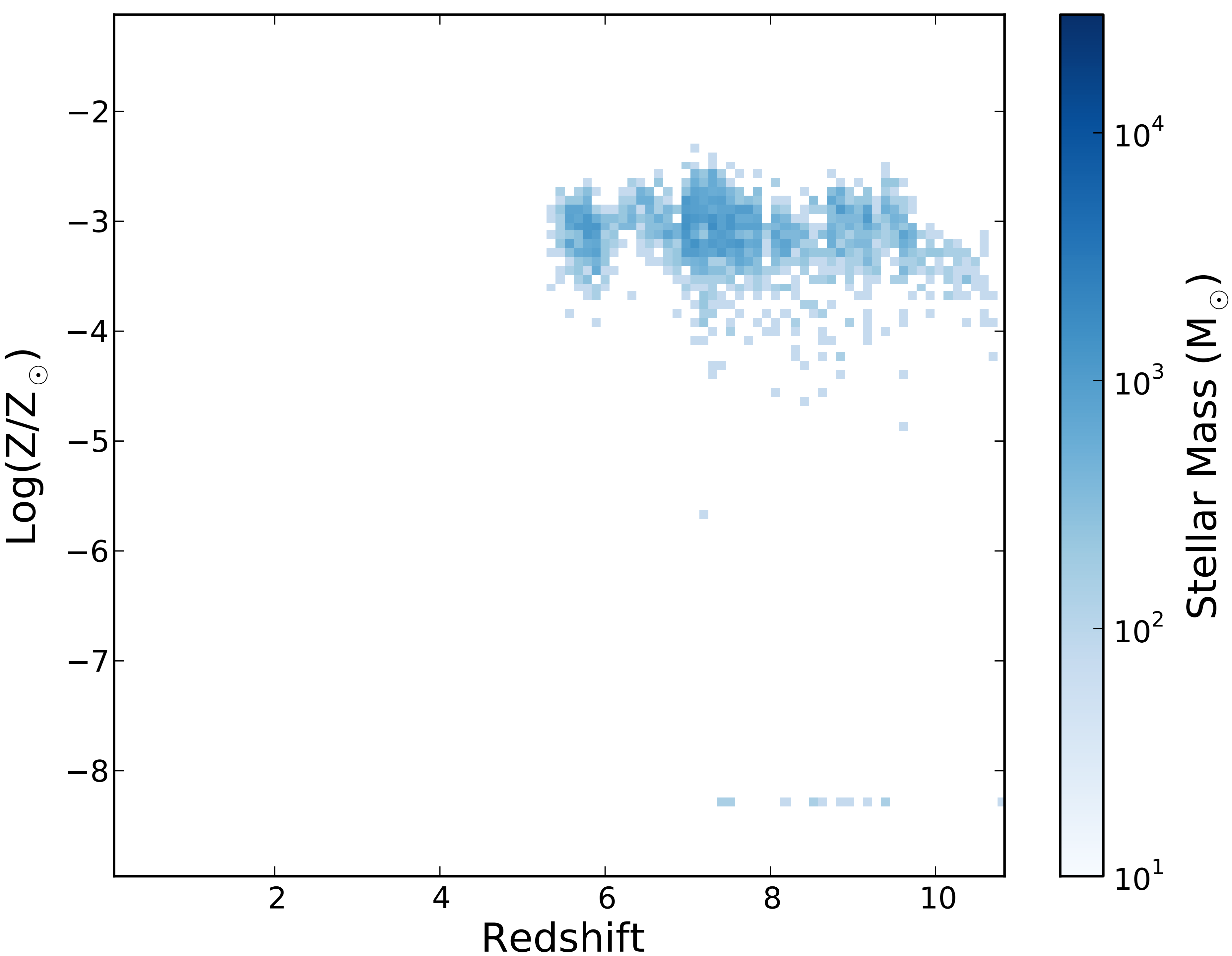
Simpson et al. in prep

New Model (purely thermal)



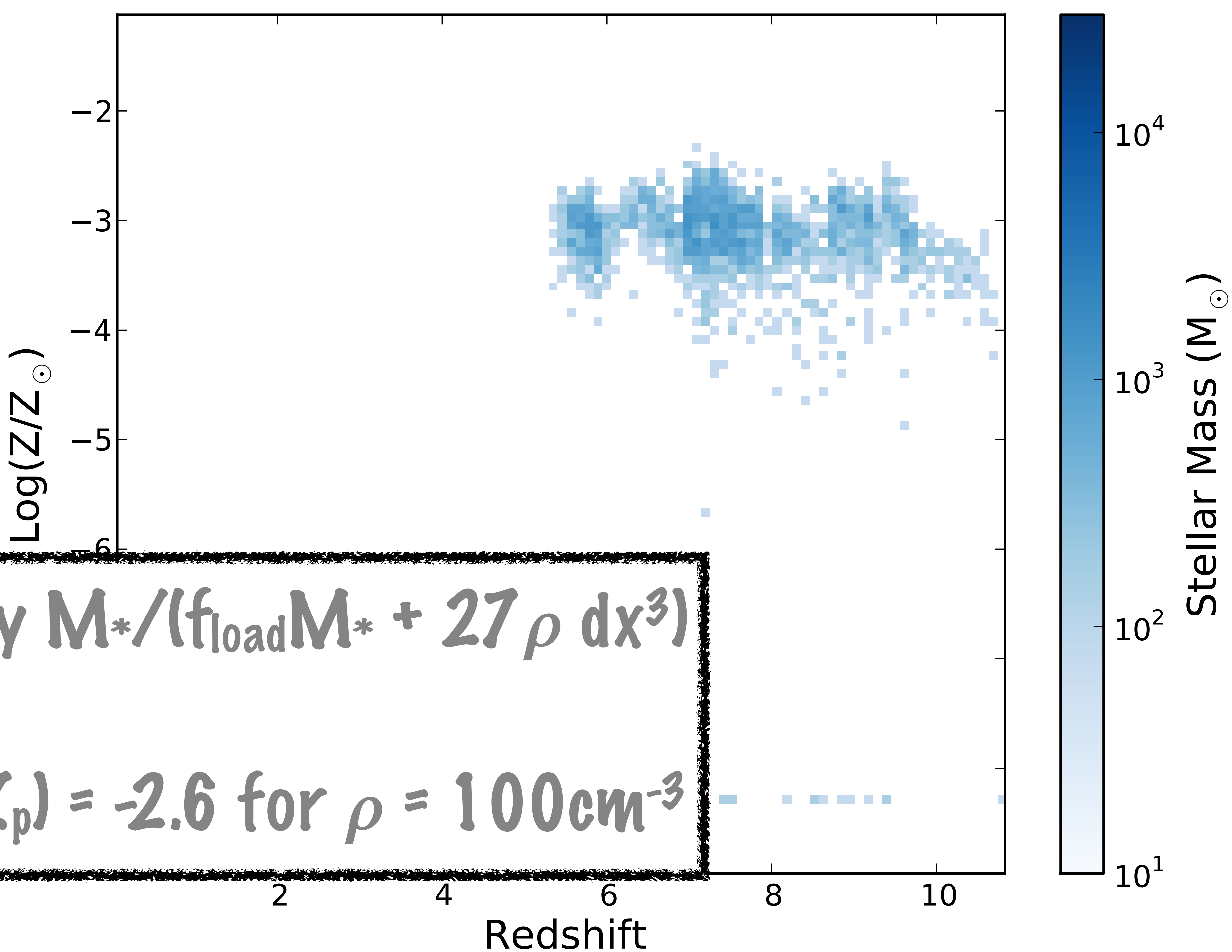
Simpson et al. in prep

New Model (30% kinetic)



Simpson et al. in prep

New Model (30% kinetic)



$Z_p = y\, M_*/(f_{load} M_* + 27\,\rho\, dx^3)$

$\log(Z_p) = -2.6$ for $\rho = 100\,\mathrm{cm}^{-3}$

Simpson et al. in prep

Summary & Conclusions

- Feedback plays an important role in shaping many dwarf properties

- Resolution is key in modeling feedback

- We need to consider multiple observables to understand feedback - SFH, mean metallicity, metallicity distribution, complex abundances, central densities, etc.

- Preliminary results suggest momentum may not be the dominant regulator of some of these galaxy properties - careful accounting of the various sources of feedback (e.g. Agertz et al., Hopkins et al.) is necessary

- Further code improvements and higher resolution calculations may provide further insights