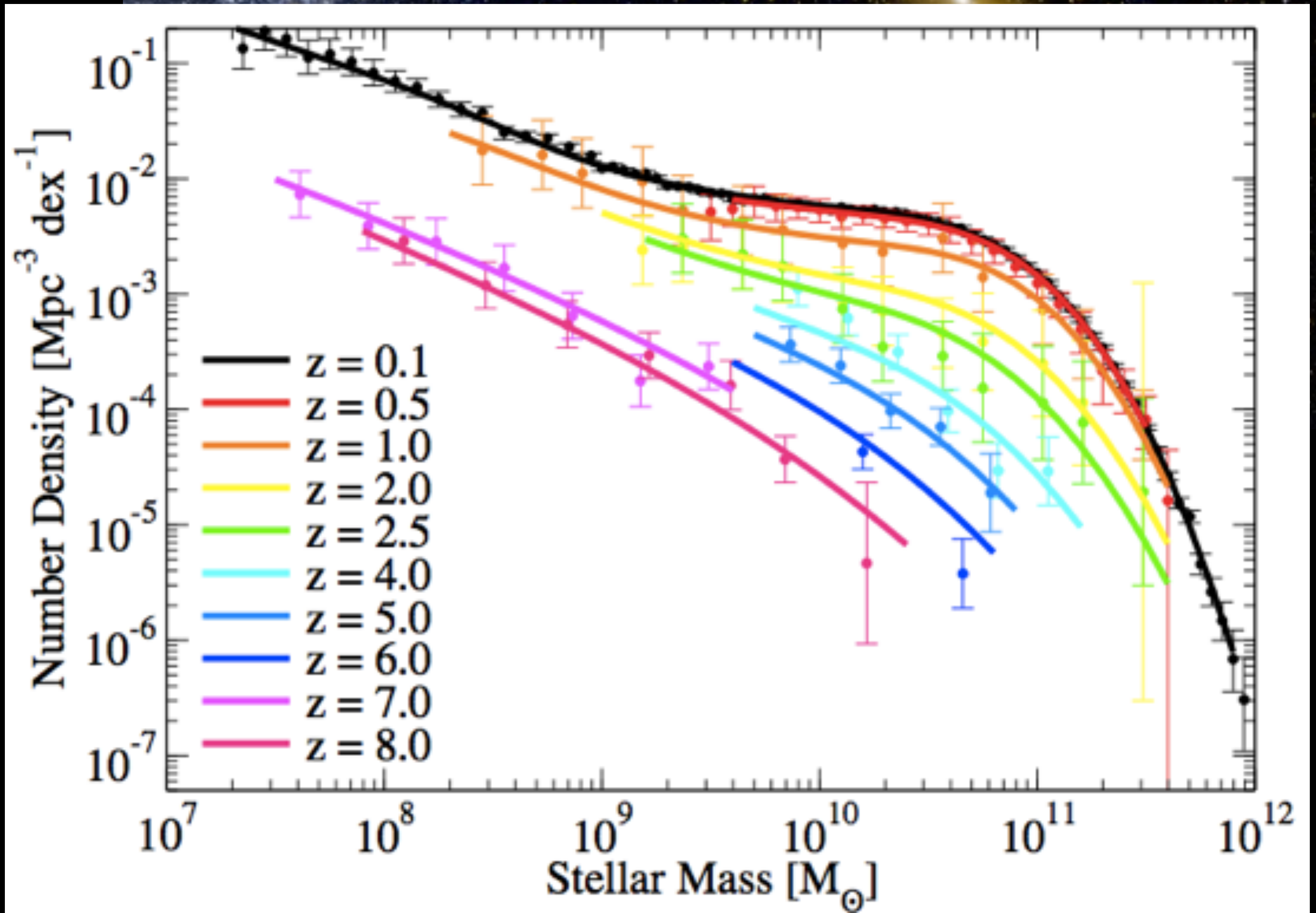
GREG STINSON (MPIA HEIDELBERG)

# WHICH STELLAR FEEDBACK MODEL IS THE BEST?

# THE GOAL

- We want to form beautiful galaxies with the right amount of stars



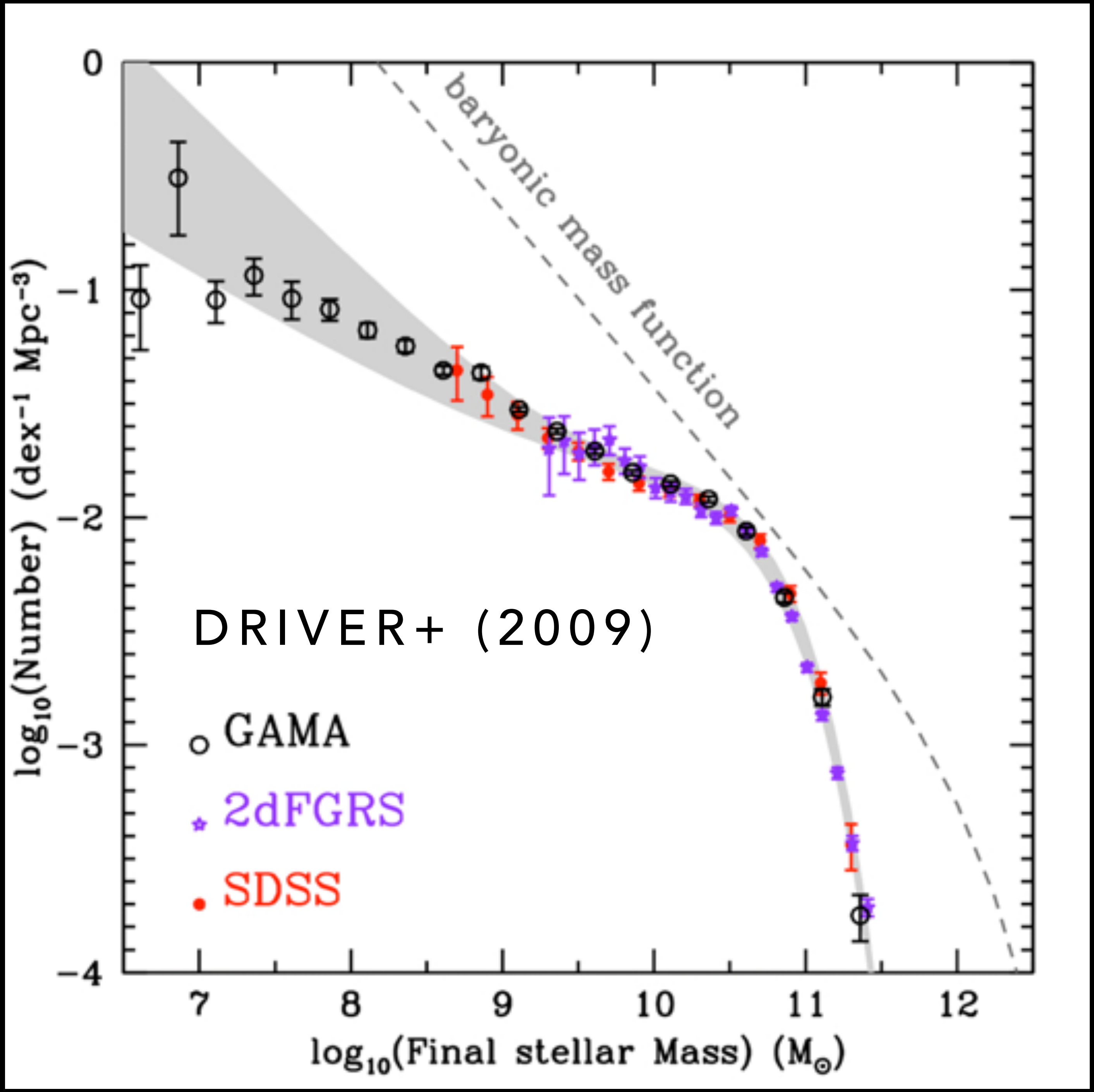

Behroozi+ (2013)

# OUTLINE

- Matching Stellar Mass Function
- ISM Model basics
    - Cooling
    - Star formation
    - Feedback:  Kinetic vs. Thermal
- Feedback Timing
- Outstanding Issues
- Hybrid Models

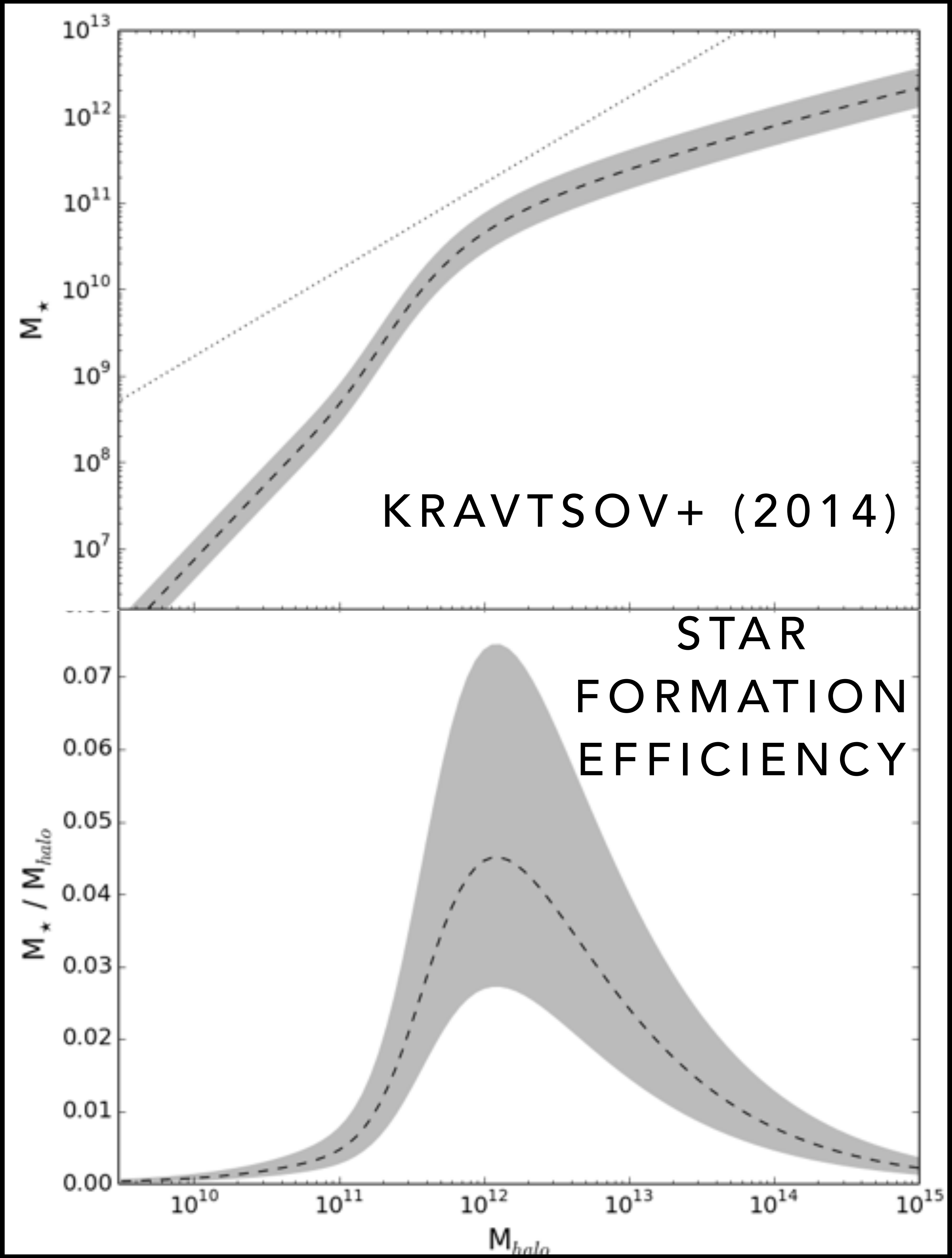
# STELLAR MASS FUNCTION

- luminosity translated to stellar mass
- **Different shape from halo mass function!**

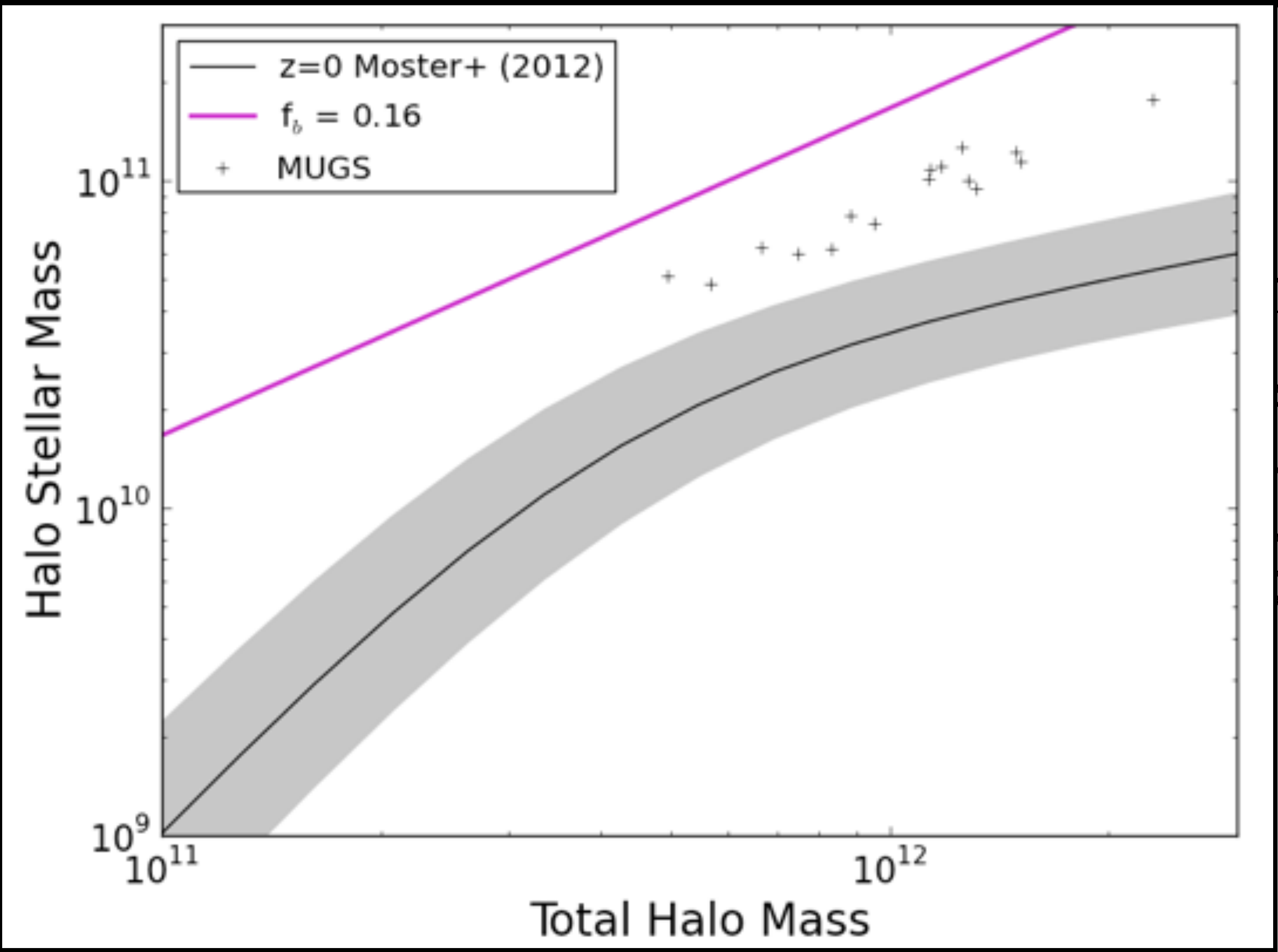


# ABUNDANCE MATCHING

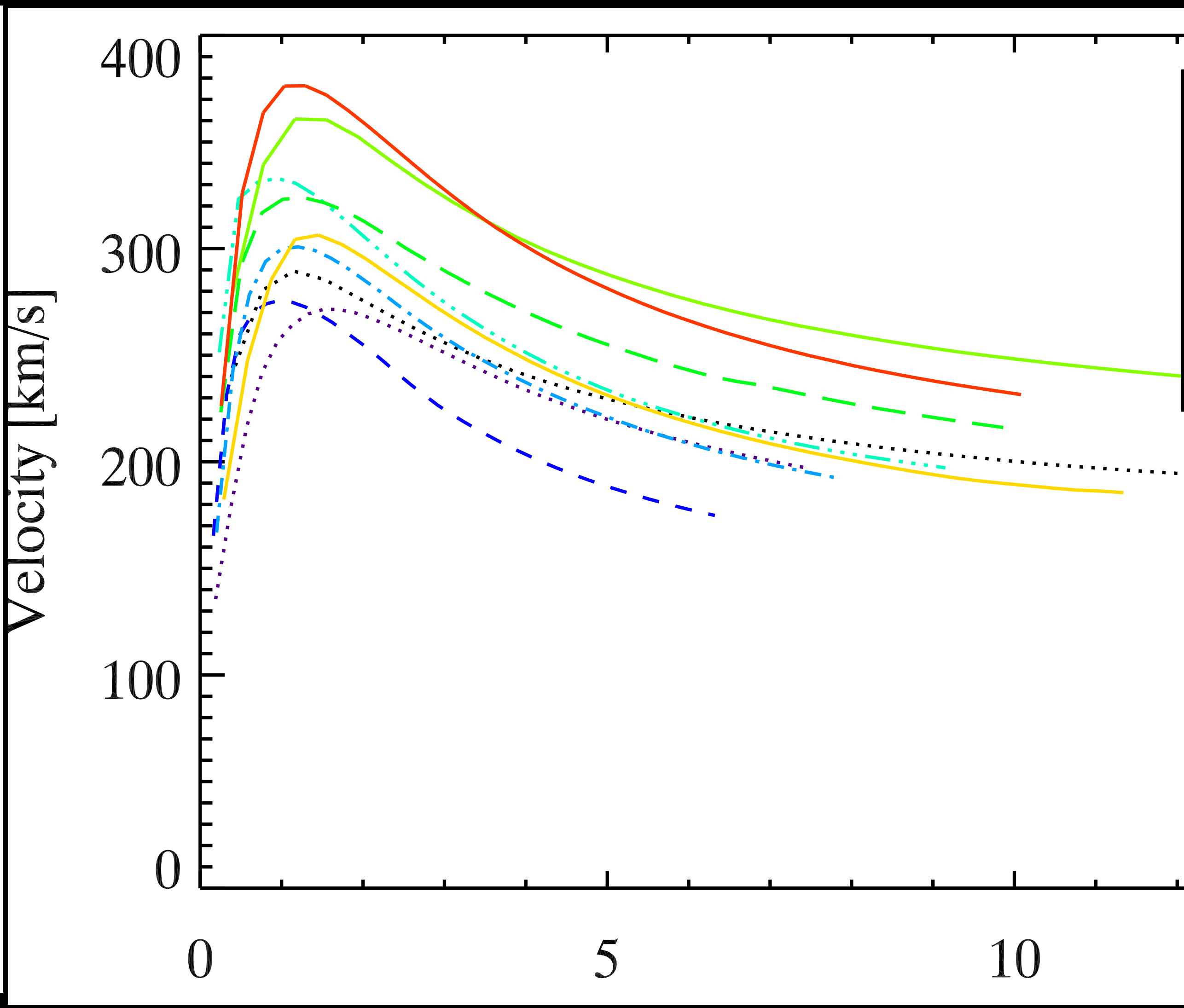
- Star formation is low efficiency at all masses (25-35% of baryons at peak: MW mass)
- Efficiency drops to low and high masses



TOO MANY STARS FORM




PRIMARILY IN THE CENTER



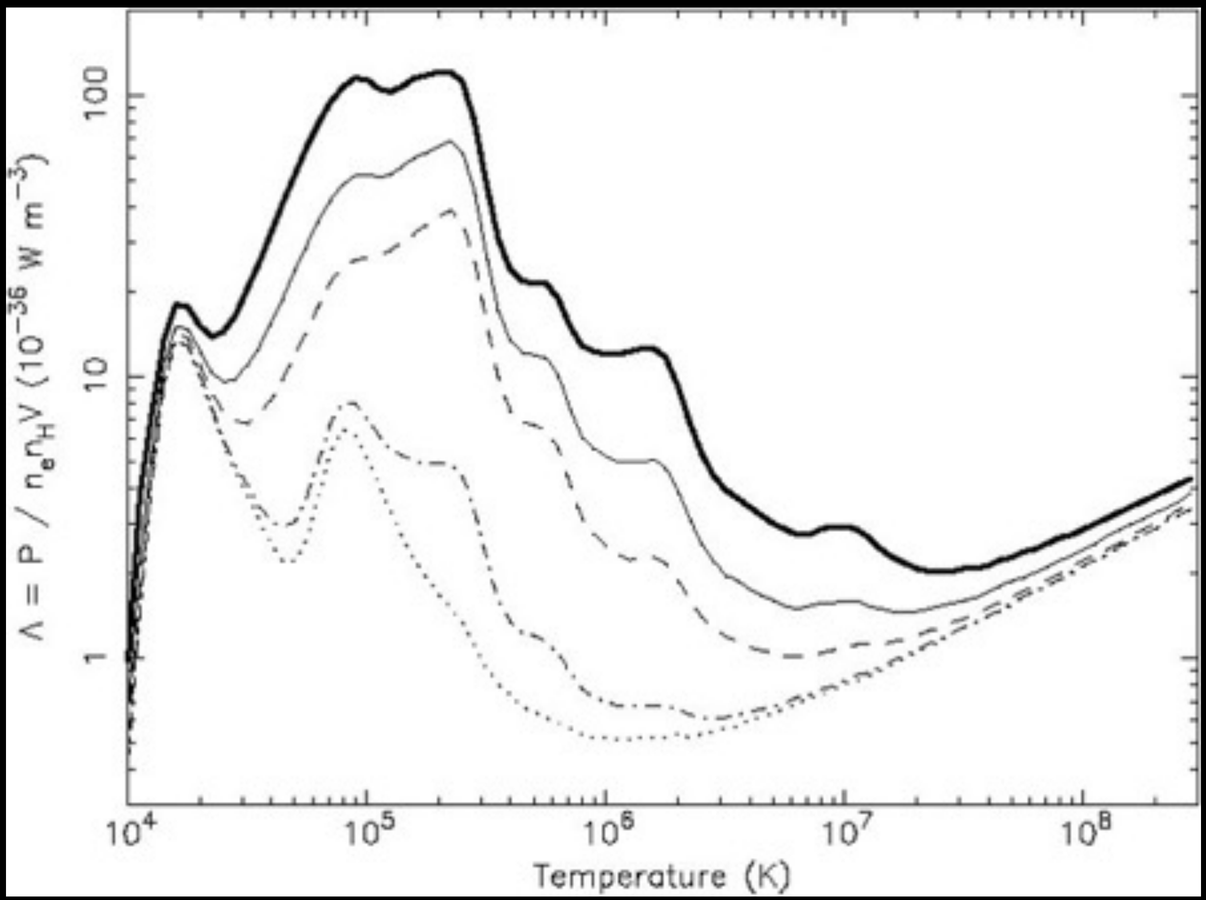

# OVERCOOLING

MUGS STINSON ET AL (2010)

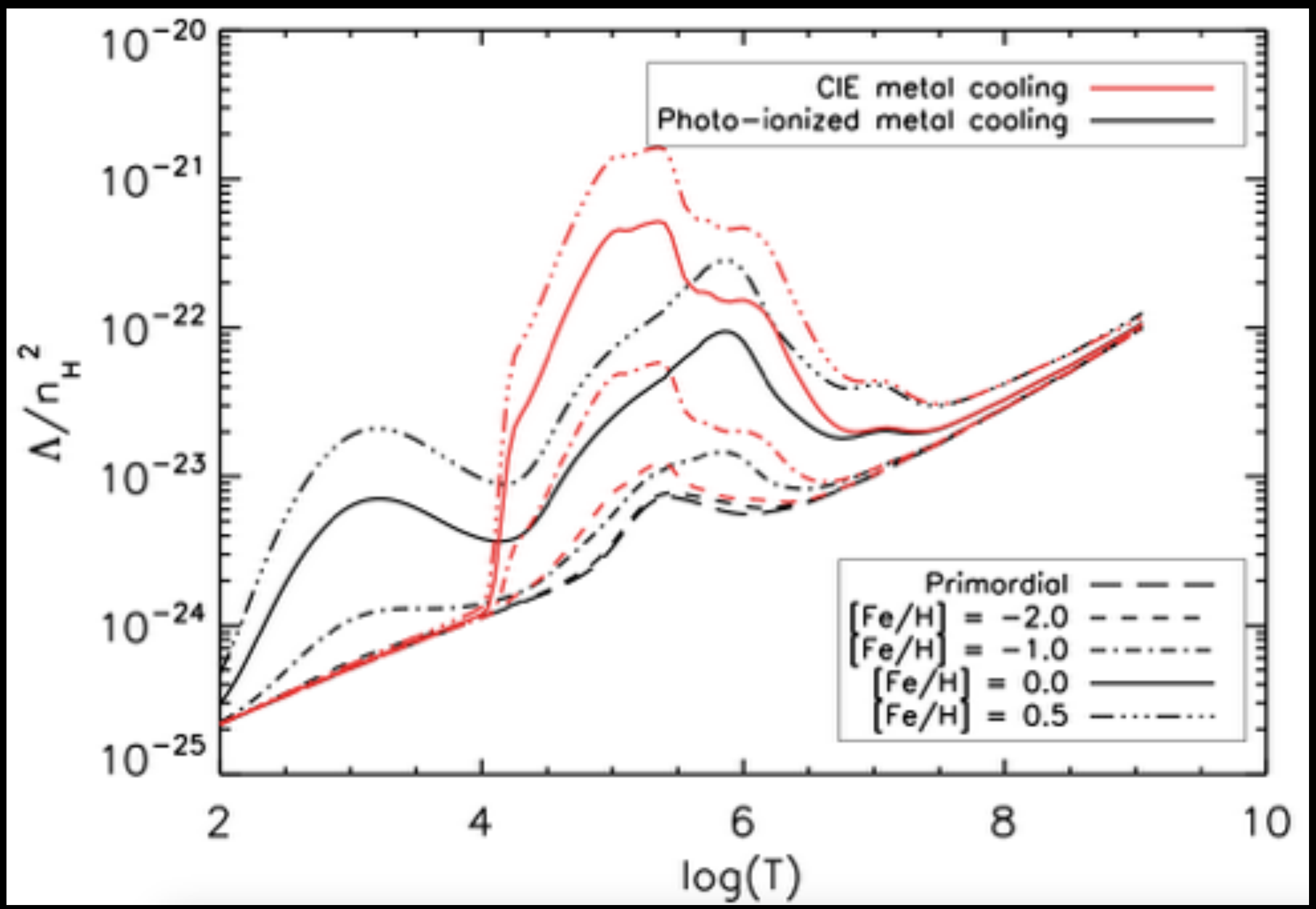
# 3 PARTS TO ISM MODEL

- Gas Cooling
- Star formation
- Energetic Feedback

# GAS COOLING



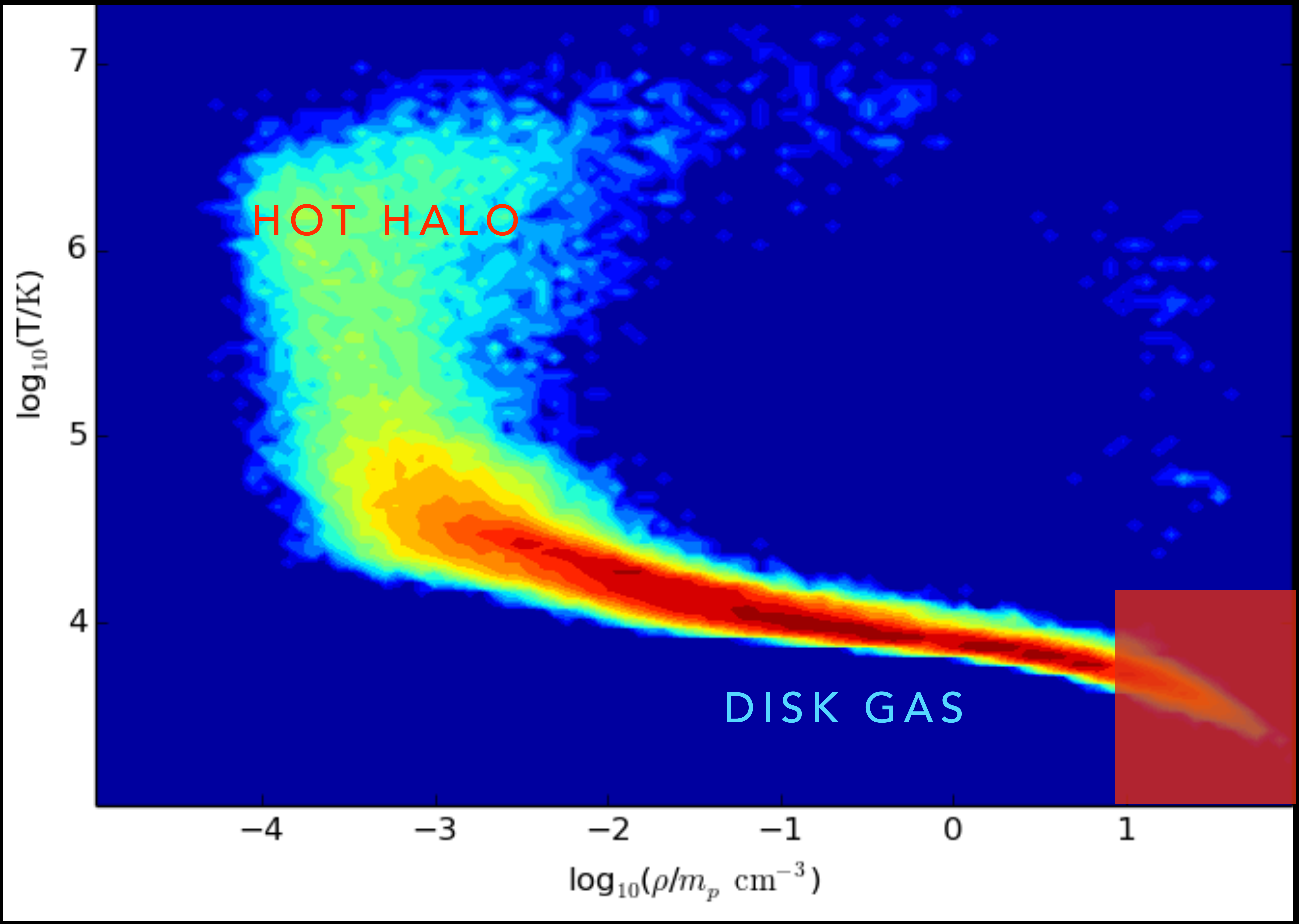

Dopita & Sutherland
$10^4$ K minimum
(Eris)




Low temperature cooling
from Cloudy
includes effects of radiation
fields (e.g. Shen+ 2010)

# STAR FORMATION CRITERIA

- Density threshold
  - EAGLE: 0.1 $cm^{-3}$
  - Governato: 100 $cm^{-3}$
  - Hopkins: $10^4$ $cm^{-3}$
  - Gnedin & Kravtsov: Molecular $H_2$
- Star formation efficiency $\dot{M}_{SF} = c_{\star} M_{gas} / t_{ff}$
  - 2% - 100% (Hopkins); see Agertz & Kravtsov (2015) 10%




highest resolved density

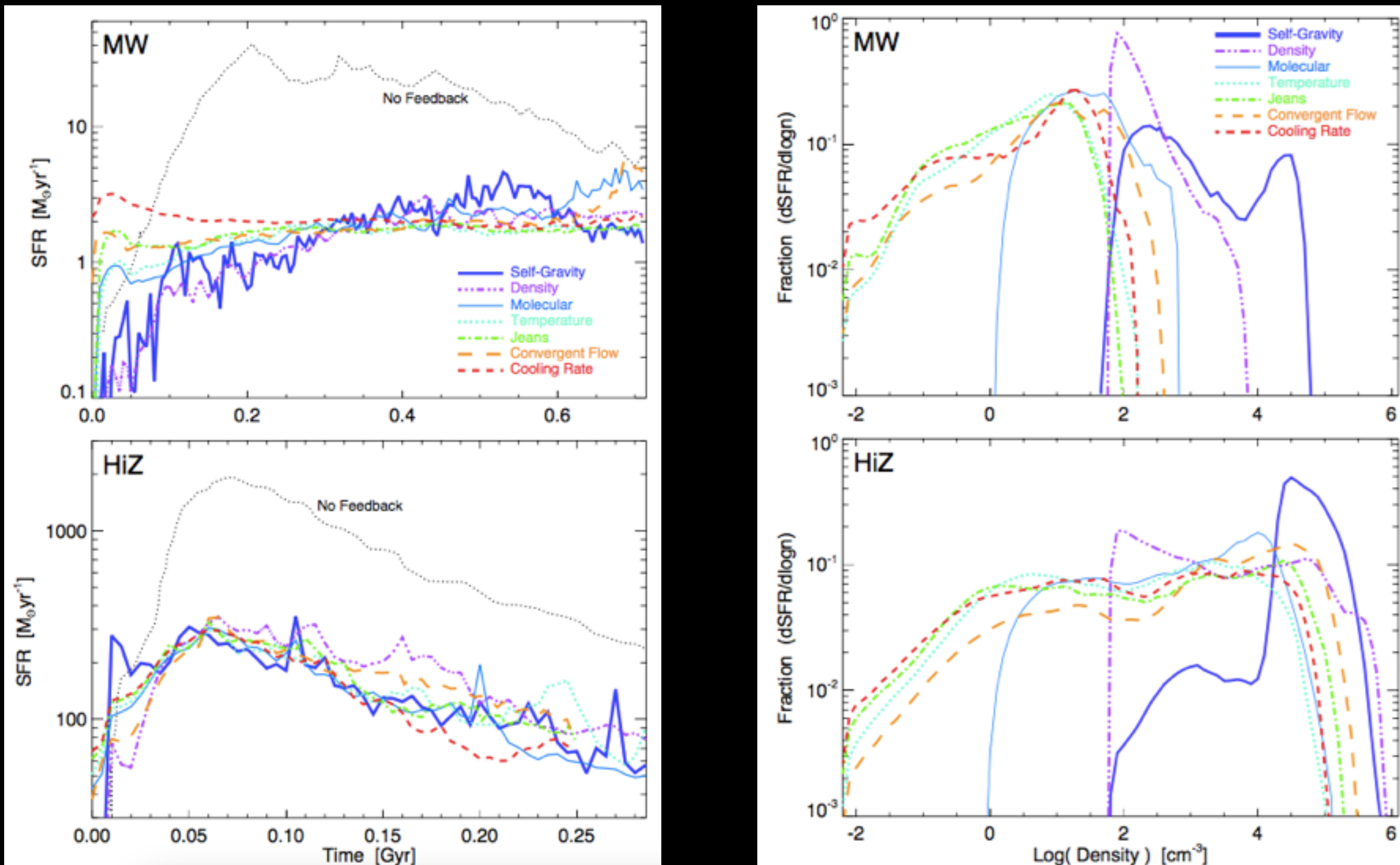
$$nth= \frac{50\text{x}10^5\ M_\odot}{(310\ \text{pc})^3}$$

$$n_{th}= 10\ \text{cm}^{-3}$$

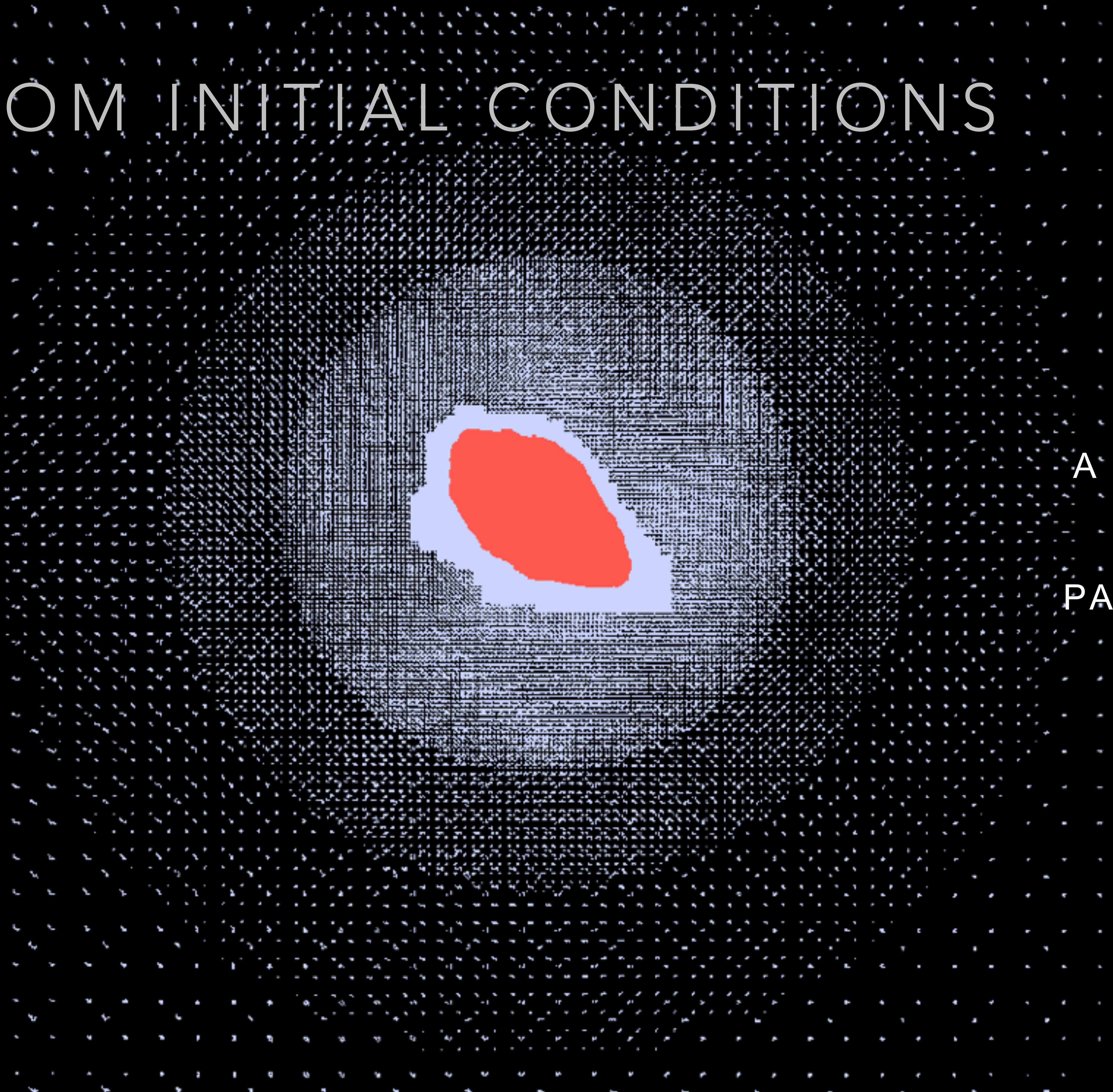
# STARS FORM FROM COOL, DENSE GAS

$T_{MAX}$ = 15000 K; $N_{MIN}$ = 10 $CM^{-3}$ (RESOLVED DENSITY)
INHERIT KINEMATICS AND CHEMISTRY FROM PARENT GAS

# STAR FORMATION RECIPE DOESN'T MATTER: HOPKINS (2013)



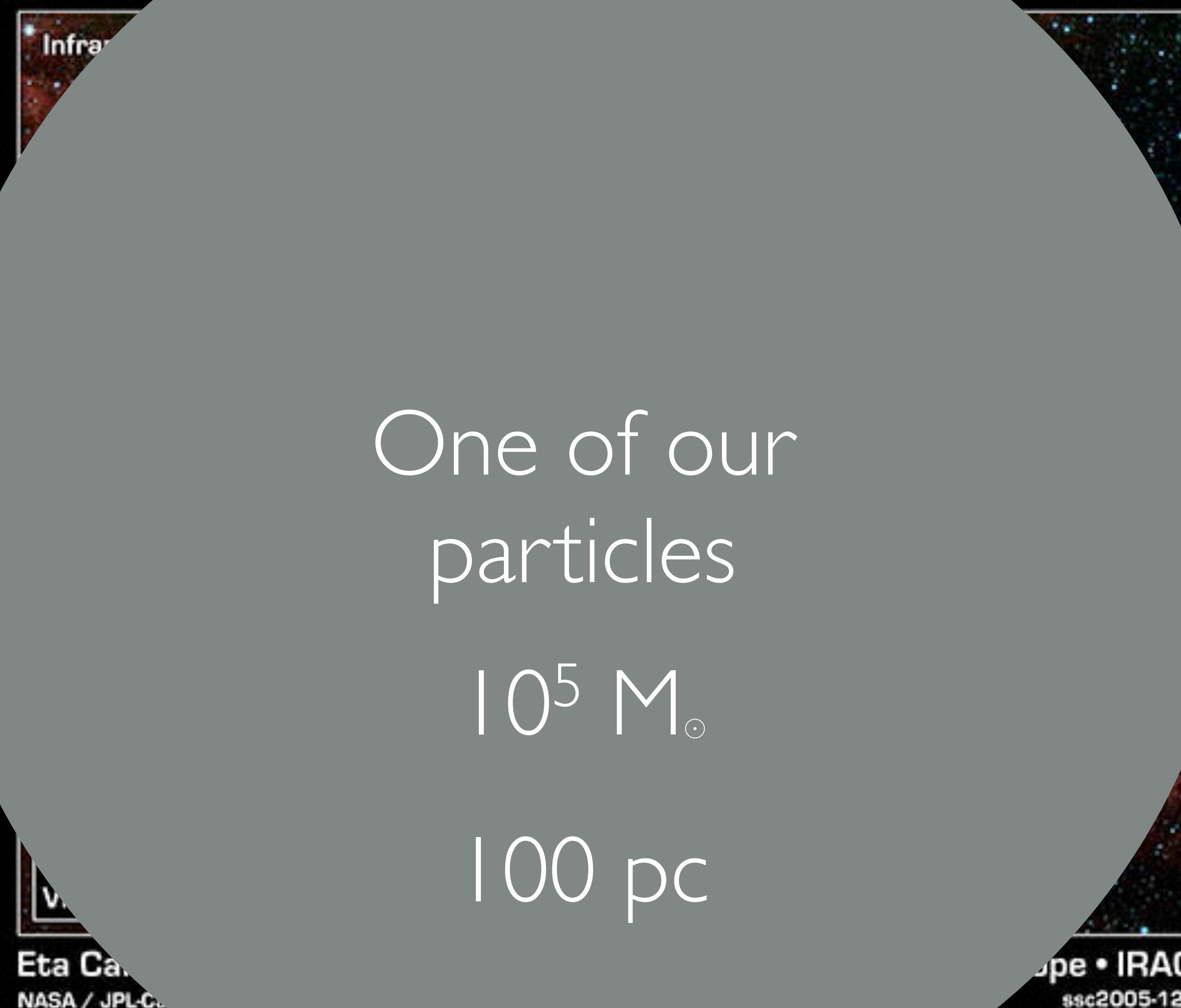
# ZOOM INITIAL CONDITIONS



A MILLION $10^5$ $M_\odot$ GAS PARTICLES IN $R_{VIR}$

# HOW DO WE MODEL STELLAR FEEDBACK?

- Ideally, stellar feedbac
  - Limit star formation
  - Provide turbulence
  - drive outflows



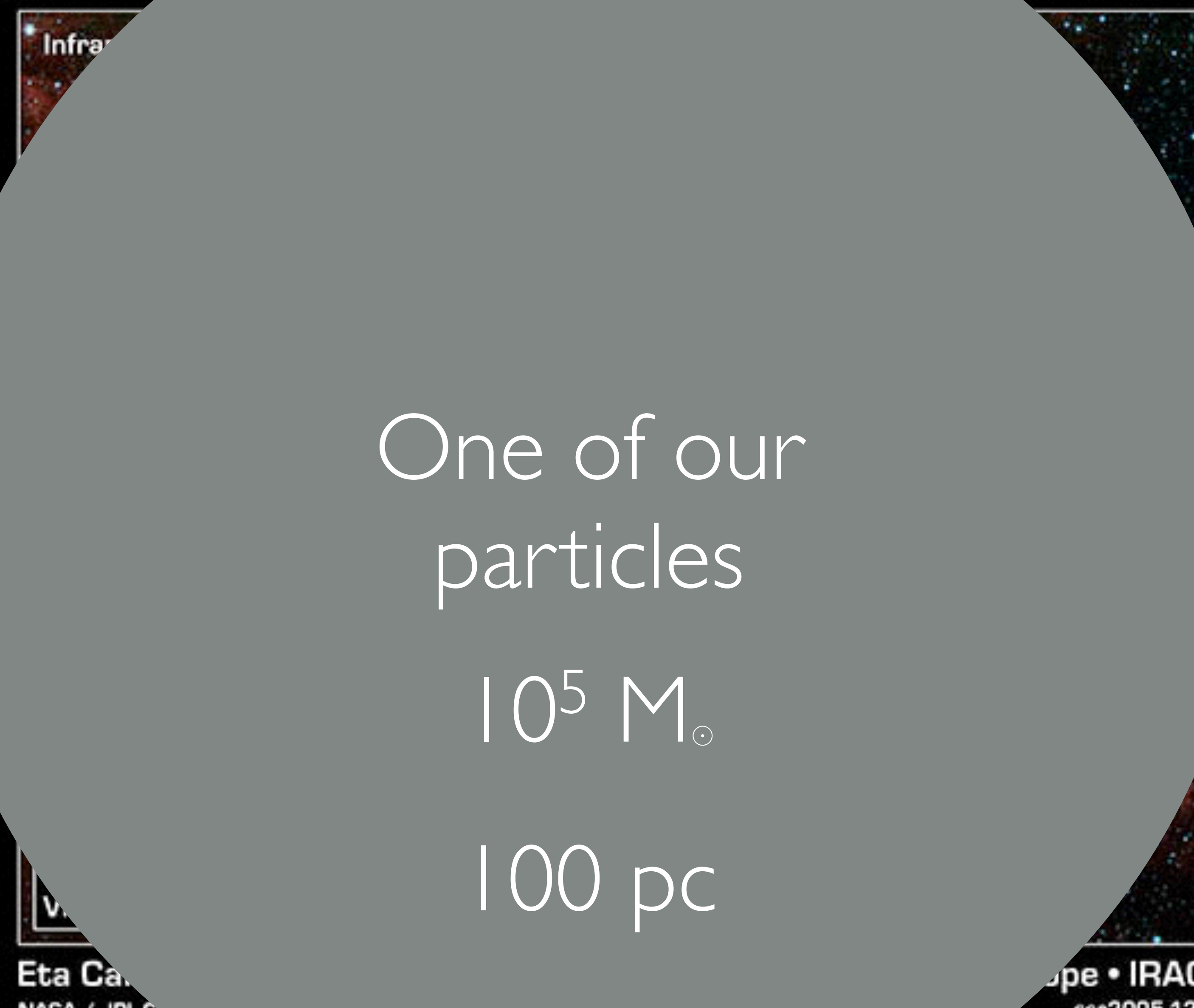

One of our particles

$10^5$ $M_\odot$

100 pc

# HOW DO WE MODEL STELLAR FEEDBACK?

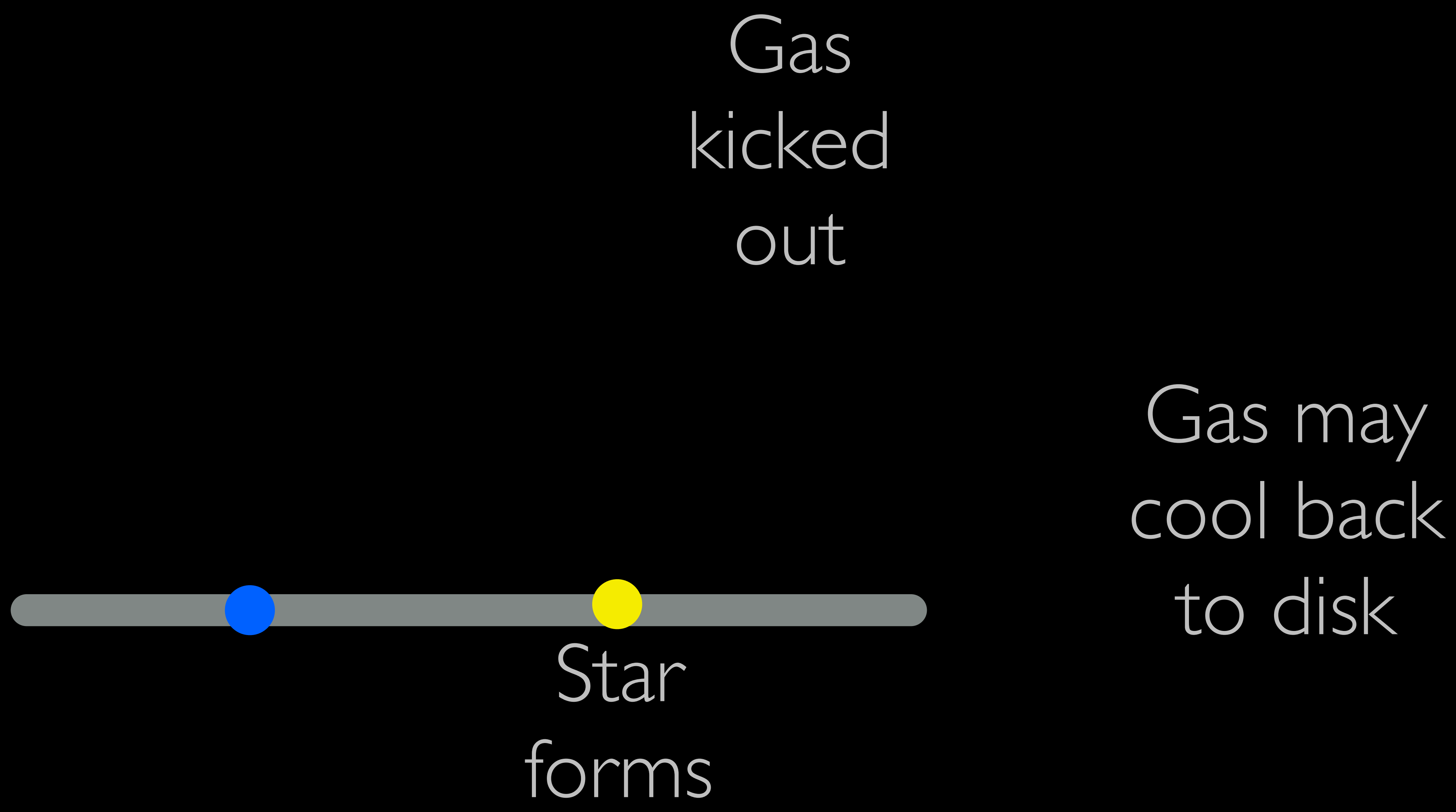
- Problems
  - Dense gas cools fast ($t_{cool} < t_{dyn}$)
  - Small amount of hot gas has a large dynamical impact
  - How do you drive observed outflows?




One of our particles

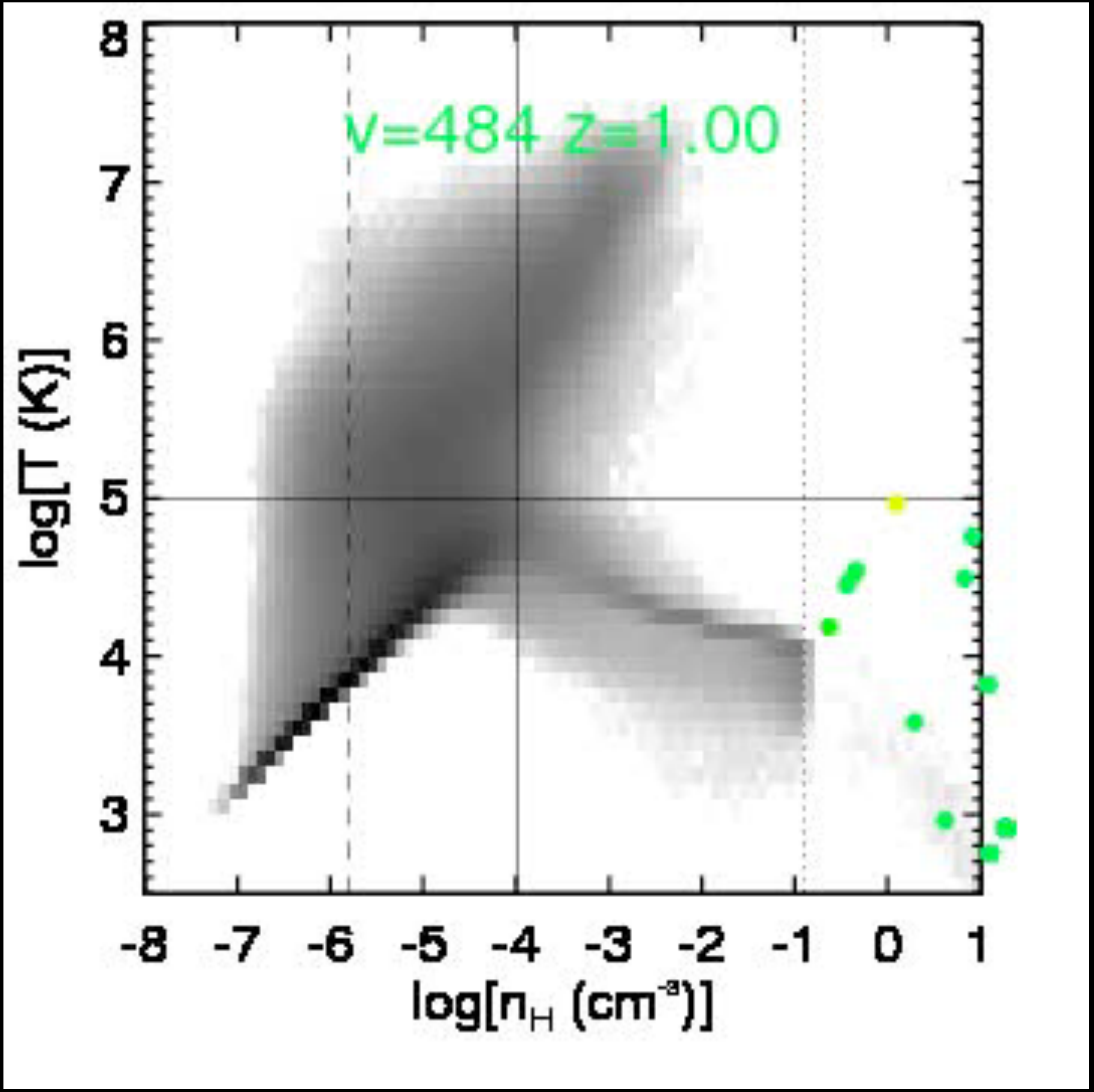
$10^5\ M_\odot$

100 pc



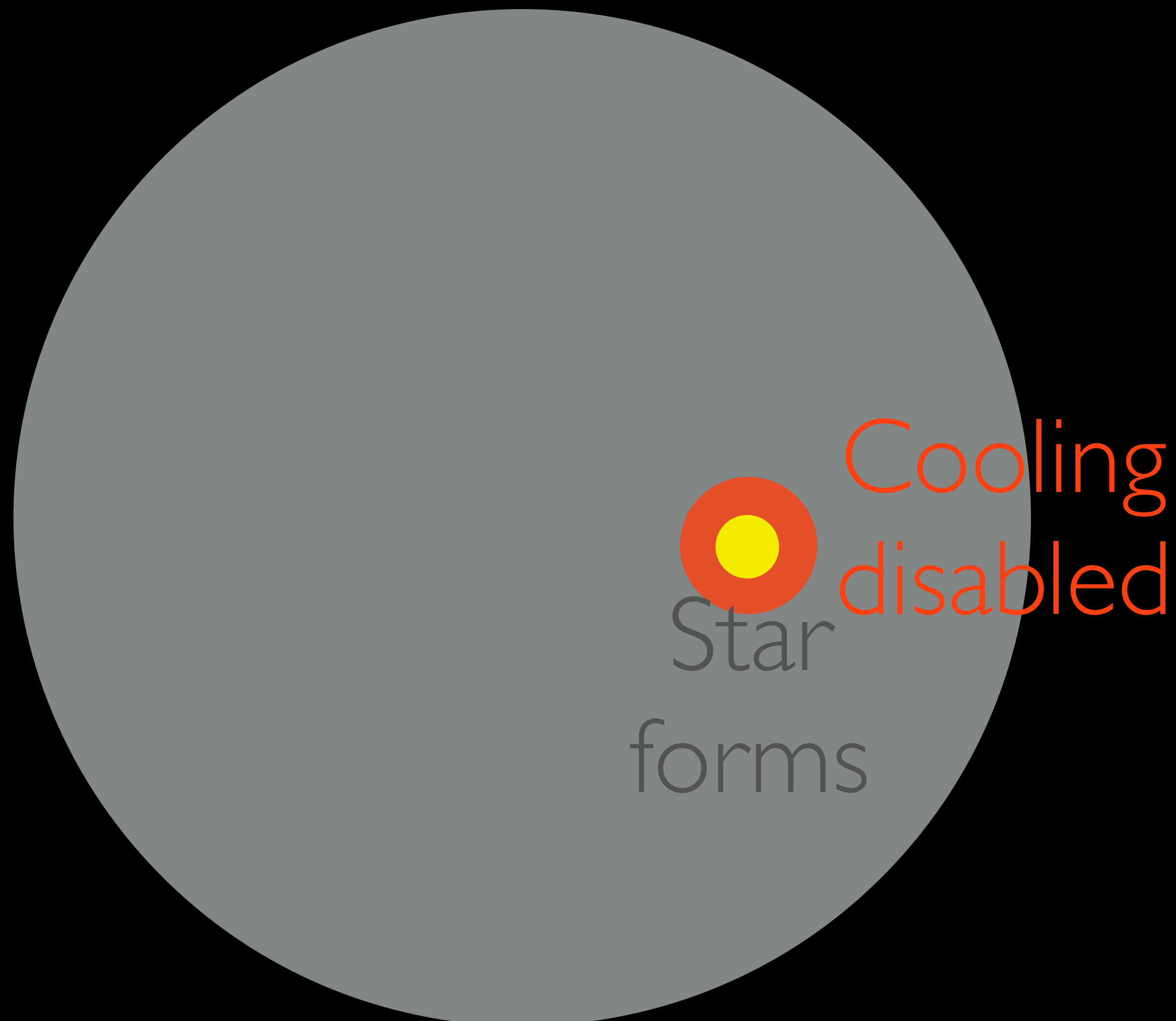

# KINETIC FEEDBACK

TURN OFF **HYDRODYNAMICS** FOR A SHORT TIME AFTER PARTICLE KICKED



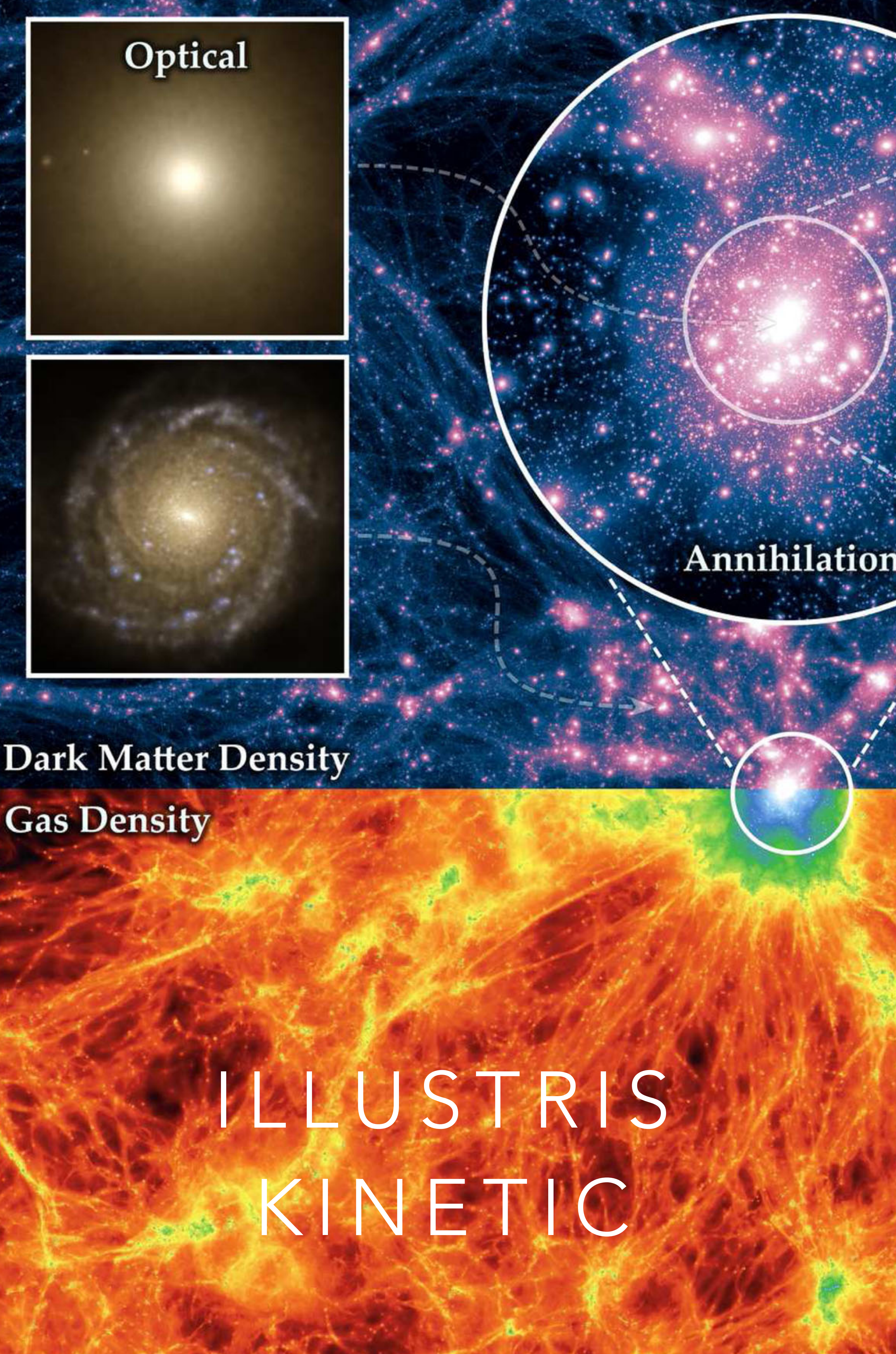

KINETIC FEEDBACK

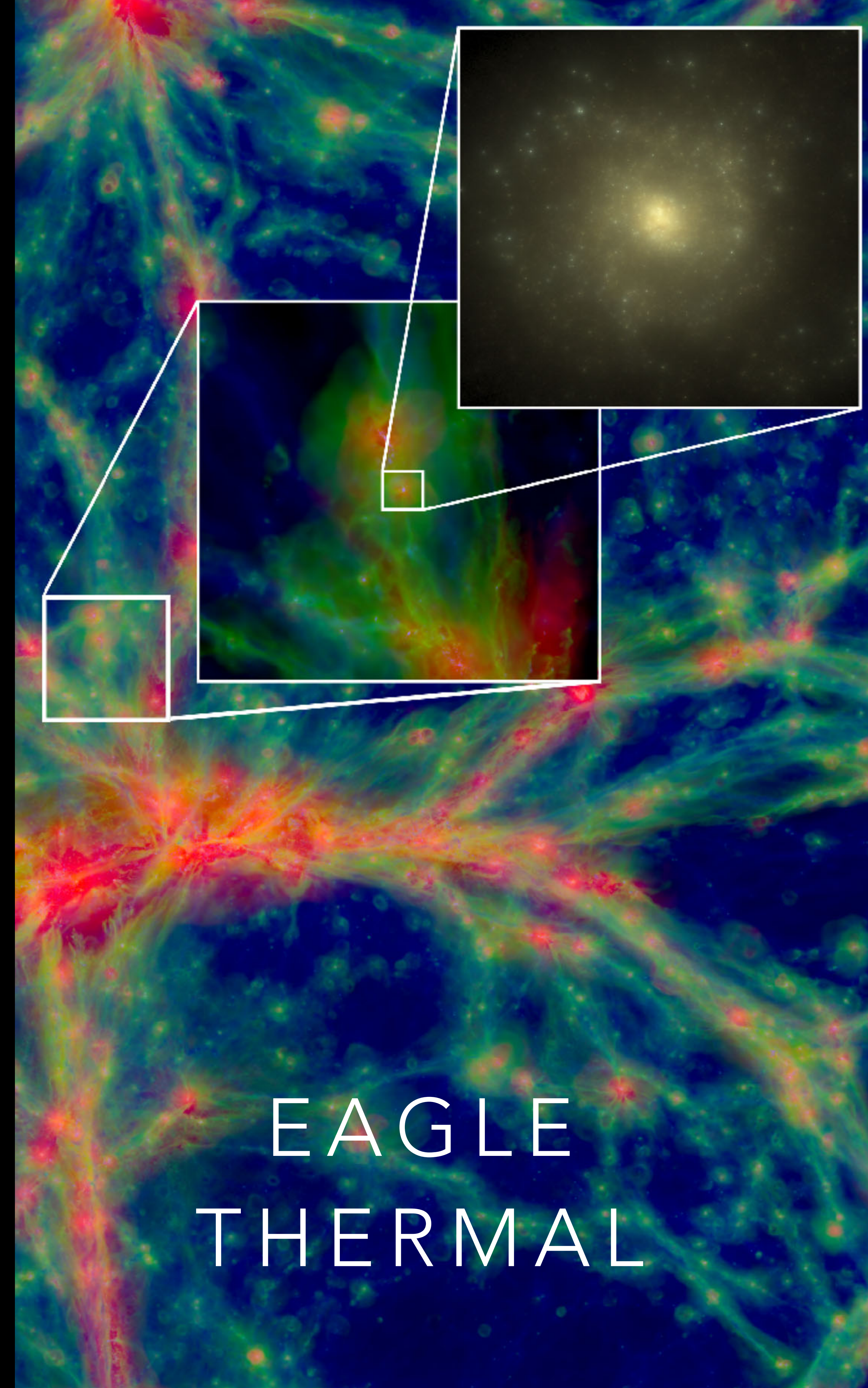
from Ben Oppenheimer

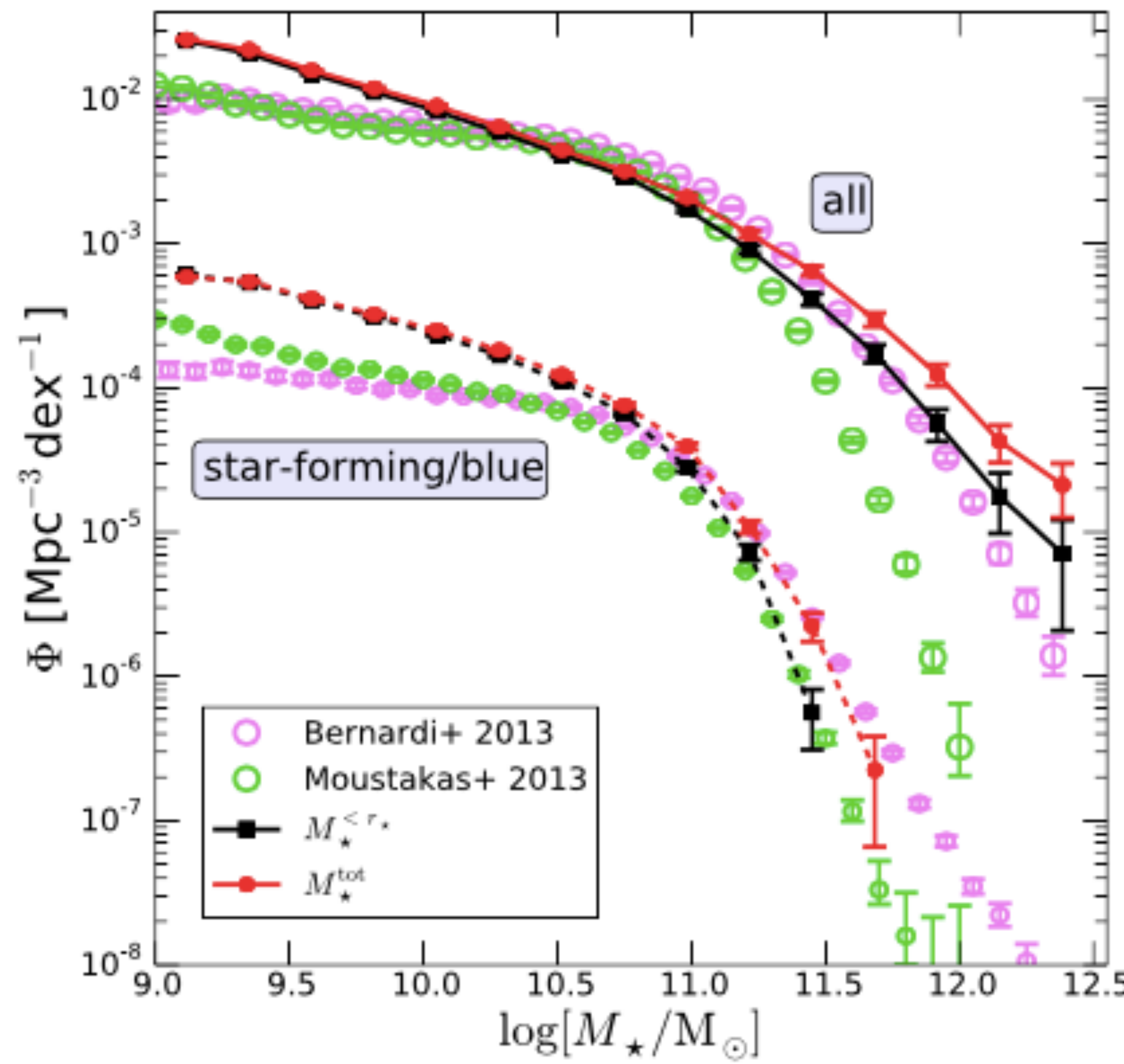


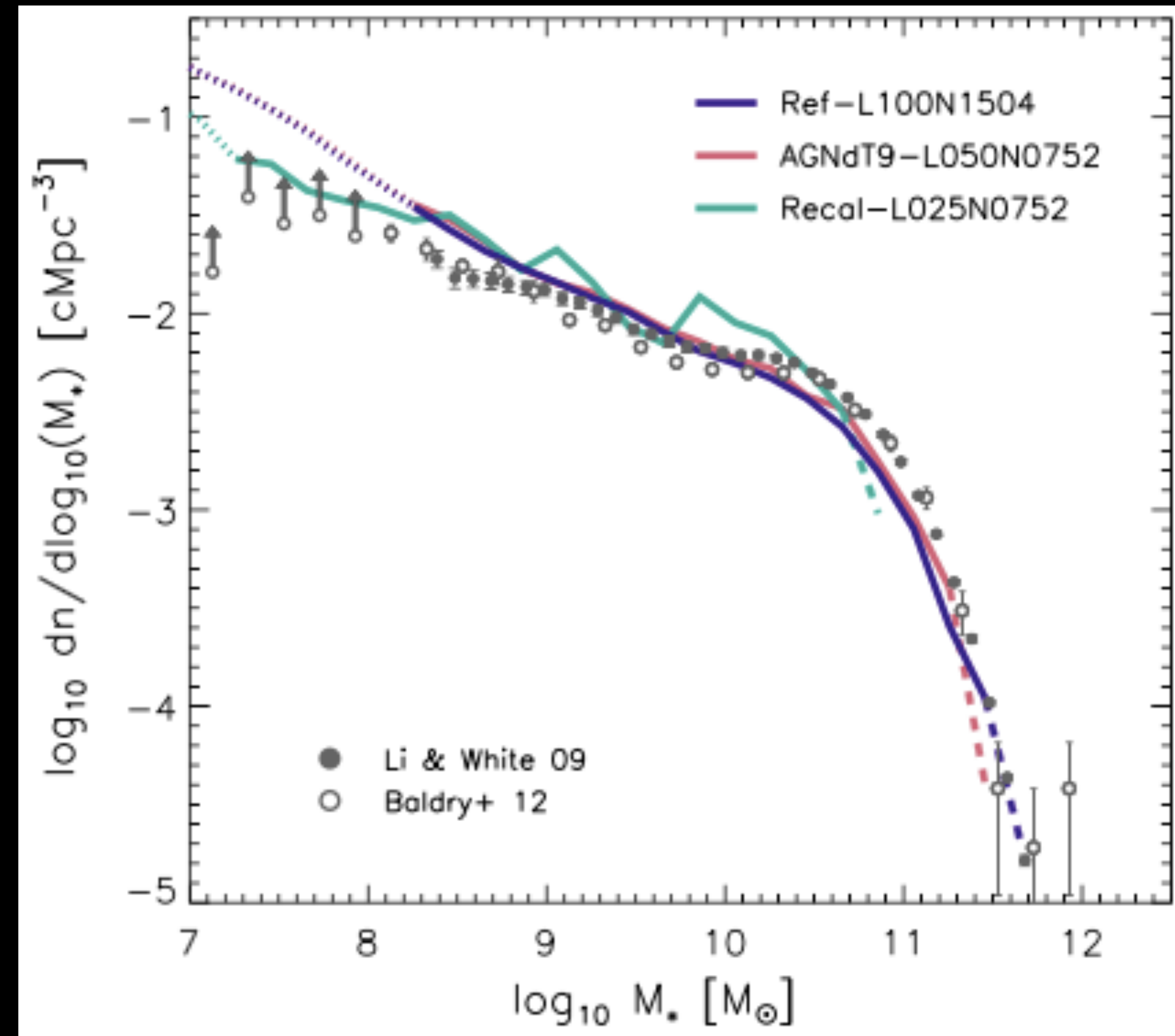

# THERMAL FEEDBACK

**LIMIT COOLING** WHILE SNII EXPLODE
THERMAL PRESSURE CAUSES OUTFLOWS


Optical
Annihilation
Dark Matter Density
Gas Density
ILLUSTRIS
KINETIC


EAGLE
THERMAL




ILLUSTRIS
KINETIC

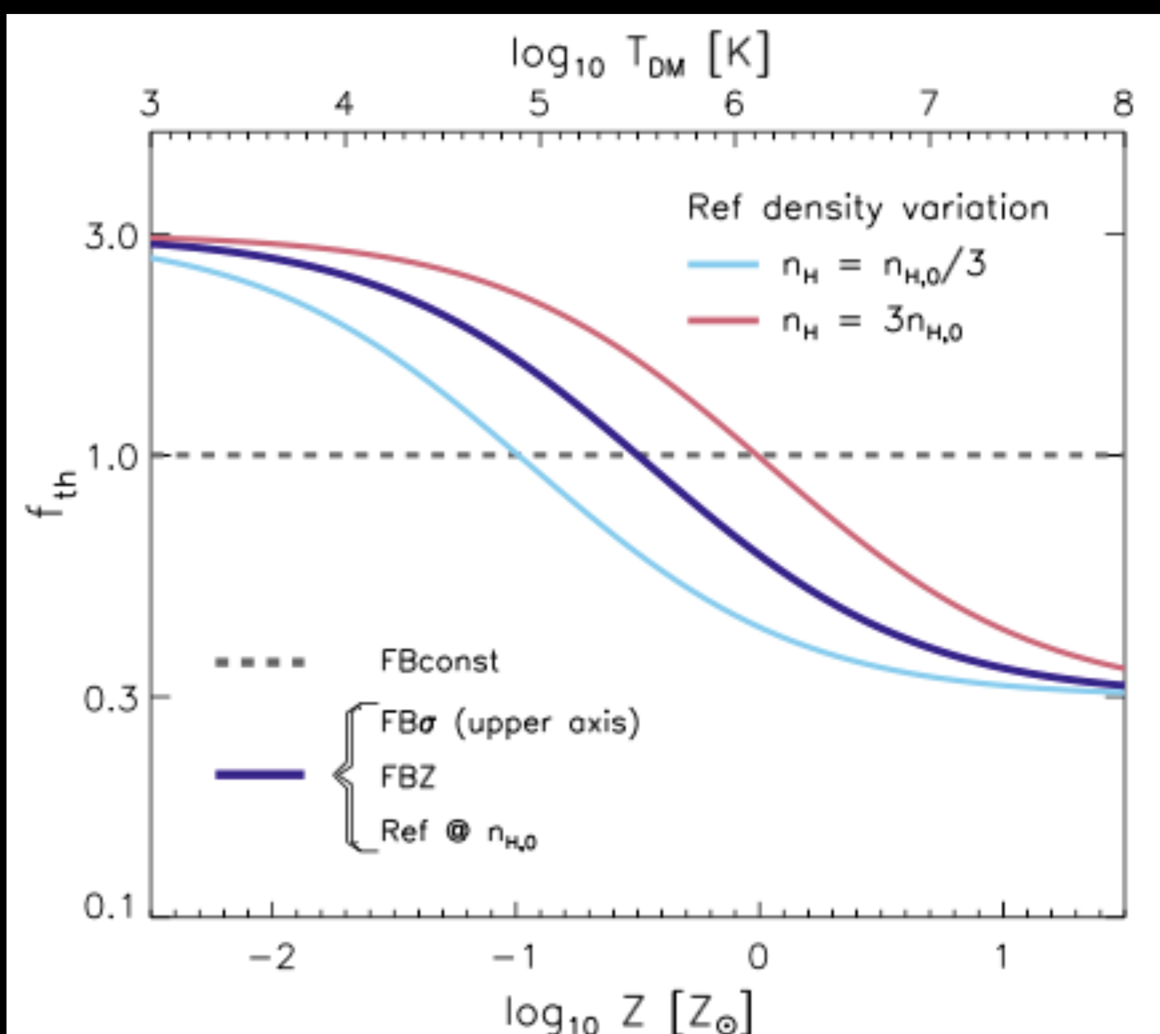
EAGLE
THERMAL

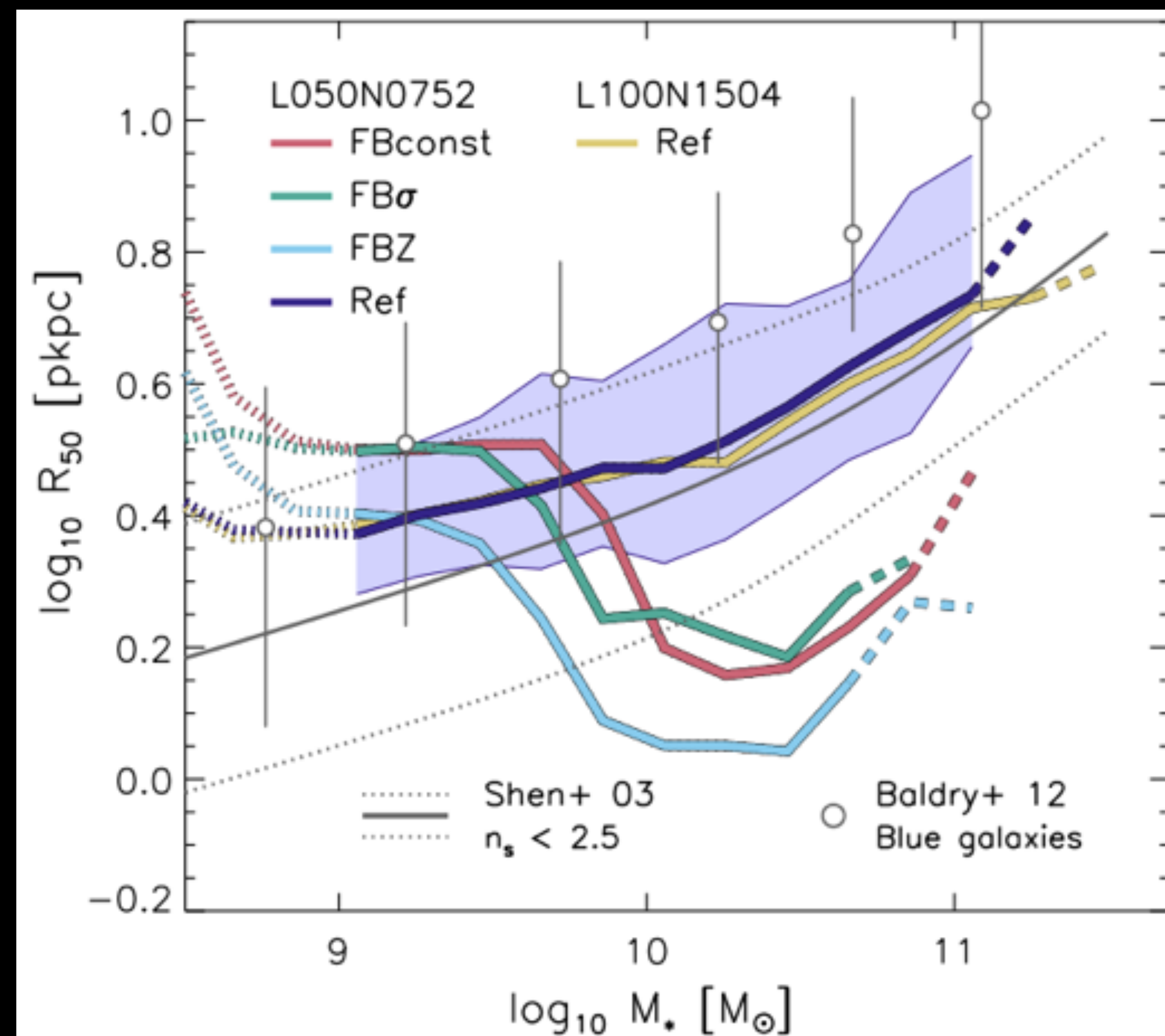
# EAGLE DETAILS

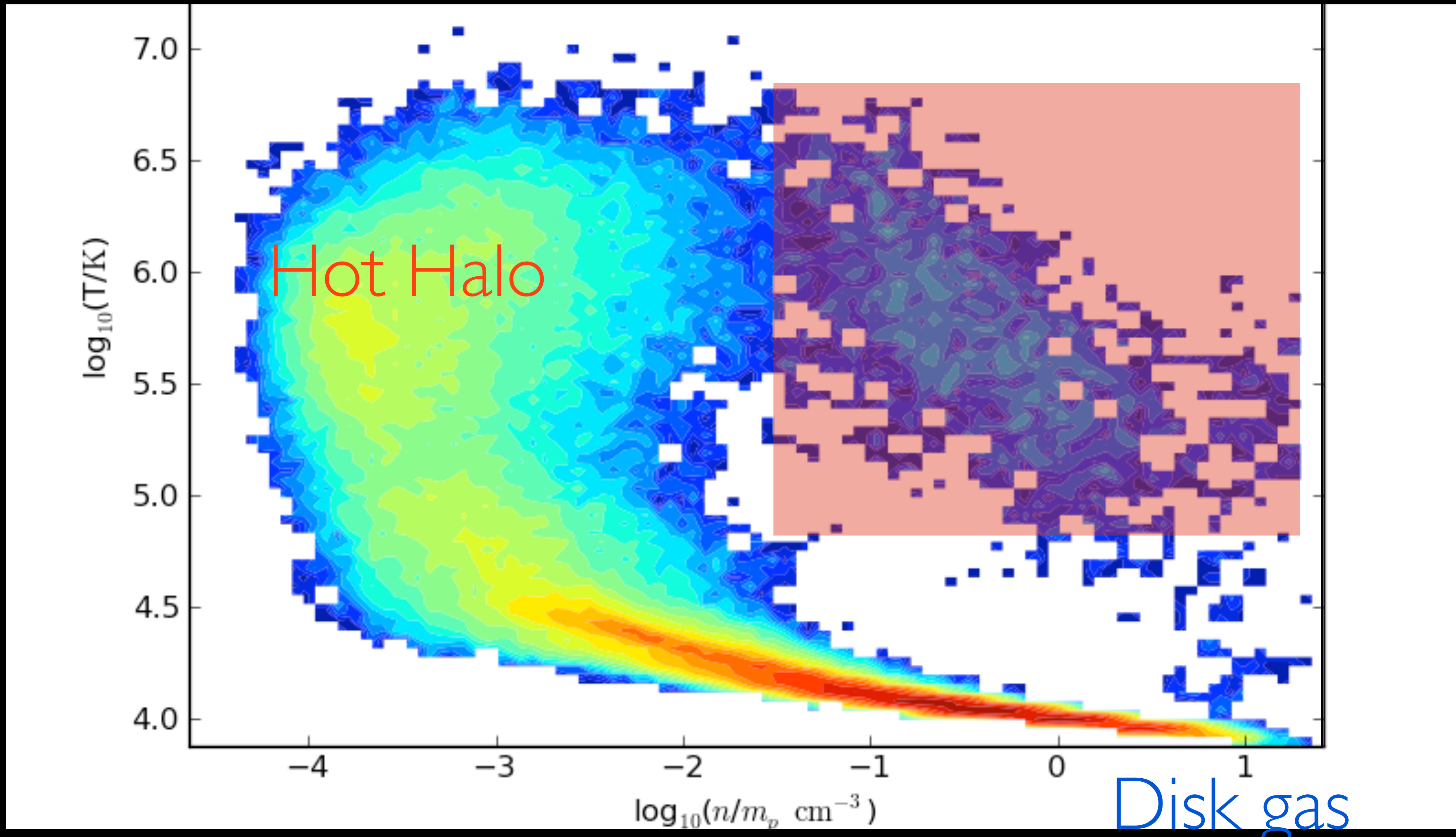
need helping blowing up dense things

$$f_{\rm th} = f_{\rm th,min} + \frac{f_{\rm th,max} - f_{\rm th,min}}{1 + \left(\frac{Z}{0.1\,{\rm Z}_\odot}\right)^{n_Z} \left(\frac{n_{\rm H,birth}}{n_{\rm H,0}}\right)^{-n_n}}$$

$$f_{\rm th,\,max} = 3 \text{ and } f_{\rm th,\,min} = 0.3$$

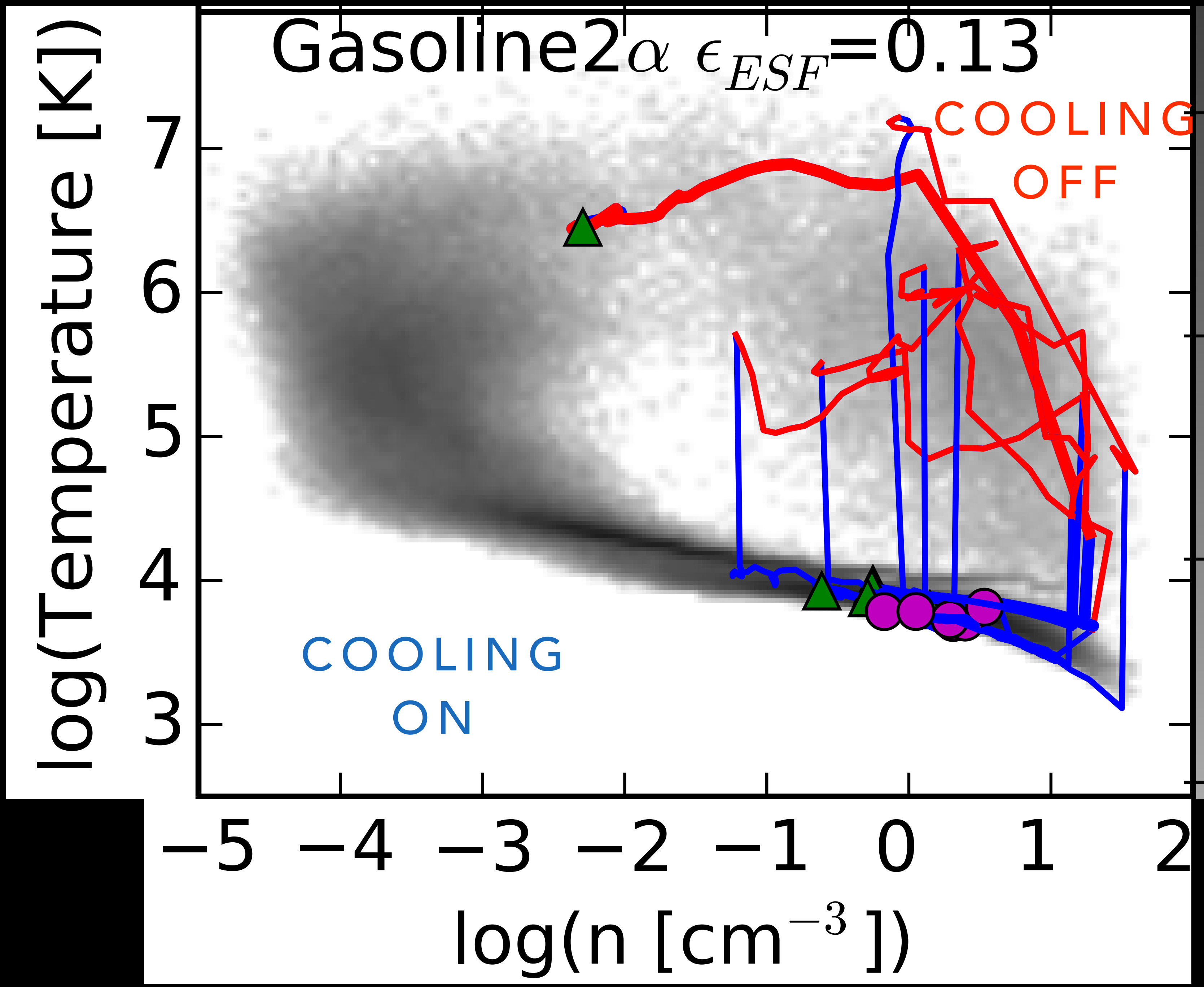





# FEEDBACK GAS IN PHASE SIMULATION DIAGRAM

DELAY COOLING BASED ON BLASTWAVE EQUATIONS (STINSON+ 2006)



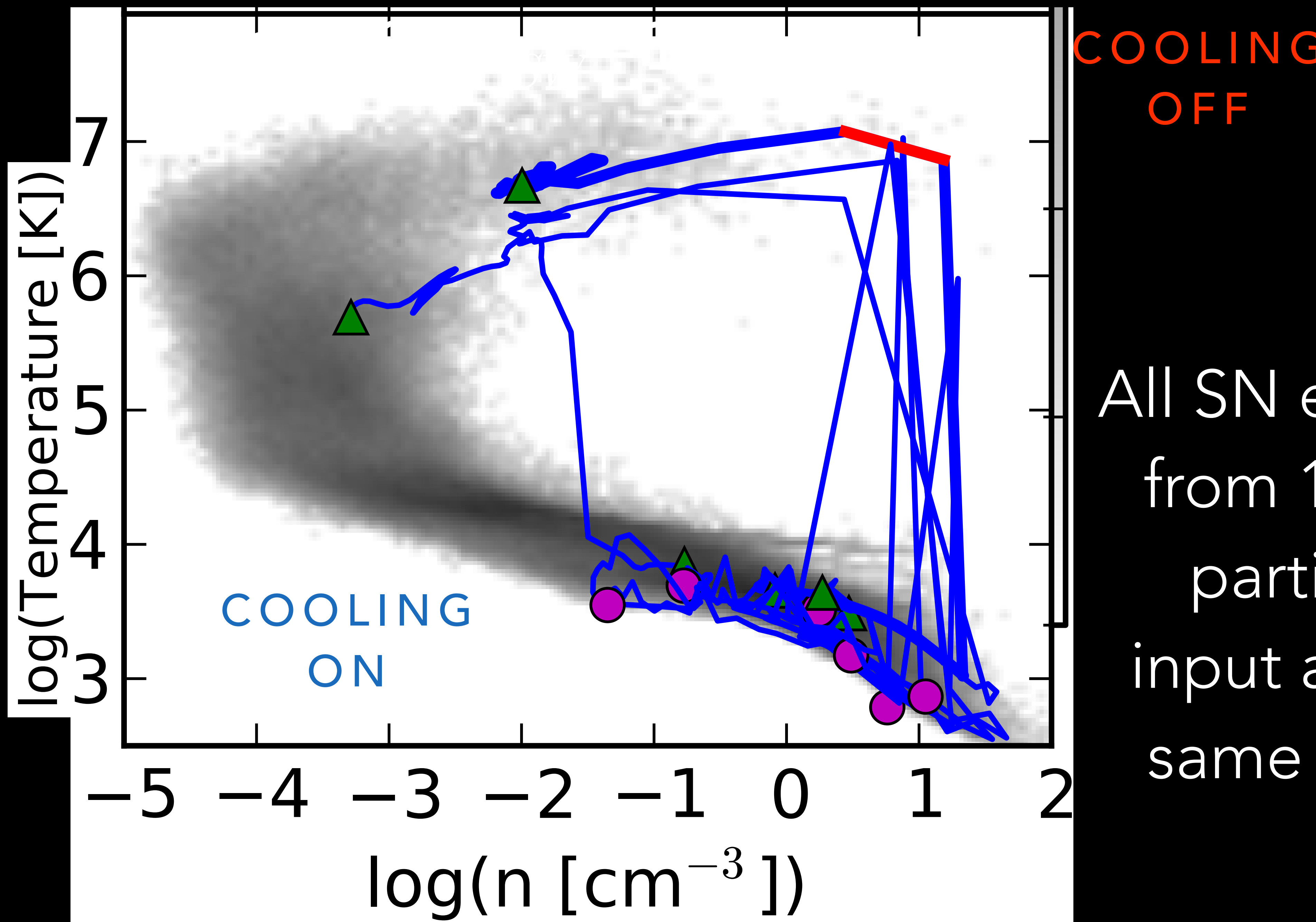

Blastwave

Eris

NIHAO

# THERMAL FEEDBACK IN PHASE DIAGRAM

STINSON+ (2006)

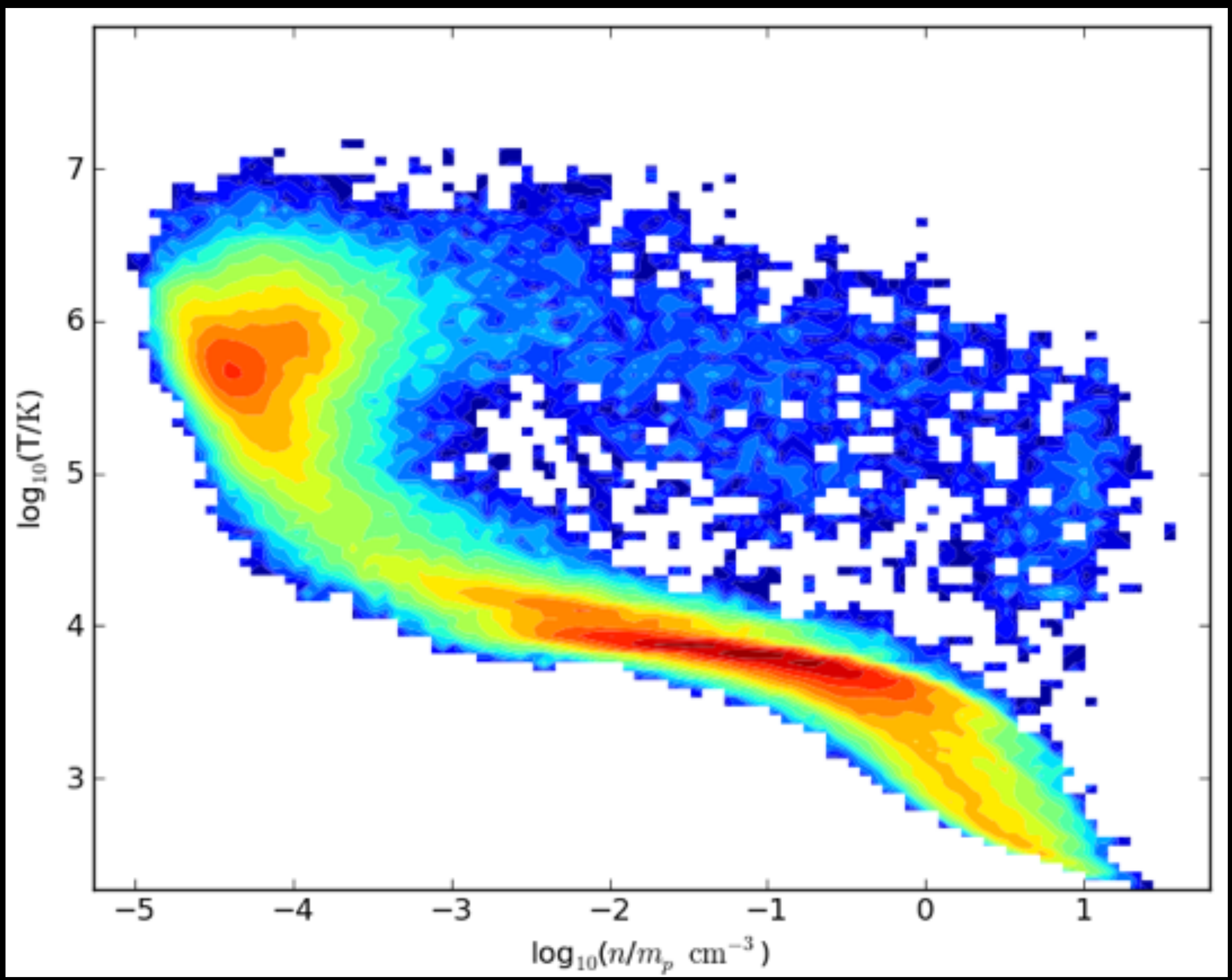



All SN energy from 1 star particle input at the same time

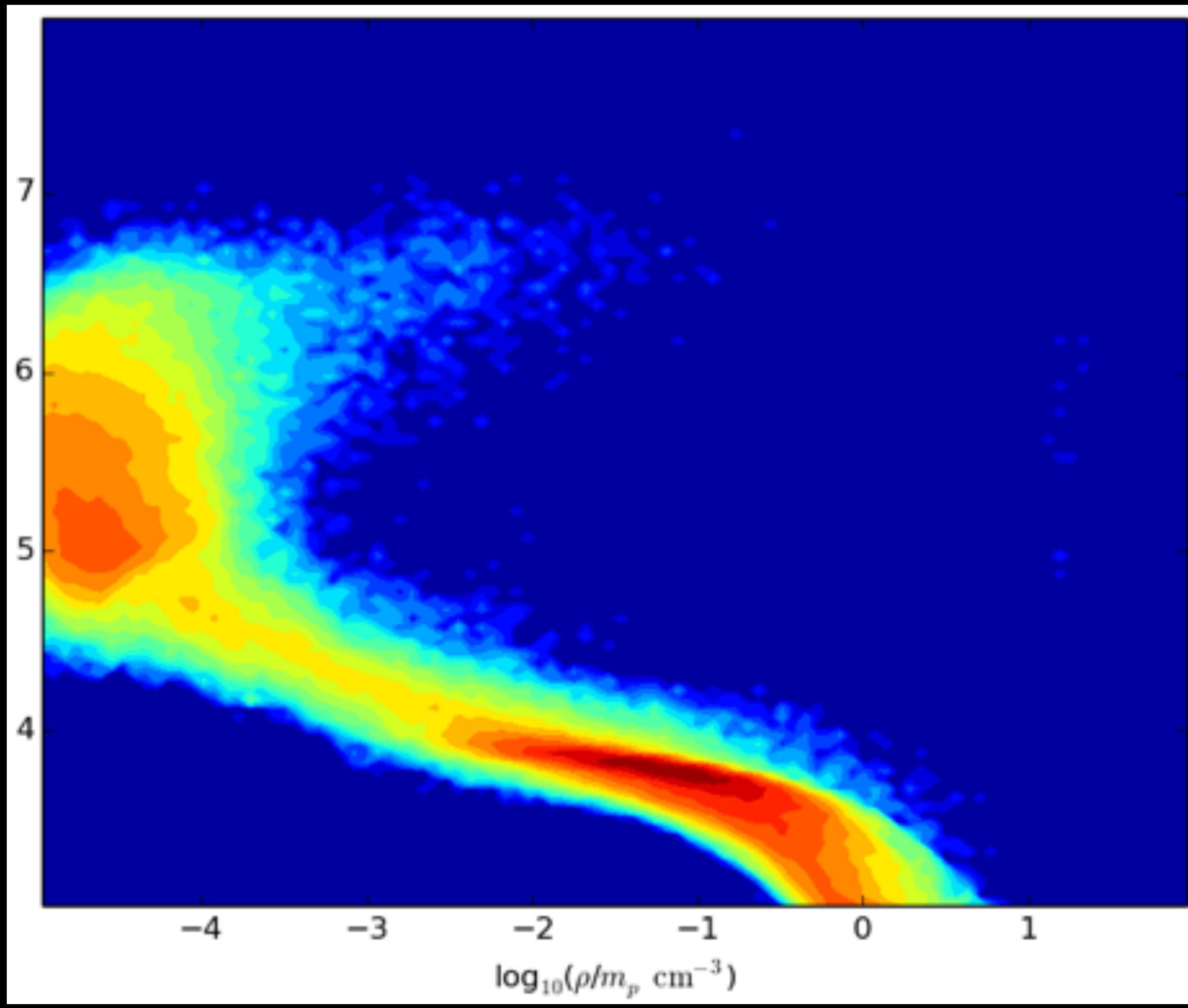
# THERMAL FEEDBACK IN PHASE DIAGRAM

DALLA VECCHIA & SCHAYE (2012)

# GAS PHASES

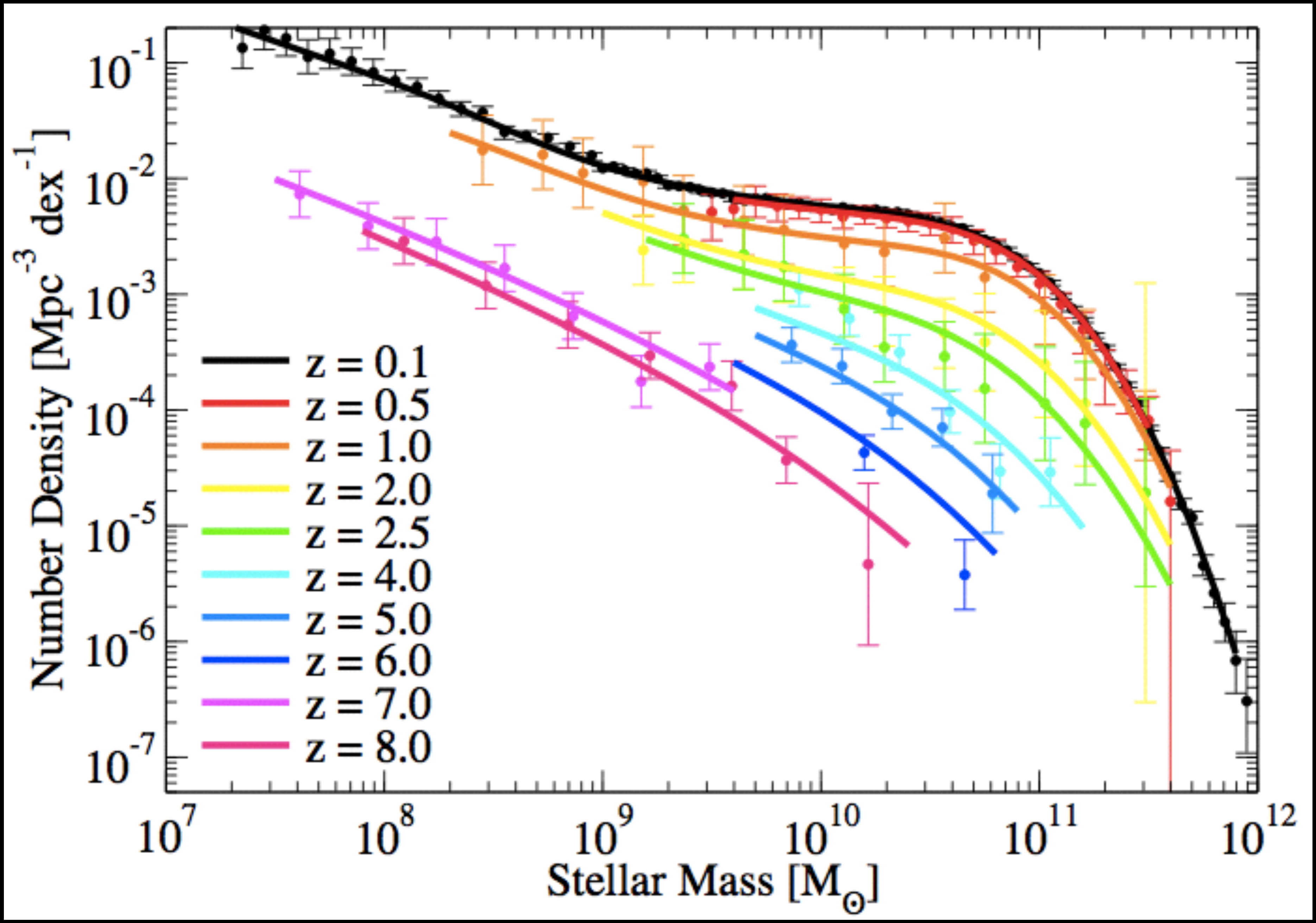



Blastwave




Dalla Vecchia & Schaye (EAGLE)

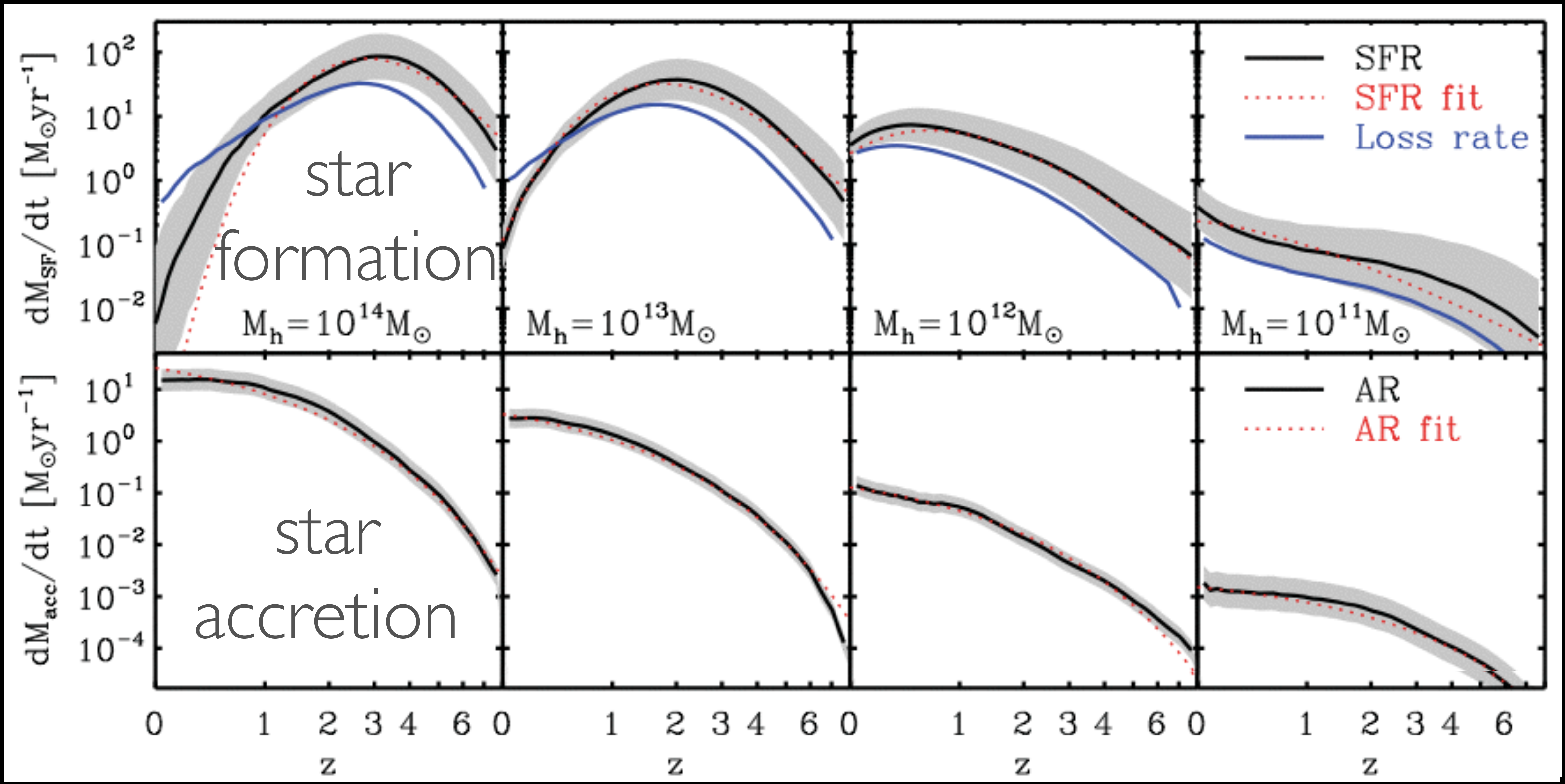
# ABUNDANCE MATCHING EVOLUTION




- Observed Luminosity Function evolution

# ABUNDANCE MATCHING EVOLUTION

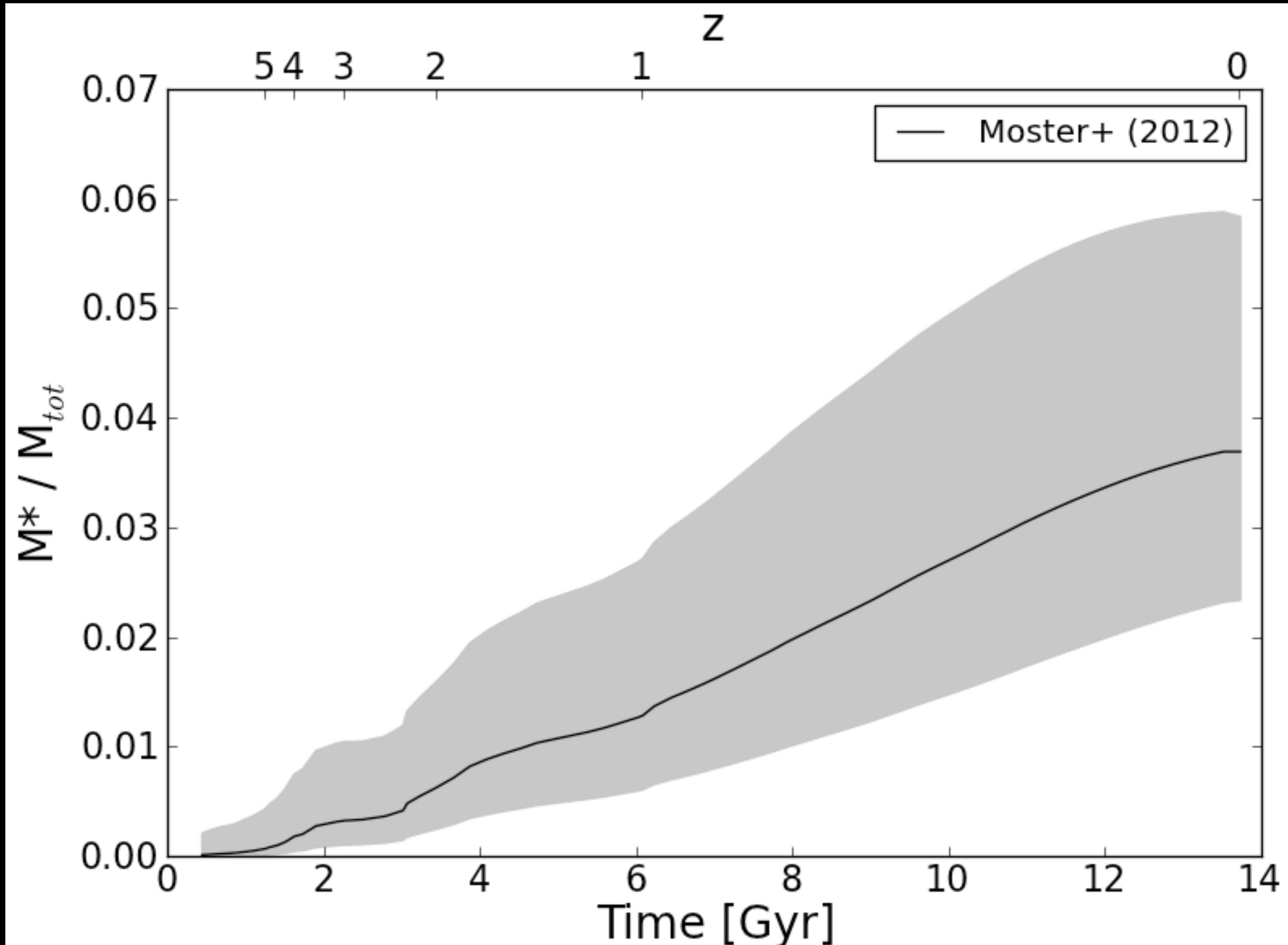
MOSTER+ (2013)



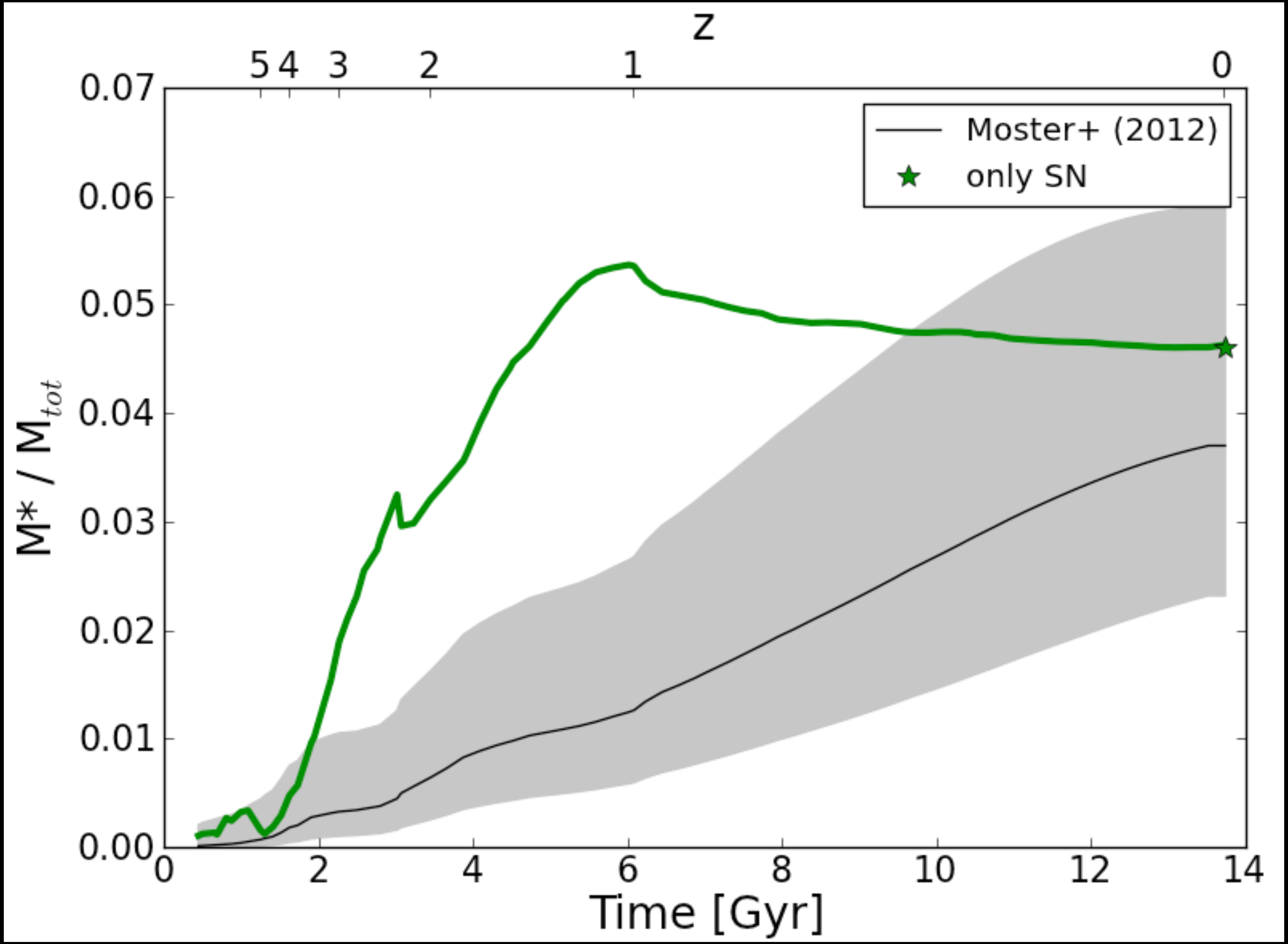

TODAY

BIG BANG

- star formation histories are mass dependent:
- **little galaxies** form stars **late**

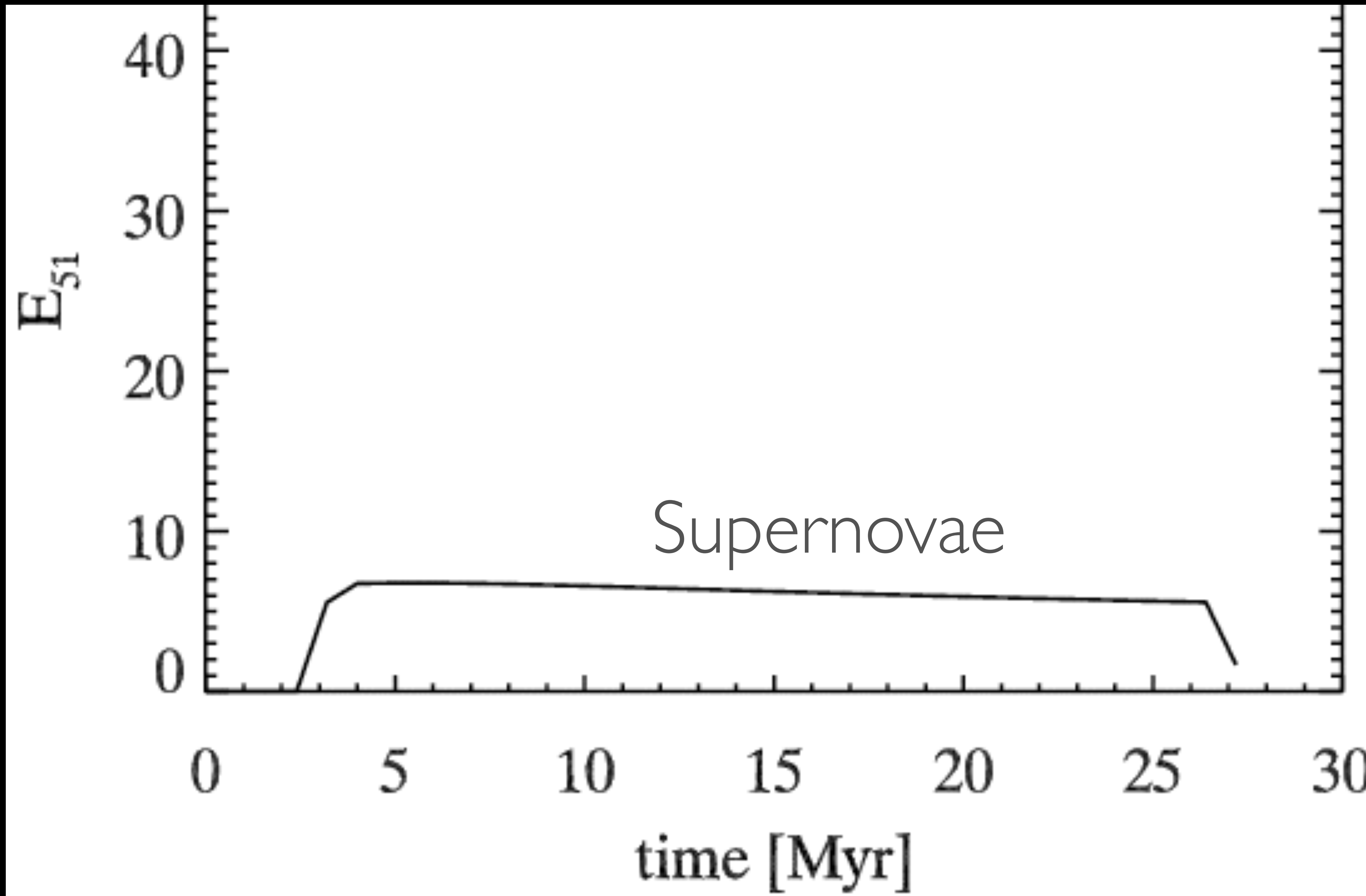



see also Guo, Qi+ (2011)
Behroozi+ (2012)



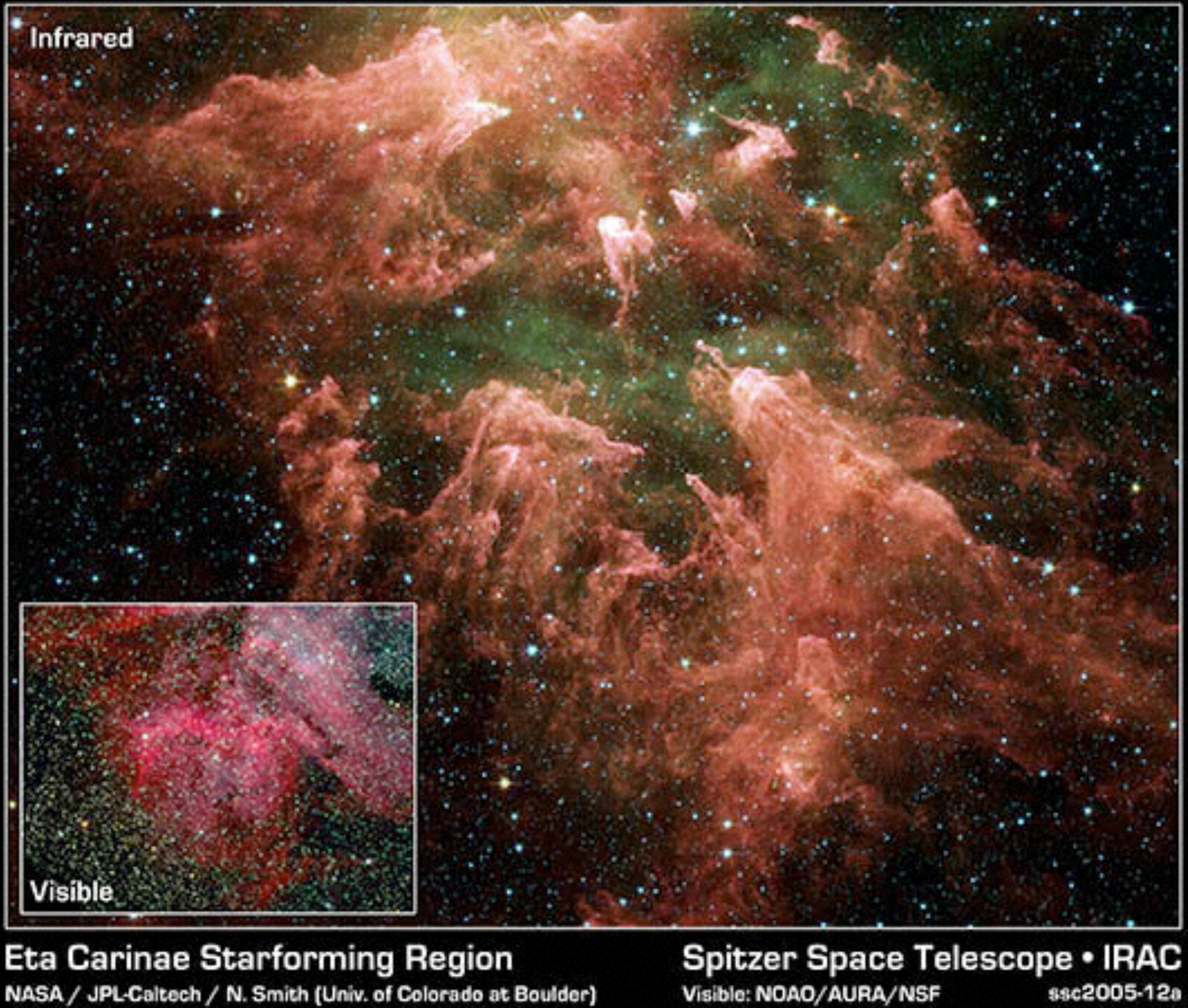

# TURN UP FEEDBACK

100% SUPERNOVA EFFICIENCY ($10^{51}$ ERG)



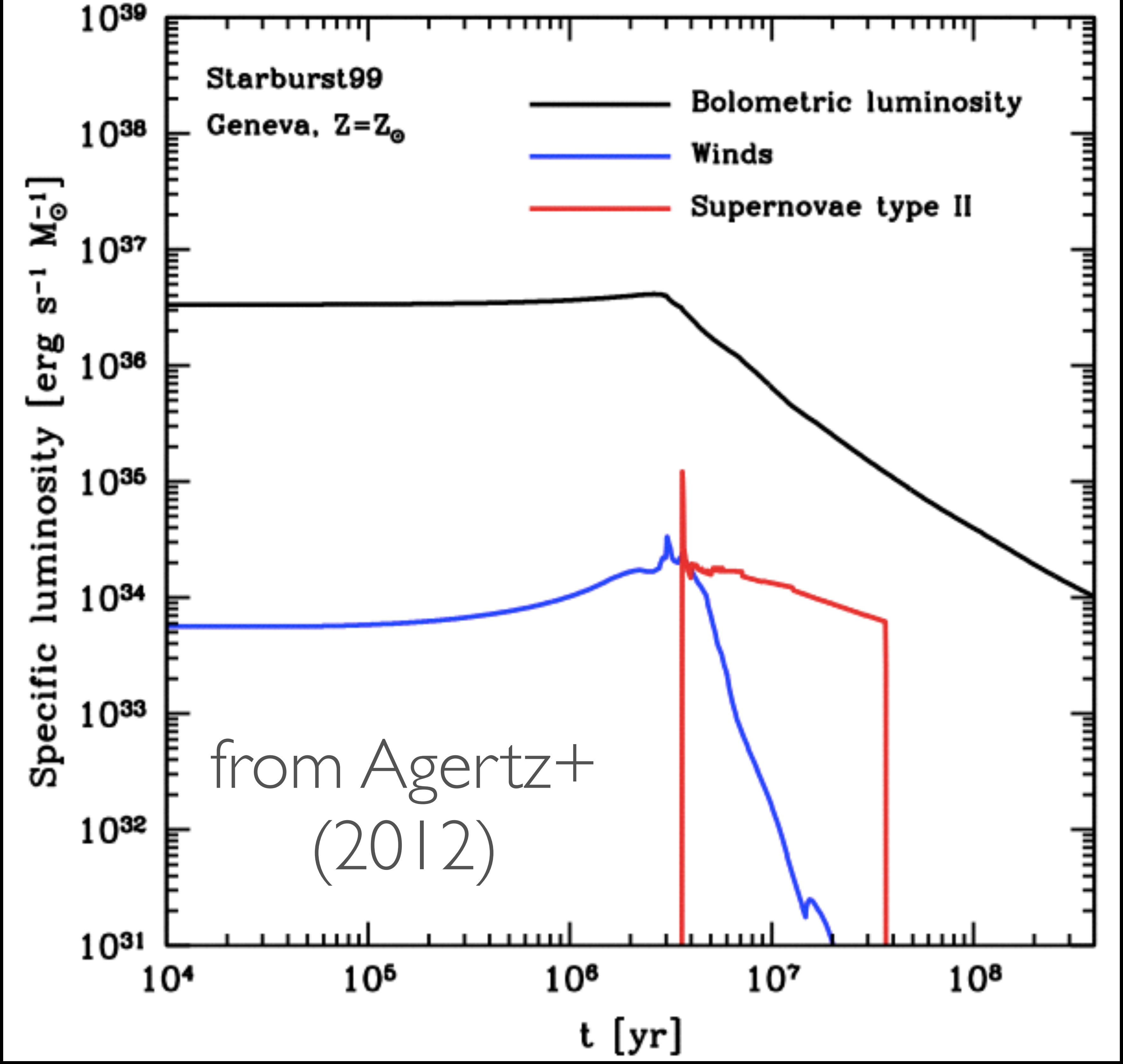

# SUPERNOVA FEEDBACK

## A HOLE

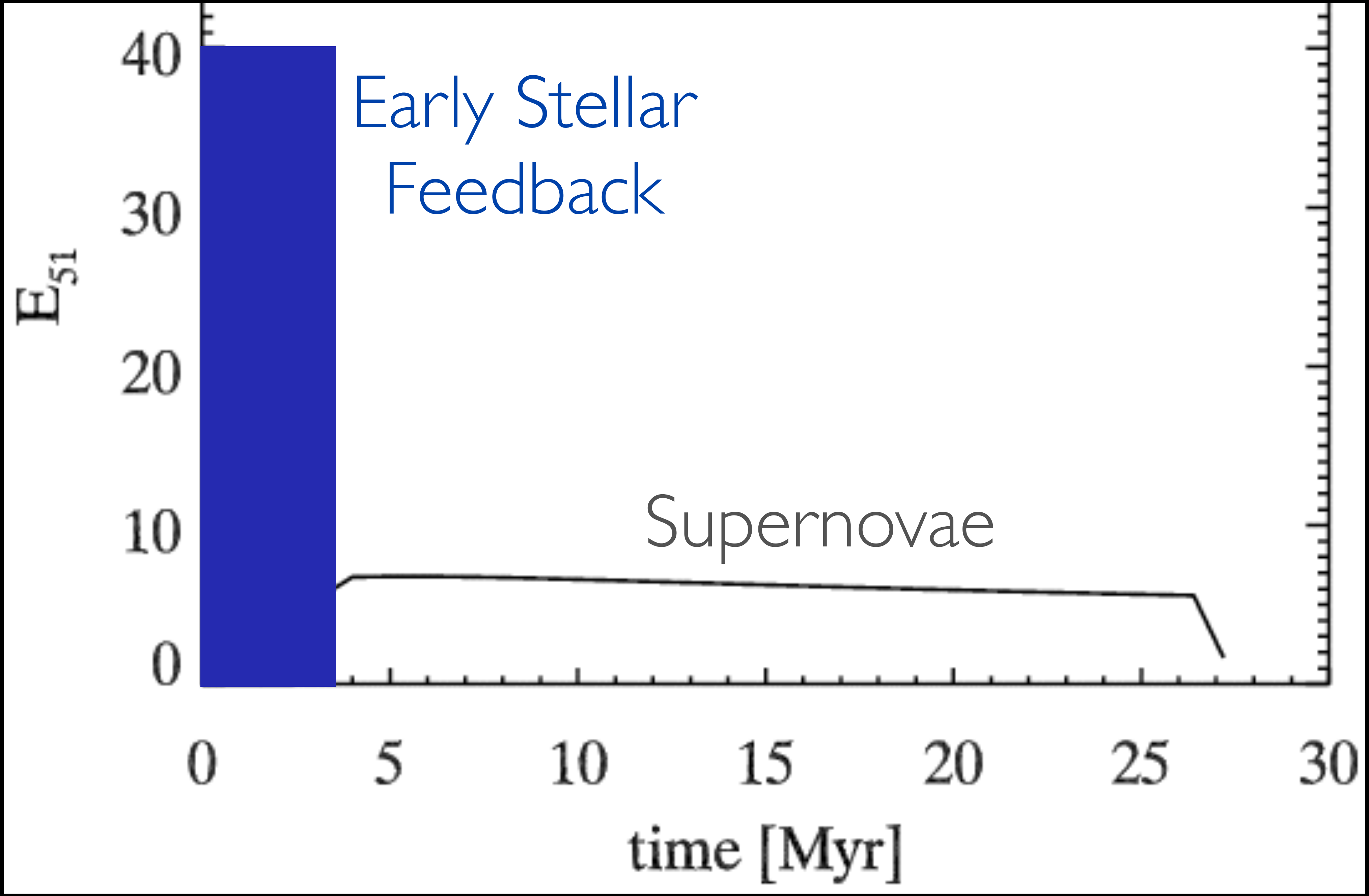



# ETA CARINAE

< 3 MYR OLD, BUT STARS ALREADY TEARING GAS APART

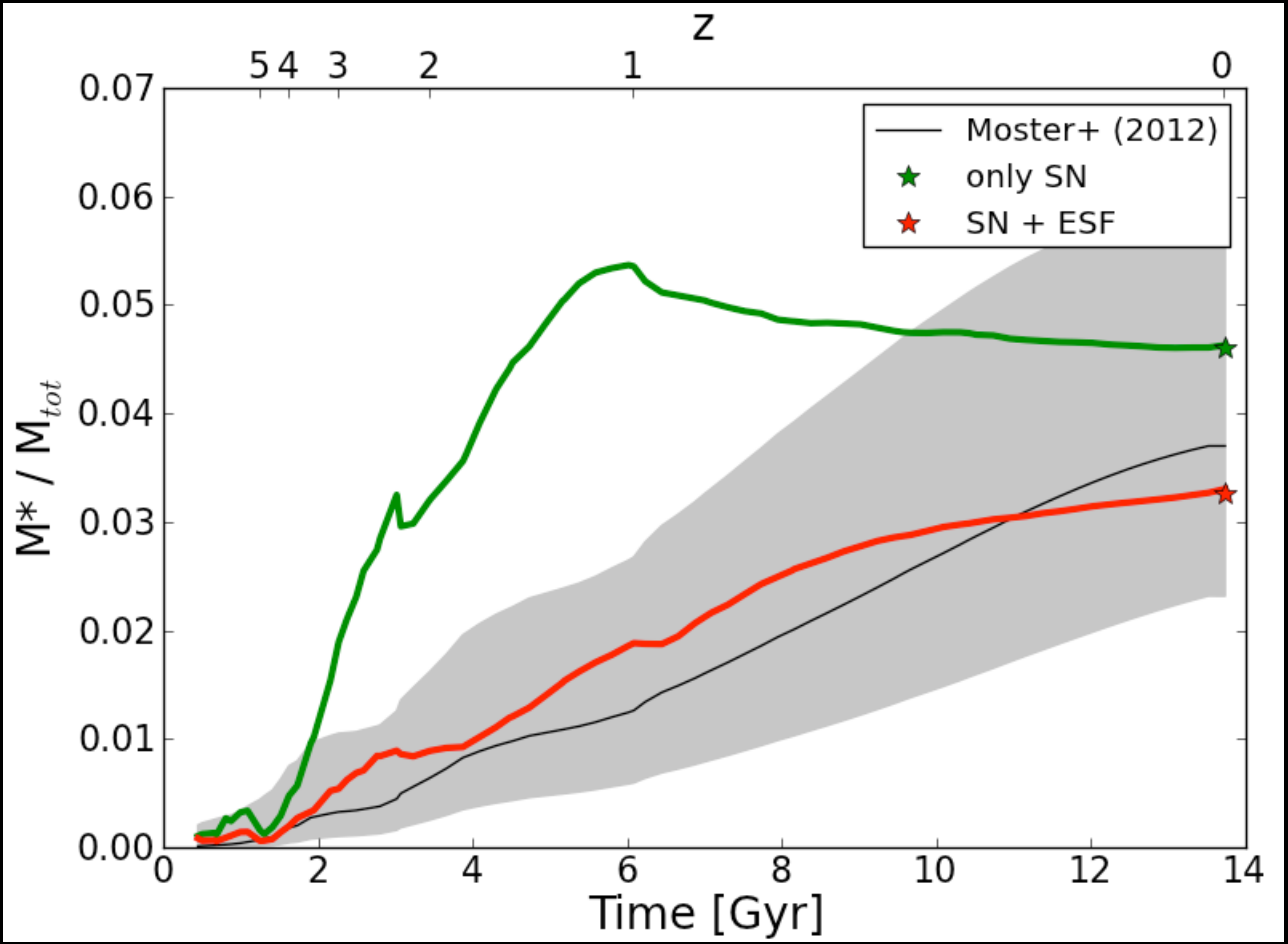


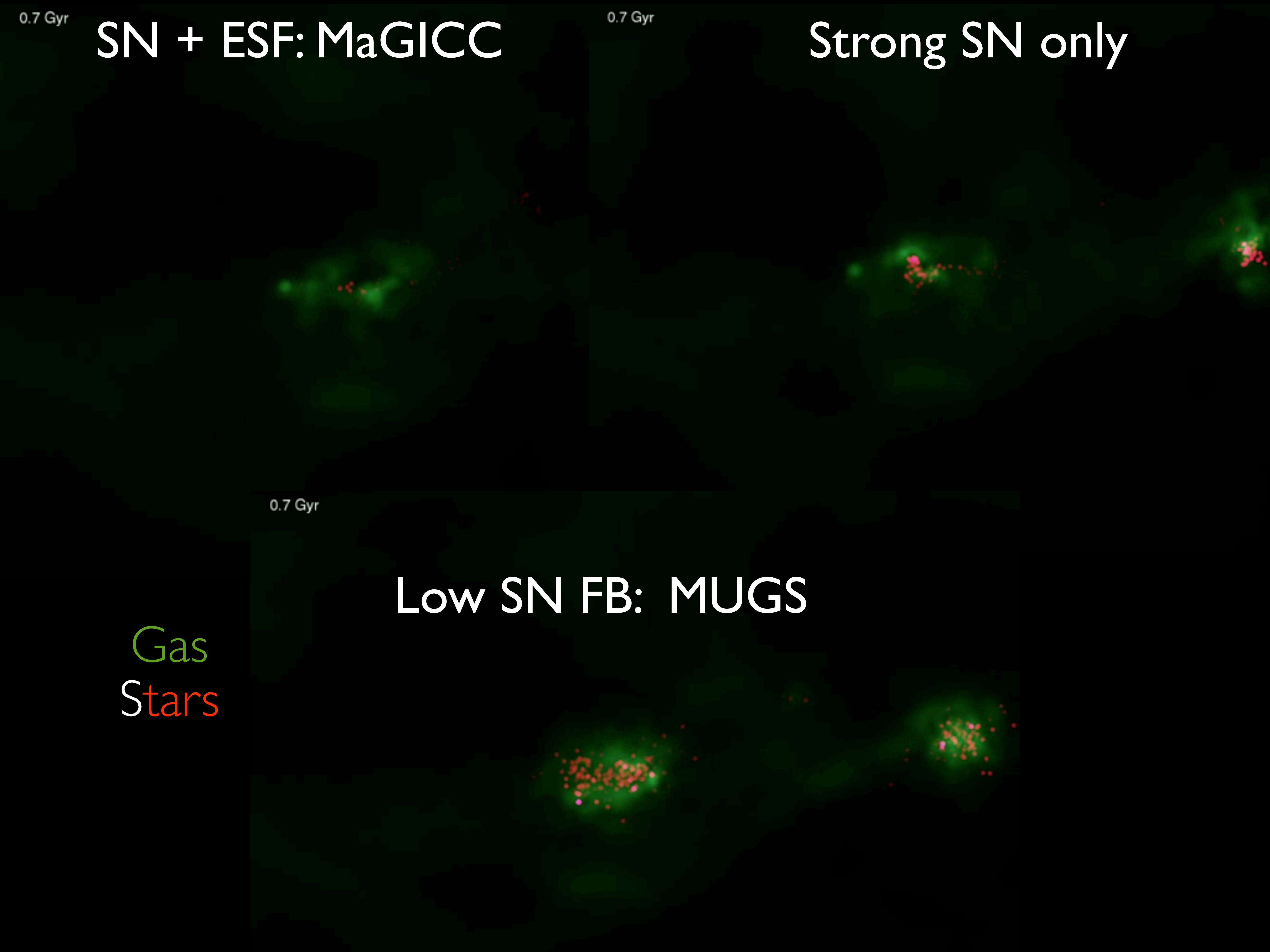
Starburst99
Geneva, Z=Z⊙
Bolometric luminosity
Winds
Supernovae type II
Specific luminosity [erg s⁻¹ M⊙⁻¹]
t [yr]
from Agertz+ (2012)

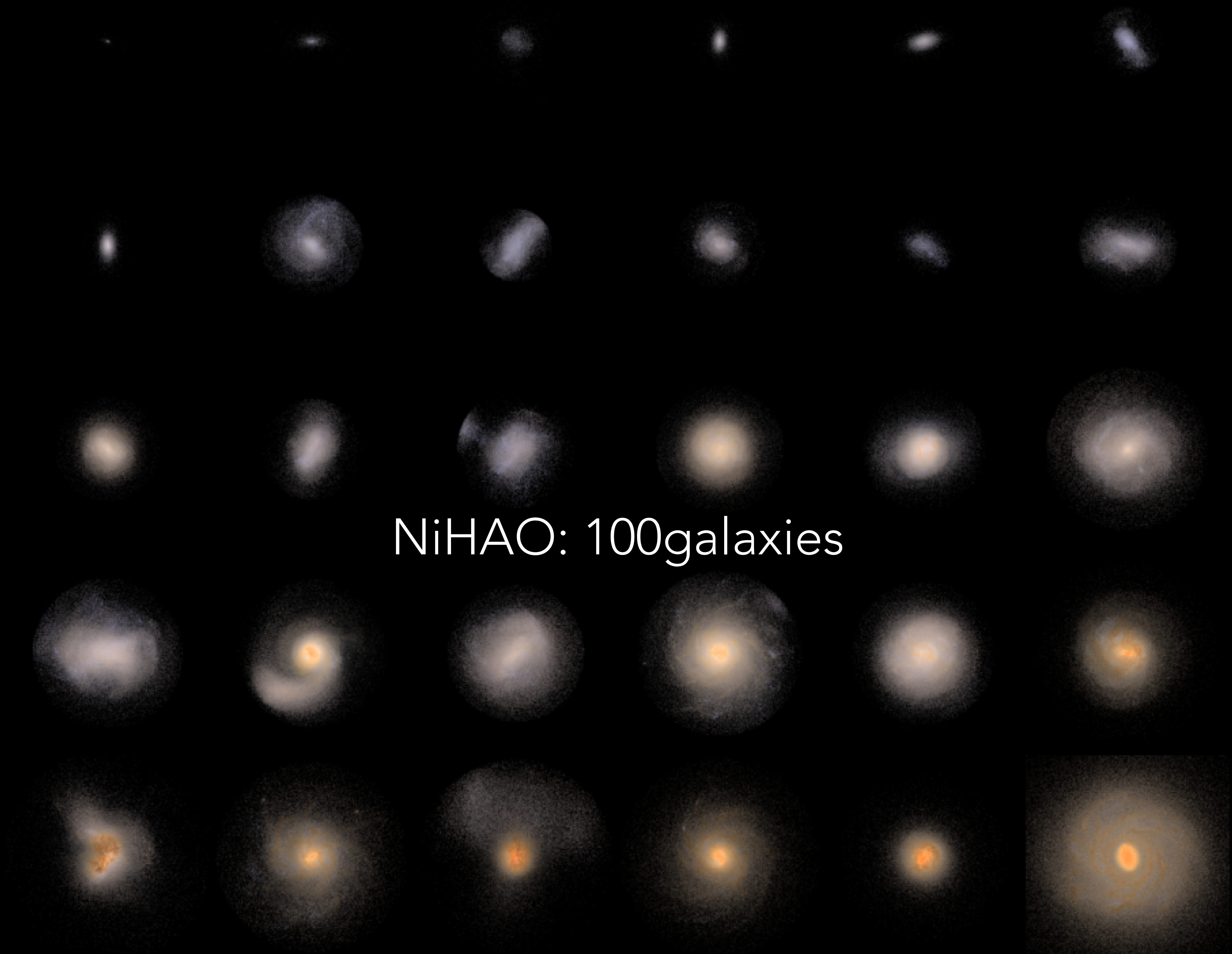



# PRE-SN STELLAR FEEDBACK

A SOLUTION

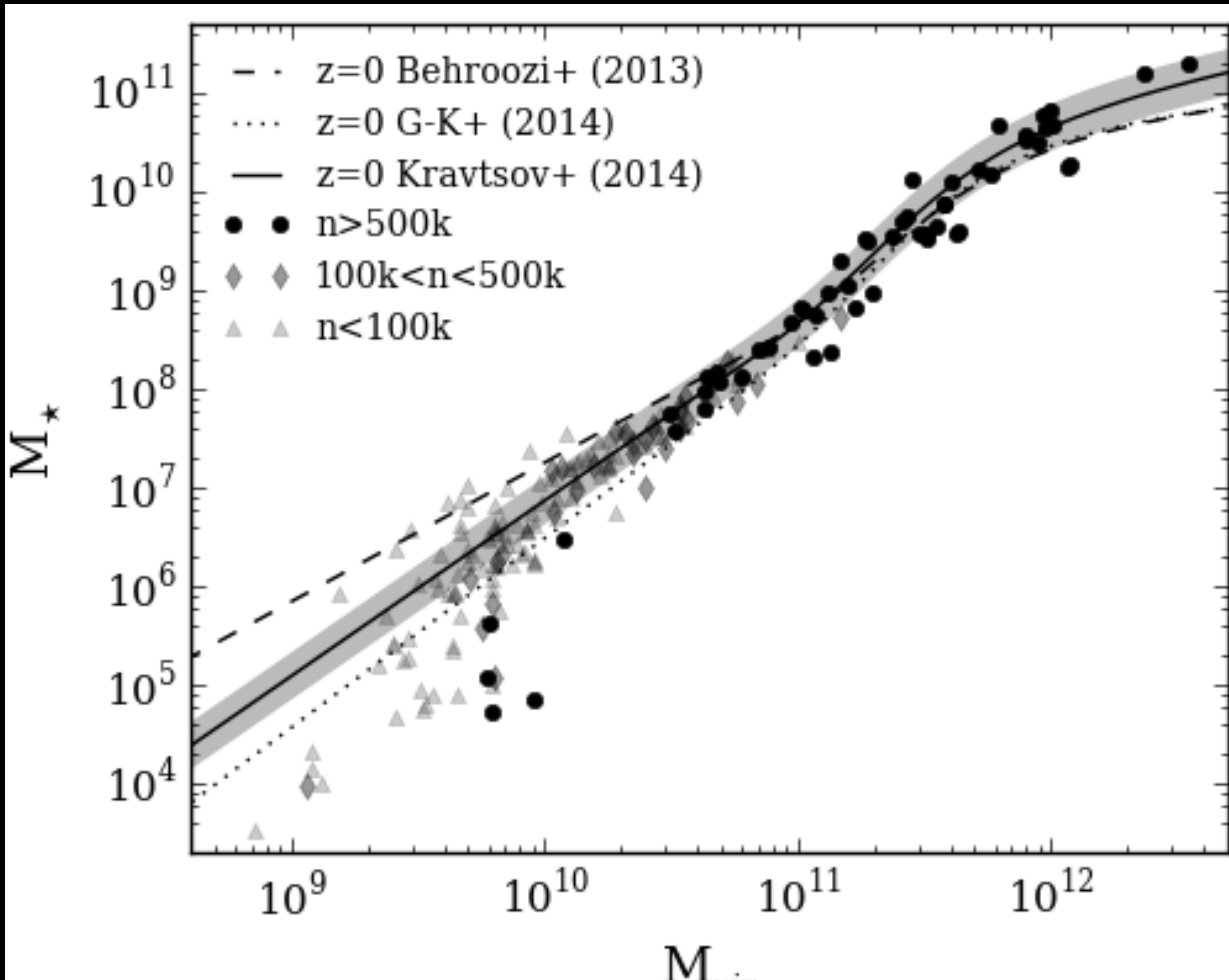

z
5
4
3
2
1
0
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
M* / M$_{tot}$
0
2
4
6
8
10
12
14
Time [Gyr]
Moster+ (2012)
only SN
SN + ESF


0.7 Gyr
SN + ESF: MaGICC
0.7 Gyr
Strong SN only
0.7 Gyr
Low SN FB:  MUGS
Gas
Stars

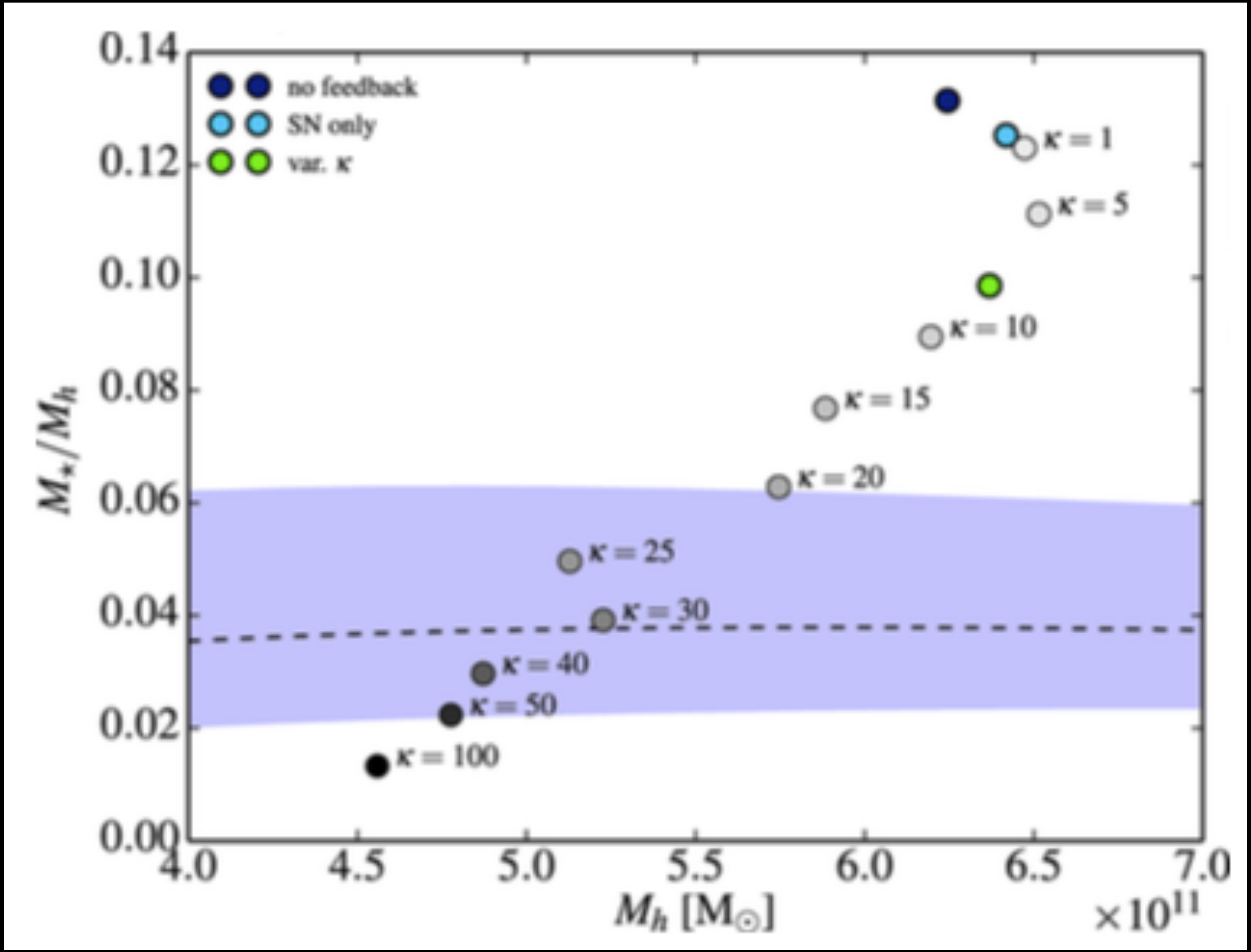

NiHAO: 100galaxies

# 100GALAXIES PROJECT

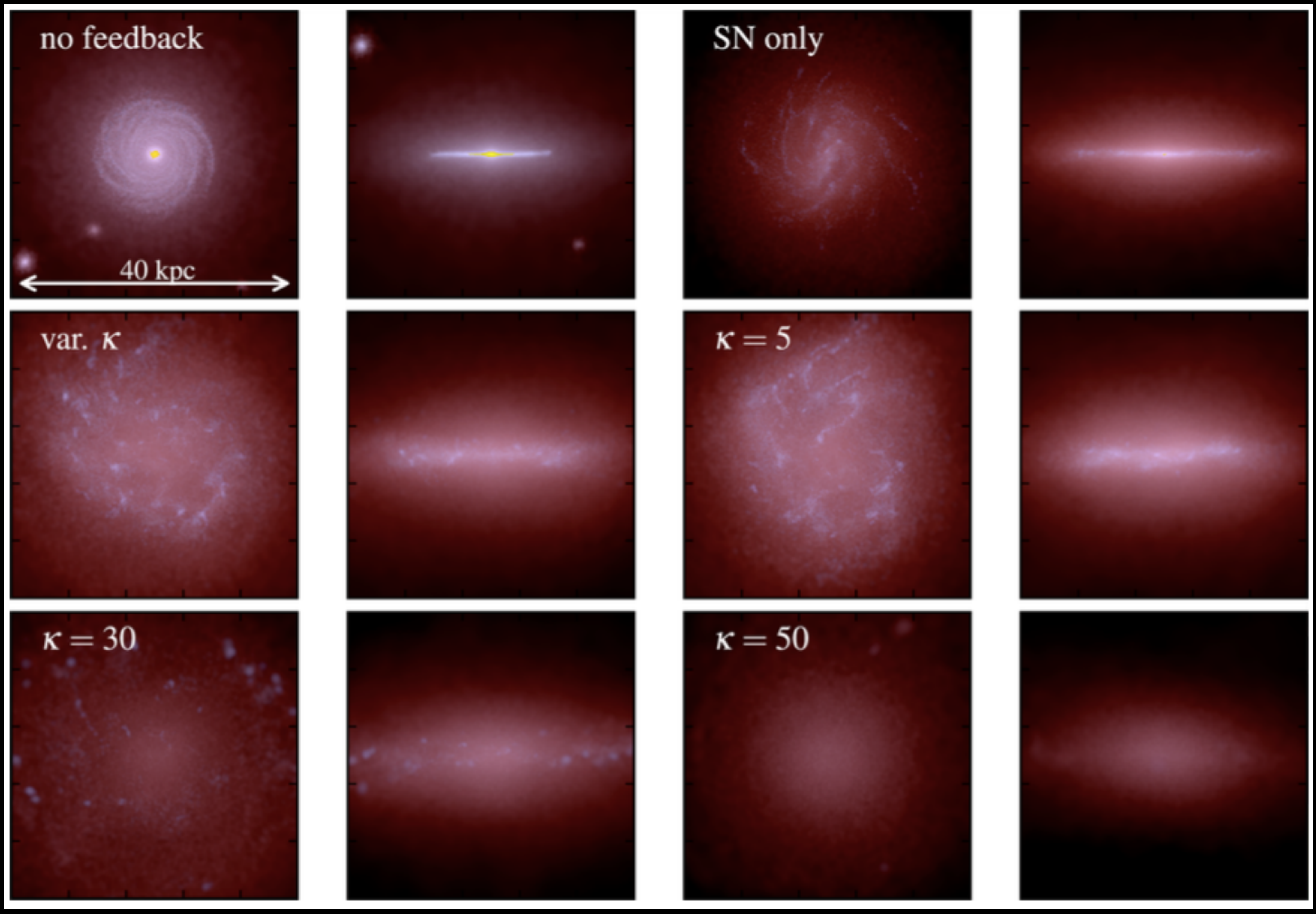
L. WANG+ (2015)



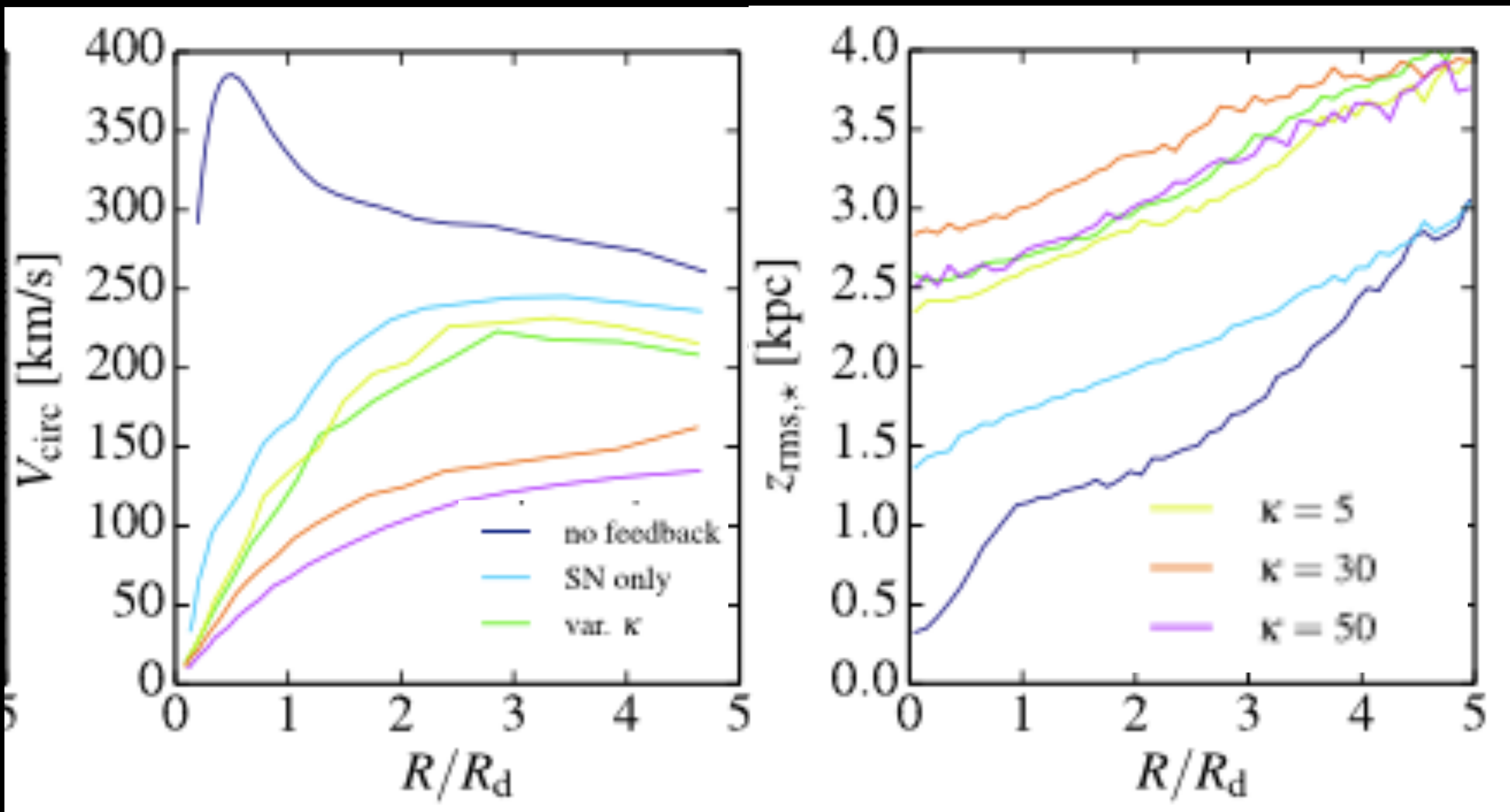
# THE DISC THICKNESS PROBLEM
# ROSKAR (2014)



# THE DISC THICKNESS PROBLEM
# ROSKAR (2014)

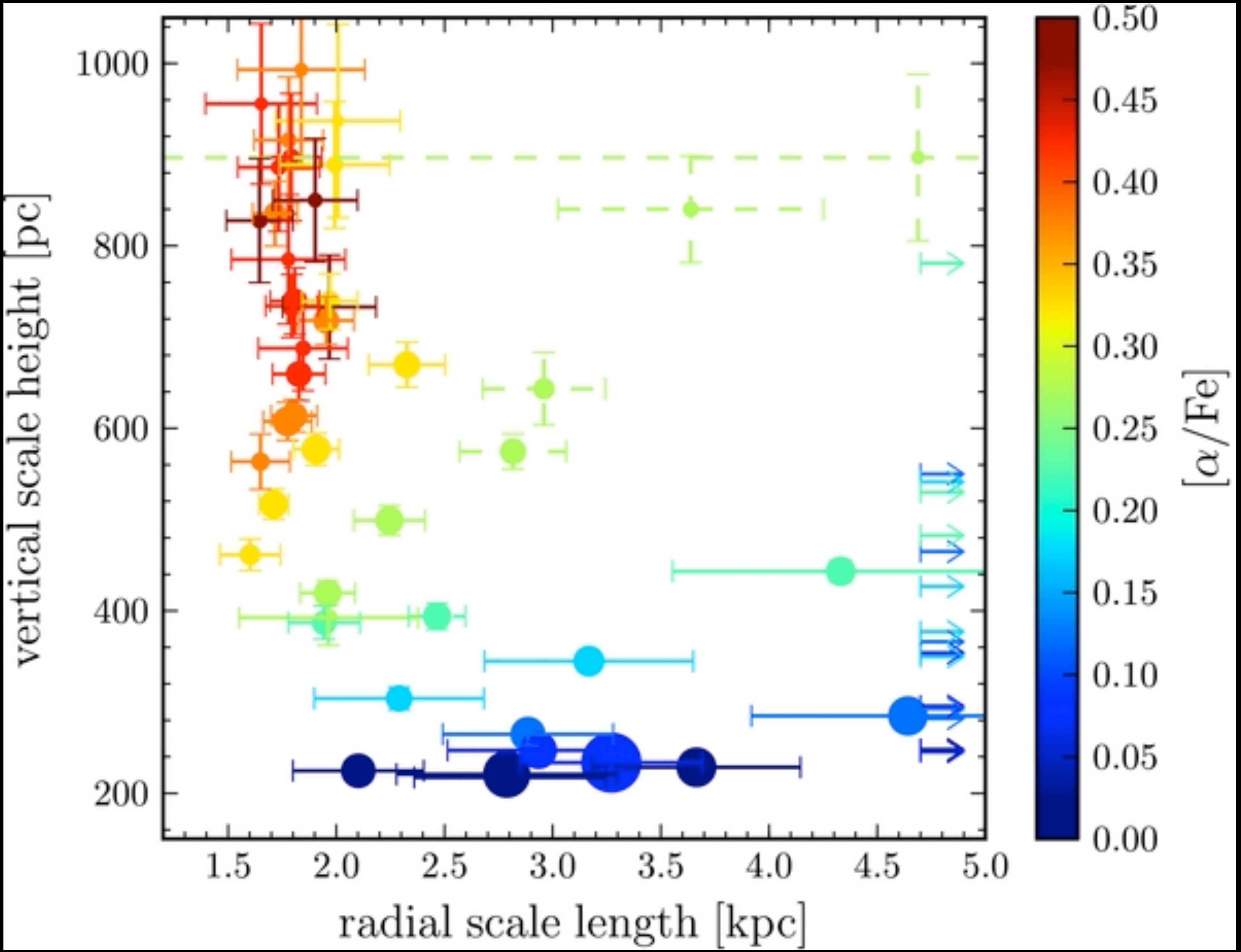


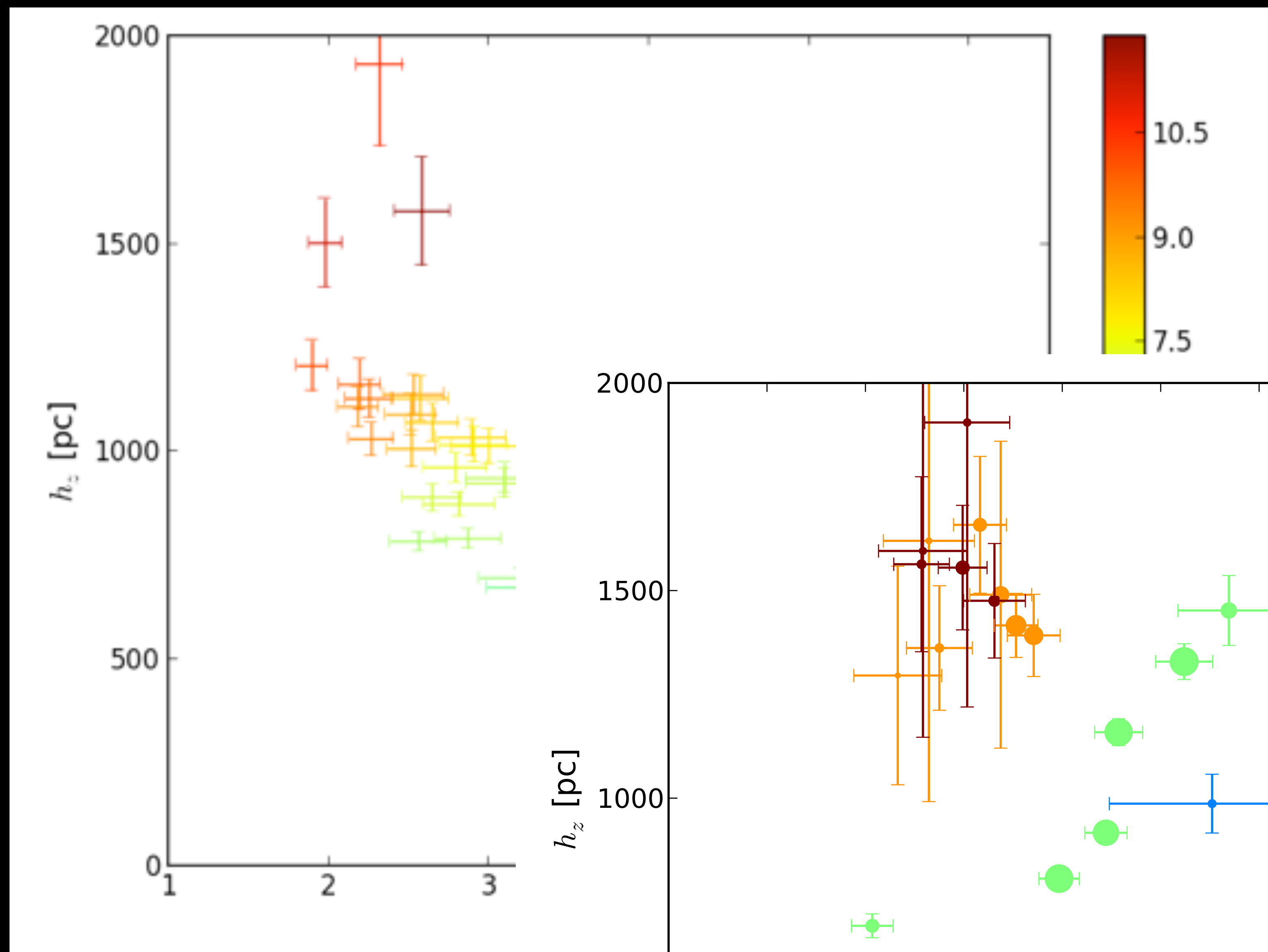
# THE DISC THICKNESS PROBLEM
# ROSKAR (2014)

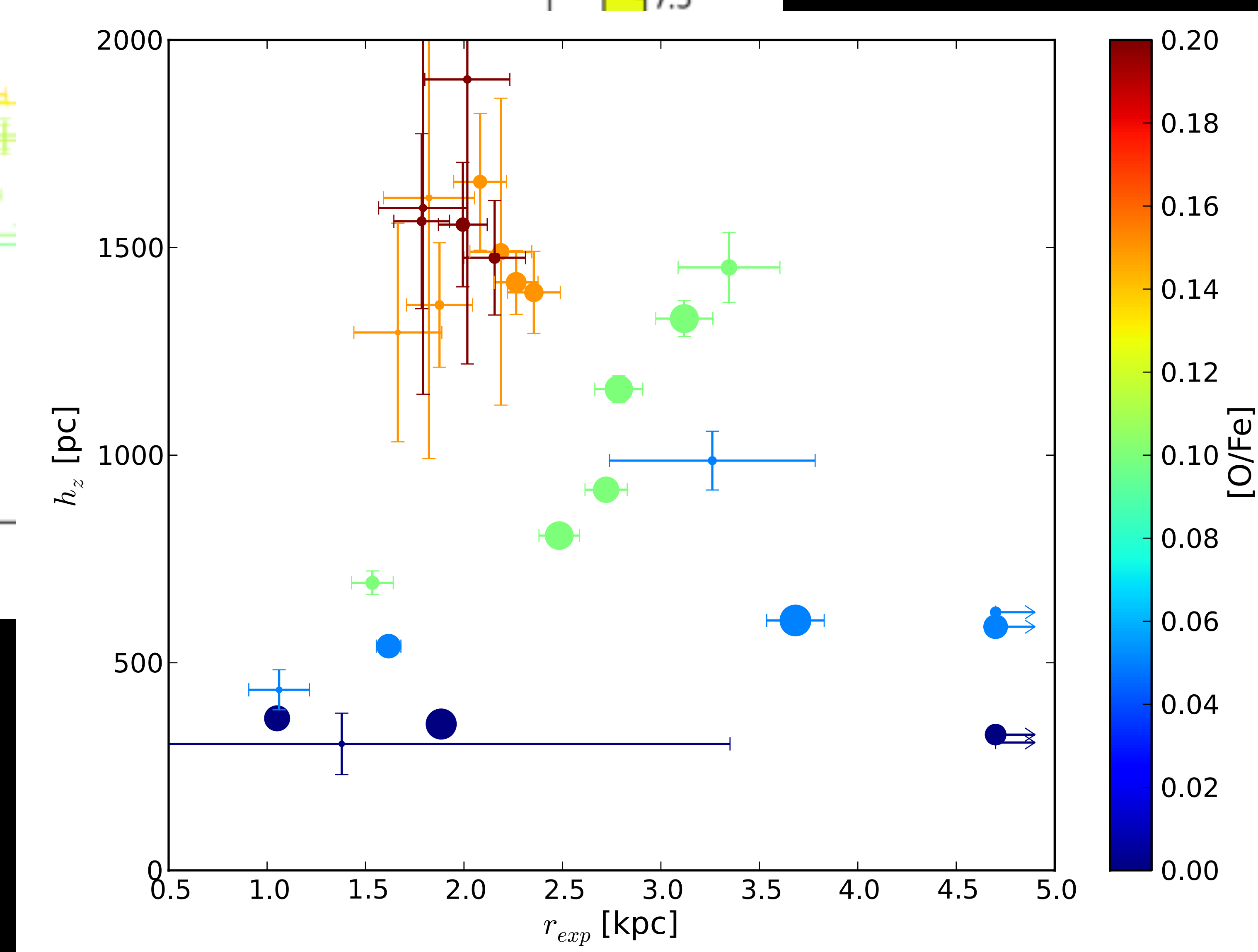


# OBSERVED MW THICK DISK

BOVY+ (2012)



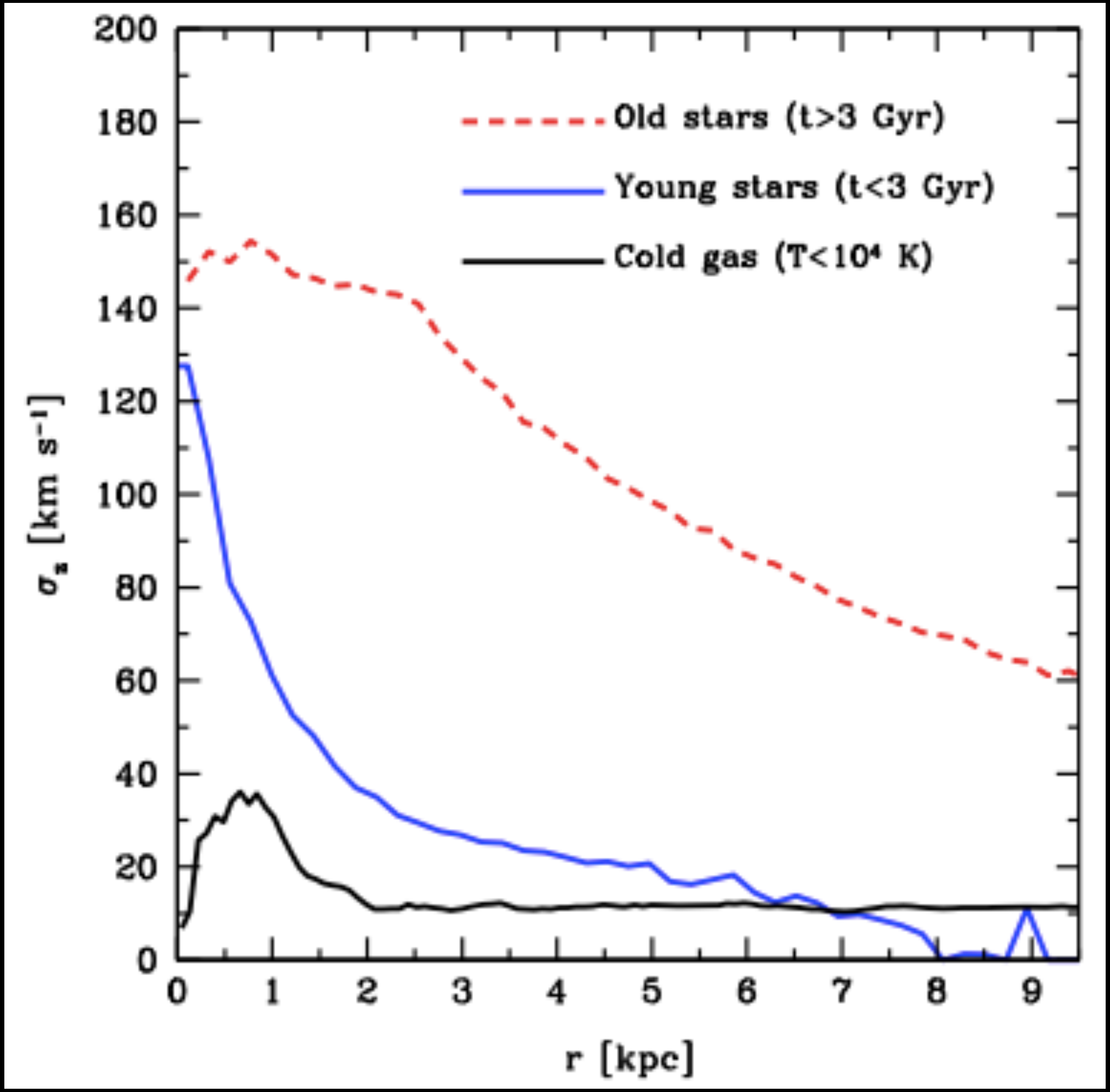



# STINSON ET AL (2013)

# BETTER BEHAVED RAMSES FEEDBACK

Agertz & Kravtsov (2014)

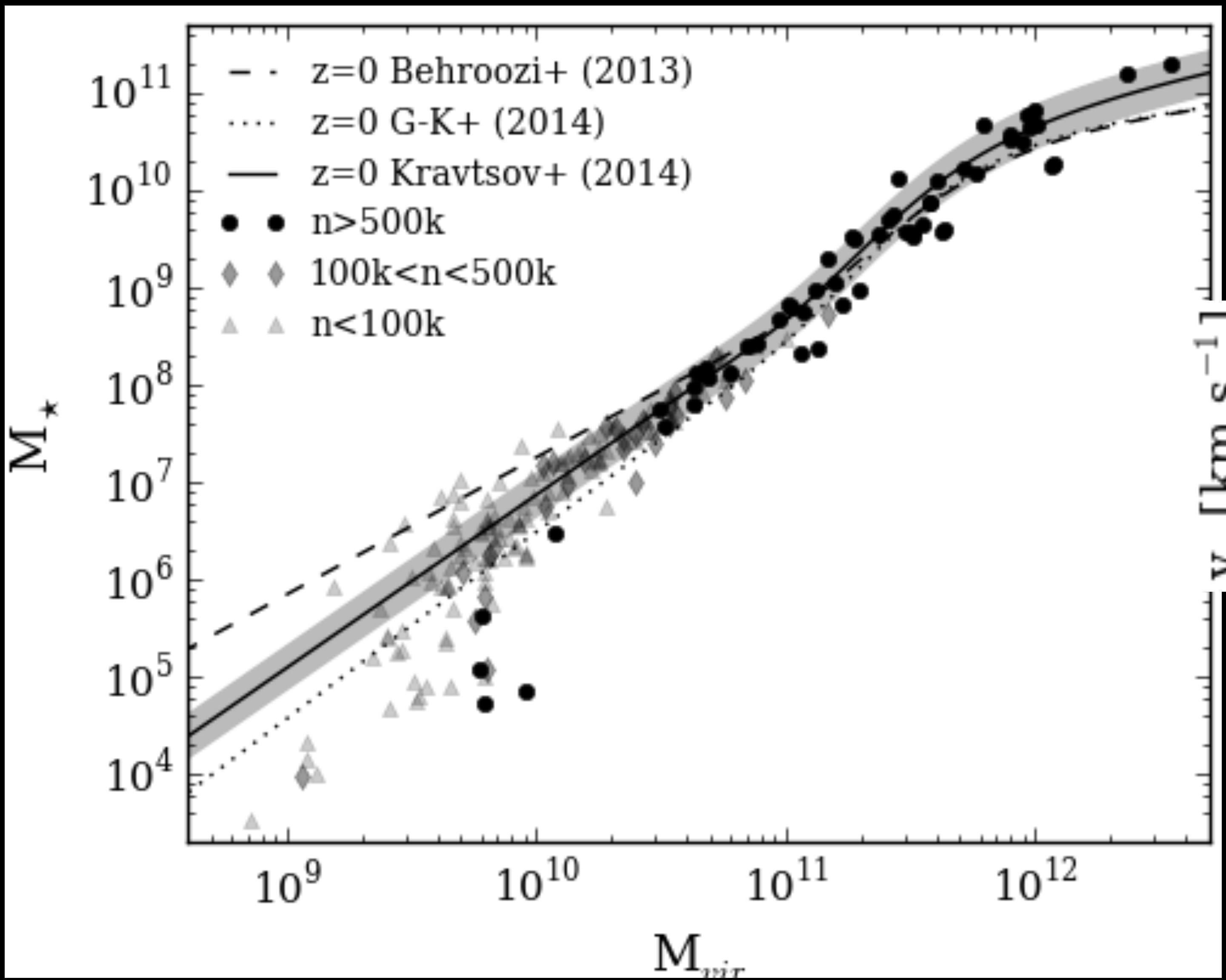


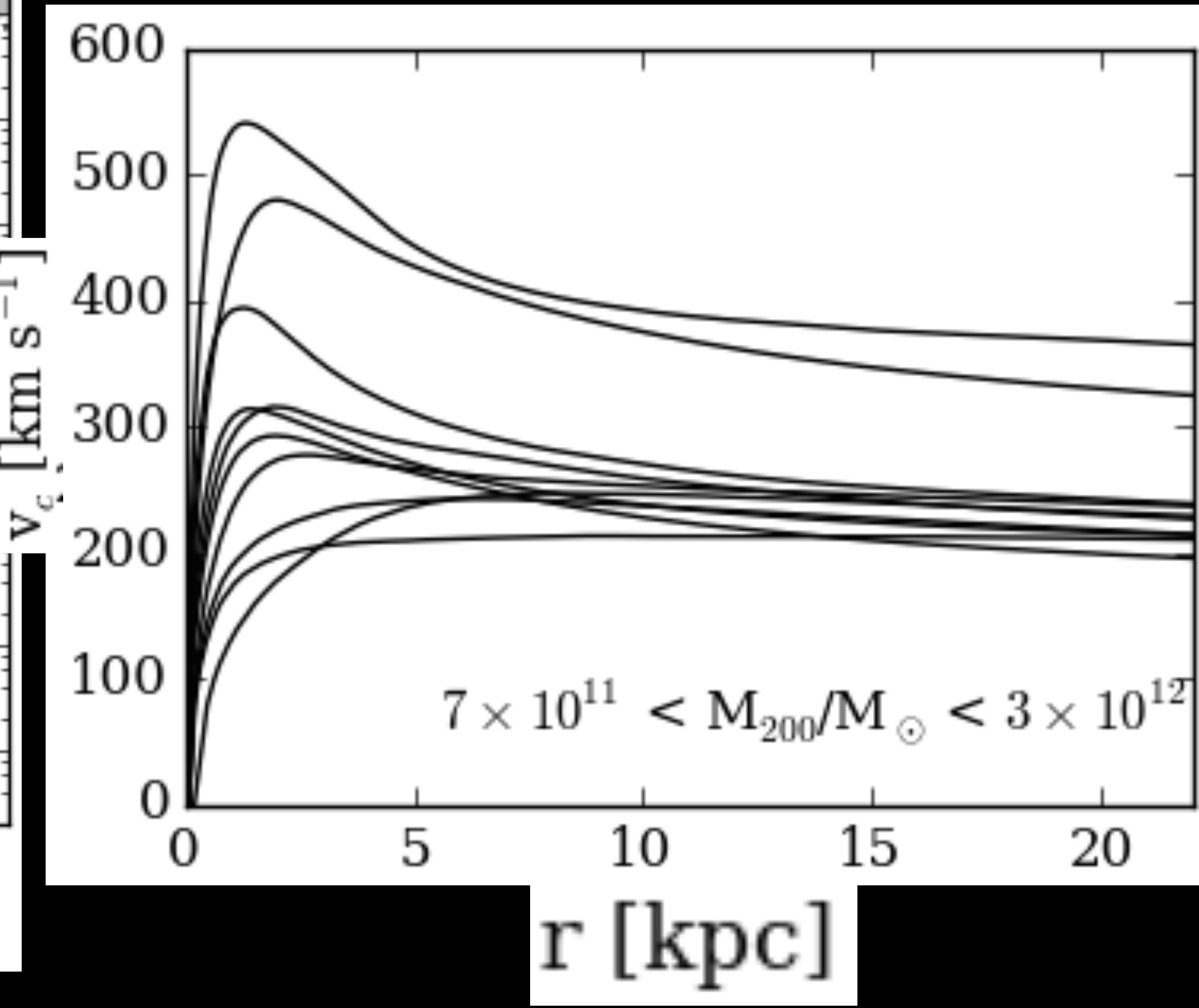

10 Myr

$E_{fb}$

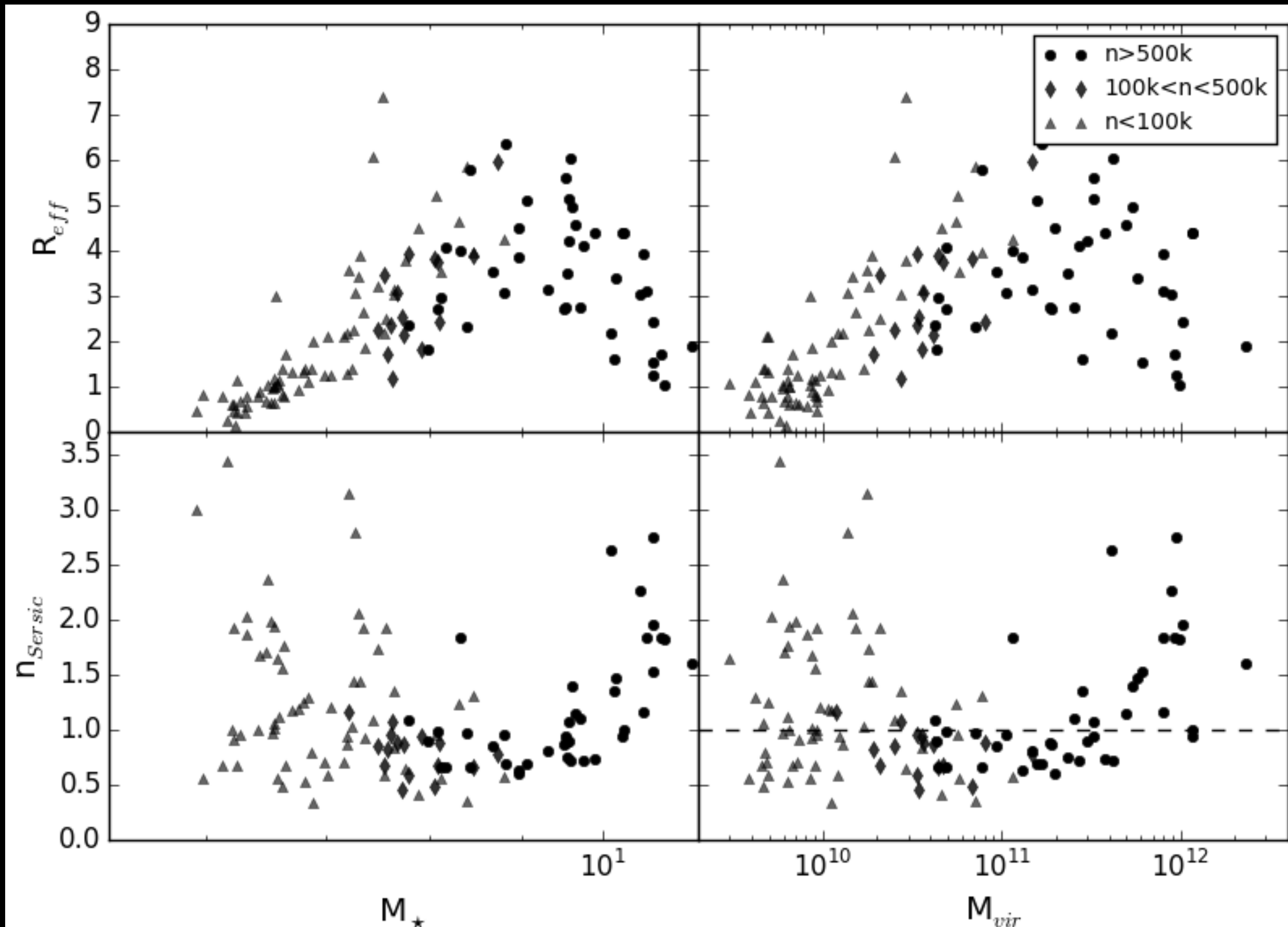
dissipation time scale

# QUENCHING CENTRAL STAR FORMATION AT HIGH MASSES



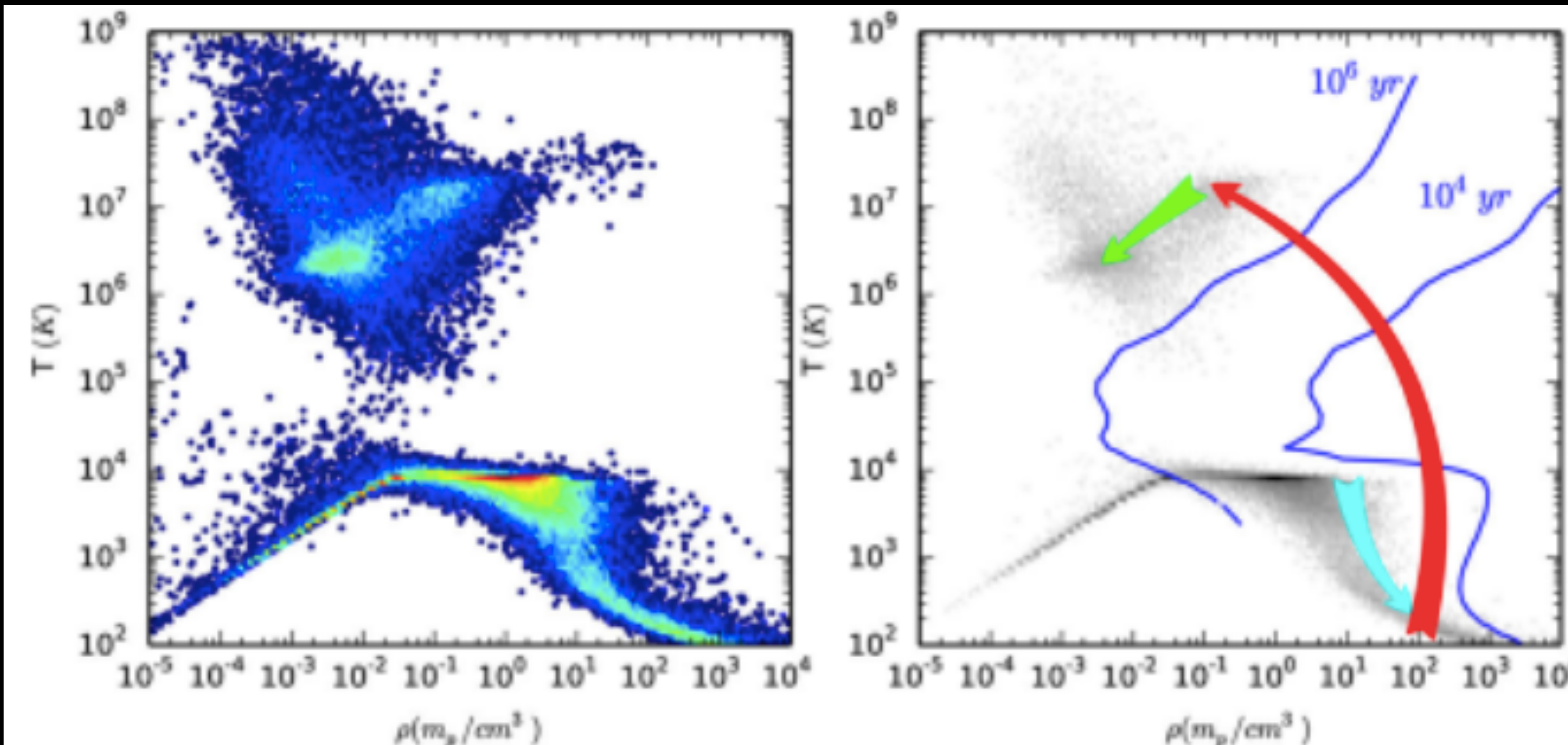
# GALAXY SIZES



# "THERMAL" IS PROBABLY WRONG KIND OF ENERGY

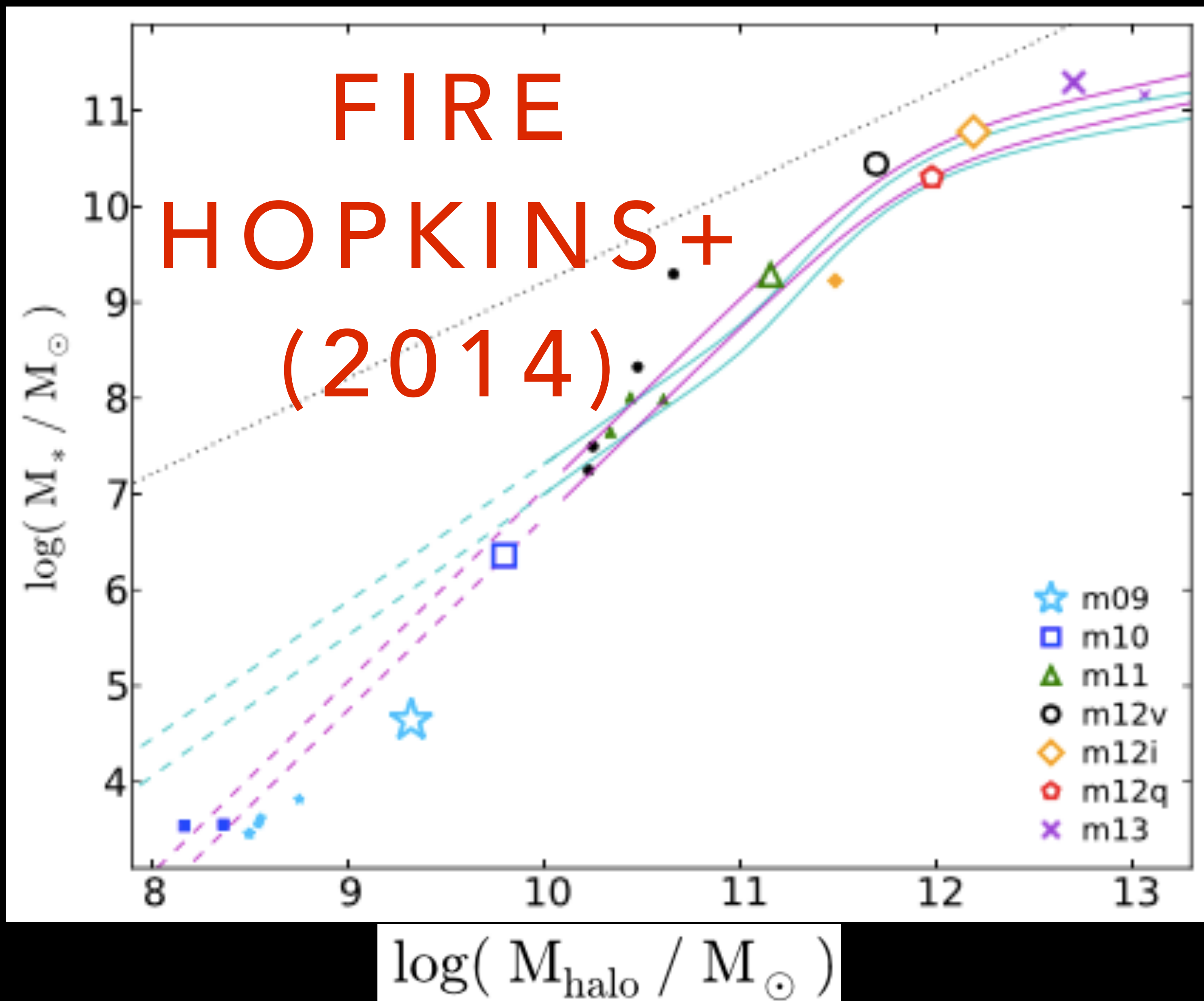
- Dissipates on the cooling timescale:  10,000 yr at SF densities
- There are other forms of energy that decay more slowly:
    - cosmic rays
    - turbulence
    - magnetic fields

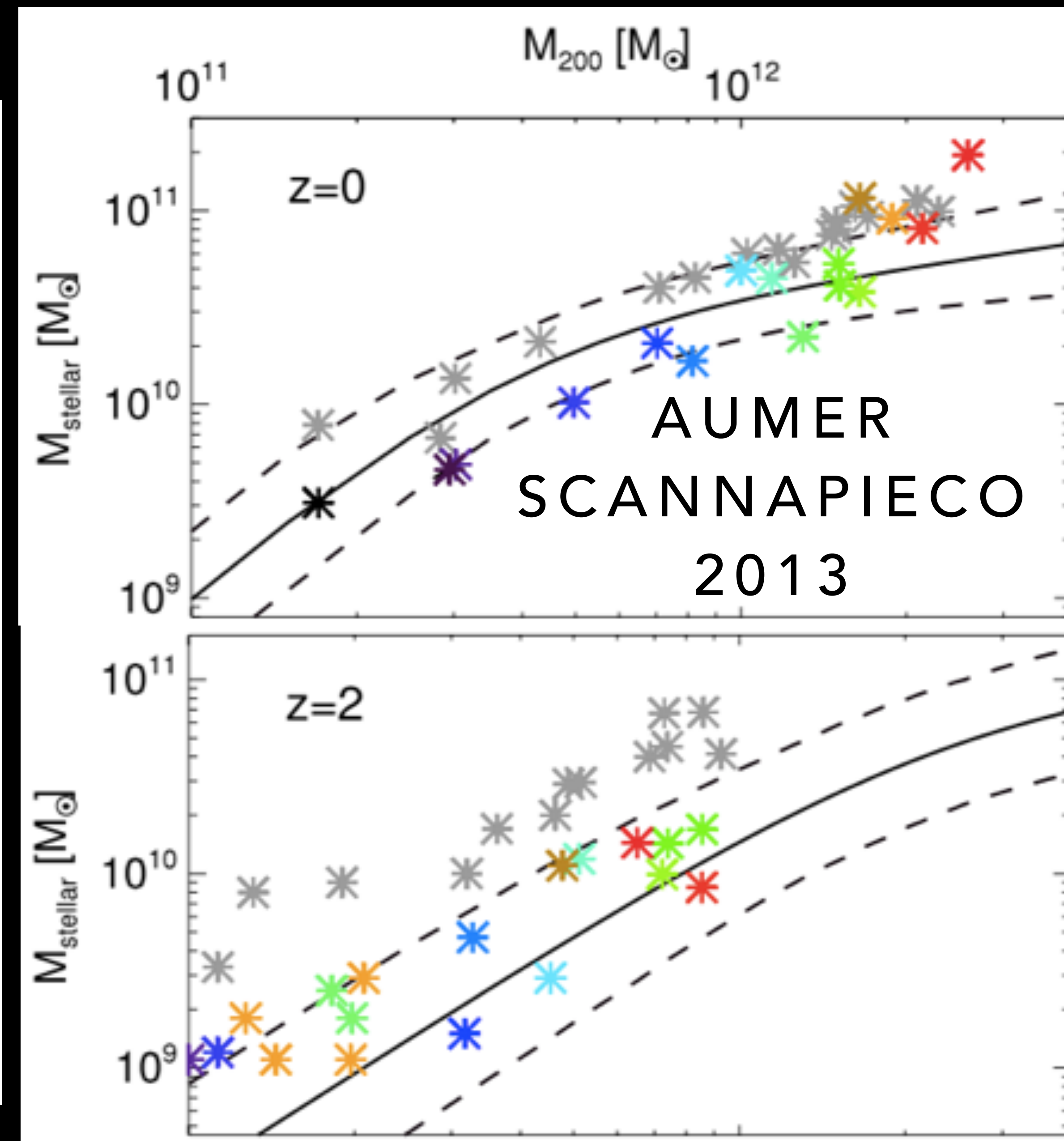
# KELLER+ (2014)




- Energy reservoir dissipates according to resolution

# HYBRID MODELS




Small scale kinetic from radiation pressure

Also thermal

Decoupled gas phases

+

Radiation Pressure

# CHARACTERISTICS OF SUCCESSFUL MODELS

- Use 100% of available SN energy
- Distribute energy locally and immediately
- Add an early contribution from stellar winds or radiation pressure