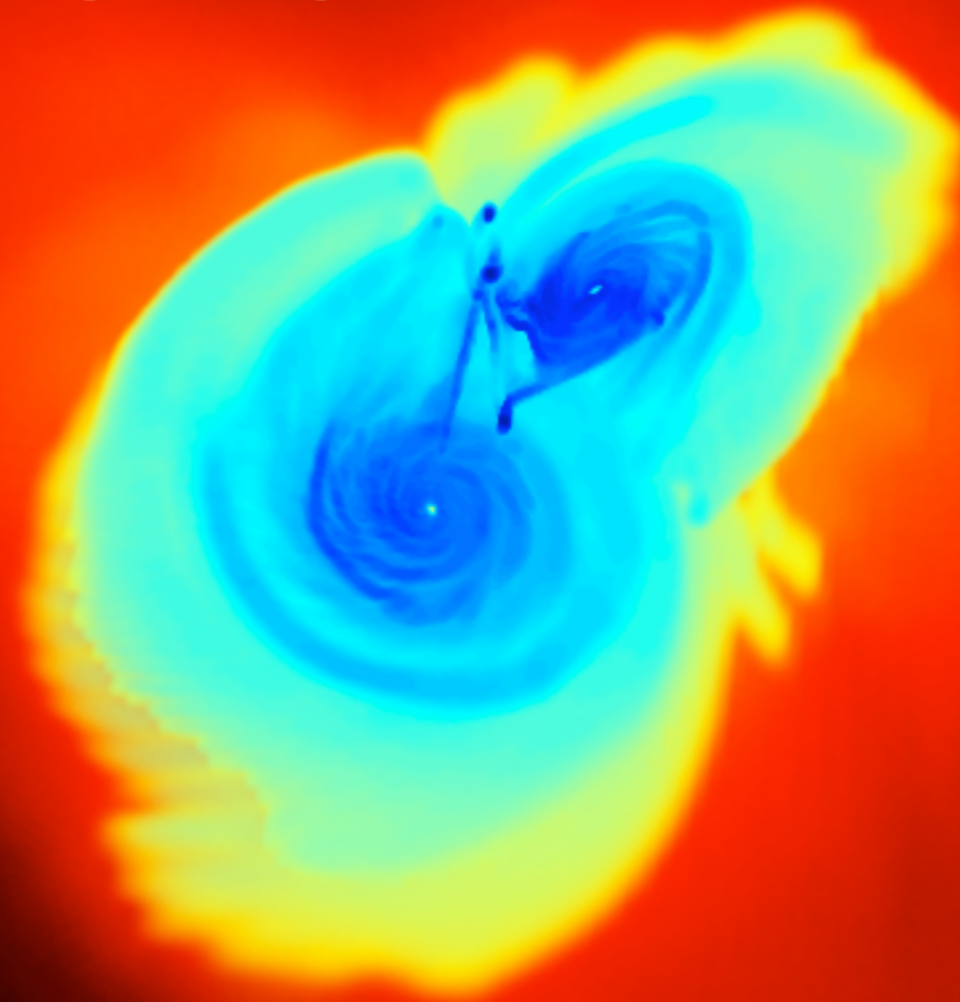


Effect of AGN Feedback on SF of Merging Disk Galaxies



Jongwon Park

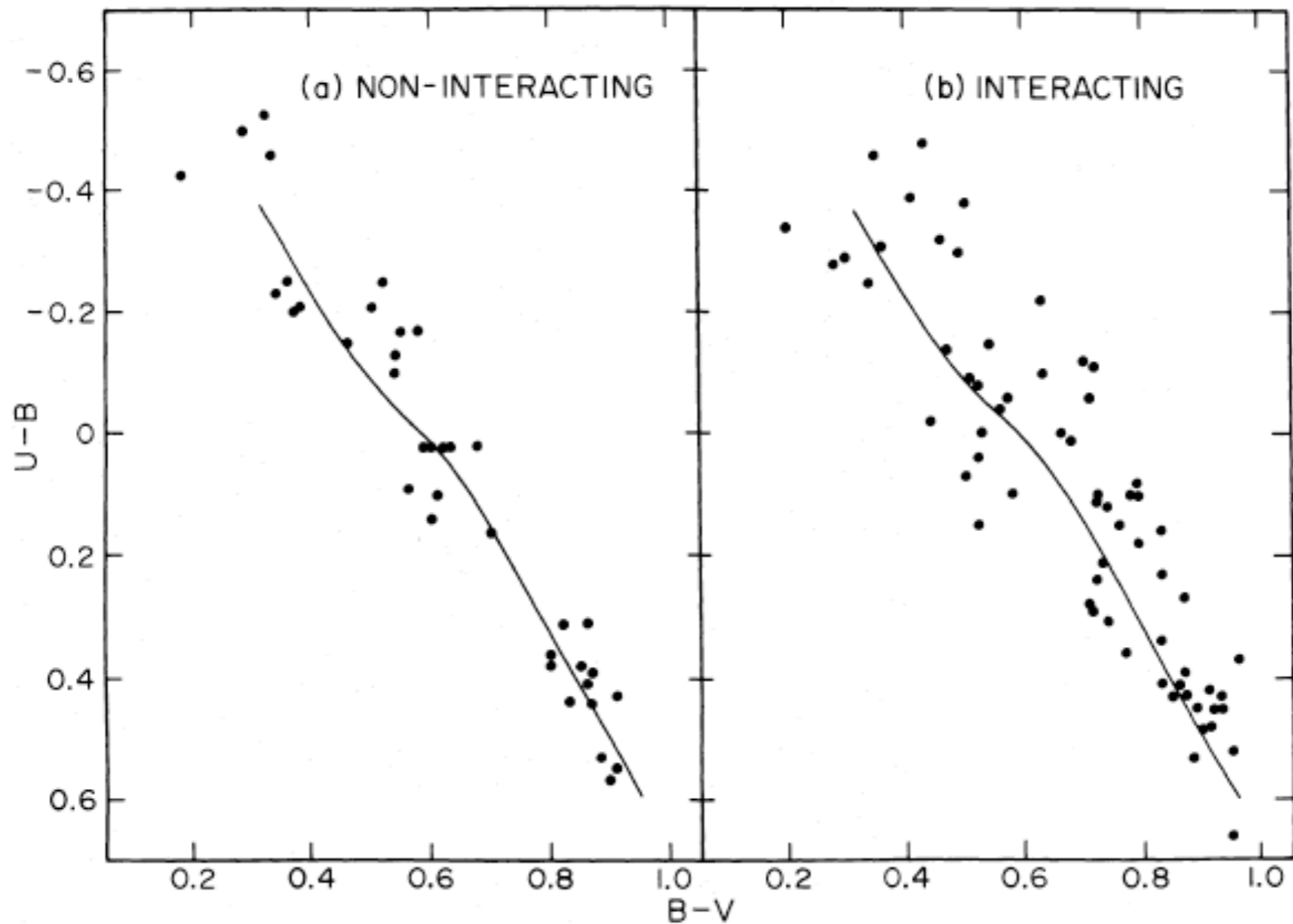
Rory Smith

Sukyoung K Yi

(Yonsei University, South Korea)

Introduction

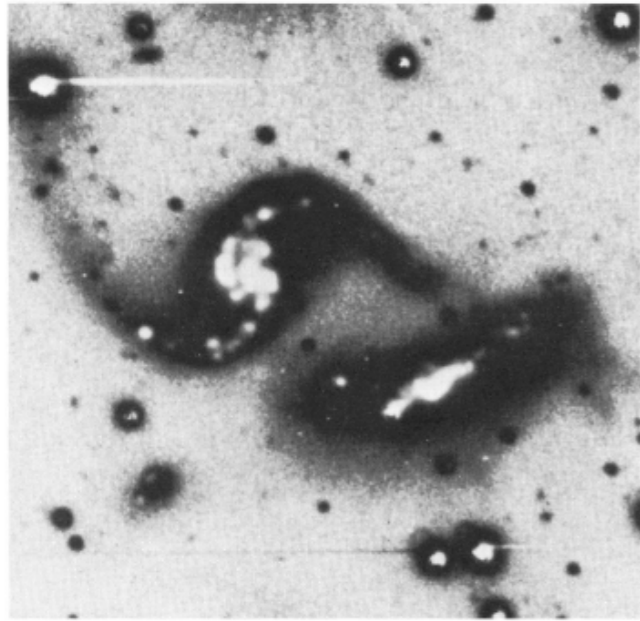
galaxy merger - “burst” of star formation



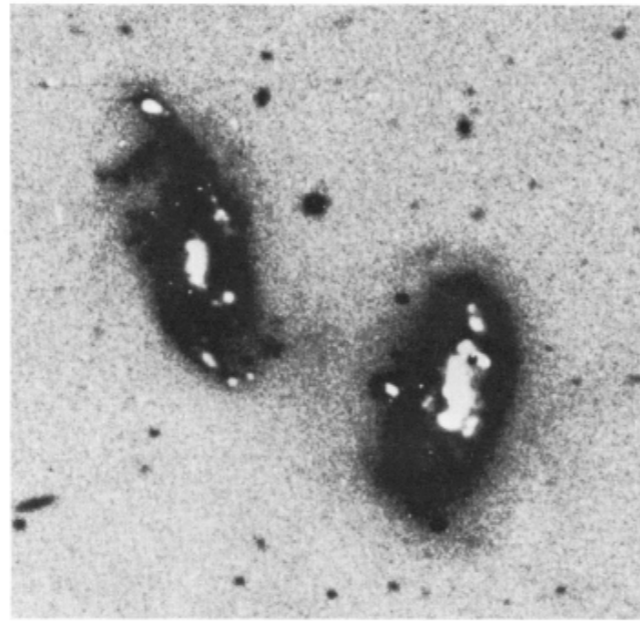
Larson & Tinsely 1978

Introduction

gas concentration by tidal field

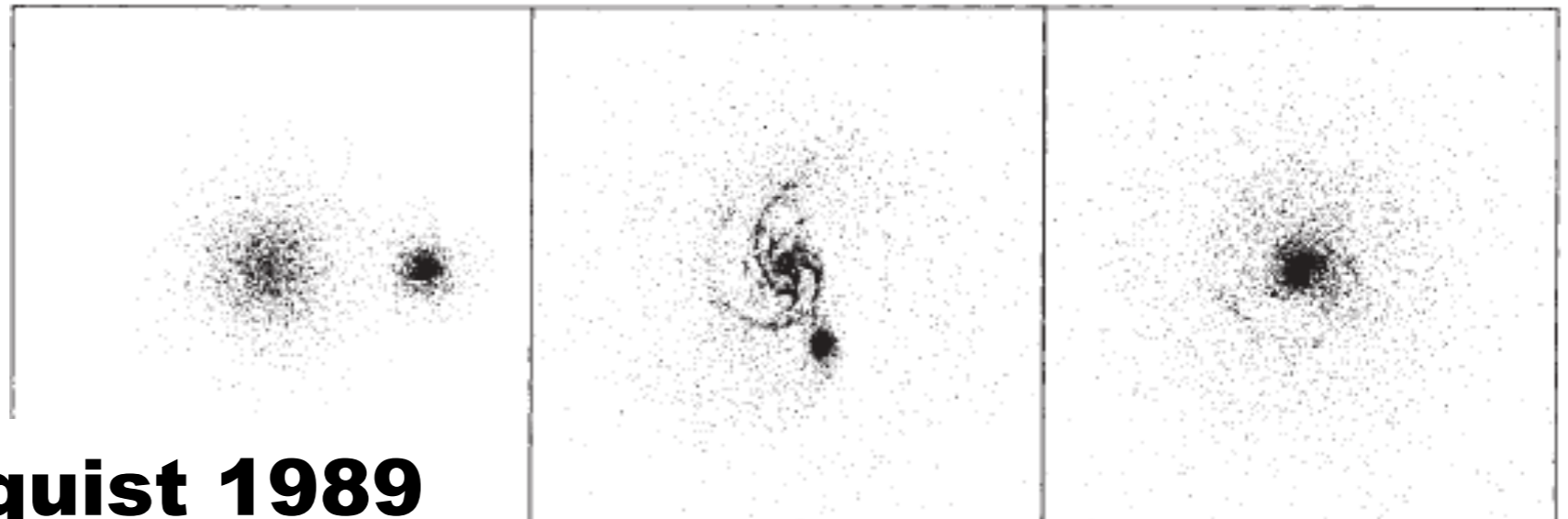


UGC 813/816



UGC 1063/1065

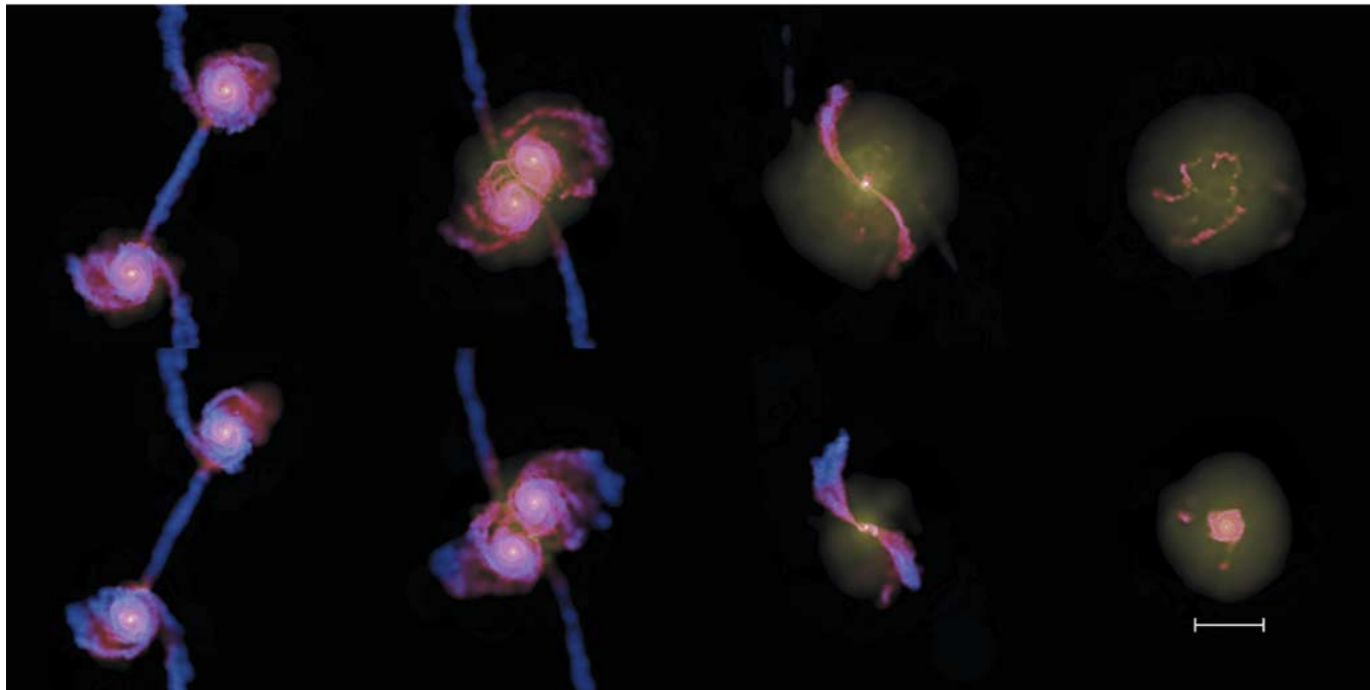
Bushouse 1987



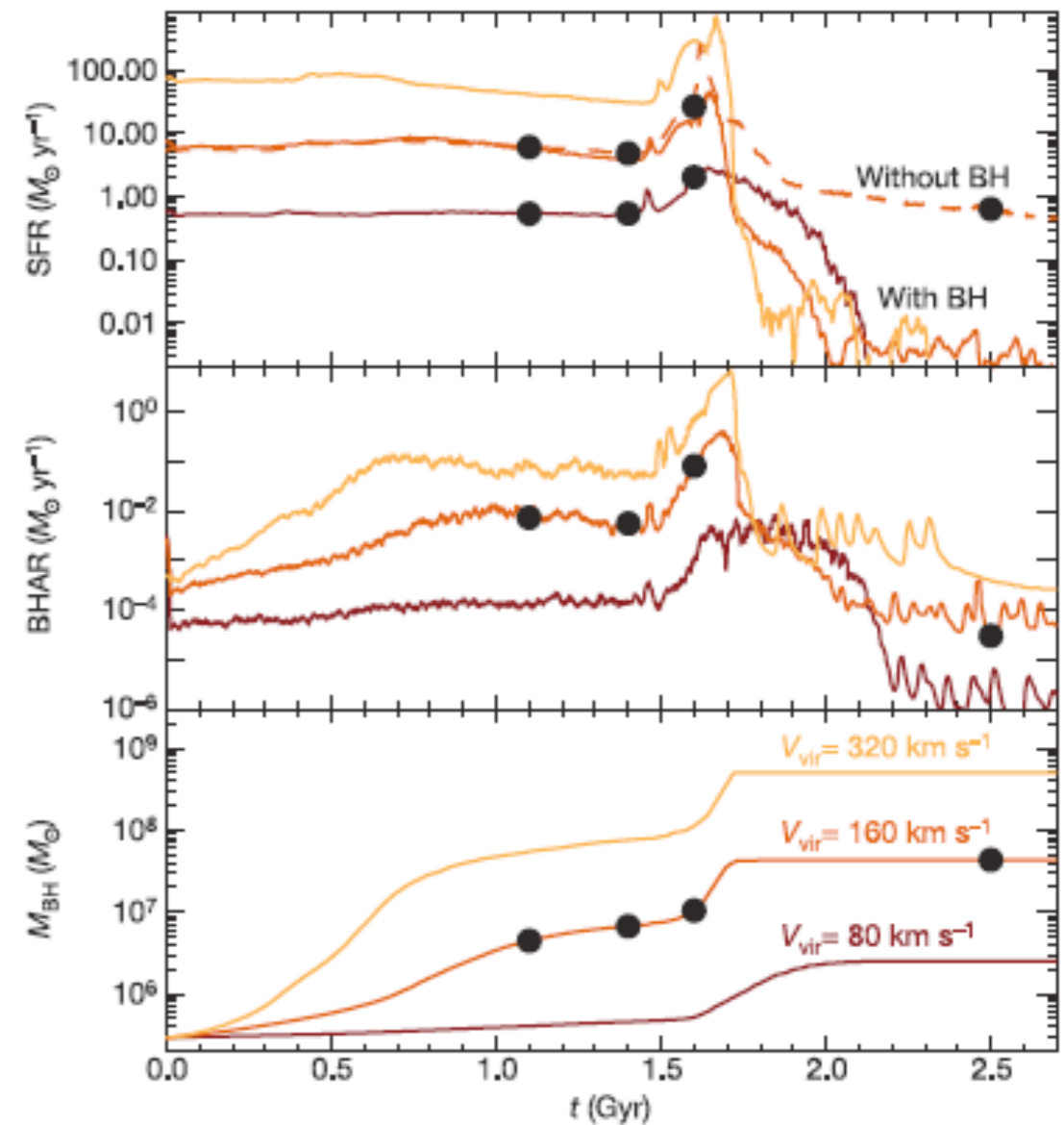
Hernquist 1989

Introduction

effect of AGN feedback on star formation



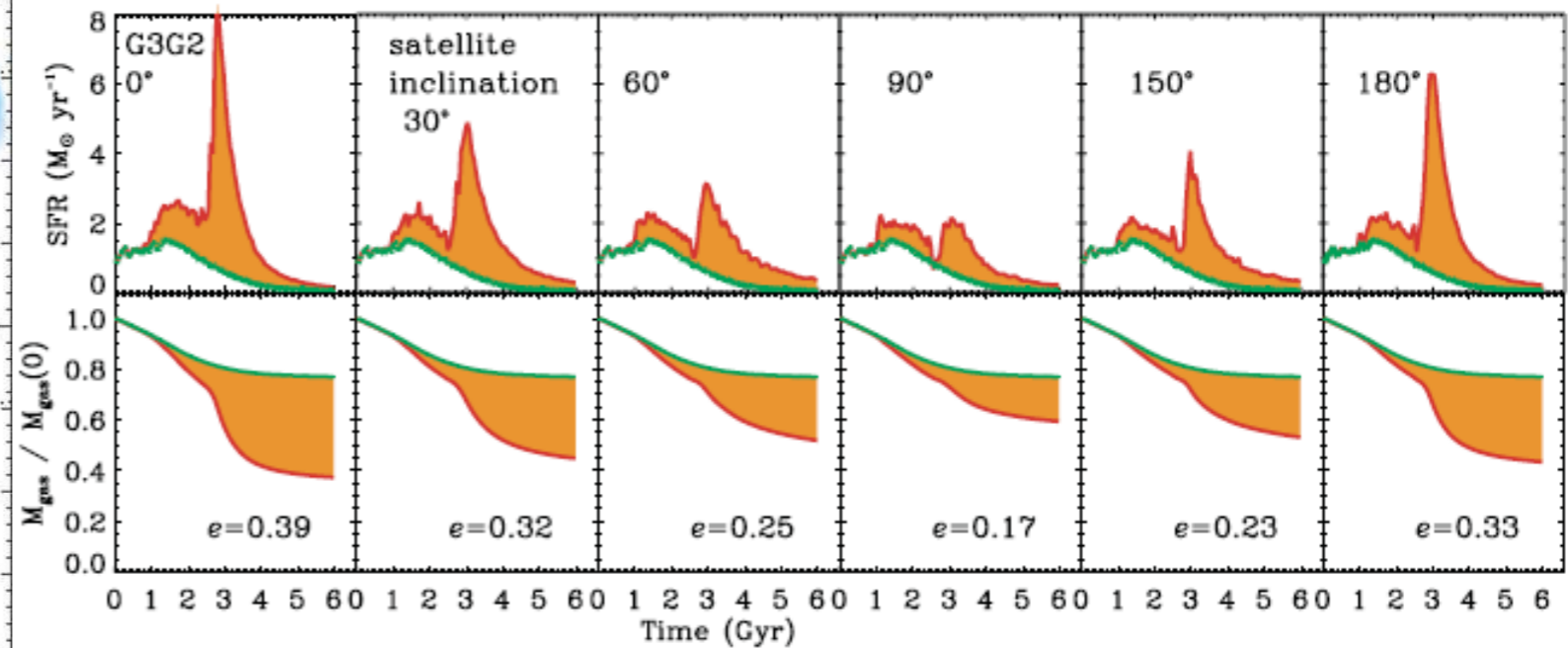
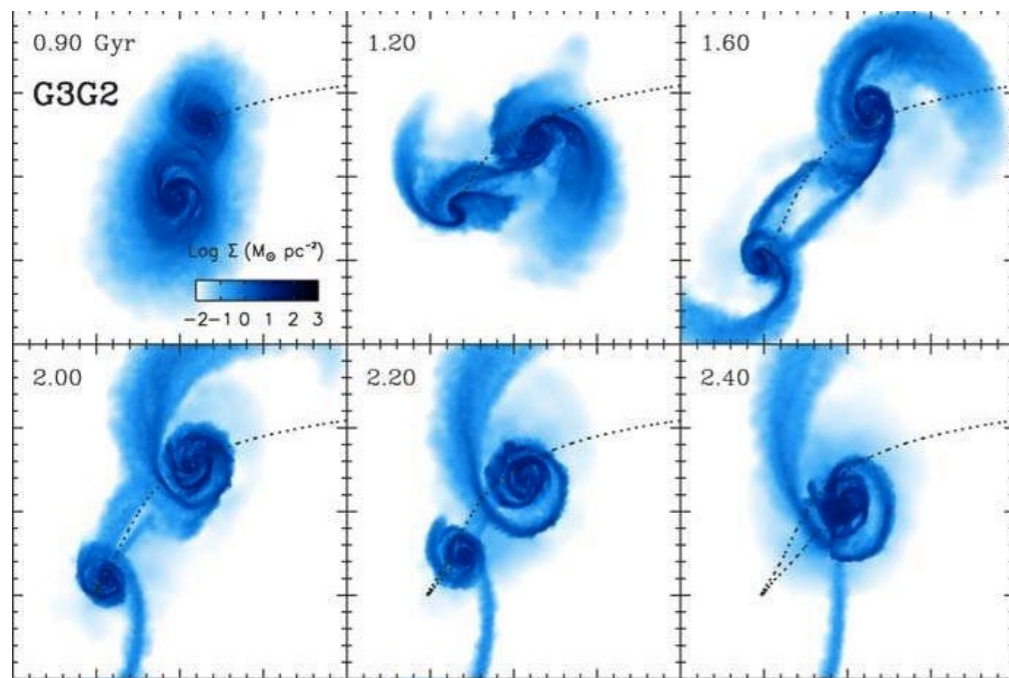
Di Matteo et al. 2005



Introduction

star formation of merging galaxies

- mass ratios, structures, etc.



Cox et al. 2008

Introduction

Merger-driven SF

- Cox et al. 2008

(large parameter space but no AGN FB)

AGN Effect on SF

- Di Matteo et al. 2005, Newton & Kay 2013

(1:1 mass ratios)

- Hayward et al. 2014

(small parameter space covered)

=> investigate **SF** of **merging galaxies** with **AGN** using idealized simulations covering **large parameter space**

Introduction

Merger-driven SF

- Cox et al. 2008

(large parameter space but no AGN FB)

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- Di Matteo et al. 2005, Newton & Kay 2013

(1:1 mass ratios)

- Hayward et al. 2014

(small parameter space covered)

=> investigate **SF** of **merging galaxies** with **AGN** using idealized simulations covering **large parameter space**

=> **mass ratios & B/T**

Simulation

boxlen - 300 kpc

- **minimum level - 7**
- **maximum level - 13 (36.6 pc)**
(11 => 13 when t=0.3 Gyr)

refinement

- **gas mass $> 5 \times 10^4 M_{\text{sun}}$**
- **$dx > L_{\text{Jeans}}/4$ (Truelove et al. 1997)**

disk galaxies

- **DM halo(NFW), bulge(Hernquist)**
stellar disk(exp+sech z)
gas disk(exp+exp), BH

SPH

- Chilingarian+ 2010 - 200 pc**
- Cox+ 2008 - 50 pc**
- Hayward+ 2014 - 120/240 pc (MW)**
- Newton & Kay 2013 - 50 pc**
- Hwang & Park 2015 - 40/70 pc**

AMR(RAMSES)

- Renaud+ 2013 - 0.05 pc**
- Teyssier+ 2010 - 12 pc**
- Gabor & Bournaud 2013 - 6 pc**
- Gabor+ 2016 - 7.6 pc**

Simulation

Star Formation

- efficiency 2%
- $n_H = 0.1 \text{ H cm}^{-3} \Rightarrow 10 \text{ H cm}^{-3} \text{ (t=0.3 Gyr)}$

Kinetic Supernovae Feedback

- Dubois & Teyssier 2008
- $\eta_{SN} = 0.1$, $\eta_w = 1.0$, $f_{ek} = 0.5$ and $r_{bubble} = 75 \text{ pc}$

AGN (after t=0.3 Gyr)

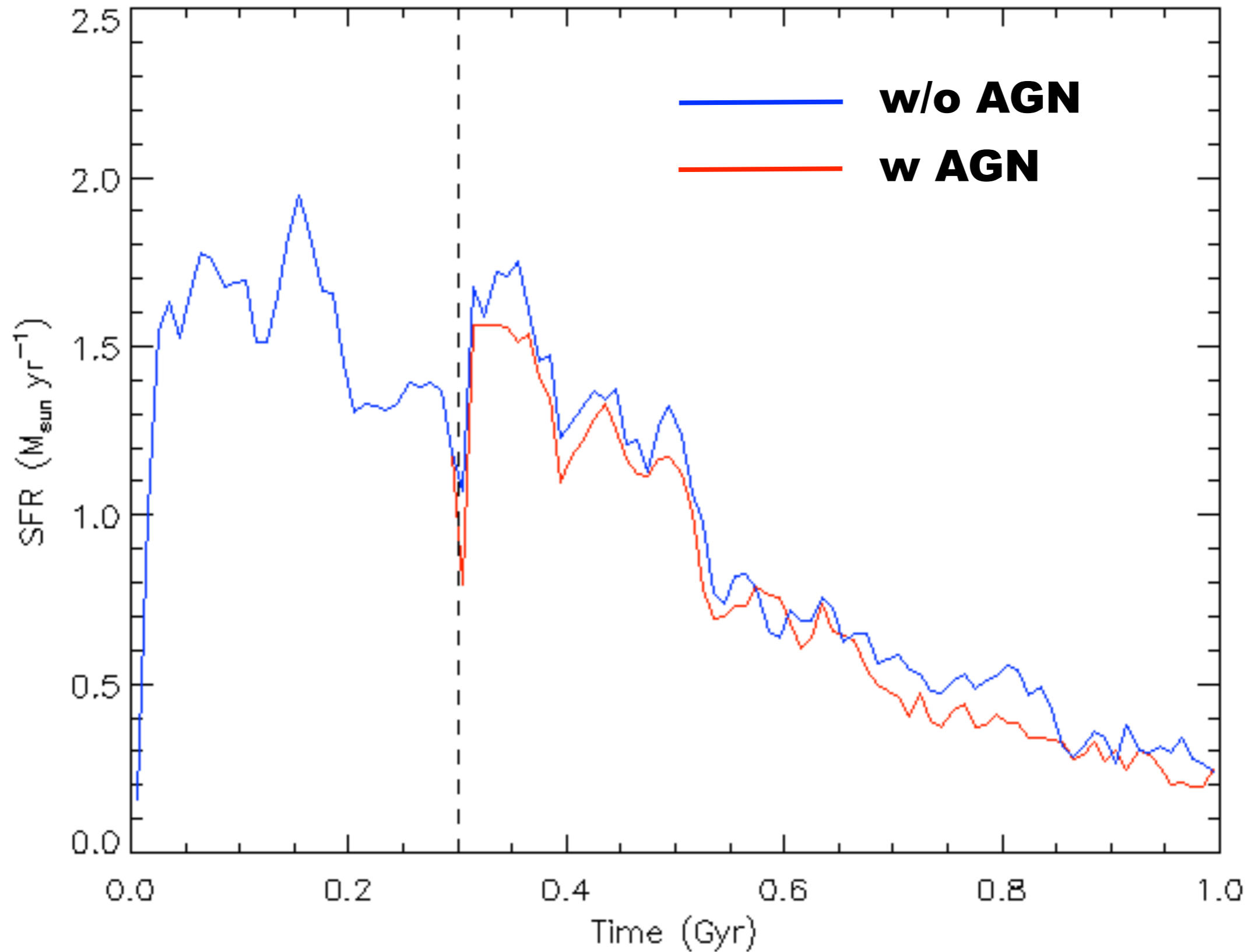
- Teyssier et al. 2011
- Dubois et al. 2012
- Gabor & Bournaud 2013
- Bondi-Hoyle accretion
- quasar mode

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{(c_s^2 + u^2)^{3/2}}$$

$$\dot{M}_{Edd} = \frac{4\pi G M_{BH} m_p}{\epsilon_r \sigma_T c}$$

$$\Delta E_{acc} = \epsilon_c \epsilon_r \dot{M}_{acc} c^2 dt$$

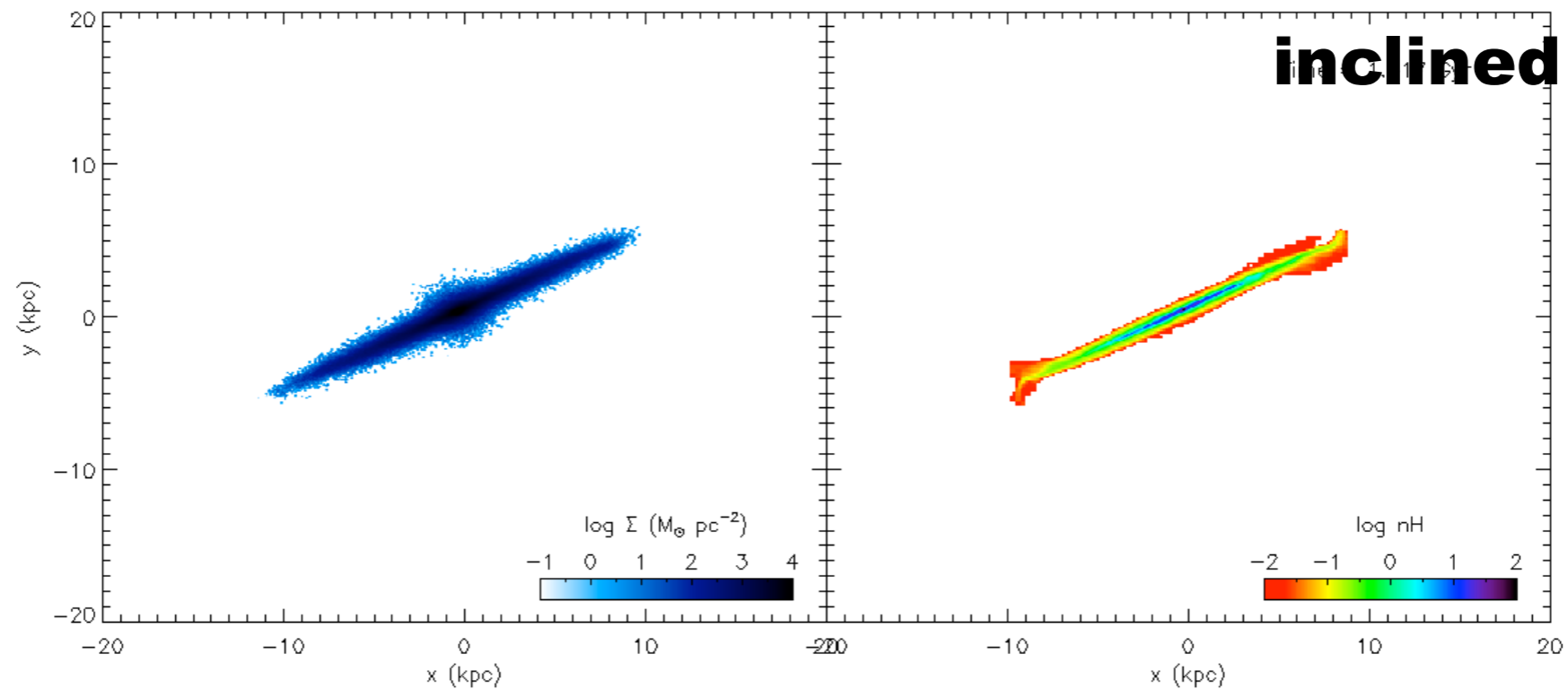
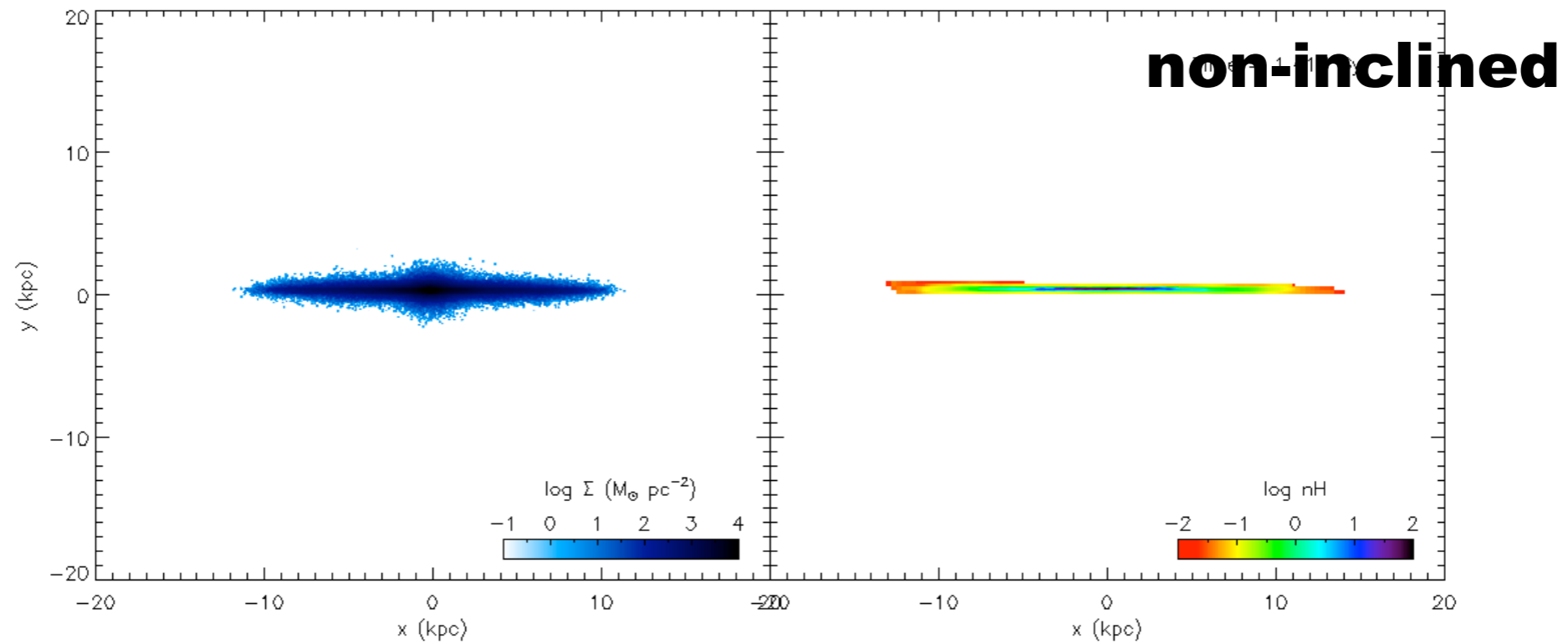
Isolated Galaxies



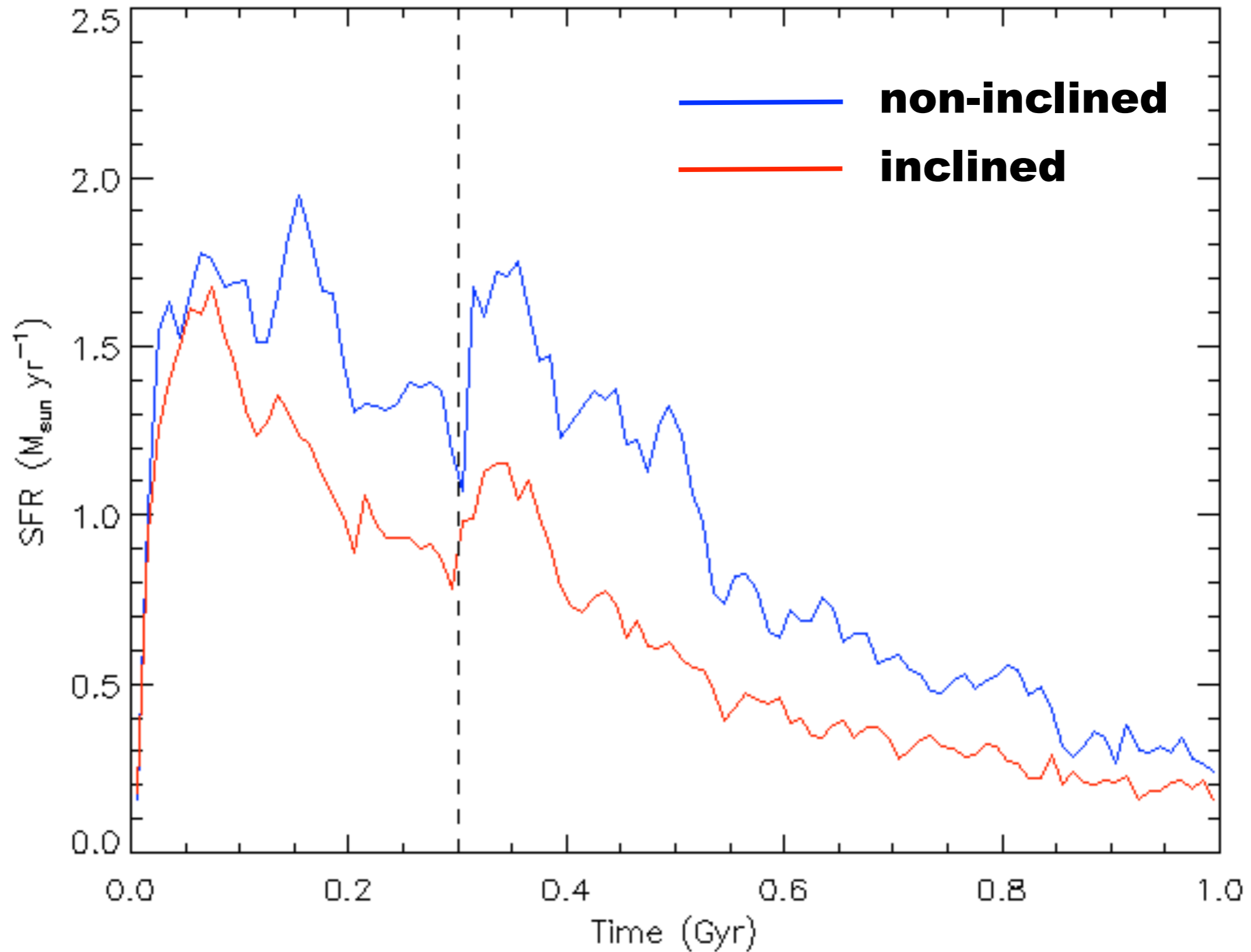
Isolated Galaxies

stars

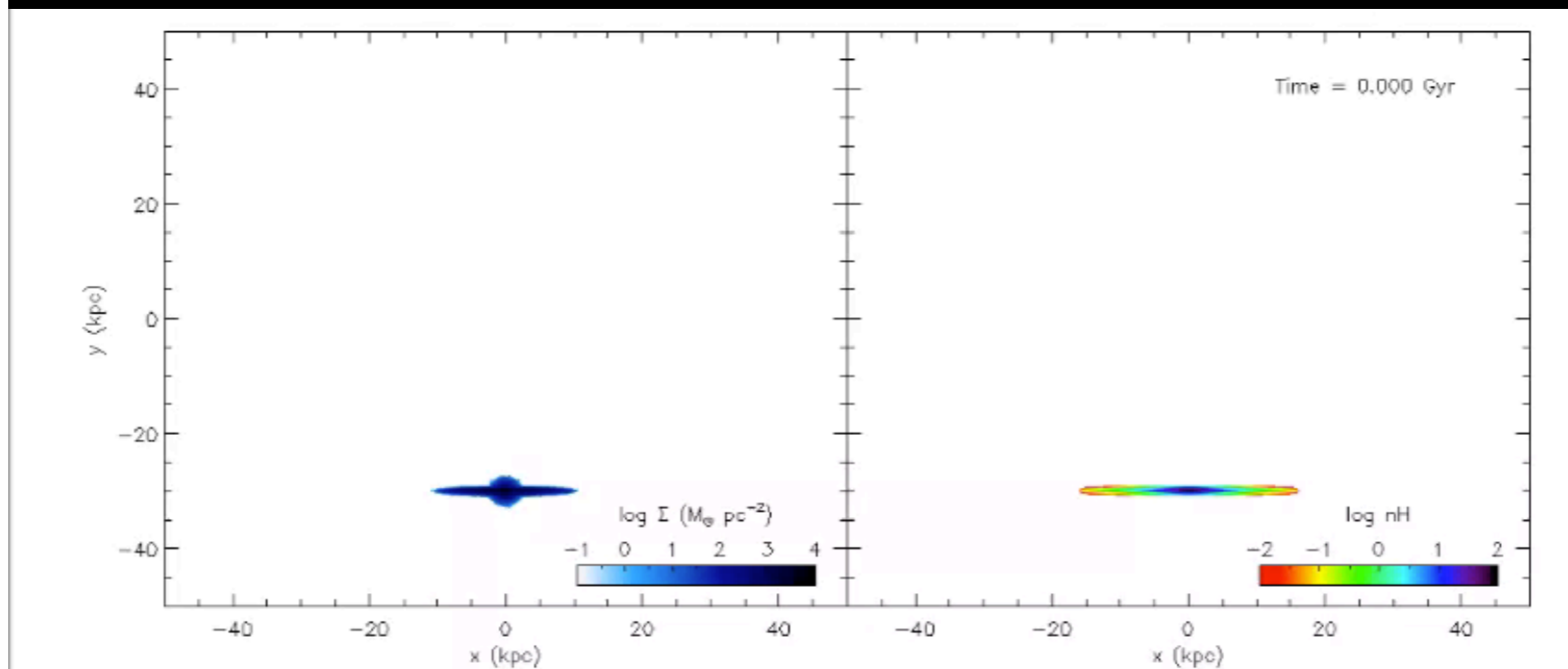
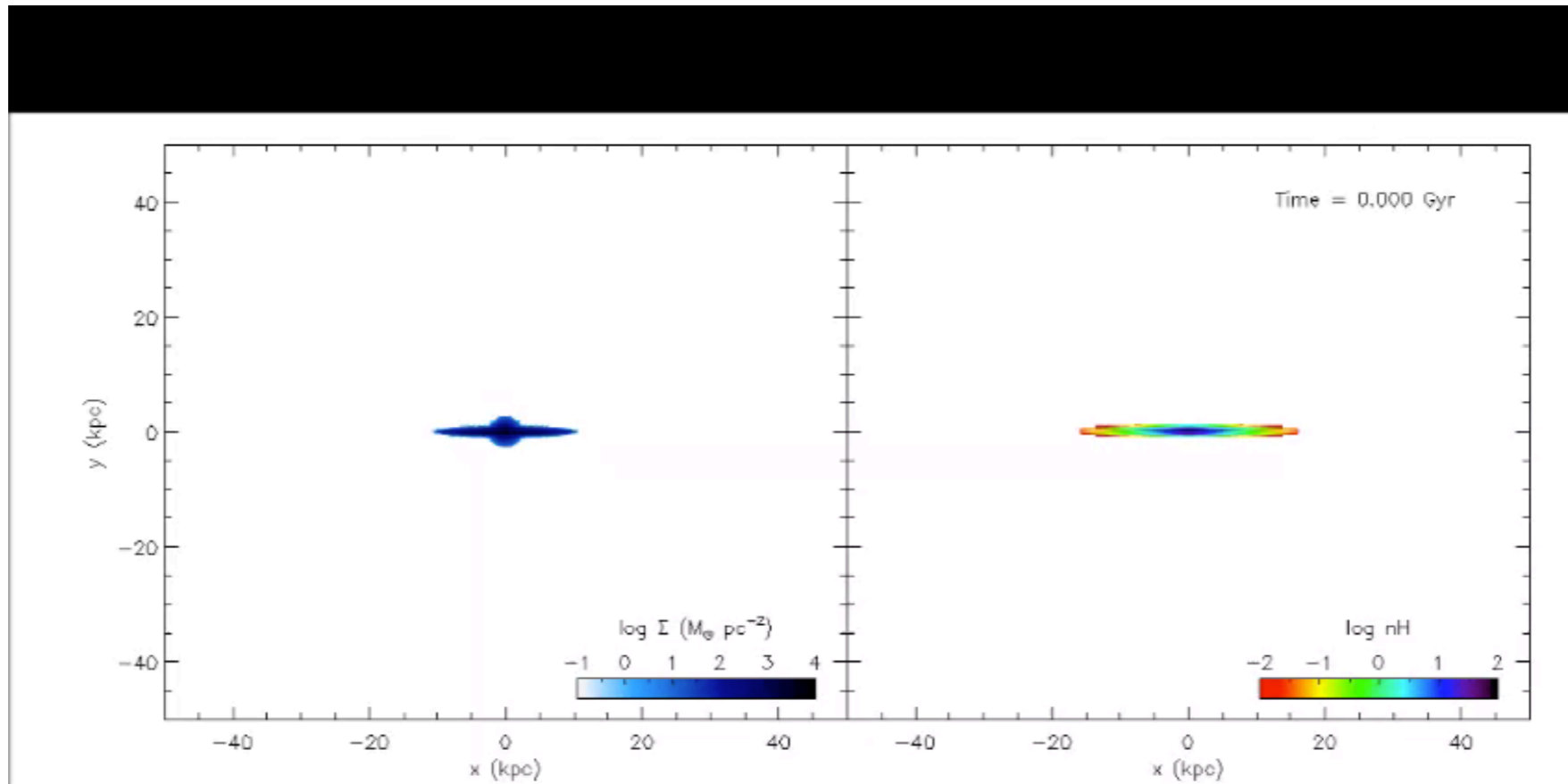
gas



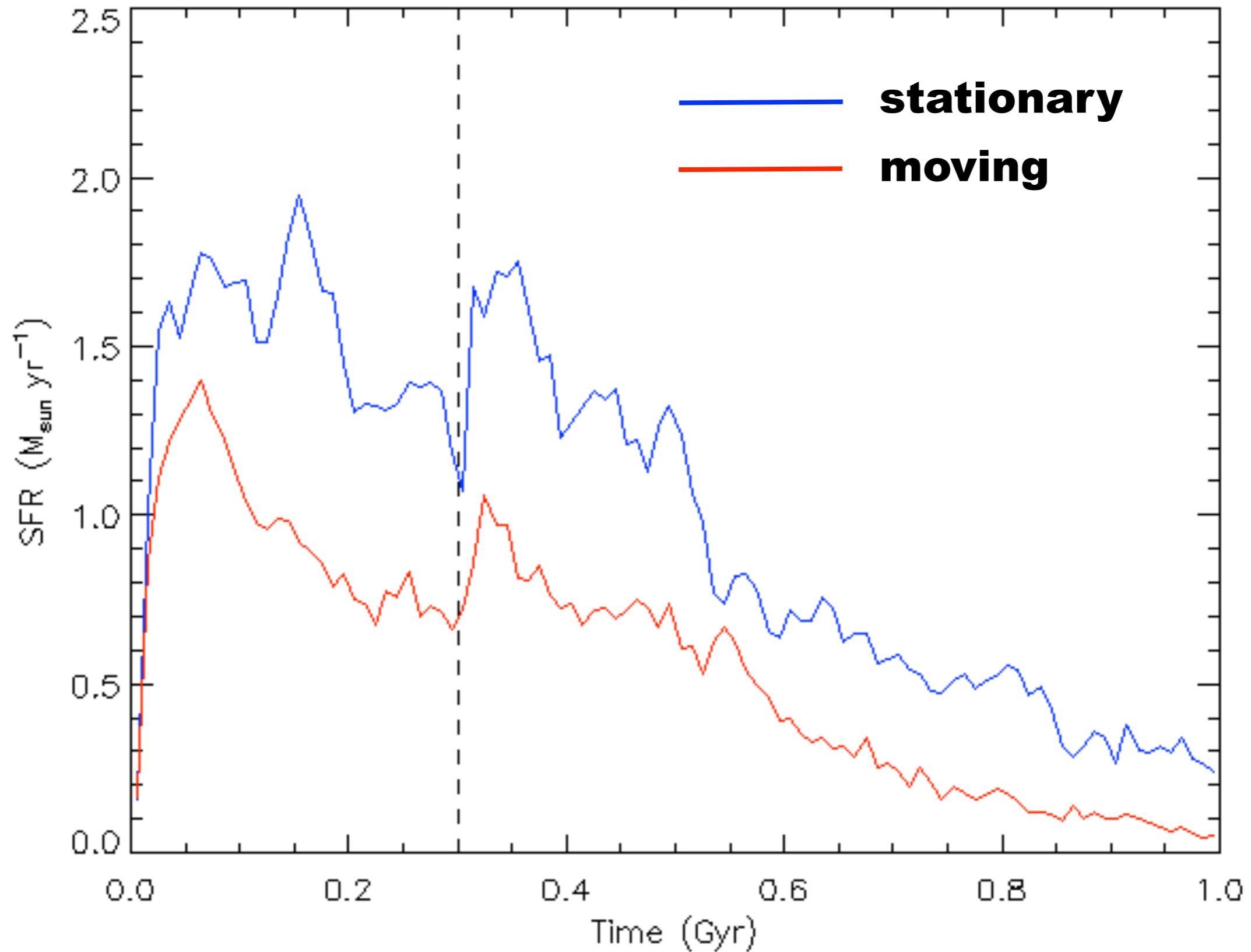
Isolated Galaxies



Isolated Galaxies

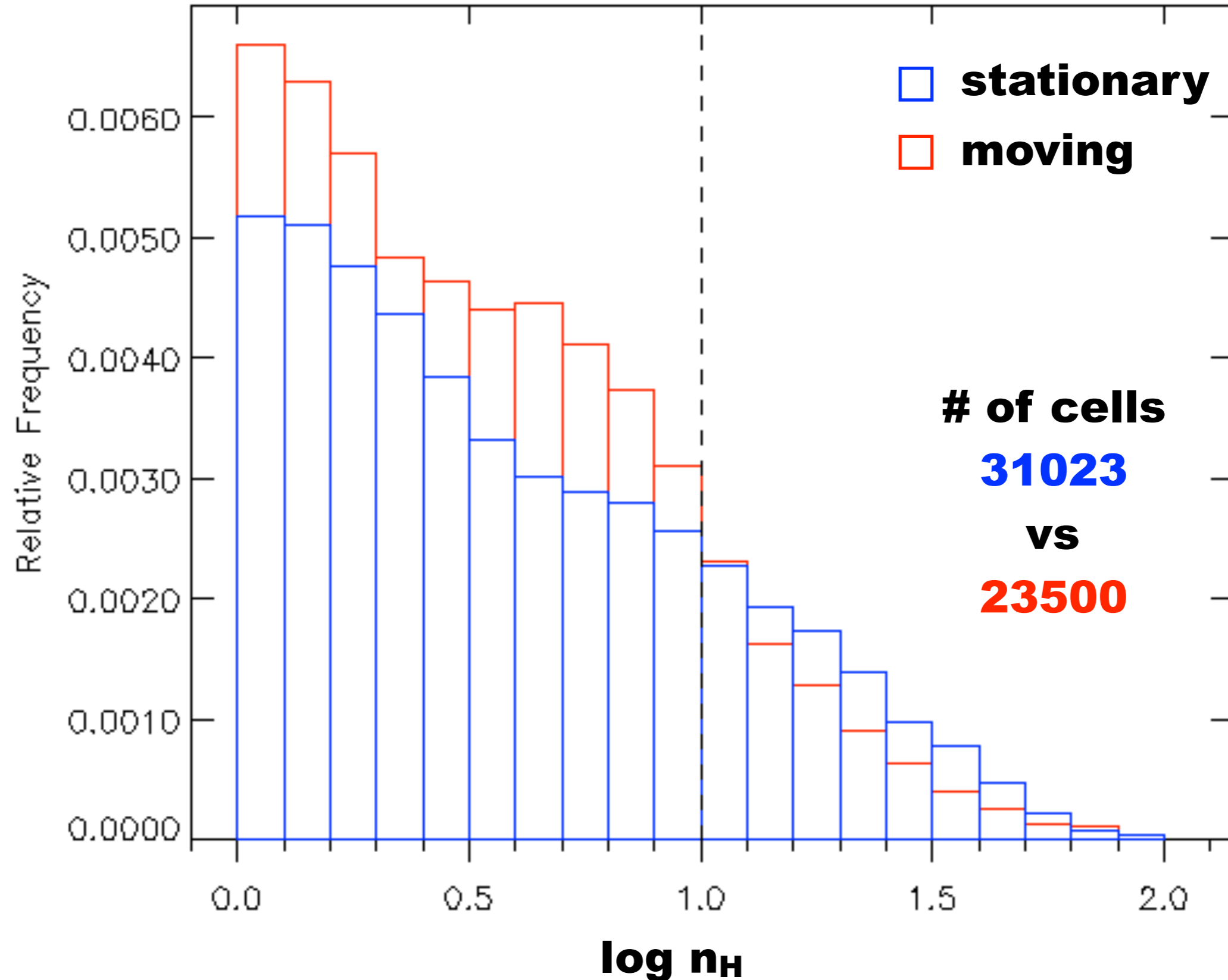


Isolated Galaxies



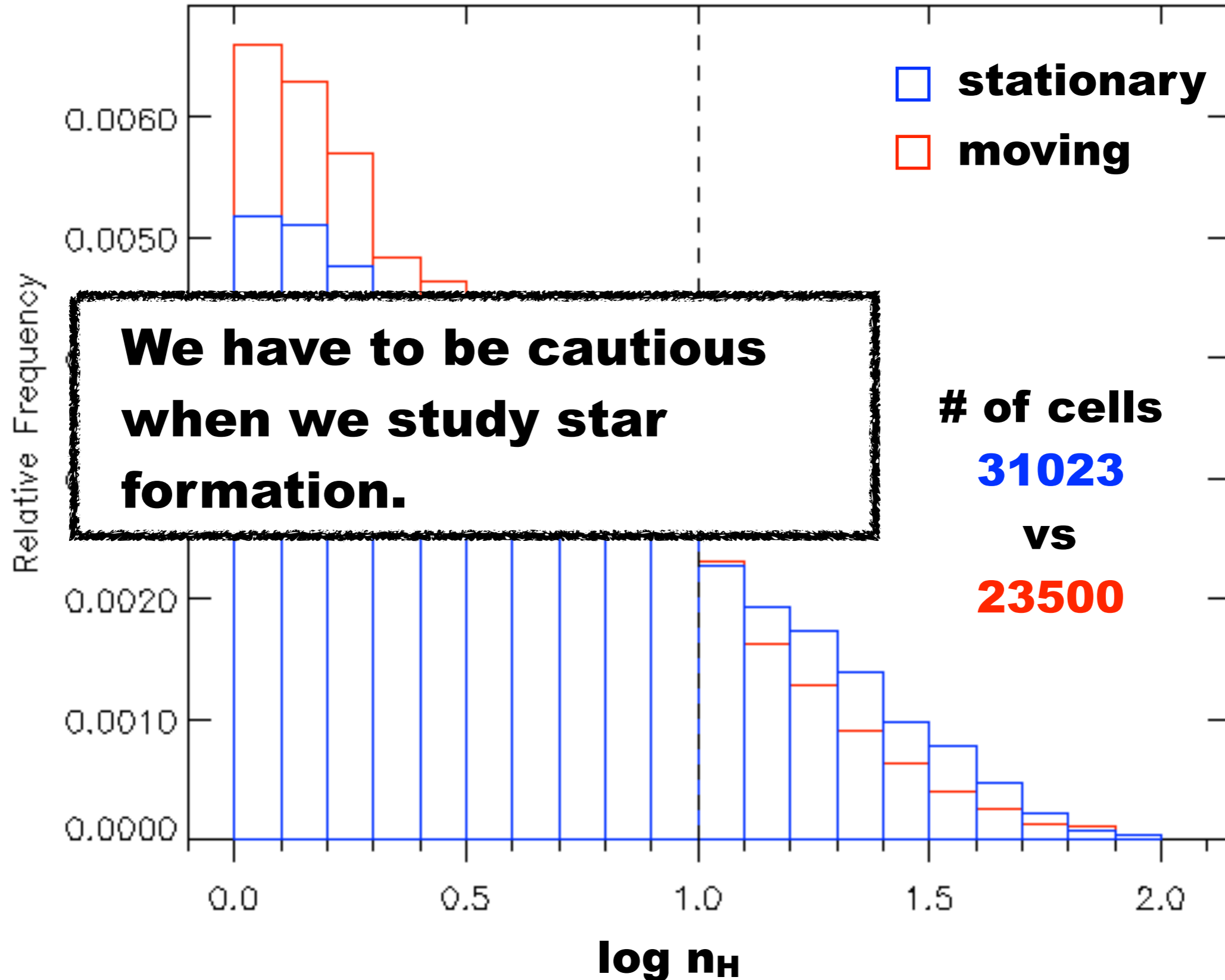
Isolated Galaxies

SF density threshold

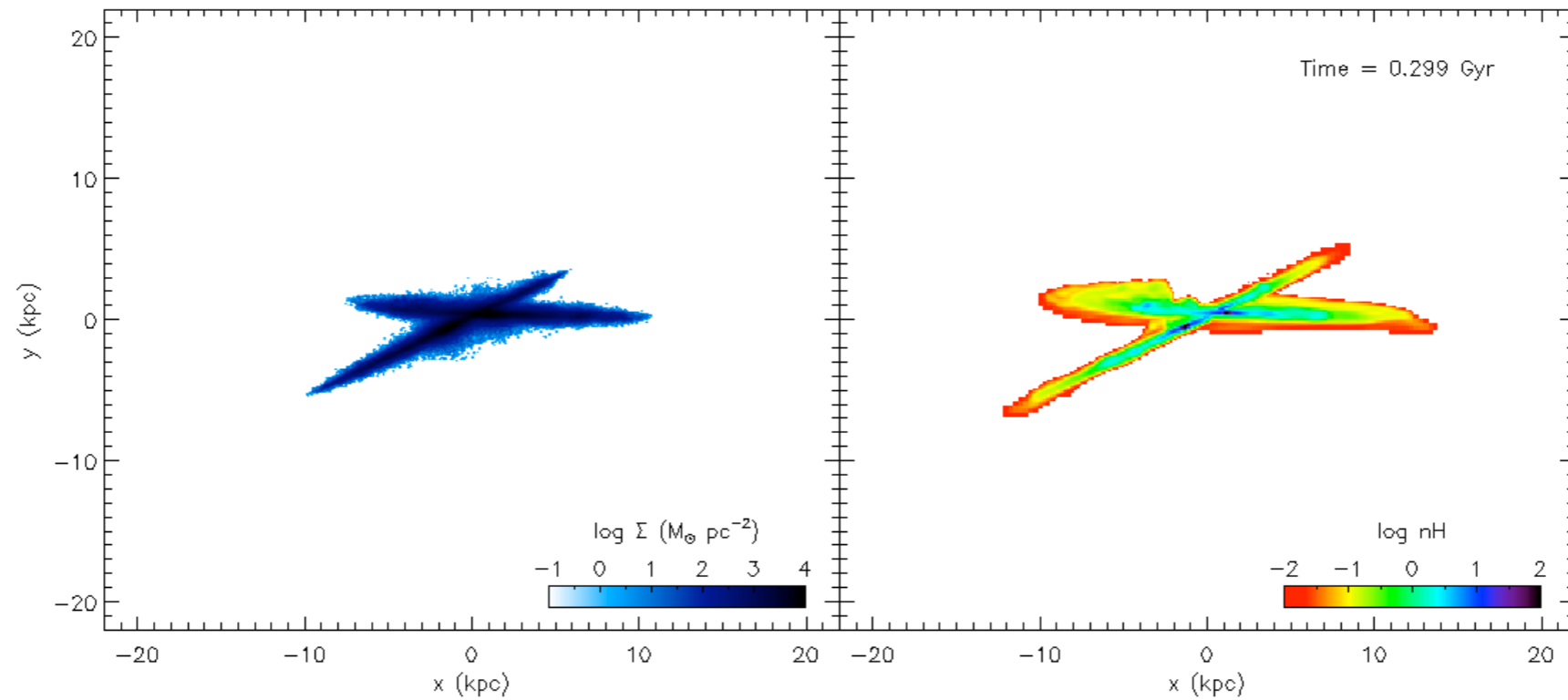
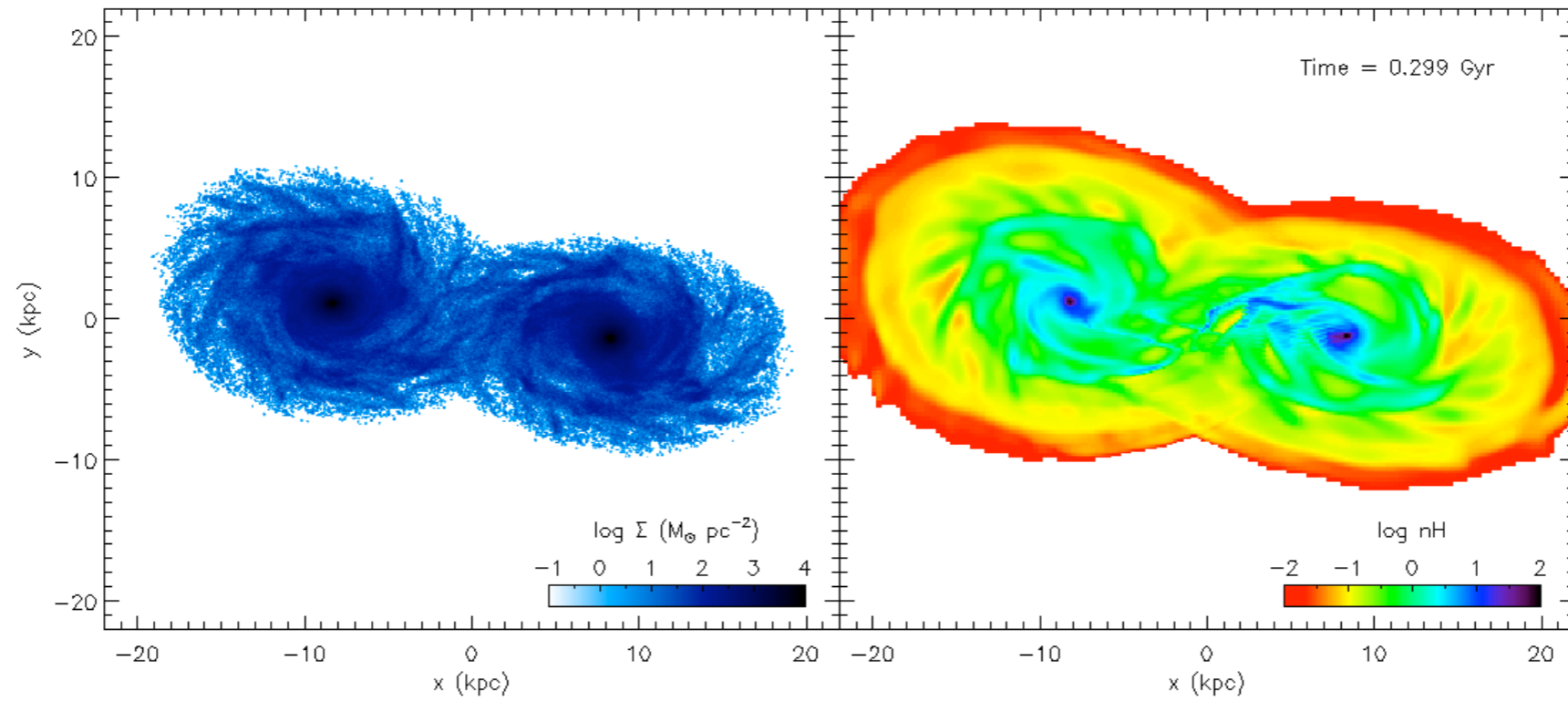


Isolated Galaxies

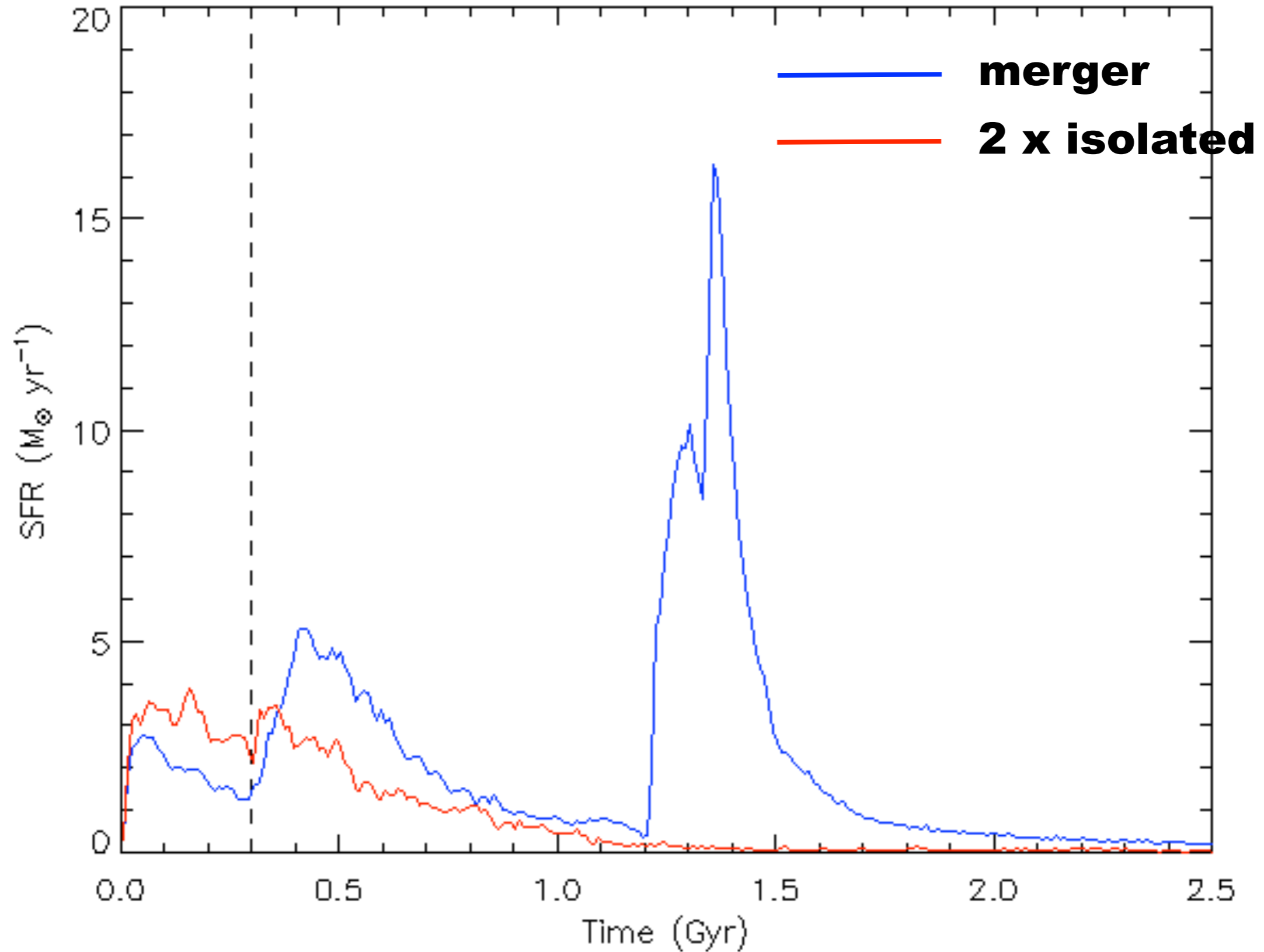
SF density threshold



Merging Galaxies



Merging Galaxies



Merging Galaxies

**merger-driven SF
burst efficiency “e”
Cox et al. 2008**

merger
2 x isolated

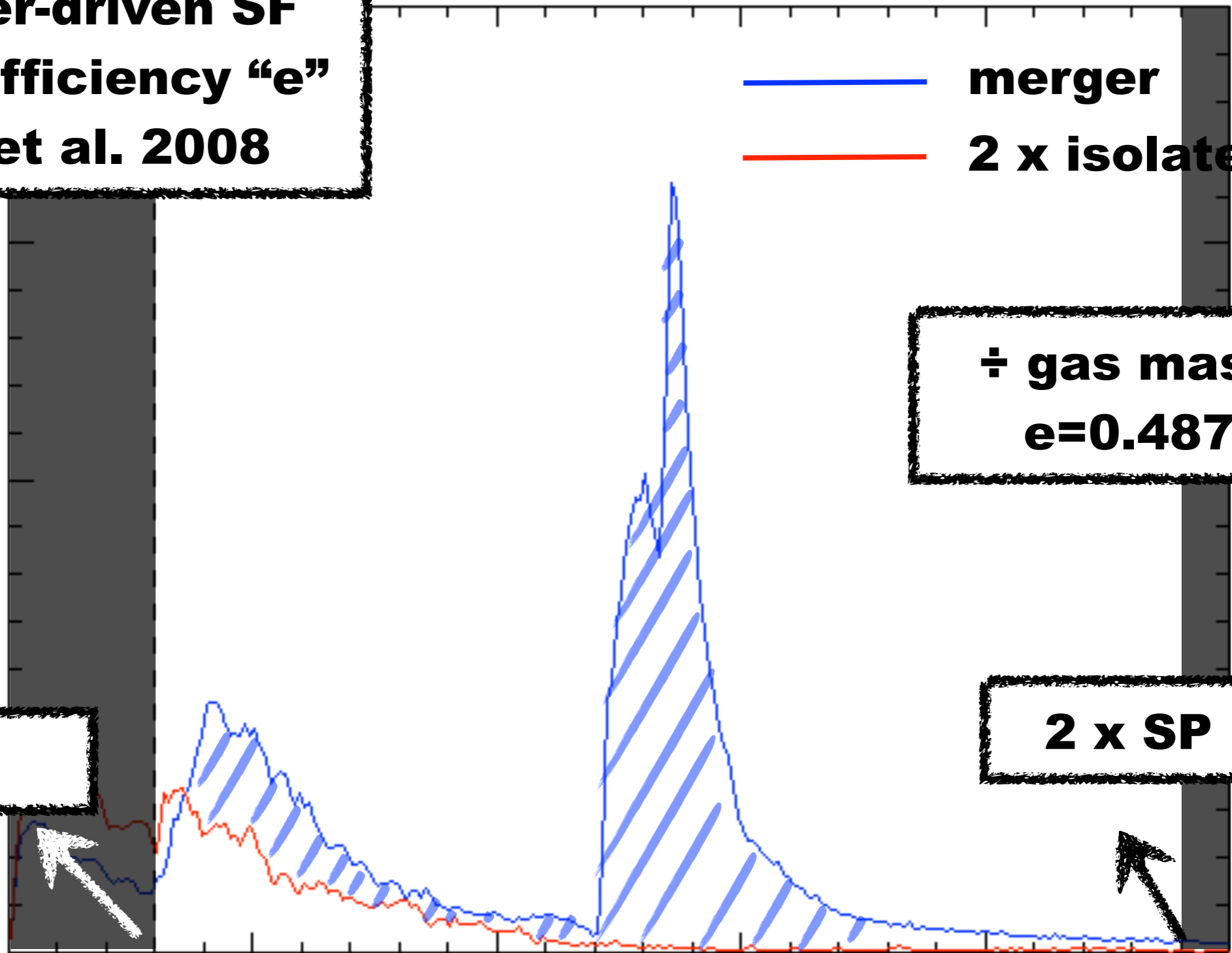
SFR ($M_{\odot} \text{ yr}^{-1}$)

**÷ gas mass
e=0.487**

FP

2 x SP

0.0 0.5 1.0 1.5 2.0 2.5
Time (Gyr)



Merging Galaxies

**merger-driven SF
burst efficiency “e”
Cox et al. 2008**

merger
2 x isolated

SFR ($M_{\odot} \text{ yr}^{-1}$)

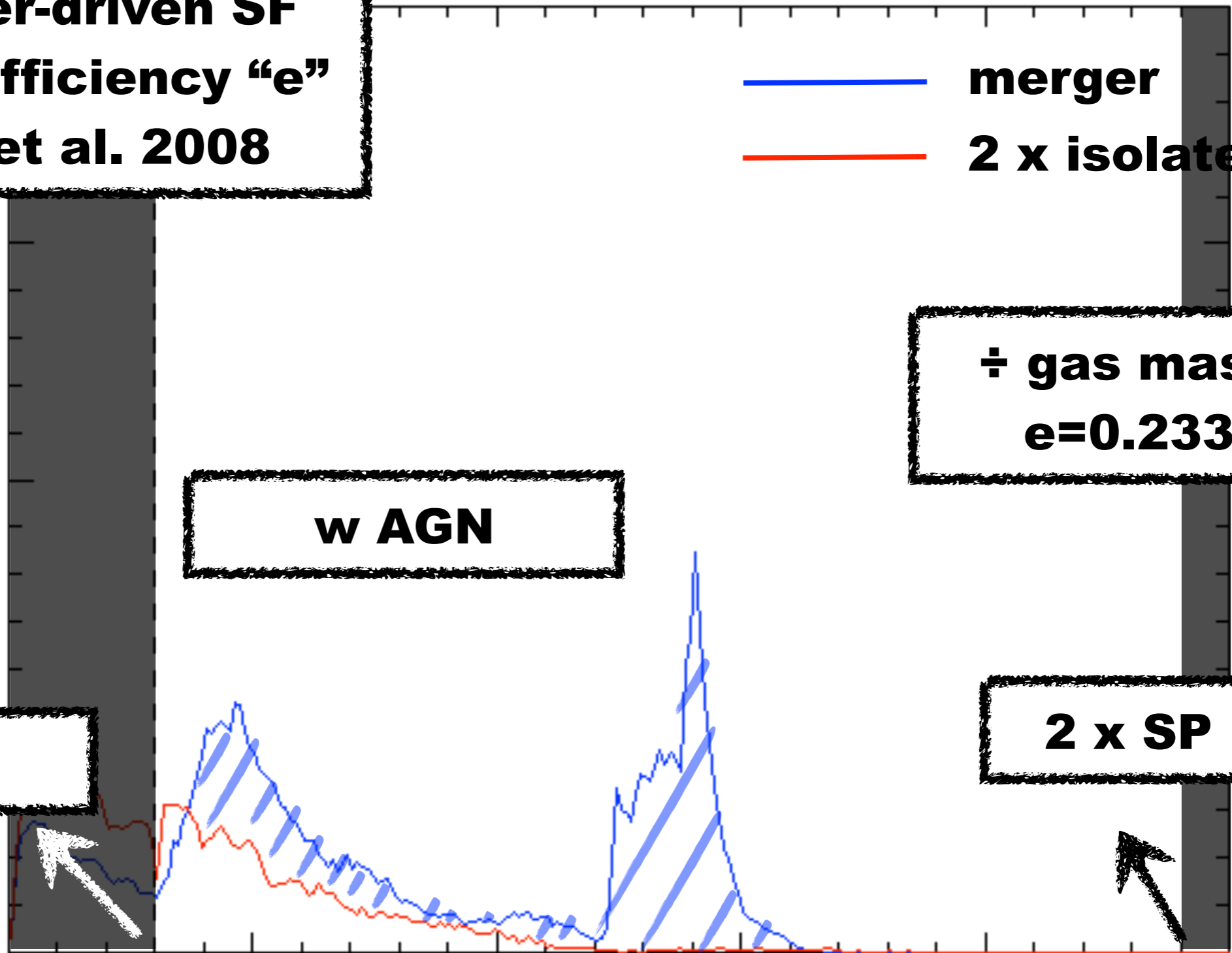
**÷ gas mass
e=0.233**

w AGN

FP

2 x SP

0.0 0.5 1.0 1.5 2.0 2.5
Time (Gyr)



Merging Galaxies

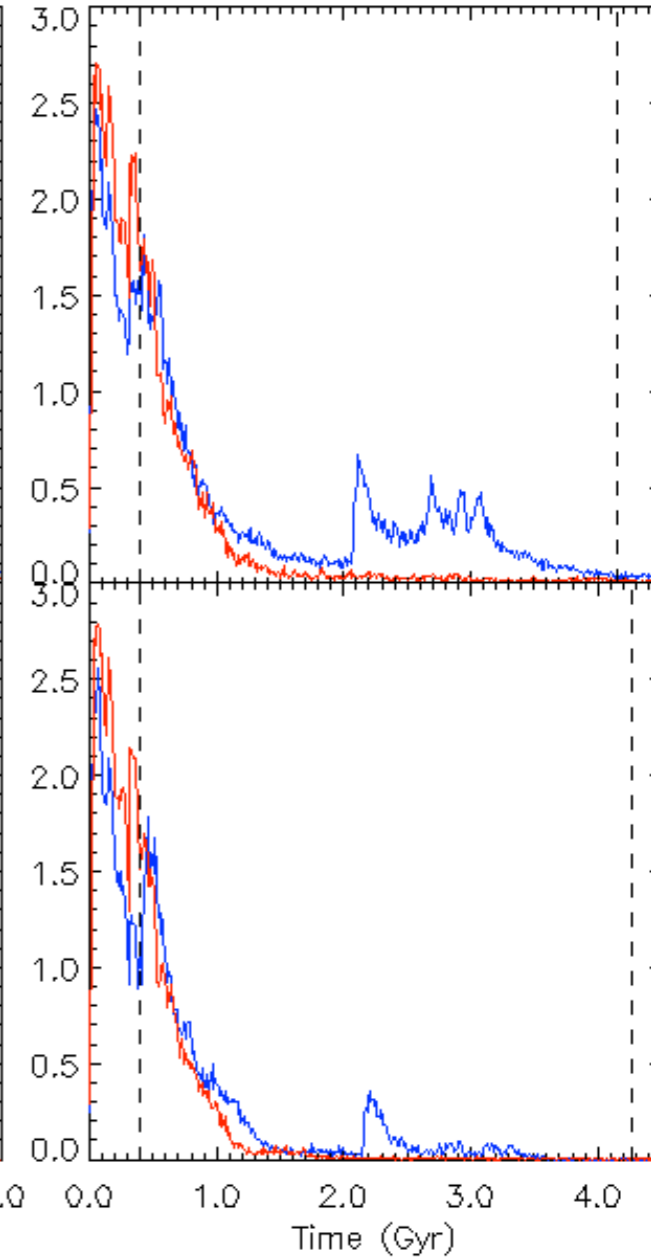
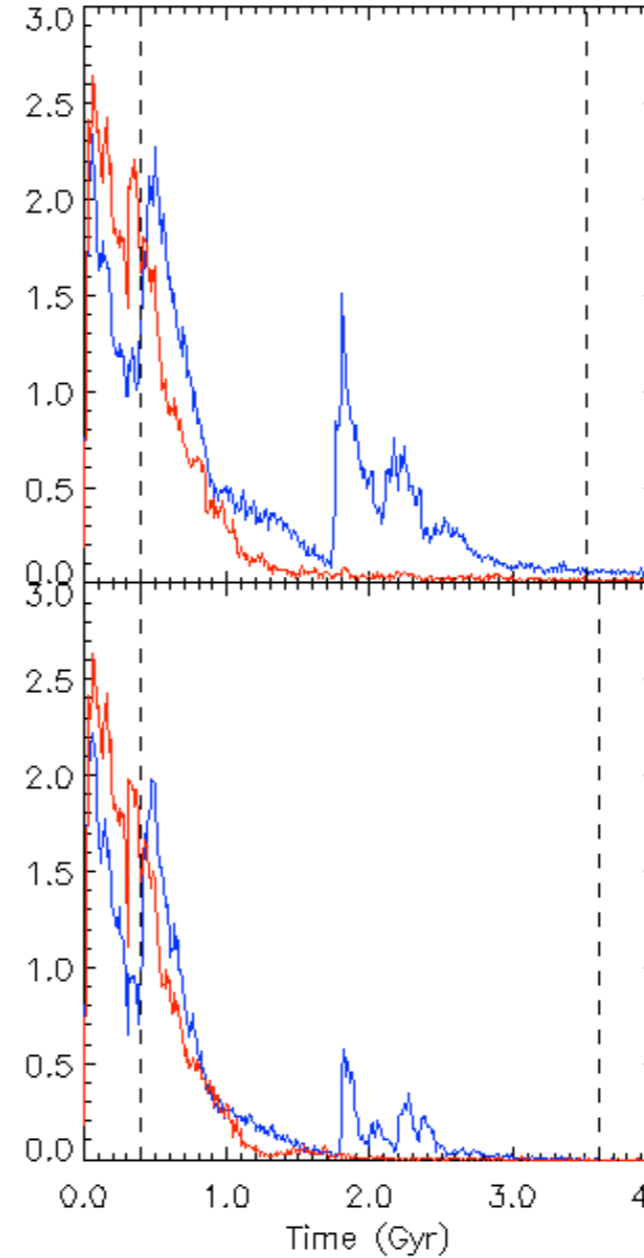
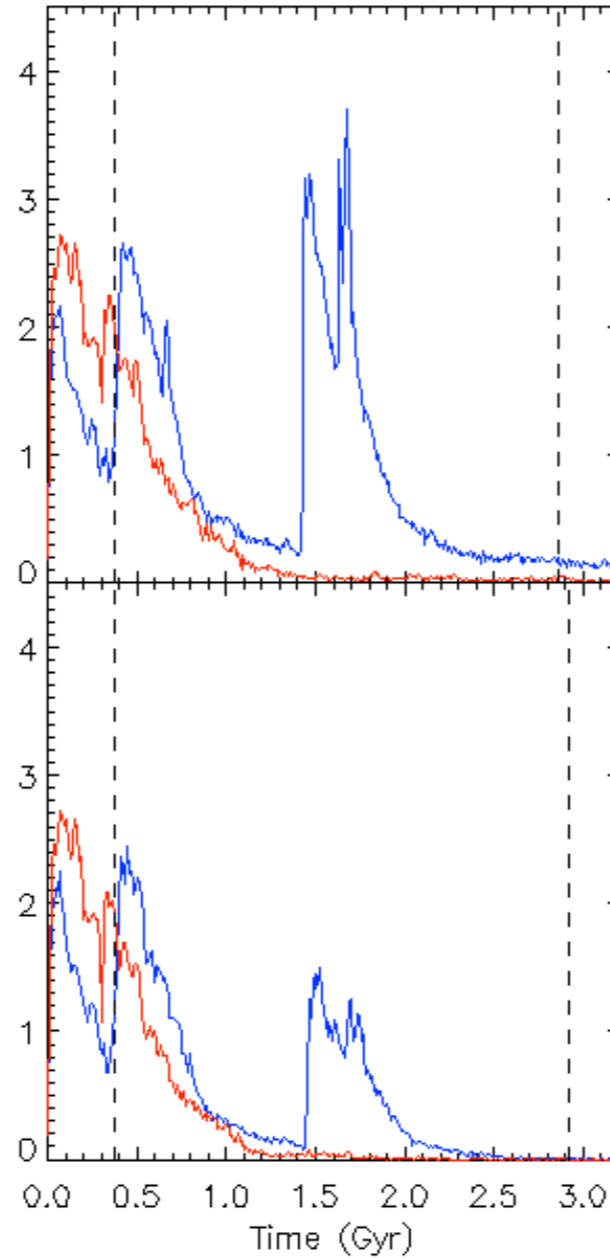
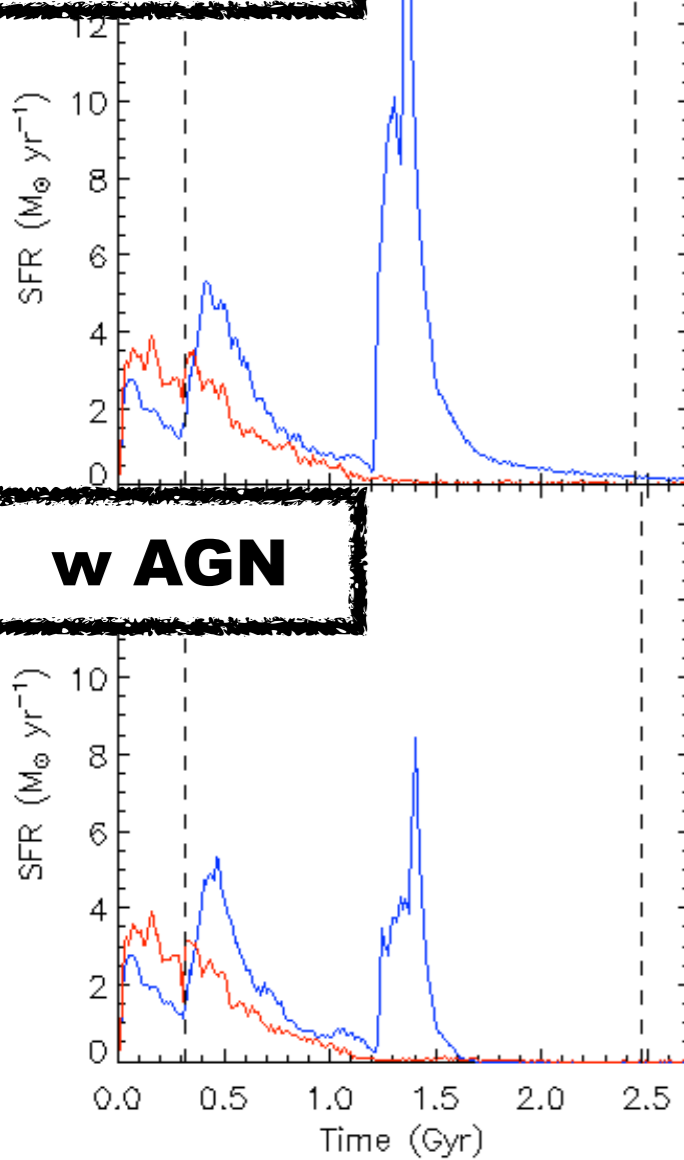
1:1

1:3

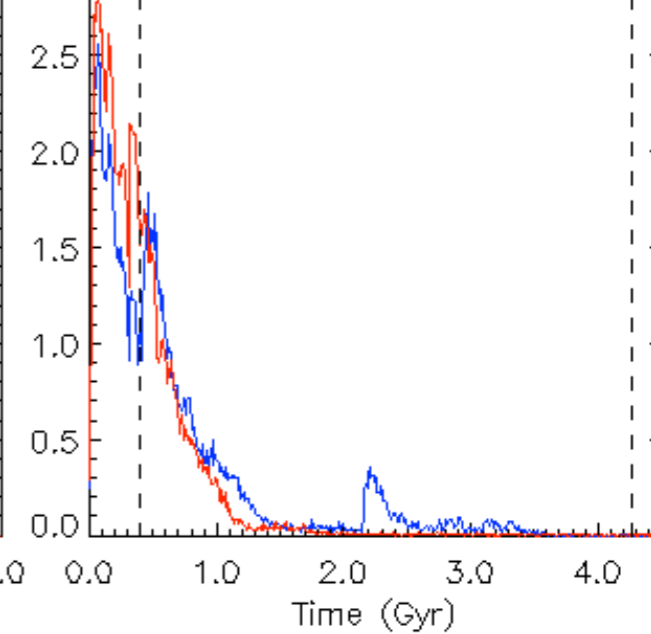
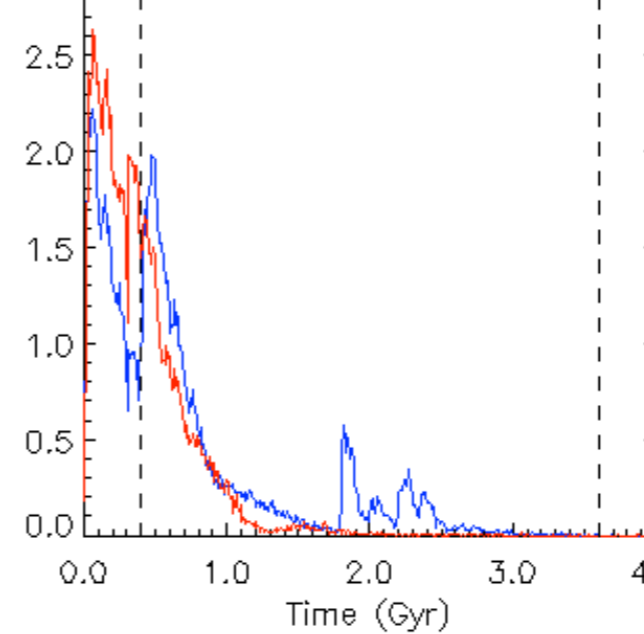
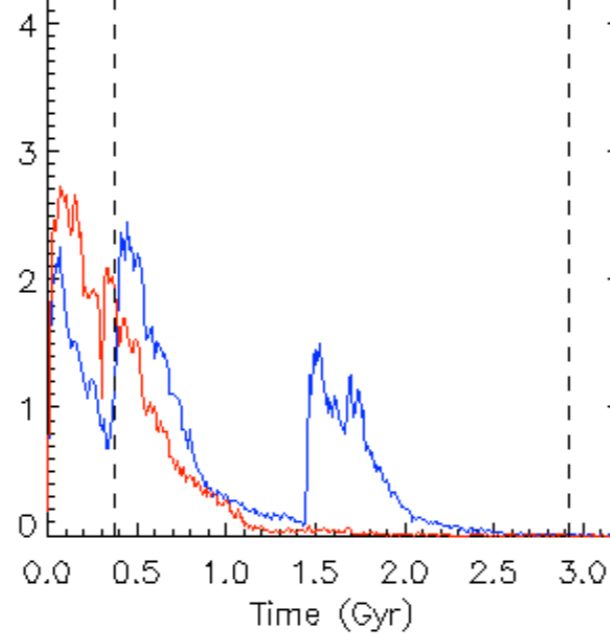
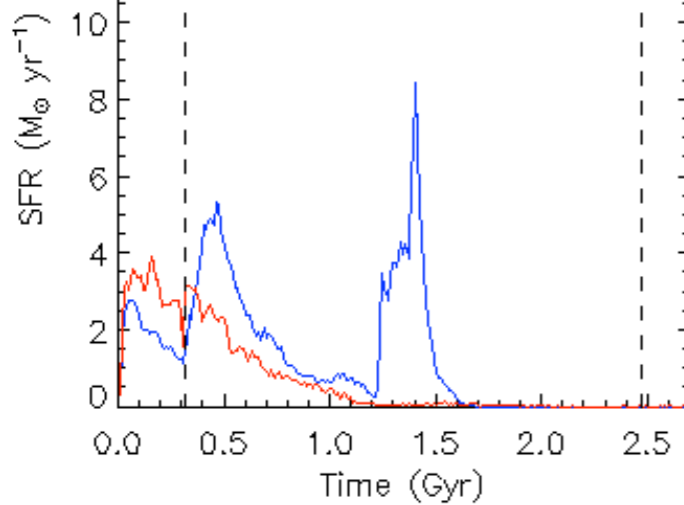
1:6

1:10

w/o AGN



w AGN



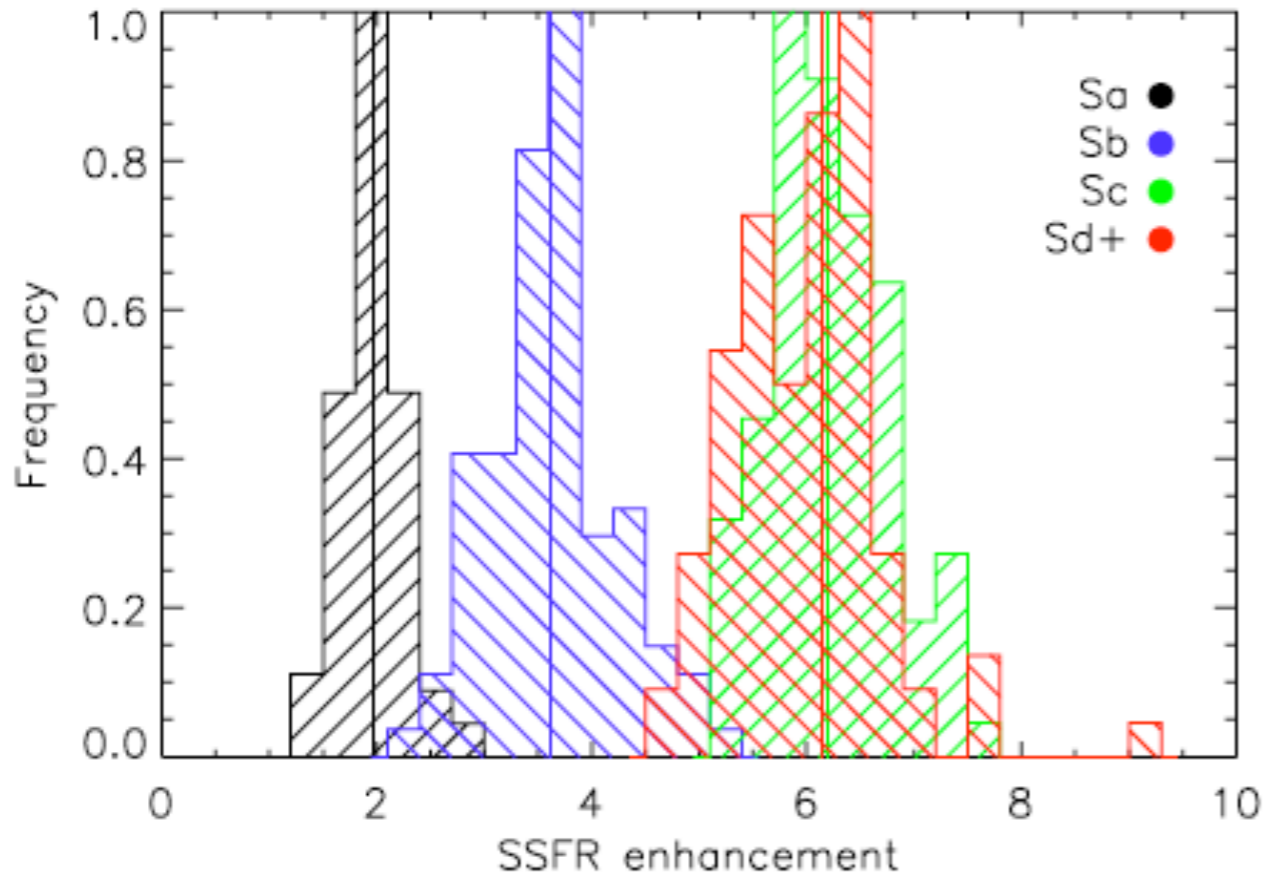
Merging Galaxies

burst efficiency

	1:1	1:3	1:6	1:10
w/o AGN	0.487	0.282	0.172	0.129
w AGN	0.233	0.135	0.059	0.0451
reduced	52%	52%	66%	65%

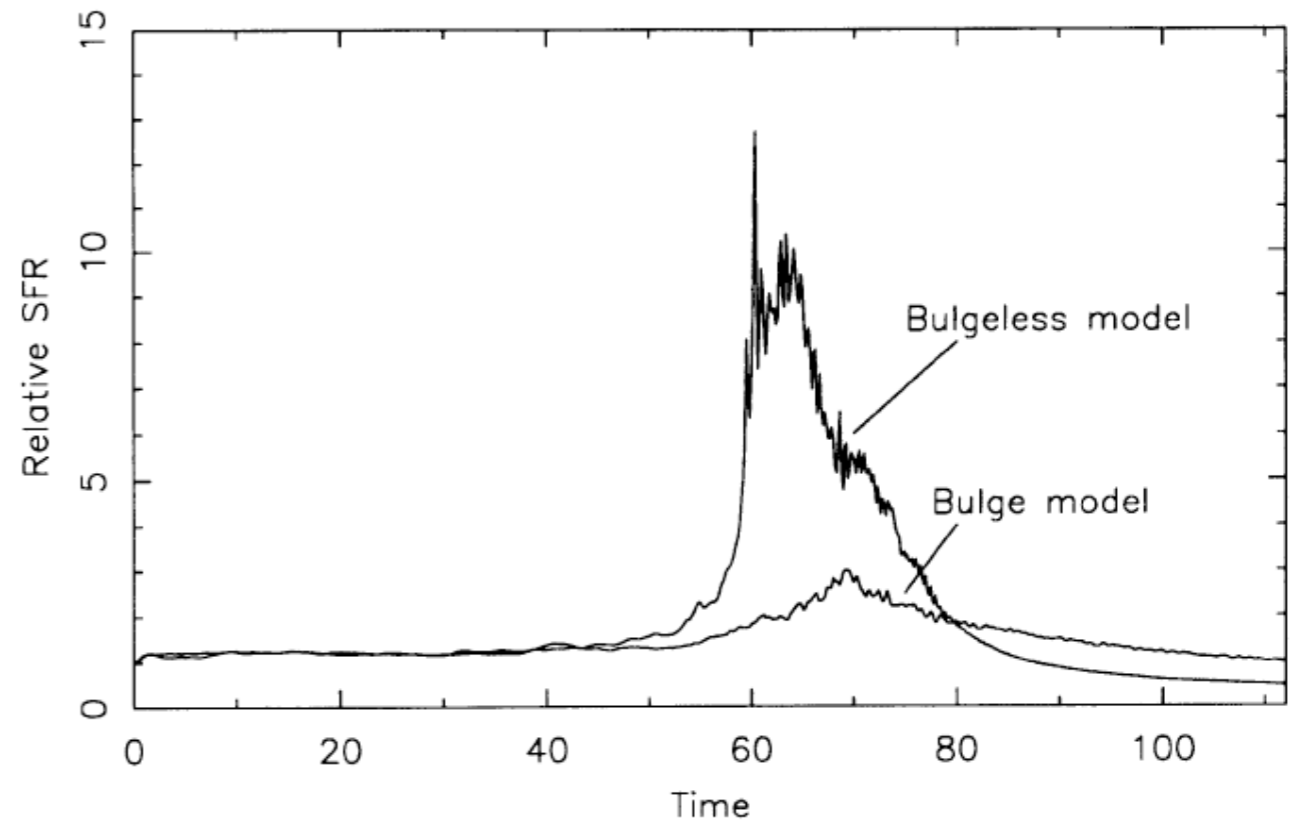
More merger-driven SF is reduced in minor mergers.

Minor Mergers & Morphology



Kaviraj 2014 (SDSS stripe82)
merger-driven SF strong in Sc & Sd
=> small bulge
gas rich

Mihos & Hernquist 1994
Suppression of gas inflow by bulge
makes difference in starburst.
=> What if there is **SMBH?**



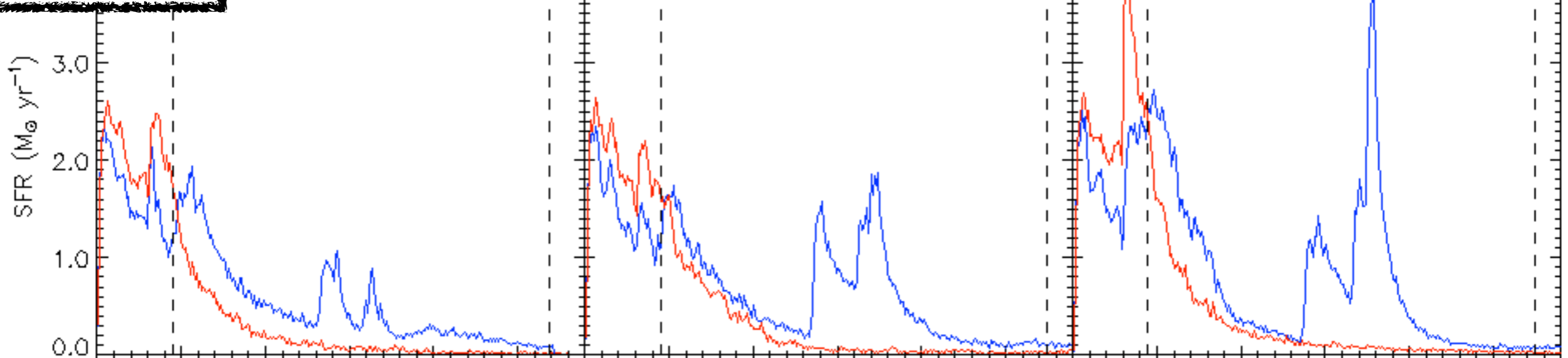
Minor Mergers & Morphology

B/T=0.4

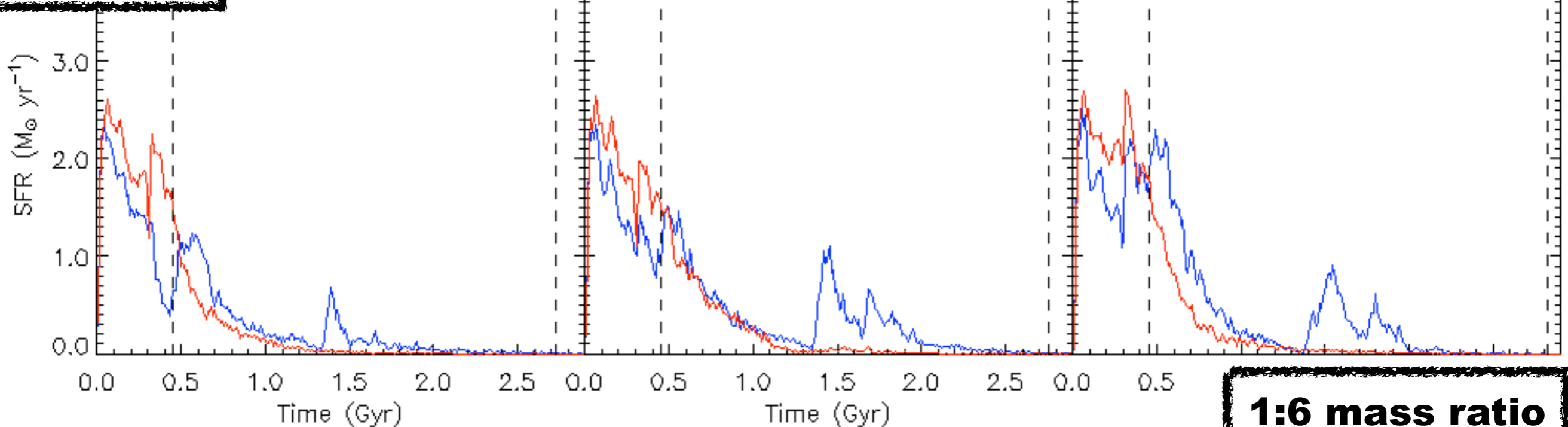
B/T=0.2

B/T=0.0

w/o AGN



w AGN

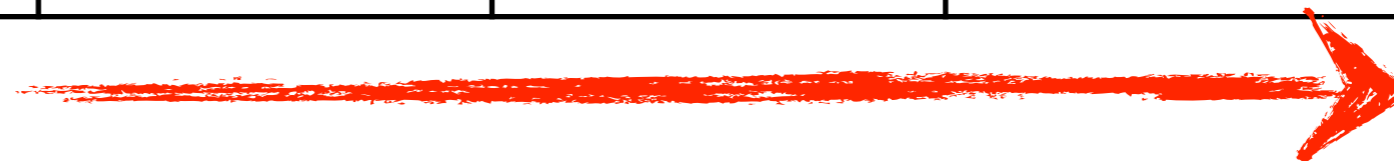


1:6 mass ratio

Minor Mergers & Morphology

burst efficiency

	B/T=0.4	B/T=0.2	B/T=0.0
w/o AGN	0.147	0.173	0.243
w AGN	0.0469	0.071	0.107



overall SF & bulge fraction - same

instantaneous value - less prominent w AGN

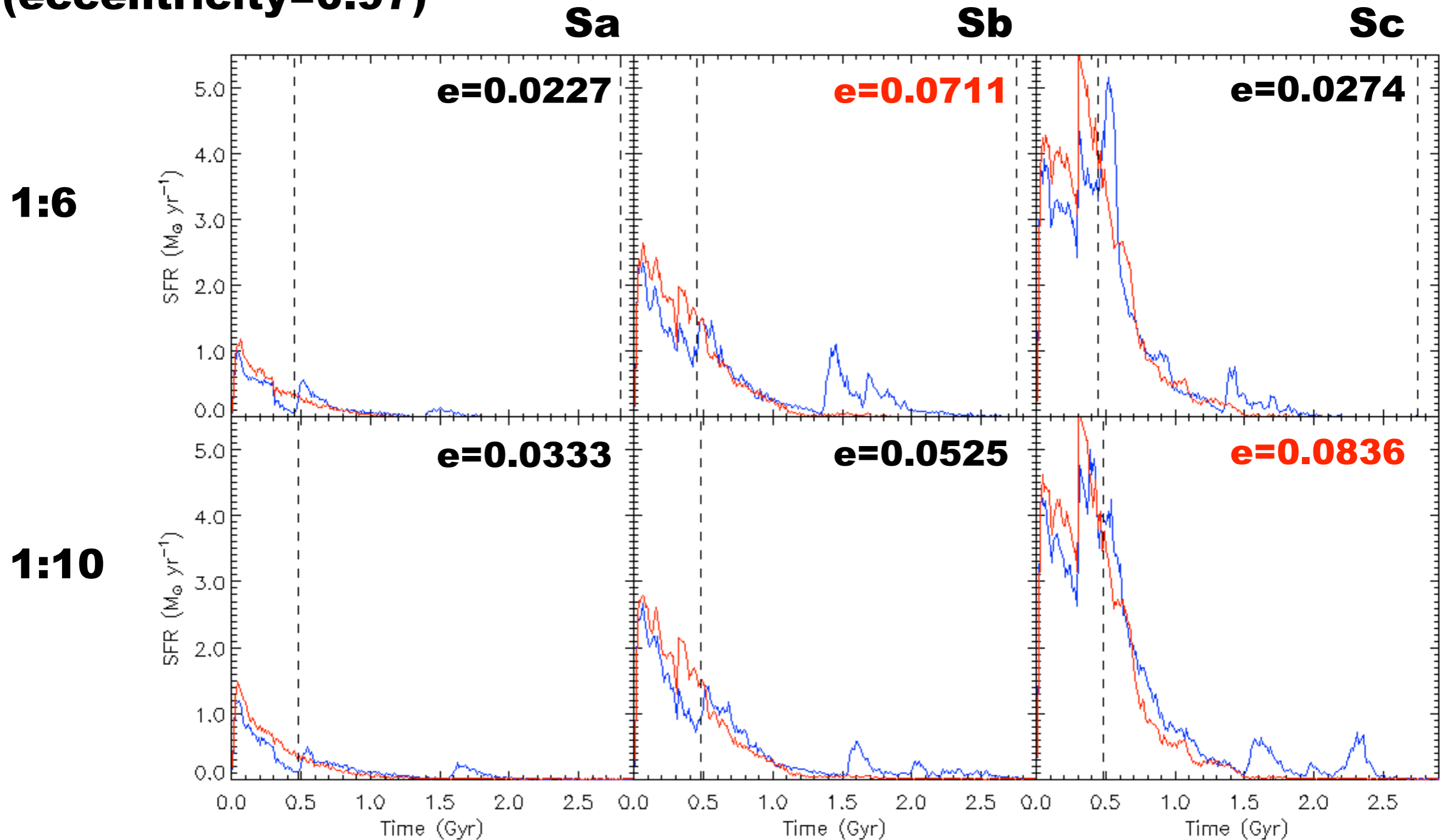
Minor Mergers & Morphology

morphology - B/T, gas fraction, M_{BH}

	Sa	Sb	Sc
Mstellar	$2.00 \times 10^{10} M_{sun}$		
B/T	0.4	0.2	0.1
f_g	0.1	0.2	0.25
M_{BH}	$8.00 \times 10^6 M_{sun}$	$4.00 \times 10^6 M_{sun}$	$2.00 \times 10^6 M_{sun}$

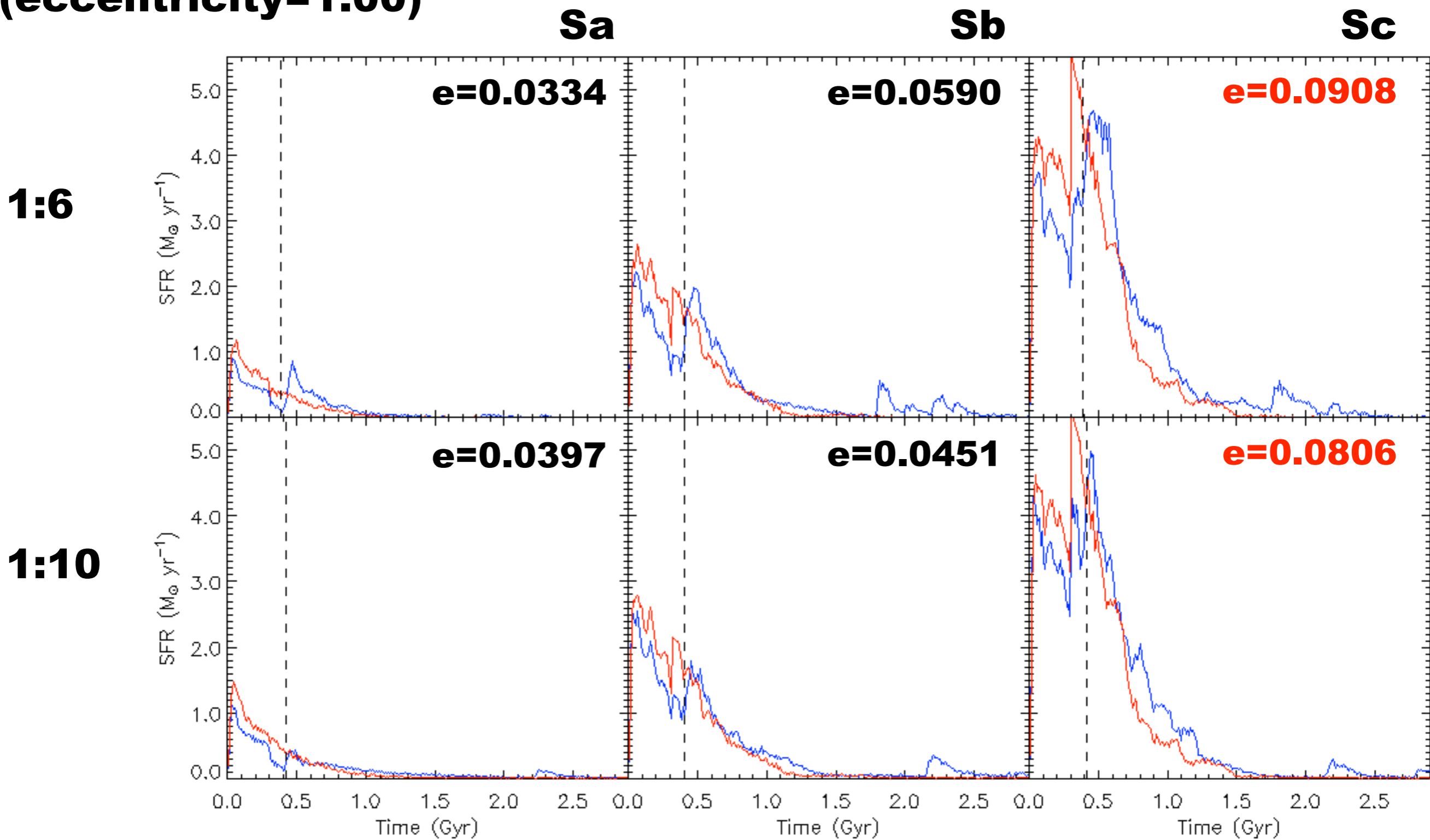
Minor Mergers & Morphology

elliptical orbit
(eccentricity=0.97)



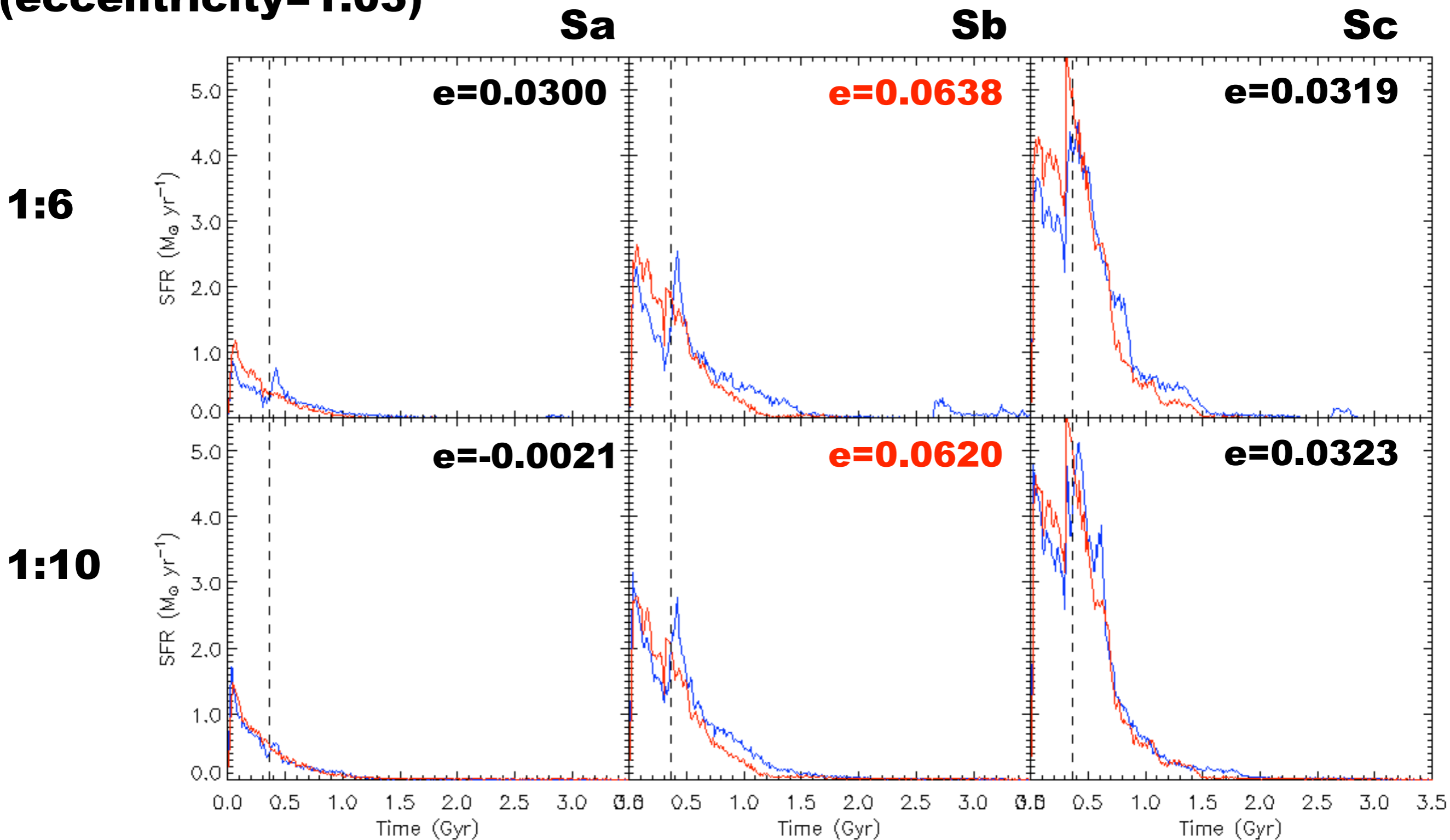
Minor Mergers & Morphology

parabolic orbit
(eccentricity=1.00)



Minor Mergers & Morphology

hyperbolic orbit
(eccentricity=1.03)



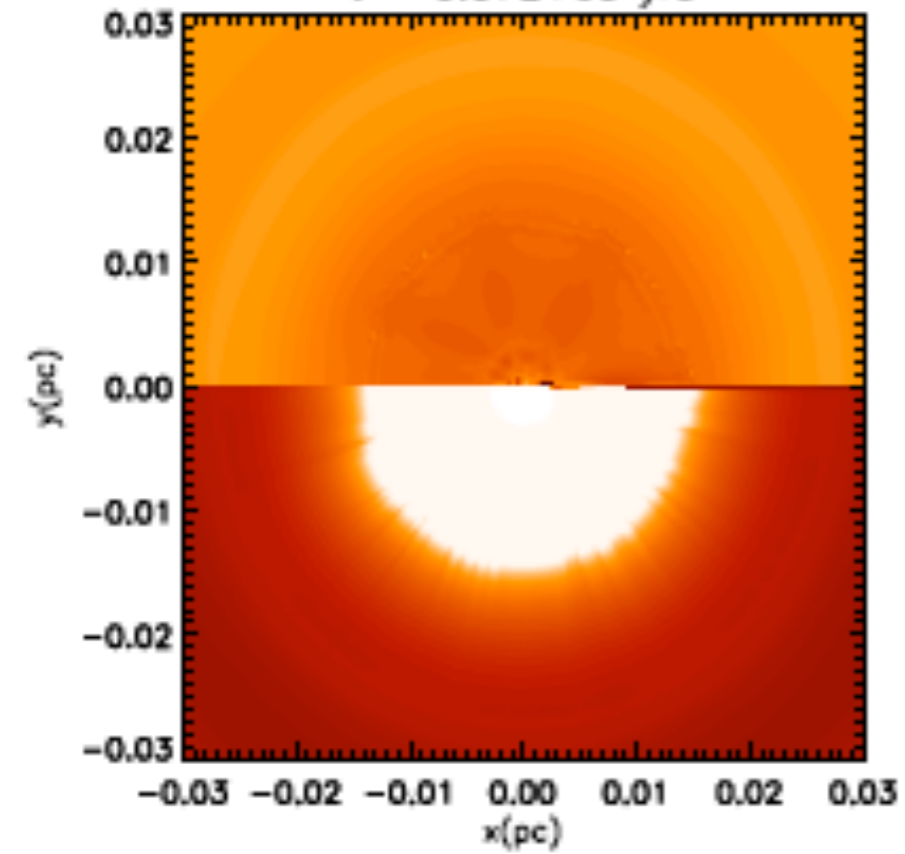
Discussion

- **With merger simulations with AGN, observational results (i.e. Kaviraj 2014) are not reproduced well.**
- **AGN prescription needs further revisions.**
 - **different results with different AGN model (Newton & Kay 2013)**
- **Usually, AGN has been dealt with in cosmological context.**
(Sijacki+ 2007, Booth & Schaye 2009, Teyssier+ 2011 Dubois+ 2012)
- **Some studied feedback from BH in smaller scales.**
(Park & Ricotti+ 2016)

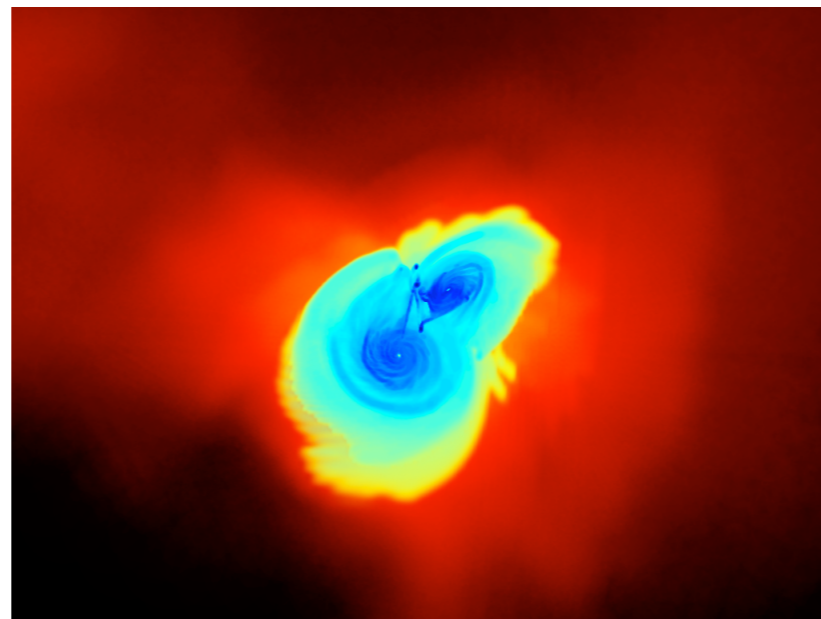
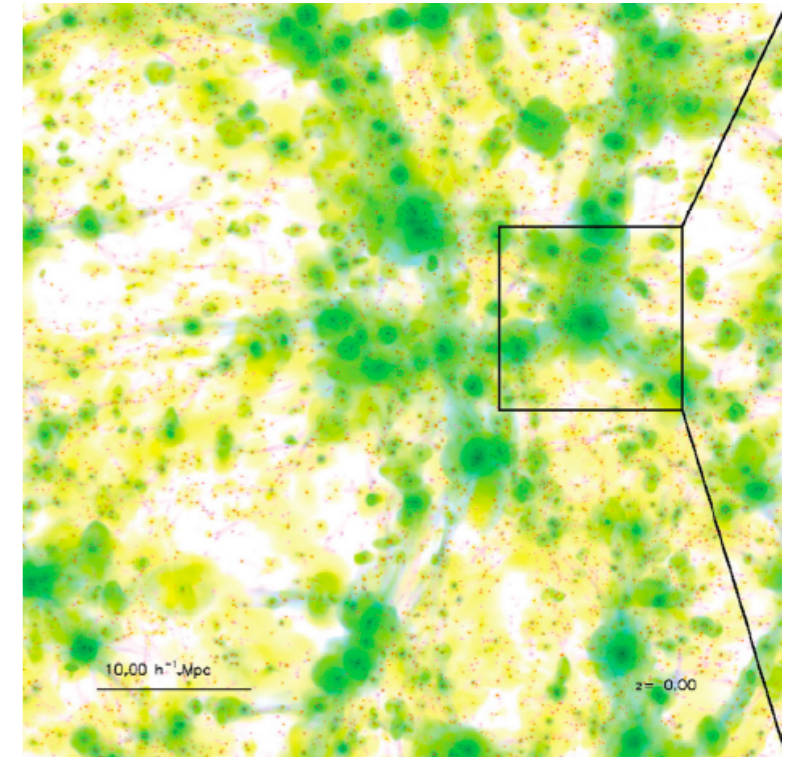
Discussion

Park & Ricotti 2012

$t = 3.57E+03$ yrs



Dubois+ 2012



**- resolution
(Renaud+ 2013
0.05pc)**

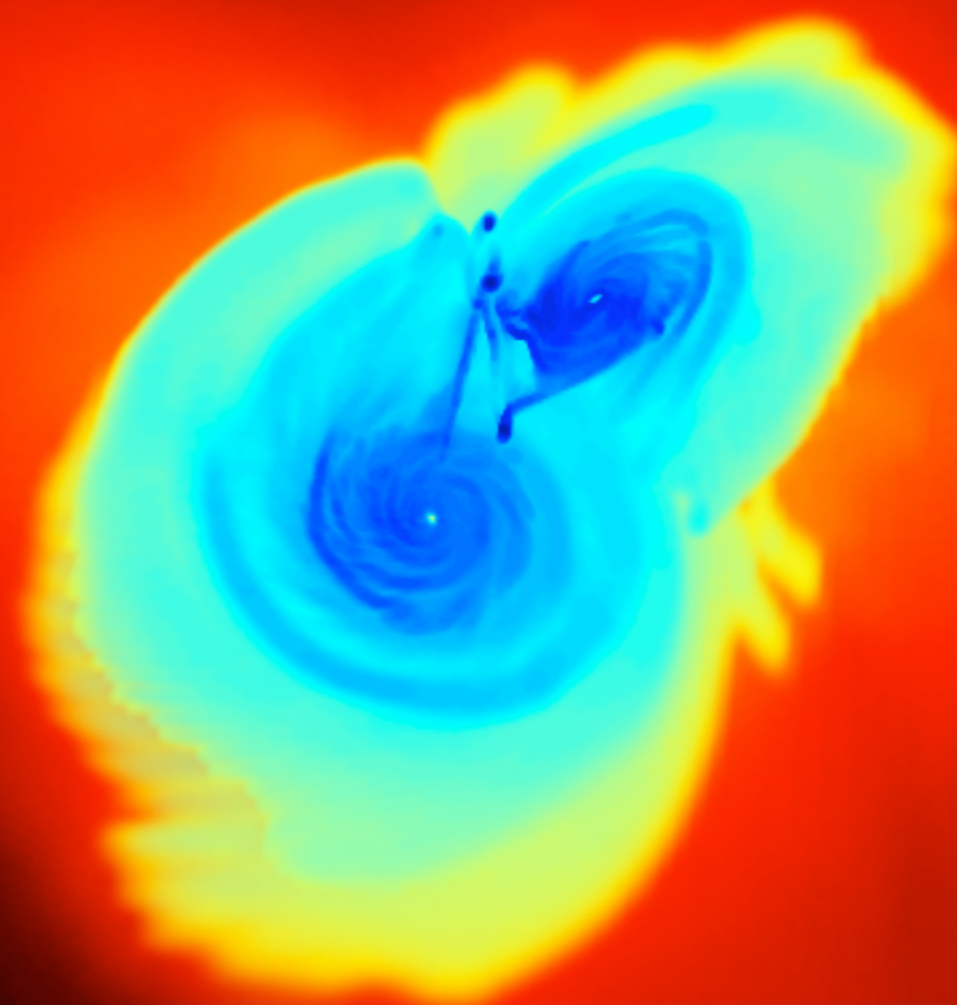
**- reproducible
observables**

**this work
(Hopefully) Park, Smith & Yi**

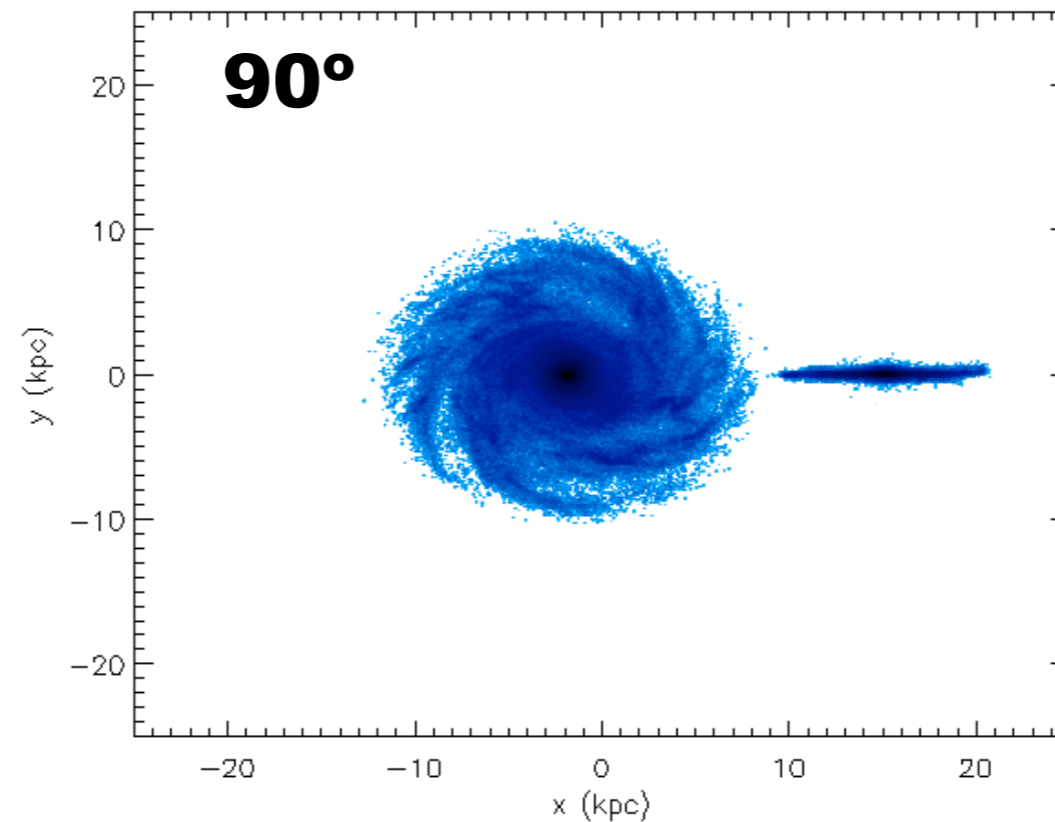
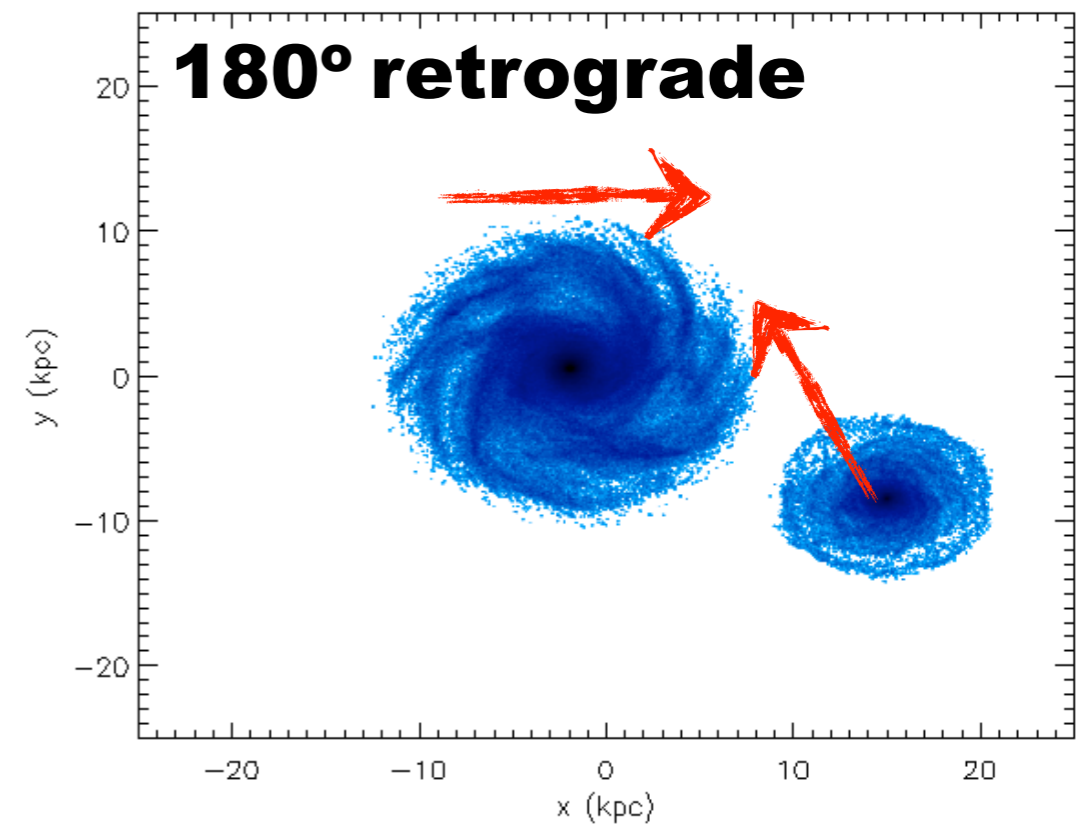
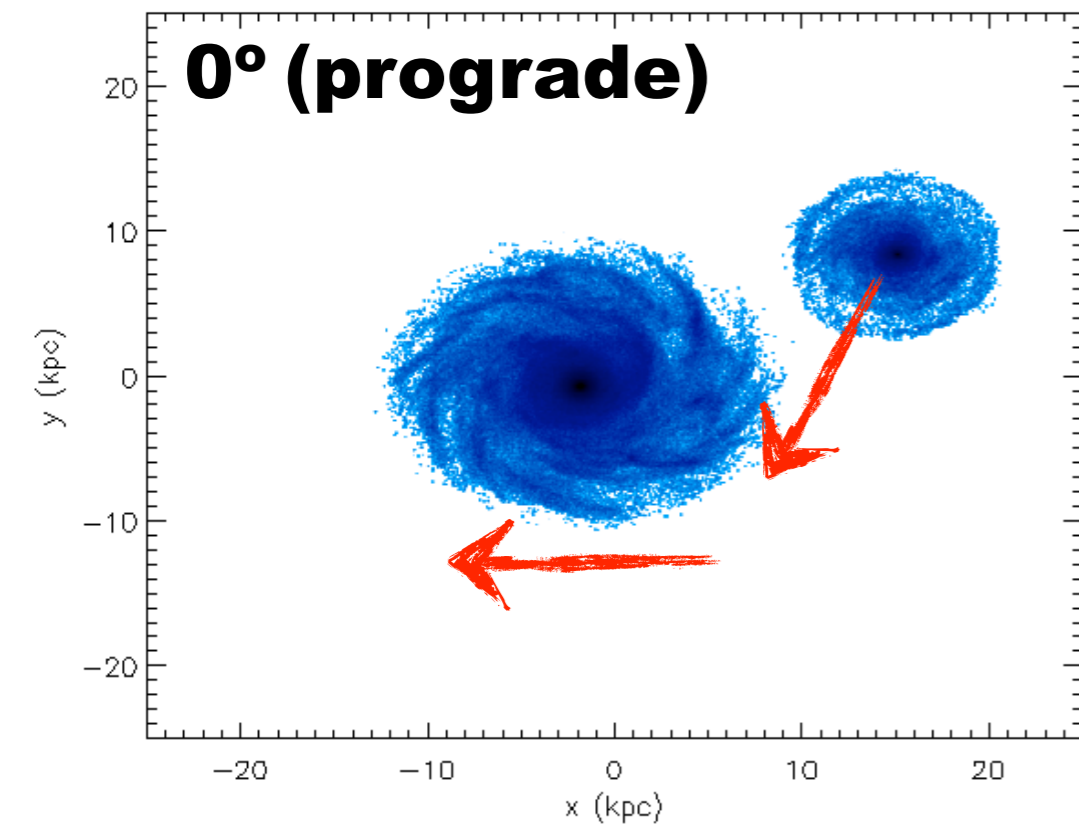
Summary

- **We studied merger-driven SF with AGN FB.**
- **With current AGN FB prescription, merger-driven SF is effectively suppressed in both major and minor mergers.**
- **Relations between merger-driven SF and various parameters are investigated and some differences (such as SF and bulge fraction) have been found.**
- **Numerical artifacts affects the study of merger-driven SF.**
- **Merger simulations with AGN FB do not reproduce observational results well, so further investigations about AGN FB are needed.**

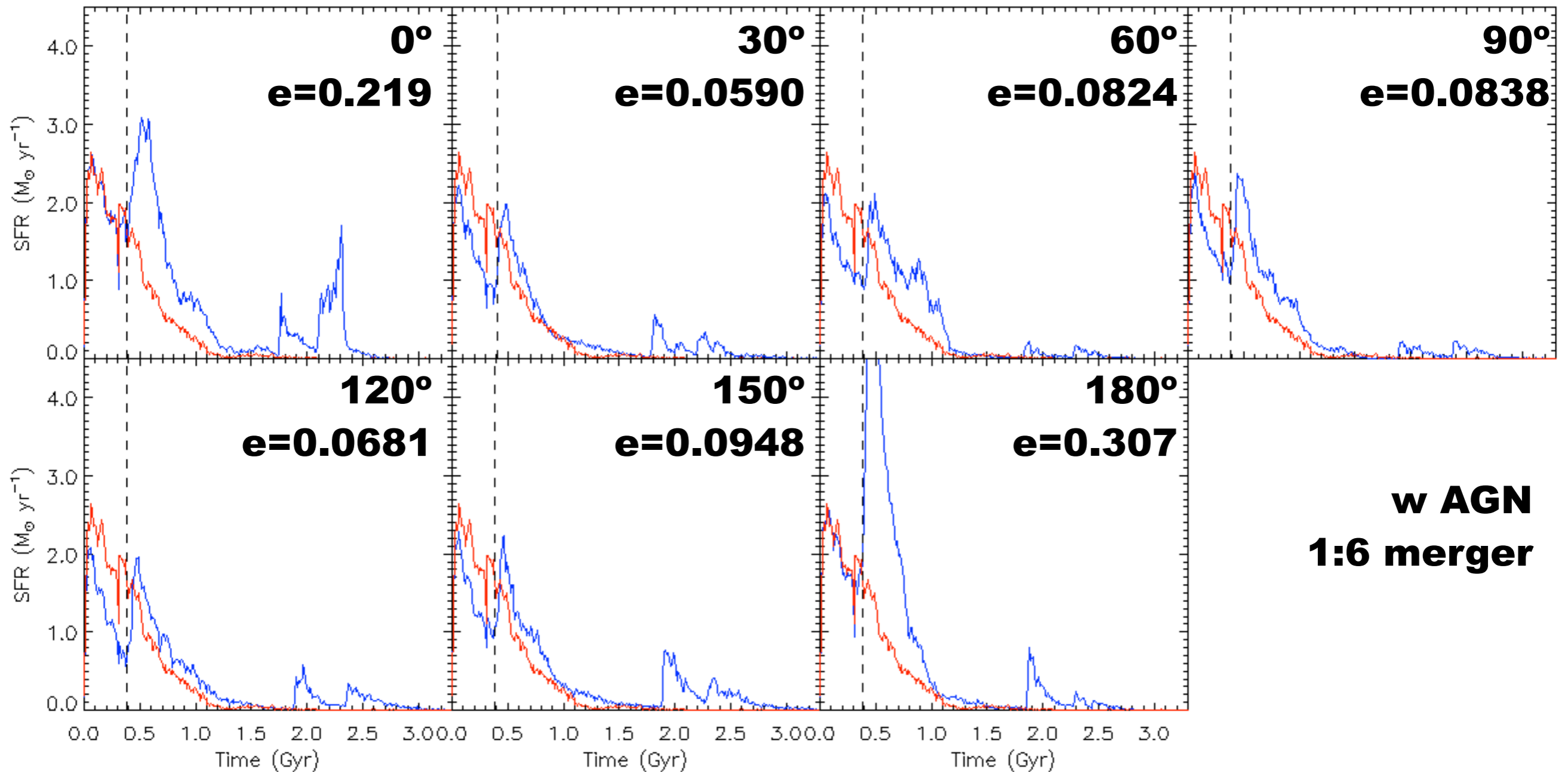
Thanks



Merger-driven SF & Inclination



Merger-driven SF & Inclination



- **Artificial diffusion makes it difficult to study the relation between SF and inclination.**
- **larger burst efficiency in retrograde merger (Cox et al. 2008 - larger burst efficiency in prograde)**

Merger-driven SF & Orbits

1:6

	e
ell	0.0711
para	0.0407
hyp	0.0638

1:10

	e
ell	0.0525
para	0.027
hyp	0.062

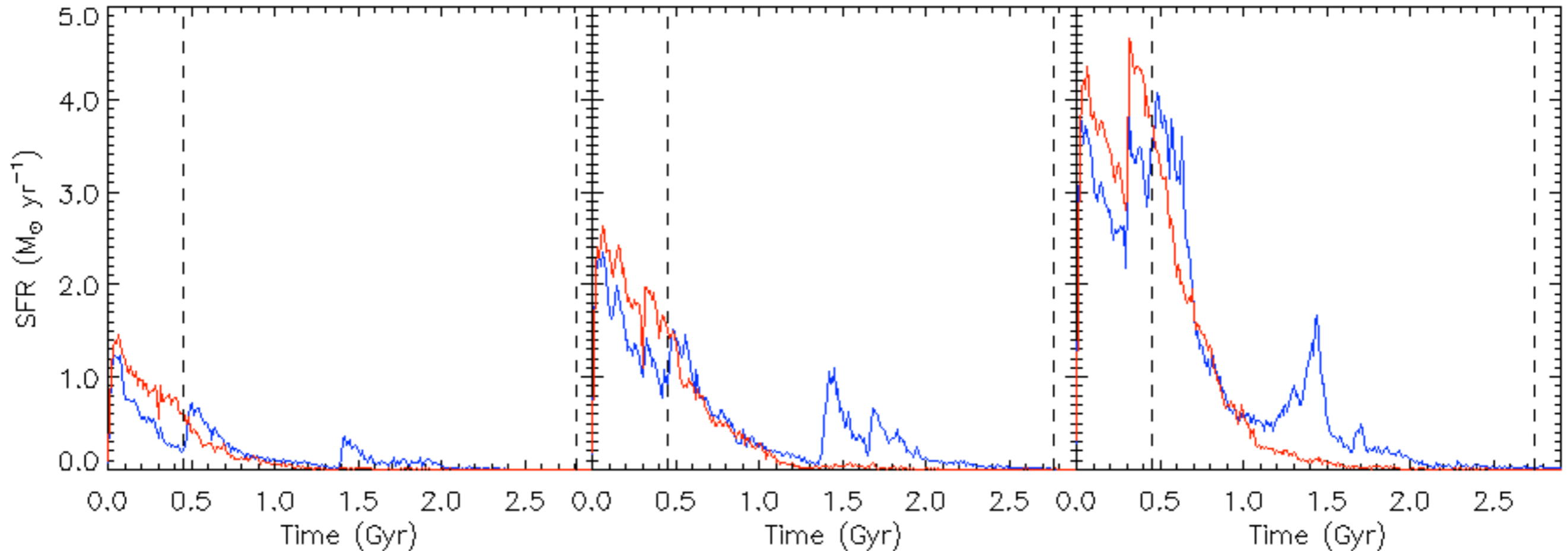
- **No significant relations between orbits and SF have been found.**

Minor Mergers & Morphology

$f_{\text{gas}}=0.111$

$f_{\text{gas}}=0.200$

$f_{\text{gas}}=0.273$



$e=0.0407$

$e=0.0711$

$e=0.0865$

cf. Cox et al. 2008

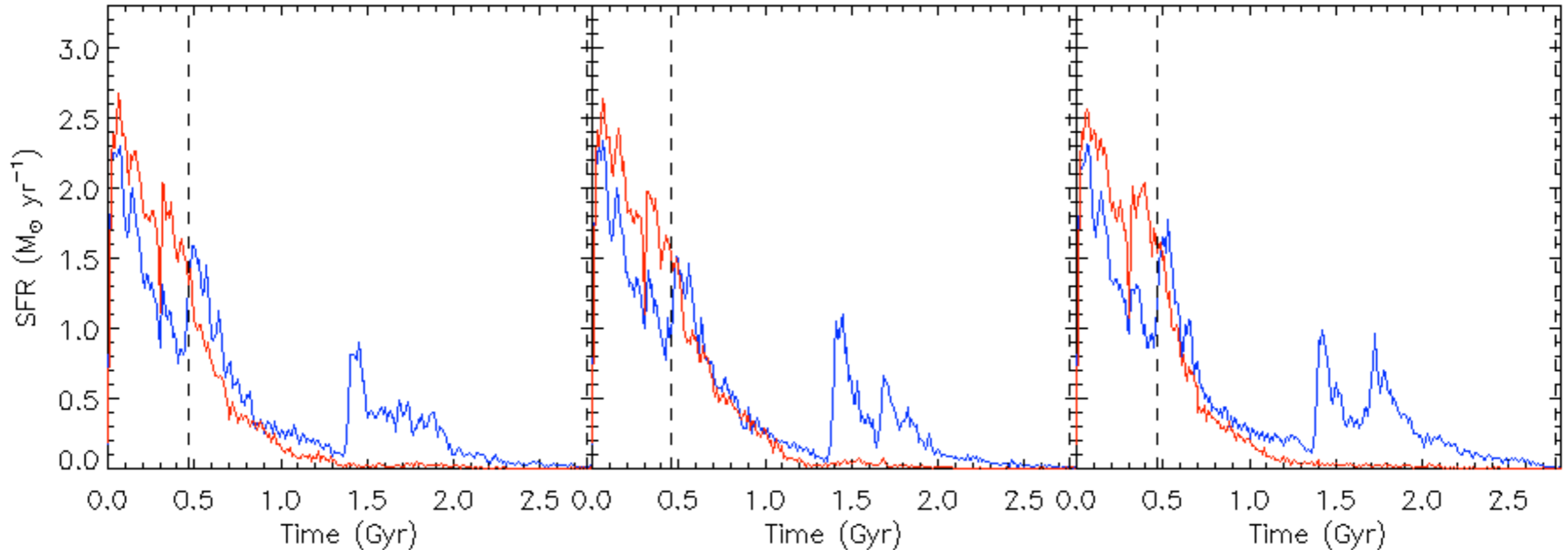
increase in gas fraction - decrease in burst efficiency

Minor Mergers & Morphology

BH=1.06x10⁷ M_{sun}

BH=0.40x10⁷ M_{sun}

BH=0.18x10⁷ M_{sun}



e=0.0876

e=0.0711

e=0.101

$$\dot{M}_{BH} = \alpha \frac{4\pi G^2 M_{BH}^2 \rho}{(c_s^2 + u^2)^{3/2}}$$

$$\dot{M}_{Edd} = \frac{4\pi G M_{BH} m_p}{\epsilon_r \sigma_T C}$$

$$\Delta E_{acc} = \epsilon_c \epsilon_r \dot{M}_{acc} c^2 dt$$

SF & Merging Time Scale

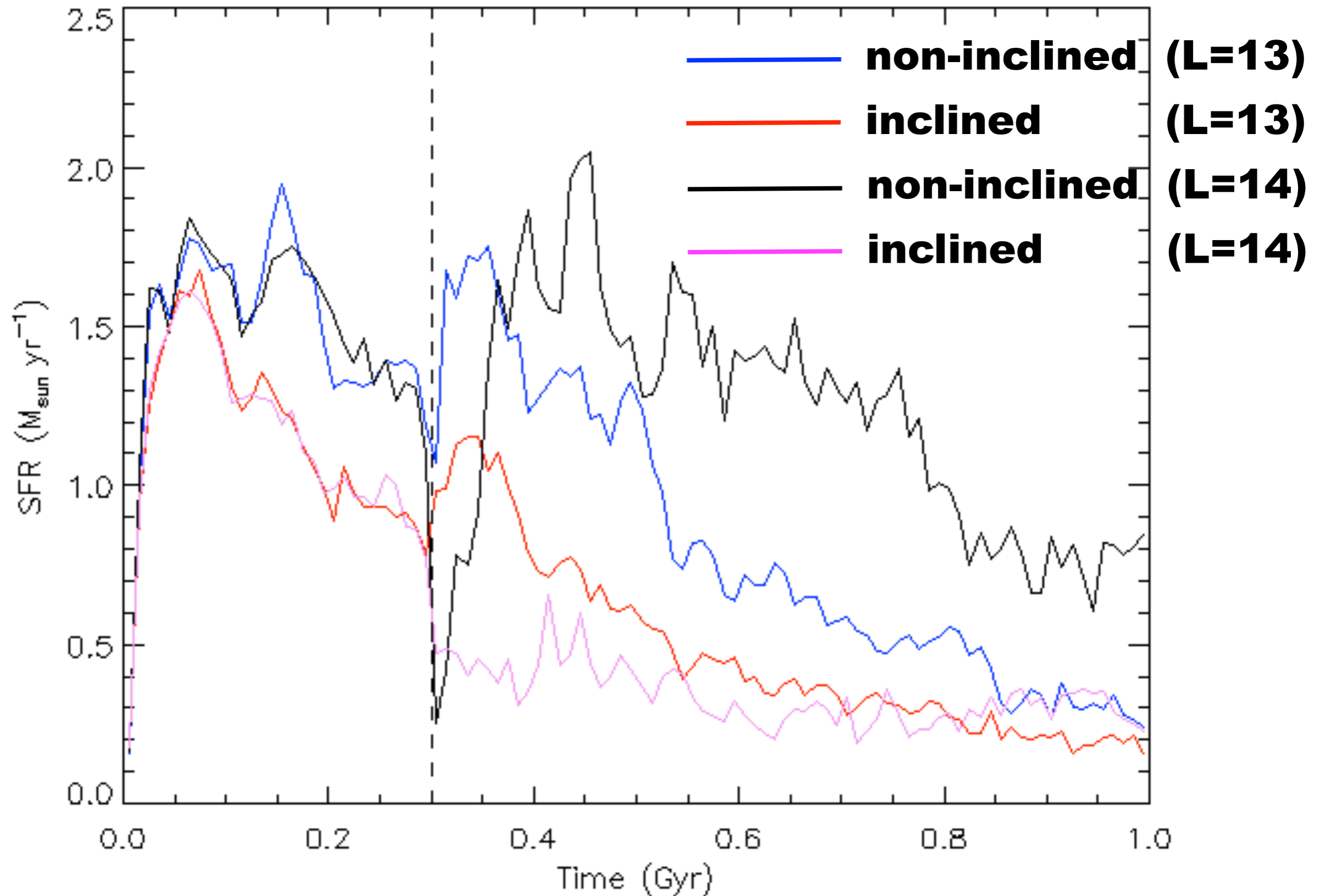
- **When consider merger-driven SF**
 - **Cox et al. 2008 : SF during **whole** simulation time**
 - **this work : SF between **FP** and **2 x SP****
 - 0 ~ FP : numerical diffusion, low resolution**
 - 2 x SP \simeq FC + 1Gyr (Lotz et al. 2008)**

simulation	merging time scale	period considered	SF enhancement	burst efficiency
1:1 w/o AGN	SP : 1.22 Gyr	~ 2.44 Gyr (x2)	$\eta=2.55$	e=0.416
	FC : 1.37 Gyr	~ 2.37 Gyr (+1)	$\eta=2.54$	e=0.414
1:1 w AGN	SP : 1.24 Gyr	~ 2.48 Gyr (x2)	$\eta=1.74$	e=0.180
	FC : 1.42 Gyr	~ 2.42 Gyr (+1)	$\eta=1.74$	e=0.180
1:3 w/o AGN	SP : 1.43 Gyr	~ 2.86 Gyr (x2)	$\eta=1.88$	e=0.215
	FC : 1.76 Gyr	~ 2.76 Gyr (+1)	$\eta=1.87$	e=0.213
1:3 w AGN	SP : 1.46 Gyr	~ 2.92 Gyr (x2)	$\eta=1.36$	e=0.080
	FC : 1.86 Gyr	~ 2.86 Gyr (+1)	$\eta=1.36$	e=0.080
1:6 w/o AGN	SP : 1.76 Gyr	~ 3.52 Gyr (x2)	$\eta=1.43$	e=0.116
	FC : 2.28 Gyr	~ 3.28 Gyr (+1)	$\eta=1.42$	e=0.114
1:6 w AGN	SP : 1.80 Gyr	~ 3.61 Gyr (x2)	$\eta=1.06$	e=0.0141
	FC : 2.67 Gyr	~ 3.67 Gyr (+1)	$\eta=1.06$	e=0.0141
1:10 w/o AGN	SP : 2.07 Gyr	~ 4.14 Gyr (x2)	$\eta=1.28$	e=0.0847
	FC : not			
1:10 w AGN	SP : 2.13 Gyr	~ 4.27 Gyr (x2)	$\eta=1.01$	e=0.00375
	FC : not			

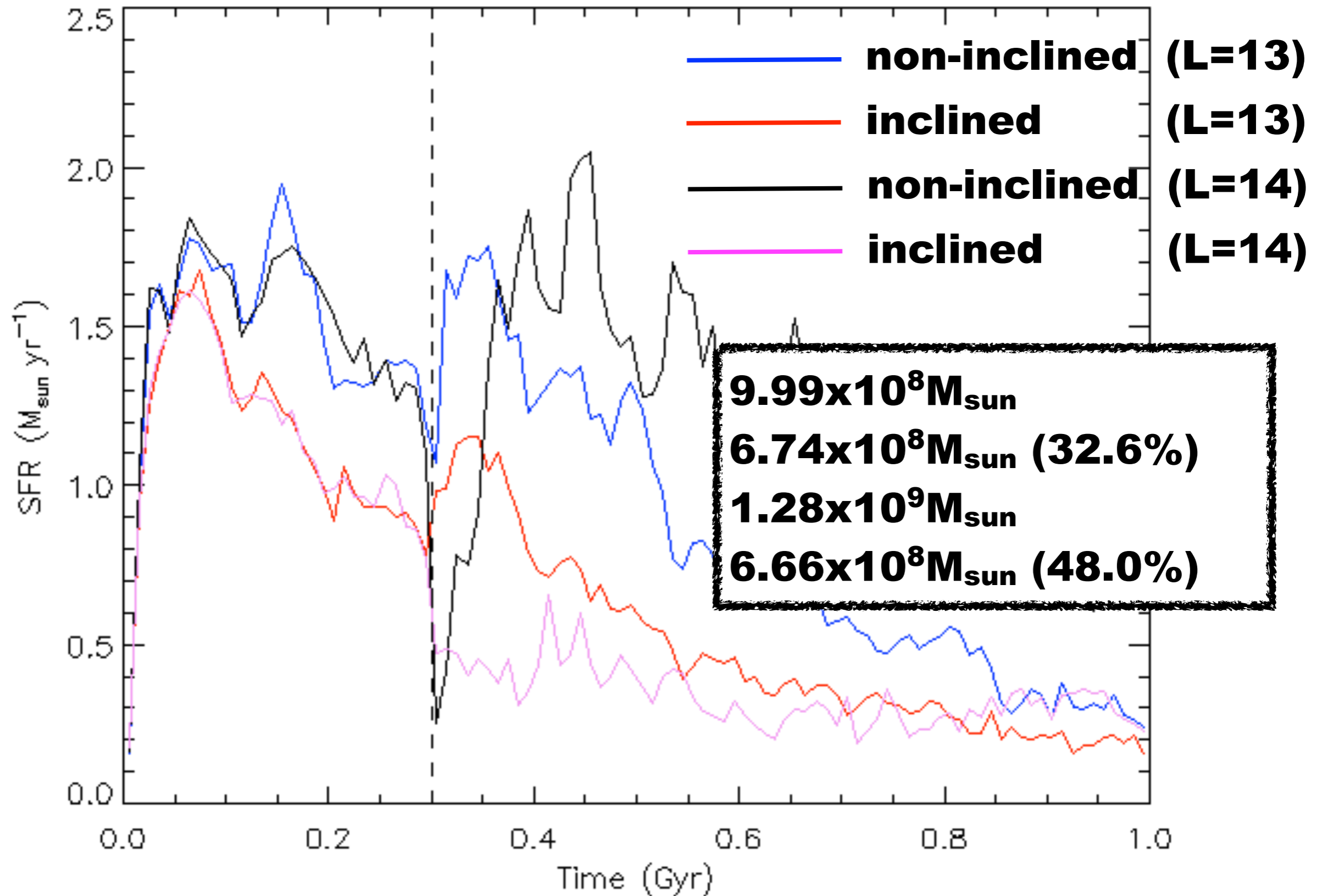
simulation	merging time scale	period considered	SF enhancement	burst efficiency
1:6 elliptic	SP : 1.38 Gyr	~ 2.76 Gyr (x2)	$\eta=1.11$	e=0.0266
	FC : 1.94 Gyr	~ 2.94 Gyr (+1)	$\eta=1.11$	e=0.0267
1:6 parabolic	SP : 1.80 Gyr	~ 3.60 Gyr (x2)	$\eta=1.06$	e=0.0141
	FC : 2.67 Gyr	~ 3.67 Gyr (+1)	$\eta=1.06$	e=0.0141
1:6 hyperbolic	SP : 2.66 Gyr	~ 5.31 Gyr (x2)	$\eta=1.11$	e=0.0271
	FC : 3.94 Gyr	~ 4.94 Gyr (+1)	$\eta=1.11$	e=0.0271
1:10 elliptic				
1:10 parabolic	SP : 2.13 Gyr	~ 4.27 Gyr (x2)	$\eta=1.01$	e=0.00375
	FC : not			
1:10 hyperbolic	SP : 3.70 Gyr	~ 7.40 Gyr (x2)	$\eta=1.14$	e=0.0374
	FC : not			

simulation	merging time scale	period considered	SF enhancement	burst efficiency
1:6 0'	SP : 1.76 Gyr	~ 3.52 Gyr (x2)	$\eta=1.78$	e=0.186
	FC : 2.27 Gyr	~ 3.27 Gyr (+1)	$\eta=1.78$	e=0.186
1:6 30'	SP : 1.80 Gyr	~ 3.60 Gyr (x2)	$\eta=1.06$	e=0.0141
	FC : 2.67 Gyr	~ 3.67 Gyr (+1)	$\eta=1.06$	e=0.0141
1:6 60'	SP : 1.85 Gyr	~ 3.70 Gyr (x2)	$\eta=1.15$	e=0.0349
	FC : 2.54 Gyr	~ 3.54 Gyr (+1)	$\eta=1.15$	e=0.0349
1:6 90'	SP : 1.91 Gyr	~ 3.82 Gyr (x2)	$\eta=1.19$	e=0.0449
	FC : 2.92 Gyr	~ 3.92 Gyr (+1)	$\eta=1.19$	e=0.0449
1:6 120'	SP : 1.88 Gyr	~ 3.76 Gyr (x2)	$\eta=1.07$	e=0.0158
	FC : 2.89 Gyr	~ 3.89 Gyr (+1)	$\eta=1.07$	e=0.0159
1:6 150'	SP : 1.91 Gyr	~ 3.82 Gyr (x2)	$\eta=1.21$	e=0.0496
	FC : 2.98 Gyr	~ 3.98 Gyr (+1)	$\eta=1.21$	e=0.0496
1:6 180'	SP : 1.85 Gyr	~ 3.70 Gyr (x2)	$\eta=2.09$	e=0.261
	FC : 3.07 Gyr	~ 4.07 Gyr (+1)	$\eta=2.09$	e=0.261

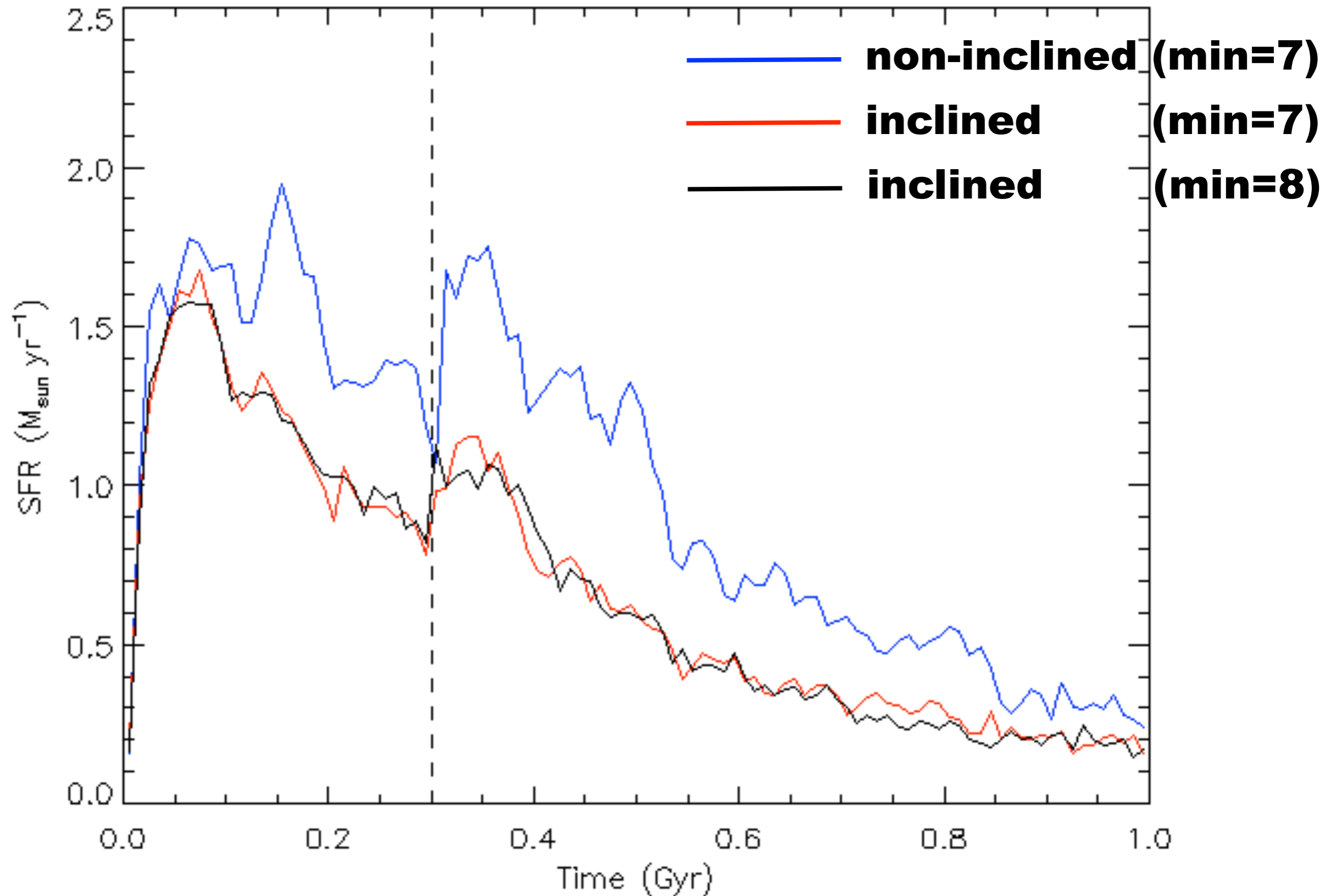
Inclined Galaxies & Resolution



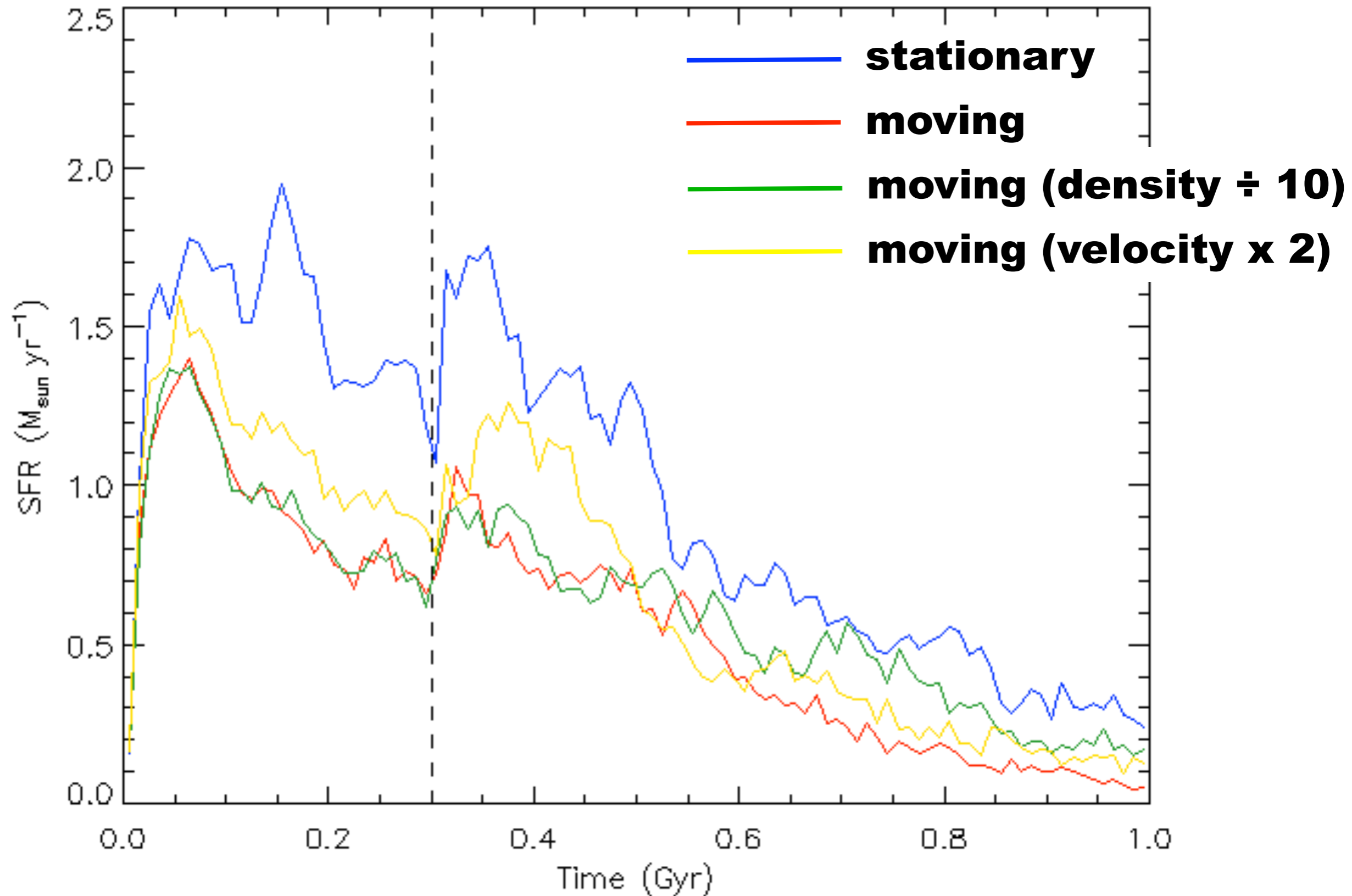
Inclined Galaxies & Resolution



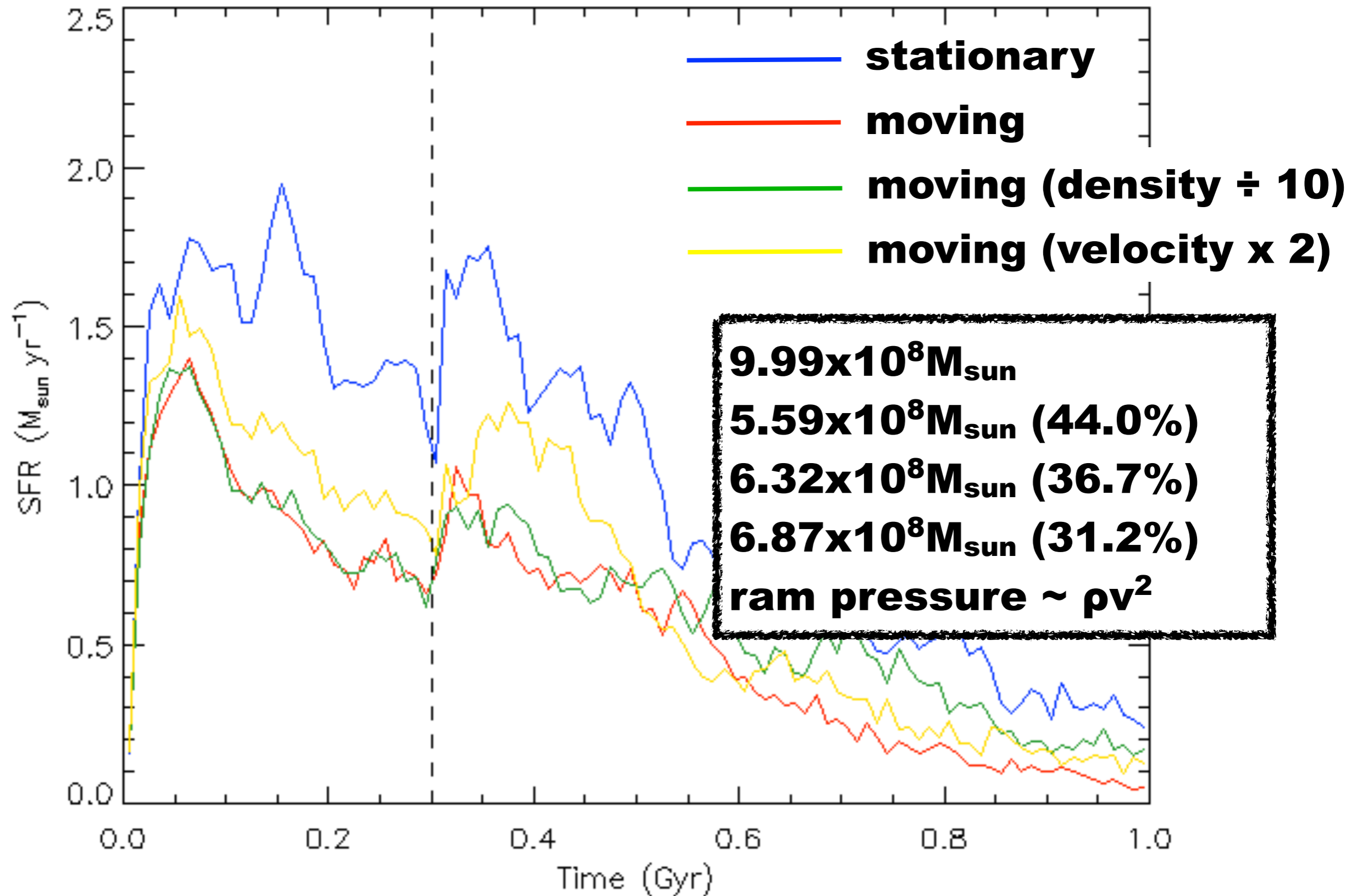
Inclined Galaxies & Resolution

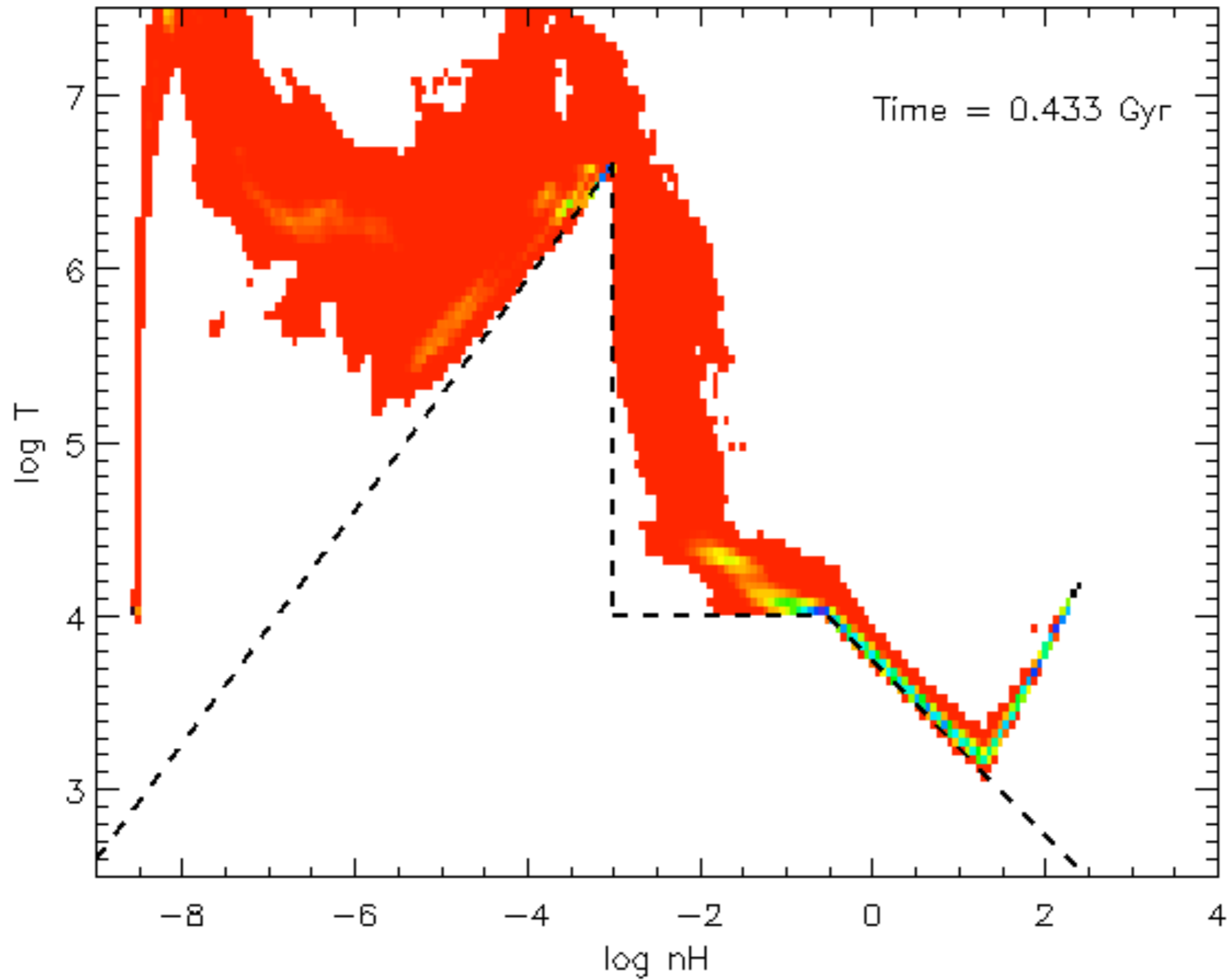


Moving Galaxies & Background



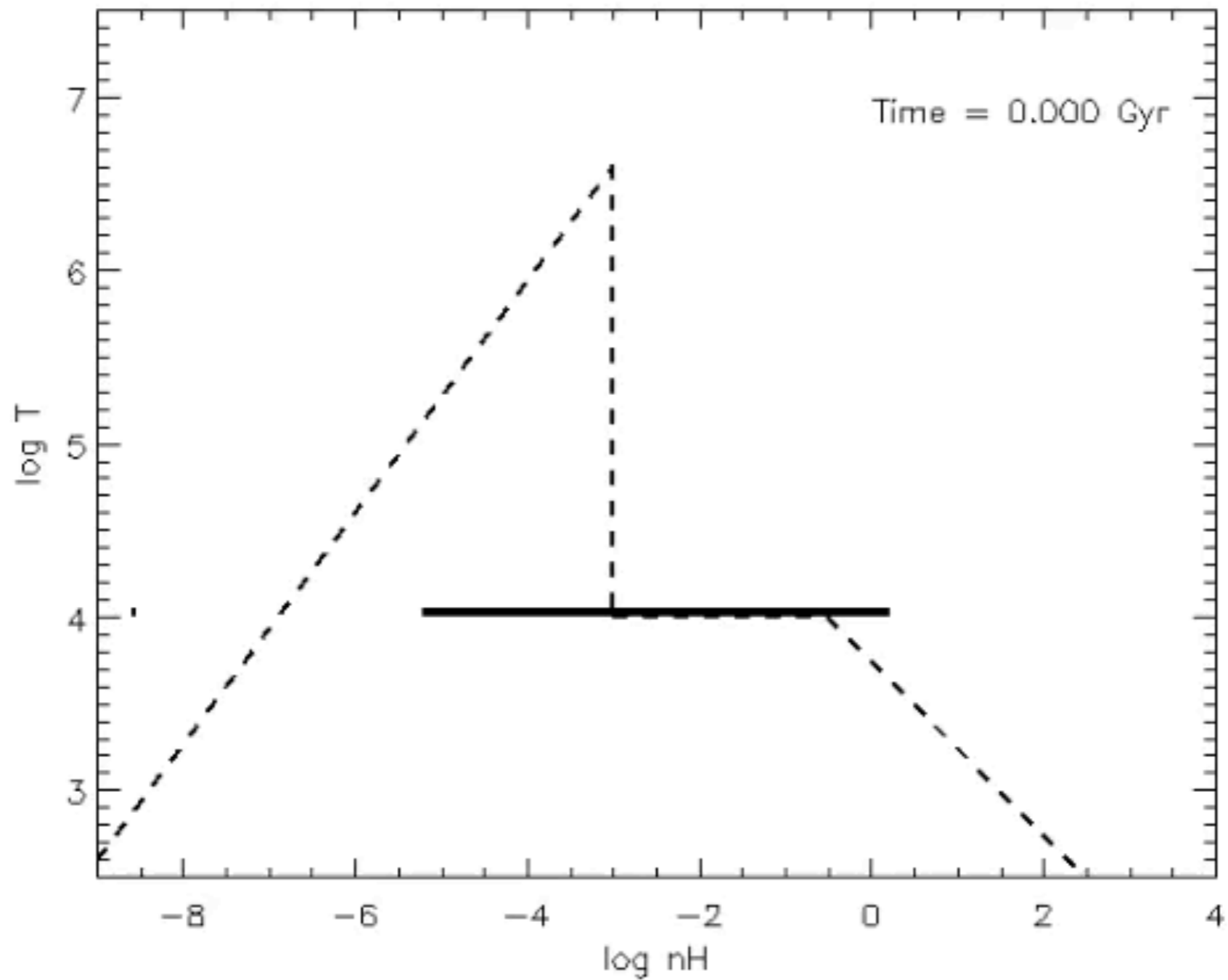
Moving Galaxies & Background





See also

Bournaud et al. 2010 & Teyssier et al. 2010



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Bournaud et al. 2010 & Teyssier et al. 2010