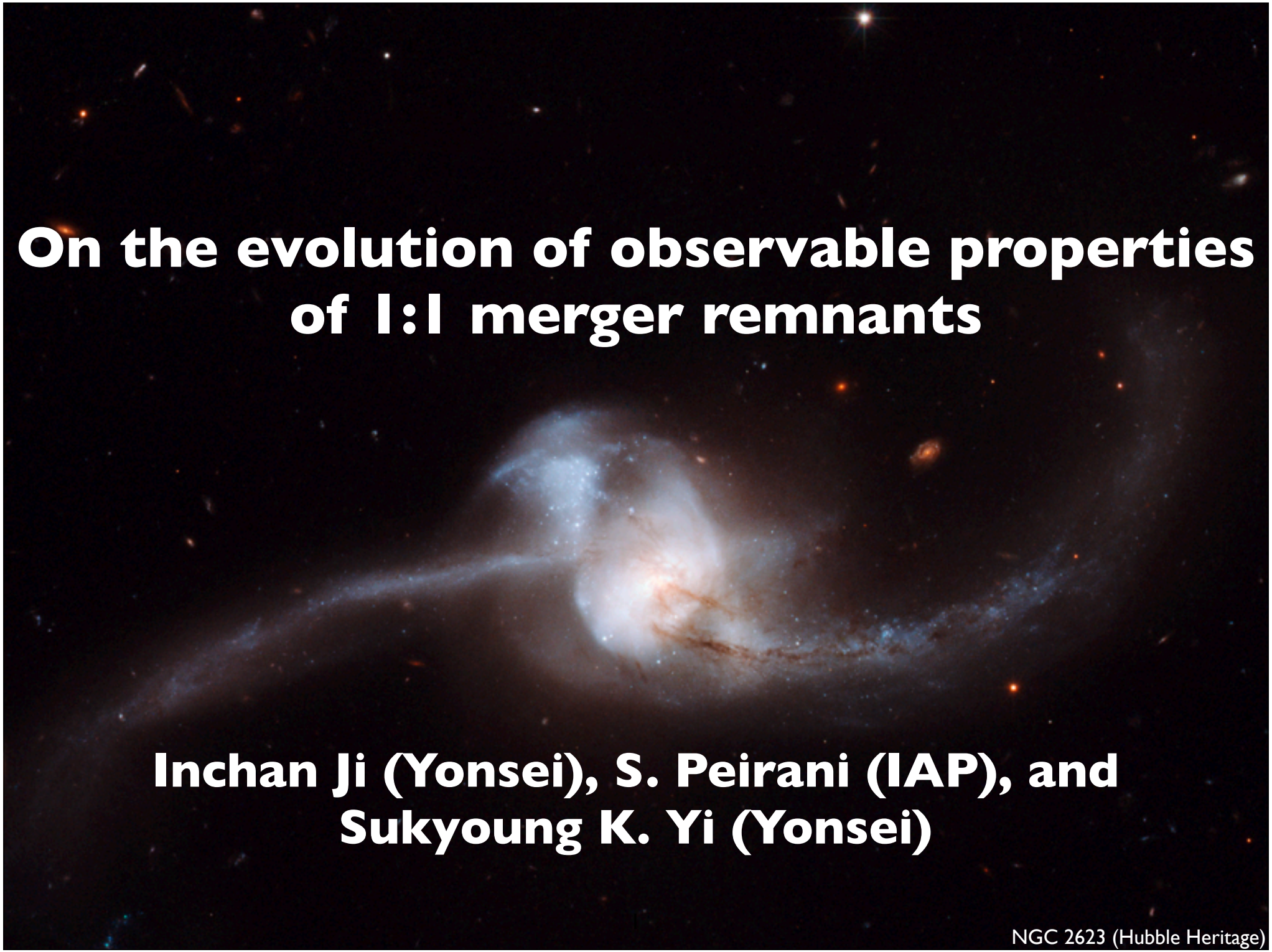
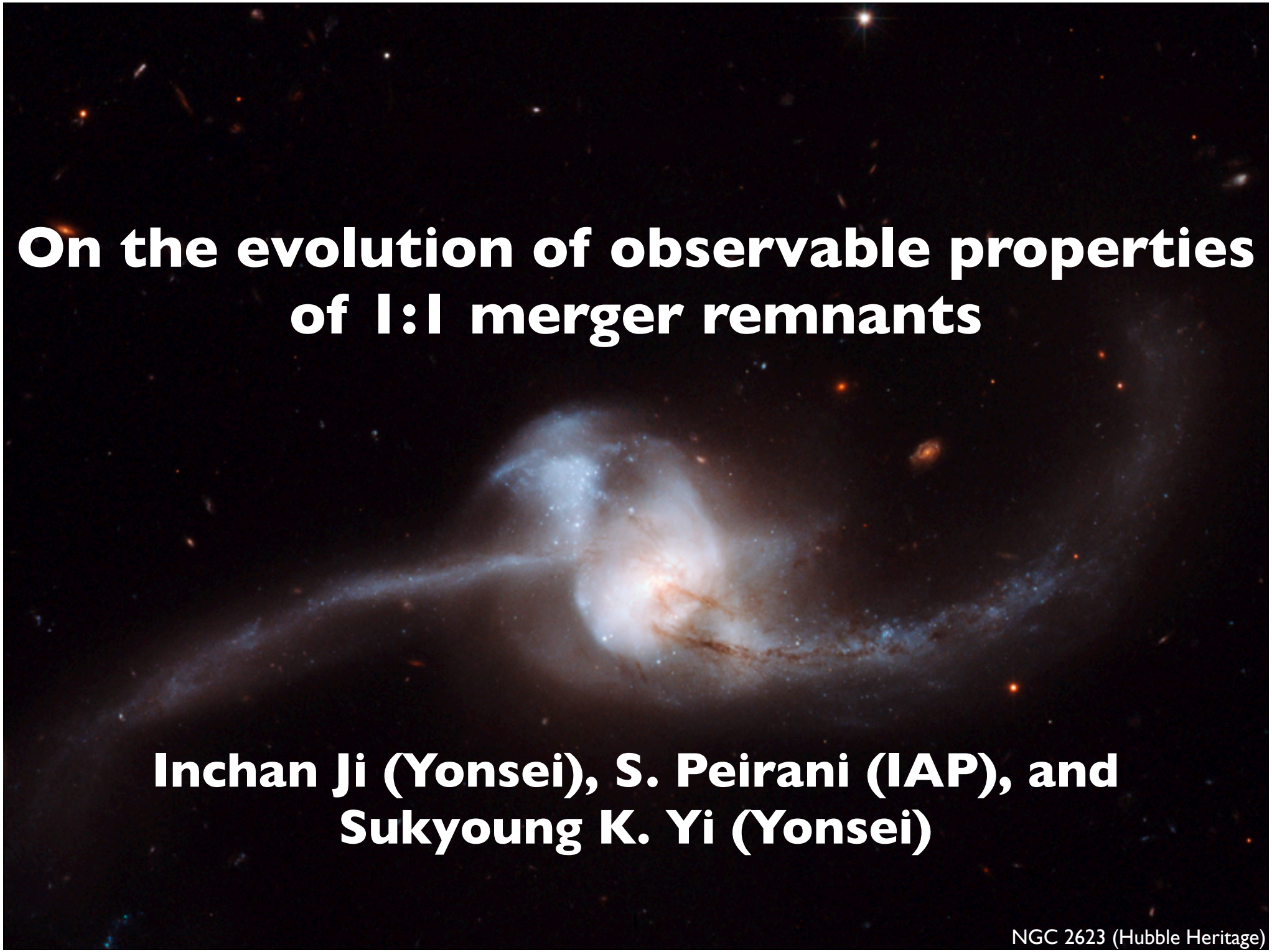
On the evolution of observable properties of 1:1 merger remnants



Inchan Ji (Yonsei), S. Peirani (IAP), and Sukyoung K. Yi (Yonsei)

NGC 2623 (Hubble Heritage)

On the evolution of observable properties of 1:1 merger remnants



Inchan Ji (Yonsei), S. Peirani (IAP), and Sukyoung K. Yi (Yonsei)

NGC 2623 (Hubble Heritage)

Introduction

1. "**Merger hypothesis**" (Toomre & Toomre 1972)
   "**Hierarchical structure formation**" (White & Rees 1978)

2. **Role of merger in galaxy evolution**

   a. Mass growth, SF, AGN, ULIRGs, morphology
   (e.g. Di Matteo et al. 2005; Cox et al. 2006, 2008)

   b. Observation, numerical simulation
   (e.g. Springel et al. 2005, Gabor & Dave 2012)

3. **Extracting observable properties from simulation**

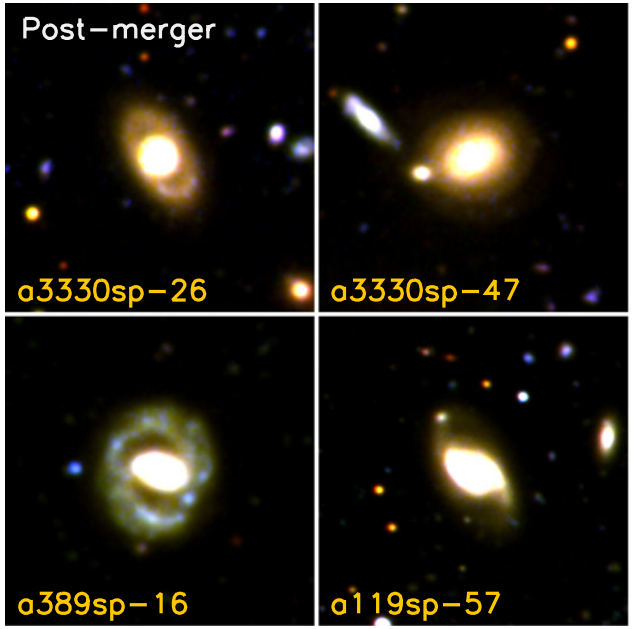
   a. Population synthesis model with hydrodynamic simulations
   (e.g. Springel et al. 2005, Kaviraj et al. 2009, etc.)

   b. Dust extinction (e.g. Calzetti et al 2000)

Motivation

1. Most of massive galaxies undergo **another merger within a few Gyr** (Stewart et al. 2008).
2. They should be an **on-going merger or a merger remnants** (Lotz et al 2006).
3. A portion of the **red early-type** galaxies with **disturbed features**: ≳ **40%** among the cluster galaxies (Sheen et al. 2012).

Therefore, it is important to examine **time evolution of merger remnants.**



Sheen et al. 2012

Goals of this study

1. **Structure** of merger remnants
2. **Star formation** and **observable properties**(magnitudes, colors) of merger remnants

Methodology

Numerical simulation

1. **GADGET2** N-body/hydrodynamics code (Springel 2005)

2. **Baryonic physics**
   a. **Gas cooling** (Sutherland & Dopita 1993)
   b. **Star formation** (Katz et al. 1996)
   c. **Supernova feedback** (Peirani et al. 2009)

3. Supported by National Supercomputing Center

Initial condition

1. **Model galaxies**
   ; Sa/Sb type

2. **Orbits**

   a. Parabolic, elliptical, and hyperbolic

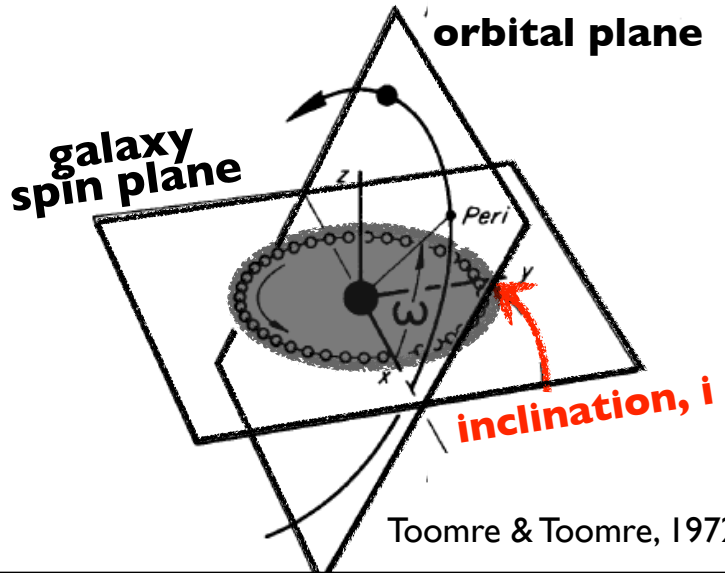
   b. inclination = 0° - 180° (30° increment)

3. **Variations**

   a. Host galaxy

   b. Pericentric distance

	Sa	Sb
Total mass	1.7x 10^{11} $M_\odot$	1.7 10^{11} $M_\odot$
f_{DM}	84%	84%
f_{stars}	15.2%	12.5%
f_{gas}	0.8%	3.5%
B/T	0.4	0.2
R_d	2.58 kpc	3.29 kpc
N	770,000	860,000



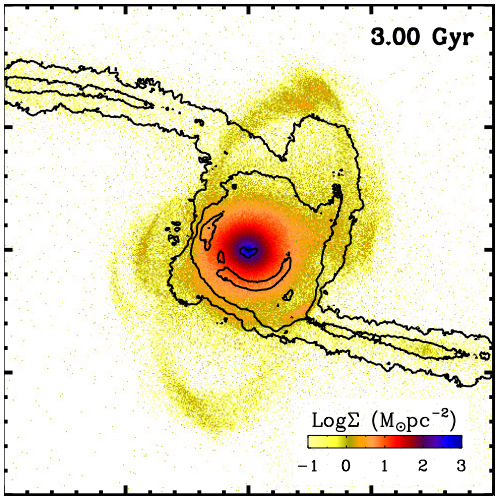
Toomre & Toomre, 1972

Ray-tracing

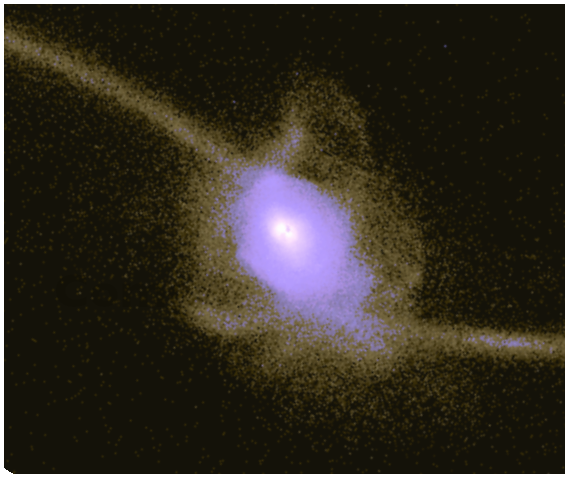
1. Population synthesis model
; Bruzual & Chalot (2003)

2. Dust attenuation
; Calzetti et al. 2000

3. SDSS ugriz filters



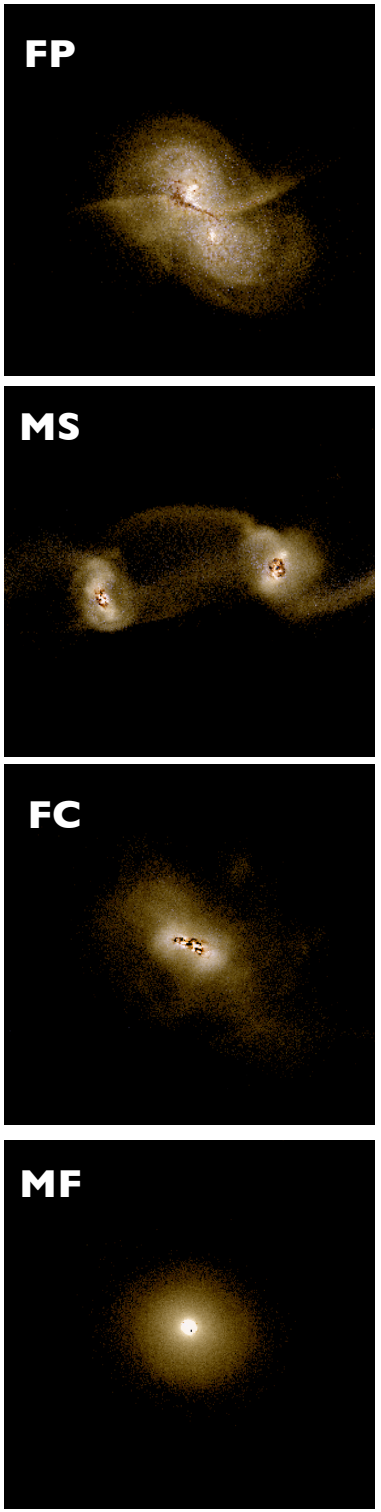
Stellar + gas column density



Observable properties

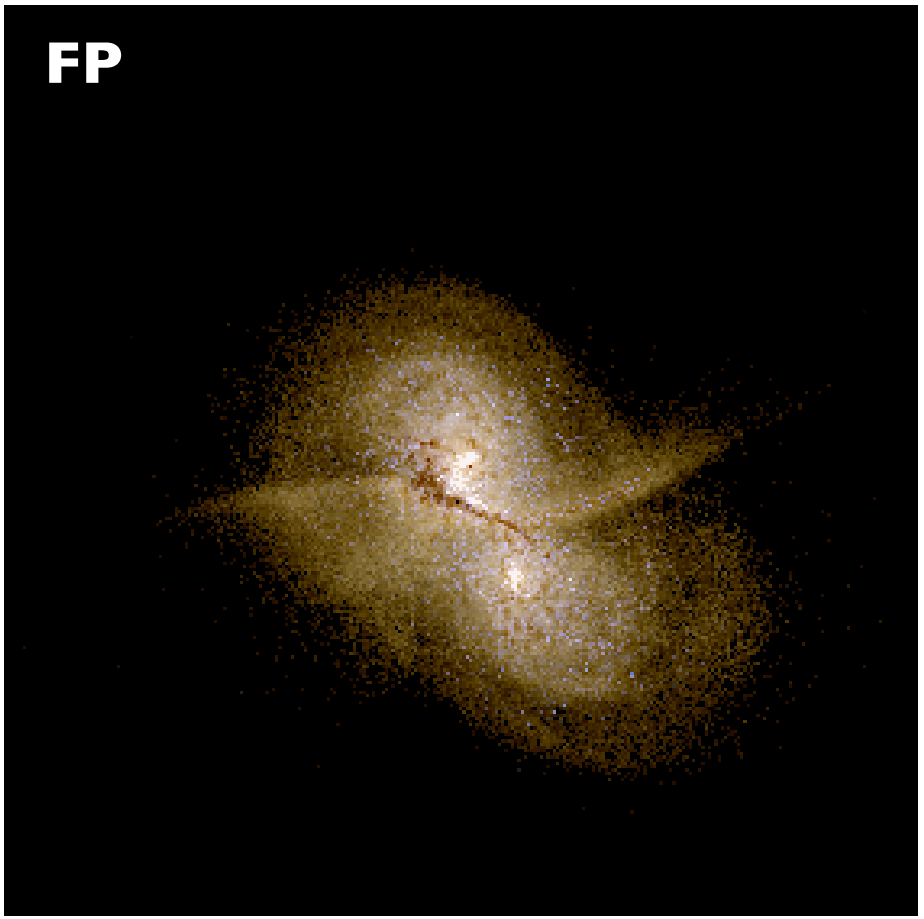
Definition of timescales

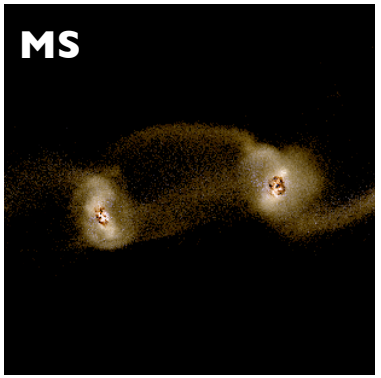
1. **FP - F**irst (perigee) **P**assage
2. **MS - M**aximum **S**eparation
3. **FC - F**inal **C**oalescence
4. **TS - T**ermination of **S**tarburst
   ; $SFR_{Merger} = SFR_{Isolation}$
5. **MF - M**erger-**F**eature time
   a. No disturbed features (visual inspection)
   b. $\mu_r \sim$ **25** and **28** mag arcsec^{-2} (MF_{25}, MF_{28})

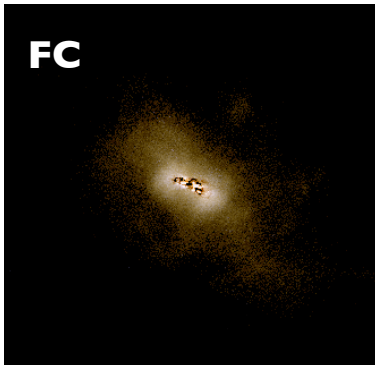


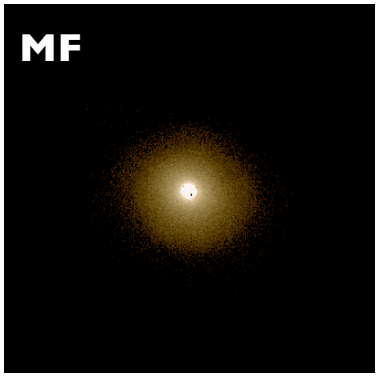
Definition of timescales

1. **FP - F**irst (perigee) **P**assage



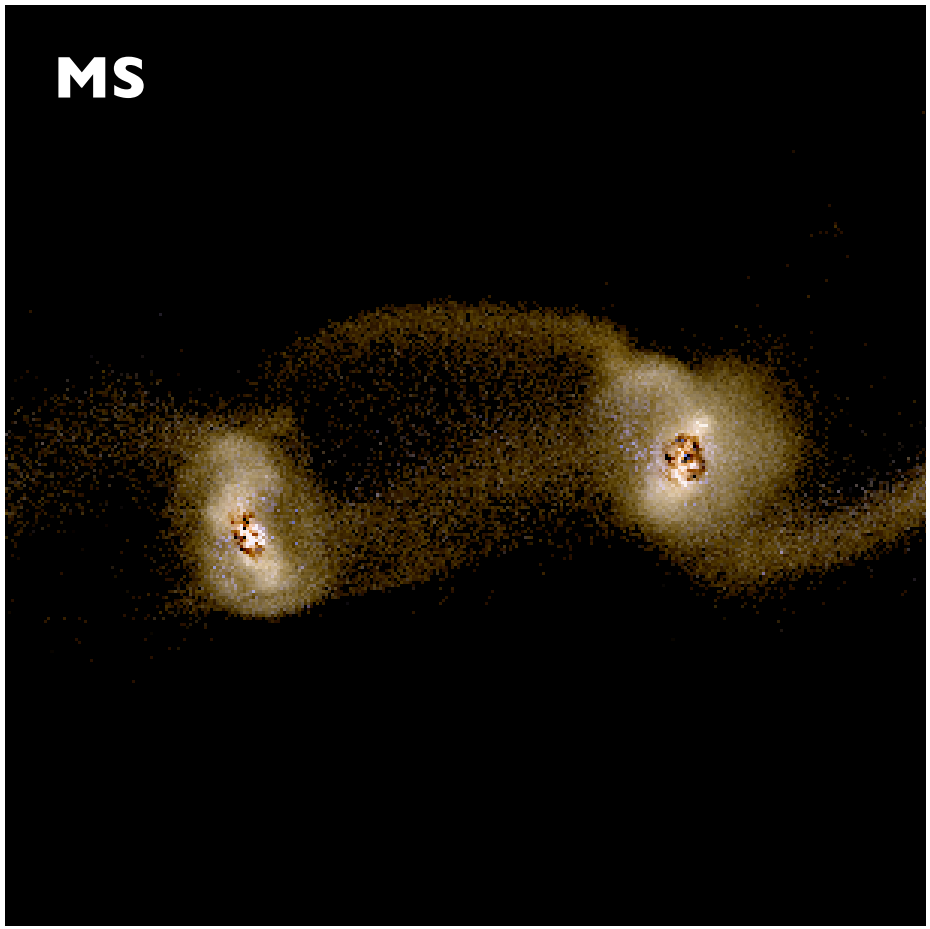


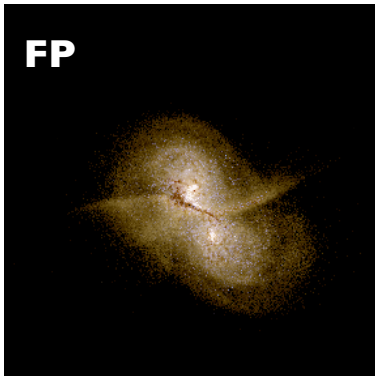


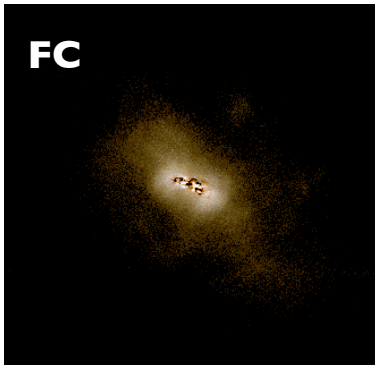


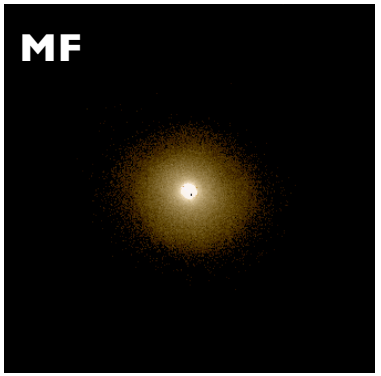
Definition of timescales

2. **MS** - **M**aximum **S**eparation



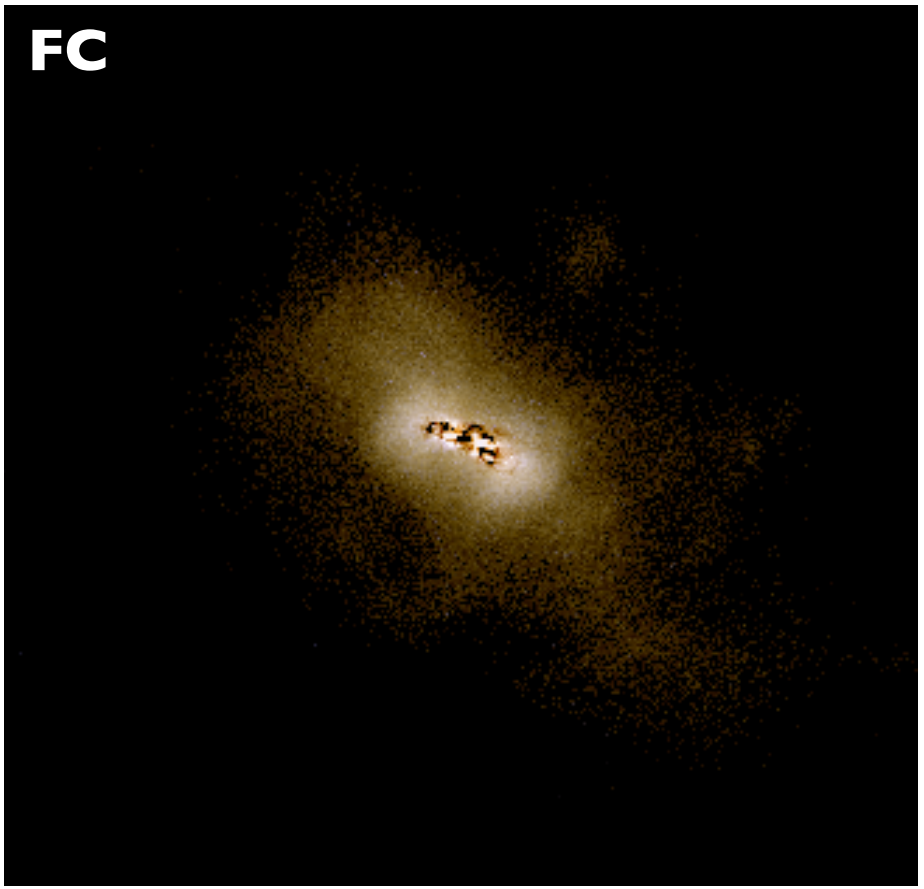


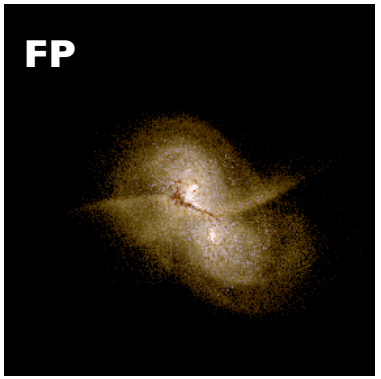


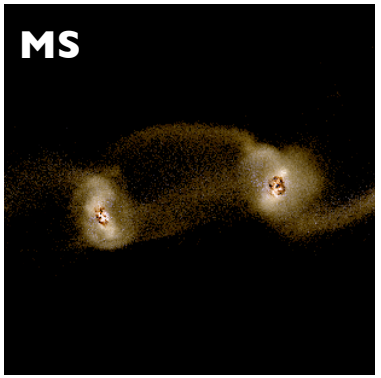


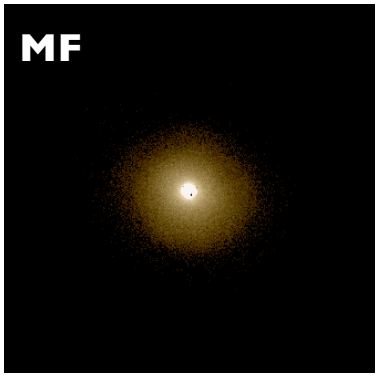
Definition of timescales

3. **FC** - **F**inal **C**oalescence





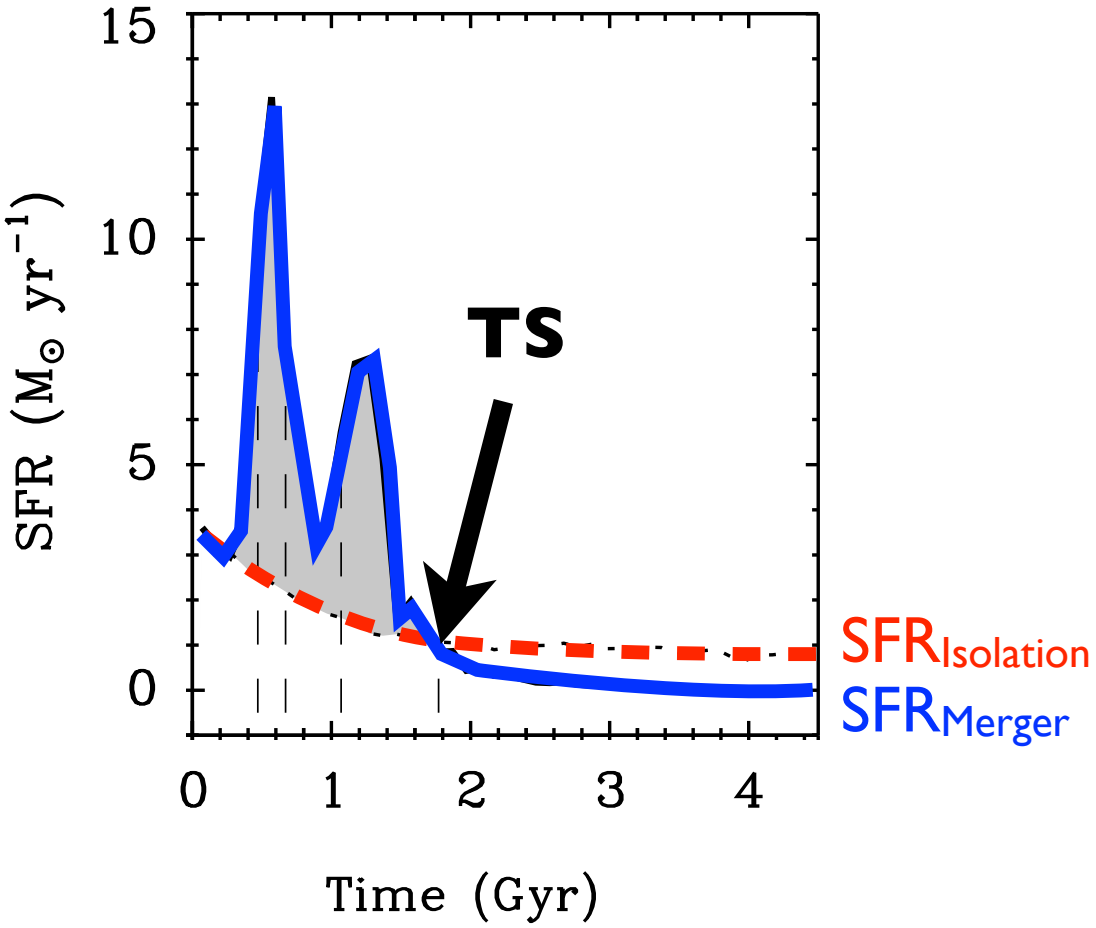


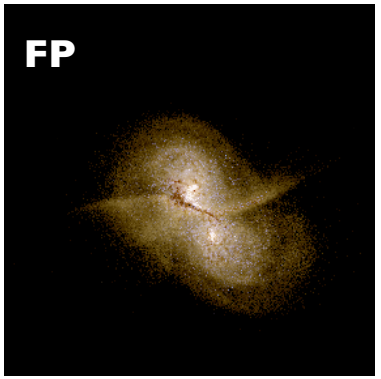


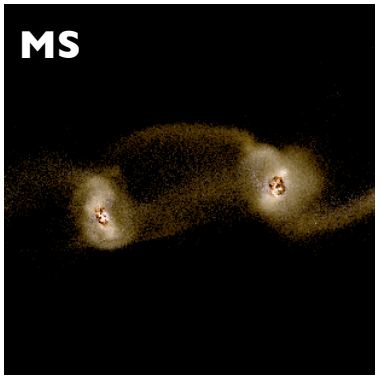
Definition of timescales

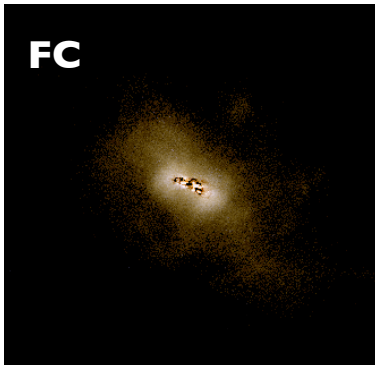
3. **TS** - **T**ermination of **S**tarburst

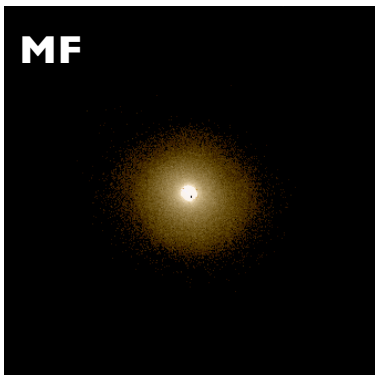
; $SFR_{Merger} = SFR_{Isolation}$





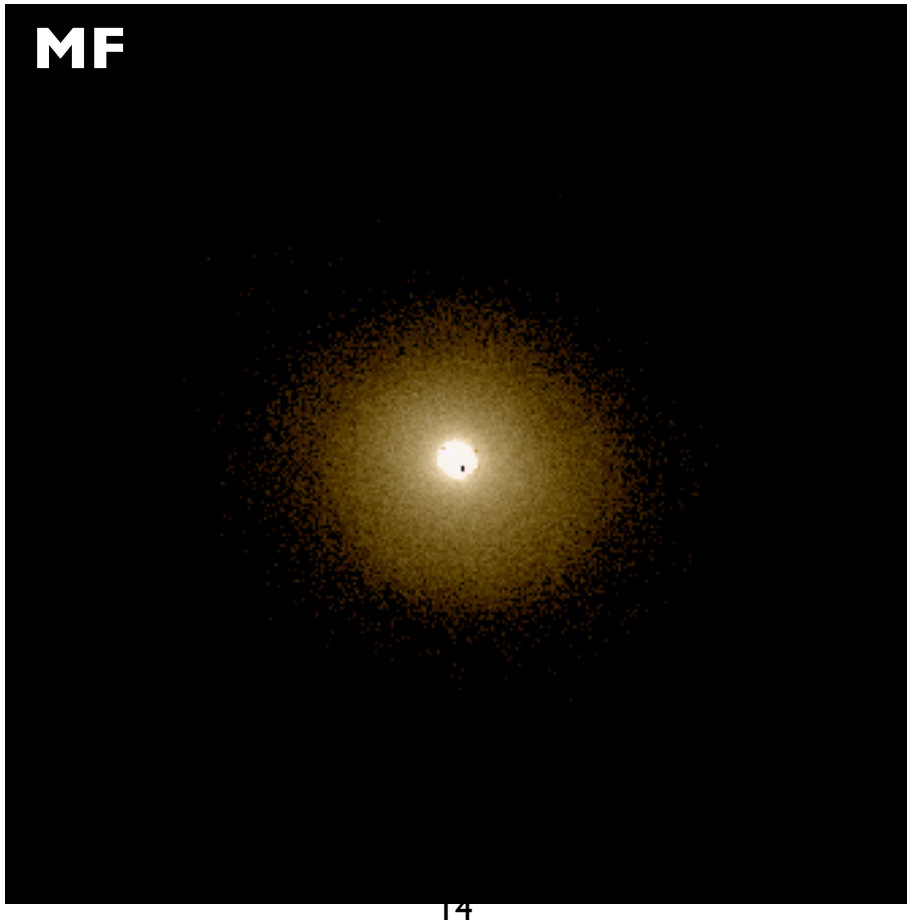


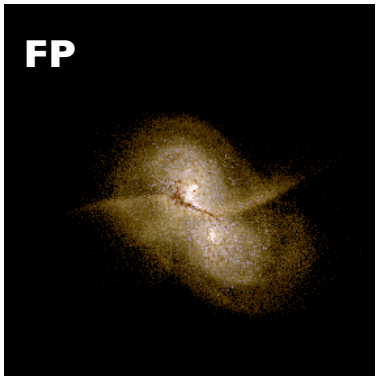


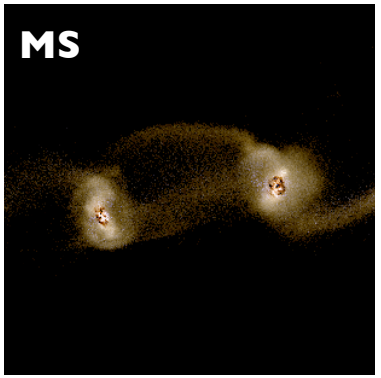


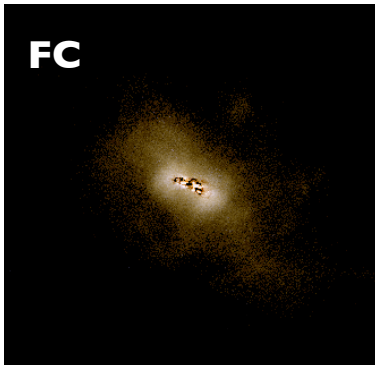
Definition of timescales

4. **MF** - **M**erger-**F**eature time
   a. No disturbed features (visual inspection)
   b. μ_r ~ **25** and **28** mag arcsec^{-2} (MF_{25}, MF_{28})

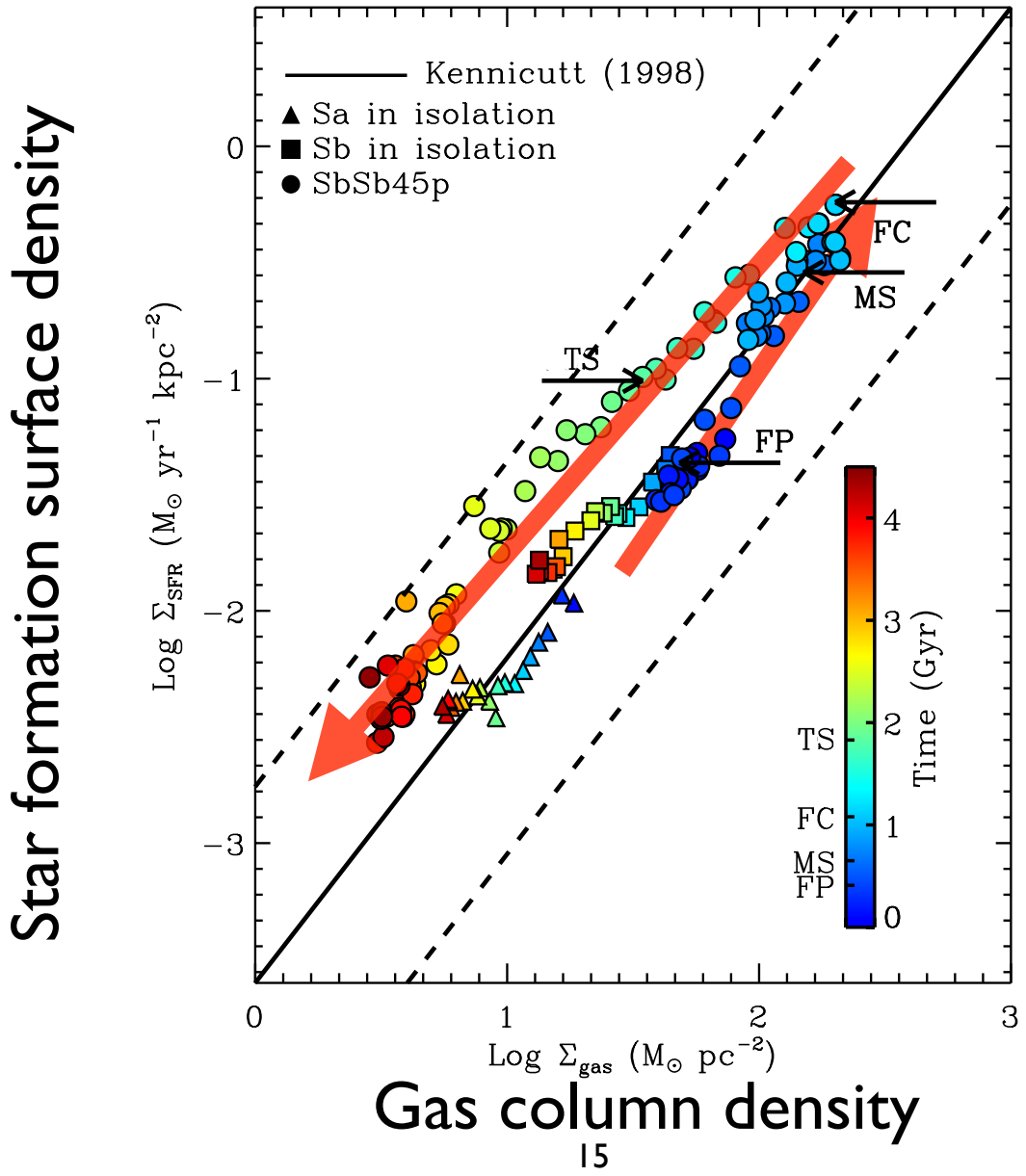






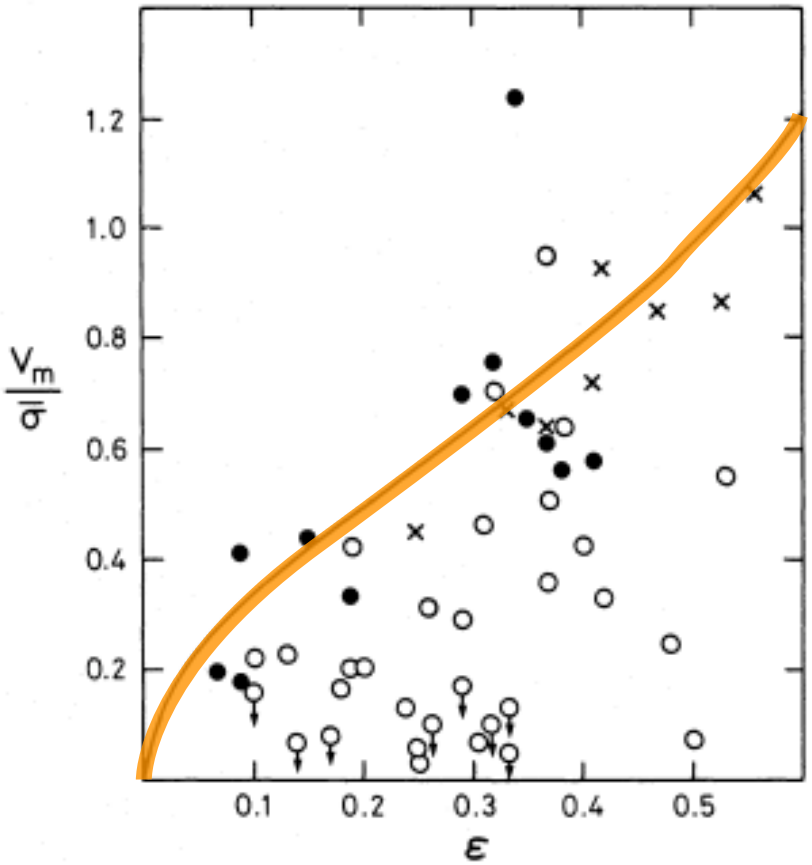


Testing star formation

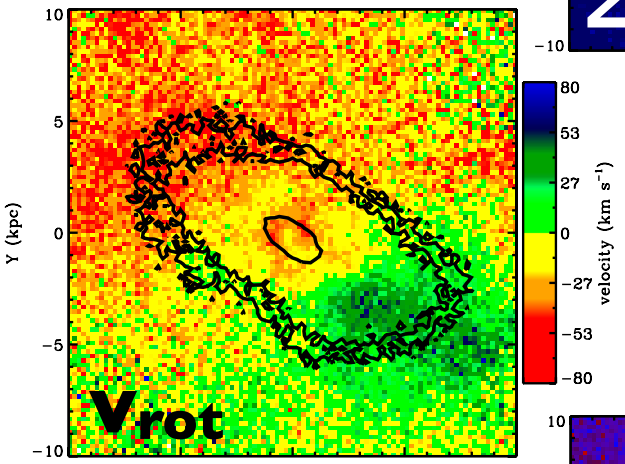


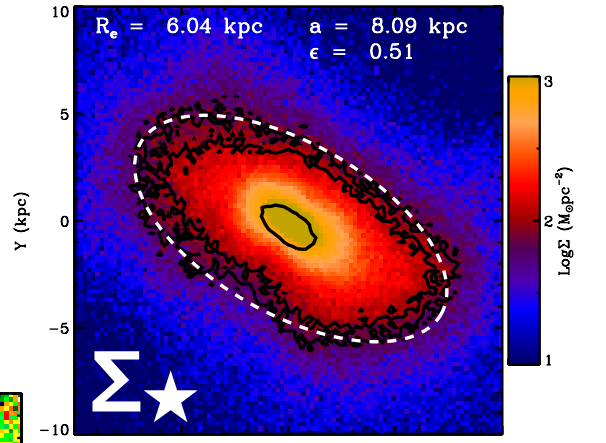
Properties of merger remnants

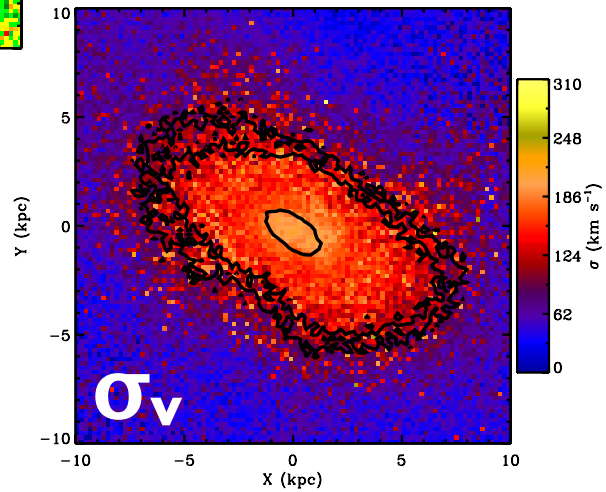
Kinematic structure



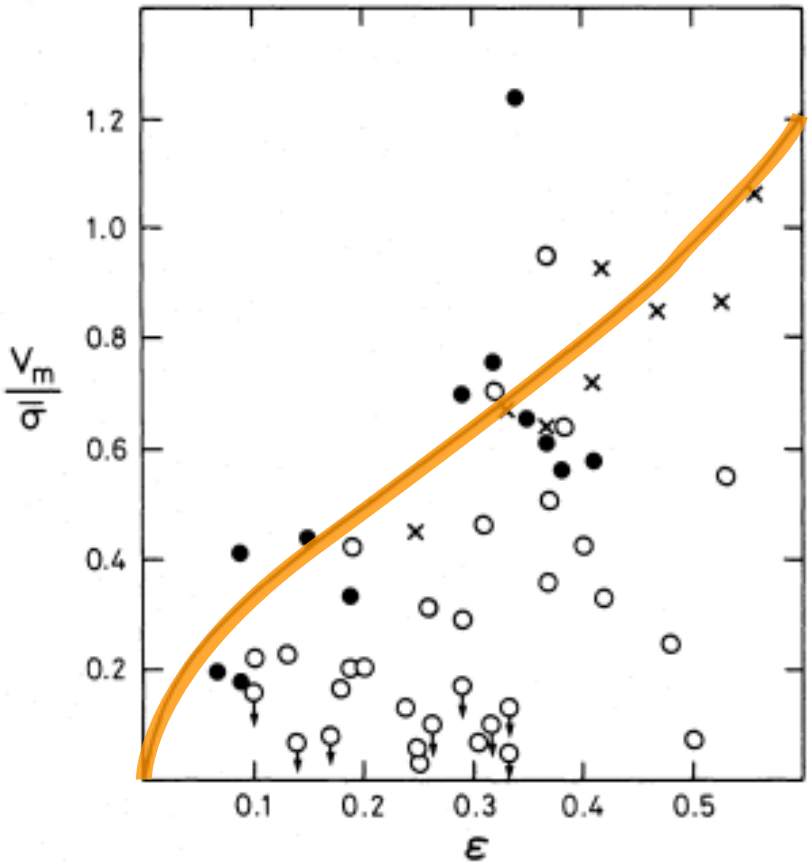
Davies et al. 1983





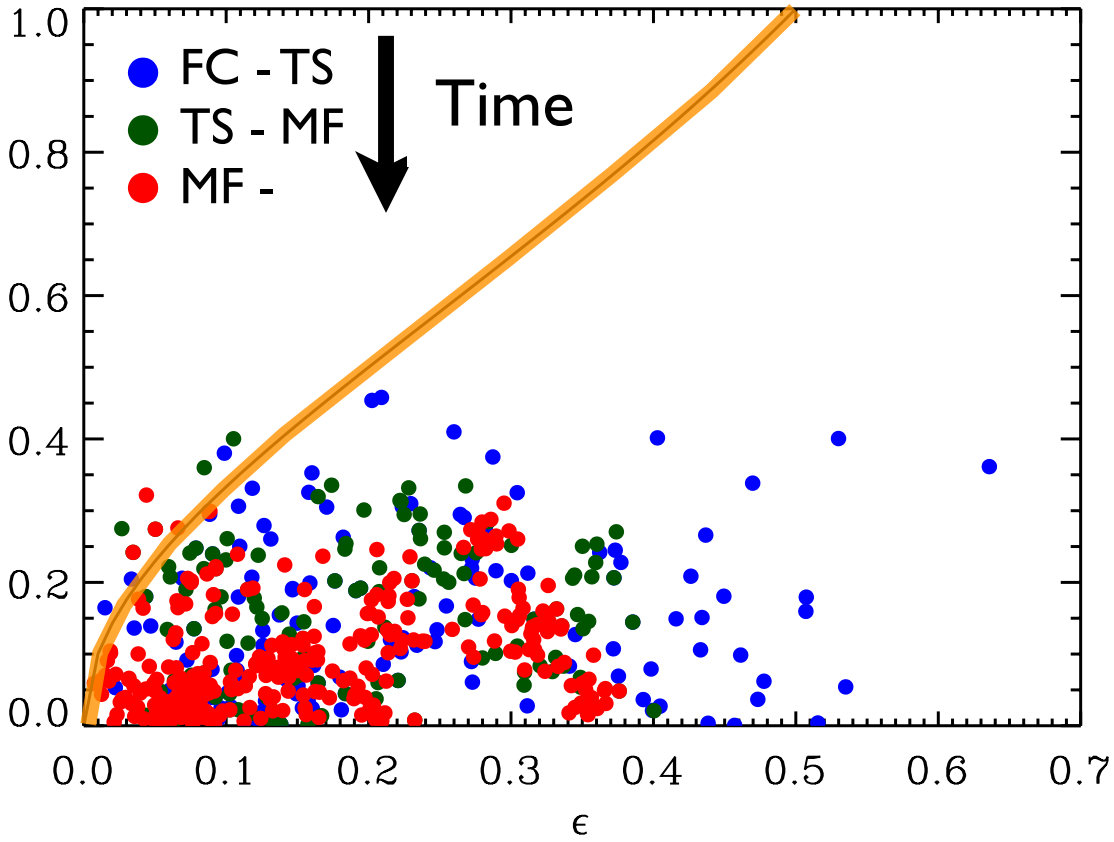


Kinematic structure

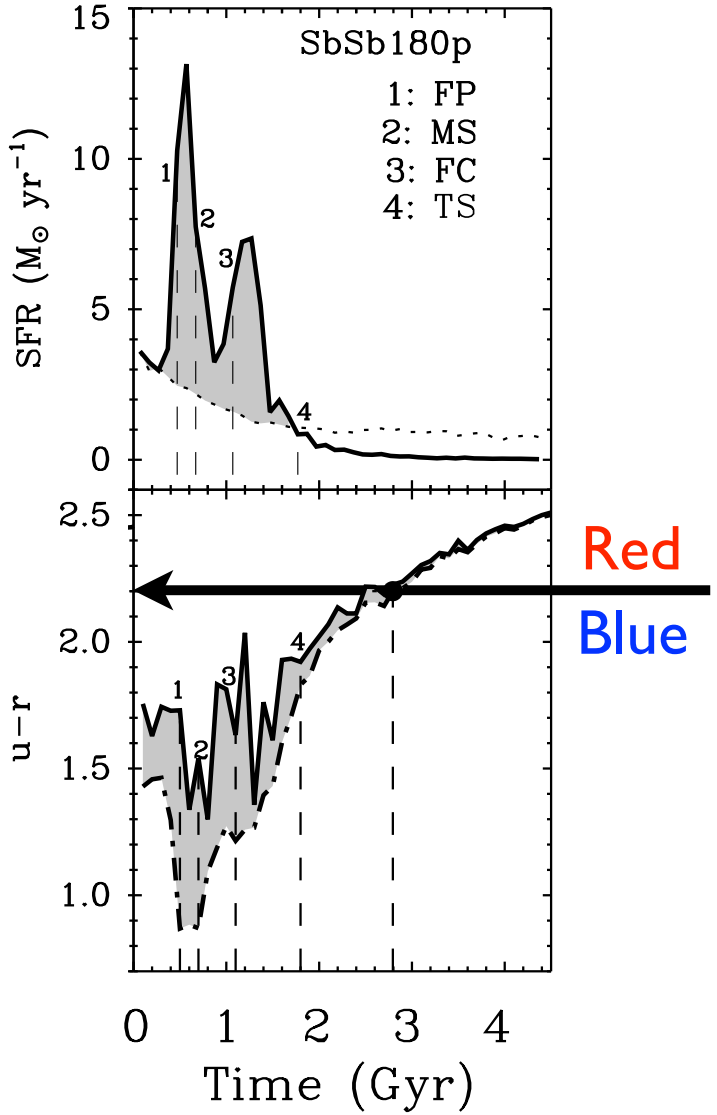


Davies et al. 1983

All simulated merger remnants



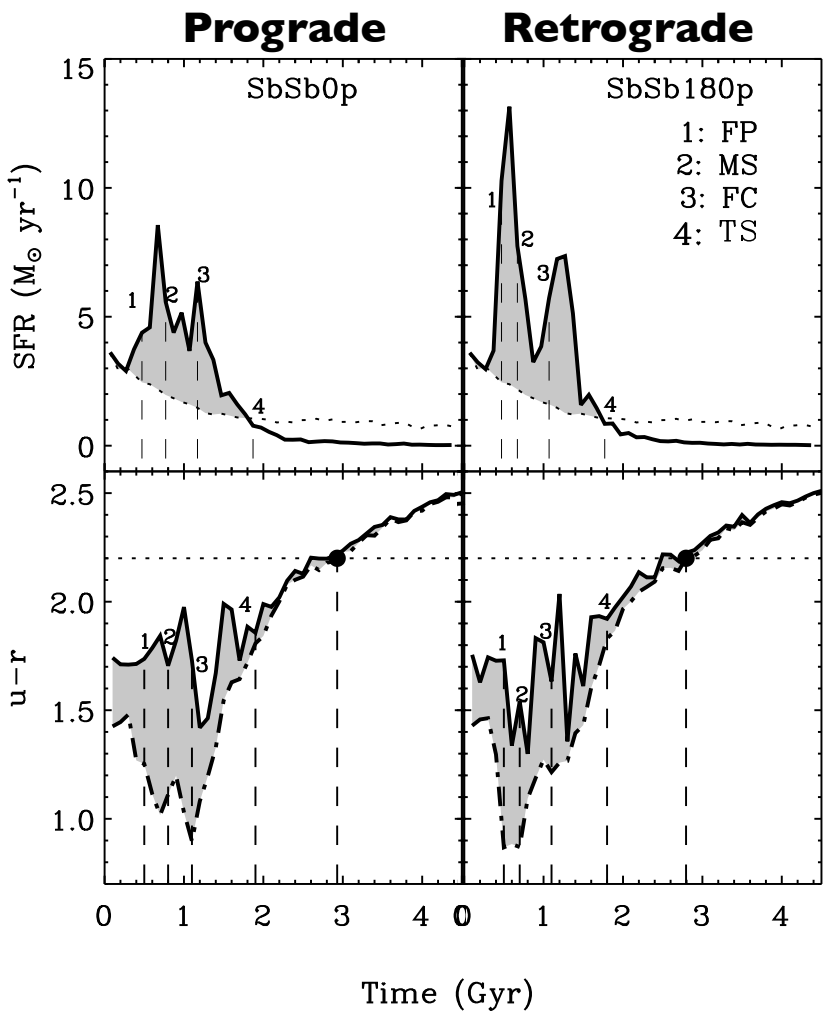
Star formation rates & u-r



u-r = 2.2 (Strateva et al. 2001)

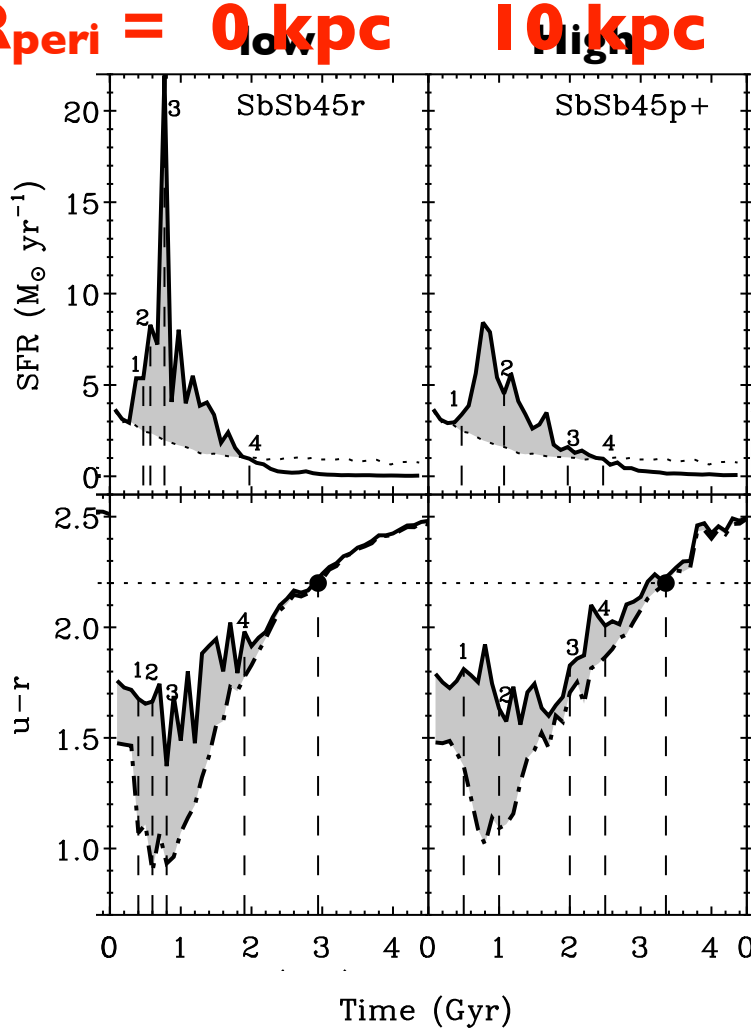
Star formation rates & u-r

1. inclination of host galaxy



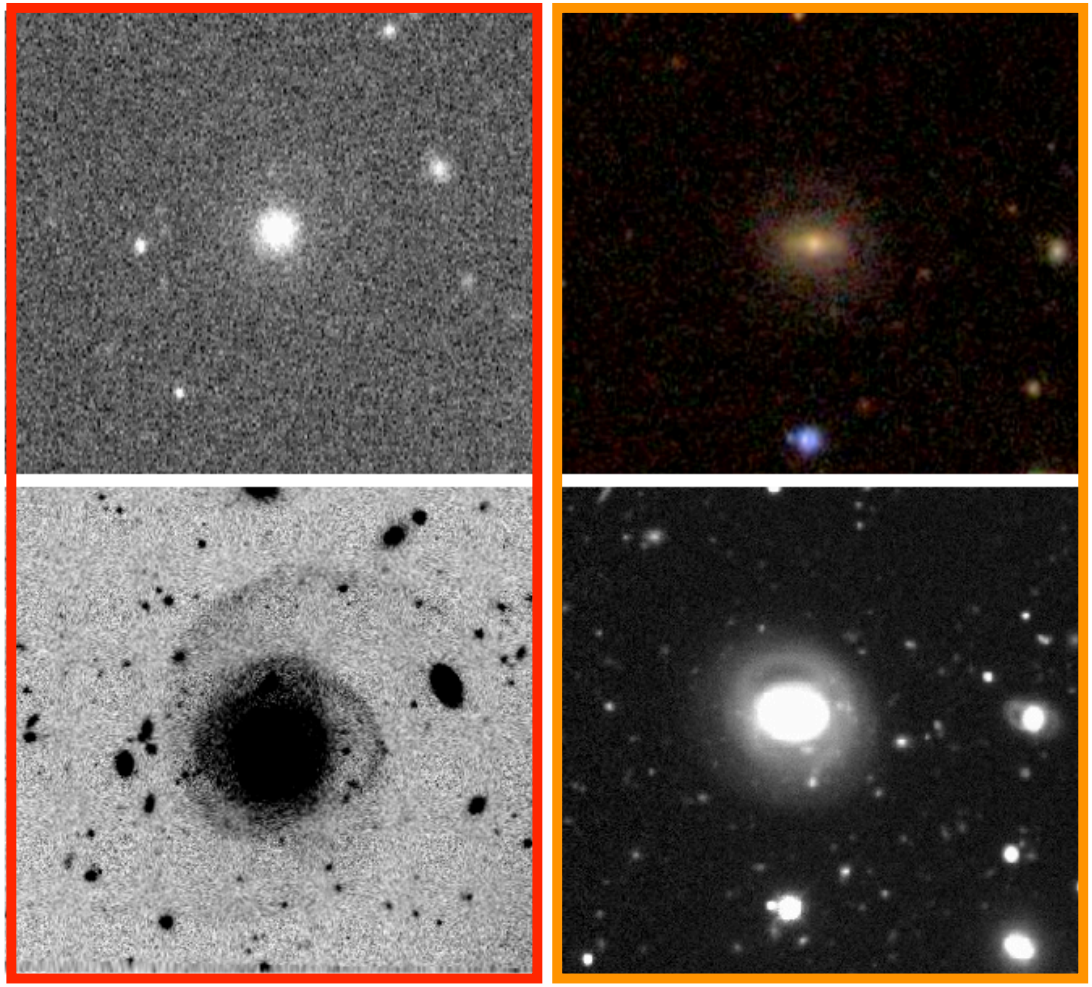
2. orbital angular momentum

R_{peri} = 0 kpc 10 kpc



Merger Feature timescale

Abell 2670 (z~0.076)



by SDSS

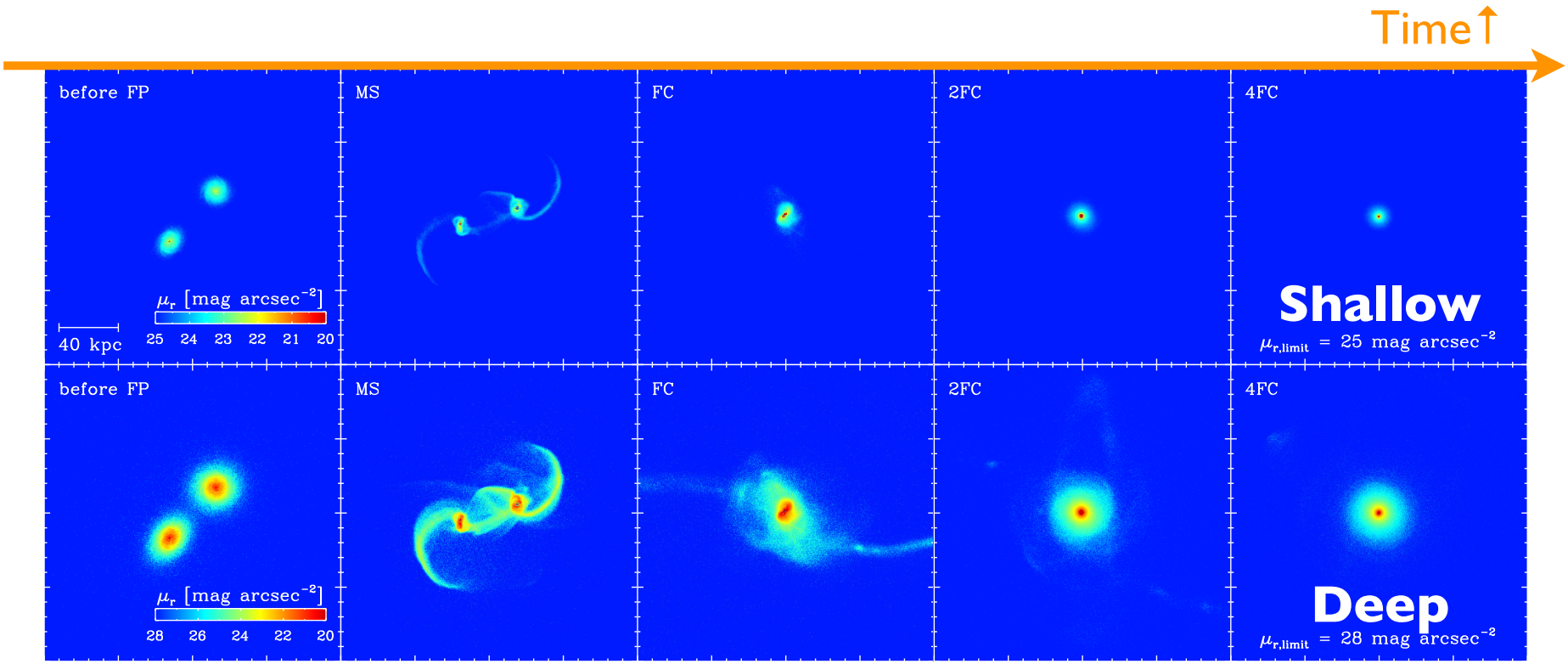
μ = 25 mag arcsec^{-2}

by CTIO r'

μ = 28 mag arcsec^{-2}

Courtesy of Y.K. Sheen

Merger Feature timescale



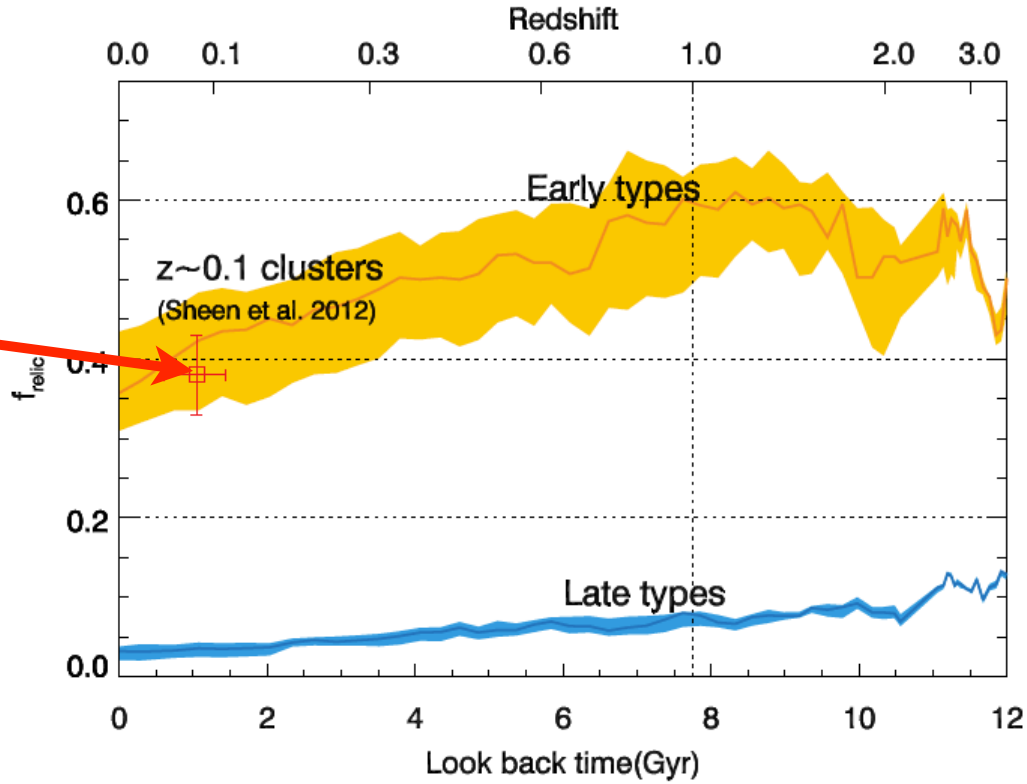
t_{MF25} / t_{FC}	t_{MF28} / t_{FC}
~ 2 ± 0.3	~ 5 ± 0.4

MF_{28} and merger relics

Table 5.2. Comparisons between cluster and field

	Class	Cluster	Field[a]
	PM	38 ± 5%	49%
Bulge-dominated[c]	I	4 ± 1%	21%
	Total	42 ± 6%	70%

Sheen et al. 2012

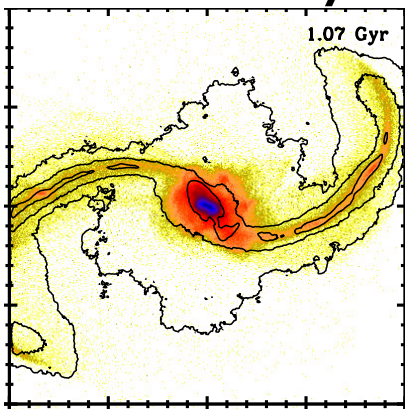


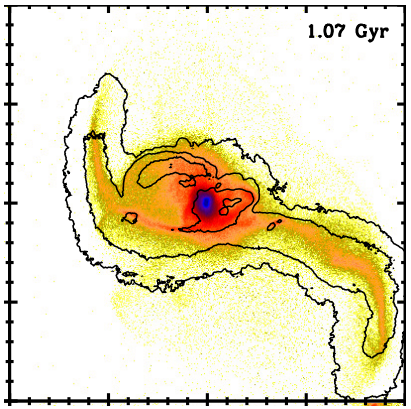
Yi et al. 2013

Merger sequence in cluster potential

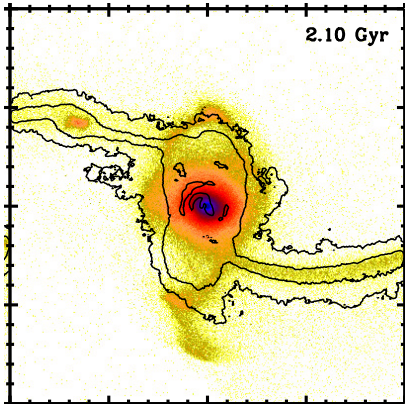
In isolated system

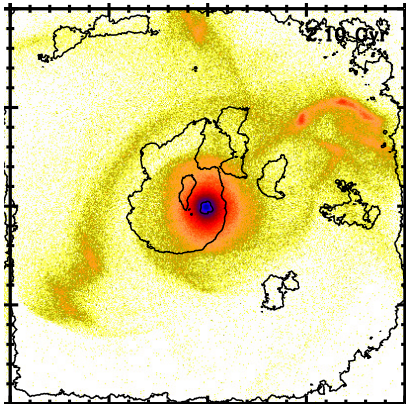
Inside cluster halo (Virgo-like)



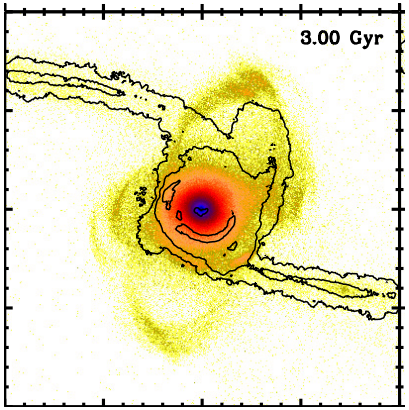


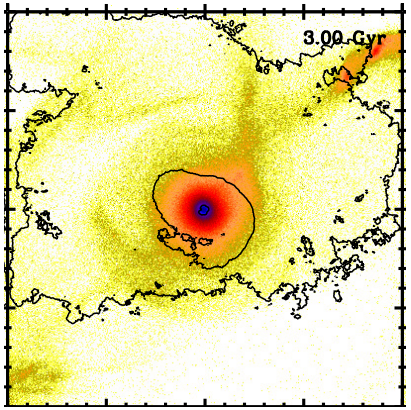
t_{FC}





$2t_{FC}$





$3t_{FC}$

Summary and Conclusion

1. SFR and color evolves spontaneously; however, apparent color during starburst does not clearly show the coevolution due to dust attenuation.

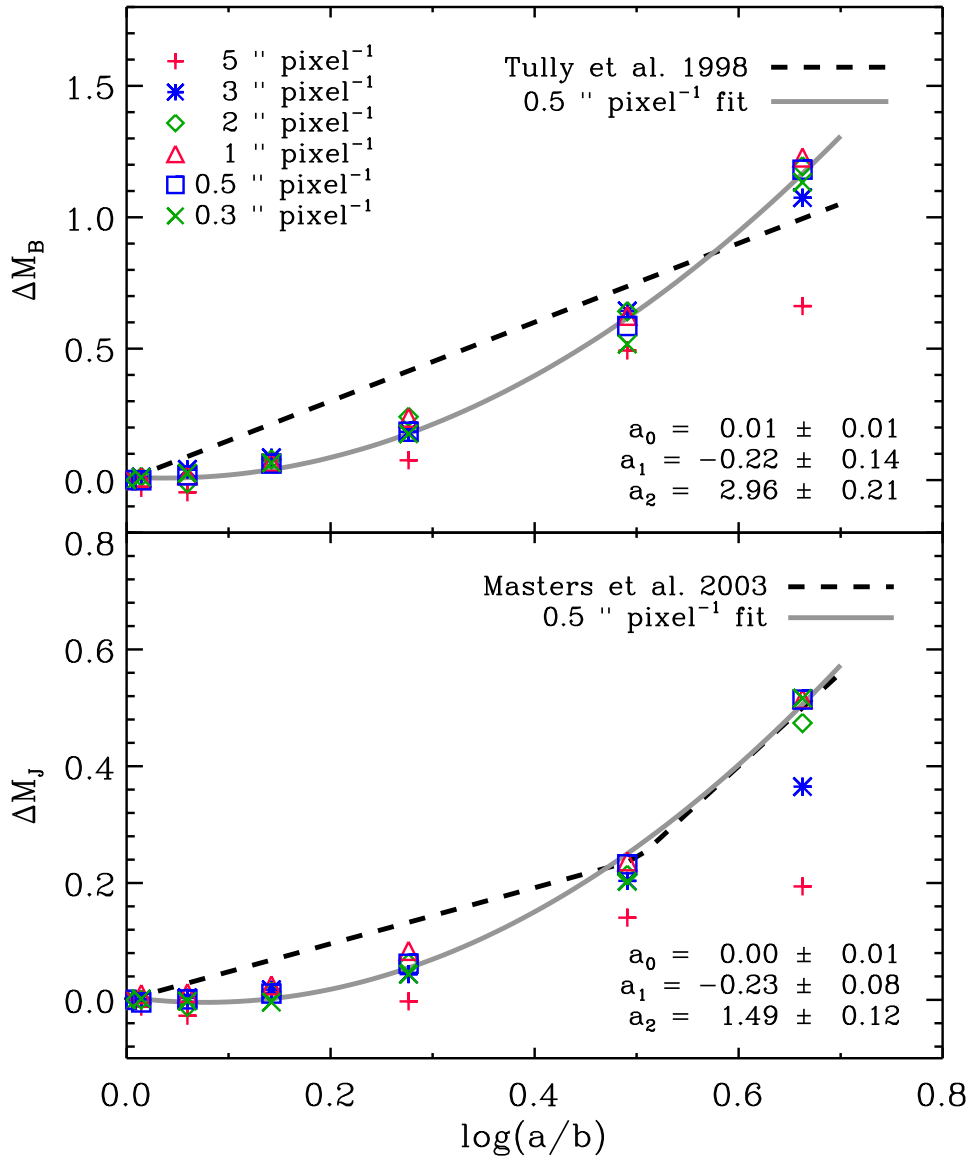
2. The merger-feature timescale measured by deeper imaging is longer. With this timescale, it is able to explain demography of early-type in clusters of galaxies.

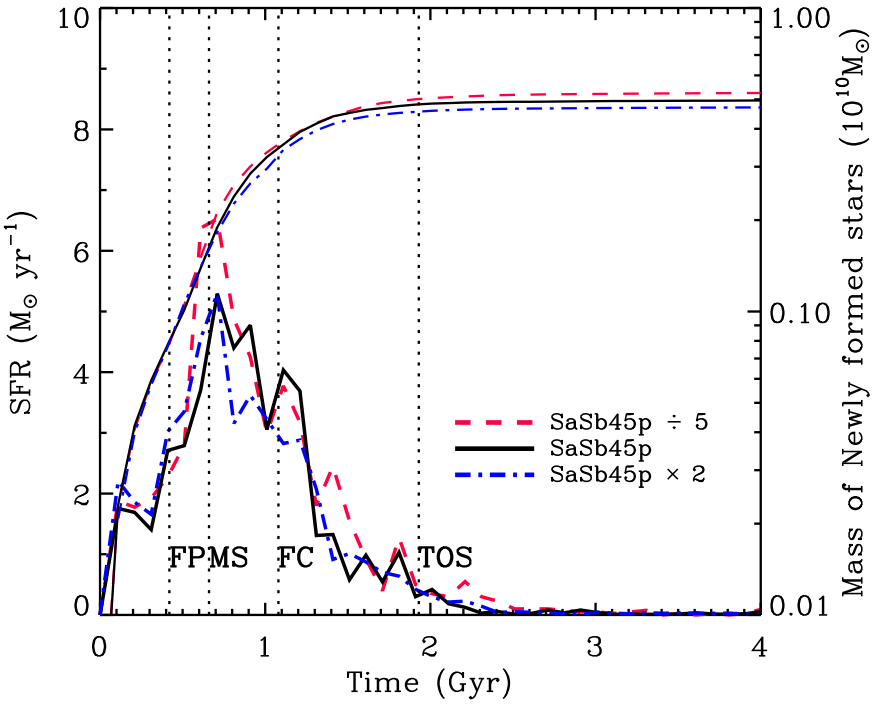
Future work

1. Expansion of parameter space

2. Submission to ApJ (July, 2013)

Thank you


5 '' pixel^{-1}
3 '' pixel^{-1}
2 '' pixel^{-1}
1 '' pixel^{-1}
0.5 '' pixel^{-1}
0.3 '' pixel^{-1}
Tully et al. 1998
0.5 '' pixel^{-1} fit
a_0 = 0.01 ± 0.01
a_1 = −0.22 ± 0.14
a_2 = 2.96 ± 0.21
ΔM_B
Masters et al. 2003
0.5 '' pixel^{-1} fit
a_0 = 0.00 ± 0.01
a_1 = −0.23 ± 0.08
a_2 = 1.49 ± 0.12
ΔM_J
log(a/b)


SFR ($M_\odot$ yr^{-1})
Mass of Newly formed stars ($10^{10} M_\odot$)
SaSb45p ÷ 5
SaSb45p
SaSb45p × 2
FPMS
FC
TOS
Time (Gyr)