P. Di Matteo

Starburst galaxies: triggering mechanisms and dependence on the environment

Strong starbursts in the local Universe are generally concentrated into the central regions of galaxies. Internal dynamical processes, related to non axisymmetric perturbations like bars, spiral patterns and lopsidedness, play an important role in driving angular momentum redistribution and determining gas inflows into the central regions. These non-axisymmetric perturbations in galaxy disks can be produced by secular evolution, through accretion from cosmological filaments, or during much more violent processes, like interactions and mergers. After reviewing the role played by asymmetries in driving gas inflows and star formation enhancements in the central regions of galaxies, I will discuss the impact interactions and mergers have in enhancing star formation, and the resulting average intensity, frequency and duration of merger-driven starbursts. Finally I will present some recent works on the effects the environment has in triggering (or limiting) bursts of star formation, discussing in particular the evolution of galaxies in compact groups and in the periphery of galaxy clusters.

STARBURST GALAXIES: TRIGGERING MECHANISMS AND DEPENDENCE ON THE ENVIRONMENT

PAOLA DI MATTEO (PARIS OBSERVATORY)

Extreme starbursts in the local Universe - Granada, 21st-25th June 2010

OUTLINE

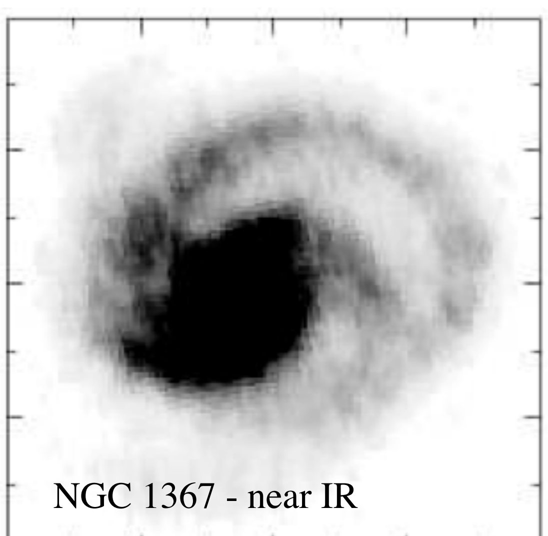
- Global asymmetries in galaxies
  - Lopsidedness
  - Bars
- Interactions and mergers and their impact in triggering SF
  - When?
  - Where?
  - What is the typical SF enhancement in interacting galaxies?
  - Dependence on the mass ratio
  - Tracing the gas inflows
- Dependence on the environment
  - Compact groups
  - Clusters

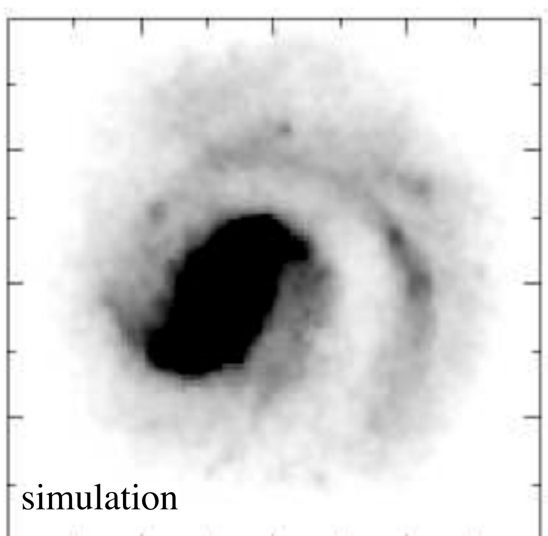
STAR FORMATION AND LOPSIDEDNESS

Spatial extent much larger along one half of a galaxy than the other

Lopsidedness is common: the stellar disks in nearly 30 % of galaxies have significant lopsidedness, with $A_1 > 0.1$

The origin of lopsidedness could be due to the disk response to a tidal encounter (Weinberg 1995, Jog 1997, Walker et al. 1996), or to gas accretion (Bournaud et al. 2005, Mapelli et al. 2008), or to asymmetries in the dark halo





Bournaud et al. 2005, A&A, 438, 507

STAR FORMATION AND LOPSIDEDNESS

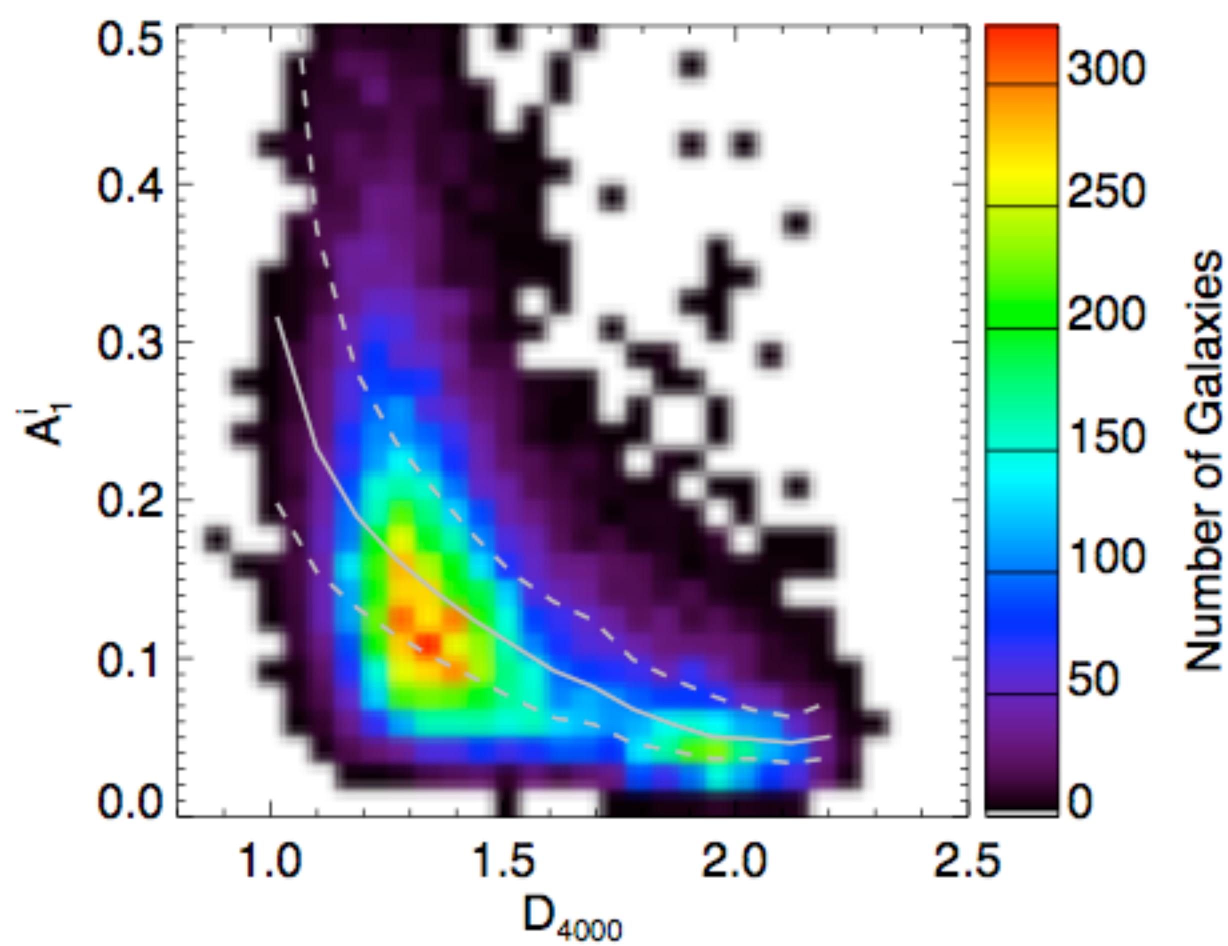
➡ Zaritsky & Rix 1997: correlation between lopsidedness and excess B-band luminosity emitted by a young stellar population

➡ Rudnick et al. 2000: both recent (< 0.5 Gyr) and current (~ 10^7 yr) SF strongly correlated with lopsidedness

➡ Reichard et al. 2009:

✓ **Strong link between lopsidedness and recent/ ongoing central star formation**

✓ At a fixed mass, more lopsided galaxies have systematically lower gas-phase metallicity



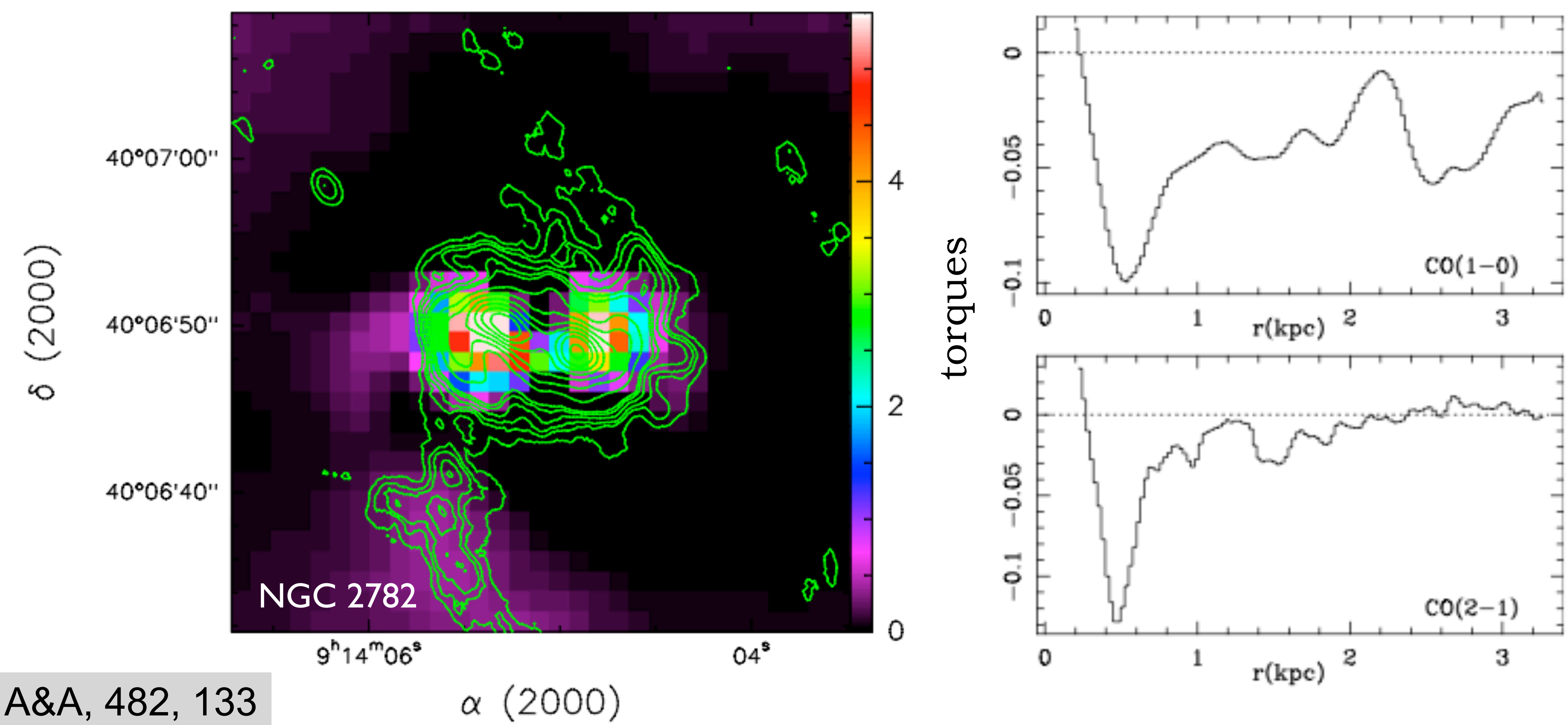
Reichard et al. 2009, ApJ, 691, 1005

THE INFLUENCE OF BARS ON STAR FORMATION

Large-scale bars are very common in disk galaxies

No sign of a drastic decline in the fraction of strong bars up to z~ 1 (Jogee et al. 2004)

Bars efficiently redistribute angular momentum in galaxies and drive gas inflows into the central (r <1-2 kpc) regions



Hunt et al. 2008, A&A, 482, 133

THE INFLUENCE OF BARS ON STAR FORMATION

- ➡ Central molecular gas concentration larger in barred than unbarred galaxies (Sakamoto et al. 1999)

- ➡ Barred galaxies show enhanced radio continuum and infrared emissions compared with unbarred ones (Hummel 1981)

- ➡ Starburst galaxies tend to be more barred compared with the non-starburst galaxies (Arsenault 1989; Ho, Filippenko, & Sargent 1997; Hunt & Malkan 1999)

- ➡ Barred galaxies have shallower metallicity gradients than unbarred galaxies (Vila-Costas & Edmunds 1992)

INTERACTIONS AND STAR FORMATION

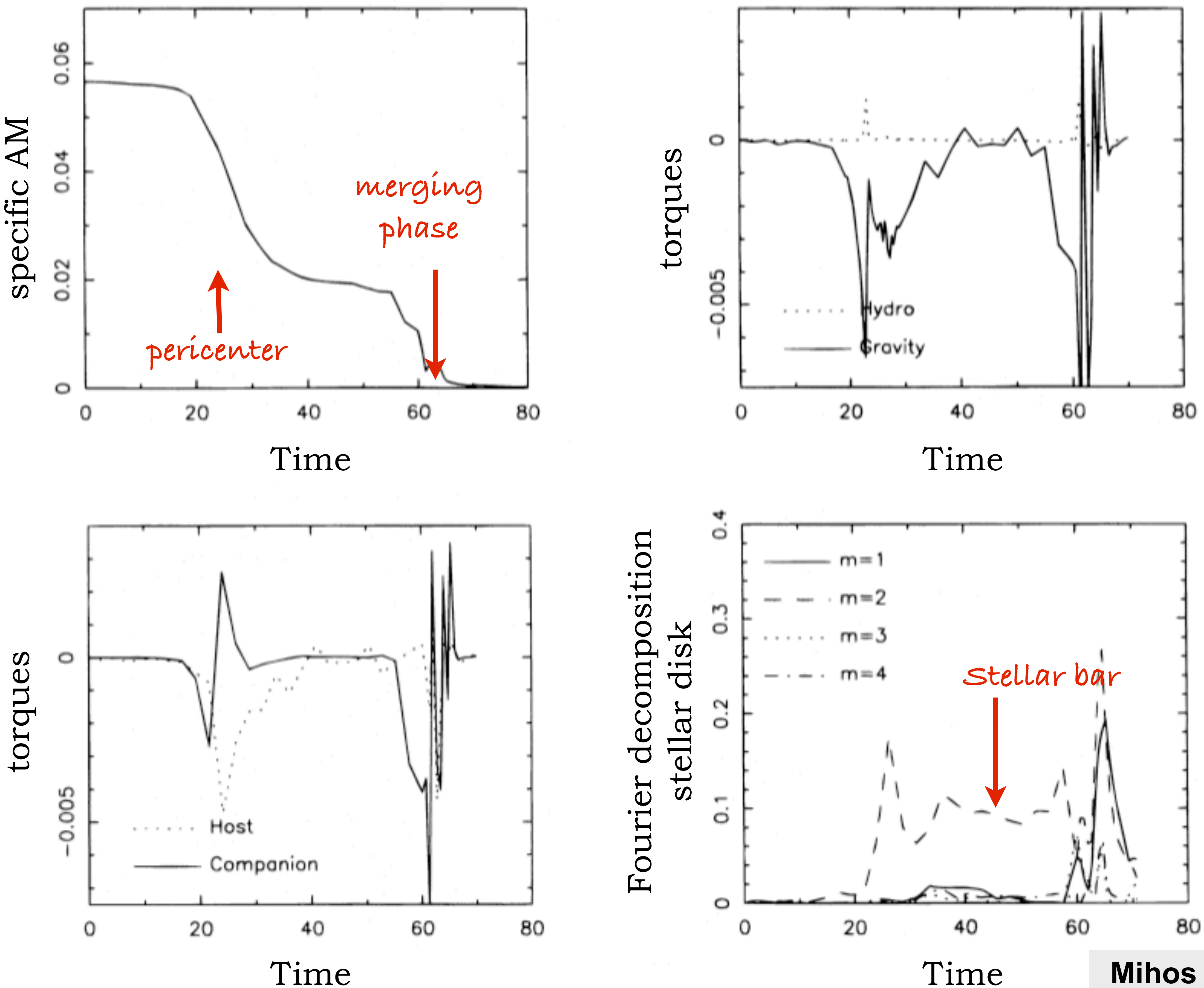
In the local Universe, the most luminous galaxies are associated to gas-rich interactions and mergers (Sanders & Mirabel 1996), **but this is not reciprocal**

Galaxy interactions and mergers are not a sufficient conditions to drive strong starbursts

- at low redshift (Bergvall et al. 2003, Knapen & James 2009)
- at intermediate redshifts (Jogee et al. 2009, Robaina et al. 2009)
- in simulations (Di Matteo et al. 2007, 2008)

The amplitude of the SF burst depends on a number of parameters: morphology, gas content, strength of the tidal effects, mass ratio...

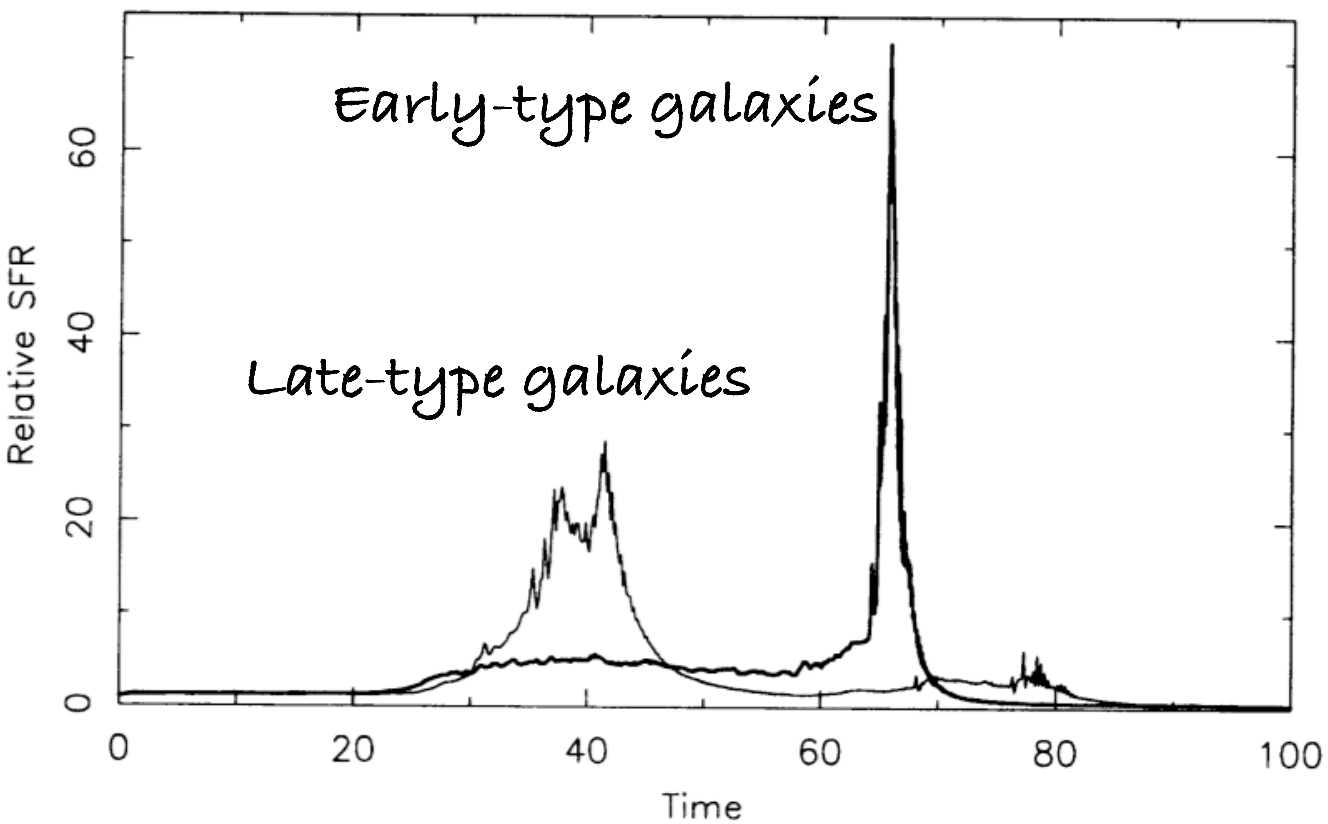
INTERACTIONS AND GAS DYNAMICS



Gas inflows generated by the gravitational torques exerted by stars of the host galaxy

Mihos & Hernquist,1996, ApJ,464, 641

SF ENHANCEMENT IN GALAXY PAIRS: WHEN?



Mihos & Hernquist,1994, ApJL,431, 9

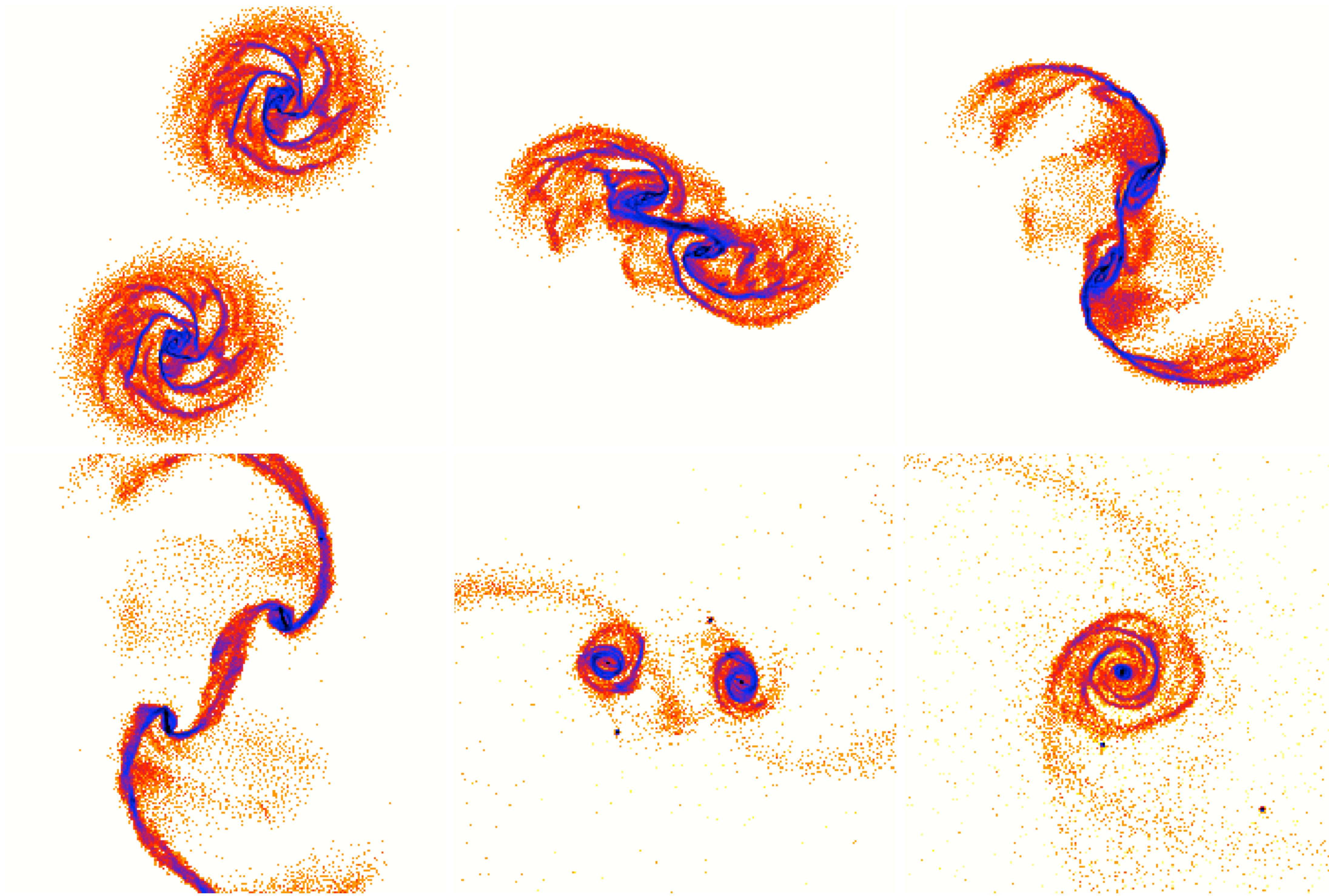
Bursts of star formation at each pericenter passage and in the final merging phase

However, **the timing of the SF burst depends on the morphology of the interacting galaxies**

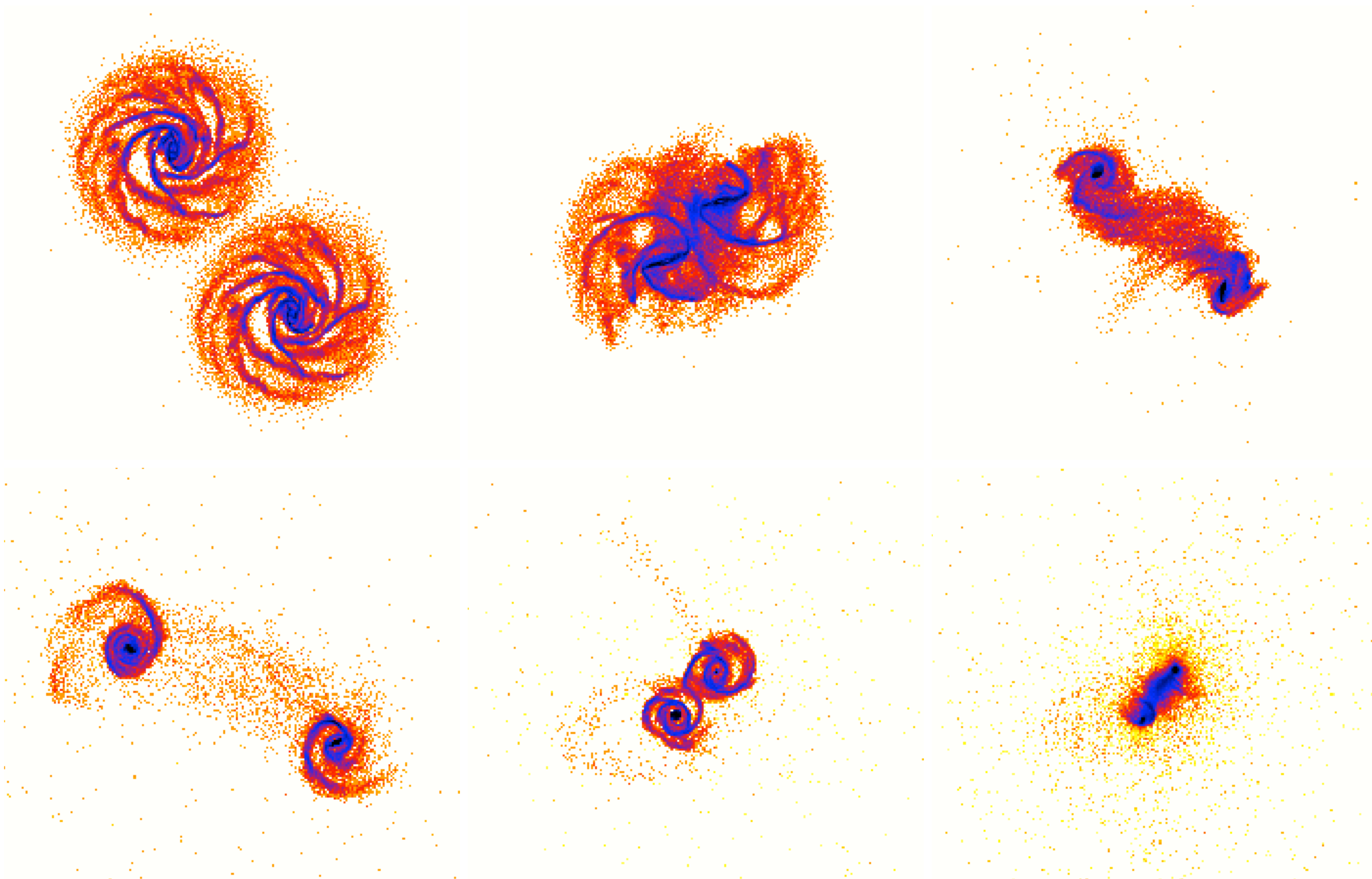
Disks of **bulgeless galaxies** are destabilised already in the early phases of the interaction
➡ **the SF peaks at the first pericenter passage**

Disks of **early-type galaxies** are less susceptible to bar formation in the first phases of the interaction
➡ gas not consumed and available to produce a **strong SF burst in the final phases of the merger**

SF ENHANCEMENT IN GALAXY PAIRS: WHERE?



SF ENHANCEMENT IN GALAXY PAIRS: WHERE?

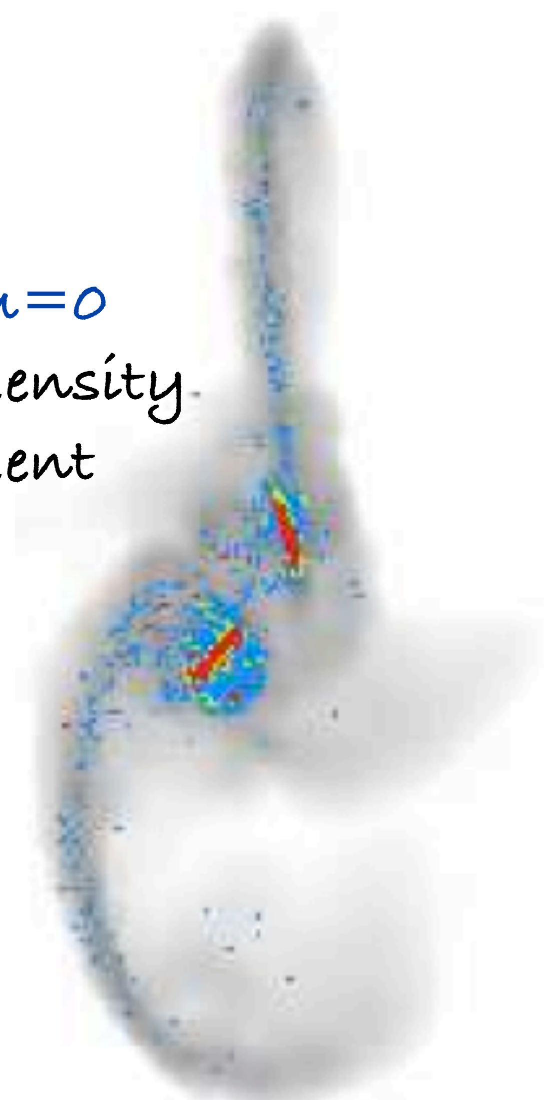


SF ENHANCEMENT IN GALAXY PAIRS: WHERE?

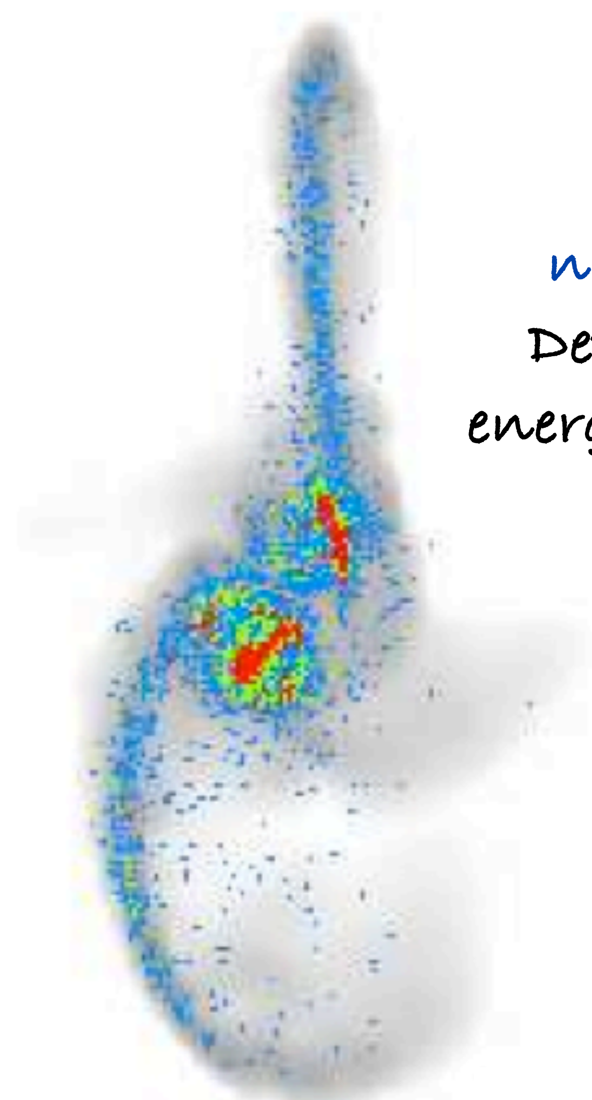
Dependence on the SF prescription:
more extended SF if the local rate of energy dissipation in shocks is included

$$\dot{\rho}_* = C_* \, \rho_g^n \, \mathrm{MAX}(\dot{u}, 0)^m$$

n=1, m=0
SF only density dependent

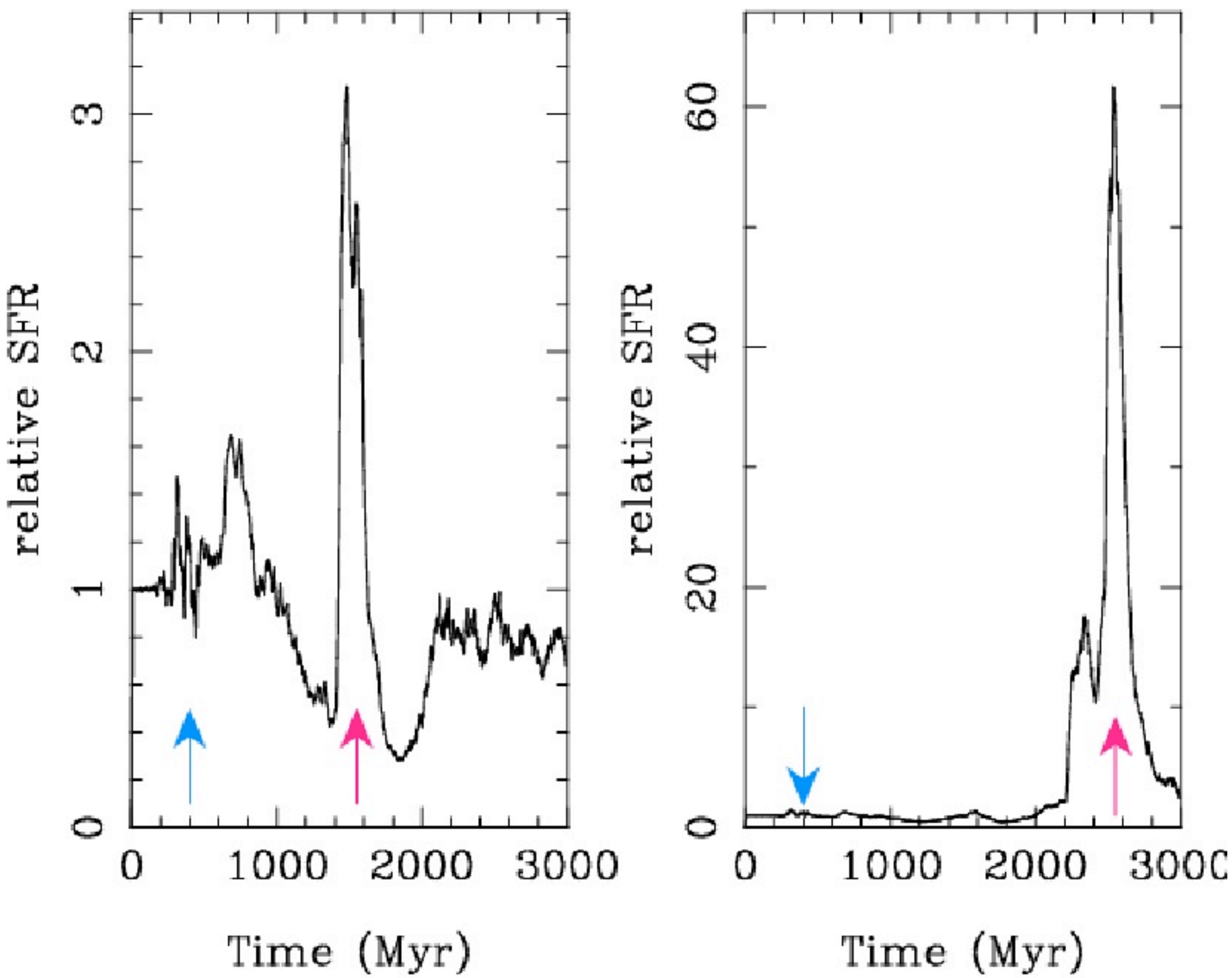


n=1, m=0.5
Dependence on energy dissipation in shocks



Barnes, 2004, MNRAS, 350, 798

SF ENHANCEMENT IN GALAXY PAIRS: AMPLITUDE

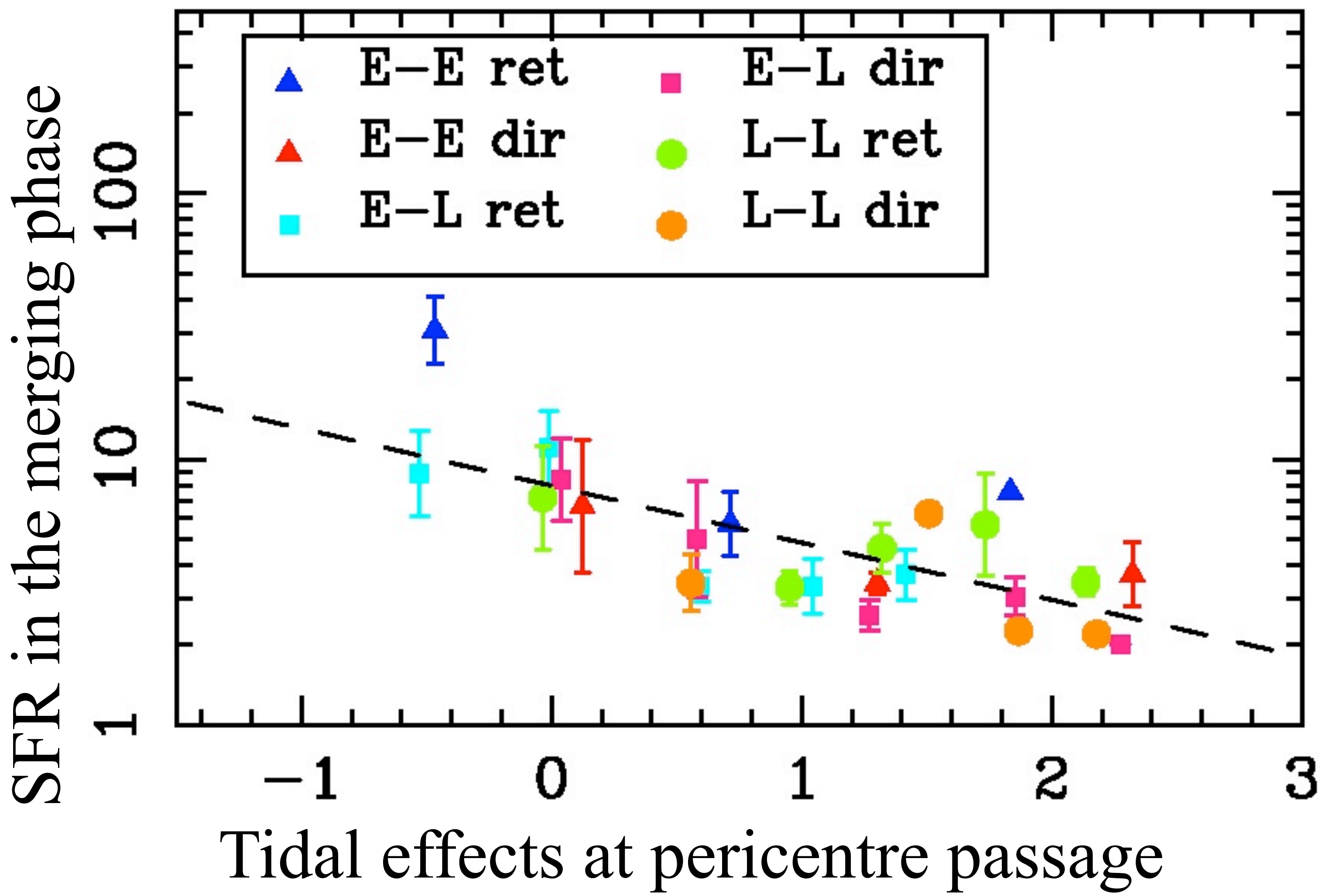


Models predict that a variety of SF histories can be found, from starburst galaxies to low SF enhancements

Di Matteo et al. 2007, A&A, 468, 61

SF ENHANCEMENT IN GALAXY PAIRS: AMPLITUDE

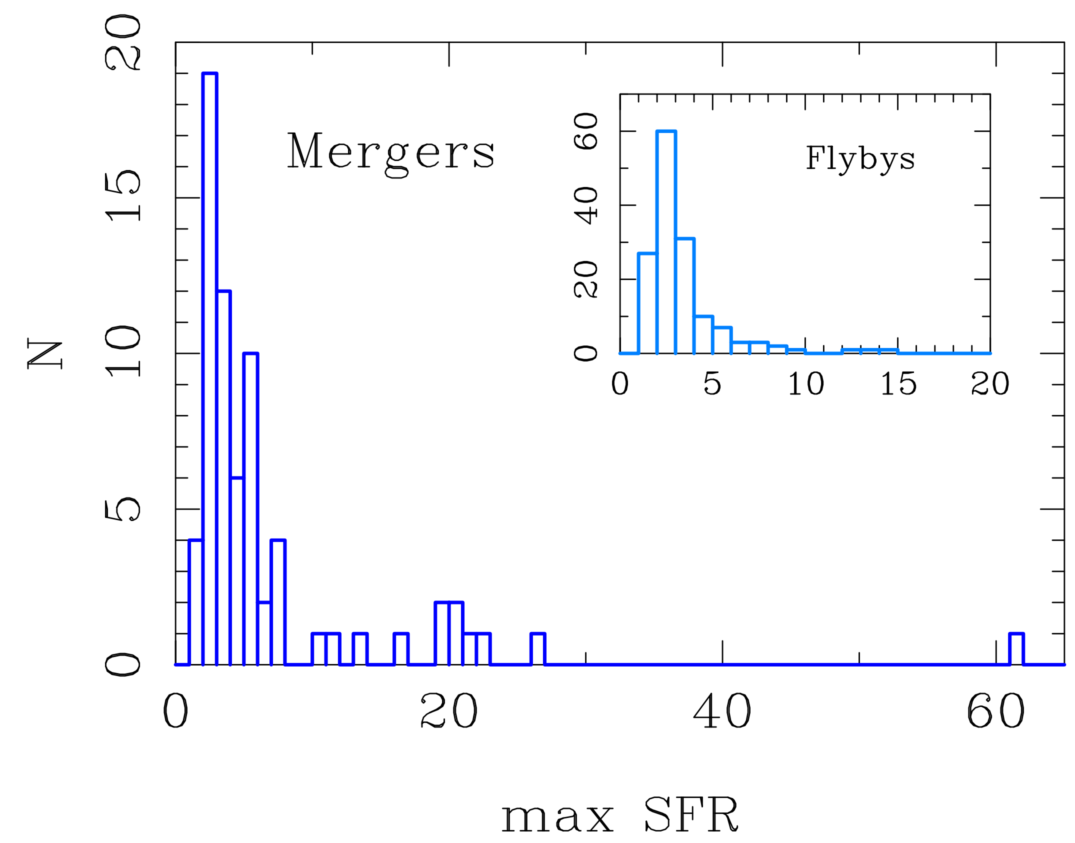
The stronger the tidal effects at the first pericenter passage, the lower the SF enhancement in the merging phase



SF ENHANCEMENT IN GALAXY PAIRS: AMPLITUDE

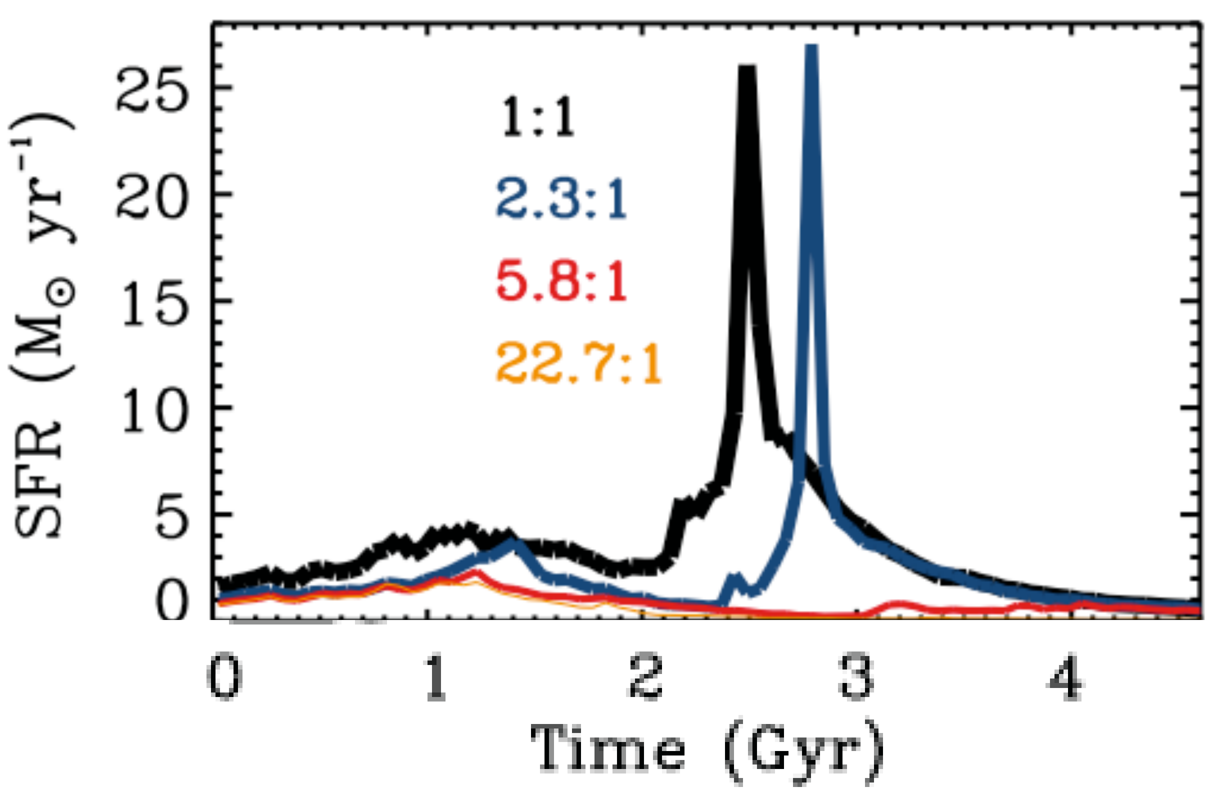
➡ **Strong starbursts** ($SFR/SFR_{iso}>5$) **are rare and found only in about 15% of major galaxy interactions and mergers**

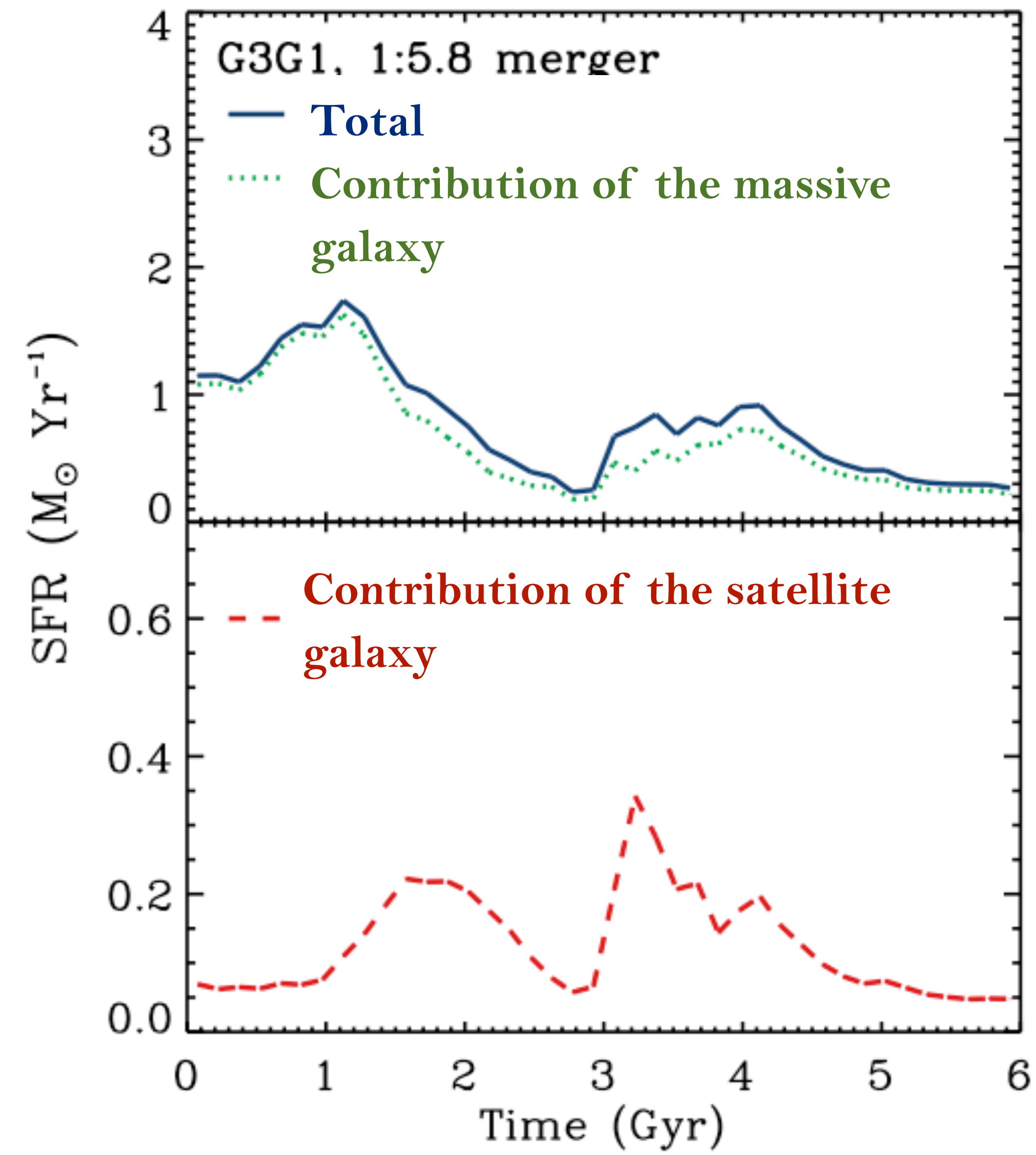
➡ Merger-driven starbursts are also rather short-lived, with a typical duration of the activity of a few 10^8 yr



LOWERING THE MASS RATIO

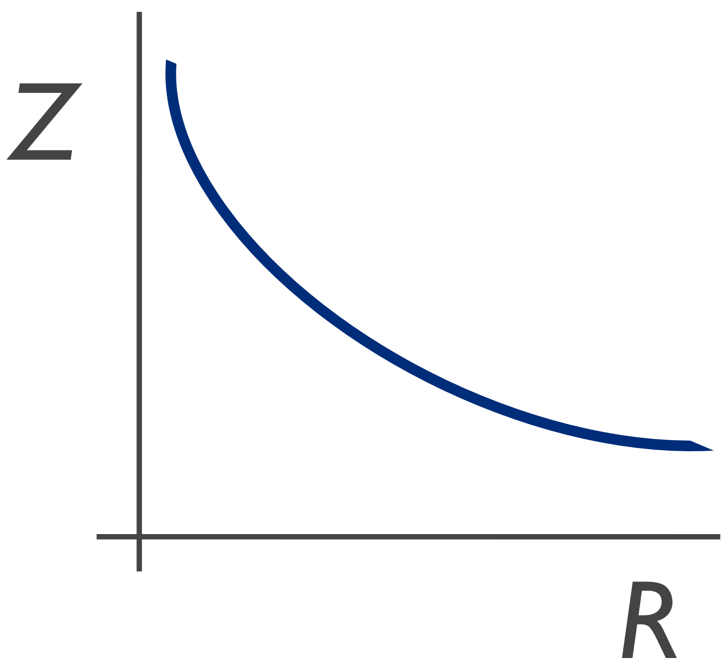
- The SF efficiency decreases with the mass ratio
- For high mass ratios, the SF enhancement takes place mostly in the satellite galaxy





Cox et al., 2008, MNRAS, 384, 386

TRACING THE GAS INFLOWS



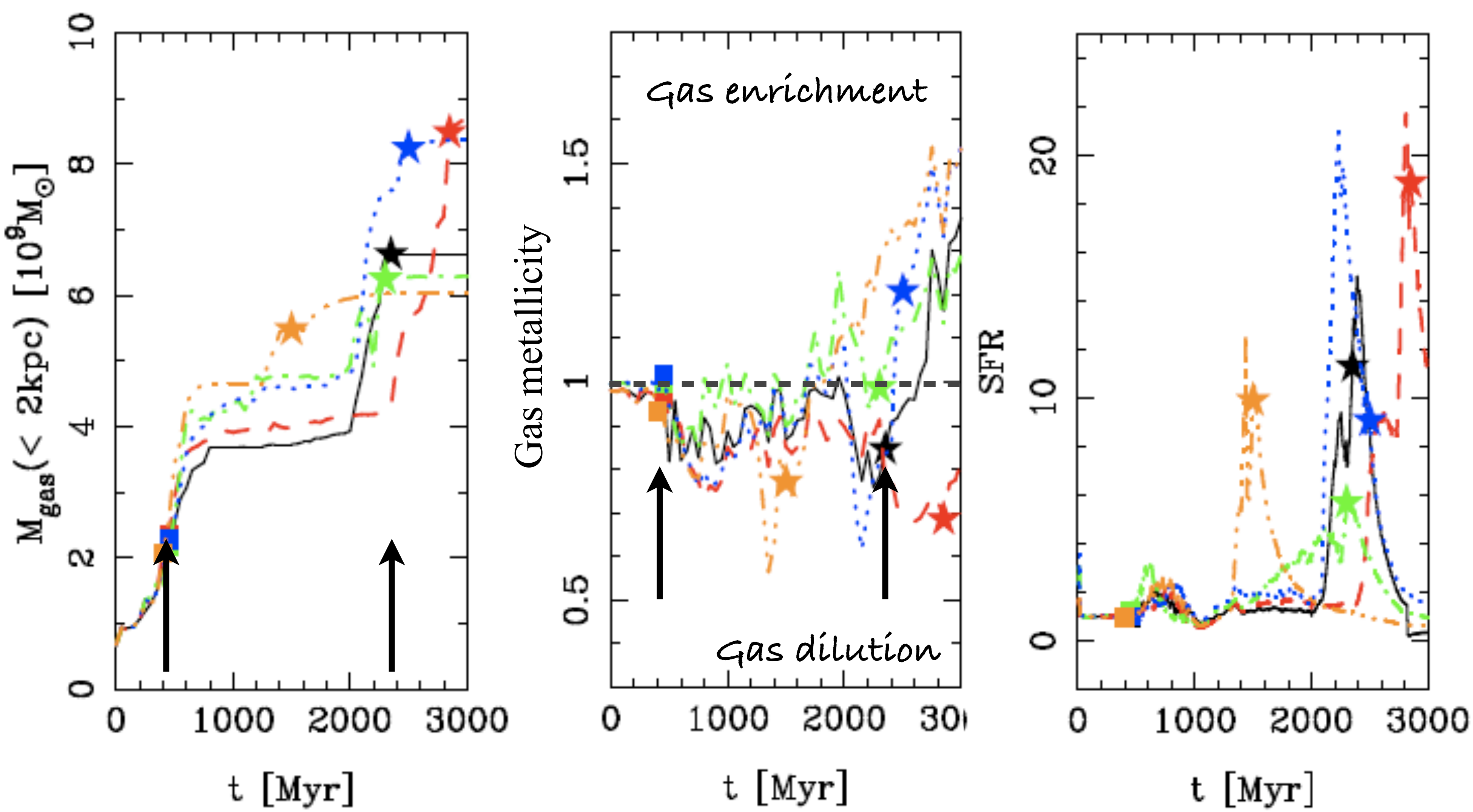
If the progenitor disks have metallicity gradients, interaction-induced gas inflows will drive **low metallicity gas from the outer disk into the central regions**, thus lowering the central (1-2 kpc) gas metallicity, **until SF will increase it again**

TRACING THE GAS INFLOWS

➡ **Kewley et al. 2006**: Galaxy pairs with close projected separations s < 20 kpc have systematically lower metallicities than either the field galaxies or the widely separated pairs

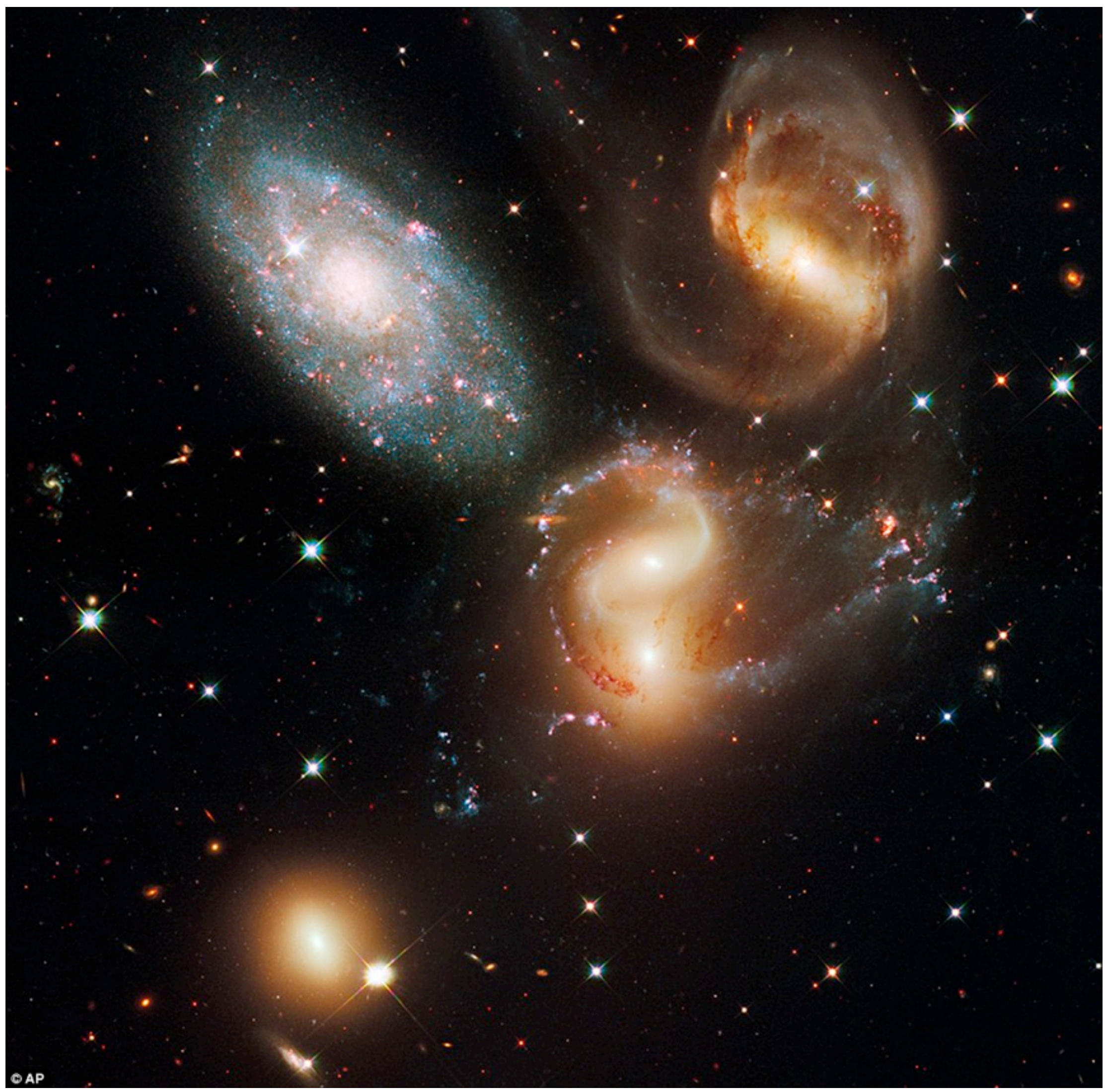
➡ **Rupke et al. 2010**: Metallicity dilution can be reproduced in simulations of interacting galaxy pairs

➡ **Montuori et al. 2010:**
The **dilution phase is very rapid**, less than 5x10^8 yr, and it is **followed by the enrichment of the ISM, due to the interaction-driven enhanced SF**



Montuori et al., 2010, A&A in press, astro-ph/1003.1374

STAR FORMATION IN COMPACT GROUPS



Compact groups constitute an unique environment to study the effects of galaxy interactions,
because of their **high densities** and **low velocity dispersions**

➡ **Continuous gravitational perturbations**

STAR FORMATION IN COMPACT GROUPS

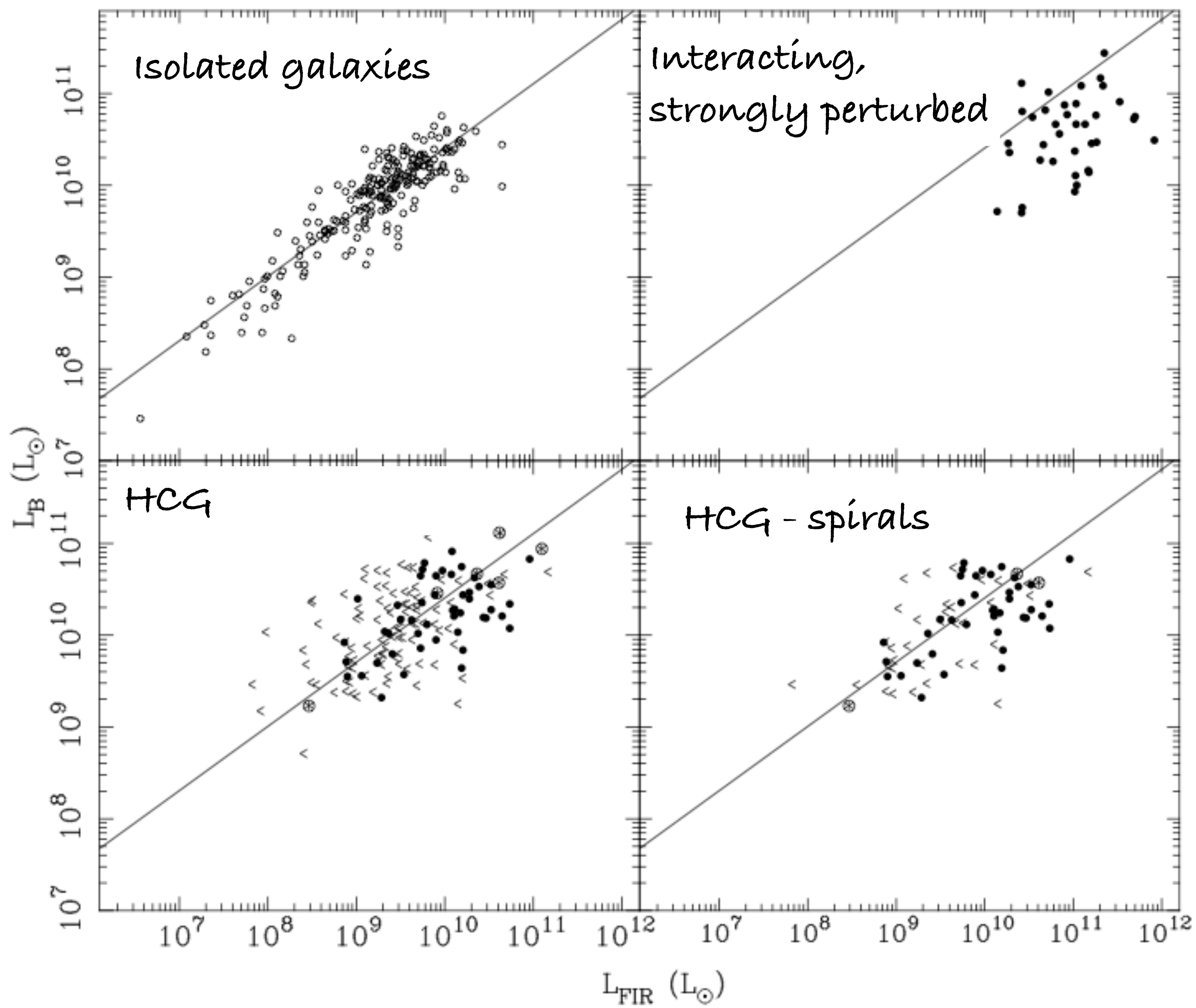
- Although **SF** is enhanced with respect to isolated galaxies, it is **of the same order as in pairs and lower than in violent interacting galaxies**

(Moles et al. 1994, Verdes-Montenegro et al. 1998)

- Galaxies in compact groups are HI deficient (Oosterloo & Iovino 1997)

- Most of them have a normal CO emission (Boselli et al. 1996, Verdes-Montenegro et al. 1998)

Efficient tidal stripping acting in reducing the observed SF rate

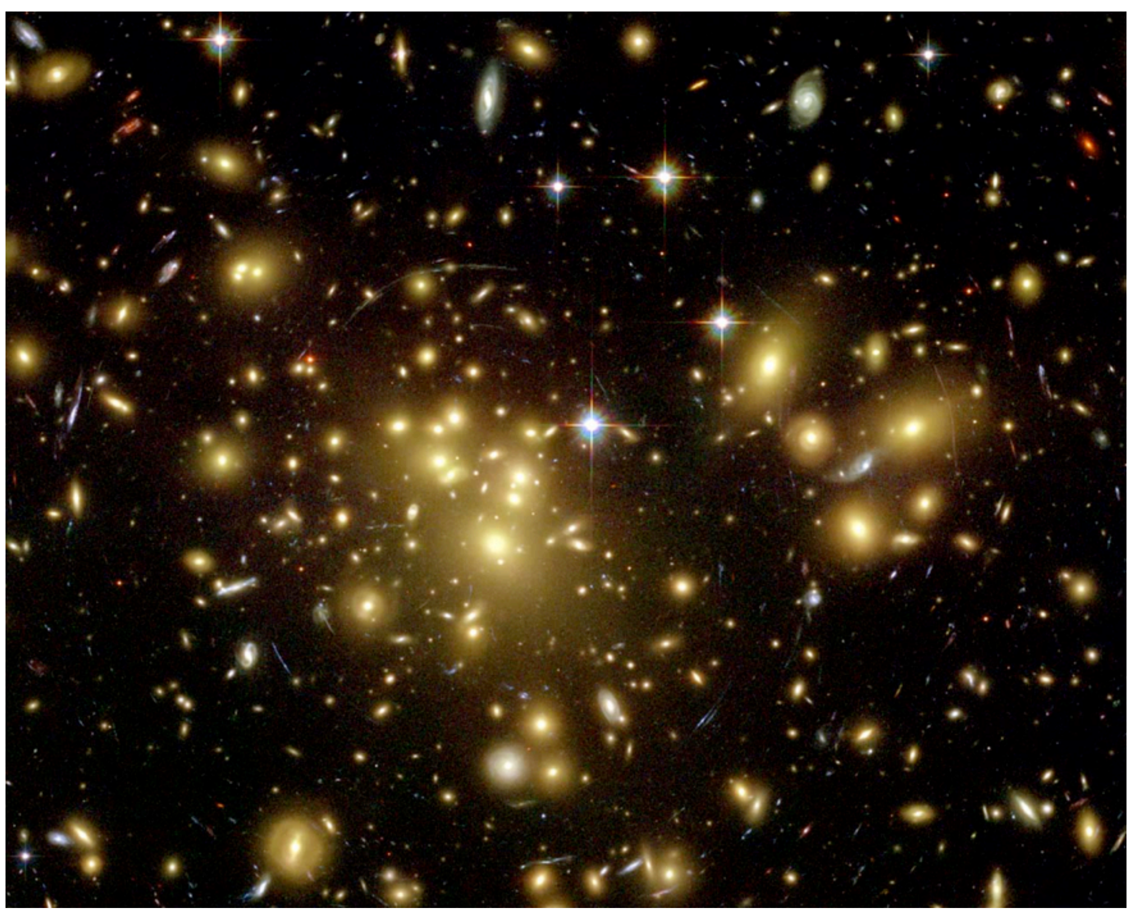


Verdes-Montenegro et al. 1998, ApJ, 497, 89

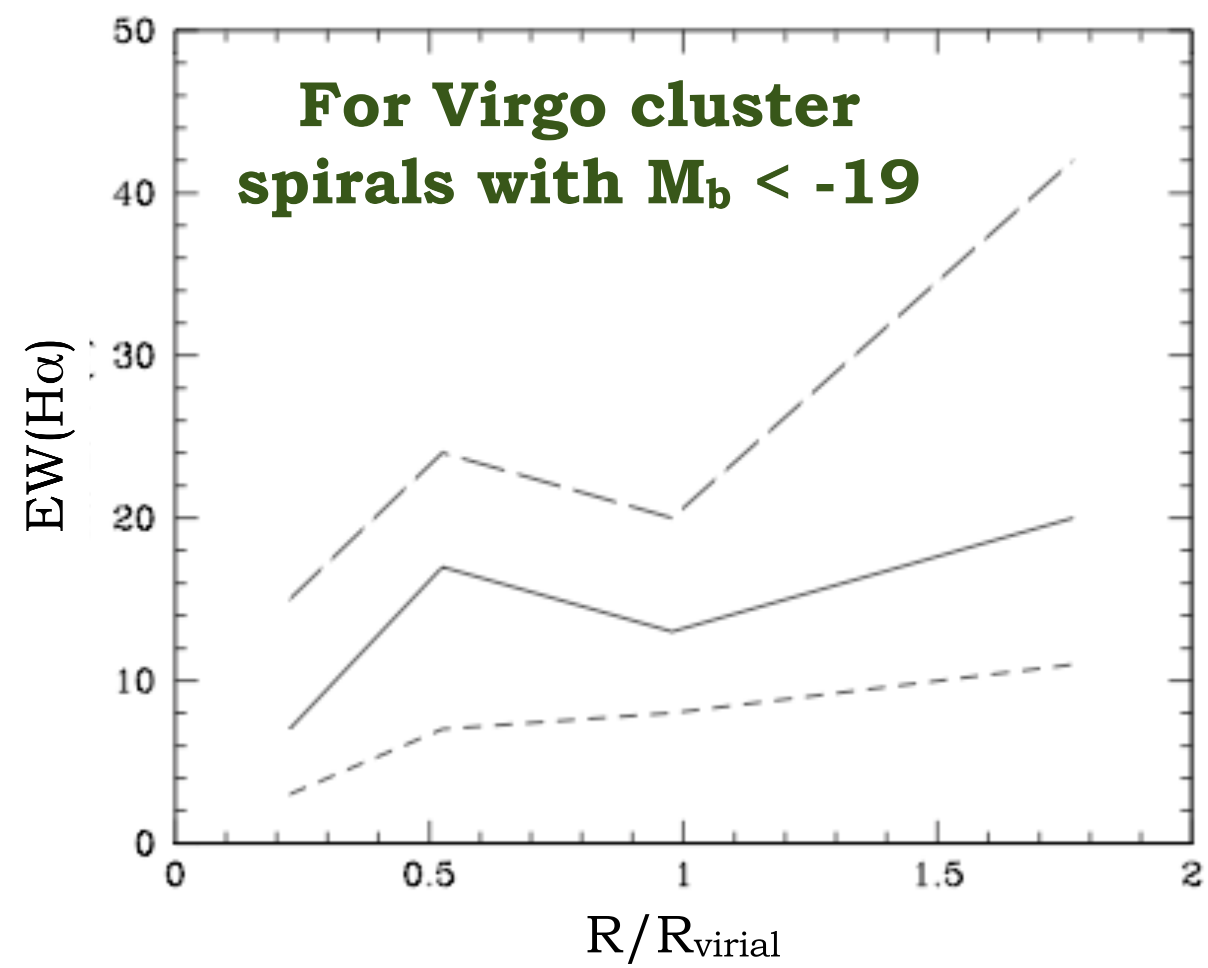
STAR FORMATION IN CLUSTERS OF GALAXIES

Morphological segregation effect (Dressler 1980):
in the center of rich clusters there are more elliptical and spheroidal galaxies with little or no current star formation than star forming galaxies

The mean SFR is found to decrease with decreasing distance from rich clusters (Lewis et al. 2002; $0.05 < z < 0.1$)



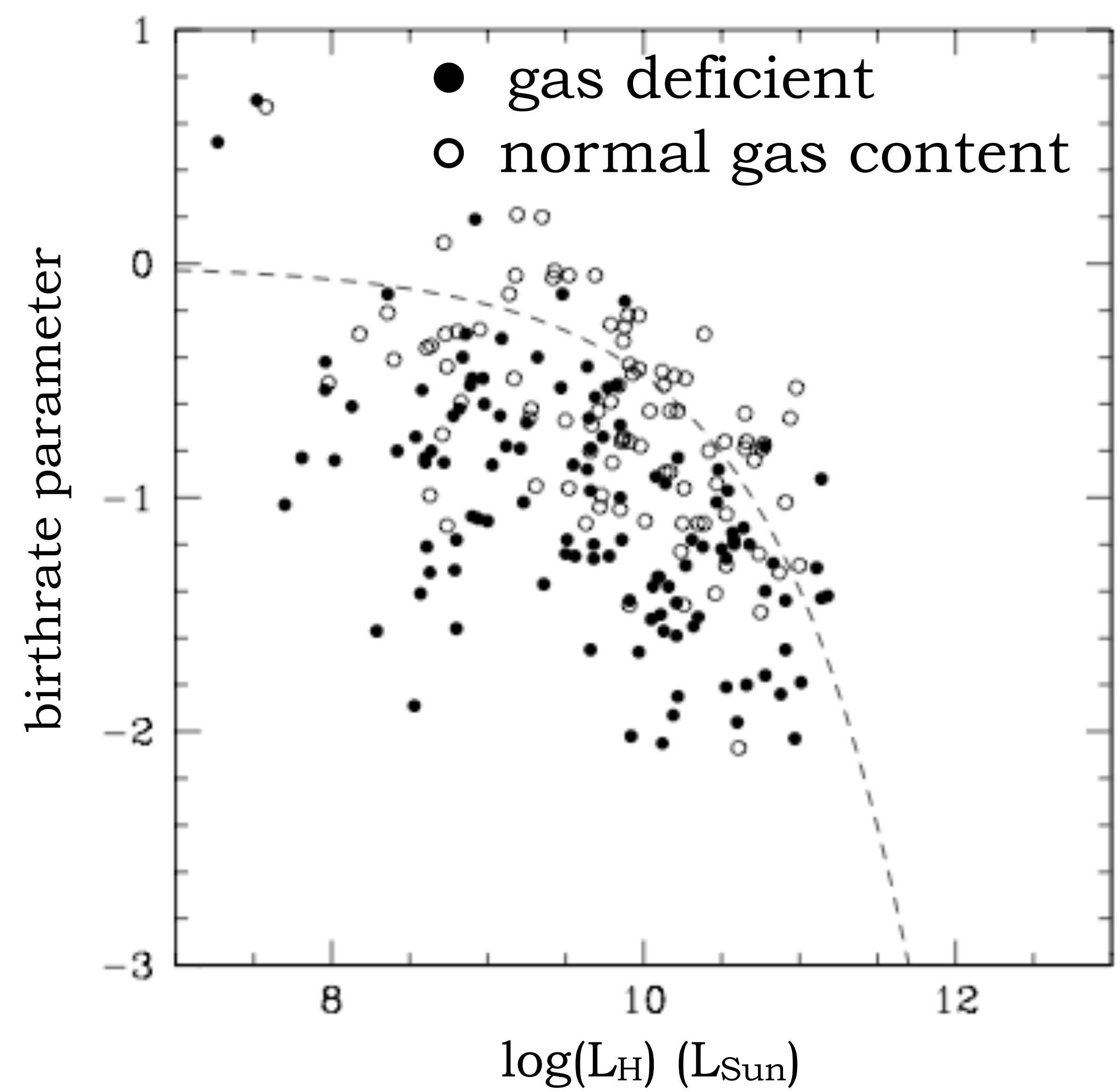
Gavazzi et al., 2002, A&A, 396, 449



STAR FORMATION IN CLUSTERS OF GALAXIES

A large fraction of spiral galaxies in Virgo have a birthrate parameter significantly lower (factor 3) than isolated galaxies of similar luminosity

Galaxies with quenched current star formation coincide with galaxies with significant gas deficiency

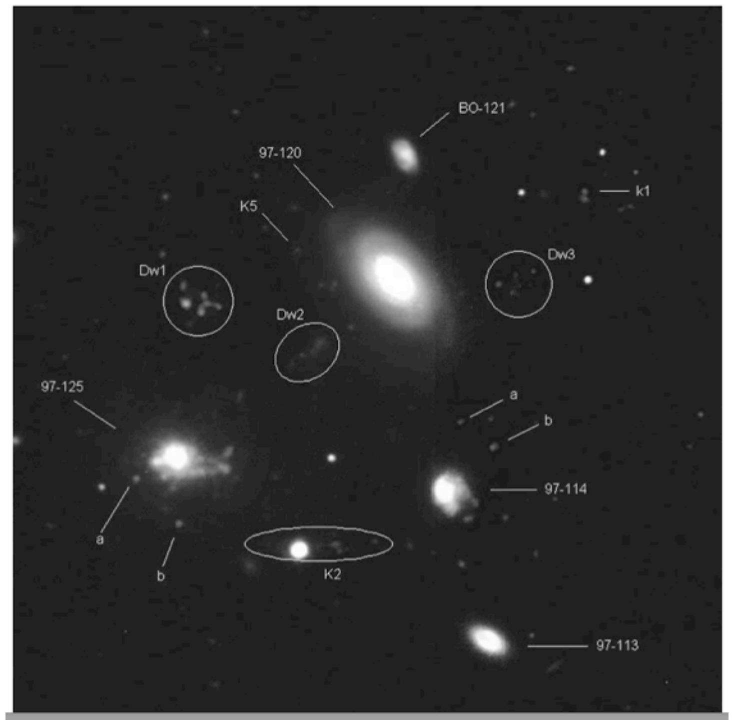


Gavazzi et al., 2002, A&A, 396, 449

Various physical mechanisms may contribute to this trend:

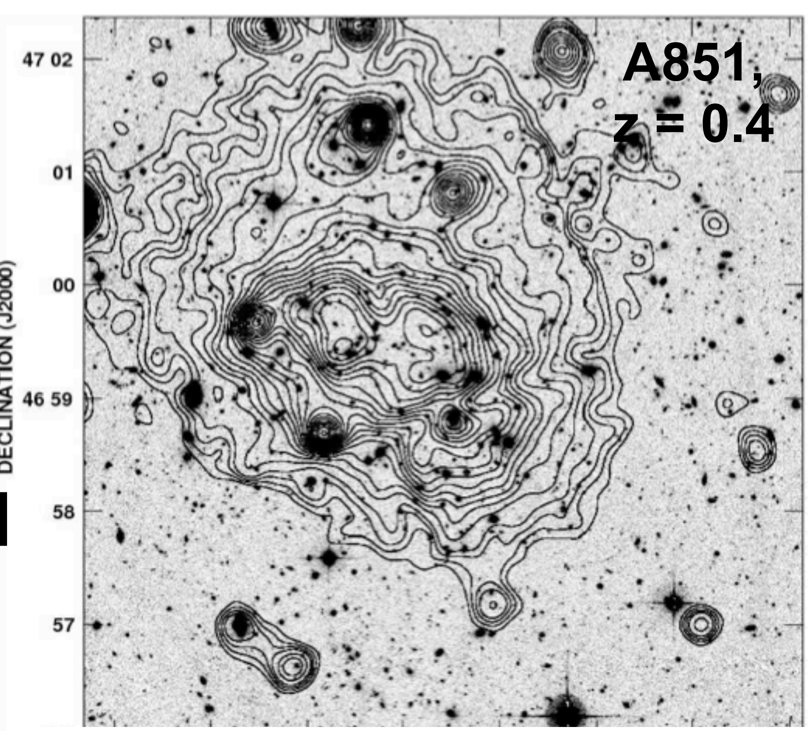
- ➡ galaxy harassment
  (Moore et al. 1996, 1998)
- ➡ ram pressure stripping
  (Gunn & Gott 1972)
- ➡ tidal stirring
  (Mayer et al. 2001)

CLUSTERS PERIPHERY AND FILAMENTS



Gavazzi et al., 2003, ApJ, 597, 210

A star formation burst in a compact group infalling onto the nearby cluster A1367:
10 dwarf galaxies in the group forming stars at a 10 times higher rate than normal galaxies of similar luminosity (Gavazzi e al. 2003)



Oemler et al., 2009, ApJ, 693, 152

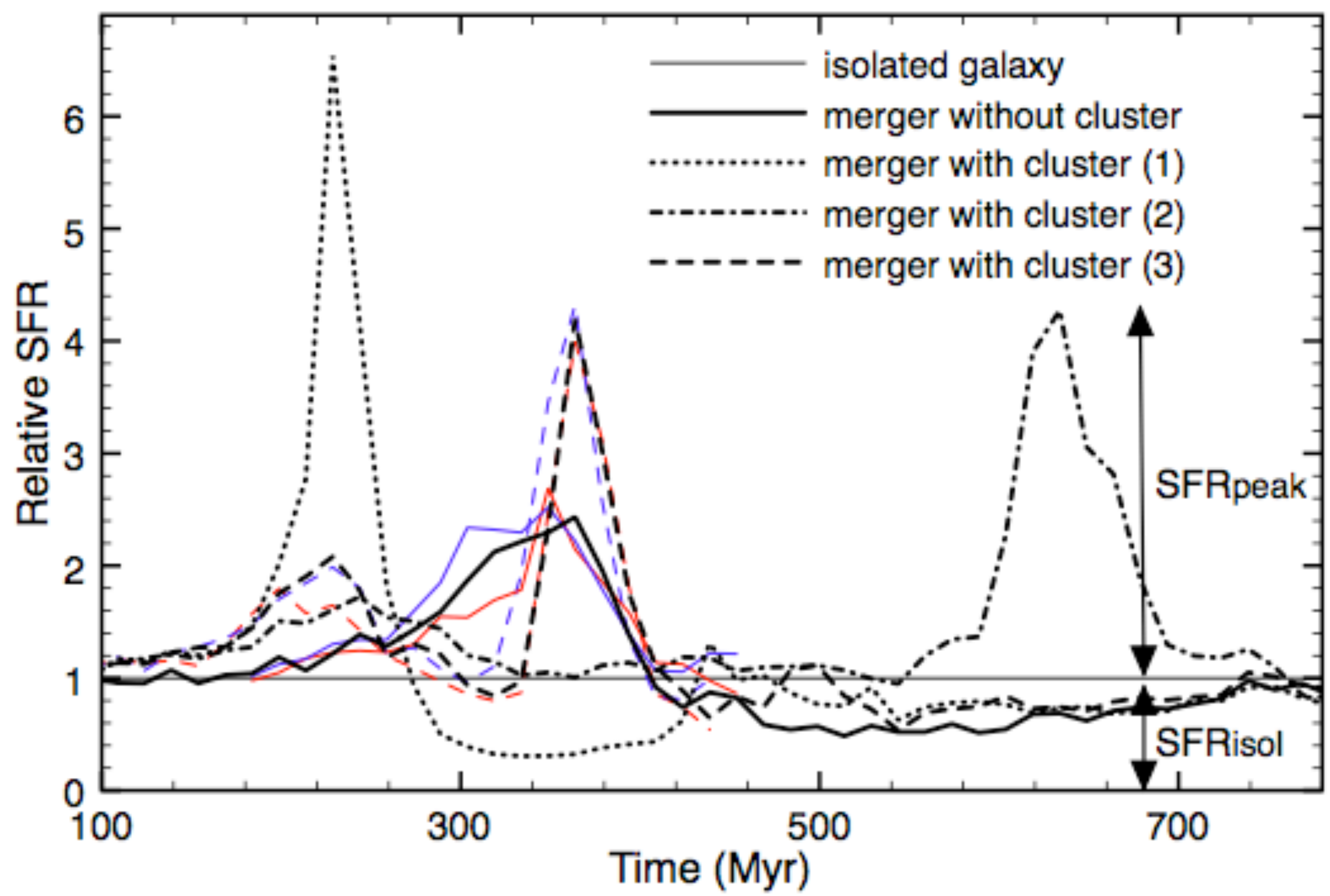
Starbursts also found in galaxy clusters at intermediate redshift, in particular:

- in infalling groups in the cluster outskirts
- in the cluster center

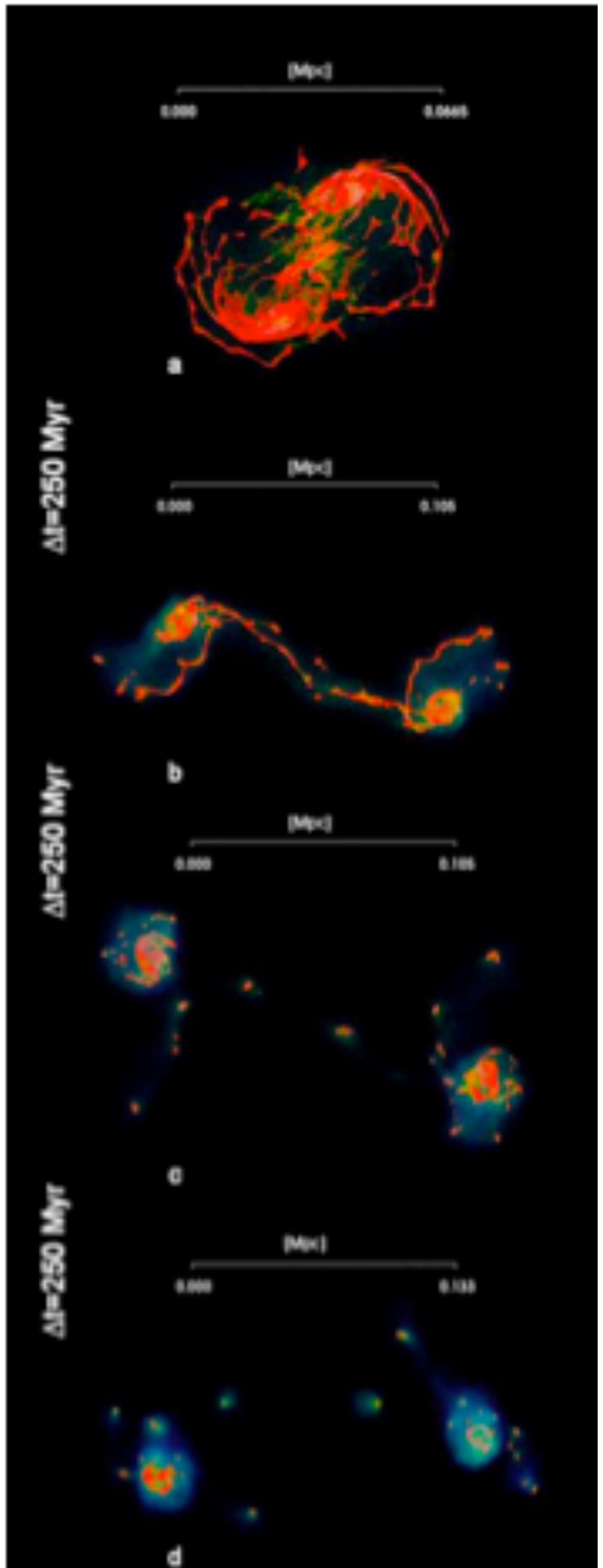
(Oemler et al. 2009)

EFFECT OF THE ENVIRONMENT

Effects of an external potential on merger-driven starbursts
Merger-driven star formation more active (by a factor 2 on average) in the vicinity of groups or clusters compared to mergers in the field
(Martig & Bournaud, 2008)



EFFECT OF THE ENVIRONMENT

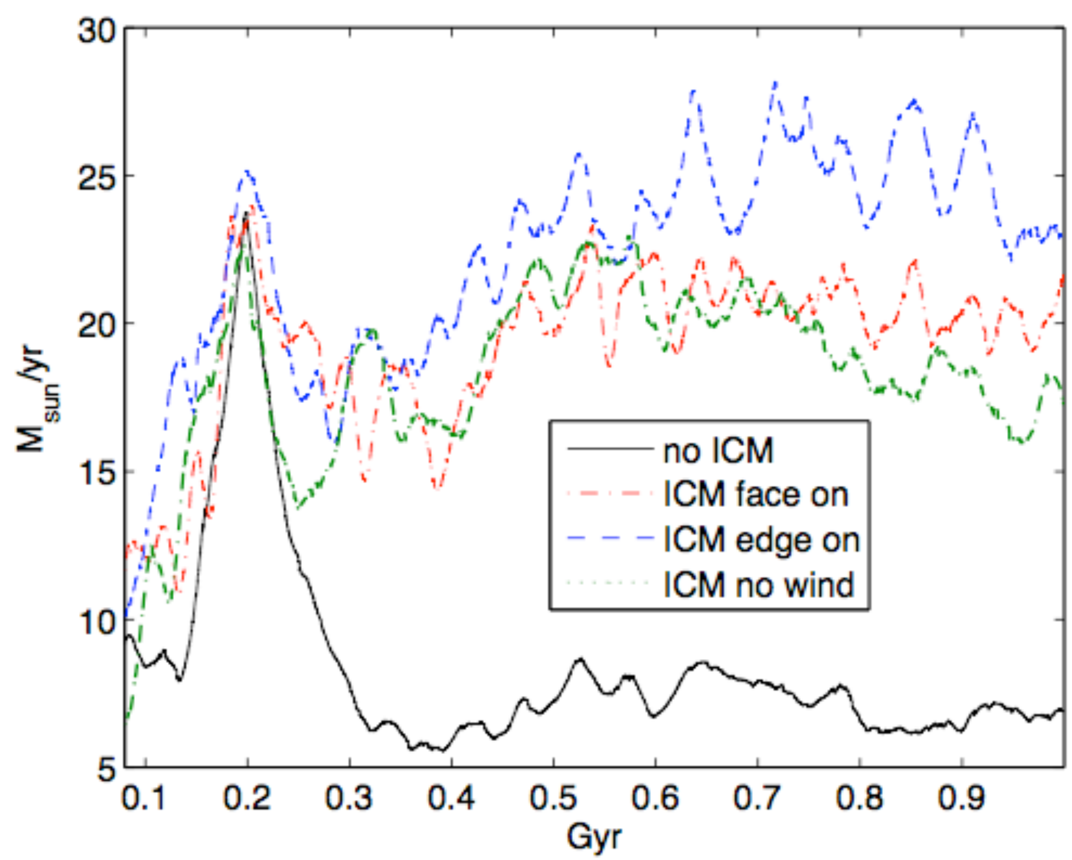


Kapferer et al., 2008

Effects of ram-pressure stripping on interacting galaxies in clusters

The SFR of the interaction is enhanced in the presence of an ambient hot and rare medium by a factor of 3

(Kapferer et al., 2008)



Kapferer et al., 2008, MNRAS, 389, 1405

CONCLUSIONS

➡ Global asymmetries important to redistribute angular momentum and to drive SF enhancements

➡ Fundamental role of interactions and mergers in driving starbursts in the local Universe

➡ However, **the amplitude and distribution of the SF enhancement depends on a number of parameters**: morphology, tidal effects, mass ratio, ...**thus determining a variety of SF histories**

➡ Dependence on the environment

➡ SF can be enhanced by a factor of 2-3 in interacting pairs in the periphery of clusters, due to the potential field of the cluster and/or ram pressure