

Environmental effects on galaxies in clusters

OBSERVATIONS:

e.g. review of Poggianti 2005

- *galaxies properties are different in cluster and field environment
+ radial trend in clusters for color, SF (star formation), morphology.
- * → Quenching star formation in galaxies: SF galaxies → passive.
- * In clusters at medium z , many more SF galaxies:
the so-called Butcher-Oemler effect;
- *Many more lenticulars (S0) at $z=0$ than at intermediate z .
- *cD or BCG+intracluster light – ICL are typical of cluster environment
- *Inversion of the SF-density relation in clusters at $z\sim 1.5$??? e.g., Santos+14

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GAL-CLUSTER DM

Dynamical friction
(Chandrasekhar) when
a massive particle moves
in a sea of small mass particles.

Example:

a galaxy moves in a sea of

DM particles. There is the formation of

An overdensity of particles in the back of the galaxy...

The DM particles decelerates the galaxy. The deceleration depends on the

Galaxy mass and velocity $dv/dt \propto M \cdot \rho_{DM} / v^2$

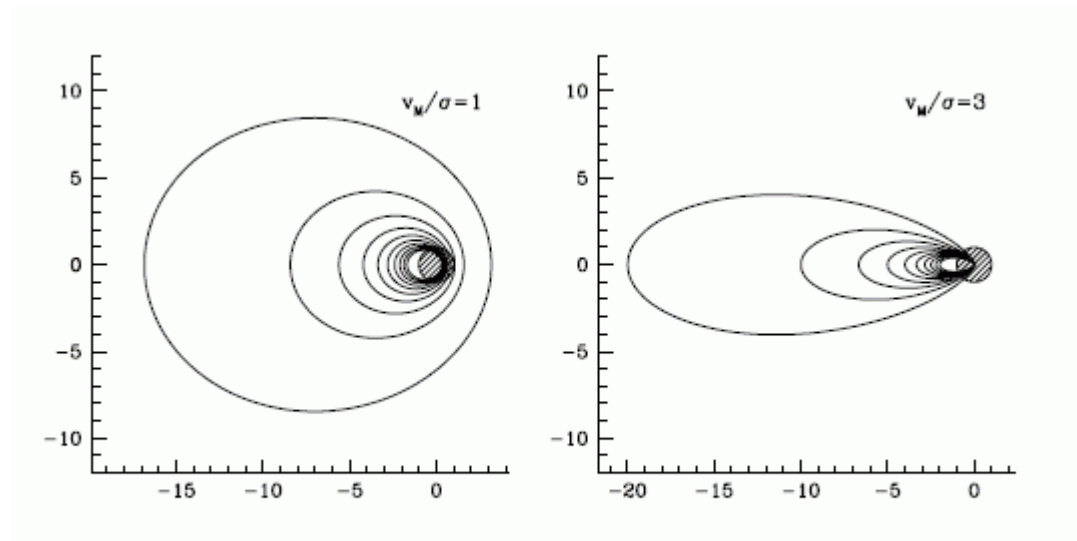


Figure 8.2 A mass M travels from left to right at speed v_M , through a homogeneous Maxwellian distribution of stars with one-dimensional dispersion σ . Deflection of the stars

$$\mathbf{f}_{dyn} = M \frac{d\mathbf{v}_M}{dt} = -\frac{4\pi \text{Ln}(\Lambda) G^2 M^2 \rho}{v_M^3} \left[\text{erf}(X) - \frac{2X}{\sqrt{\pi}} e^{-X^2} \right] \mathbf{v}_M$$

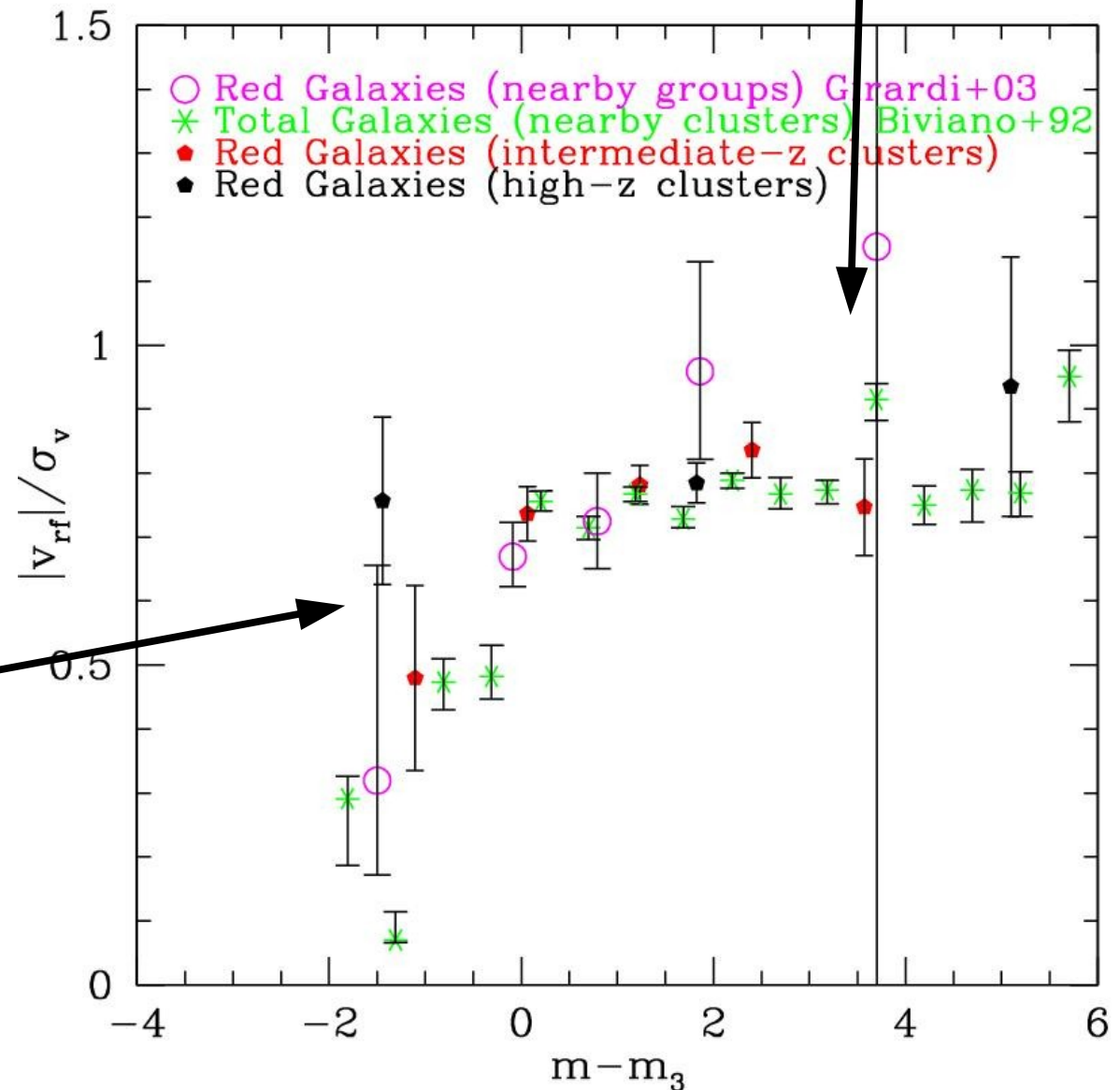
where

Luminosity segregation of galaxies in the velocity space

(Biviano 1992; MG+03...;
Barsanti's thesis 2016 in prep.)

Luminous (massive)
gals are slowed down by...
dynamical friction?

Most galaxies are in a state of
velocity equipartition,
in agreement with theory
of the violent relaxation.



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GAL-CLUSTER

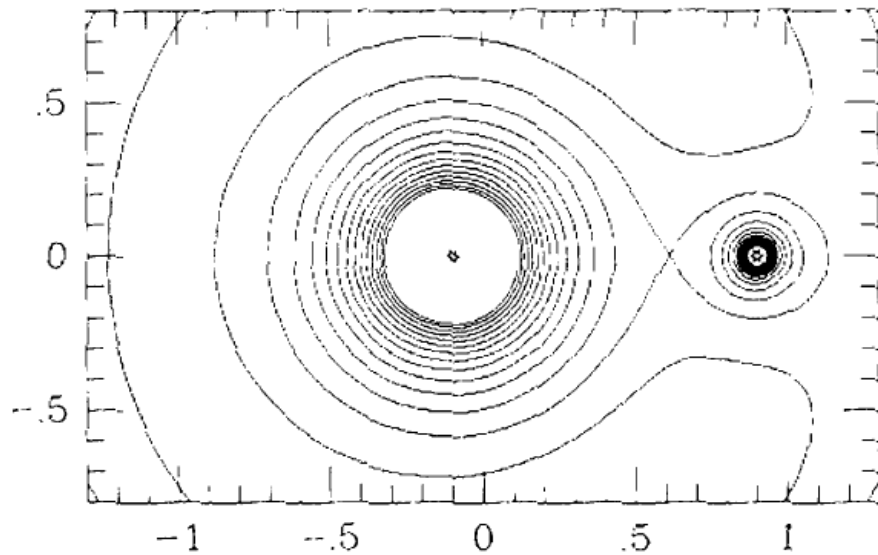


Figure 7-8. Contours of equal effective potential

Roche Lobe theory and
The tidal radius.

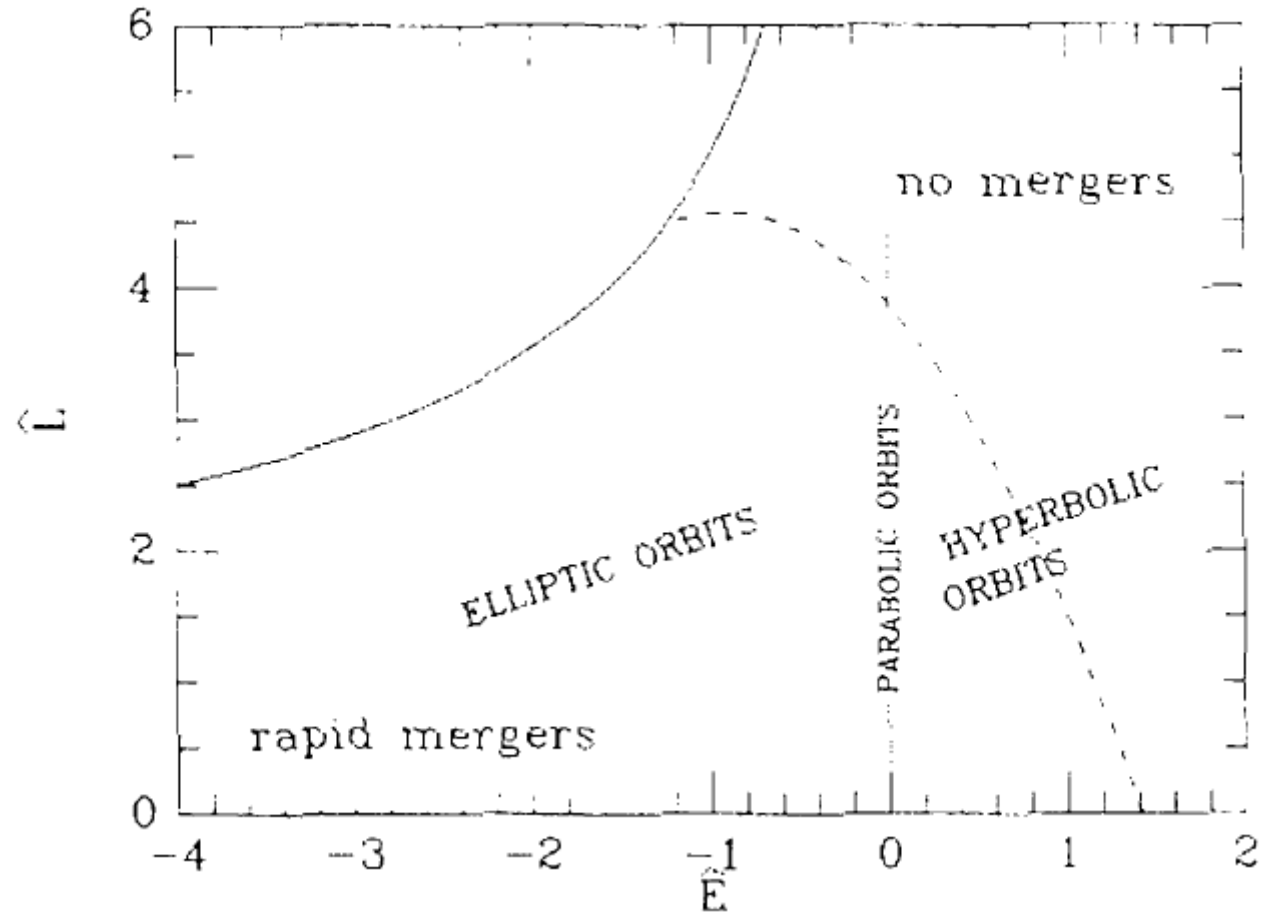
Credit to Binney & Tremaine

Environmental effects on galaxies in clusters

GAL-GAL

*Merger;

Small relative velocities of the encounter favors the galaxy merger.



Credit to Binney & Tremaine

GAL-GAL

* Tidal stripping;

* Harassment defined as frequent high speed galaxy encounters within clusters.

Mergers from observations and N-body simulations.

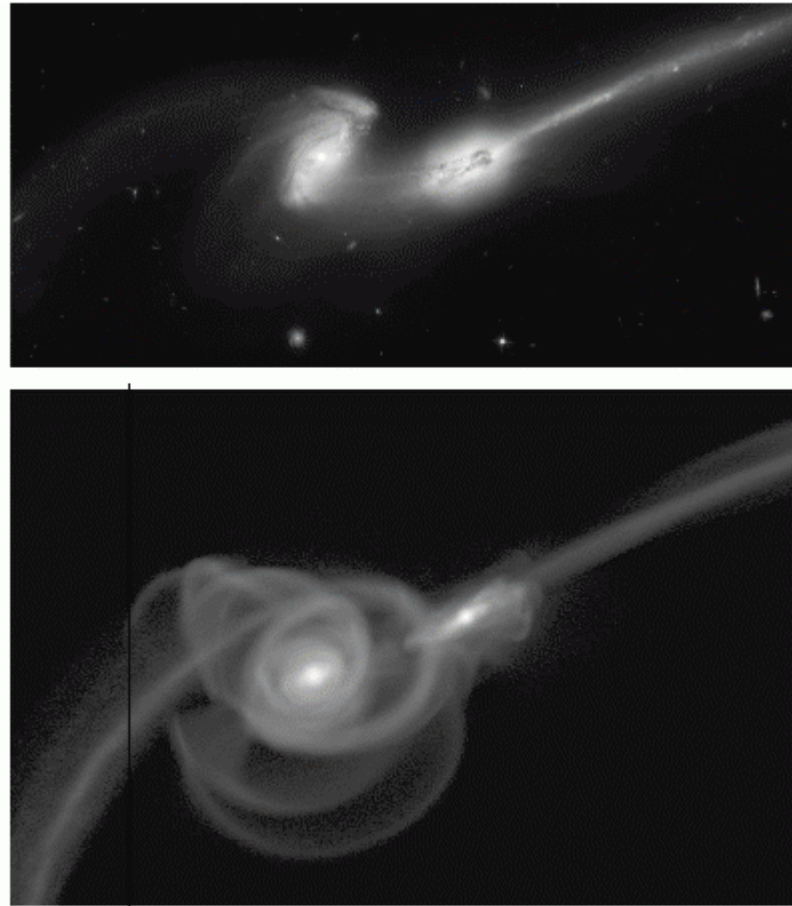


Figure 8.15 The Mice, NGC 4676, a pair of interacting galaxies at a distance of 95 Mpc. Top: optical image from the Hubble Space Telescope. Bottom: an N-body model. Credit for HST image: NASA, H. Ford (JHU), G. Illingworth (UCSC/LO), M. Clampin (STScI), G. Hartig (STScI), the ACS Science Team, and ESA. Credit for N-body model: J. Dubinski (Dubinski & Farah 2006).

Credit to Binney & Tremaine

Environmental effects on galaxies in clusters

GAL-ICM

*Ram pressure (Gunn & Gott 1972): a galaxy in motion with velocity v within the ICM. Pressure is proportional to the density of ICM

$$P \propto \rho_{\text{ICM}} v^2$$

$$F_{\text{press}} > F_{\text{grav}} \rightarrow \rho_{\text{ICM}} v^2 \pi R_{\text{gal}}^2 > G f M^2 / R_{\text{gal}}^2, \text{ where } f = M_{\text{gas}} / M$$

i.e. the fraction of stripped gas.

It is more efficient at the cluster center!

Proof: anemic spirals (i.e. no/little HI) and now the “jellyfish” galaxies, this process can also trigger starburst.

*Stripping for evaporation (also in the case that galaxy is at rest,

due to $T_{\text{ICM}} = 7 \text{ keV} = 10^8 \text{ K} \gg T_{\text{gal}} = 1 \text{ keV}$

$$dM_{\text{evap}} / dt \propto T_{\text{ICM}}^{5/2}$$

*Stripping for turbulence and viscosity $dM_{\text{t,v}} \sim 0.3 dM_{\text{evap}} / dt$

Credit:

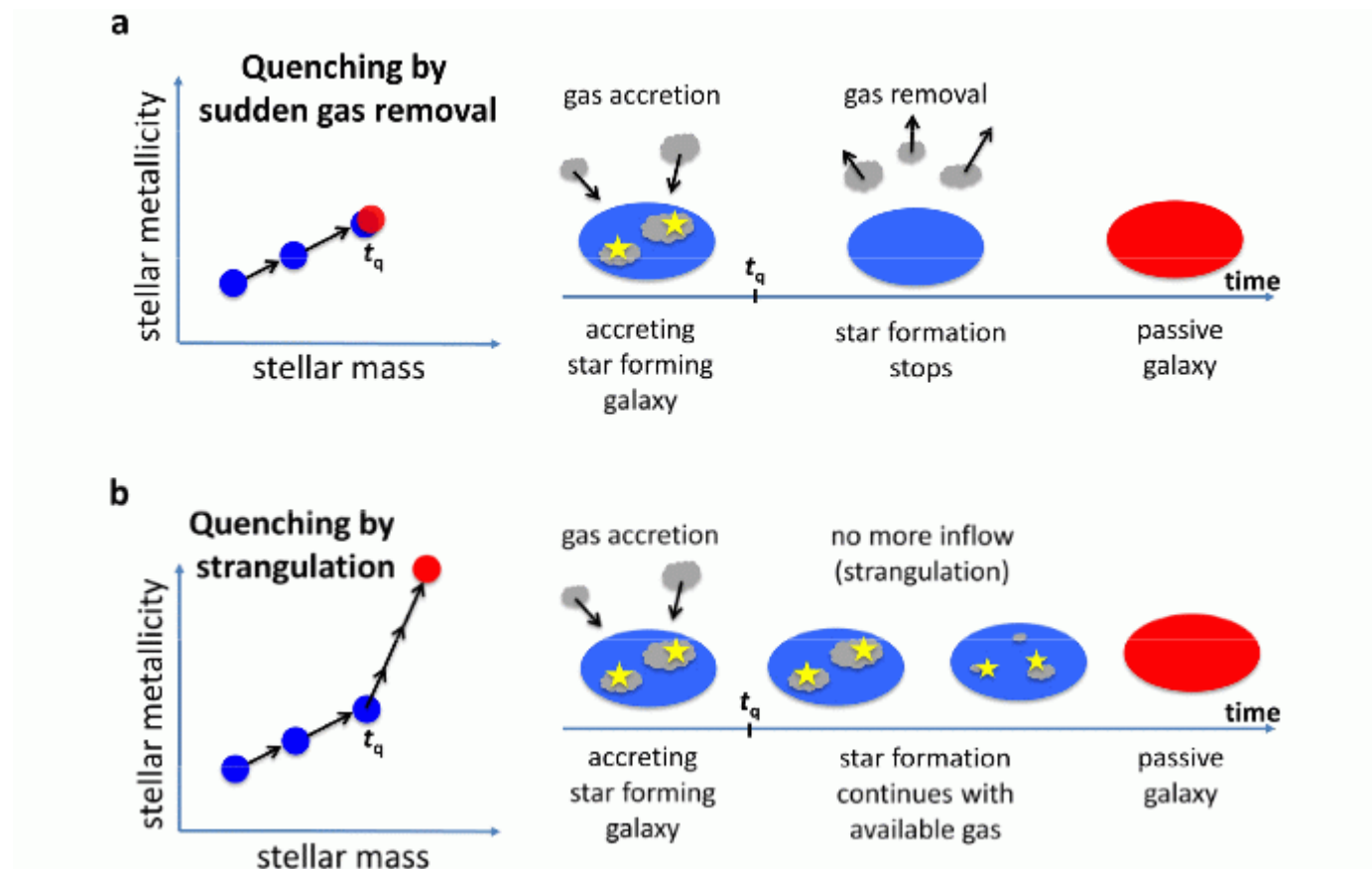
NASA, ESA, CXC

Example of
Jellyfish galaxy
(i.e. stripped of the gas)
in the
NORMA
CLUSTER



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RECENTLY Strangulation (the supply of gas is halted) seems the better according to the study of Peng, Maiolino, Cochran Nature 2015
The question is still discussed!



Credit to Pen et al. 2015, Nature

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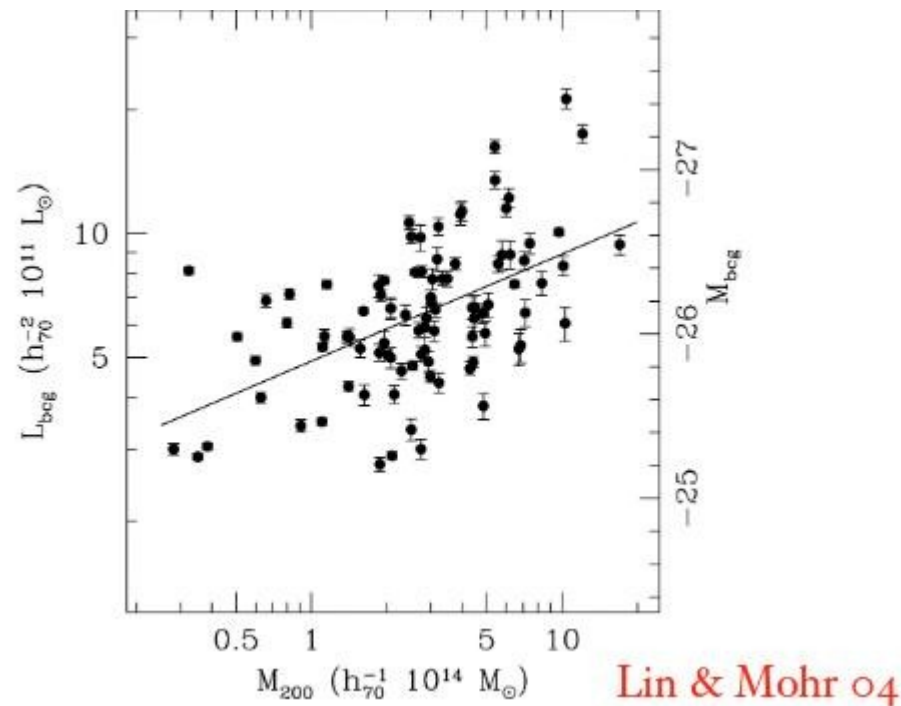
Formation of cD galaxies

*Cannibalization of galaxies slowed down by dynamical friction, that is debris cumulation.

*Central position: it is non subjected to the tidal radius troncation.

*“Cooling flows”, $T_{\text{cooling}} \propto \rho_{\text{ICM}} T_{\text{ICM}}^{1/2}$

BCGs Brightest cluster members grow as the cluster grow. M_{200} is the cluster mass.



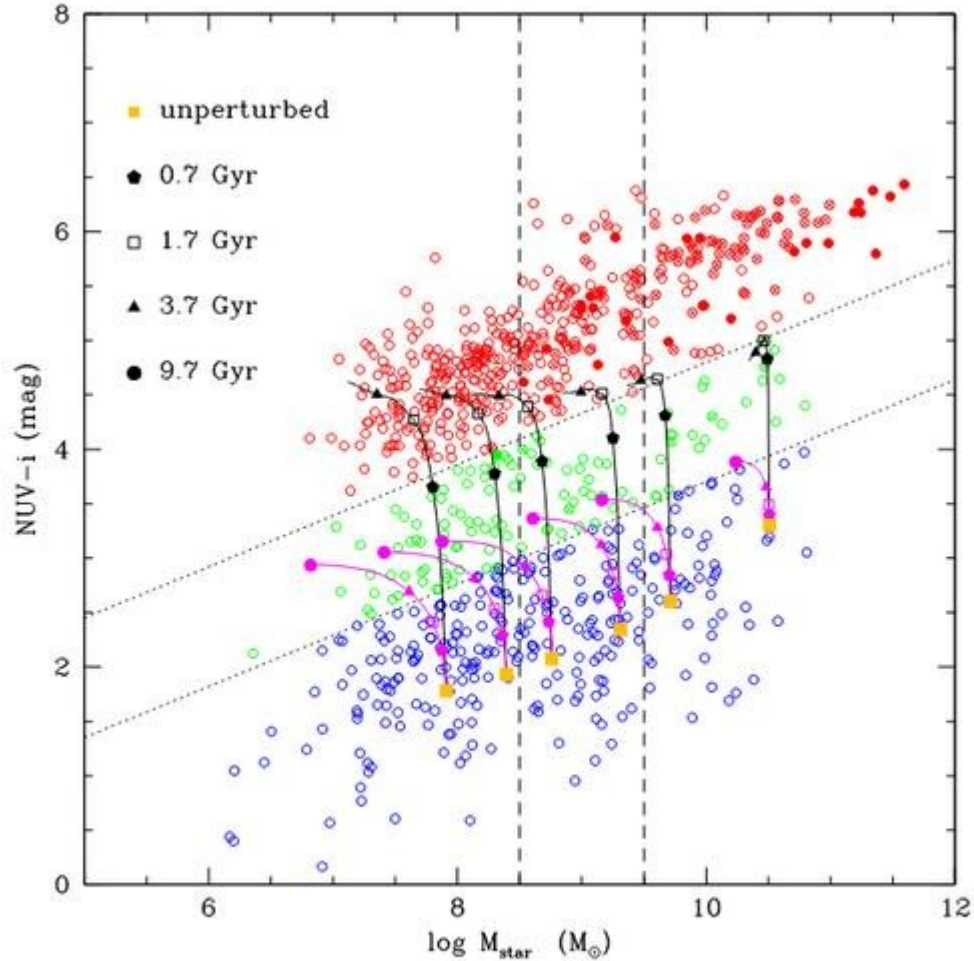
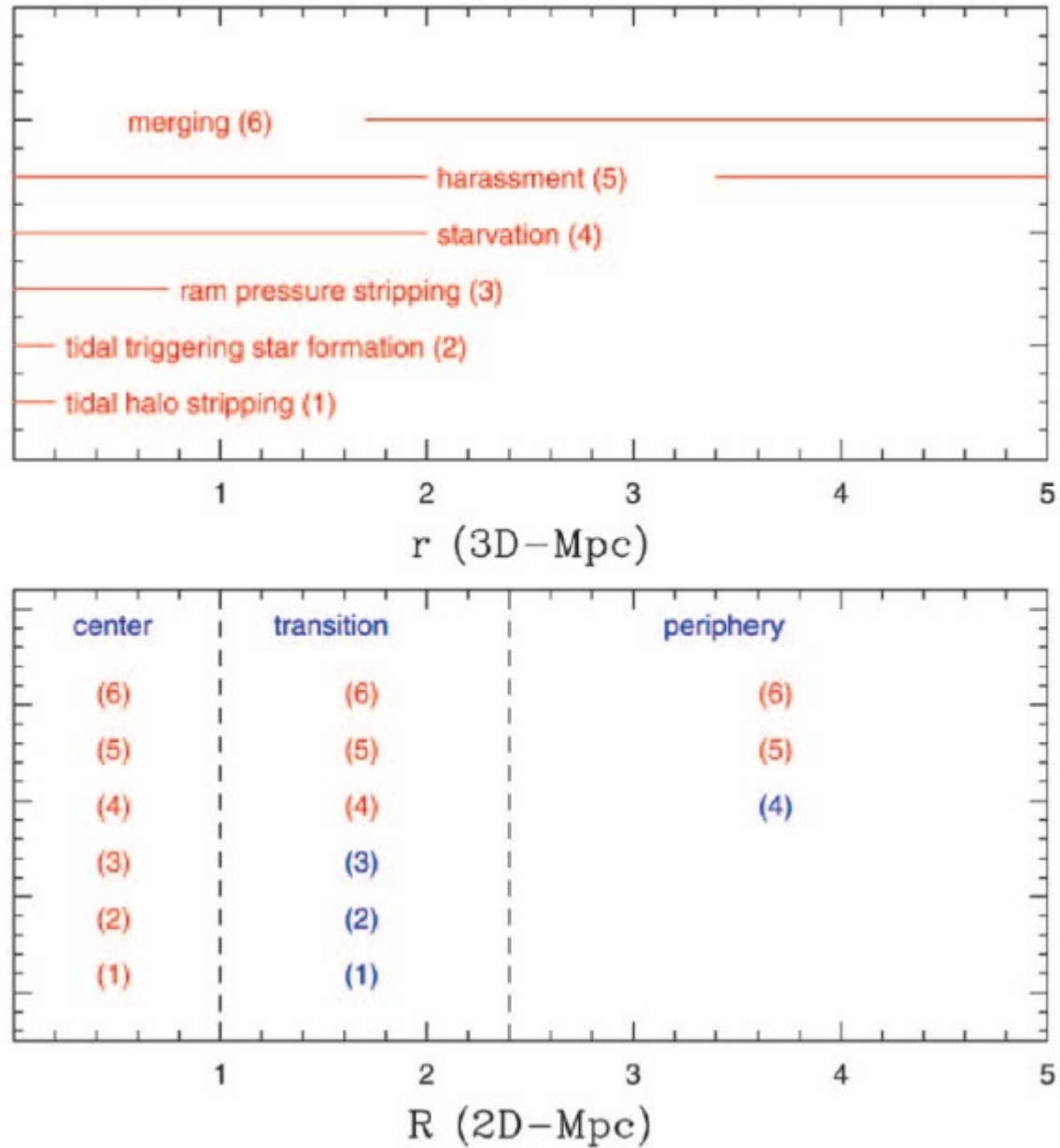


Fig. 10. The extinction corrected $NUV - i$ (AB system) vs. M_{star} relation for all galaxies of the sample. Filled symbols are for slow rotators, crosses for fast rotators. Symbols are colour coded as in Fig. 2. The large orange filled squares indicate the models of unperturbed galaxies of spin parameter $\lambda=0.05$ and rotational velocity 40, 55, 70, 100, 130, 170, and 220 km s^{-1} . The magenta lines indicate the starvation models. The black lines show the ram pressure stripping models. Different symbols along the models indicate the position of the model galaxies at a given look-back time from the beginning of the interaction.

Credit to Boselli et al., 2014,
A&A, 570, A69. See also
Boselli and Gavazzi A&A review vol.22,
p.58 2014
Green circles= gals fo green valley
(=HI deficient see Fig.2).
Magenta lines = starvation models
Black lines = ram pressure models

Comparison between different effects



Credit to Treu et al. 2003, ApJ