THE ROLE OF WET VS DRY MERGERS IN ELLIPTICAL FORMATION:

CLUES FROM COSMOLOGICAL HYDRODYNAMICAL SIMULATIONS

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ORIGIN OF EARLY-TYPE GALAXIES

- **When were their stellar populations born? Where?**
- **When was their mass assembled?**

VERY CONVENIENT:

study this problem in connection with the global cosmological model + hydro simulations

A set of observations suggests that Es formed according with the *monolithic collapse scenario*

- **Scaling relations: the FP** (Djorgovski & Davis 1987; Dressler et al. 1987; Faber et al. 1987)
- **Lack of significant structural and dynamical evolution of the relations** (Treu & Koopmans 2004; Trujillo et al. 2004; McIntosh et al. 2005)
- **Average luminosity evolution is consistent with passive evolution of their stellar populations, that could explain the evolution of the FP relation (i.e., it keeps the tilt) (van Dokkum et al. 2001; … ; di Serego – Alighieri et al. 2005)**
- **In E galaxies, most SF occurred: i), at high zs, ii), on short timescales, and, moreover, iii), at higher zs and on shorter timescales for increasing E mass (Cadwell el al. 2003; Bernardi et al. 2003; Thomas et al. 2005; Jiménez el al. 2006; Noesk et al. 2007).**
- **A population of massive, relaxed spheroids with old stellar populations was already at place by z = 1.5 -2 (zf > 2.4; Cimatti et al. 2002, 2004; Stanford et al. 2004; Mobasher et al. 2005; Glazebrook et al. 2005)**

However, another set of recent observations suggests that mergers at zs below 1.5 - 2 could have played an important role in E assembly

- **The signatures of merging observed by the moment out to intermediate zs** (Le Fevre et al. 2000; Conselice et al. 2003; Cassata et al. 2005; Bell et al. 2005)
- **The growth of the total stellar mass bound up in bright red galaxies by a factor of about 2 since z=1** (Bell et al. 2004; Conselice et al. 2005: Faber et al. 2005)
- **The need for a young stellar component in some E galaxies, in particular the existence of blue cores in relaxed systems** (van Dokkum & Ellis 2003; van del Wel et al. 2004; Menateau et al. 2004)
- **The increase of the E size at fixed stellar mass from z=1.5 up to z=0** (Trujillo et al. 2007)

PARADOXICAL and CHALLENGING!!

Demands:

Passive-evolving stellar populations and a FP that preserves its tilt

Mass assembly is an on-going process and some SF is still on at $z < 1.5$

THE METHOD

INITIAL CONDITIONS: Montecarlo realization of the initial spectrum of density Perturbations (WMAP) in a periodic box. Particles sample mass elements.

EVOLUTION: Newton laws, hydro equations: DEVA code AP3M-SPH (Serna et al. 2003)

SUBRESOLUTION PROCESSES: Modelling SF, chemical evolution, BHs

SF: Simple phenomenological probabilistic implementation

Threshold gas density

Efficiency parameter (Kennicutt-Schmidt-law-like algorithm, Kennicutt 98)

CHEMICAL EVOLUTION: Probabilistic implementation

→

Metal-enriched gas-again particles coming from passive evolution

ELOs: elliptical-like-objects (relaxed stellar sphroids, small disk compoanent (if any), few cold gas

ELO FORMATION: CLUES FROM HYDRO SIMULATIONS

ELOs are assembled out of the mass elements that at high z are enclosed by those overdense regions R whose local coalescence length (Vergassola et al. 1994) **grows much faster than average, and whose mass scale (total mass enclosed by R), is of the order of an E galaxy virial mass**

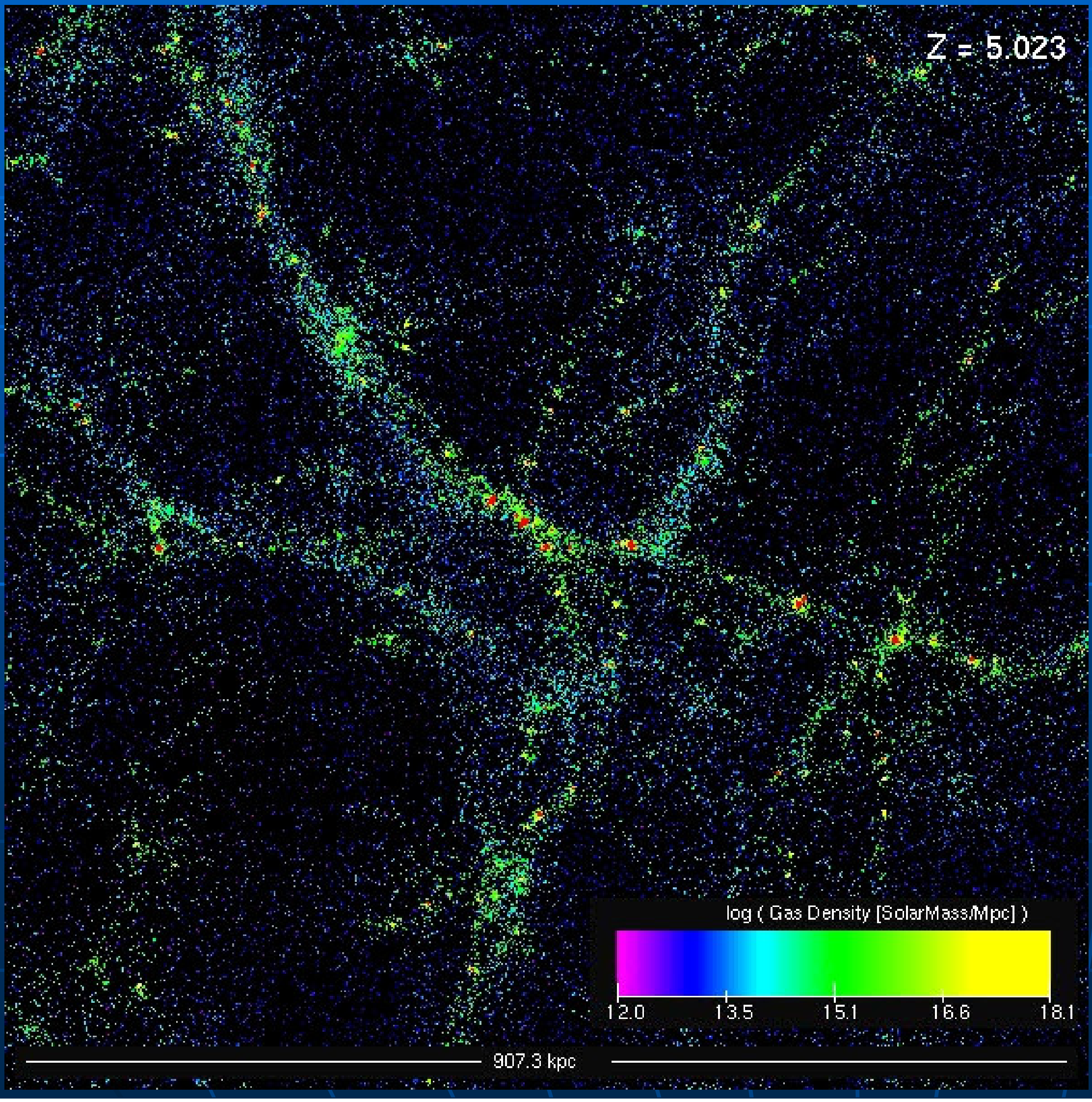
These overdense regions act as flow convergence regions (FCR) towards which mass elements flow

ADHESION MODEL (Shandarin et al.; Vergassola et al. 1994)

Flow singularities unavoidable (Mathematical Theory)
Flow mass elements: involved (not involved) into singularity formation: dense, cold gas (diffuse, hot gas)

Singularity Patterns → Cell Structure

PROGENITOR OF AN ELO AT z=5: cell structure



PROGENITOR OF AN ELO AT z = 5.

A projection of a 900 side box at z = 5.02. Red: stars. The other colors mean gas density according with the code in the bar. This region will transform later on into a virtual elliptical. At this high redshift we can appreciate the cellular structure, the denser regions already turned into stars, and dense (cold) gas flowing towards the node at the center of the FCR through filaments.

A formation scenario emerges where mergers play a very important role,

but

a clear difference appears between **wet** and **dry** mergers

IN A COSMOLOGICAL CONTEXT, remember that:

Halo Mass Assembly

- Analytical models, as well as N-body simulations and the merger rate inferred from observations, **two different phases**
- first, **violent fast phase**: high mass aggregation rates
- Later on, **slower phase**: lower mass aggregation rates

(Wechsler et al. 2002; Zhao et al. 2003; Salvador-Solé, Manrique, & Solanes 2005; Conselice this meeting).

BARYONS IN THE FAST PHASE PHYSICS

… when most dissipation occurs

(HYDRO SIMULATIONS)

- At a given scale, **overdense** regions first expand slower than average, then they **turn around and collapse** through fast global compressions, involving the cellular structure elements they enclose and in particular nodes connected by filaments, that experience

fast head-on fusions

(i.e., multiclump collapse, see Thomas, Greggio & Bender 1999).

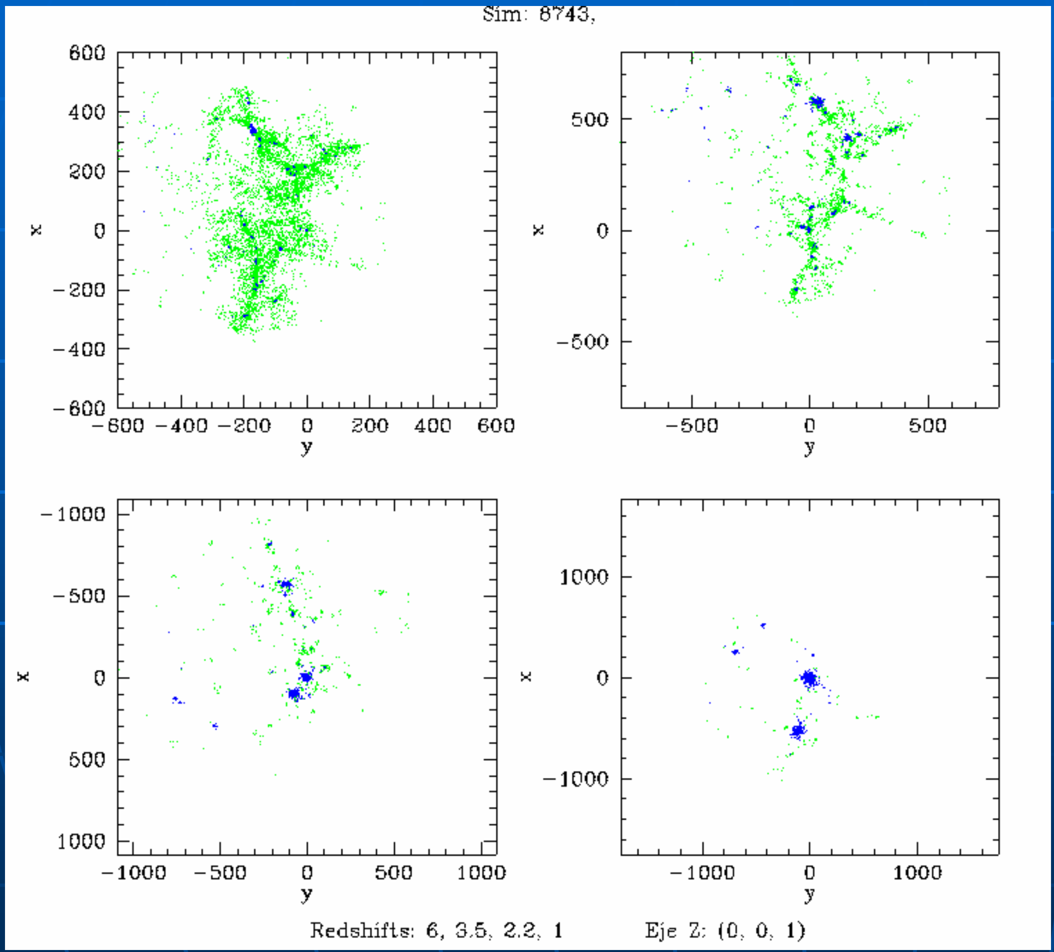
- These fast head-on mergers result in **strong shocks and high cooling rates** of their gaseous component, and, consequently,

strong and very fast SF bursts

transform most of the available cold gas at the FCR into stars

- **Most of the dissipation involved in the mass assembly of a given ELO occurs in this violent early phas**e at high z (6 – 2.5)
- The dissipation rate history is reflected by the star SF rate history
- **At the end of this phase, most stars are already formed, the ELOs are virialized and the Fundamental Plane is in place**

FLOW CONVERGENCE REGION DYNAMICS
(MERGERS & CELL STRUCTURE)



Projections, at different redshifts, of the baryonic particles that at z = 0 form the STARS of a typical massive ELO. Green: cold gas particles. Blue: stellar particles. The redshift decreases from left to right and from top to bottom. Note the clumpy collapse of two different FCRs between z = 3.5 and z = 2.2 (fast phase) with ELO formation, and their merging between z = 2.2 and z = 1 to give massive ELOs (slow phase).

WALLS → FILAMENTS → CLUMPS

THE PHYSICS OF HIGH z MERGERS

- Clumpy, collapse-induced (multimerger)
- Dissipative
- Following filaments
- Head-on (low relative orbital J)
- Fast gas consumption
- Strong SF bursts

SLOW PHASE PHYSICS

… when most mergers involved in E formation are **DRY**

- In general, only a modest amount of energy dissipation or SF

DRY MERGERS

- A strong SF burst and dissipation follow a major merger only if enough gas is still available at the FCR
- Unlikely in any case, and it becomes more and more unlikely as the mass scale increases **(downsizing).**

- **Fusion rates** are generally **low**
- The average number of mergers (major or minor) is about 1,
- About a 50% of ELOs in the sample have experienced a major merger event at $2 < z < 0$ (Lefevre and Lin talks)

THE PHYSICS OF MERGERS AT THE SLOW PHASE

- Cell structure erased at proto-ELO FCRs
- No dissipative
- Two- (or few-) body
- Relative orbital J, excep for the more massive ELOs
- Baryon orbital decay

- Diffuse gas heating

PUTTING THE TWO PHASES TOGETHER

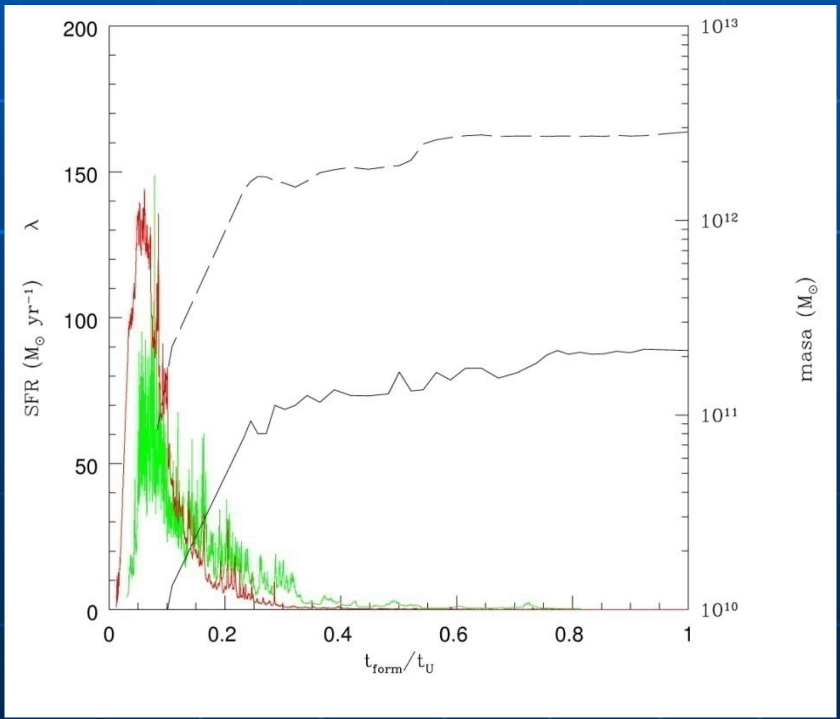
SOME CONSEQUENCES OF THIS PHYSICAL SCENARIO

DISSIPATION, STAR FORMATION, MASS ASSEMBLY

Most dissipation involved in ELO assembly takes place at an early violent phase: z>1.5 -2

In the subsequent quiescent phase, ELO stellar mass growth preferentially occurs through non-dissipative processes, so that the SFR considerably decreases.

FAST SLOW



(No gas coming from passive evolution reckoned)

GREEN: SFRH of a massive ELO as a function of universe age

RED: Cooling RH

BLACK: Merger Aggreg. Tree

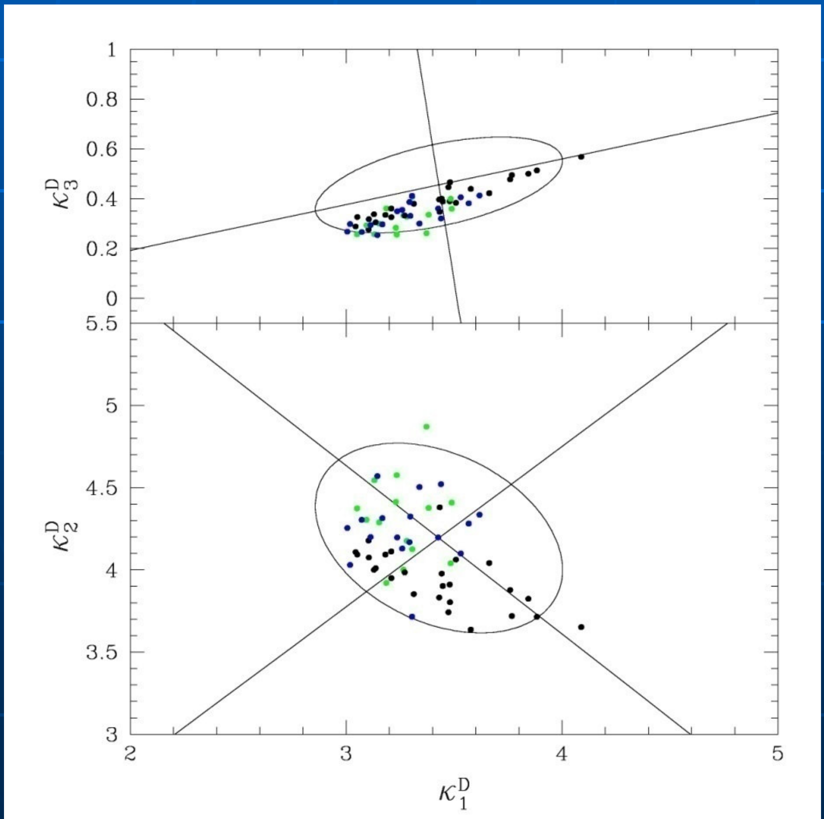
DT et al. 2006
Observations: Bell et al. 2004; Bundy, Ellis 2005; Faber et al. 2006

THE FUNDAMENTAL PLANE AND ITS LACK OF EVOLUTION

(Oñorbe et al. 2005; 2006; Observations: Van Dokkum et al. 2001; Treu et al. 2005; di Serego-Alighieri et al. 2005)

ELO stellar masses, projected half- stellar mass radii, and stellar central l.o.s. velocity dispersions define a dynamical Fundamental Plane (FP), consistent with observations.

Physical origin of the FP lies in the systematic decrease, with increasing ELO mass, of the relative amount dissipation experienced by the baryonic mass component along ELO mass assembly. This result hints to a possible way to understand the tilt of the observed FP in a cosmological context.



Edge-on projection (top panel) and nearly-face-on projection (bottom panel) of the dynamical FP of ELOs in the kappa^{D} variables (Bender et al. 1993). We also draw the respective concentration ellipses (with their major and minor axes) for the SDSS early-type galaxy sample from Bernardi et al. (2003) in the z-band.

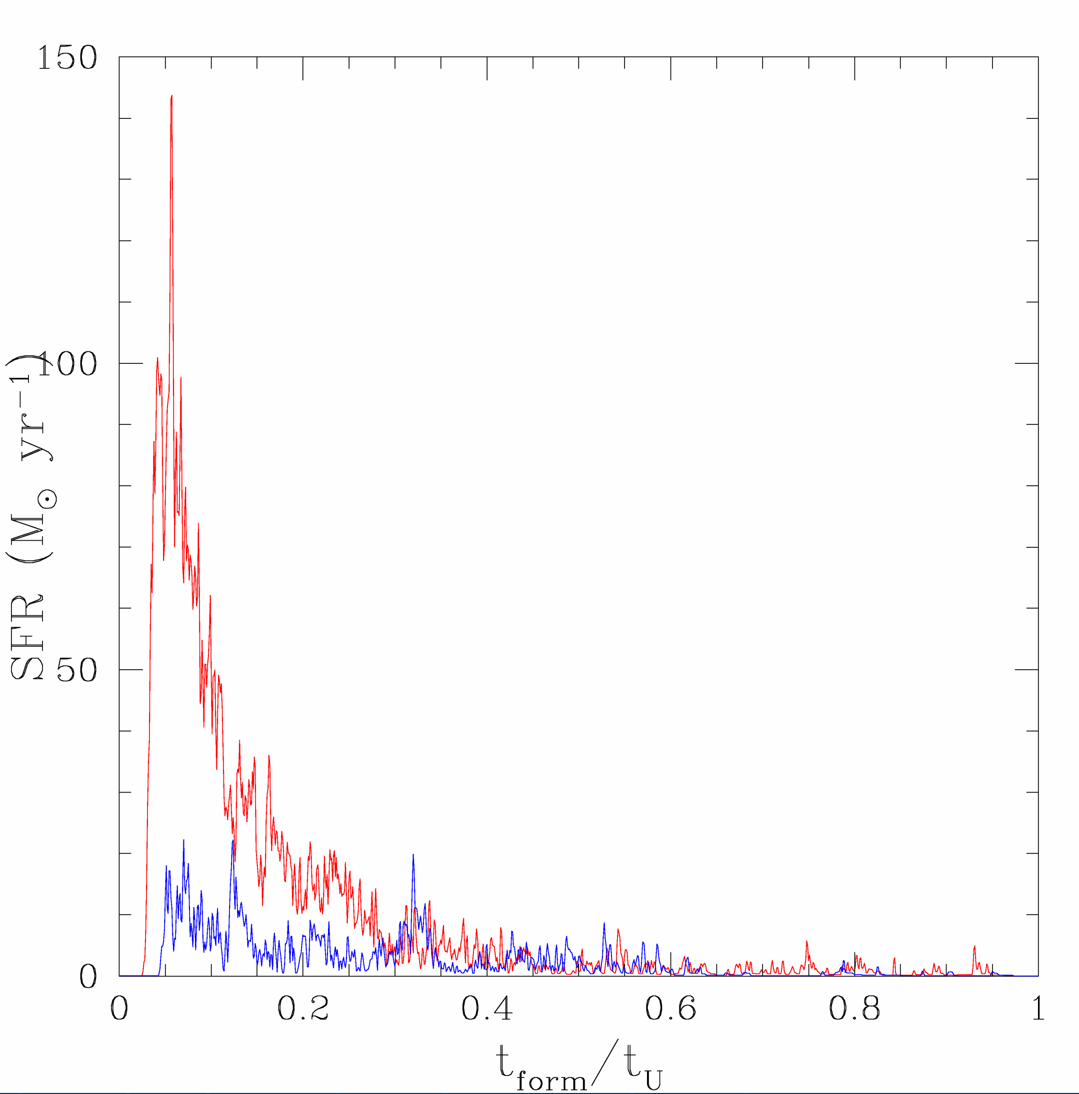
BLACK: z=0
GREEN: z=1
BLUE: z=1.5

MASS EFFECTS IN STELLAR AGE DISTRIBUTIONS

The star formation rate histories of two typical ELOs versus the Universe age. Red: a massive ELO. Blue: a less massive ELO: Note the age effects according with the ELO mass.

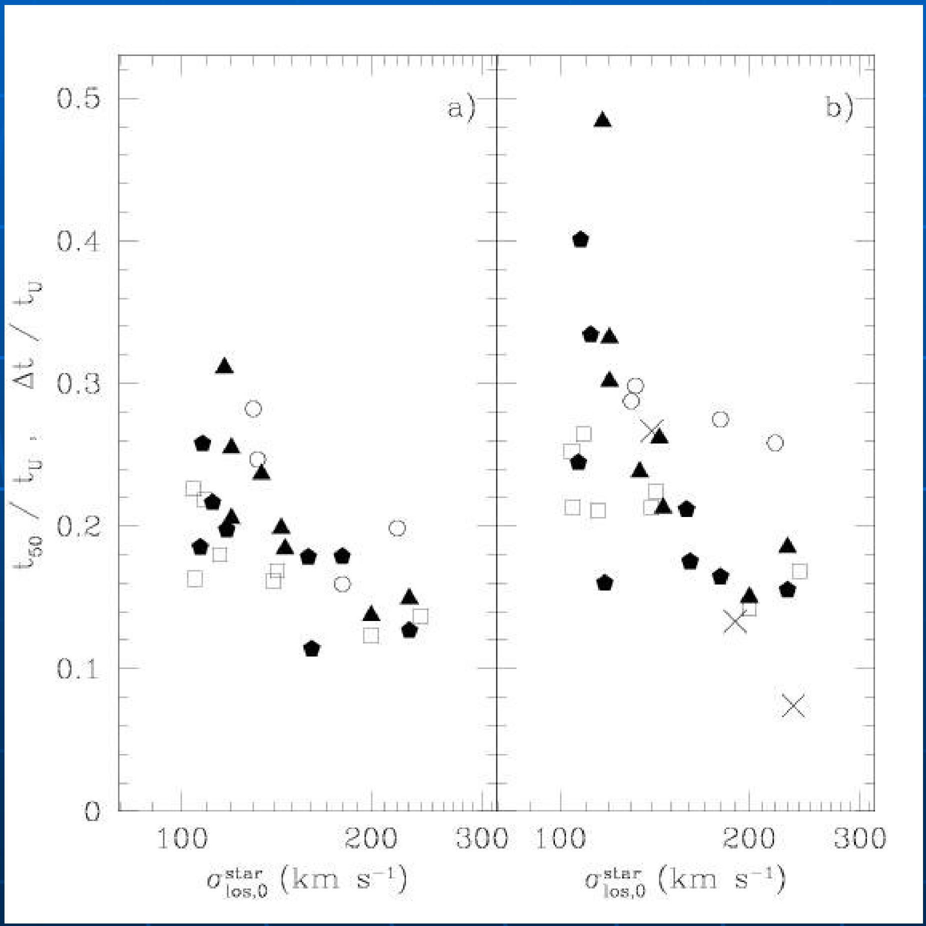
ADHESION MODEL

Clustering process (gas transformation) begins earlier on and goes faster with increasing ELO mass



AGE EFFECTS IN STELLAR POPULATIONS

More massive ELOs have older means and narrower spreads in their stellar age distributions than less massive ones, in consistency with observations (DT et al. 2004). These correlations hint at a possible way to reconcile age effects in ellipticals, and, particularly, the increase of α /<Fe> ratios with $\sigma_{los,0}$, with the hierarchical clustering paradigm. See also talks by Sanchez-Blazquez and Forbes.



(a) Age of the universe in units of the actual universe age at which the 50 per cent of the total ELO stellar mass at z=0 was already formed, versus their corresponding stellar central l.o.s. velocity dispersion.
(b) Same as (a) for the width of the stellar population age distribution. Crosses are width estimations from elliptical data.

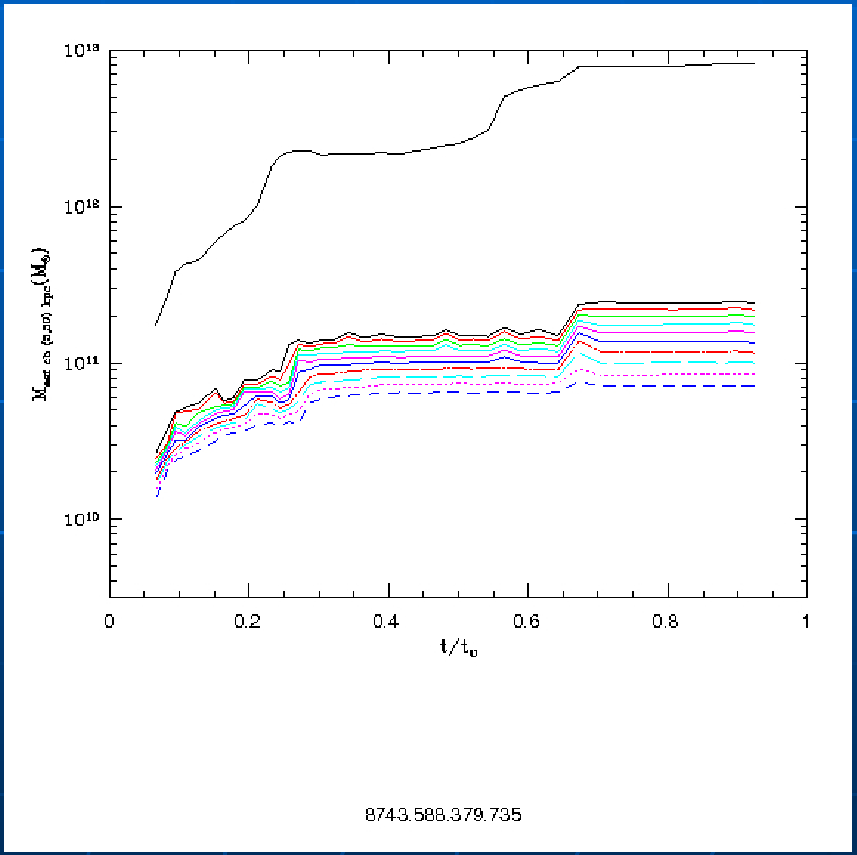
Mass Aggregation Tracks at Fixed Radii

Slow phase: **Halo Shielding of the Baryonic Object**

Mass Assembly

3D Mass Distribution
(Salvador-Solé et al., 2007, in prep.)

Effective radii at fixed M_* Increases (Trujillo et al. 2007)

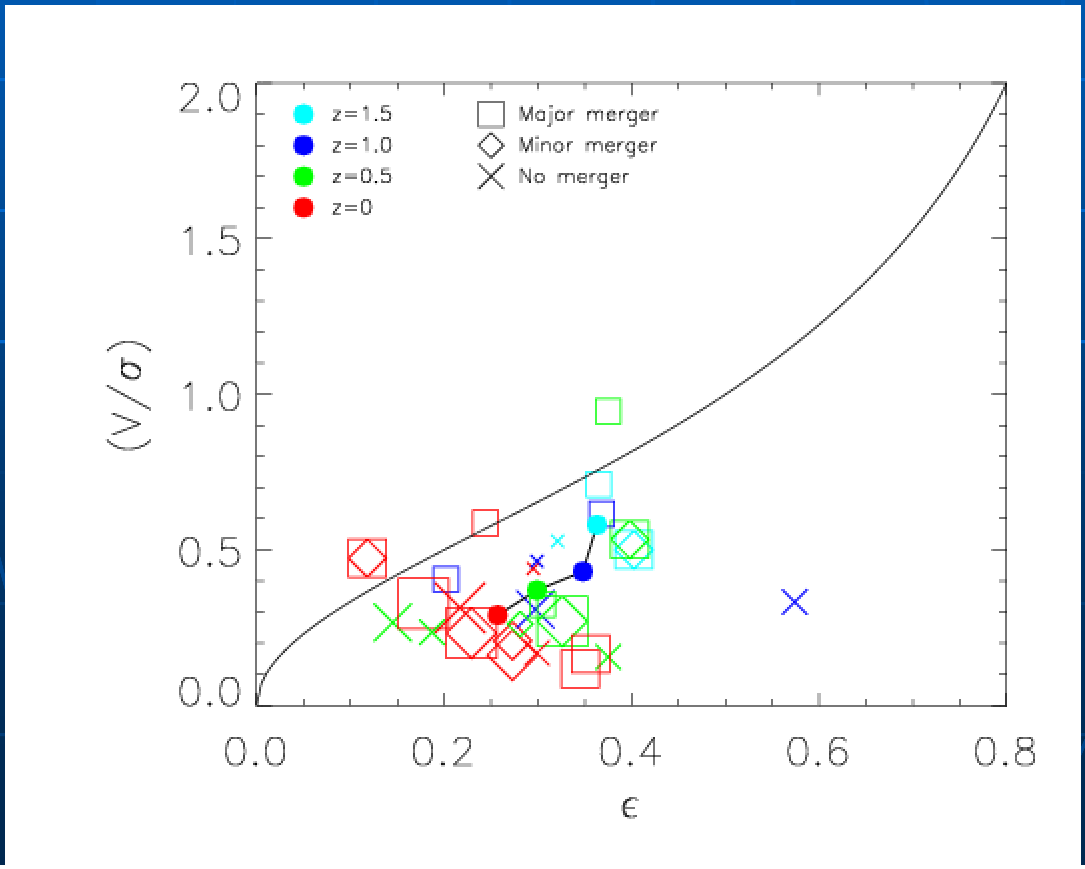


FAST
SLOW

SHAPE & KINEMATICAL TRANSFORMATIONS

- Shape transformation (ellipticity decreases)
- Kinematical Transformation (rotational support decreases) González-García et al., in prep.

Binney plot 1982



SUMMING UP

THE ROLE OF **WET**

vs

DRY MERGERS

in elliptical formation

A SCENARIO FOR E FORMATION

- Two phases
- Star Formation and Mass Assembly do not go together (DT et al. 2006; de Lucia et al. 2006)
- Way out for apparently paradoxical observations

Within this scenario we can understand the role of mergers:

THE ROLE OF WET MERGERS

- Mass assembly
- Star formation
- Set Fundamental Plane
- Metal and dust formation
- Metal diffusion
- Diffuse gas heating
- BHs?

THE ROLE OF DRY MERGERS

- Mass Assembly
- Last 3D ELO shaping
- Disky goes Boxy: Shape, kinematical transformations (rotational support decreases)
- Concentration decreases

- FP relation roughly preserved
- Metal gradient erasing
- Diffuse gas heating and expelled
- Diffuse stellar light
- BHs?