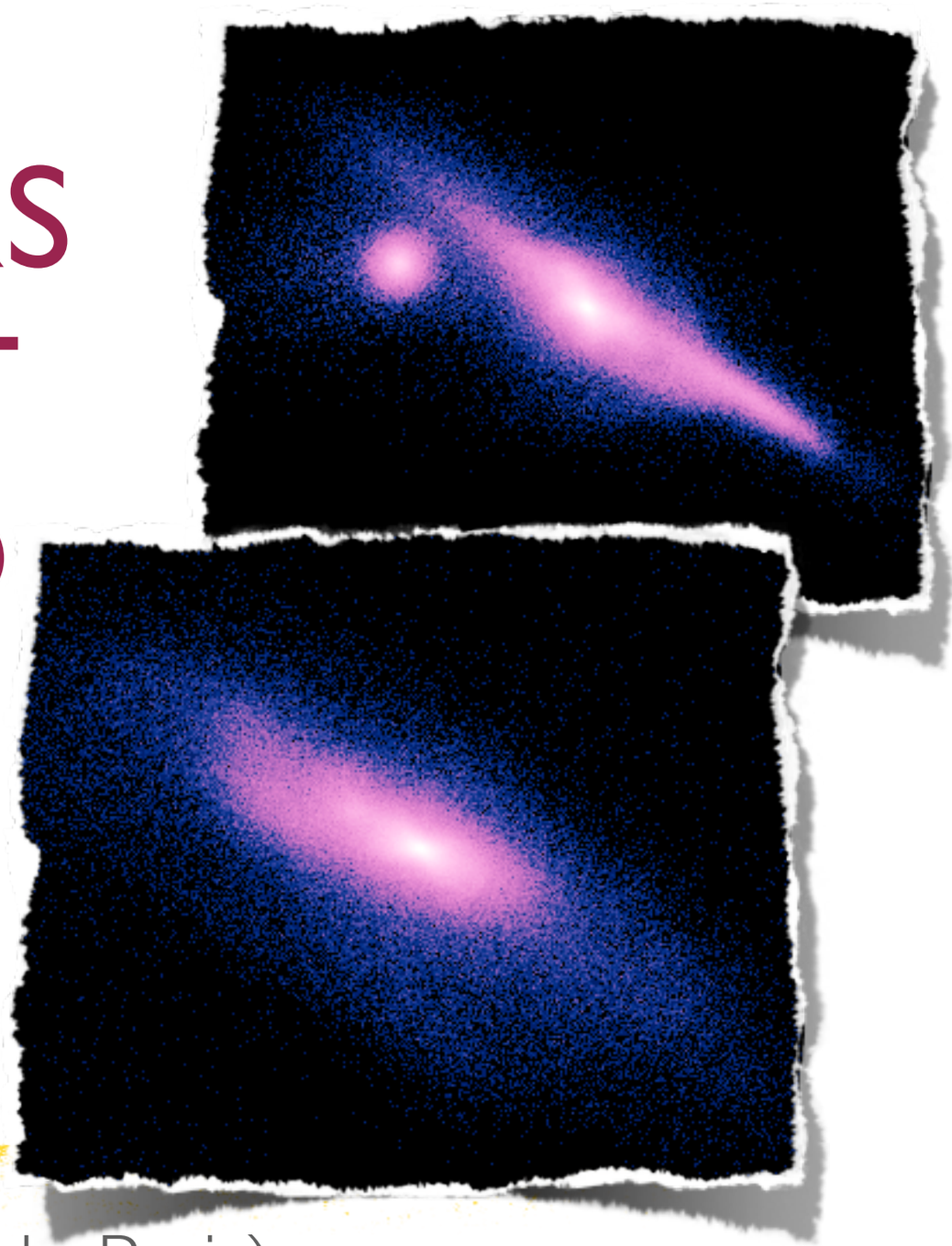
GAS-POOR MERGERS AND THEIR IMPACT ON THE OBSERVED PROPERTIES OF GALAXIES



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DRY MERGERS

- They should be important to explain the massive early-type galaxy population in the local Universe

(Bell et al. 2006, Tran et al. 2005, Bezanson et al. 2009)

- They could explain some structural properties of massive Es (boxy isophotes, cores..)

(Naab et al. 2006)

DRY MERGERS

- **Angular momentum redistribution during dry mergers**
  - How galaxies acquire, lose and redistribute AM during mass assembly?
  - Mergers are an important mechanism for redistributing AM
  - Start with the simplest cases (no dissipative component)
- **Phase-space mixing**
  - How does it affect the metallicity gradient of a galaxy?

THE SIMULATIONS (1)

- The simulations have been run using a Tree-SPH code (Semelin & Combes 2002)

- Early-type galaxy models (Ellipticals, S0, Sa)

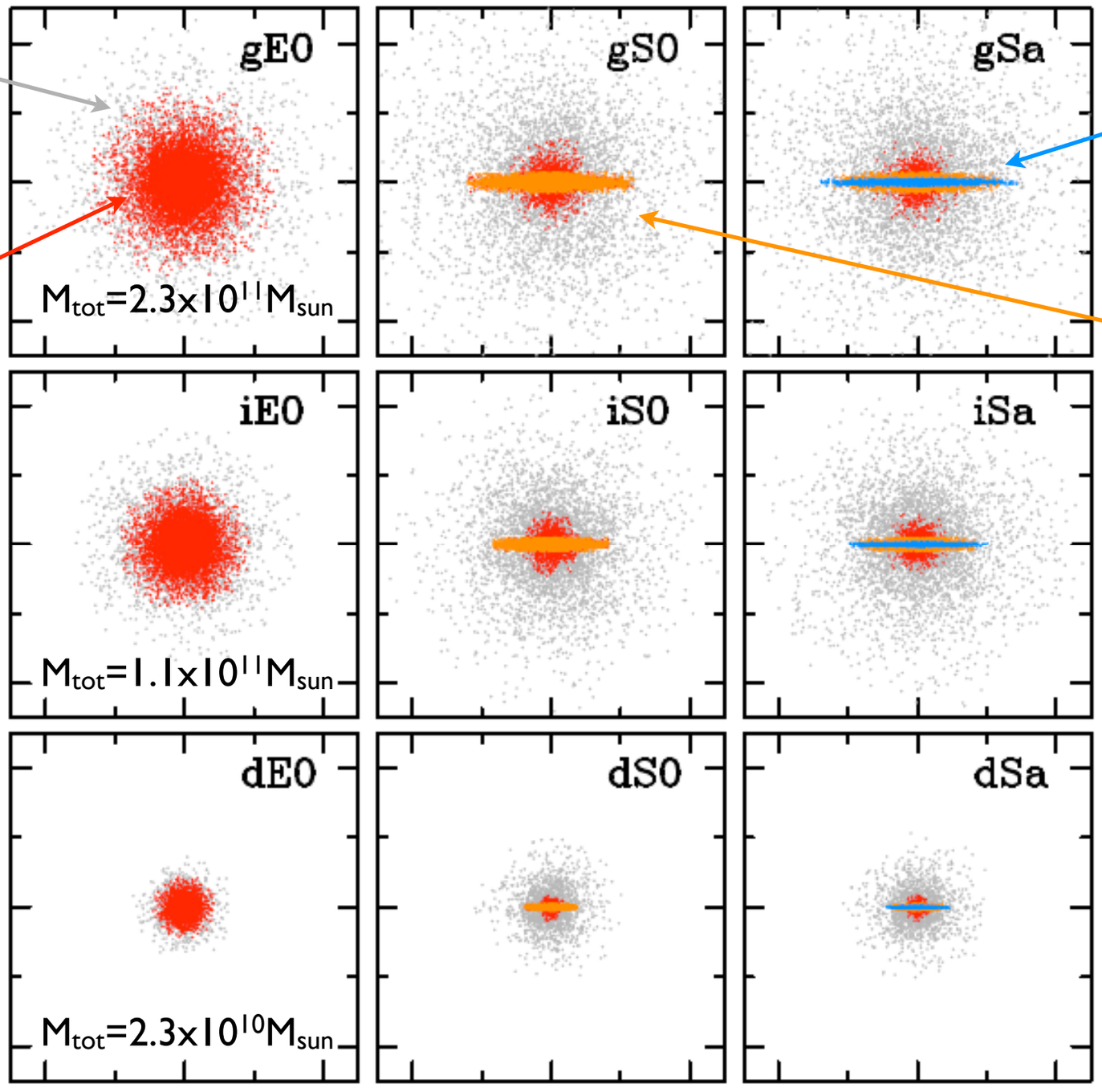
- Different mass ratios (1:1, 1:2, 1:10, 1:20)

- Different orbits (direct, retrograde, different inclinations, initial orbital energies, orbital angular momenta)

THE SIMULATIONS (2)

Spherical, initially not-rotating dark halo

Spherical, initially not-rotating pressure supported stellar component



Gaseous disk, 10% of the stellar disk mass

Rotationally supported stellar disk

THE SIMULATIONS (*3*)

Total number of particles per galaxy:

- **120k** (lowest resolution)
- **480k** (intermediate resolution)
- **960k** (highest resolution)

http://galmer.obspm.fr
Chilingarian et al. A&A submitted

ANGULAR MOMENTUM EVOLUTION IN DRY MERGERS

(1) The simplest case:

the merger of two spherical, initially not-rotating pressure supported systems

Di Matteo, Jog, Lehnert, Combes & Semelin 2009, A&A, 501, L9

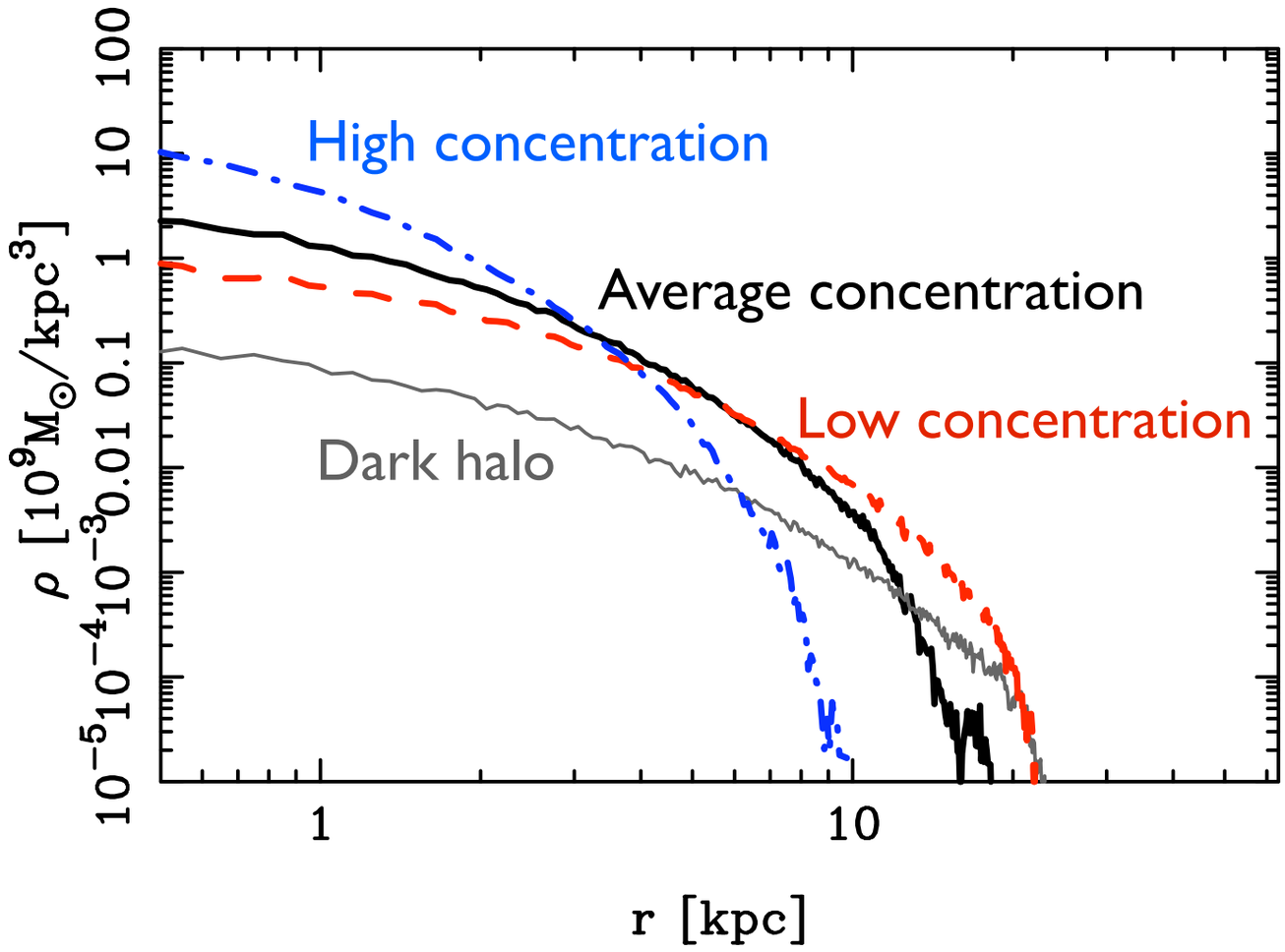
THE INITIAL MODELS

1:1 mergers of two E0 galaxies

Variety of initial orbital energies and AM

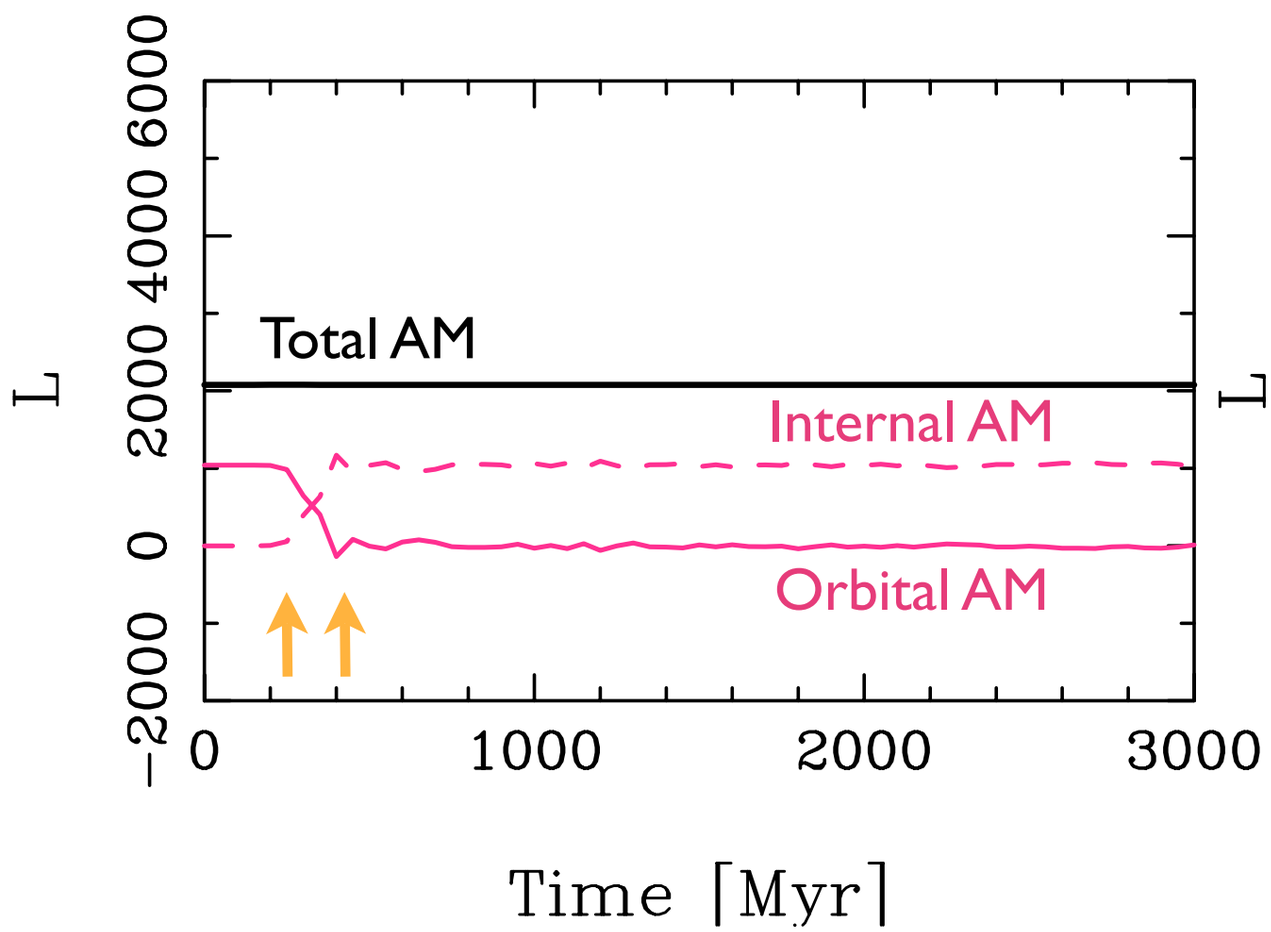
THE INITIAL MODELS

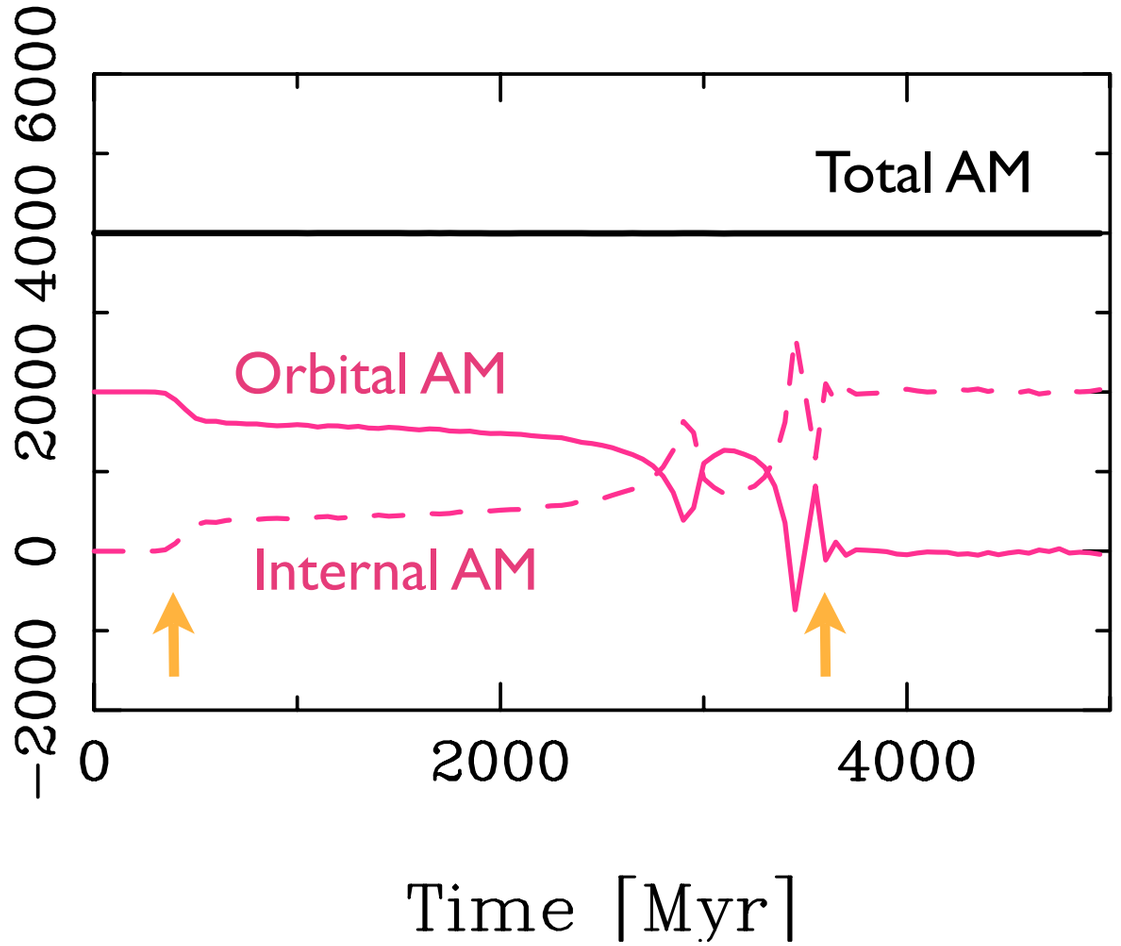
- 1:1 mergers of ellipticals
- 3 different central densities for the stellar component
- the DM contributes to 10-30% of the mass inside the stellar half-mass radius (Barnabe et al. 2009)



EVOLUTION OF THE TOTAL AM (1)

Two mergers with increasing initial orbital AM





EVOLUTION OF THE TOTAL AM (2)

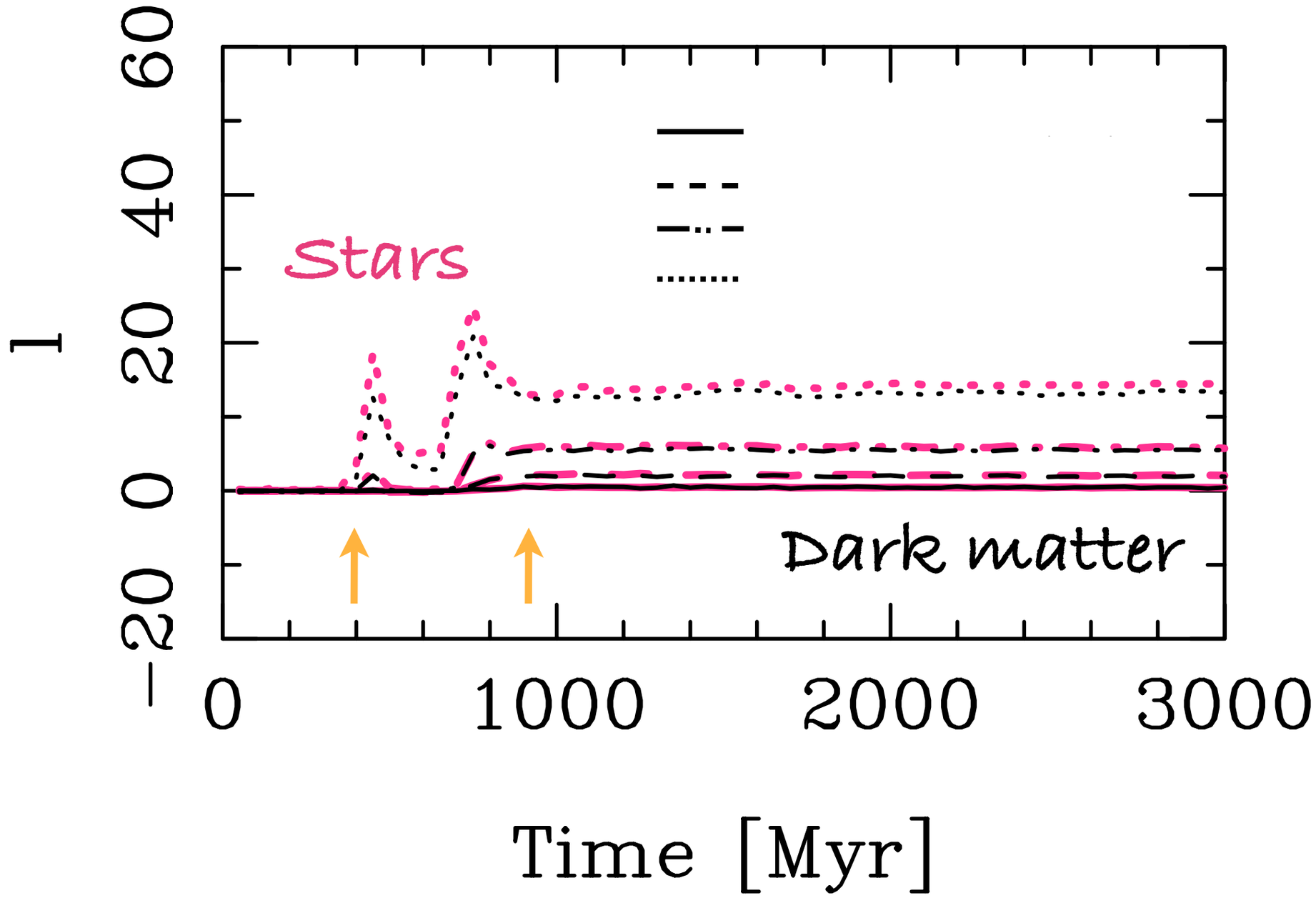
- The total AM is (obviously) conserved during the interaction

- **At each close passage** between the two galaxies, **part of the orbital AM is converted into internal rotation** of the two systems

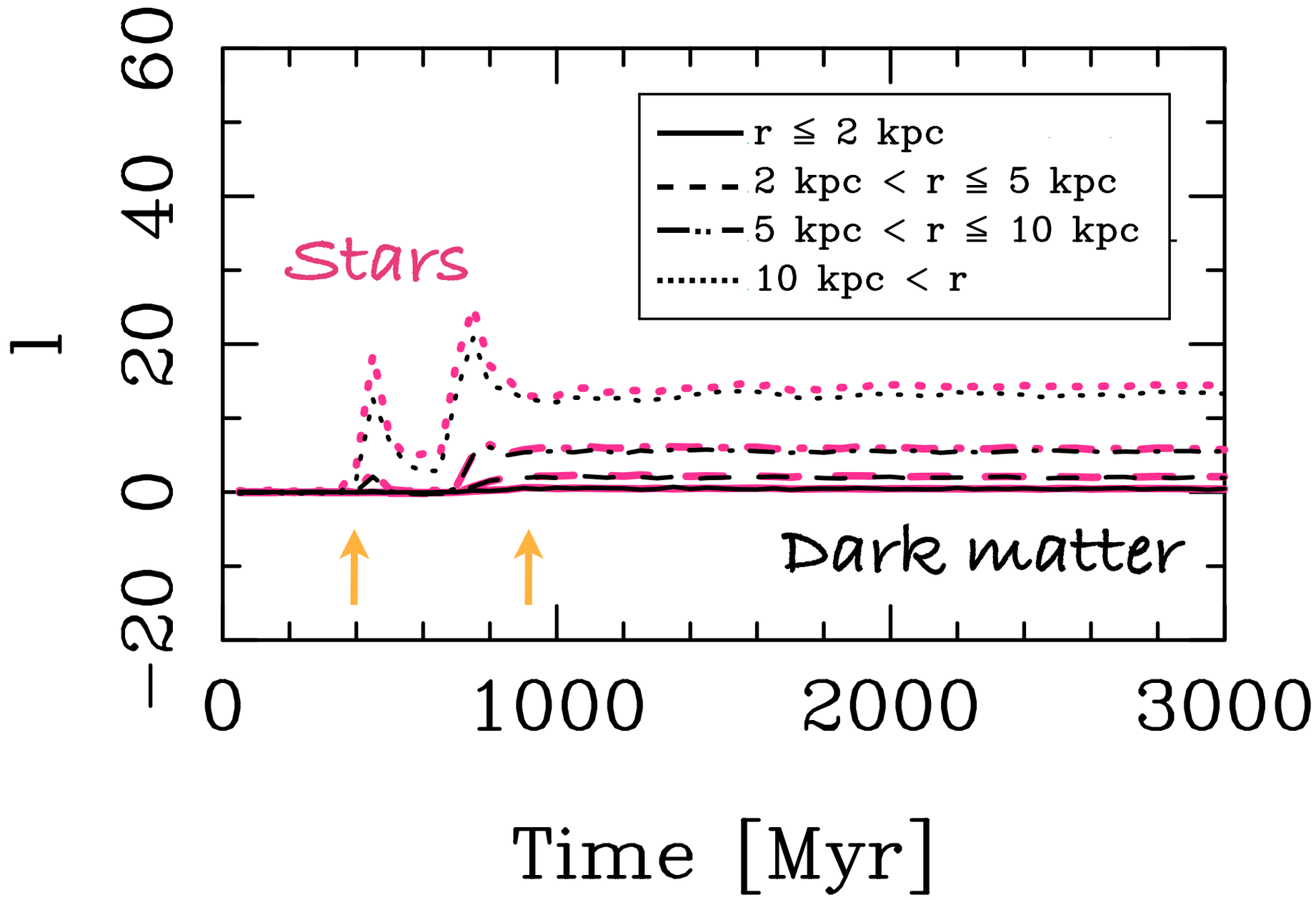
- This process ends when all the orbital AM has been converted into internal AM

- Because of AM conservation, **the final amount of AM in the remnant galaxy depends on the initial amount of orbital AM**

EVOLUTION OF THE SPECIFIC AM

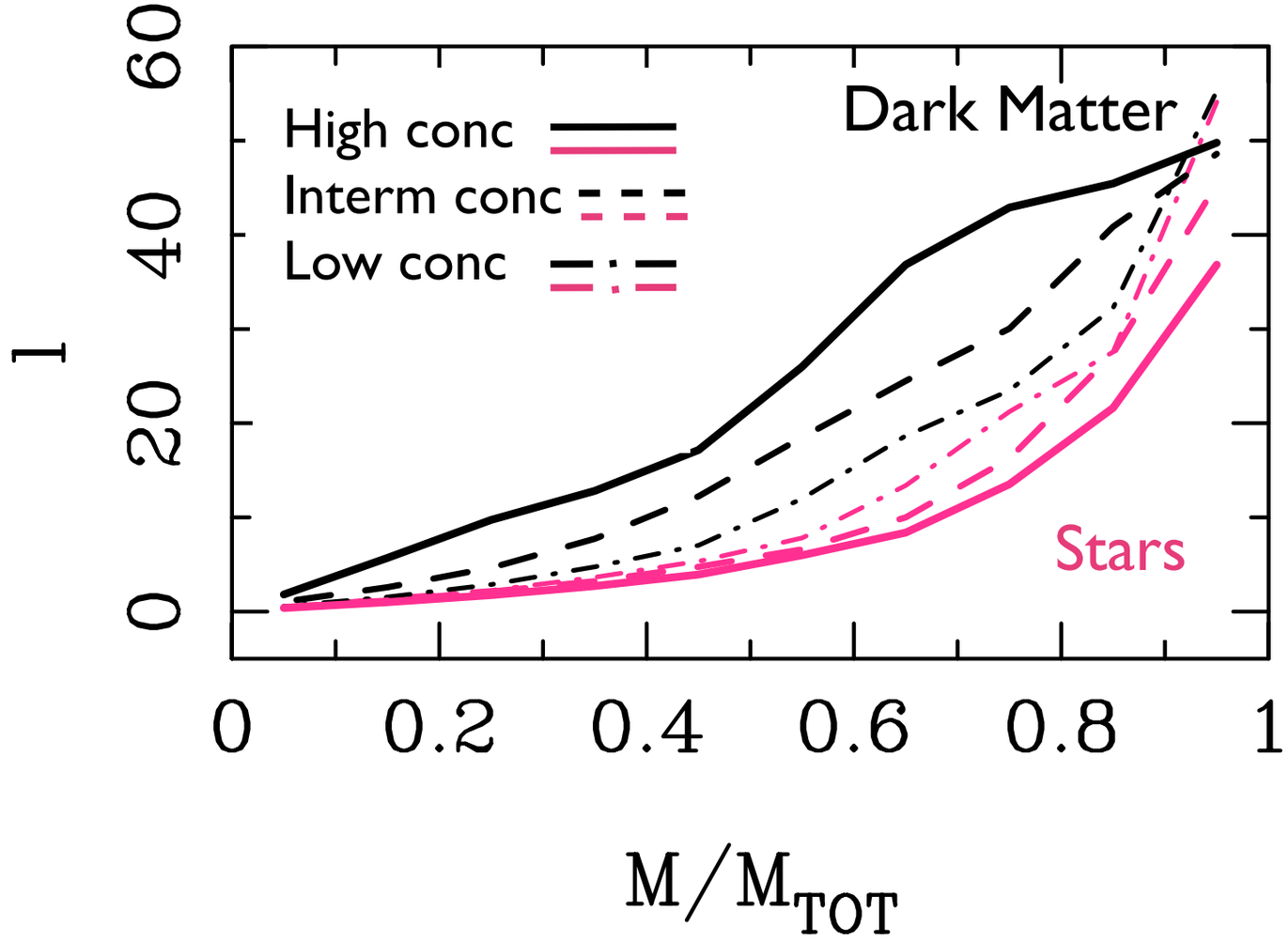


EVOLUTION OF THE SPECIFIC AM

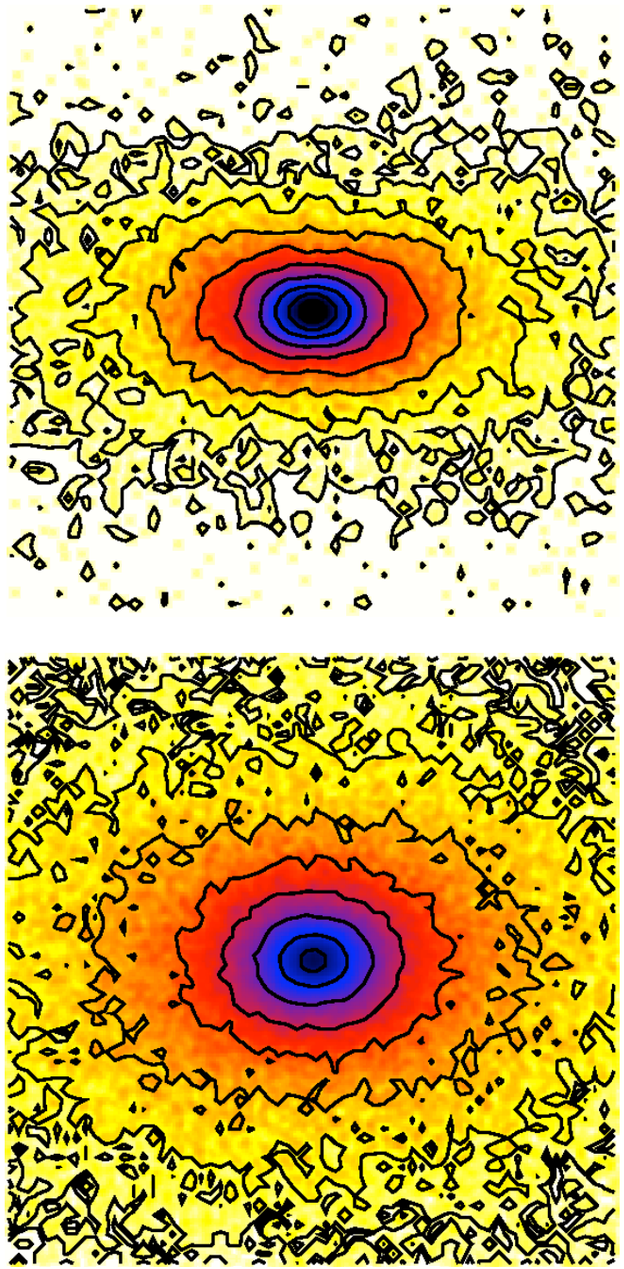


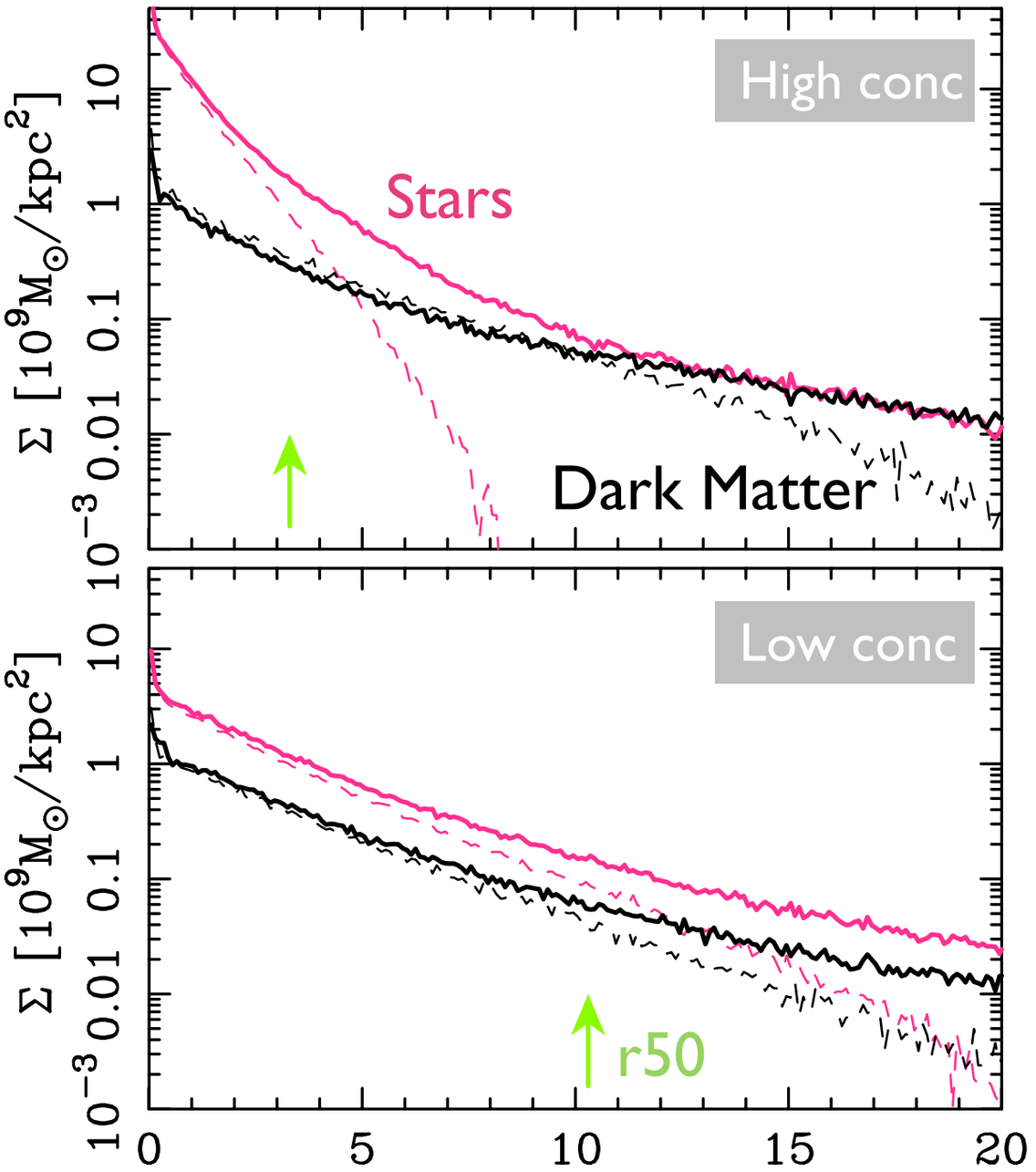
SPECIFIC AM IN THE REMNANT

Stellar components with low concentrations are more susceptible to tidal torques, hence **acquire a higher percentage of the initial orbital AM**



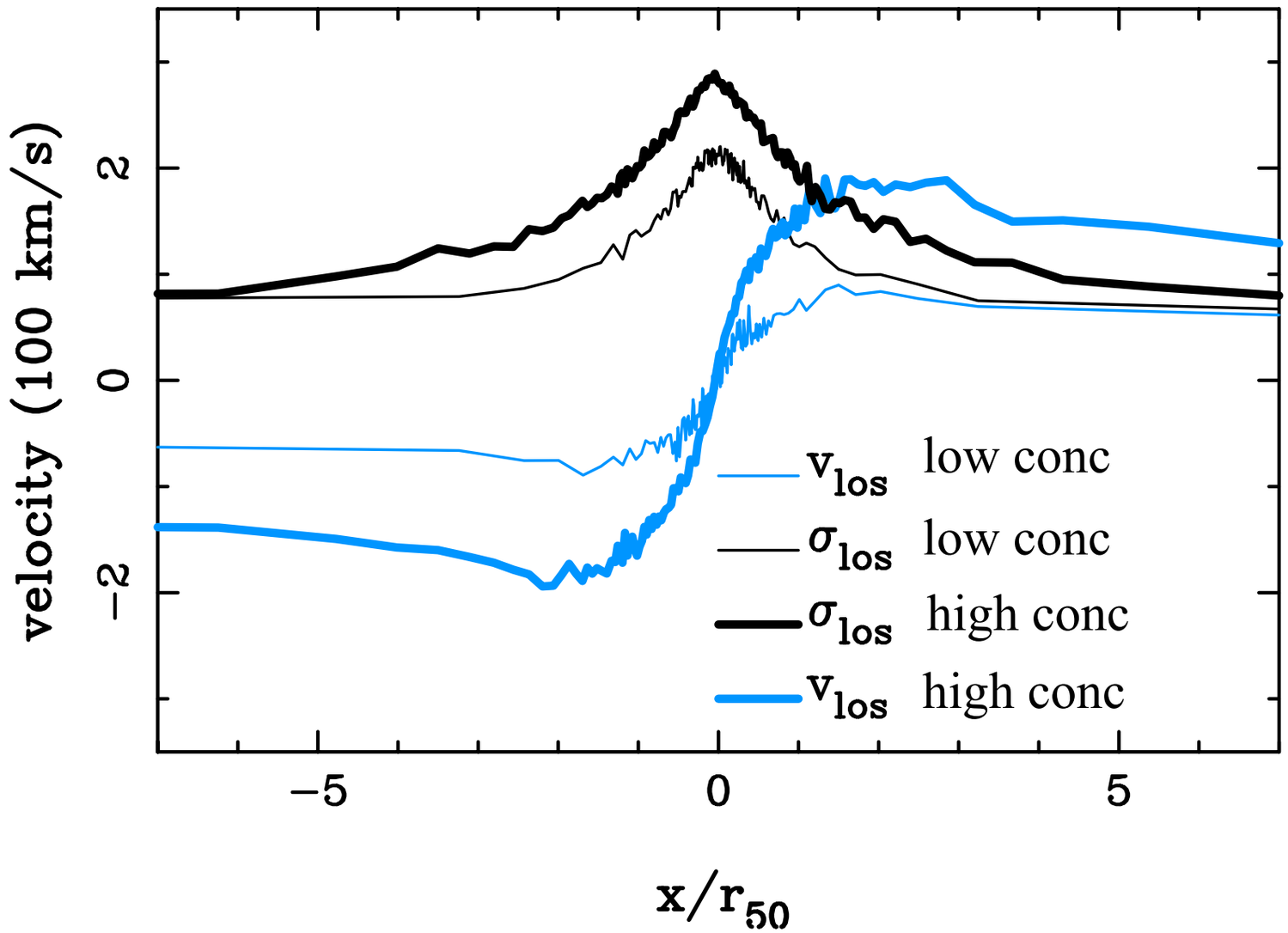
WHAT DO THESE REMNANTS LOOK LIKE? (1)



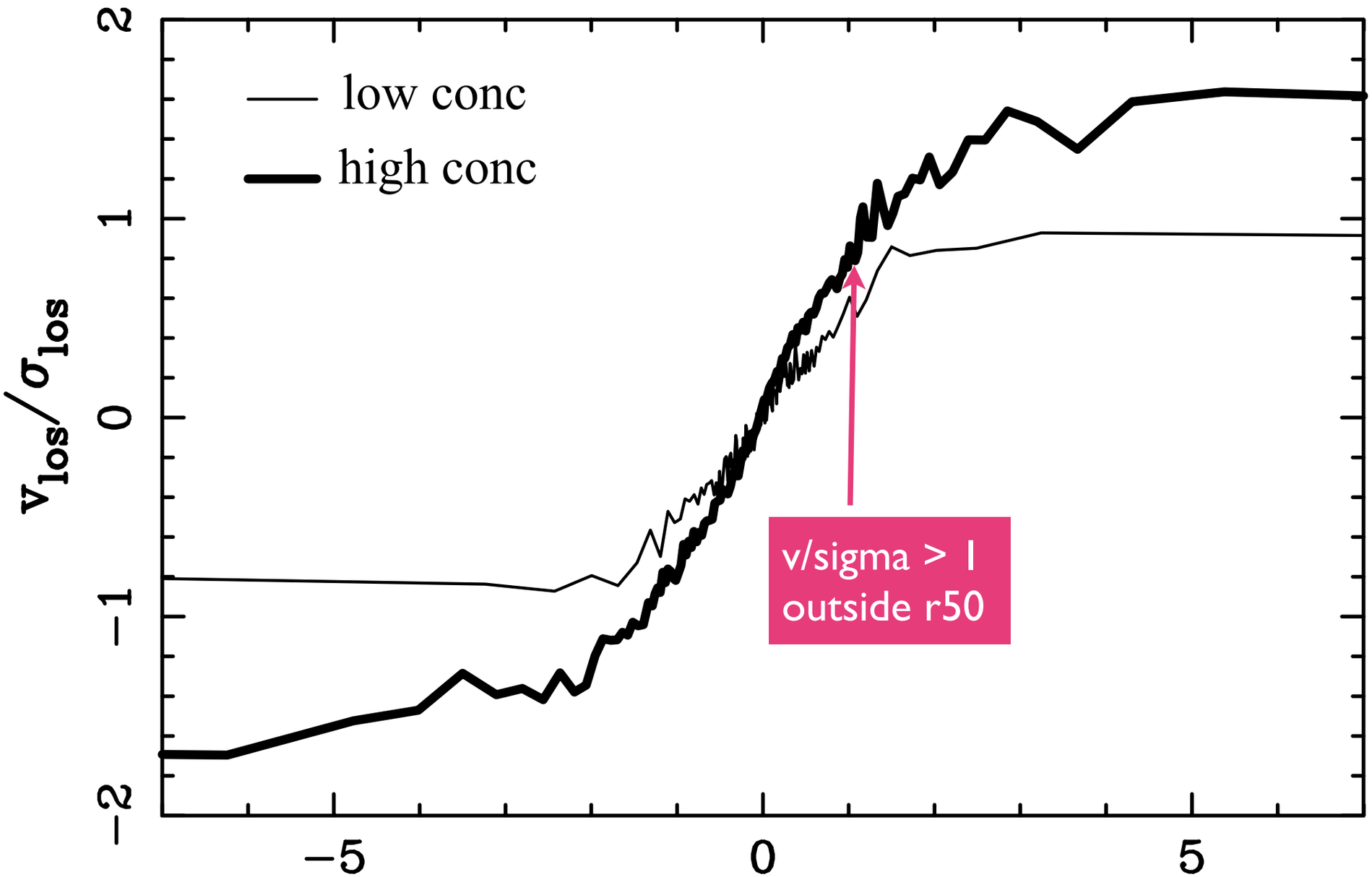


WHAT DO THESE REMNANTS LOOK LIKE? (2)

The stellar component of the most concentrated systems shows a **higher central velocity dispersion**, a **steeper dispersion profile**, a **higher value of the line-of-sight velocity**

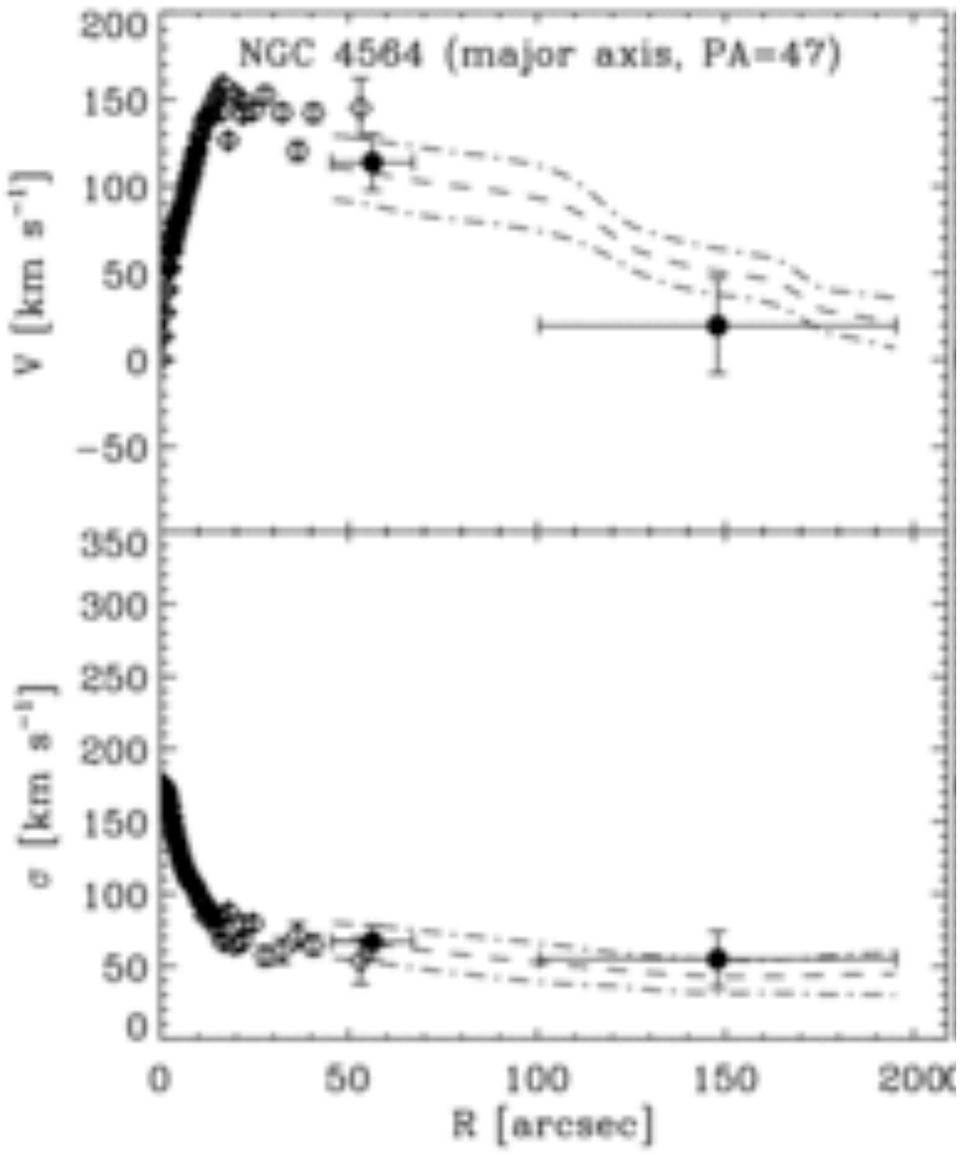


WHAT DO THESE REMNANTS LOOK LIKE? (3)



WHAT DO THESE REMNANTS LOOK LIKE? (3)

Most of the galaxies studied by
Coccato et al. (2009) show a *v*/σ ratio not greater than 0.6, while a fraction of them have **kinematics that become increasingly supported by rotation in the outer parts**, qualitatively in agreement
with the hybrid merger remnants discussed here



HOW DO THESE REMNANTS LOOK LIKE? (4)

.... Some of them look like **rotationally dominated systems with an elliptical-like morphology**

- The **morphological properties** of a galaxy are **not univocally related to the dynamical ones**

- Systems with hybrid properties:

  - Spiral-like morphology but v/sigma <1

    (Jog & Chitre, 2002; Bournaud et al. 2004, 2005)

  - Elliptical-like morphology but v/sigma > 1

    (Di Matteo et al. 2009, A&A Letters)

ANGULAR MOMENTUM EVOLUTION IN DRY MERGERS

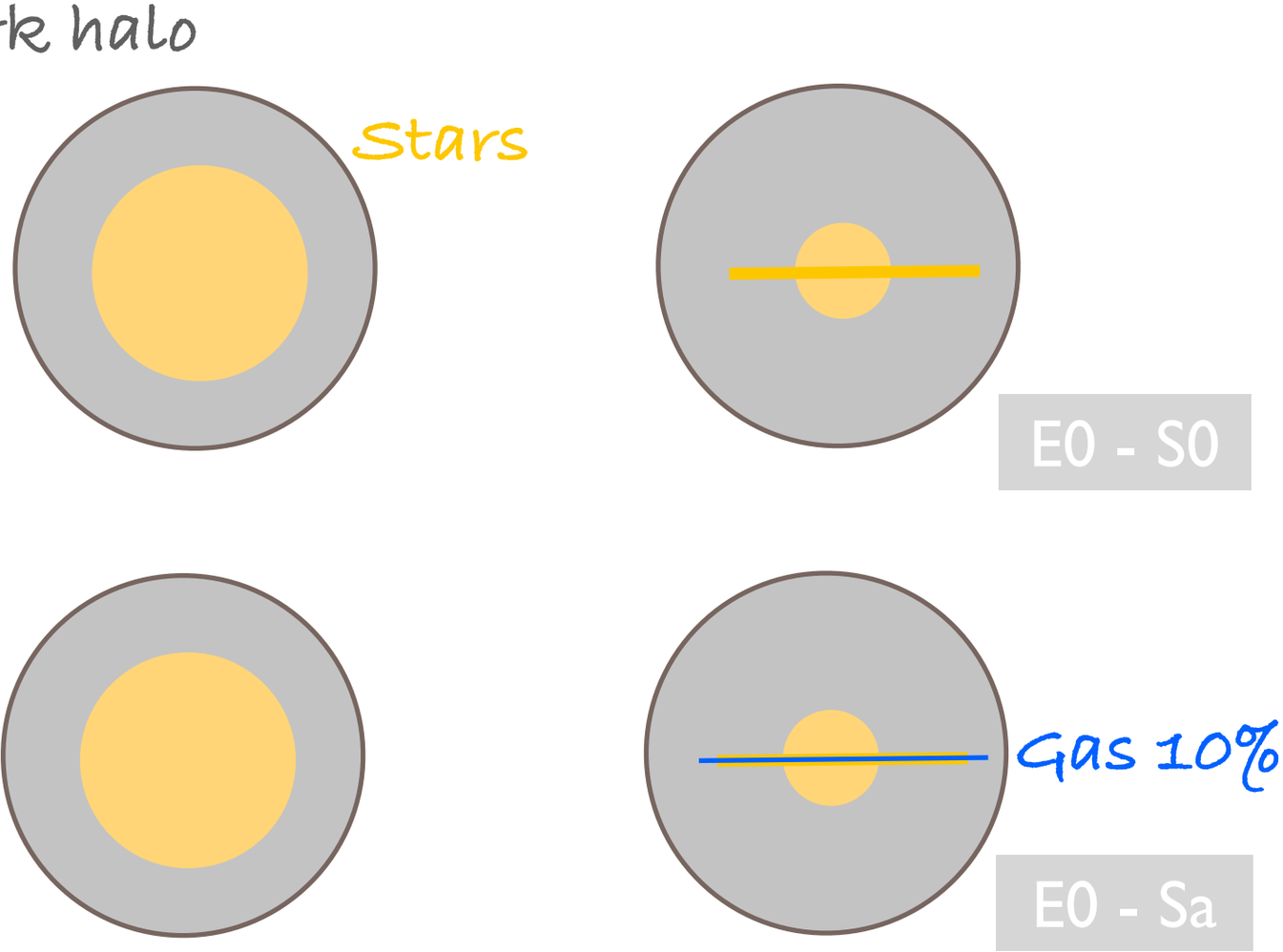
(2) Mixed pairs:

the merger of an elliptical and a spiral (S0 or Sa) galaxy

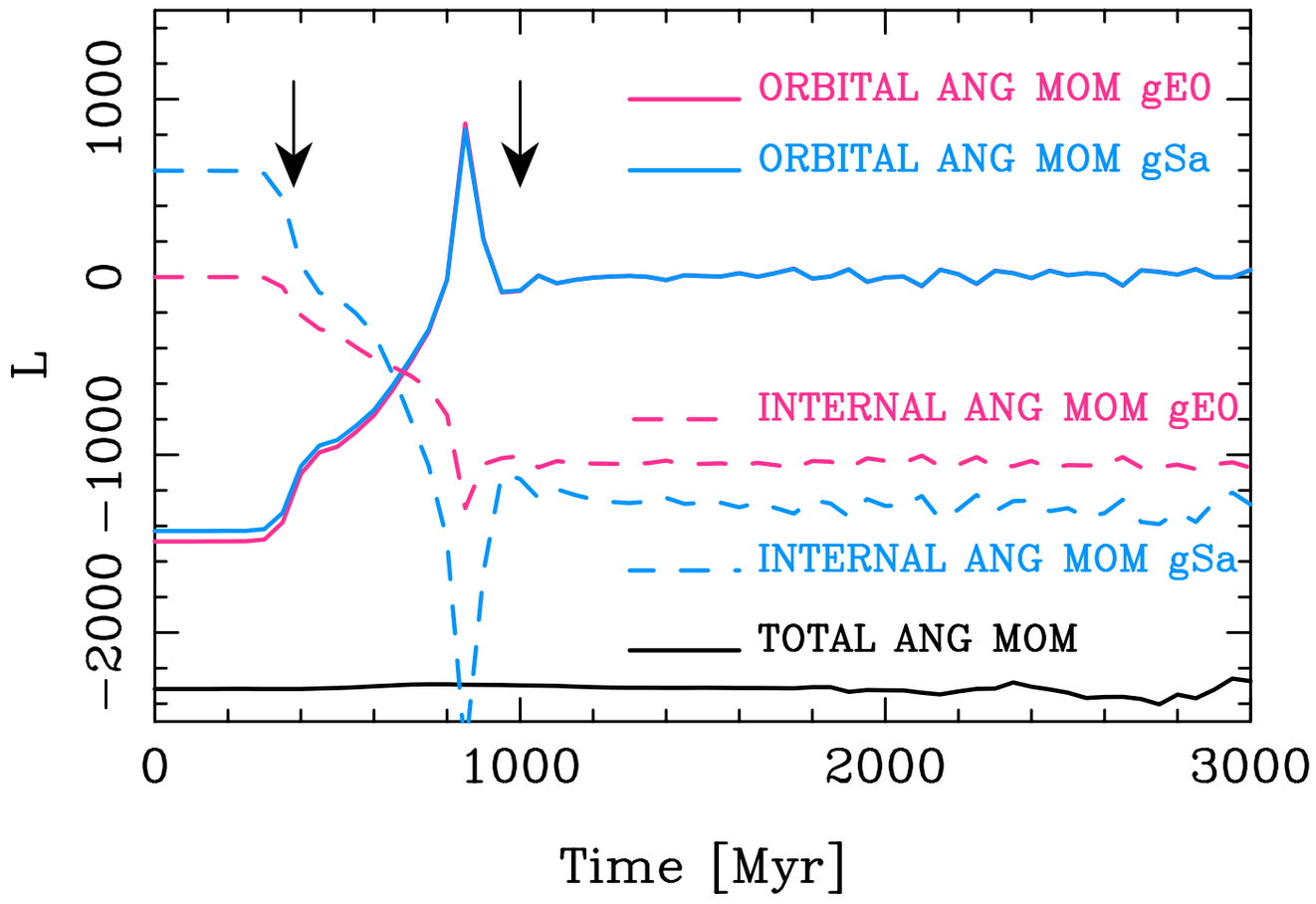
Di Matteo, Combes, Semelin, Combes 2008, A&A

THE INITIAL MODELS

1:1 mergers of elliptical-spiral systems on retrograde orbits

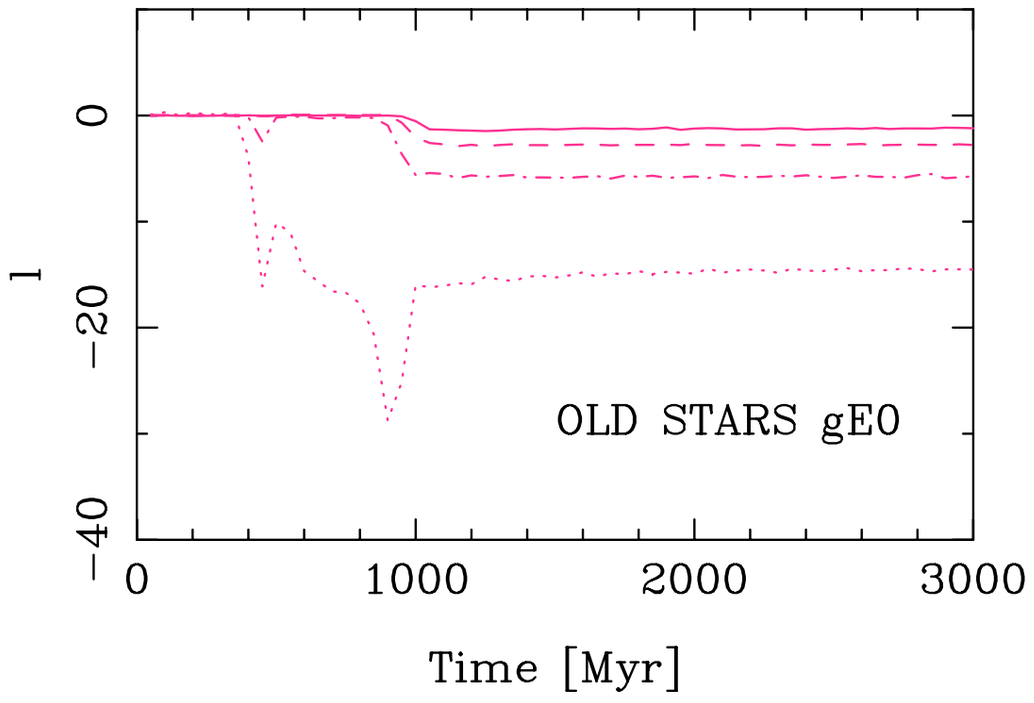


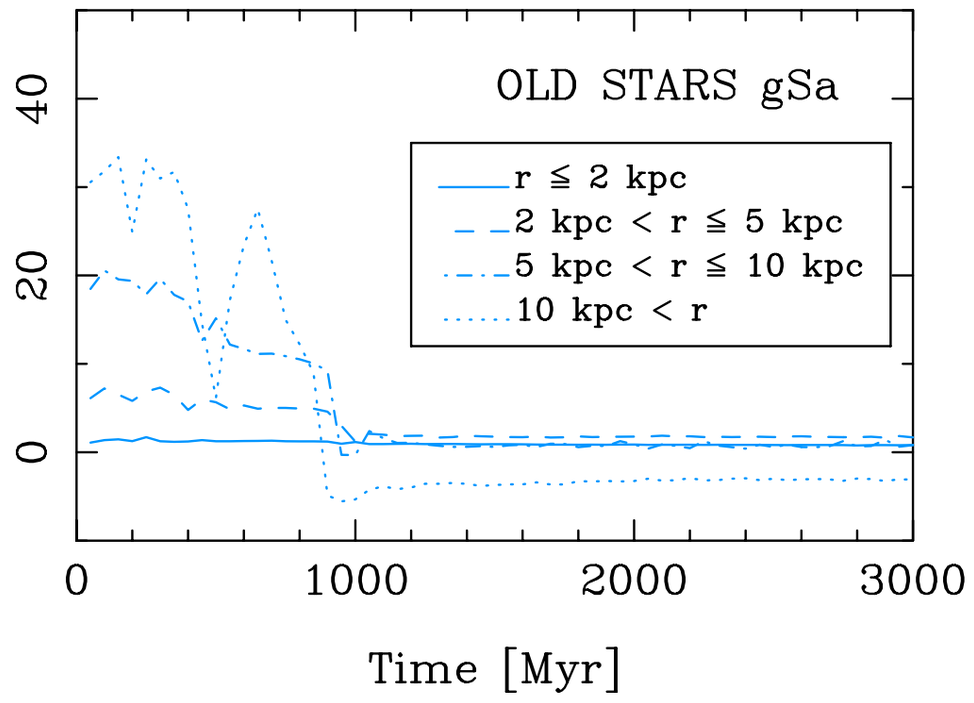
EVOLUTION OF THE TOTAL AM



The orbital AM is converted into internal AM of the two galaxies

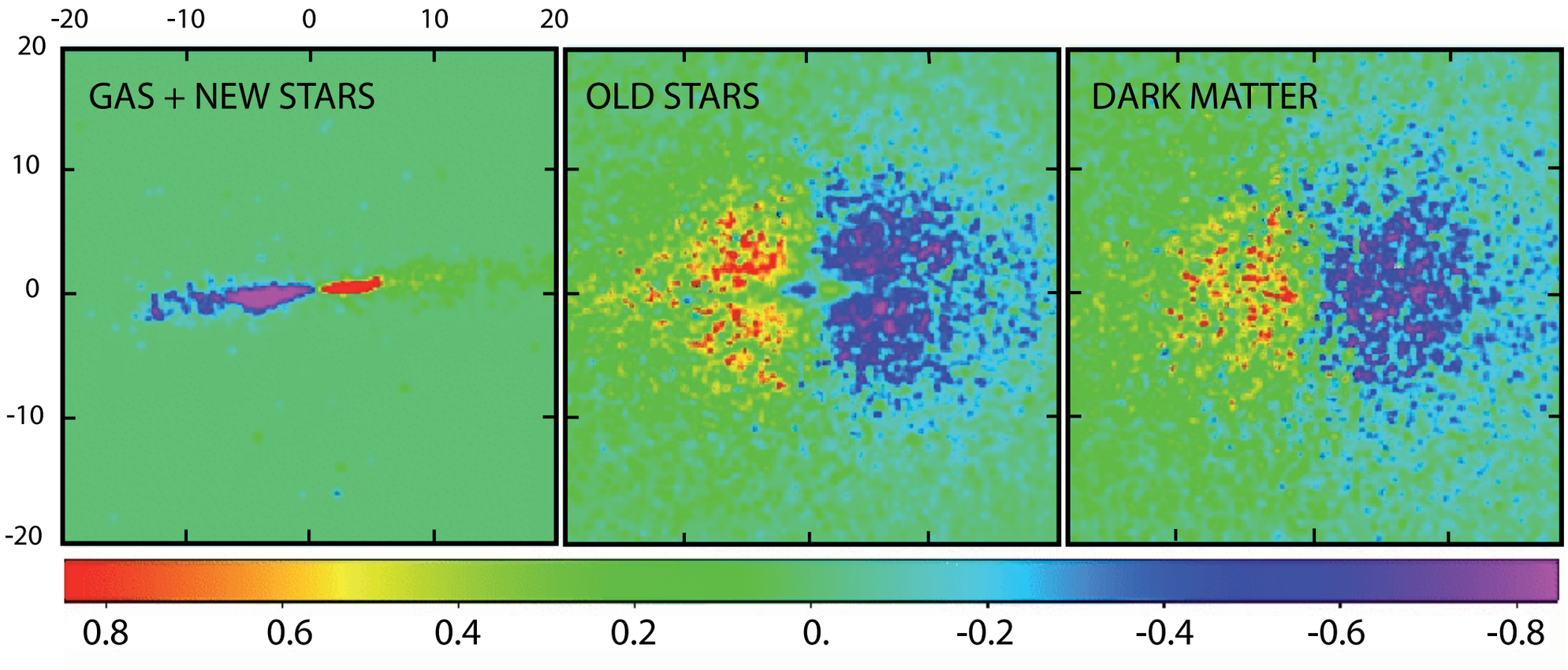
EVOLUTION OF THE AM





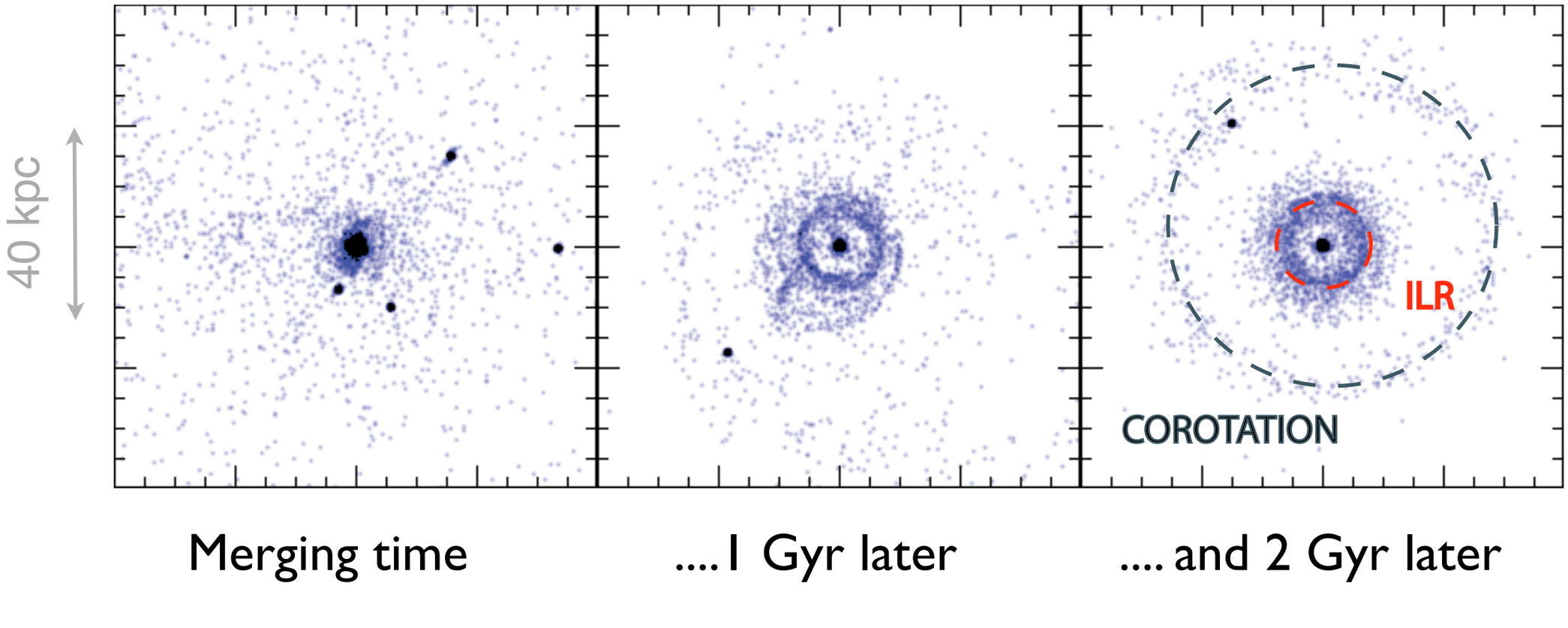
- The outer regions acquire orbital AM first
- Stars in the outer part of the spiral galaxy acquire sufficient AM to invert their initial spin
- Stars in the inner part preserve part of their initial AM

VELOCITY MAPS



Counter-rotation in the old stellar component and in the gas (when present)

GAS DISTRIBUTION



COUNTER-ROTATION IN MIXED MERGERS

A new mechanism to explain the observed counter-rotating components in early-type galaxies, **by major mergers of E-S galaxies**

- Other possibilities:
  - spiral-spiral retrograde mergers with or without gas

    (Hernquist & Barnes, 1991; Balcells & Gonzalez, 1998; Jesseit et al. 2007, Bournaud et al. 2009)

  - minor mergers of elliptical galaxies

    (Kormendy 1984; Balcells & Quinn 1990)

ANGULAR MOMENTUM EVOLUTION IN DRY MERGERS

(3) Minor mergers:

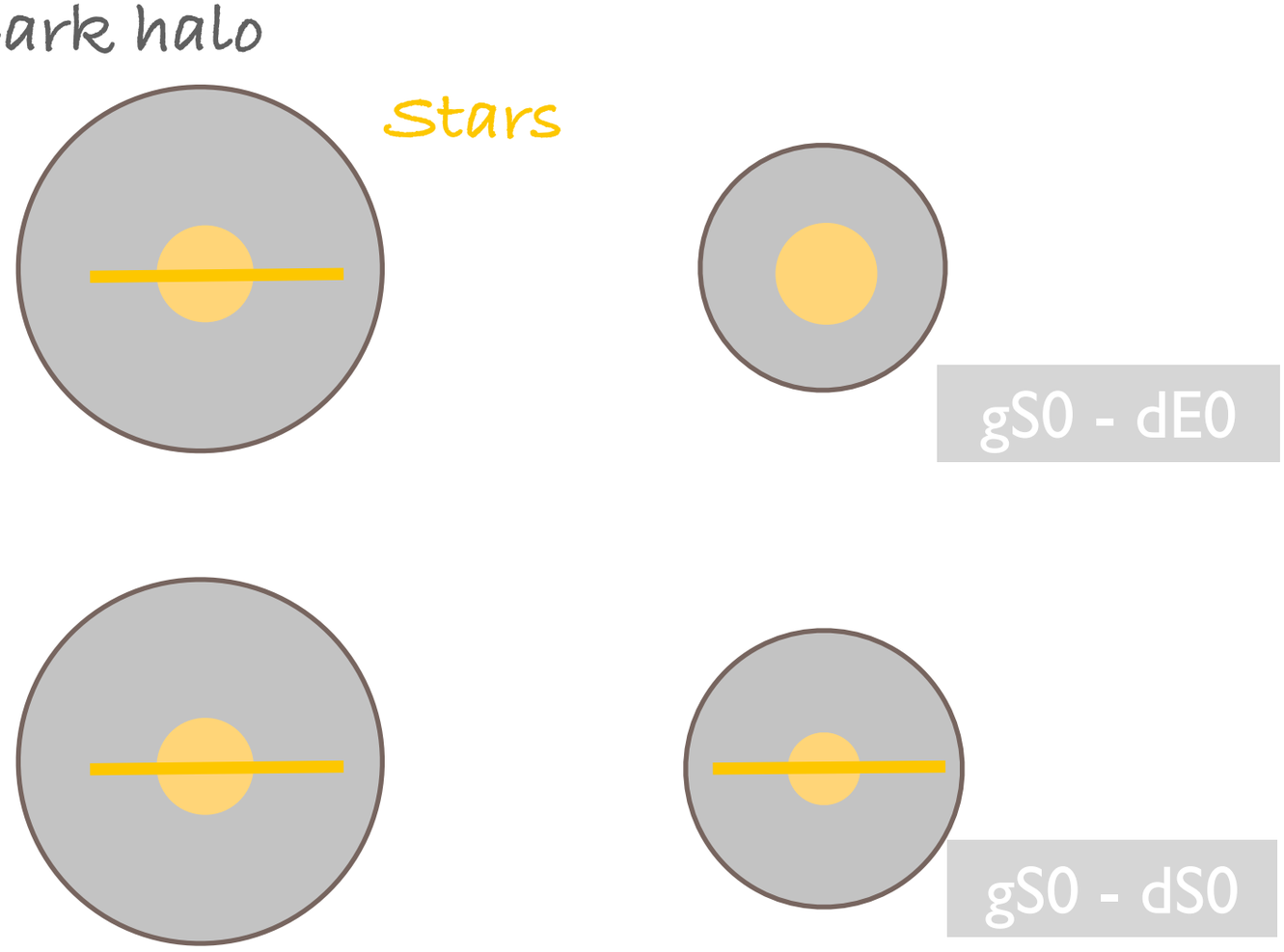
10:1 and 20:1 mergers between a S0 galaxy and a (disky or elliptical) satellite

Qu, Di Matteo, Lehnert, van Driel & Jog, in prep

Yan Qu's thesis

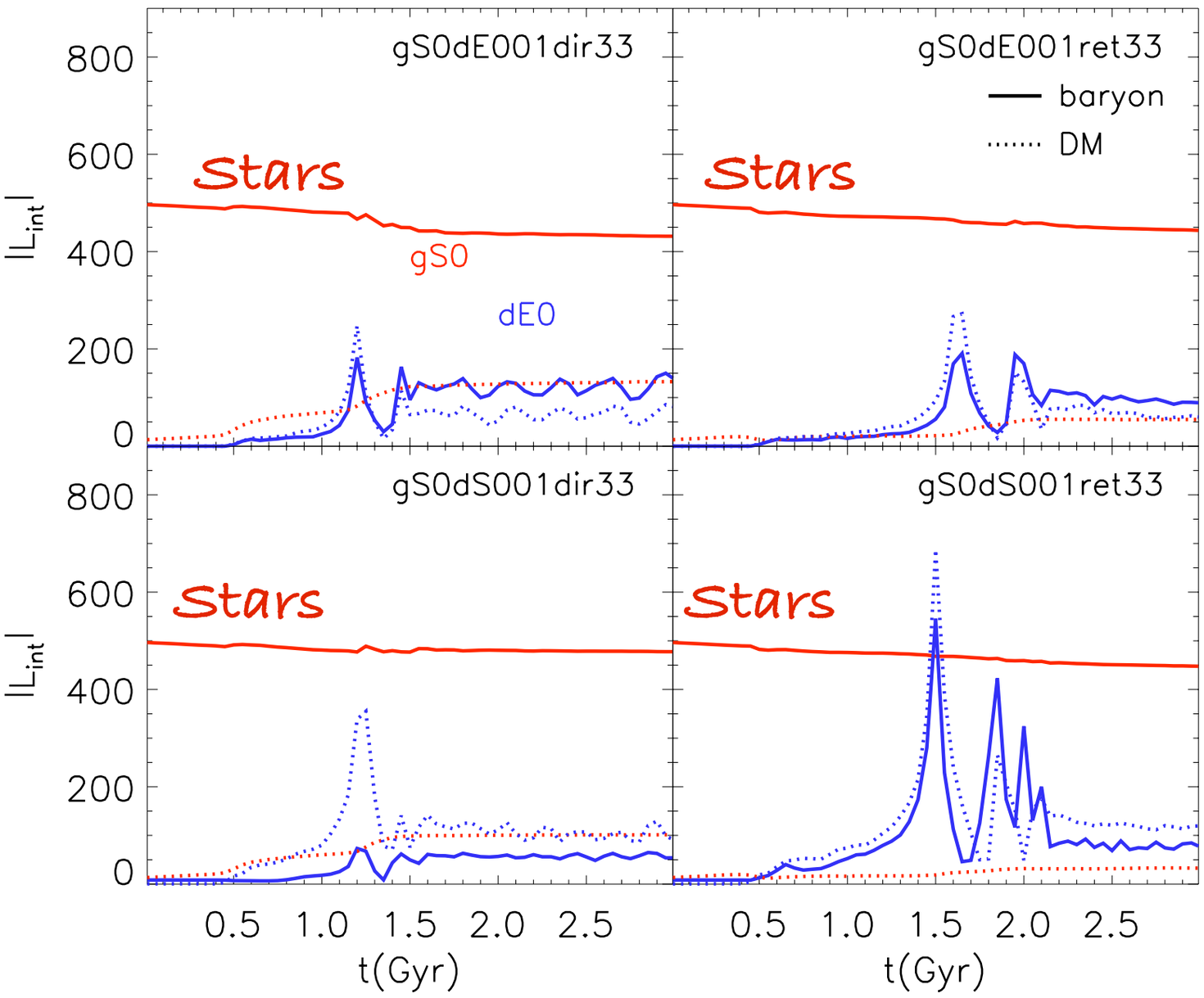
THE INITIAL MODELS

10:1 and 20:1 mergers between a S0 galaxy and a disky or elliptical satellite



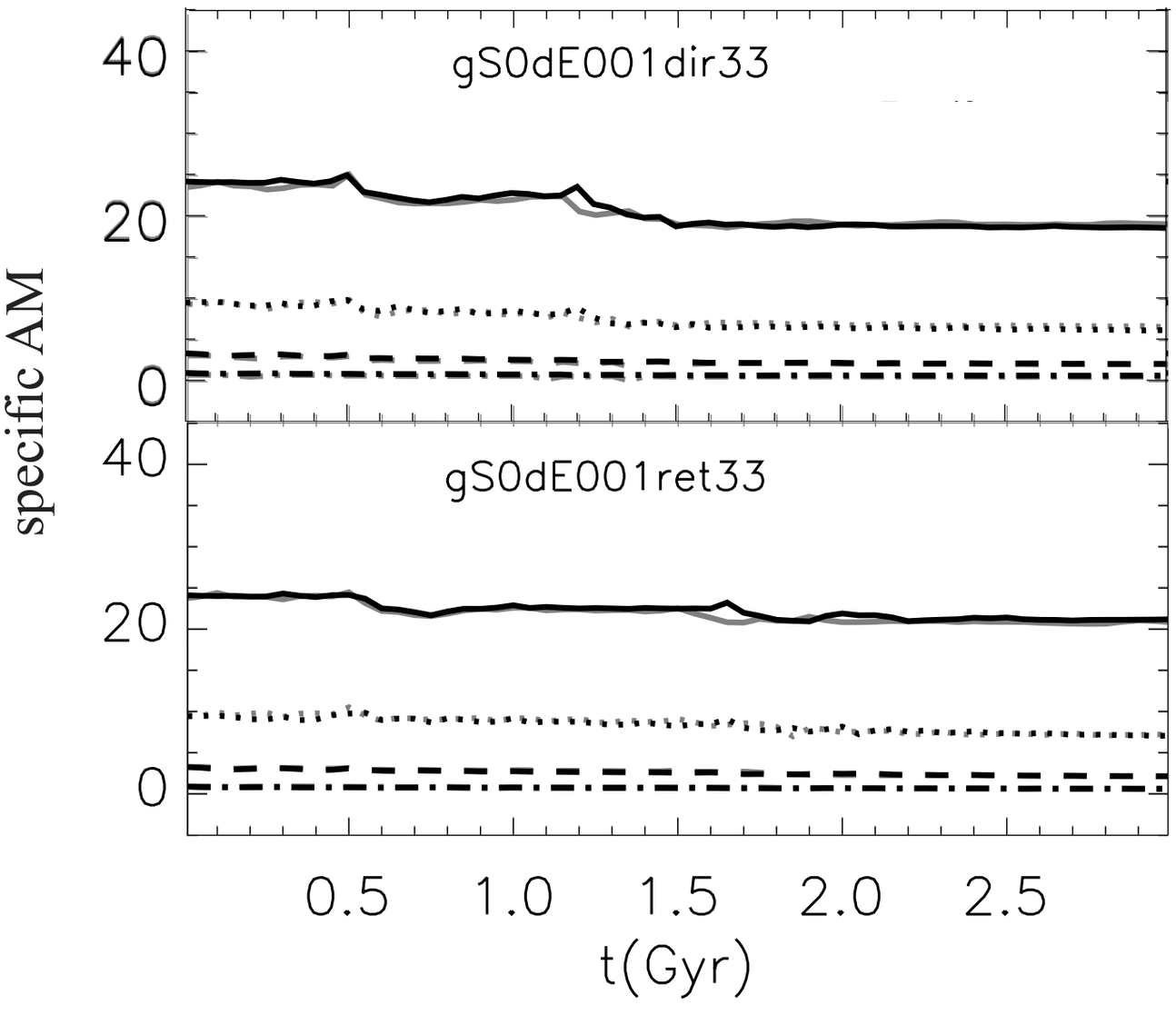
No restriction on the orbital geometry: direct, retrograde mergers, variety of initial orbital energies and AM

TOTAL AM OF THE STELLAR COMPONENT



Indipendently on orbital parameters and satellite morphology, **stars in the disk of the primary lose AM during the merger process.**

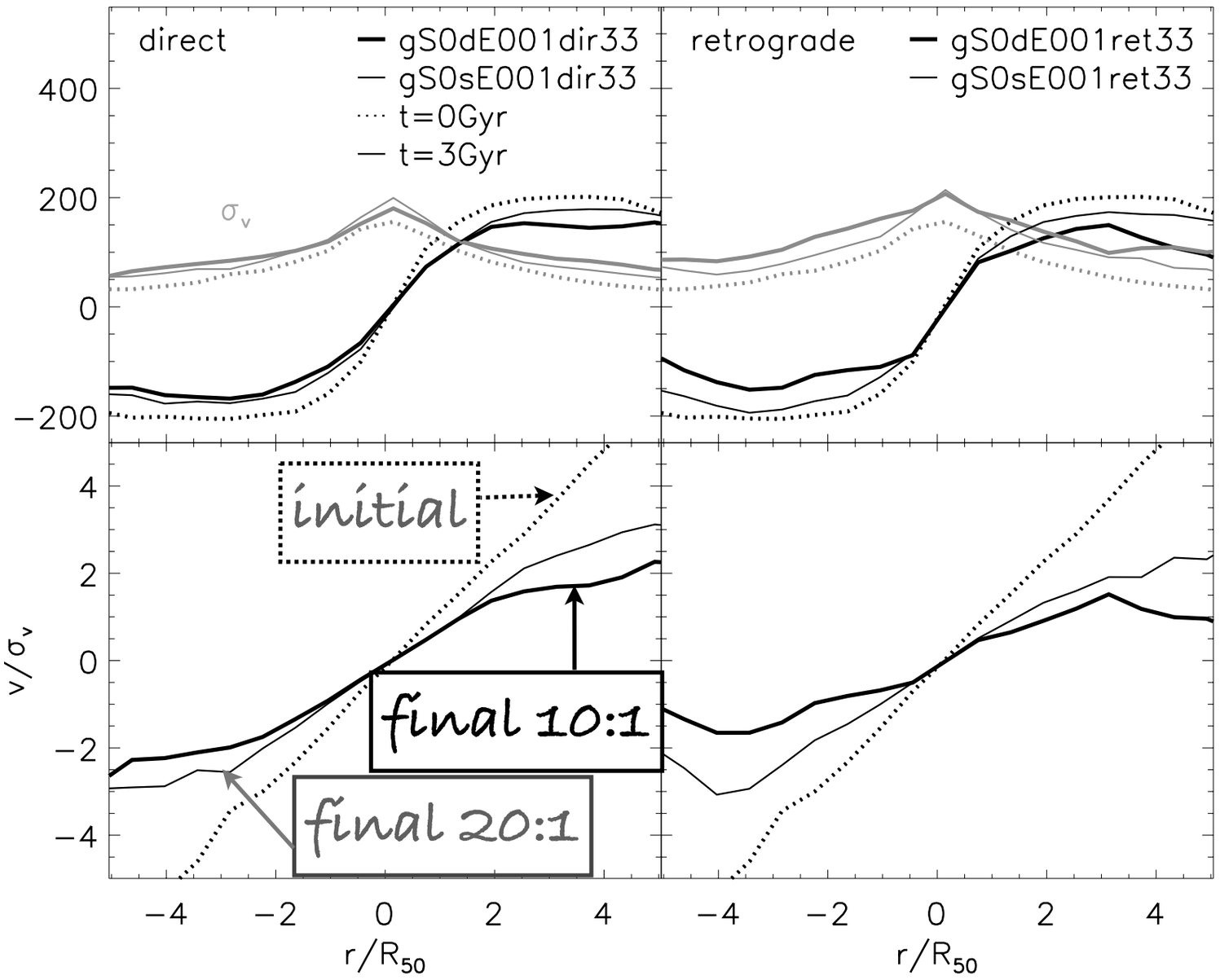
SLOWING DOWN OF THE STELLAR DISK (1)



- $\leq R_{50}/2$
- $R_{50}/2 < r \leq R_{50}$
- $R_{50} < r \leq 2R_{50}$
- $2R_{50} < r \leq 5R_{50}$

The decrease of the specific AM is particularly effective outside 1 R_{50}

SLOWING DOWN OF THE STELLAR DISK (2)



The v/sigma ratio decreases not only because of disk heating but **also because of a decrease in the AM of the stellar disk**

Toward an earlier-type, slower rotator system

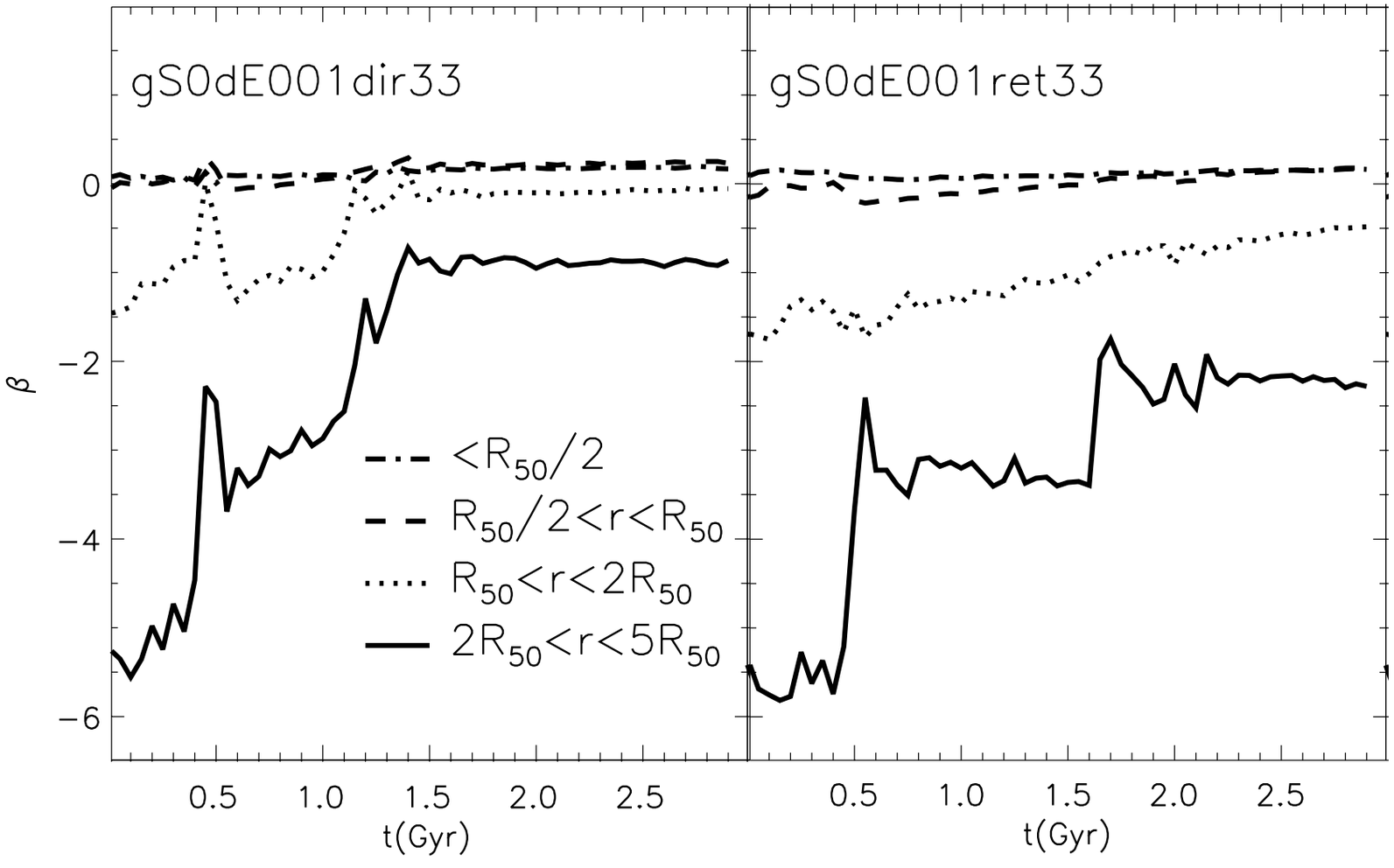
STELLAR VELOCITY ANISOTROPY

$$\beta = 1 - \frac{<\sigma_t^2>}{2<\sigma_r^2>}$$

beta > 0 => radial anisotropy

beta = 0 => isotropy

beta <0 => tangential motions



CONCLUSIONS

- Angular momentum redistribution during a merger affects all the component of a galaxy

- The amount of rotation found in the stellar component of the remnant depends on:
  - orbital parameters
  - morphology of the interacting systems
  - mass ratio

- The study of the AM redistribution allows to understand the formation of fast-rotating stellar halos, CR structures, the slowing down of stellar disks, ..

ON THE EVOLUTION OF METALLICITY GRADIENTS IN MAJOR DRY MERGERS

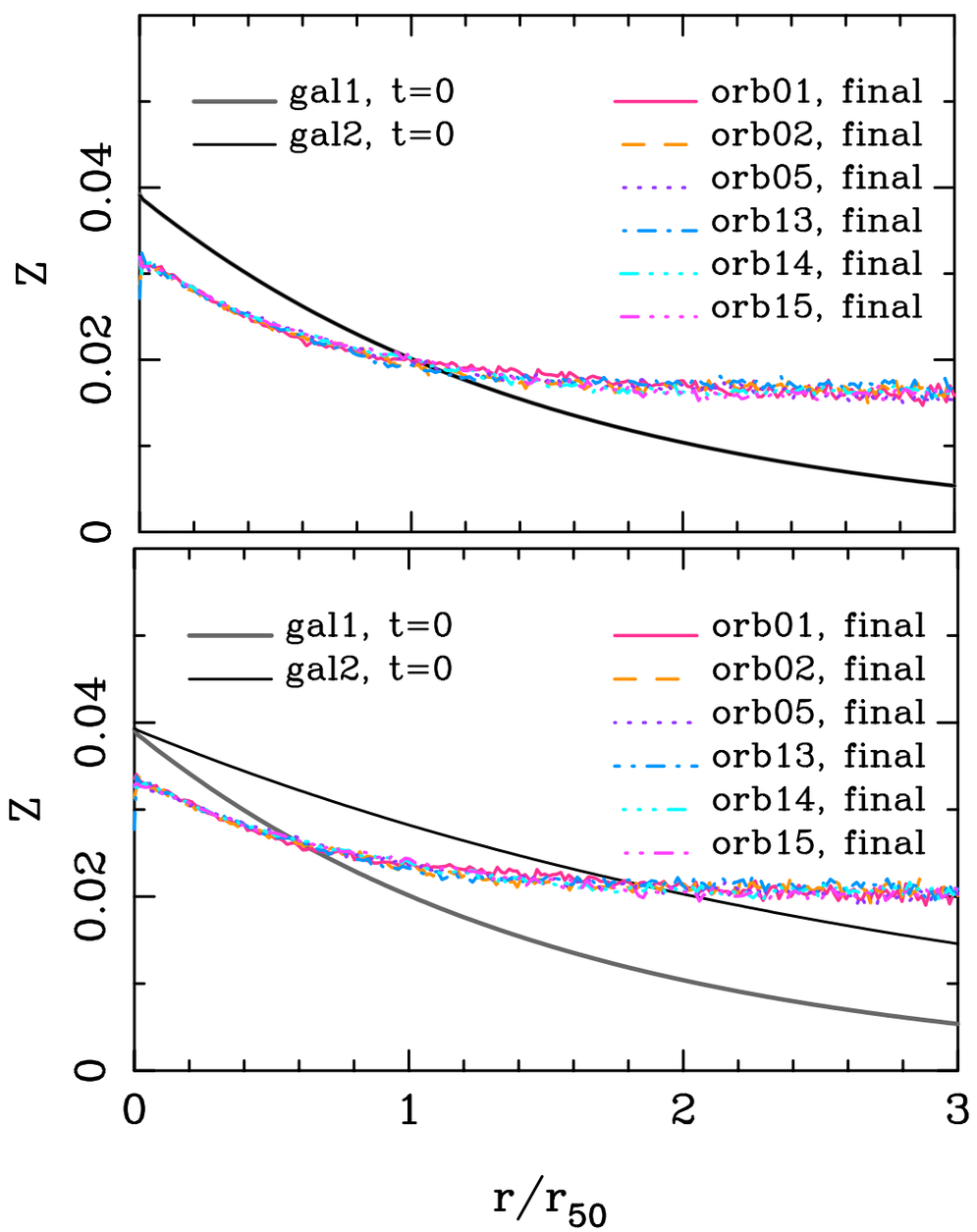
1:1 Mergers of two ellipticals:
(1) Mergers of two initially not-rotating spherical systems;
(2) Subsequent mergers between the remnant of mergers at step (1)

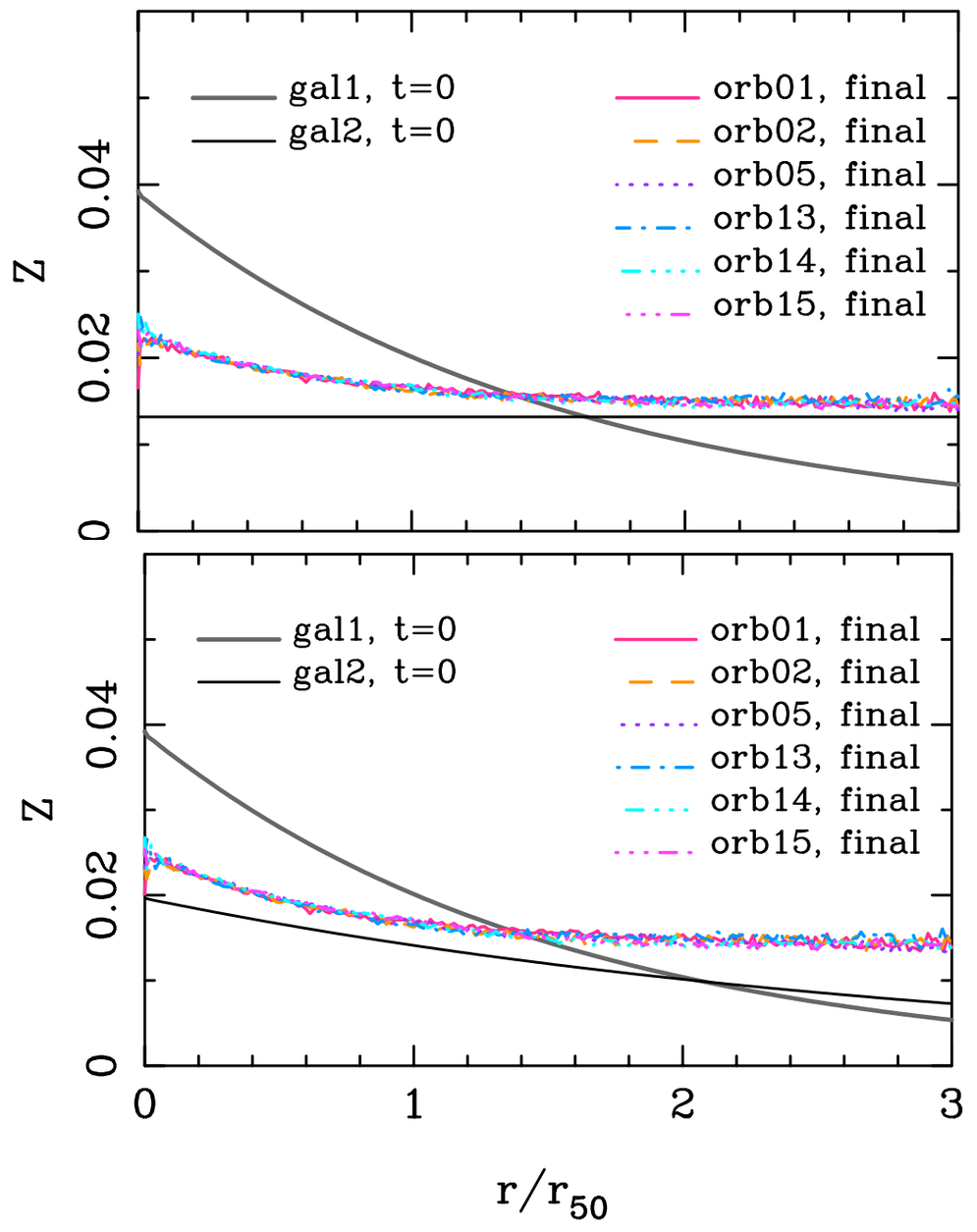
Di Matteo, Pipino, Lehnert, Combes, Semelin 2009, A&A

SOME QUESTIONS

- Could dry mergers lead to metallicity gradients as observed in elliptical galaxies in the local Universe?
- Do dry mergers always lead to a flattening of the initial (i.e., pre-merger) gradient?
- Under what conditions does this flattening occur?
- What is the magnitude of the flattening that is typically produced for a range of initial conditions?

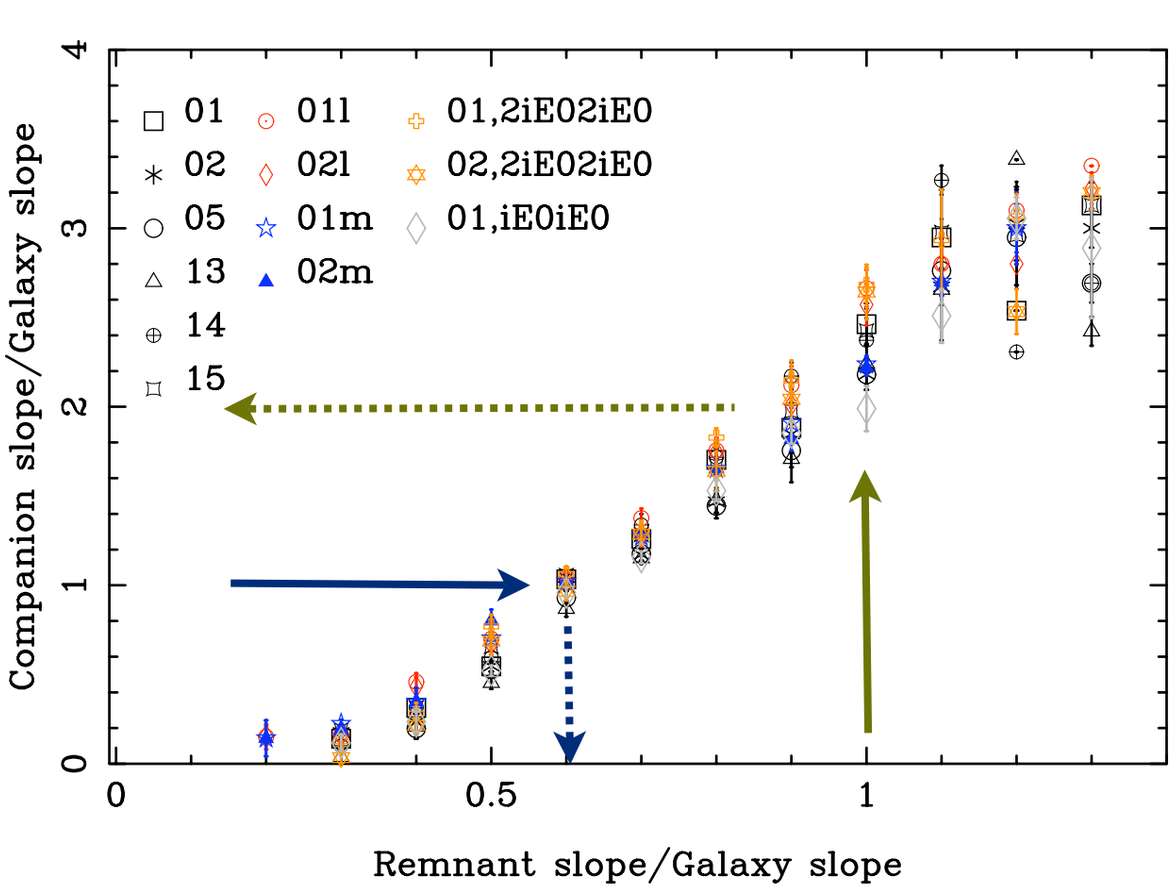
THE EVOLUTION OF SOME METALLICITY GRADIENTS





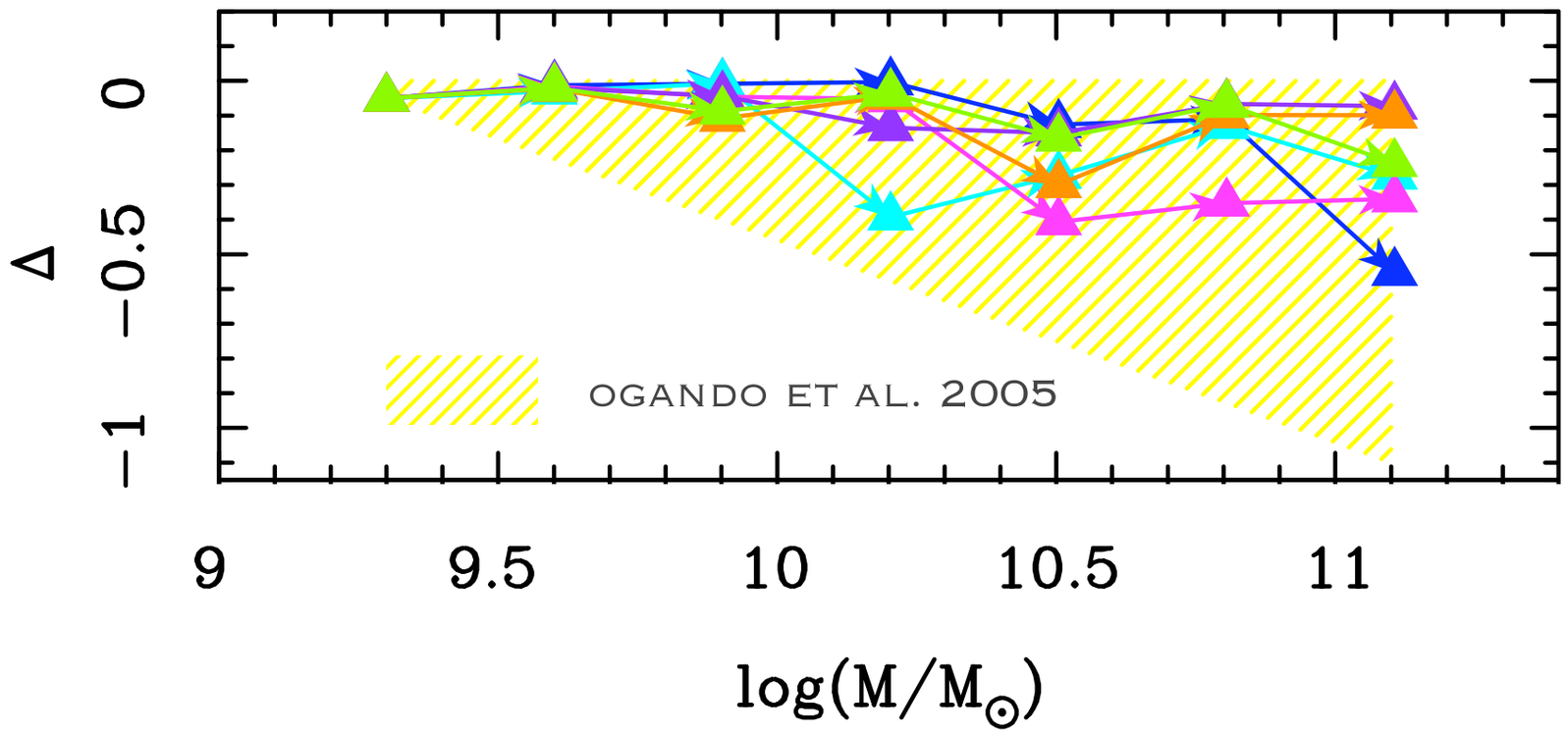
THE EVOLUTION OF SOME METALLICITY GRADIENTS

slope= log(Z(r50)) – log(z(0.1r50))



- For a merger between **two Es having identical initial MS, the metallicity profile of the remnant flattens**, with a final gradient about **0.6 times the initial one**
- **Remnants can have metallicity gradients greater than that of the progenitor elliptical galaxy**, every time the companion has a slope two times greater than the parent
- Ellipticals can maintain their original pre-merger metallicity gradient if the companion slope is sufficiently steep.
- **The final remnant gradient does not depend on the orbits** of the progenitor ellipticals

ARE DRY MERGERS COMPATIBLE WITH THE MG OF ELLIPTICALS IN THE LOCAL UNIVERSE?



If dry mergers can occur among ellipticals having different gradients, randomly distributed in the shaded area shown in the plot, a sequence of such events does not lead to a clear trend. In turn, **a sort of random walk, with increasing and decreasing slopes, seems to be the general outcome**