XXXII Canary Islands Winter School of Astrophysics

Galaxy clusters in the local Universe

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Lecture 5 (part 2):

Orbits

Based on:

Solanes & Salvador-Solé (1990), A&A, 234, 93 (***β(r)***)

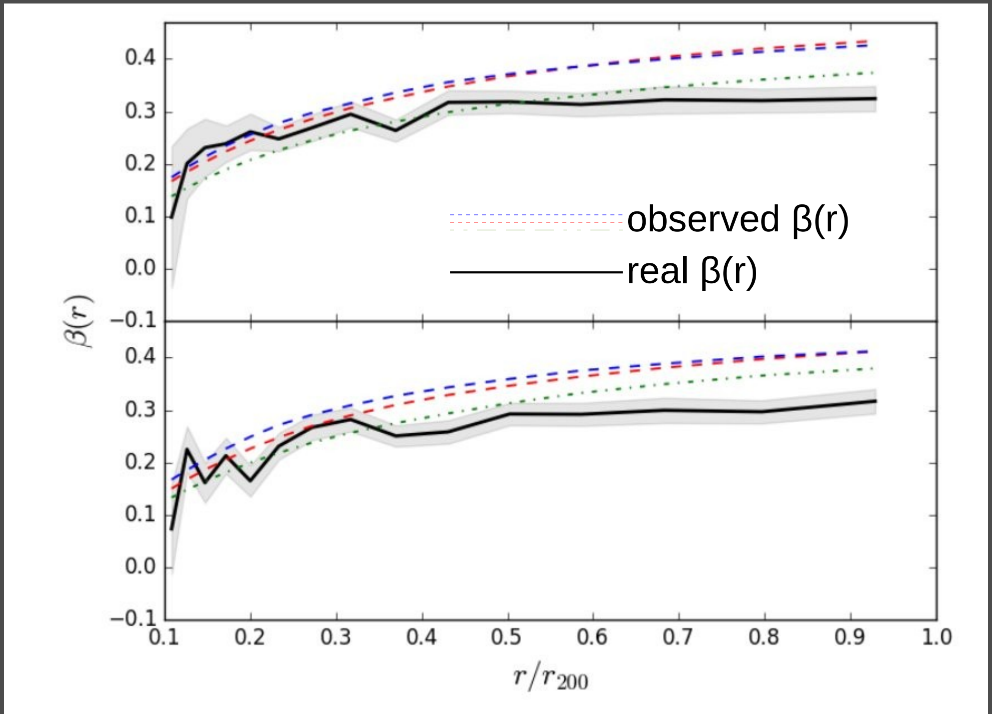
Mamon, AB, Boué (2013), MNRAS, 429, 3079 *(the **MAMPOSSt** method)*

AB et al. (2013), A&A, 558, A1 (***β(r)***)

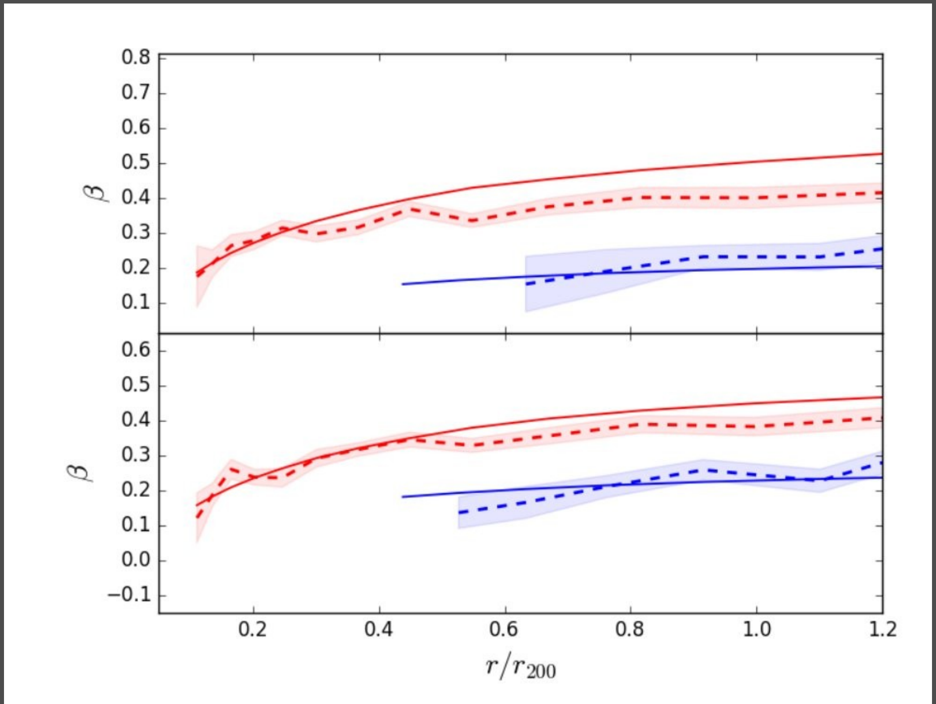
Orbits

MAMPOSSt allows to estimate both M(r) and **β(r)** $\equiv 1 - (\sigma_\theta/\sigma_r)^2$

While we determine M(r) for the total matter (dominated by DM), β(r) and σ(r) are determined for the gravitational potential tracers, galaxies, and can be different for different types of galaxies



Tagliaferro, AB et al. (2021): MAMPOSSt β(r) tested vs two numerical simulations, using "observed" (dashed) or real (dot-dashed) members



Tagliaferro, AB et al. (2021): MAMPOSSt β(r) tested vs two numerical simulations, showing good agreement both for red and blue galaxies

Orbits

We can also use M(r) determined via gravitational lensing analysis or from X-ray and/or SZ emission by the intra-cluster plasma, combined with projected phase-space information for cluster galaxies to determine $\beta(r) \equiv 1 - (\sigma_\theta/\sigma_r)^2$

This is called the "**Jeans inversion**"

(*Binney & Mamon 1982, Solanes & Salvador-Solé 1990, Dejonghe & Merritt 1992*)

Observables
$n(R)$, $\sigma_{los}(R)$

+M(r)

→ **β(r), σ(r)**

$$H(R) = \frac{1}{2}\Sigma(R)\sigma_p^2(R)$$

$$K(r) = 2\int_r^\infty H(x)\frac{x\,dx}{\sqrt{x^2-r^2}}$$

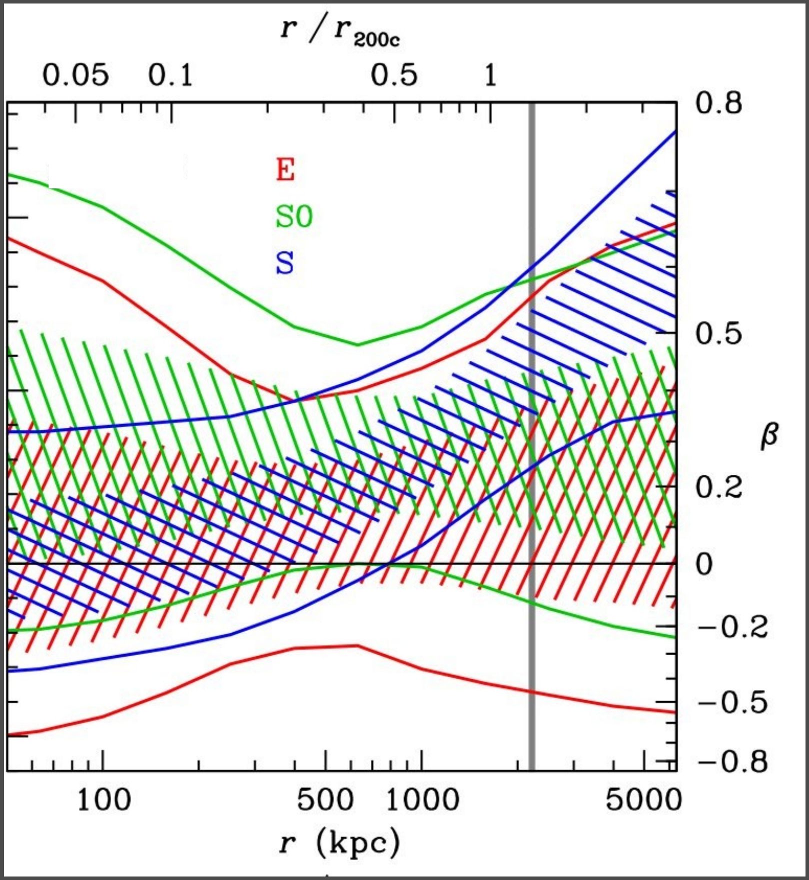
$$\Psi(r) = -GM(r)\nu_g(r)/r^2$$

from the Abel inversion of Σ(R)

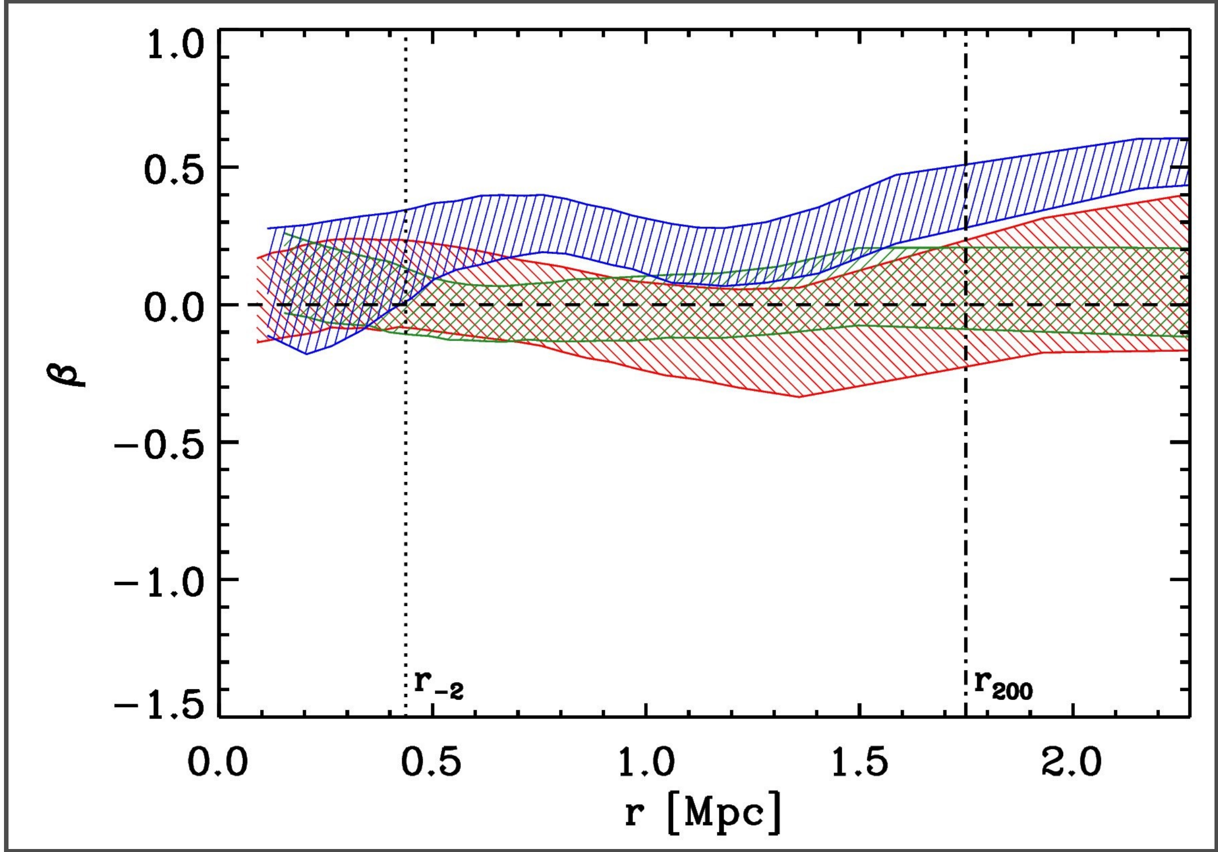
$$[3-2\beta(r)]\sigma_r^2(r) = \frac{-1}{\nu(r)}\int_r^\infty \Psi(r)dx - \frac{2}{\pi r\nu(r)}\frac{dK(r)}{dr}$$

$$\beta(r)\sigma_r^2(r) = \frac{1}{\nu(r)r^3}\int_0^r x^3\Psi(x)dx + \frac{1}{\pi r\nu(r)}\frac{dK(r)}{dr} - \frac{3K(r)}{\pi r^2\nu(r)} + \frac{3}{\pi r^3\nu(r)}\int_0^r K(x)dx$$

Orbits



β(r) for E, S0, S via MAMPOSSt, using the clusters from WINGS *(Mamon et al. 2019)*

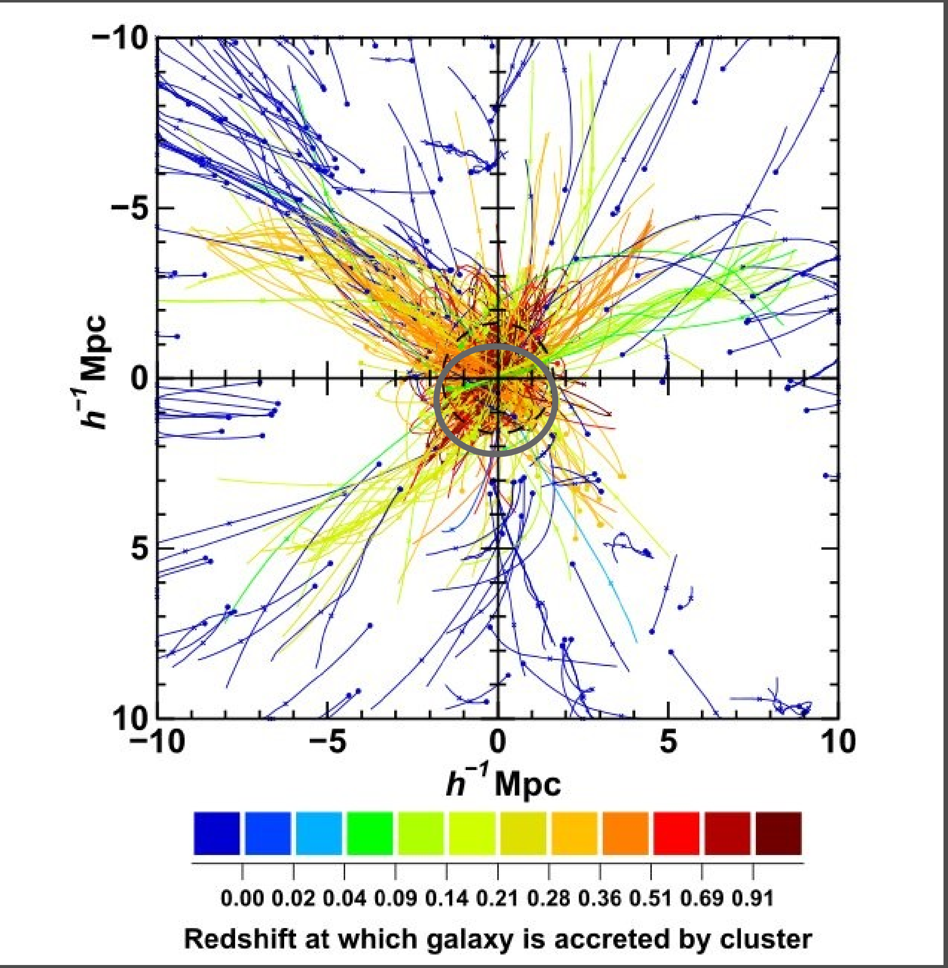


β(r) for E, S0, S via the Jeans inversion, using the clusters from WINGS and M(r) from *Mamon et al. (2019)*

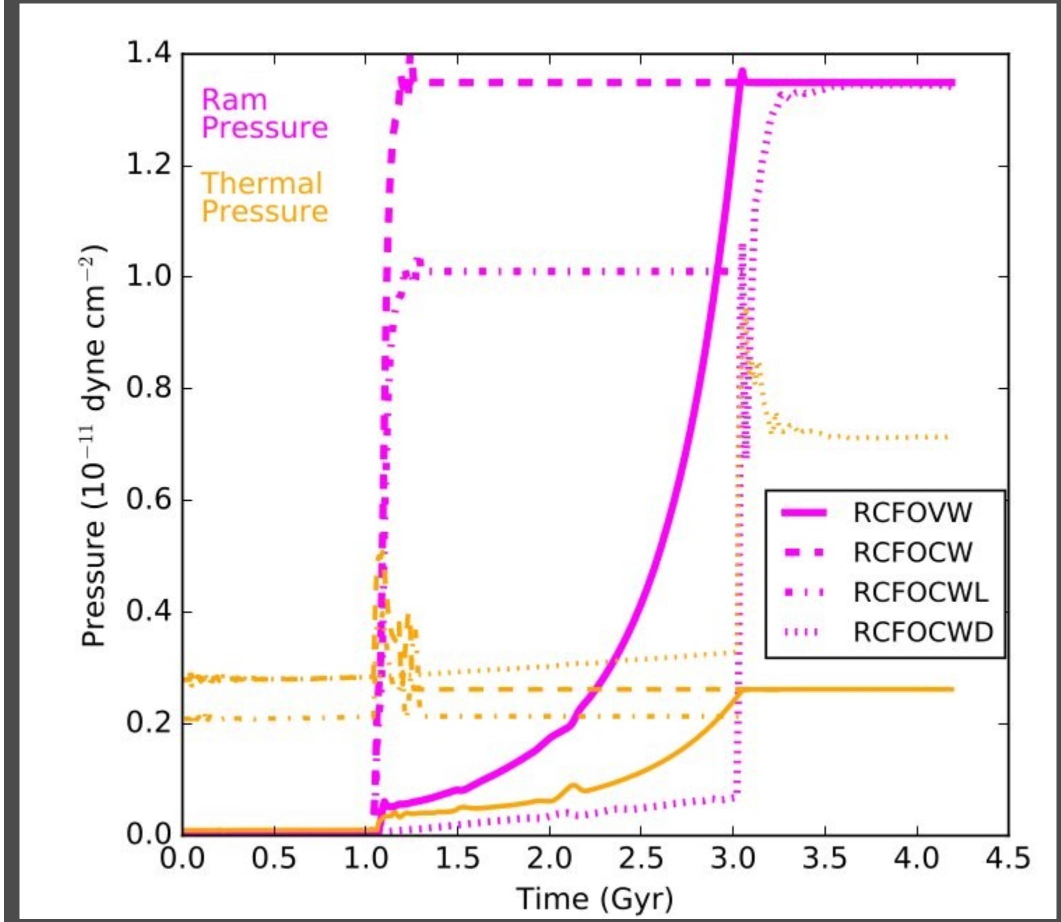
The Jeans inversion does not require choosing a model for β(r), unlike MAMPOSSt, so the solution is more general, but it requires smoothing of the data, as well as interpolation of the observed profiles to R=0 and extrapolation to ∞

Orbits

Physical processes depend upon the location within the cluster, but galaxies move...
it is important to know the orbits of galaxies in clusters - that is, β(r)



Haines et al. (2015): Individual galaxy orbits in a massive halo from the Millennium simulation



Tonnesen (2019): the ram pressure that a galaxy experiences changes during its orbit through the cluster, and this changes the amount of gas loss compared to a situation of constant ram pressure

Orbits

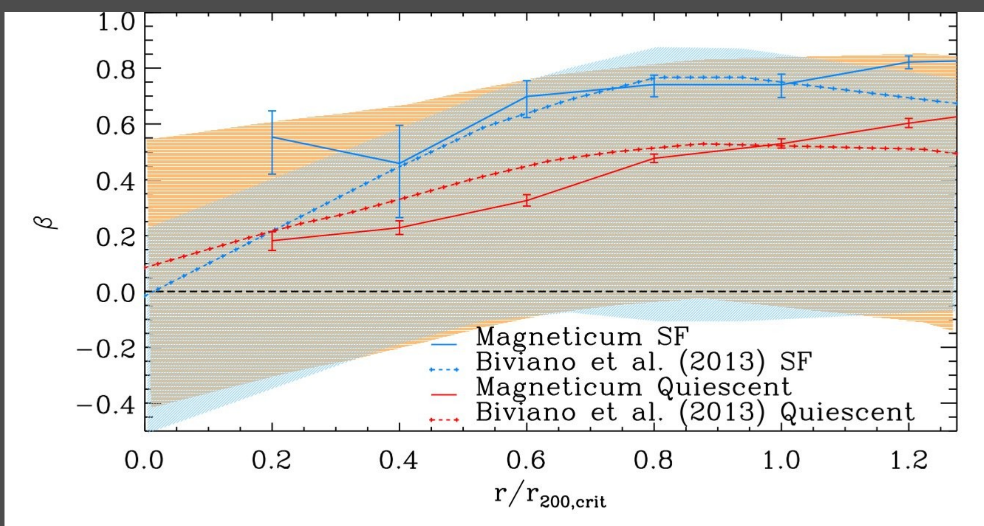
Observations suggest that passive/red/early-type galaxies are on less radially elongated orbits than star-forming/blue/late-type galaxies, in agreement with results from hydrodynamic simulations but not with those from semi-analytical models

⇒ **constraints on the evolution of galaxies in clusters**

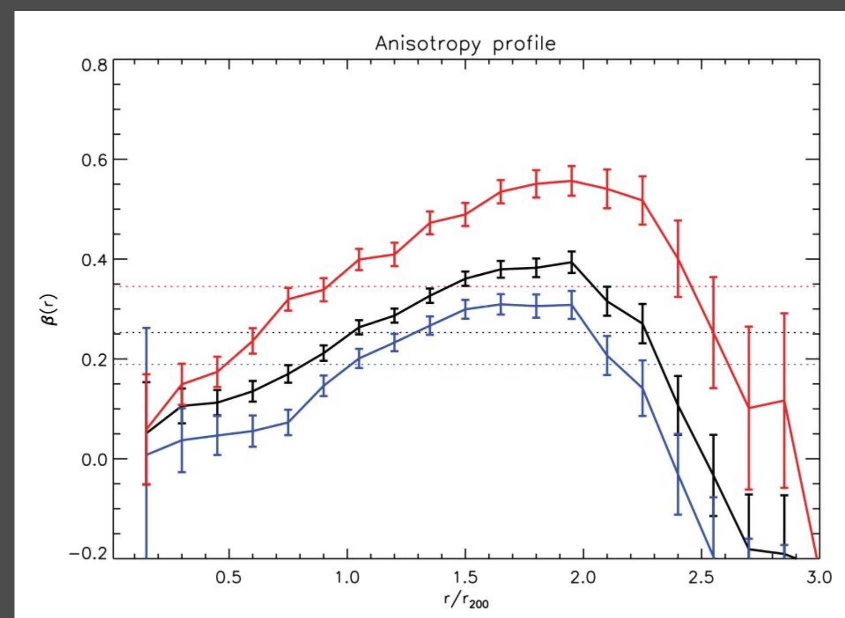
Galaxies enter the cluster on radially elongated orbits from the surrounding LSS.
If they survive the hostile cluster environment their orbits become less radial with time due to a variety of processes (change of gravitational potential, radial orbit instability, dynamical friction).
If they do not survive, we can only observe them on radial orbits, during their first or second infall.

$\beta_{red} < \beta_{blue}$ ⇒ Blue galaxies turn red at first pericenter, orbital evolution is efficient

$\beta_{red} > \beta_{blue}$ ⇒ Blue galaxies on tangential orbits do not turn red and orbital evolution is not efficient



Lotz et al. (2019): the orbits of satellites in the Magneticum Pathfinder simulations are similar to those of observed galaxies (of different types)

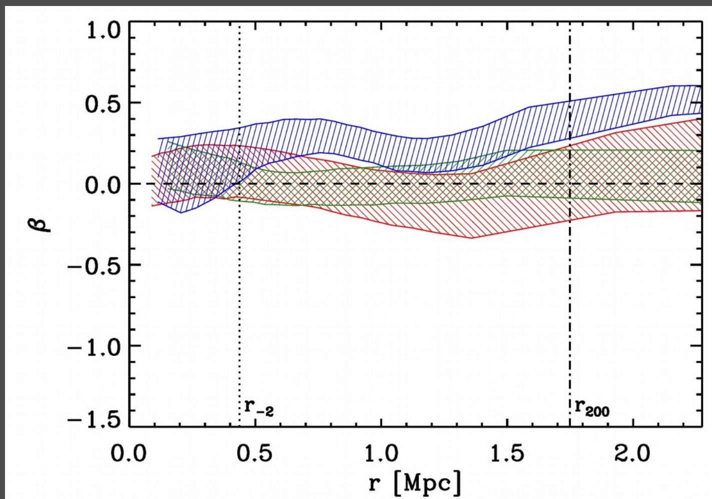


Iannuzzi & Dolag (2012): red galaxies have more radial orbits than blue galaxies in the SAM of *Guo et al. (2011)*

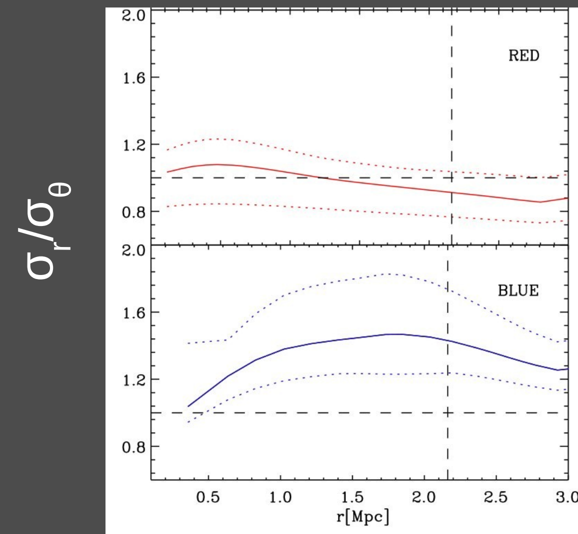
Orbits

But observational results on $\beta(r) \equiv 1 - (\sigma_\theta/\sigma_r)^2$ of passive galaxies are still controversial:

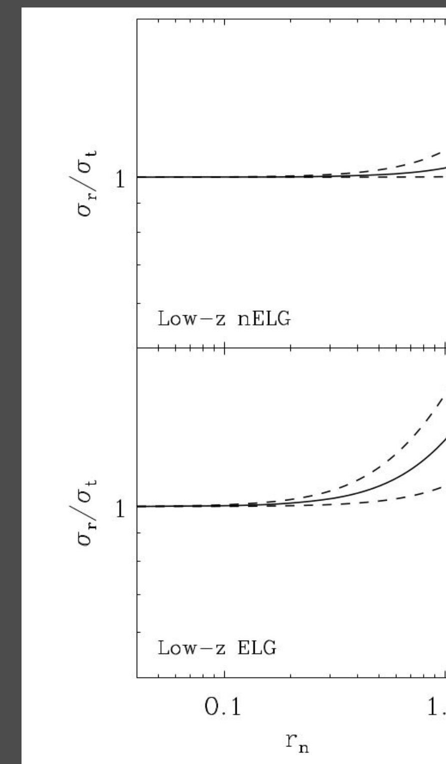
Clusters at low-z:



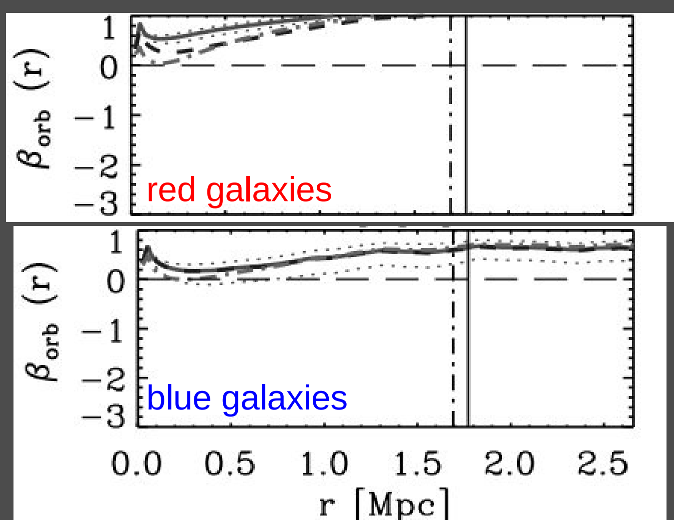
β(r) for the WINGS clusters (based on *Mamon et al. 2019*)



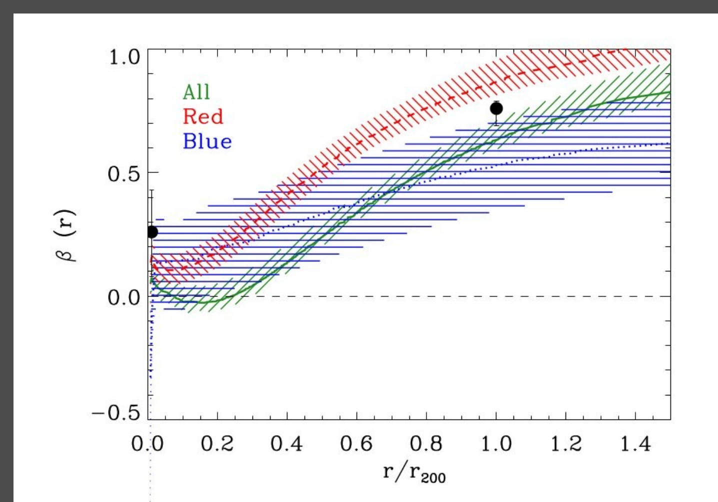
Abell 2142 (*Munari, AB, Mamon 2014*)



ENACS
(AB & Poggianti 2009)



Abell 2199 (*Hwang & Lee 2008*)

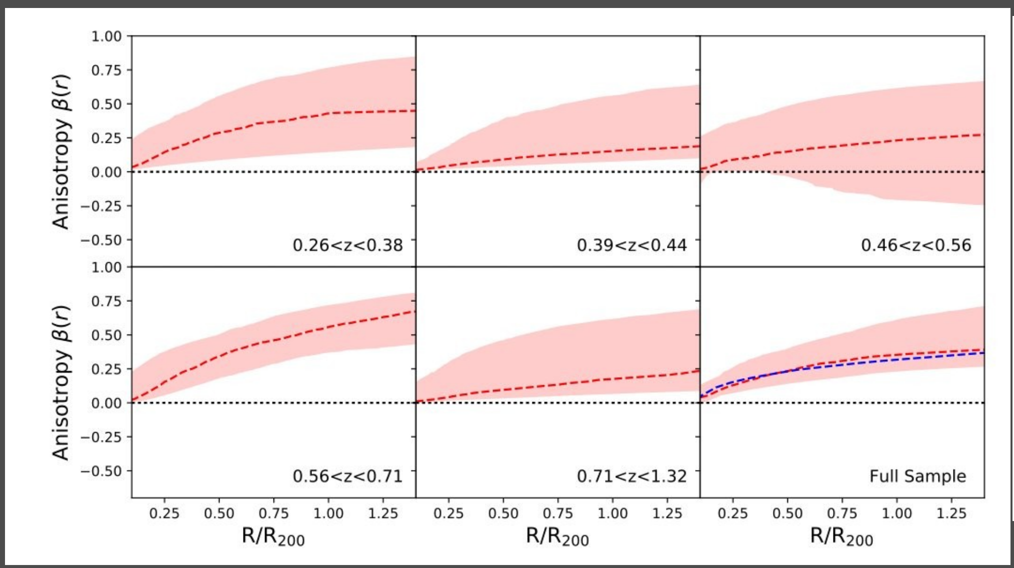


Abell 85 *(Aguerri et al. 2017)*

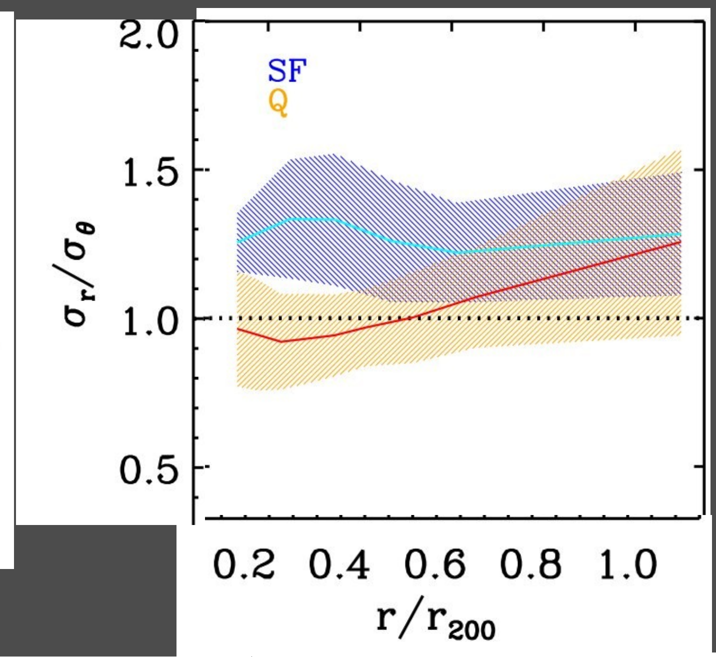
Orbits

At 0.2<z<1.4, the β(r) of passive/red and star-forming/blue galaxies are more similar than at z<0.2 ➔ differential orbital evolution in the last ≈2 Gyr (a cluster dynamical time)?

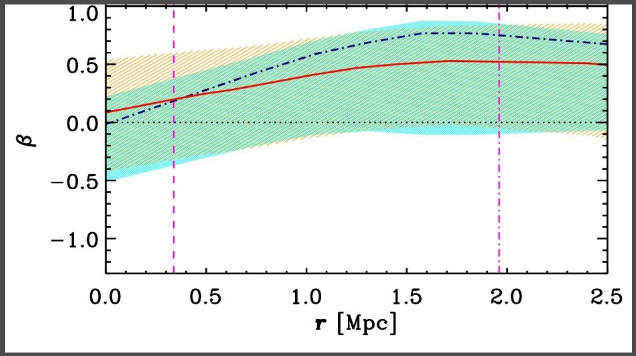
Clusters at medium- and high-z:



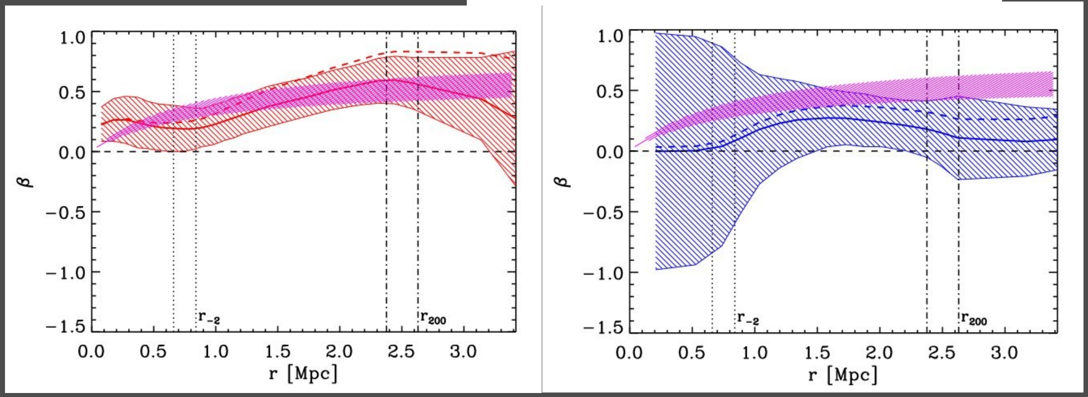
Passive galaxies in SZ-selected clusters (*Capasso et al. 2019*)



Passive and star-forming galaxies in GOGREEN clusters at 0.9≤z≤1.4 (*AB et al. 2021*)



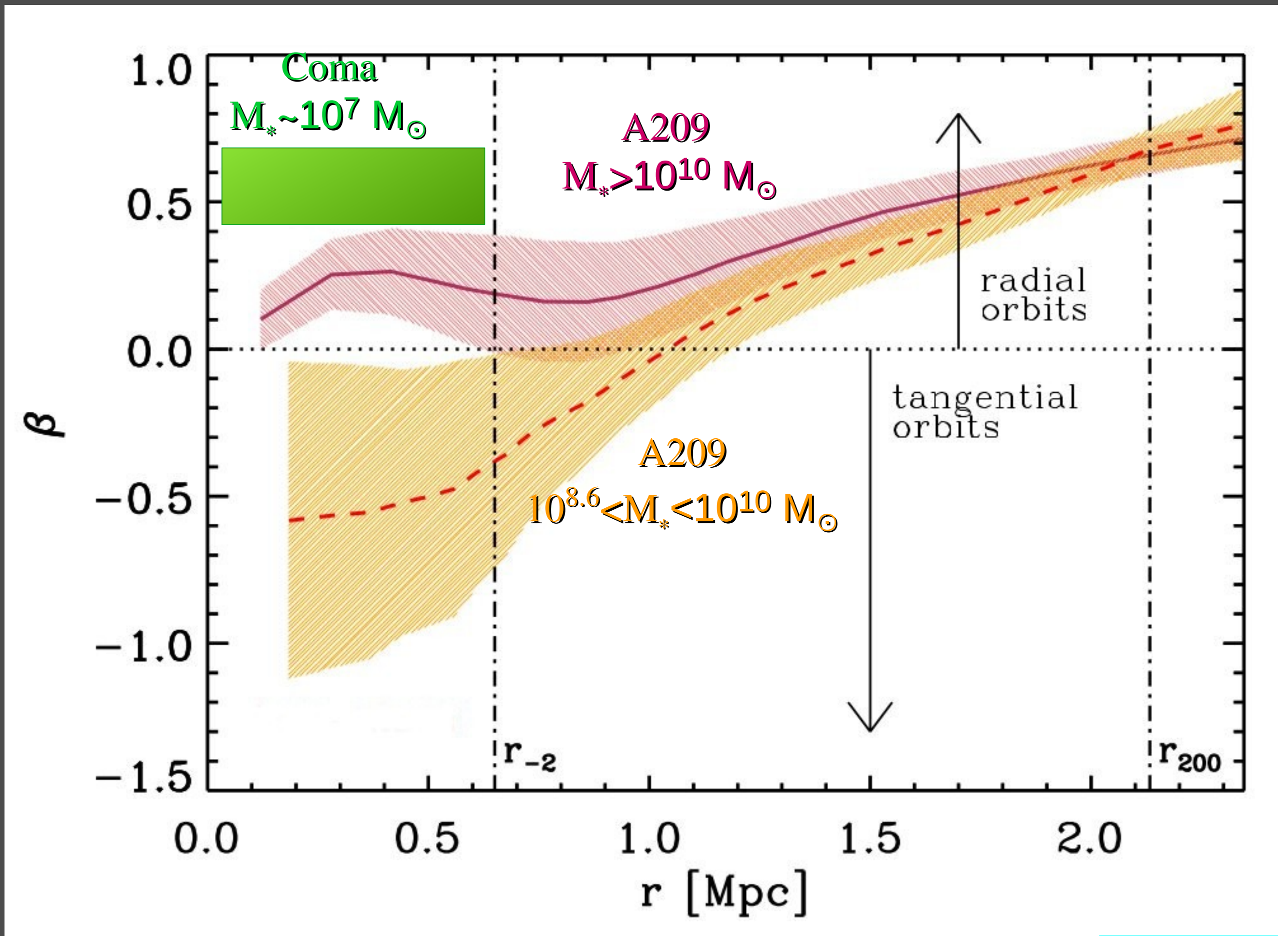
Passive and star-forming galaxies in MACS1206 at z=0.44 (*AB et al. 2013*)

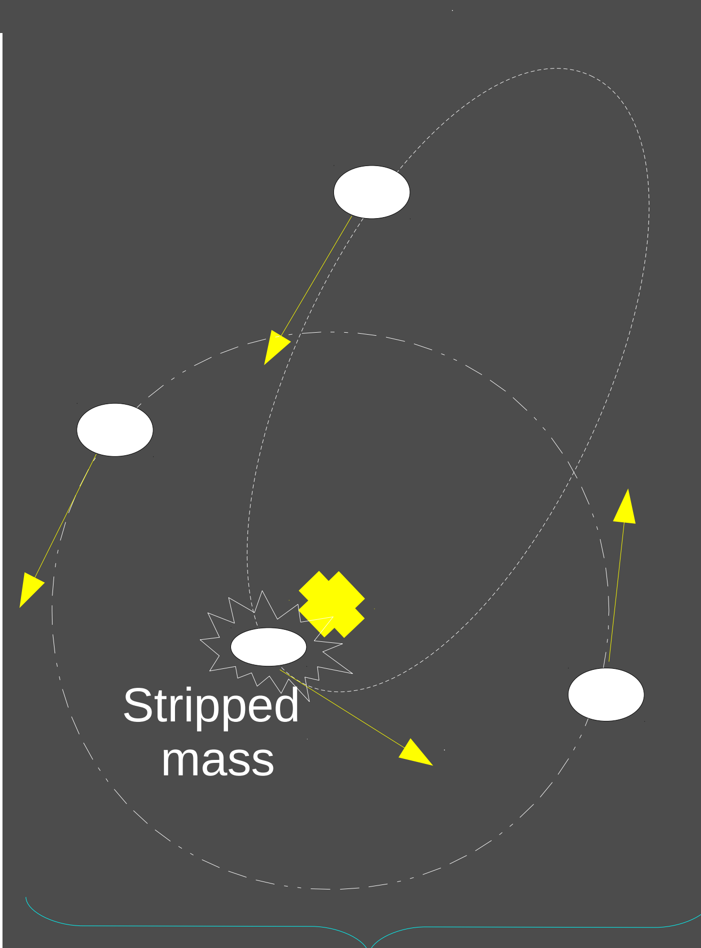


Passive and star-forming galaxies in Abell S1063 at z=0.35 (*Mercurio et al. 2021*)

Orbits

The orbits of cluster galaxies may depend not only on their color/type but also on their stellar mass:



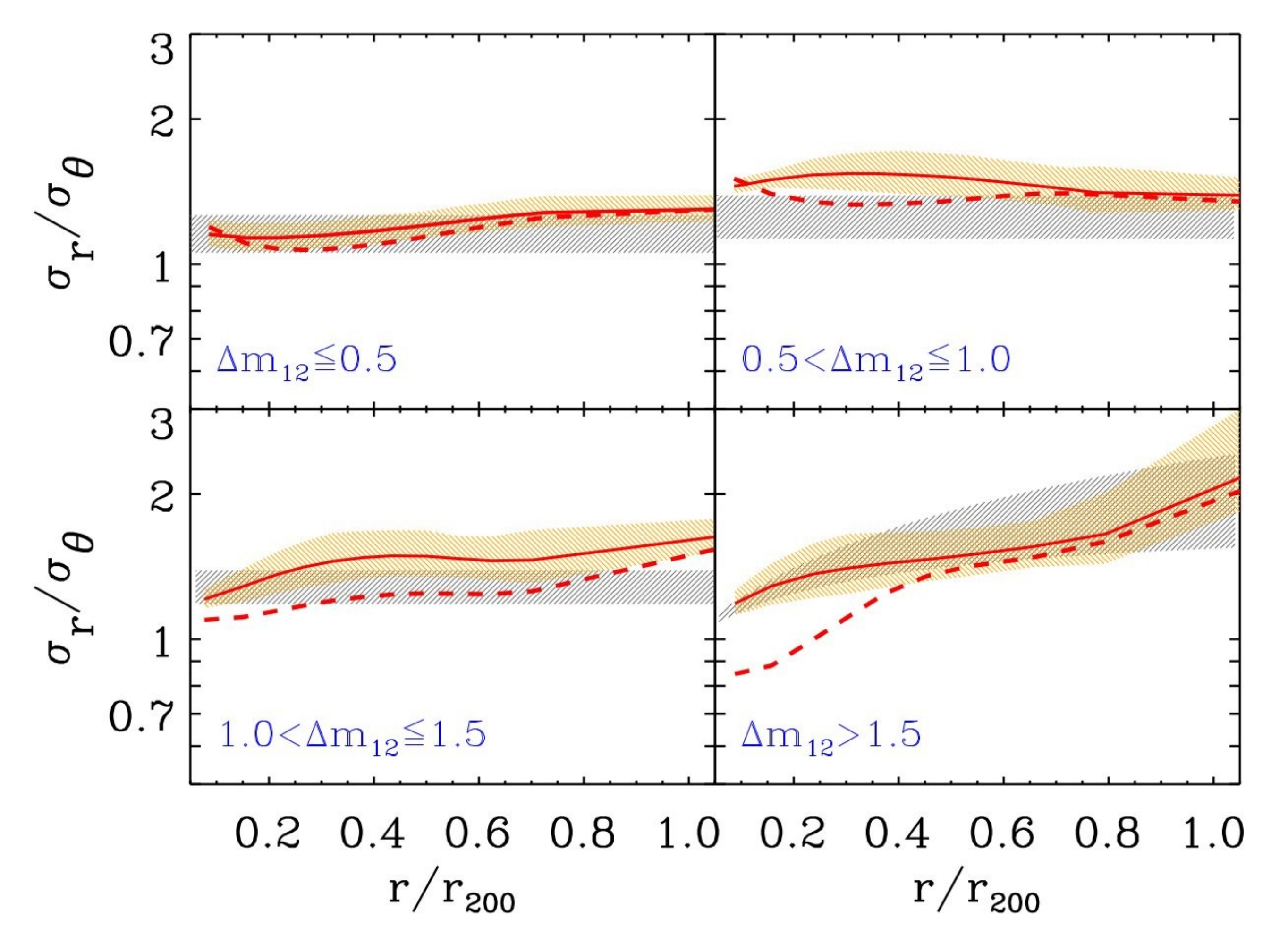


Passive galaxies in clusters:
CLASH-VLT data for z=0.21 A209 cluster
(*Annunziatella et al. 2016*)
VIMOS data for dwarfs in z=0.023 Coma cluster
(*Adami et al. 2009*)

Galaxies on radial orbits have small pericenter, they feel strong tidal field. High-mass galaxies do not suffer much, intermediate-mass galaxies loose mass and become dwarfs, except those that are on more tangential orbits and avoid the center.

Orbits

The orbits of cluster galaxies may be related to the type of clusters they belong to:



Zarattini, AB, Aguerri et al. (2021): based on the FOGO survey

Clusters (groups) with a larger mag difference between the 1st and the 2nd ranked galaxies (e.g. "fossils") have galaxies on more radial orbits... because:

Radial orbits can create a large Δm_{12} as a result of tidal effects near pericenter

and/or

Large Δm_{12} are indicative of no recent major mergers (since each new infalling group comes in with a central bright galaxy, thus Δm_{12} ↓), and major mergers make orbits more isotropic