WINGS: how ellipticals, S0s and spirals populate different phase-space regions in regular and irregular clusters

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Astronomy & Astrophysics

Structural and dynamical modeling of WINGS clusters

I. The distribution of cluster galaxies of different morphological classes within regular and irregular clusters

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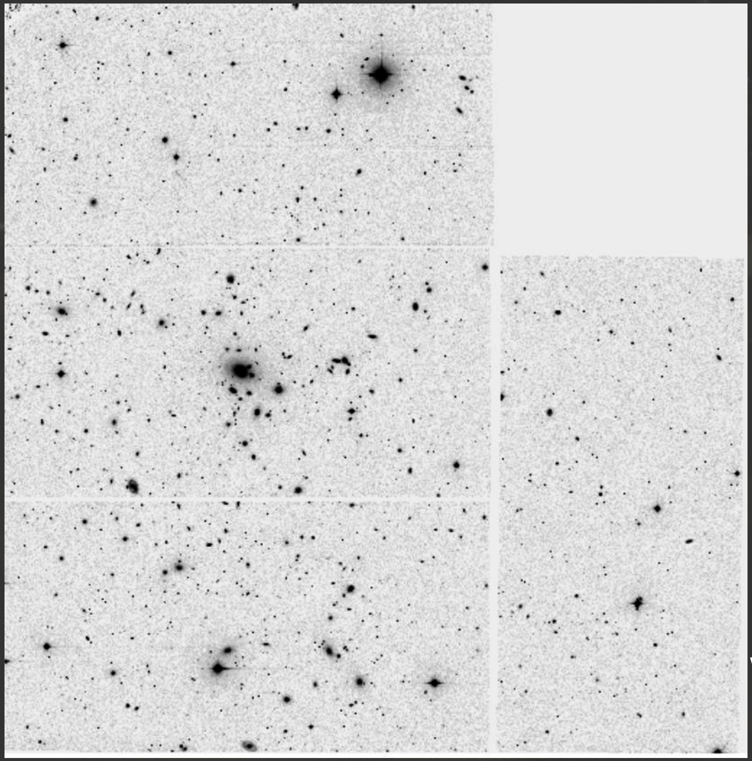
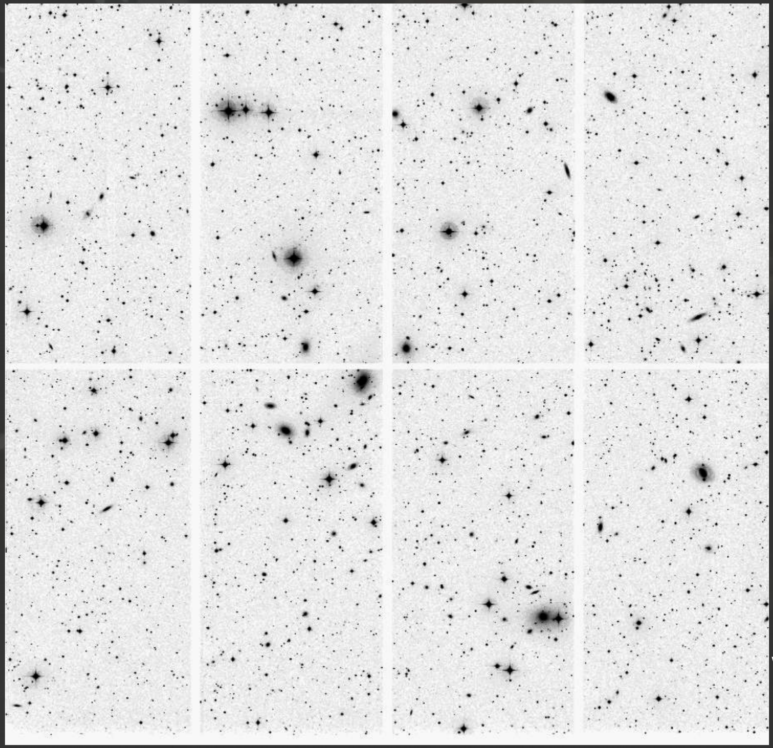
The data-set:

PI: Gianni Fasano & Bianca Poggianti

Photometric survey of 76 nearby ($0.04<z<0.07$) clusters of galaxies
(Fasano+06, Varela+09, Valentinuzzi+09, Omizzolo+14)



A151
WFC@INT
34’×34’



A3556
WFI@MPG
34’×33’

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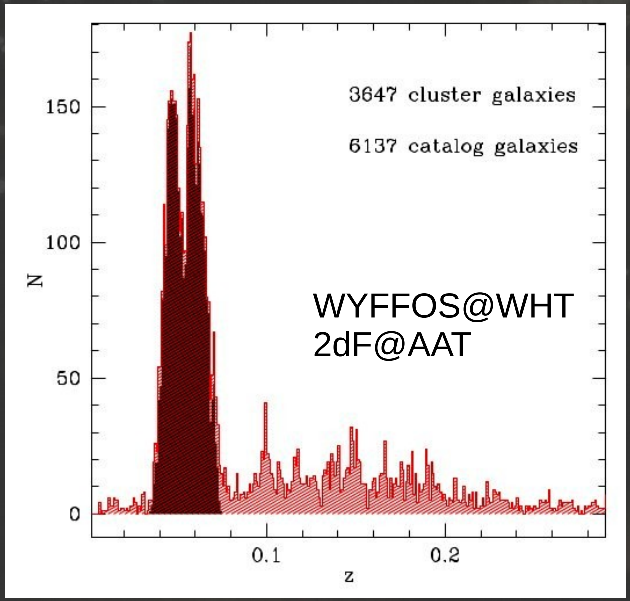
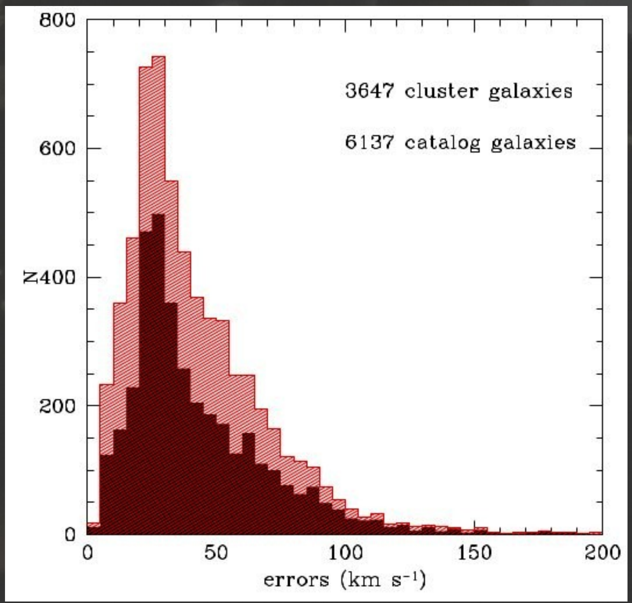
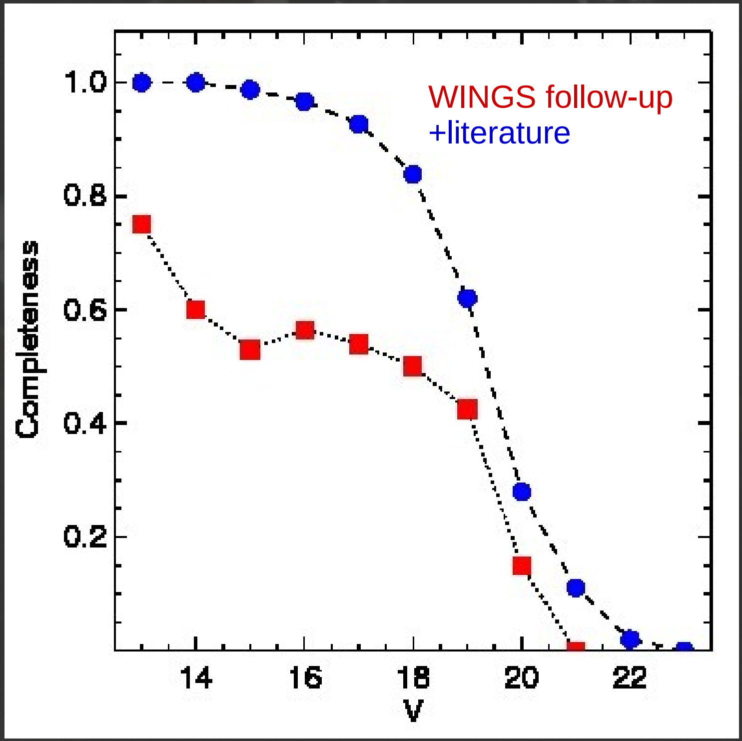
with spectroscopic follow-up for ~6000 galaxies in 48 clusters
+ additional ~4000 galaxy redshifts from SDSS and NED *(Cava+09)*
rms uncertainty on galaxy velocities ~90 km s^{-1}







Spectroscopic completeness

The data-set:

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Photometric survey of 76 nearby (0.04<z<0.07) clusters of galaxies *(Fasano+06, Varela+09, Valentinuzzi+09, Omizzolo+14)*

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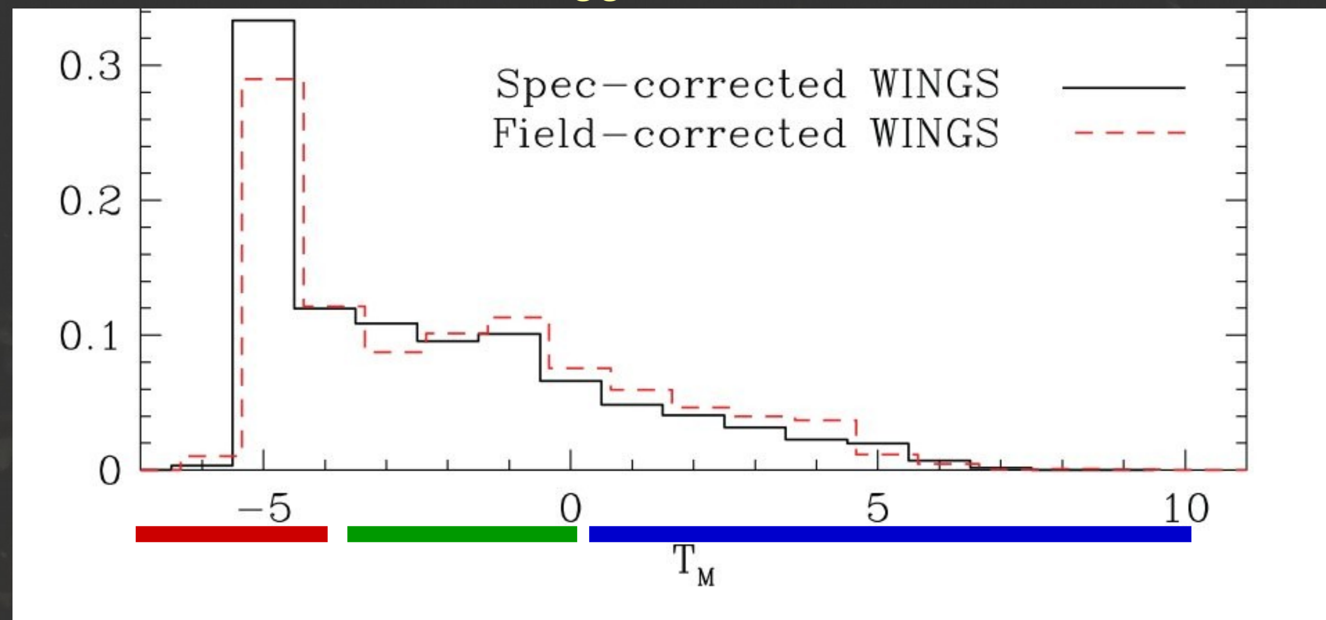


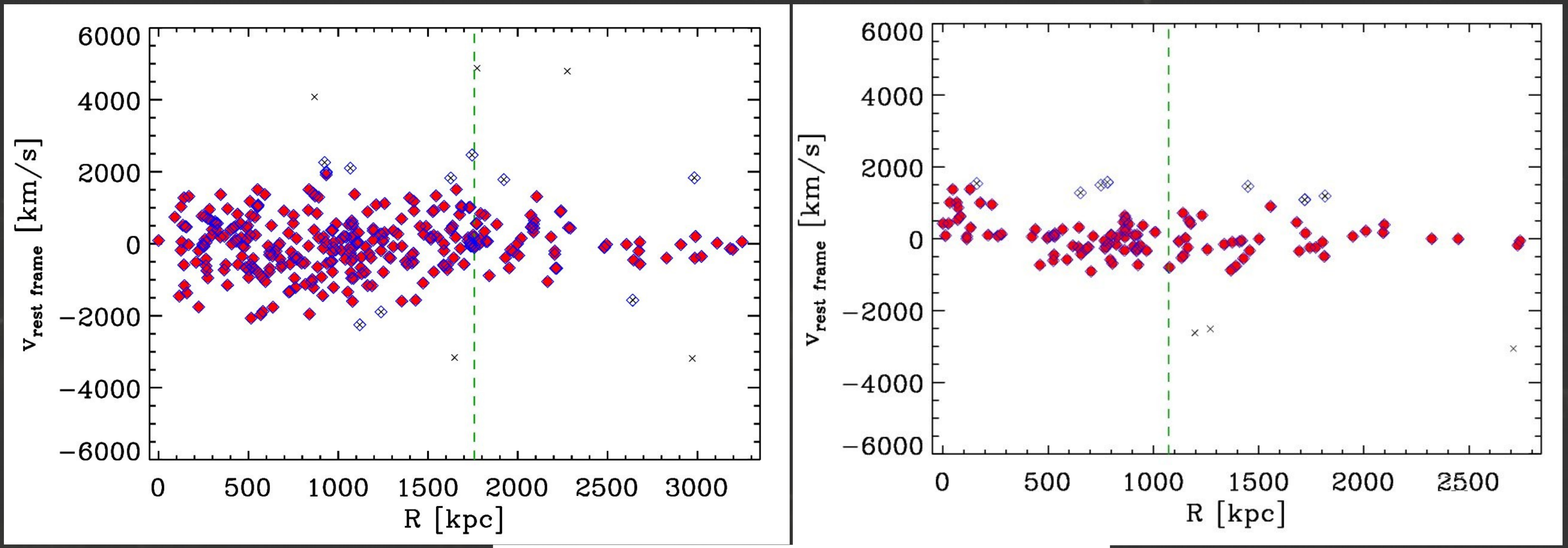
with galaxy structural and morphological information *(Pignatelli+06, Fasano+12, D'Onofrio+14)*
Galaxy morphologies determined using MORPHOT *(Fasano+12)*:
we define three broad morphological classes for the present study:

E (Ellipticals)
S0
S (Spirals+Irregulars)

The selection of cluster members

In each cluster, identify member galaxies by the Clean procedure *(Mamon, AB, Boué 13)* based on the location of galaxies in projected phase-space {Radii, rest-frame velocities} and on the *Navarro, Frenk, White 96* model for the cluster mass distribution.

Our results do not depend on the choice of the cluster center (BCG and X-ray emission)

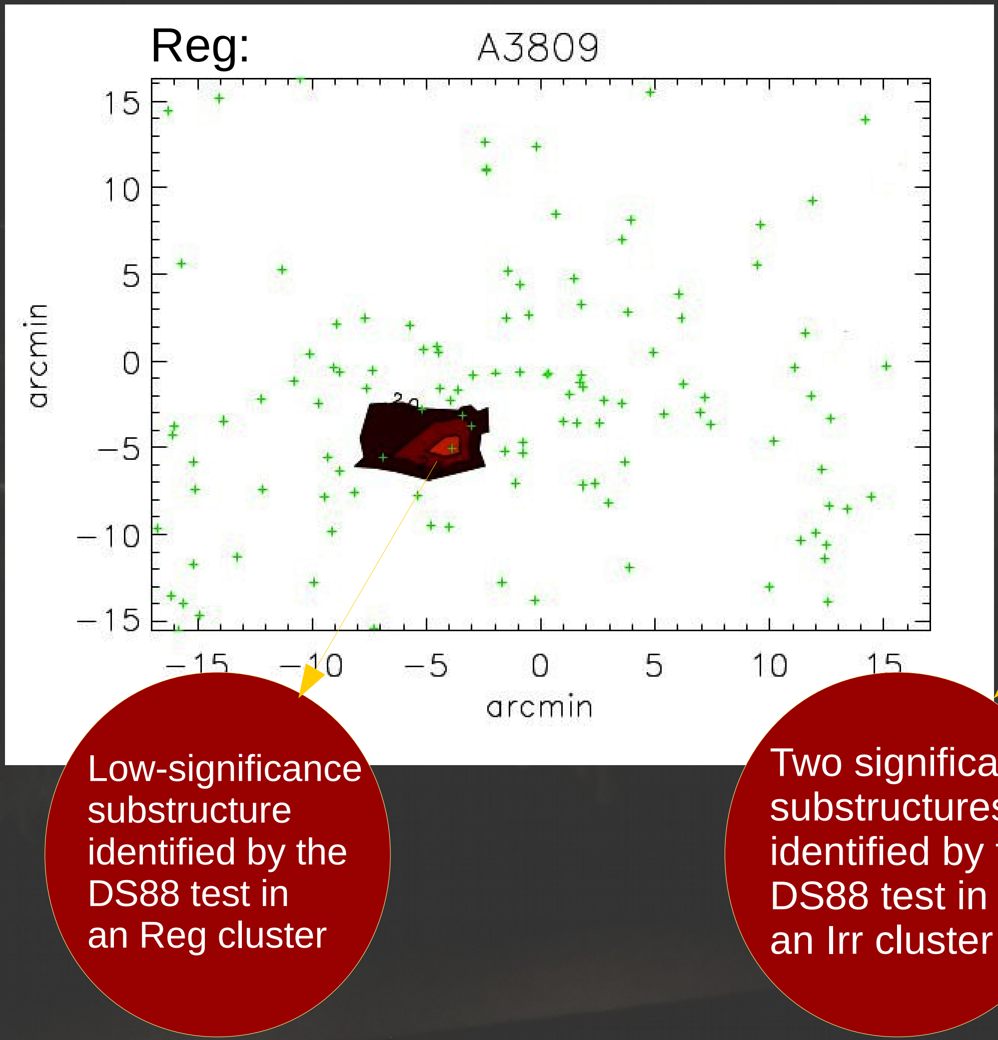


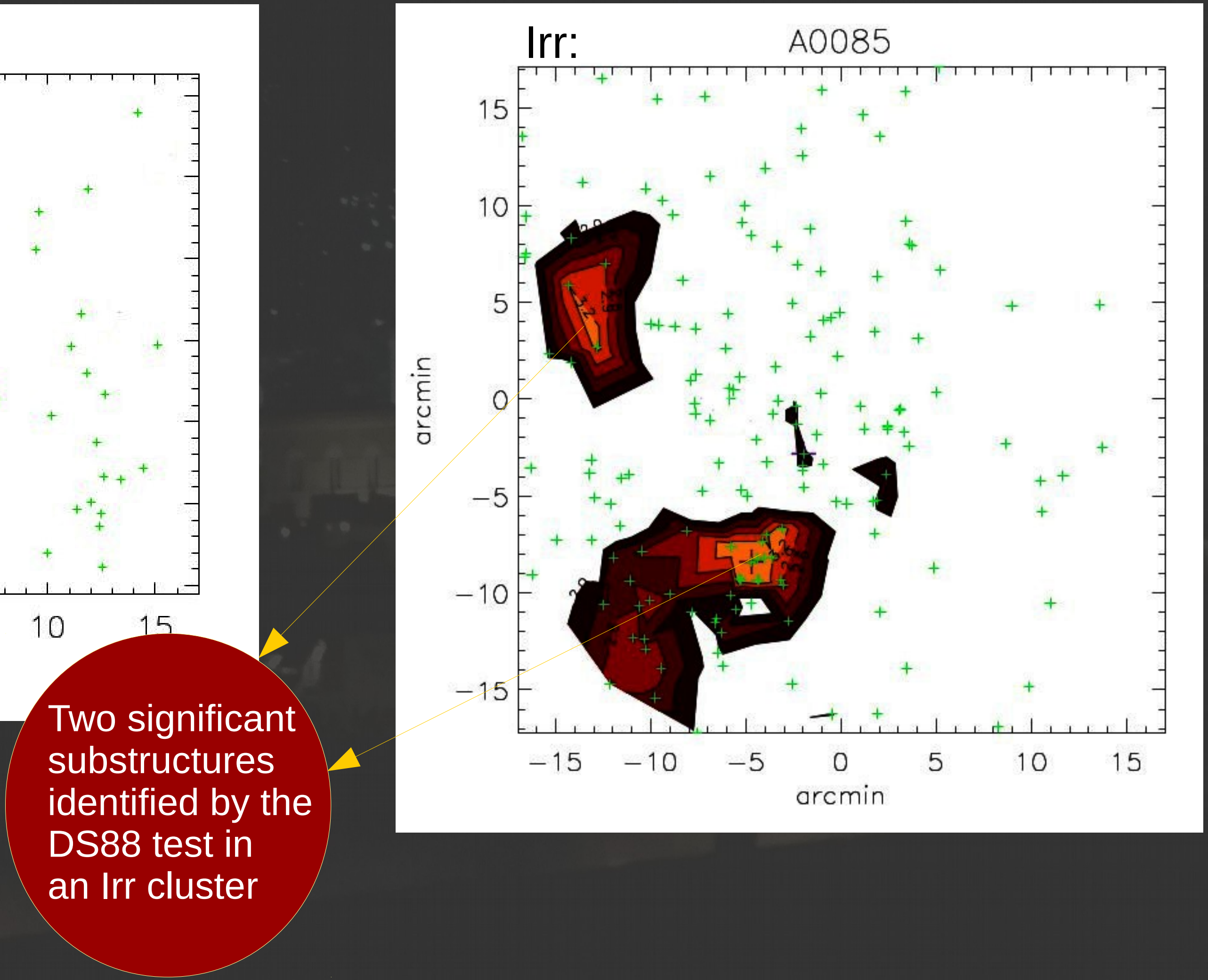
Selected members are the filled diamonds

Good statistics → select only the 68 clusters with $N_m \geq 30$ member galaxies

Regular and Irregular clusters

Identify 54 Regular ("**Reg**") and 14 Irregular ("**Irr**") clusters based on the *Dressler & Shectman 88 (DS88)* test for the presence of substructures, that maps the mean velocity and velocity dispersion across the cluster and identifies significant deviations compared to the values for the whole cluster





The stacked samples of clusters

For better statistics, stack the clusters in projected phase-space, $\{R_n, v_n\}$ i.e.,

- rescale cluster galaxy radii by their cluster r_{200}, $R_n \equiv R/r_{200}$
- and cluster galaxy rest-frame velocities by their cluster v_{200}, $v_n \equiv c\,(z-z_c)\,(1+z_c)^{-1} / v_{200}$

This stacking procedure makes sense since the mass distribution of clusters is quasi-homologous in units of M_{200} (the mass concentration of WINGS clusters changes very little with mass, *AB+17*)

3 independent estimates of r_{200} ($r_{200} \leftrightarrow v_{200}$ given the cluster redshift z_c, and the cosmology) per cluster, from

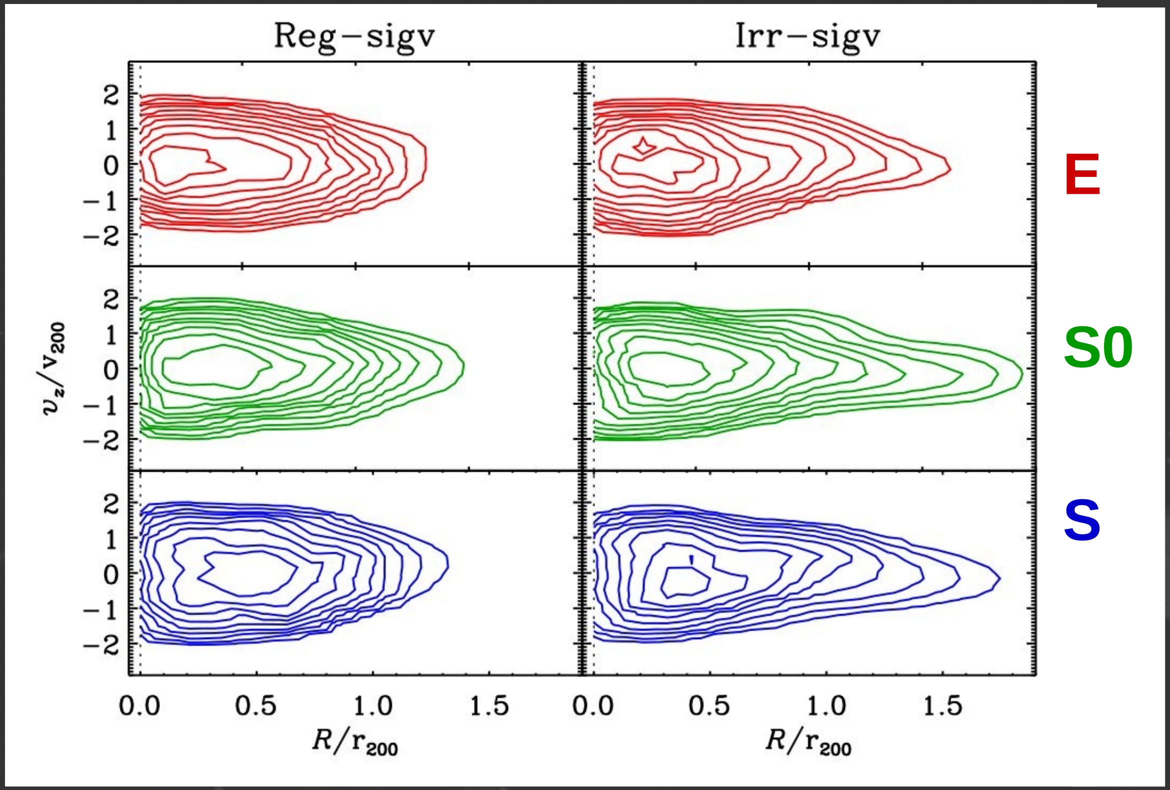
1) the cluster velocity dispersion σ (estimated on the selected member galaxies)
2) the cluster X-ray temperature T
3) the cluster richness N (number of selected member galaxies)

We find similar results using any of the three r_{200} estimates,
→we consider the σ-based r_{200} estimate in the rest of this talk

Reg stack contains ~ 5000 member galaxies, Irr stack ~ 1800

The stacked samples of clusters

Number-density maps in projected phase-space $\{R_n, v_n\}$
contours are spaced logarithmically



KS-2D test:

E, S0, S have significantly (prob<0.01) different $\{R_n, v_n\}$ distributions

Which is the origin of these differences?

The stacked samples of clusters

Number-density maps in projected phase-space $\{R_n, v_n\}$
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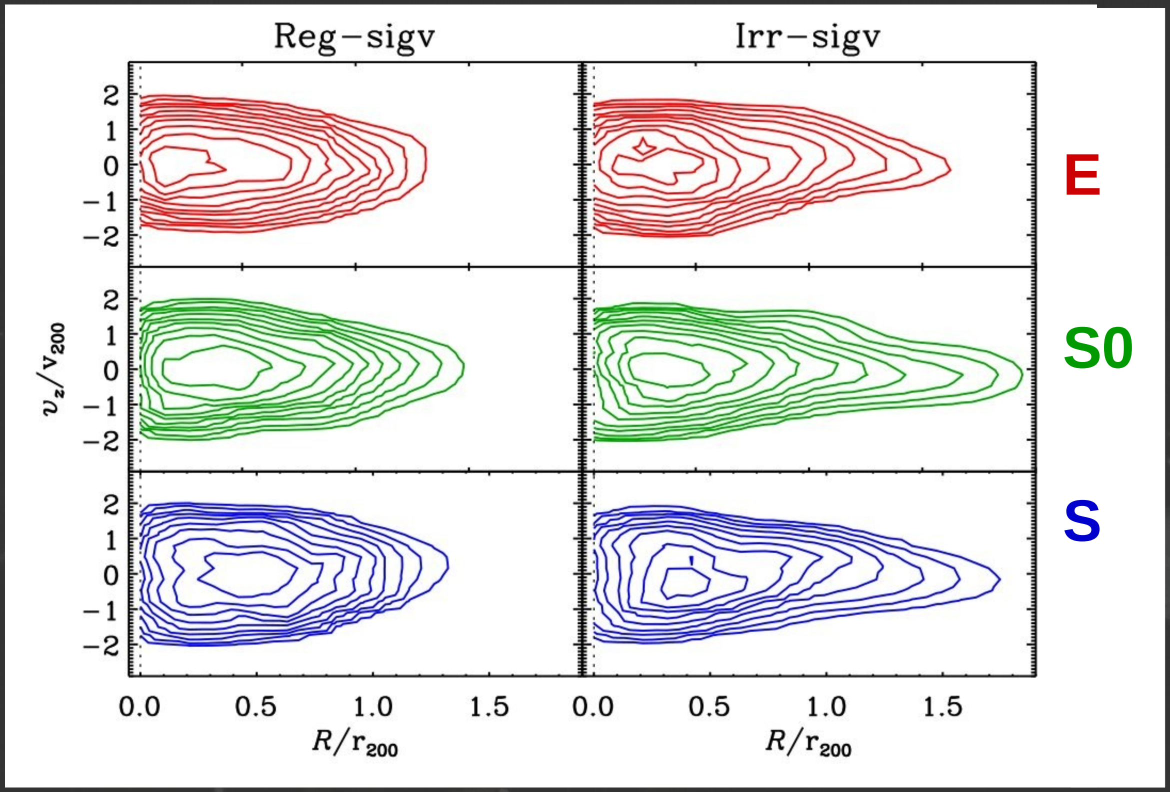
Velocity dispersion profiles



Number density profile

KS-2D test:

E, S0, S have significantly (prob<0.01) different $\{R_n, v_n\}$ distributions

Which is the origin of these differences?

Decouple the information along the radius and velocity axes

The number density profiles

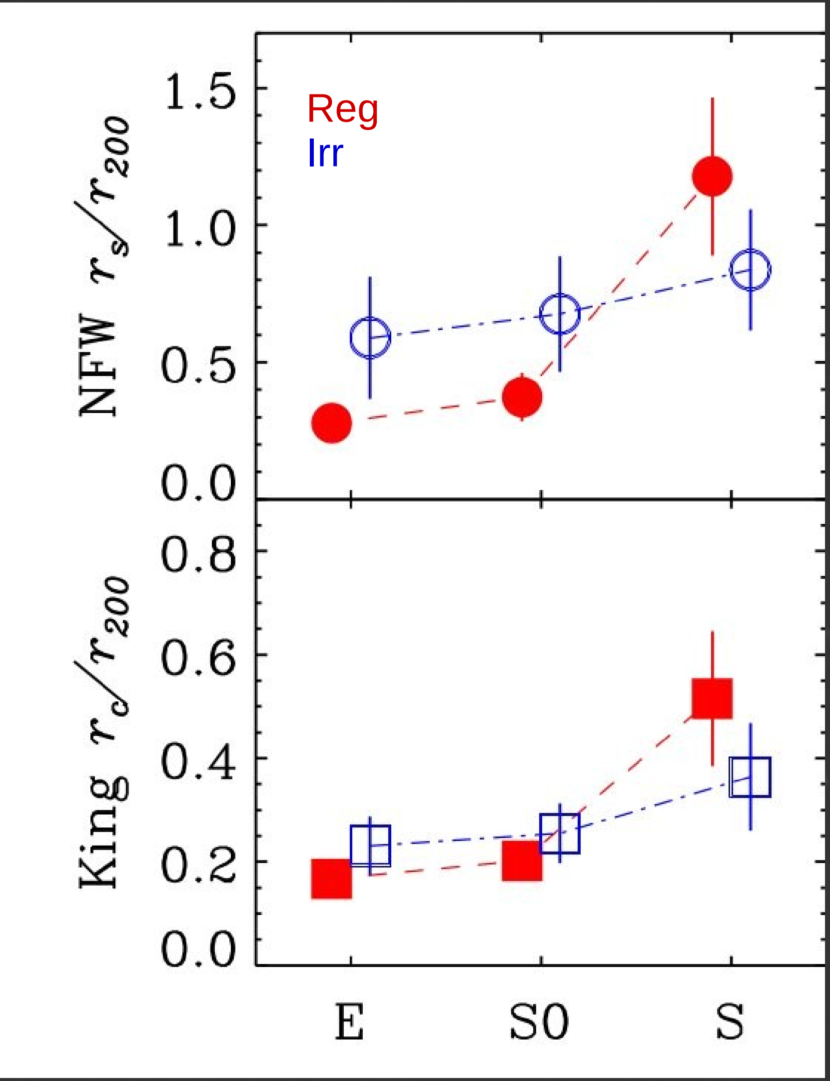
Fit the radial distribution of cluster galaxies with two models:

- the cuspy NFW model *(Navarro+96)*, characterized by the scale radius r_s
- the cored *King (1962)* model $\Sigma(R) \propto [\,1 + (R/r_c)^2\,]^{-1}$

➔ We find that NFW fits better than King, on average, particularly so for earlier morphological types

The scale radius (r_s/r_{200}) increases from E to S0 to S, as expected from the morphology-density (and the related morphology-radius) relation *(Dressler 80; Whitmore+93).* This is true for both Reg and Irr clusters, and for both models (NFW and King).

➔ r_s/r_{200} (Reg) > r_s/r_{200} (Irr) both for E and S0, i.e. E and S0 have a more concentrated spatial distribution in Reg than in Irr clusters. This is not the case for S.



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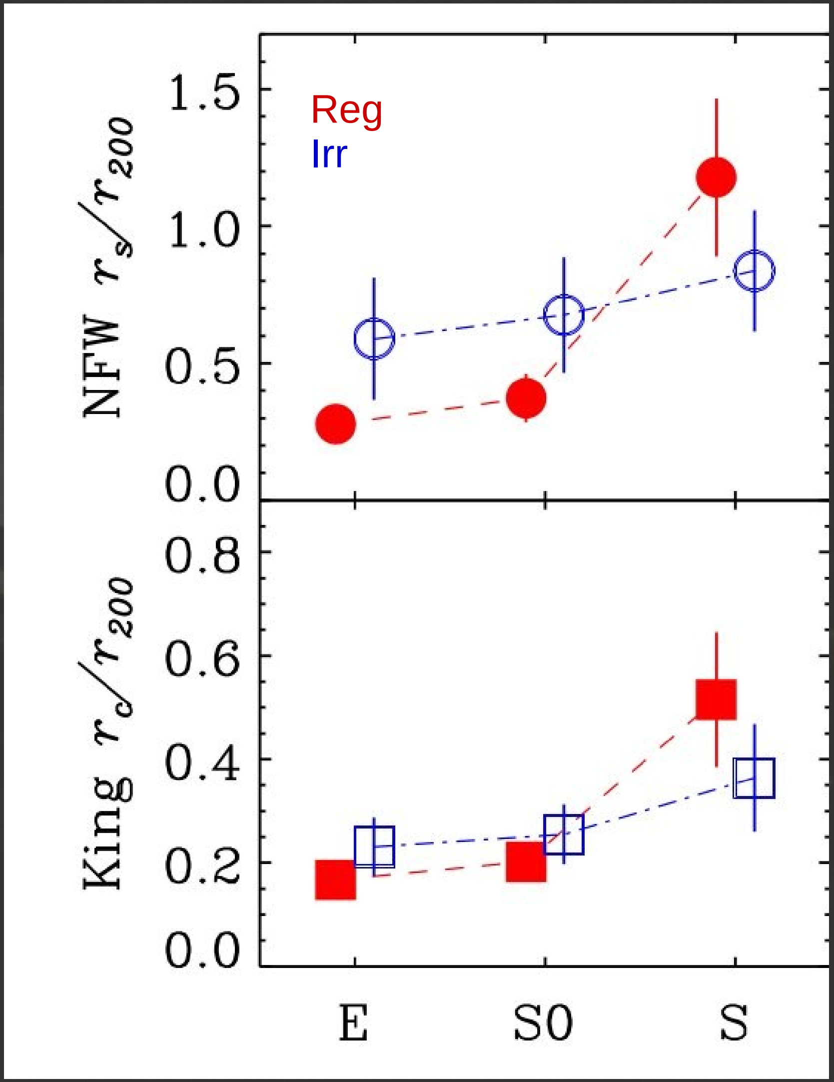
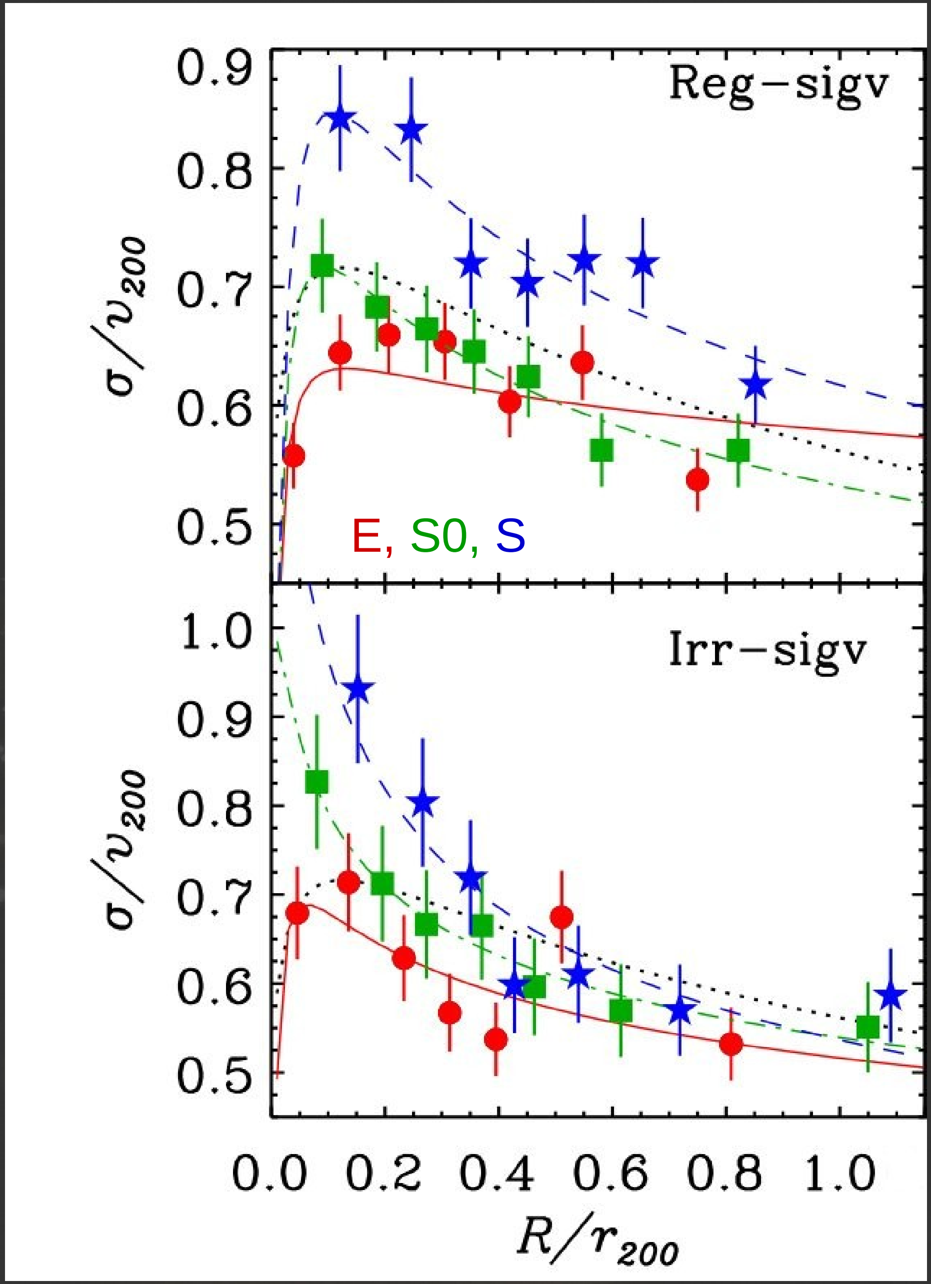


Possible interpretation:

Dynamically-relaxed (Reg) clusters have a higher mass concentration than unrelaxed (Irr) clusters, consequence of major mergers *(Jing 00; Neto+07)*.

Galaxies that have settled down in dynamical equilibrium in the cluster potential trace the mass distribution and reflects the mass concentration (E, S0), those that are recent arrivals do not (S).

The velocity dispersion profiles (VDPs)



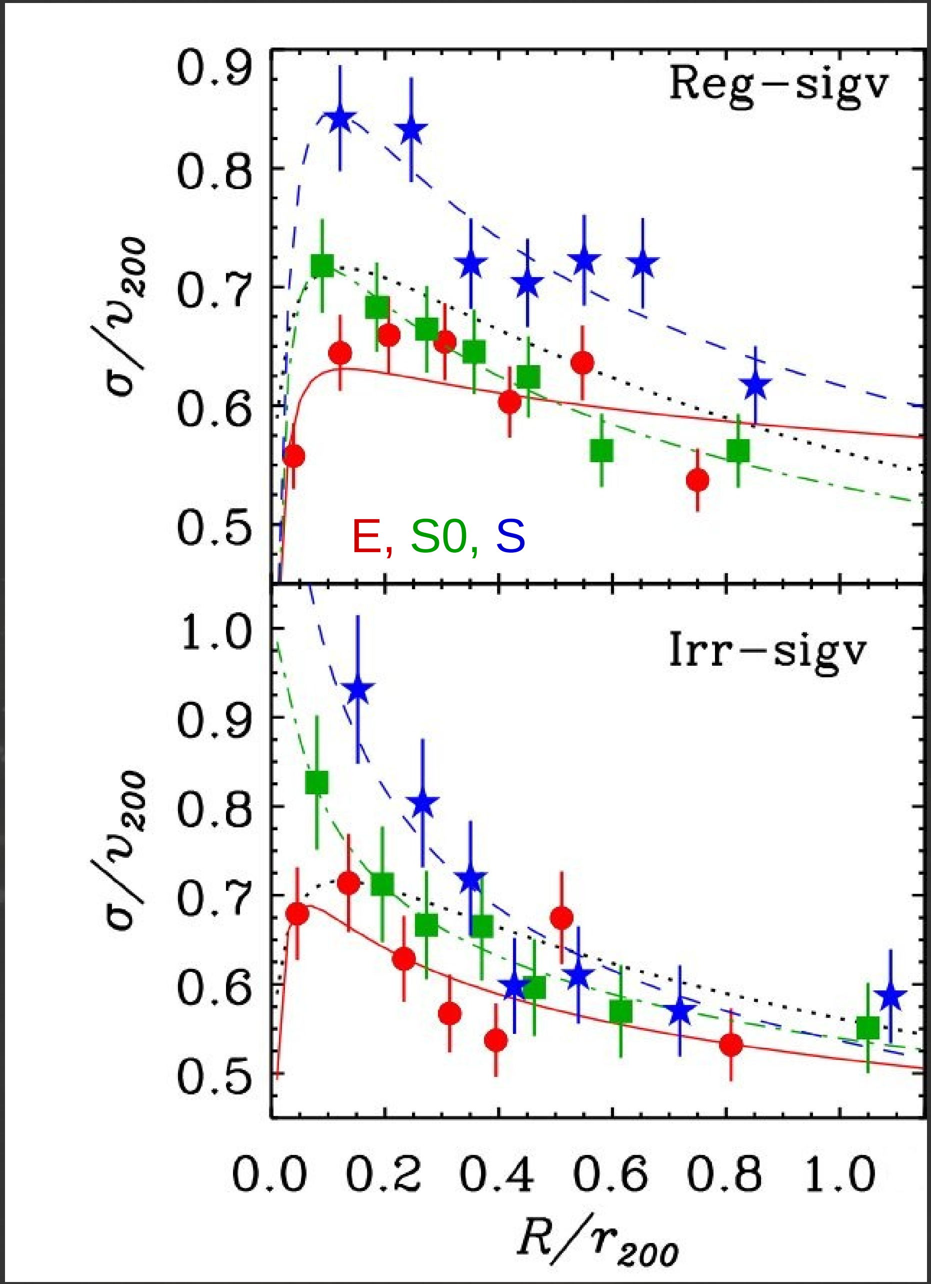
χ^2 comparison of the VDPs:

- VDP(E) ≈ VDP(S0)
  (most similar in Reg)
- VDP(E) ≠ VDP(S)
- VDP(S0) ≠ VDP(S) in Reg clusters
- VDP(S0) $\lesssim$ VDP(S) in Irr clusters
  (no significant difference)

Solid red, dot-dashed green, and dashed blue lines: phenomenological model fits to E, S0, and S VDPs;

dotted line: theoretical expectation for a c=3 NFW M(r) with typical velocity anisotropy (as observed in cosmological simulated cluster-sized halos)

The velocity dispersion profiles (VDPs)



χ^2 comparison of the VDPs:

Possible interpretation:

E are an old cluster population

S are recent arrivals (still accreting)

If S0 evolve from S after S accretion, their VDP should be close to S initially; with time, by some unknown process, the S0 VDP becomes more similar to the E VDP

→In Reg clusters, most S0 have evolved from S a long time ago; in Irr clusters many S0 are recent arrivals, recently evolved from infalling S.
This difference can be related to the different accretion rate of Reg and Irr clusters

Solid red, dot-dashed green, and dashed blue lines: phenomenological model fits to E, S0, and S VDPs;

dotted line: theoretical expectation for a c=3 NFW M(r) with typical velocity anisotropy (as observed in cosmological simulated cluster-sized halos)

Conclusions

Based on ~7000 galaxies with redshifts and morphologies in 68 z<0.07 WINGS clusters, we find that E, S0, S have different projected phase-space distributions:

1) the radial distribution of E and S0 is more concentrated in Reg than in Irr clusters
2) the radial distribution of S is the same in Reg and Irr clusters
3) the velocity dispersion profile (VDP) of E and S are different in Reg and Irr clusters
4) in Reg clusters the VDPs of S0 and E are similar, and different from the VDP of S
5) in Irr clusters, the VDP of S0 is intermediate between the VDPs of E and S

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Based on ~7000 galaxies with redshifts and morphologies in 68 $z<0.07$ WINGS clusters, we find that E, S0, S have different projected phase-space distributions:

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1)+4) → E and S0 (mostly) are a dynamically relaxed population that follows the cluster mass distribution, that is less concentrated in Irr clusters because of ongoing mergers
2)+3) → S are (mostly) an infalling population, still to fully dynamically relax in the cluster potential, so their spatial distribution does not reflect the mass distribution
5) → S0 evolve (mostly) from infalling S, caused by cluster-specific processes

S0 cannot originate in groups before cluster assembly (pre-processing), or they would share the phase-space distribution of S, but they do not. As S → S0, they also change their phase-space distribution. We see this change taking place in clusters experiencing strong mass accretion (Irr), while this change is completed in dynamicaly relaxed clusters (Reg).

2/3 cluster S0 form after $z \approx 0.4$ (*Postman+05; Smith+05*) → timescale for morphological and phase-space evolution ≤ 3 Gyr ≈ dynamical timescale (≈ 2 Gyr; *Sarazin 86*)

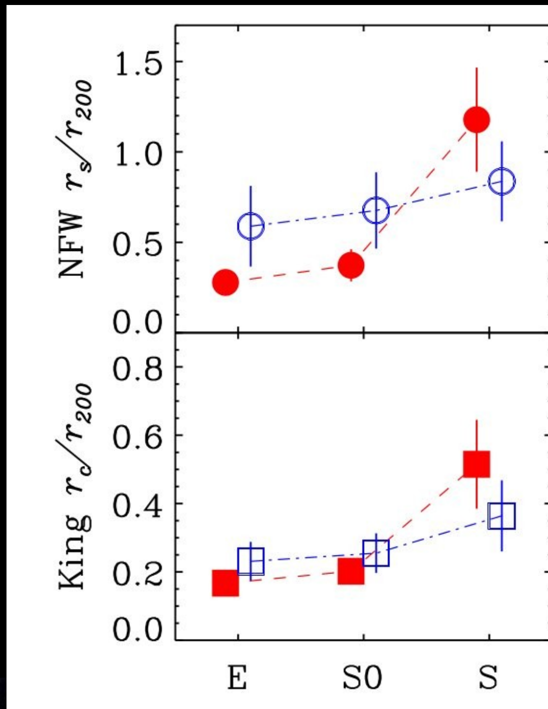
Work in progress

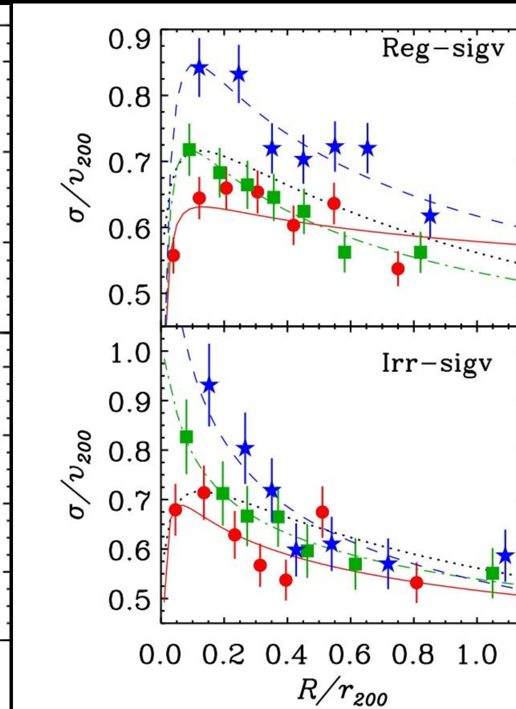
- Solve the Jeans equation for dynamical equilibrium:
  which are the orbits of E, S0, S?
  (cannot be done for Irr clusters, however)

- S0 in Irr clusters should be more similar to S than S0 in Reg clusters:
  can we see this age difference in the Irr and Reg S0 spectra?

- Subclusters are groups infalling into clusters;
  what is the fraction of S0 in subclusters?
  How does it compare to the cluster one and to the S0 fraction in field groups?
  Is the subcluster environment protecting S against transformation into S0
  (intra-group gas shielding against ram-pressure)
  or stimulating S → S0 transformation
  (cluster tidal field compressing the infalling groups and provoking S+S interactions)?

All (or part) of this work can benefit from the WINGS extension,
OmegaWINGS *(Gullieuszik+15; Moretti+17; D'Onofrio+in prep.)*


NFW r_s/r_{200}
King r_c/r_{200}
E
S0
S


Reg−sigv
Irr−sigv
σ/v_{200}
R/r_{200}


Gee, thanks.
I'M A NOBODY
NOBODY'S PERFECT