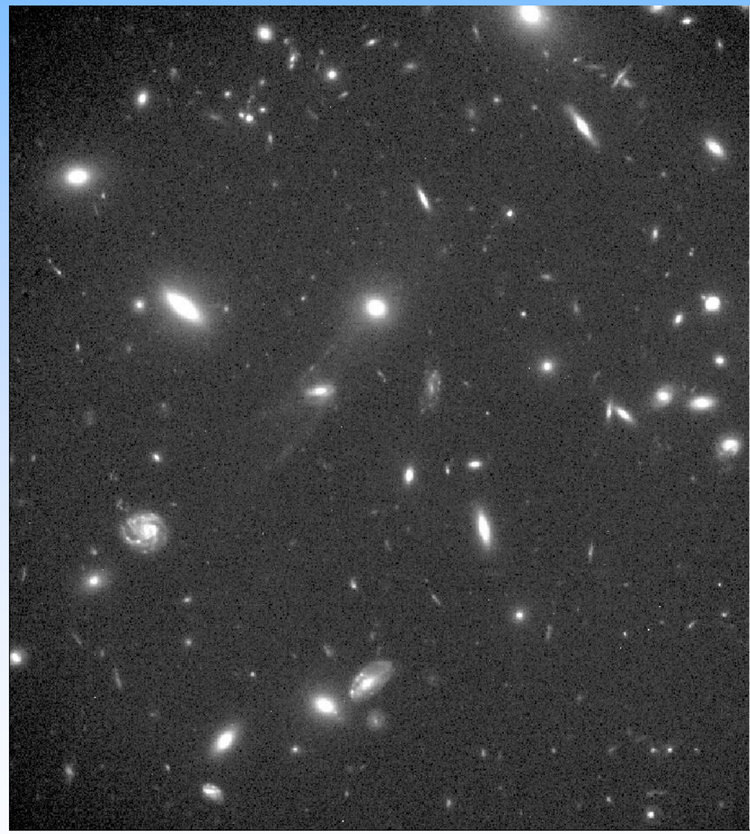
Galaxy Transformation in Clusters

Coma

CL0939
z=0.41



From Groups to Clusters

The **Local Group** : 35 members around Milky Way & M31 within 1 Mpc

Nearby groups :

Sculptor group	:	6 members	D~1.8 Mpc
M81 group	:	8 members	D~3.1 Mpc
Centaurus group	:	17 members	D~3.5 Mpc
M101 group	:	5 members	D~7.7 Mpc
M66+M96 group	:	10 members	D~9.4 Mpc
NGC 1023 group	:	6 members	D~9.6 Mpc

Census very incomplete : low – luminosity dwarfs like Sag dSph cannot be detected beyond our Local Group

galaxy group <50 members,

galaxy cluster >50 members

Local Galaxy Clusters

Virgo (W. Herschel 18th century)
10° × 10°   D~16 Mpc
~   250 normal galaxies
> 2000 dwarf galaxies

irregular cluster : 2 big Es: M87 & NGC 4479,
not particularly rich

Coma : regular rich cluster (+ substructure)
D~ 90 Mpc
~ 10,000 galaxies

Abell Catalog of Galaxy Clusters

G. Abell 1958: POSS northern sky
w/o Milky Way disk (extinction)

Cluster := >50 members within m_3 and m_3+2 mag,
m_3 := mag of 3rd brightest member,
within angular radius q_A=1.7'/z, z=redshift estimate
(from 10th brightest galaxy assumed to be universal)

1682 galaxy clusters within 0.02 < z < 0.2
(z>0.02 --> cluster fits on ~6° ´ 6° POSS plate,
z<0.2 --> sensitivity limit of POSS plates)

extended to include 4076 clusters by
Abell, Corwin, Olowin 1989

both catalogs not free from projection effects !!!

Galaxy Clusters

Galaxy Clusters : R_{cl}~ 2 - 10 Mpc, N_{gal} = 50 . . . >10.000.

Zwicky (1933) measured radial velocities of galaxies in Coma : velocity dispersion $\sigma \sim 1000$ km/s

calculated visible mass of galaxies with M/L (E/S0)=10
→ $M_{gals} \sim 10^{13}\, M_\odot$ and escape velocity

found : typical galaxy velocity > escape velocity
→ cluster should dissolve on $t \sim 10^9$ yr

Coma = relaxed cluster, much older than 10^9 yr

Cluster mass (and escape velocity) must be much higher than the visible mass (= mass in galaxies)

Virial theorem : $M_{dyn} = 3\,\pi/2G \cdot R_{cl}\sigma^2$

$R_{cl} \sim 1$ Mpc → $M_{dyn} = 10^{15}\, M_\odot$

Evidence for Dark Matter : M(DM)/M(gals)~100

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Galaxy Clusters

Anisotropy in the velocity dispersion or non-spherical mass distribution could affect the mass estimate

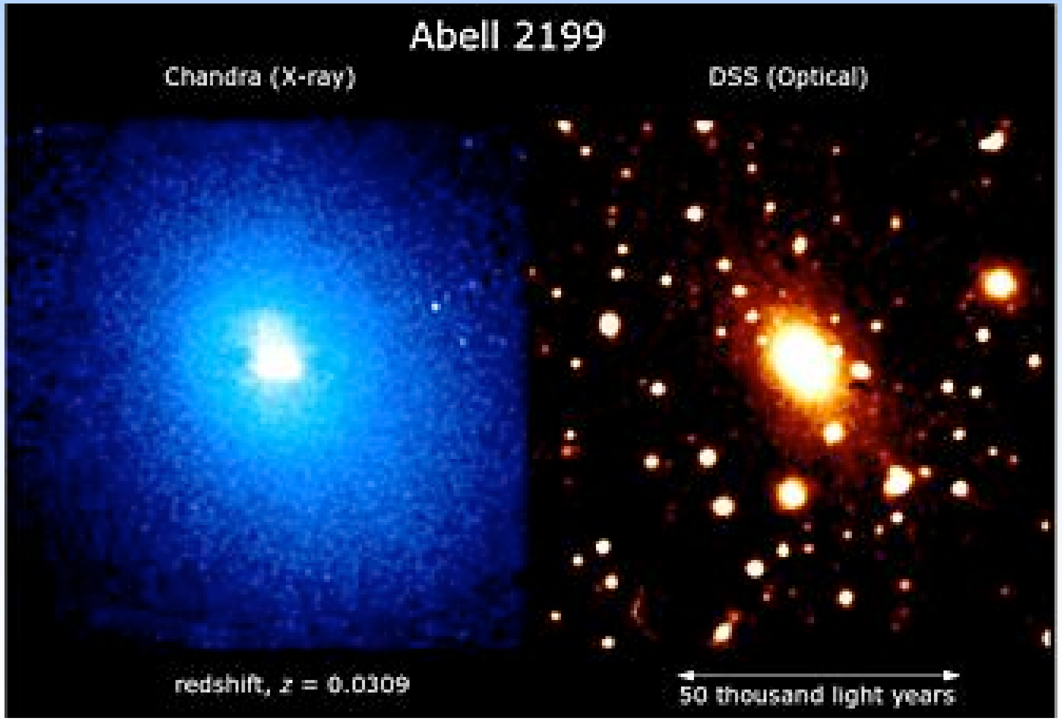
→ alternative mass estimates : X-rays !

UHURU satellite (1970) detected X-radiation in centres of rich clusters. Assume the X-ray gas in galaxy centres is in hydrostatic equilibrium

→ mass estimates : ~80% M_{cl} = Dark Matter

Intra Cluster Medium ICM

Galaxy clusters contain hot ($10^{7\text{-}8}$ K) X-ray emitting gas : Intra Cluster Medium ICM.
ICM heated by the gravitational energy released by the formation of the cluster from smaller structures. Kinetic energy gained from the gravitational field is converted to thermal energy by shocks. The ICM is highly ionised.
Abundance ~ 1/3 $Z_{\odot}$.



Galaxy Clusters

Cooling flows :

X-emitting gas loses energy, cools on

$$t_{cool} := u/\epsilon^{ff}$$

$u = 3/2\ nkT$: energy density of the X-gas
ϵ^{ff} : Bremsstrahlung emissivity

$t_{cool} \gg t_{Hubble}$ over most of the cluster
→ hydrostatic equilibrium

exception : dense cores of rich clusters :
cooling gas flows towards centre, increases density,
accelerates cooling, increases L_X

X-ray observations : show density & temperature
structure in cores of some rich local clusters
(Fabian et al.)

Fate of cooling gas : star formation !?
? Cooling rate ↔ star formation rate ?

Galaxy Clusters

Scaling relations for galaxy clusters :

$T_X \sim M / R_{vir}$

within R_{vir} : $<\rho> \sim 200\ \rho_{cr}$, typically $R_{vir} = 1 - 3$ Mpc

with ρ_{cr} critical density of the universe

$\rightarrow$ virial mass $M_{vir} = 4\pi/3 \cdot 200\ \rho_{cr}\ R_{vir}{}^3$

$\rightarrow T_X \sim M_{vir} / R_{vir} \sim R_{vir}{}^2 \sim M_{vir}{}^{2/3}$

Observations show very tight correlation between T_X and M_{vir}, better than between σ^3 and M_{vir}

(outlyers: unrelaxed clusters)

Typical $M_{vir} \sim 10^{14\text{-}15}\ M_\odot$,

~5% galaxies, ~10% ICM, ~85% DM

Galaxy Clusters

2-body relaxation between galaxies unimportant :

$$t_{rx}=t_{cross} \cdot N_{gal}/\ln N_{gal} \gg t_{Hubble}$$

σ independent of galaxy type and luminosity or mass

→ motion of galaxies in clusters not thermalized.

Violent relaxation still ongoing on crossing timescale,
→ clusters still in formation.

~ 5 - 10 % of all luminous galaxies live in clusters today.

Galaxy Clusters

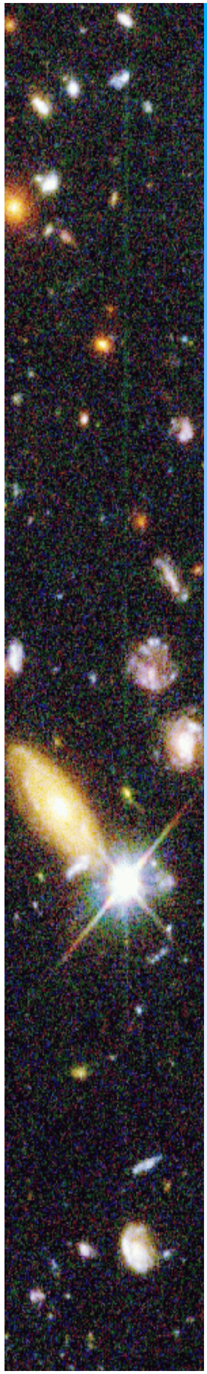
Dynamical friction :

gravitation of a moving galaxy causes inhomogeneity in an initially homogeneous galaxy distribution : overdensity along trajectory, strongest behind the moving galaxy

→ braking : $dv/dt \sim - m\rho v / v^3$ ρ : mass density
most massive galaxies feel strongest dynamical friction
→ mass segregation, formation of cD galaxy

Between galaxies in clusters :

☆ hot X-ray gas : $T \sim 10^8$ K, $M_{X\text{-gas}} \leq 5\ M_{stars}$
☆ intracluster stars, PNe, GCs : ~ 10% of optical light



Galaxy Transformation in Clusters

Galaxy populations in rich local clusters very different from field galaxy population

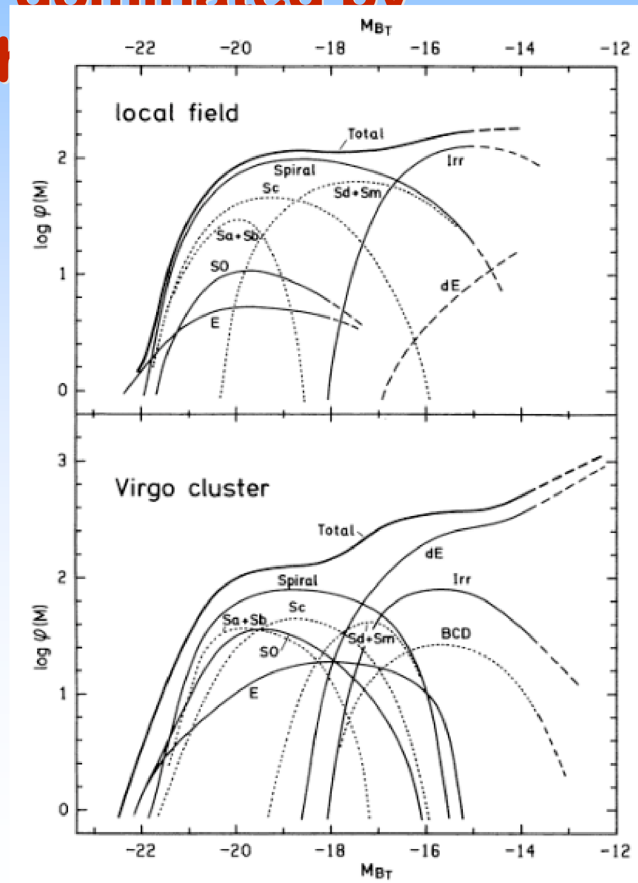
Field galaxy population dominated by SFing spirals, inner regions of nearby clusters dominated by

- **passive Es, S0s, dEs, dSph**
- **faint galaxies : steep faint end slope of LF in clusters**

(Trentham+01, 02, 05)

$N_{dwarfs}/N_{big\ gals}$ (clusters) $\gg N_{dwarfs}/N_{big\ gals}$ (field)

$\alpha \ll -1.1$



Galaxy Populations in Clusters

Central regions of nearby rich clusters : ~80% S0s, dEs, Es

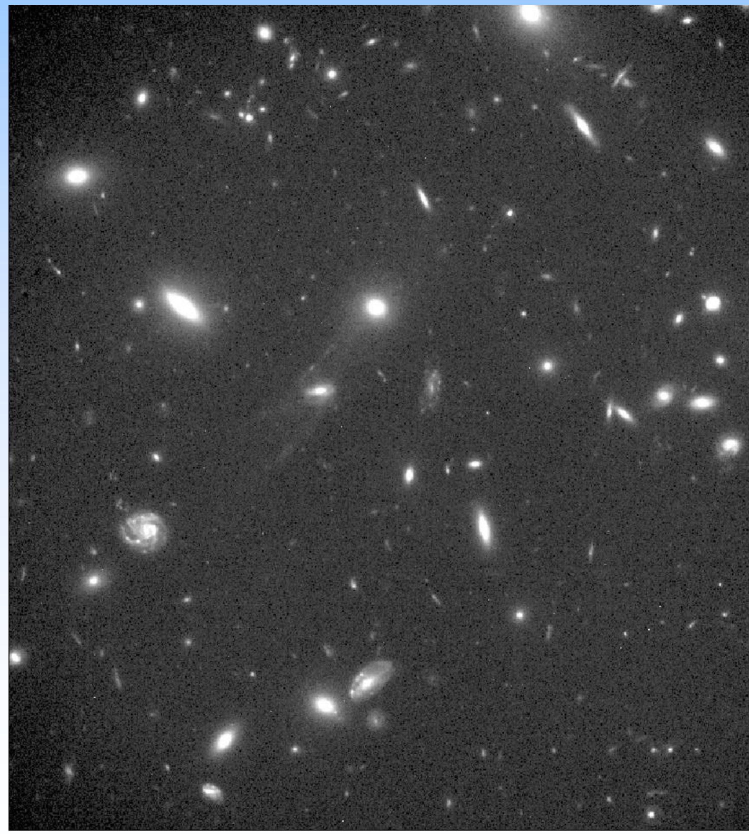
Rich clusters at $0.3 \le z \le 0.8$: high spiral, low S0, similar E fractions

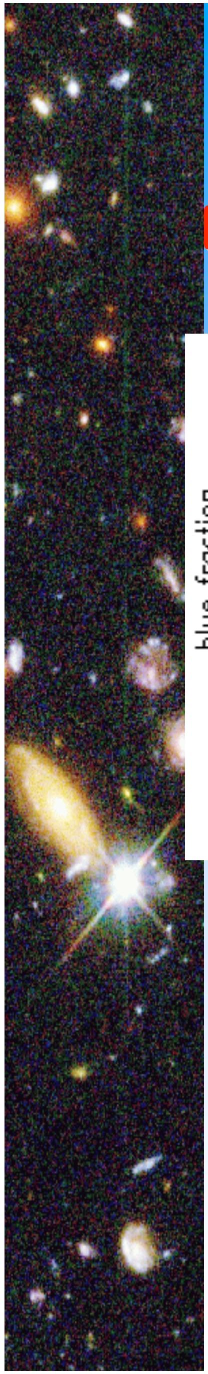
(Dressler 1980, Dressler et al. 1997, van Dokkum et al. 2000)

-> significant transformation spirals -> S0s from z~0.5 to z=0

Coma

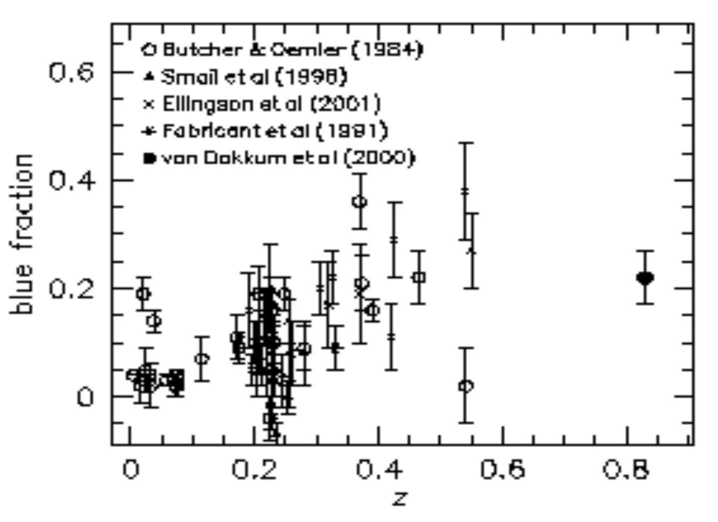
CL0939
z=0.41





Butcher – Oemler Effect

Distant clusters have significant populations of blue* galaxies
not seen in local rich clusters (Butcher & Oemler 1978, 1984)



blue* : bluer than CMR red sequence

(van Dokkum 2001, Dahlen et al. 2004)

× 5 increase in blue galaxy fraction

$f_b = N_{blue} / N_{tot}$

from z~0.5 to z~0

☆ most blue galaxies are low-mass spirals & Irrs
(Smail et al. 1997)

☆ some show SF, others strong Balmer absorption lines
-> recent starburst (Dressler & Gunn 1983)

☆ some red galaxies also show strong Balmer lines
(E+A, k+a) -> post - starbursts (spectroscopic BO-effect)

-> progenitors of S0s ?

Butcher – Oemler Effect

Redshift evolution of the blue galaxy fraction

$$f_b = N_{blue} / N_{tot}$$

due to

- decreasing galaxy infall rate (Kauffmann 1996, Diafero et al. 2001)
- decreasing HI content & SFR (field gals) (Madau et al. 1996)
- increasing ICM content (Evrard et al. 1999)

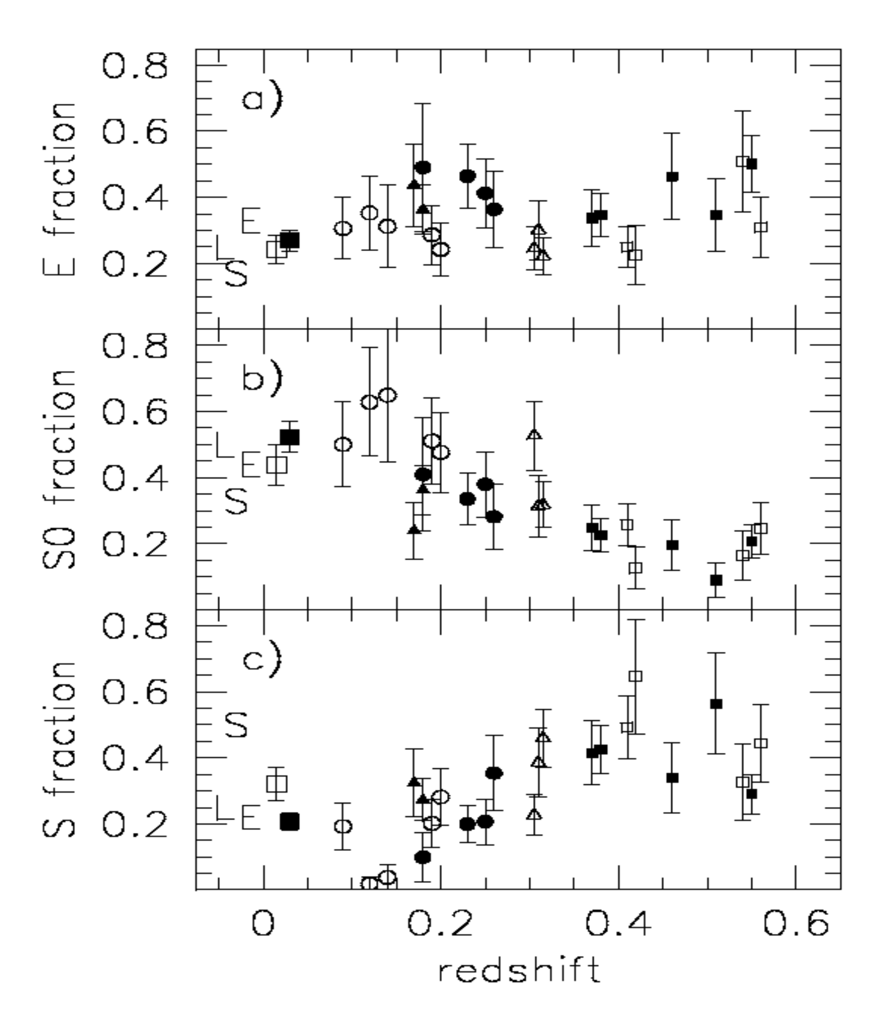
Continuous addition of “young” S0s with low M/L

–> **Progenitor Bias**

slows down the redshift evolution of the <M/L>

–> **reduces redshift evolution of FP**

Evolution in the Cluster Galaxy Population



Redshift evolution of galaxy morphologies (MORPHS sample)

E fraction ~const.

S0 fraction ↘ for z ↗

Spiral fraction ↗ for z ↗

(Fasano et al. 2000, 2001, Couch et al. 1998)

significant transformation : spirals ➜ S0s from z~0.5 to z=0 within the last 5 Gyr

Galaxy Transformation Processes

Field spirals falling into a cluster get transformed into S0s, dSphs, dEs through interactions

☆ with other cluster galaxies : harassment

☆ in infalling groups : merging

☆ with the dense hot ICM (X-rays) : ram pressure stripping/ sweeping : HI anemic -> SF truncation/strangulation (if disk/halo gas gets stripped)

All processes observed to work in certain cases

? t(spectral transformation) <->

t(morphological transformation) ?

? progenitors - transition stages - end products ?

? relative importance of diff. transformation channels

& ev. dependence on cluster properties ?

Galaxy -- ICM Interactions

$P_{ICM} > P_{ISM}$ ➜ ram pressure ➜ disk stripping, sweeping

➜ HI anemic spirals ➜ SF truncation

$t_{trunc} \sim 10^8$ yr

$P_{ICM} > P_{halo\ gas}$ ➜ halo gas stripping

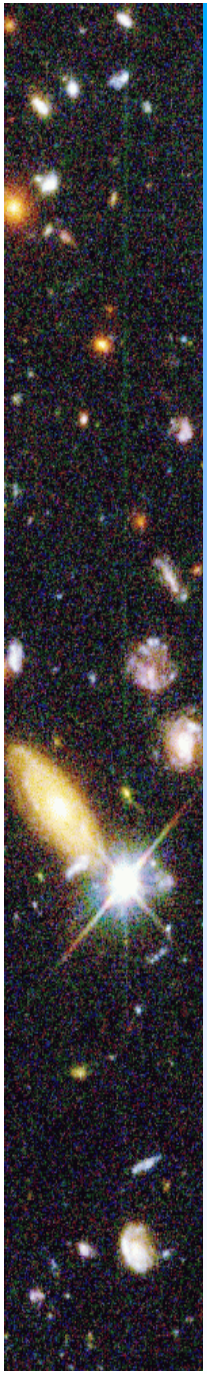
➜ accretion truncation ➜ SF strangulation

$t_{strang} \sim 10^9$ yr

When SFR ➜ 0 : disk surface brightness ↘ very rapidly,

disk harder to detect,

➜ apparent B/D ratio ↗



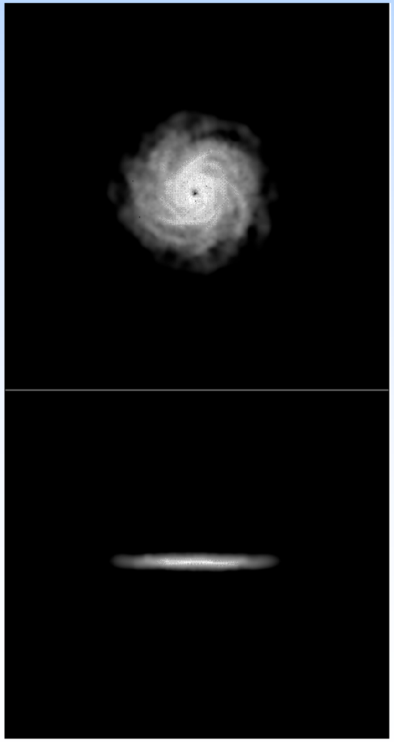
Galaxy Harassment in Clusters

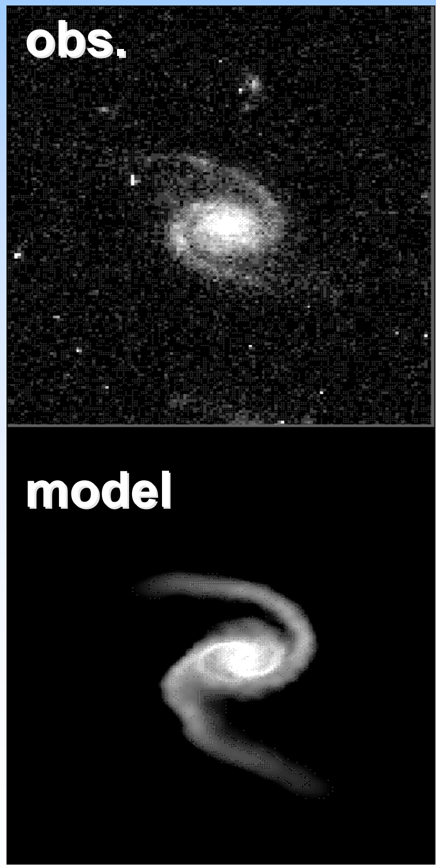
$v_{Gal} \gg v_{\star}$: few mergers, many fast & destructive encounters/fly-by's (Moore+96)

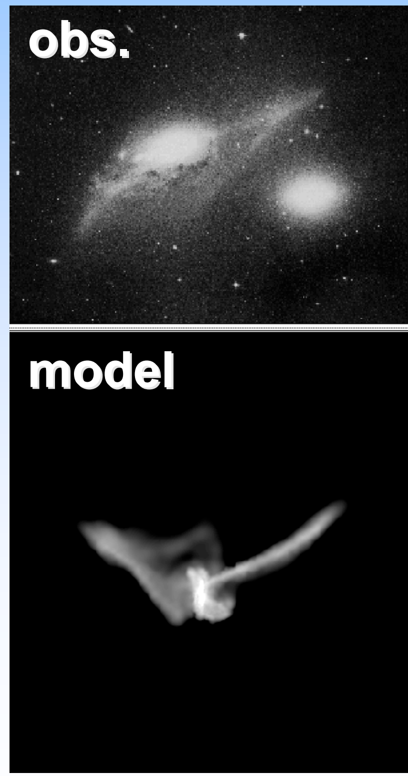
Spirals ➜ S0s & dSphs & dEs

(?) luminous, blue, SFing — faint, red, passive

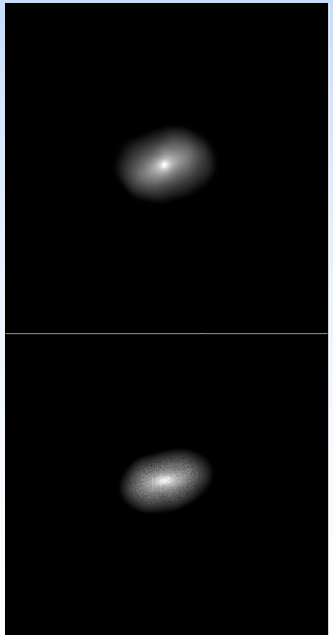
Infalling spiral







after 3 Gyr



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Collective Starburst in an infalling Group

Collective Starburst in a Group falling into A1367

(Gavazzi et al. 2003)

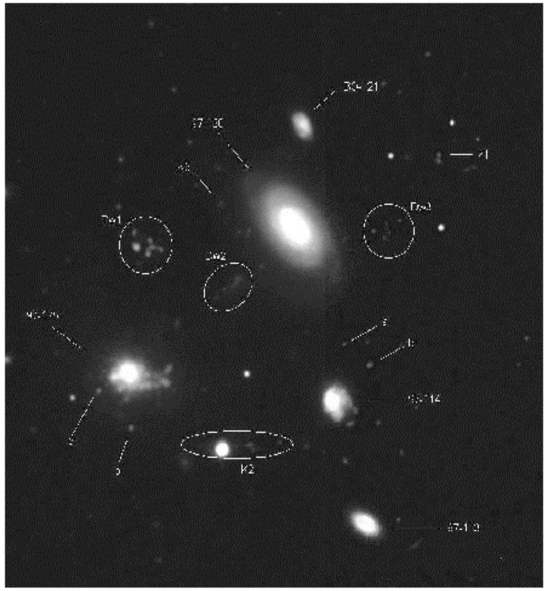

FIG. 1.—The 5 × 5 arcmin² field centered on the group of galaxies projected near the X-ray center of A1367. Blue corresponds to the Hα emission of hydrogen ionized by massive ($M > 10\ M_{\odot}$) currently ($t < 20$ Myr) forming stars. Along with two bright galaxies (CGCG 97-114 and CGCG 97-125), 10 dwarf systems are simultaneously experiencing a burst of star formation. The yellow color corresponds to the red (r' band) emission by old stars. All the Hα-emitting objects are redshifted by 1800 ± 150 km s⁻¹ with respect to the cluster systemic velocity, thus belonging to a distinct group falling into the cluster from the front side.

R

H_{α}

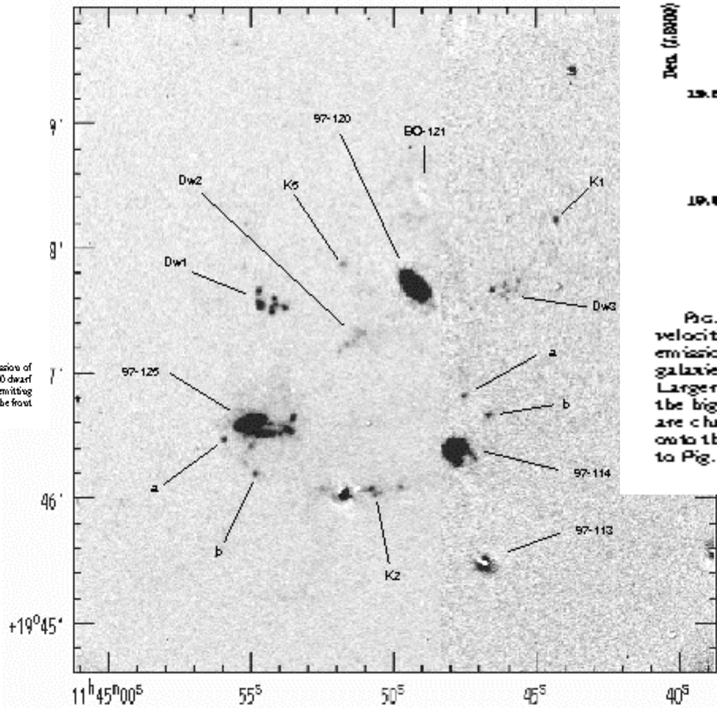

FIG. 3.—Net (Hα + N[II]) band frame of the BIG group

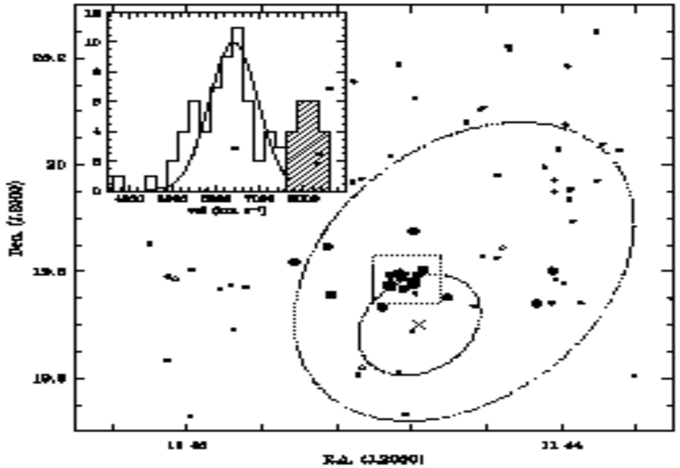

FIG. 4.—Celestial distribution of galaxies with known recessional velocities in the cluster of galaxies A1367, with two contours of the X-ray emission sketched around the X-ray center (*cross*). Small symbols mark galaxies within the Gaussian velocity distribution of the cluster (see inset). Larger circles refer to galaxies with redshift exceeding 7700 km s⁻¹, i.e., in the high-velocity tail of the distribution (*shaded*). Note that these galaxies are clustered in a small region, revealing the existence of a group falling onto the cluster. Galaxies inside the small square box (BIG), corresponding to Fig. 3, have been all detected in Hα.

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ICM - ISM Interaction

SFing galaxies avoid central region

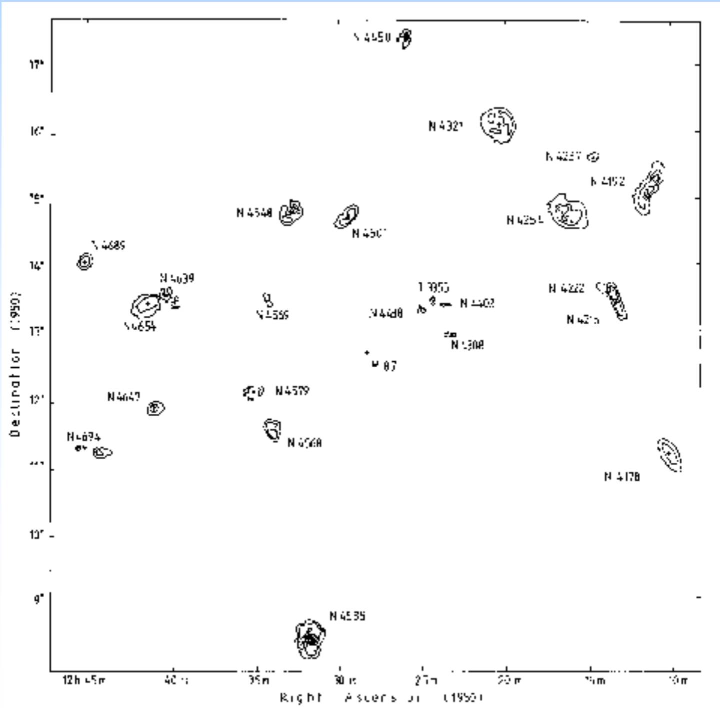
ring of HI – anemic spirals around center.

Role of hot, dense Intra Cluster Medium (ICM),

seen in X-rays :

Ram pressure stripping/sweeping

(Cayatte+90 Gavazzi+05)



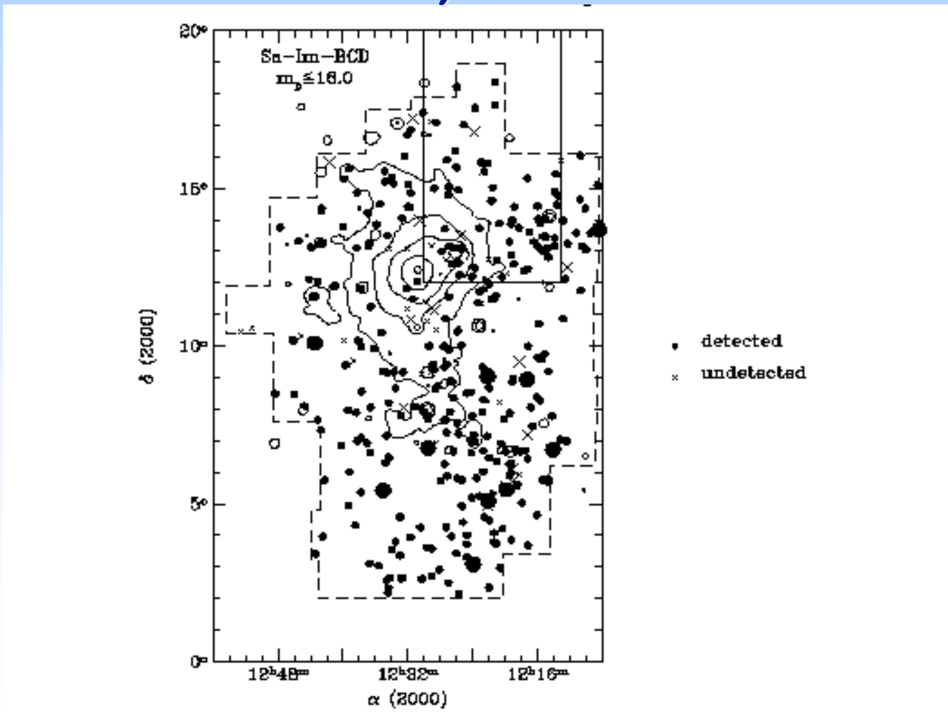


Fig. 1. The Virgo cluster region considered in the present analysis. The dashed broken line represents the boundary of the VCC catalog and the rectangle the area covered by the HIJASS blind HI survey. Superposed are the X-ray contours from ROSAT (Bohringer et al. 1994). All 355 late-type (Sa-Im-BCD) members of the Virgo cluster with [illegible] symbols refer to objects observed in this work.

ICM - ISM Interaction

HI mapping of Coma galaxies :

(Bravo-Alfaro+00)

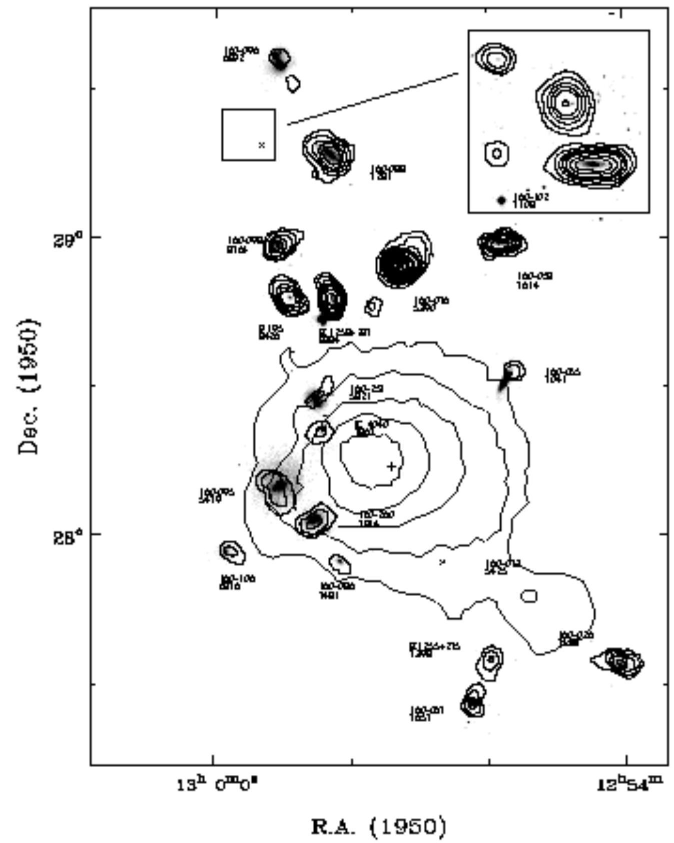


FIG. 2—Composite plot of individual H I maps of spiral galaxies of Coma observed with the VLA. Galaxies are shown at their proper position (except those in the rectangle, where the position of CGCG 160-102 is indicated with a times sign) and they are magnified by a factor of 7. The H I maps are overlaid on DSS optical images. The first contour is the same for all galaxies, corresponding to 3×10^{19} cm^{-2}. Their identifications and central velocities (in km s^{-1}) are indicated. The large-scale contours sketch the X-ray emission as observed by Vikhlinin et al. (1997). The cross indicates the cluster center, coincident with the elliptical NGC 4874.

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Cluster Substructure & Galaxy Distribution

Distribution of Emission Line and E+A Galaxies related to substructure in the Coma cluster

(Poggianti+04)

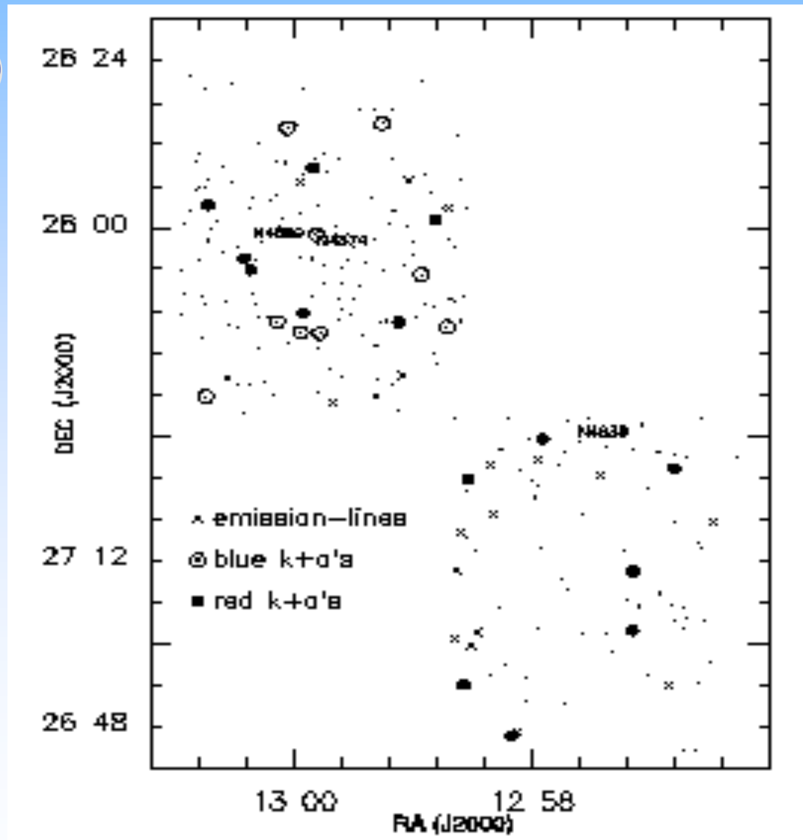
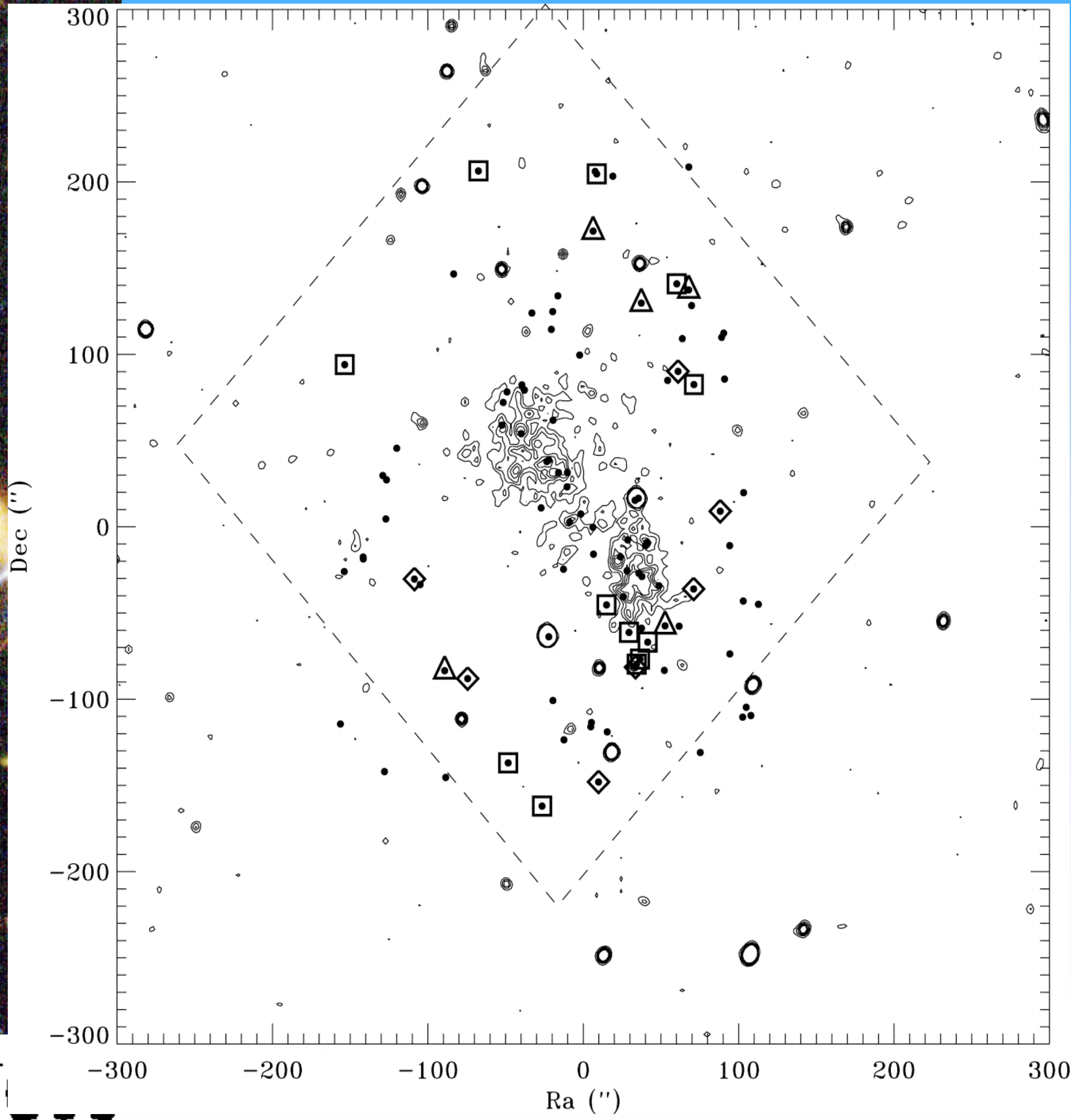


FIG. 5.—Projected position on the sky of k (*small circles*), red and blue k+a (*large circles*), and emission-line (*crosses*) galaxies. The location of the three dominant galaxies (NGC 4874, NGC 4889, and NGC 4839) is labeled.

Distant Galaxy Cluster :
Cl 0152 – 1357 @ z = 0.837



(Homeier+ 05)

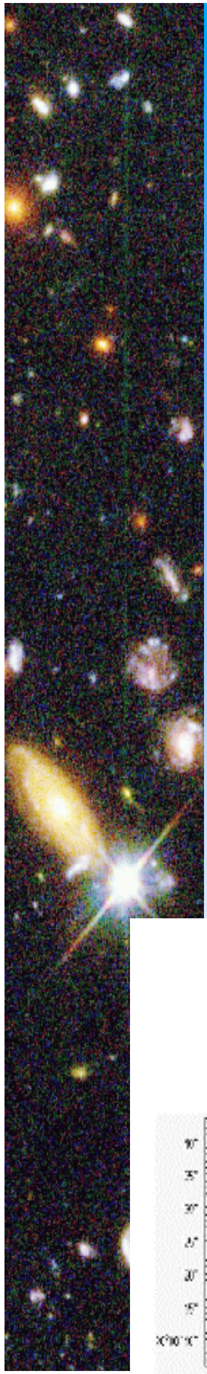
X contours : Chandra

SFing galaxies :

△ compact

□ Sp/Irr

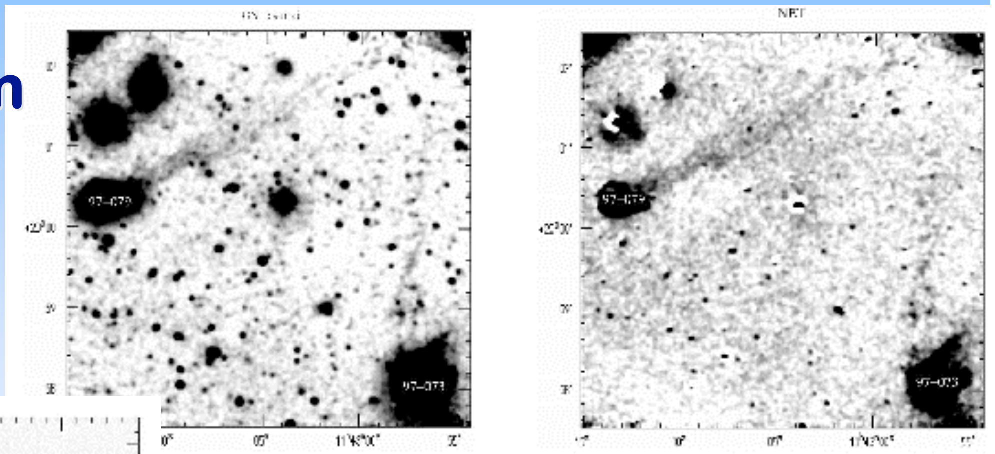
• red cluster sequ.



Direct Evidence for Galaxy - ICM Interaction
(in combination with galaxy – galaxy interaction)

(Gavazzi+01)

75 kpc H_α trails behind 2 Irrs in A1367
vigorous SF at opposite sides of galaxies
evidence for ram pressure
during high-speed motion
towards cluster center
tails cross each other
-> interaction ~50 Myr ago



r Hα + [N II] ON band (*left*) and NET exposures (*right*) of the region containing the two galaxies under study shown at high contrast to als. The upper corners of the images suffer from filter vignetting.

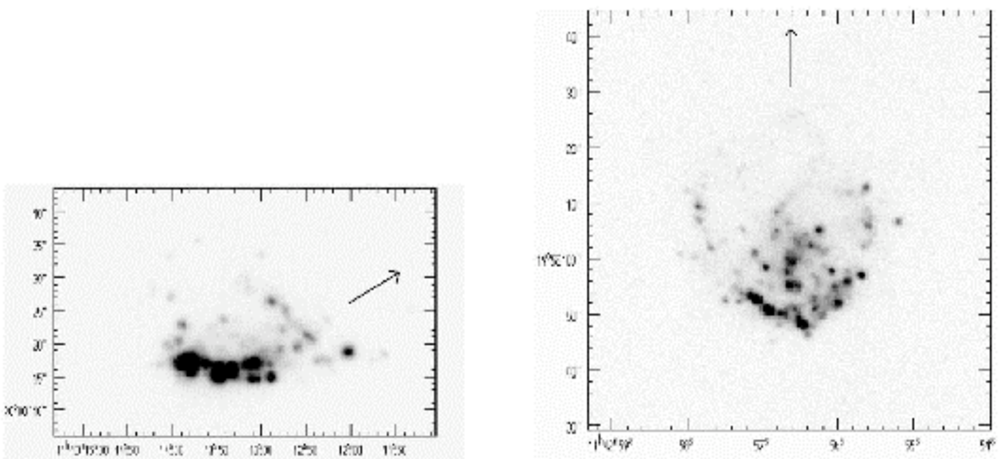


FIG. 1.—Hα + [N II] NET image taken with the WHT with 0.″85 seeing showing the bright parts of 97−079 (*left*) and 97−073 (*right*). J2000.0 celestial coordinates are given. The center of the cluster is at the southeast. An arrow marks the direction of the low-brightness tail (see Fig. 2).

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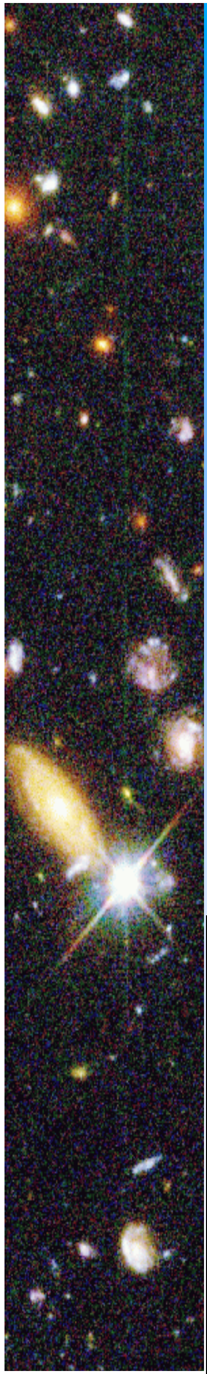


Formation/Transformation of S0s

Major merger : spiral + spiral –> E or (luminous) S0

∗ (incomplete) violent relaxation : deVaucouleurs profile + gradient

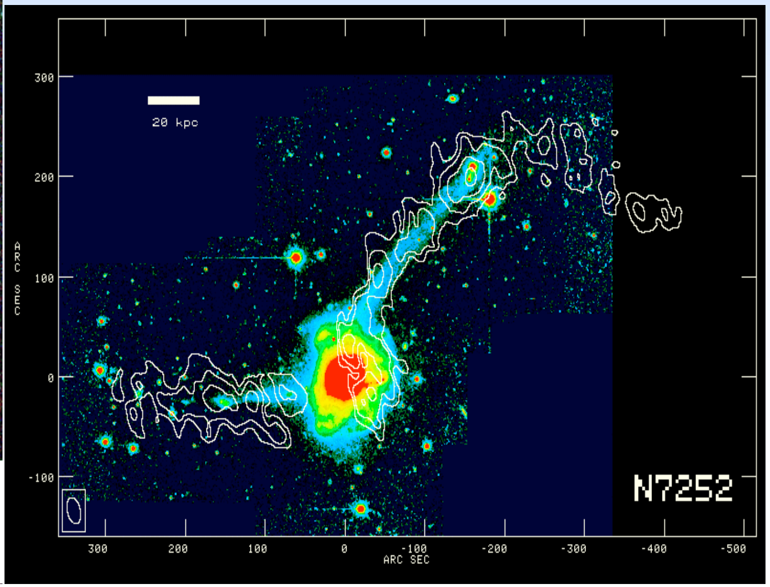
∗ late backfall of HI from tidal tails –> rebuild disk (disky E or S0) within ~3 Gyr

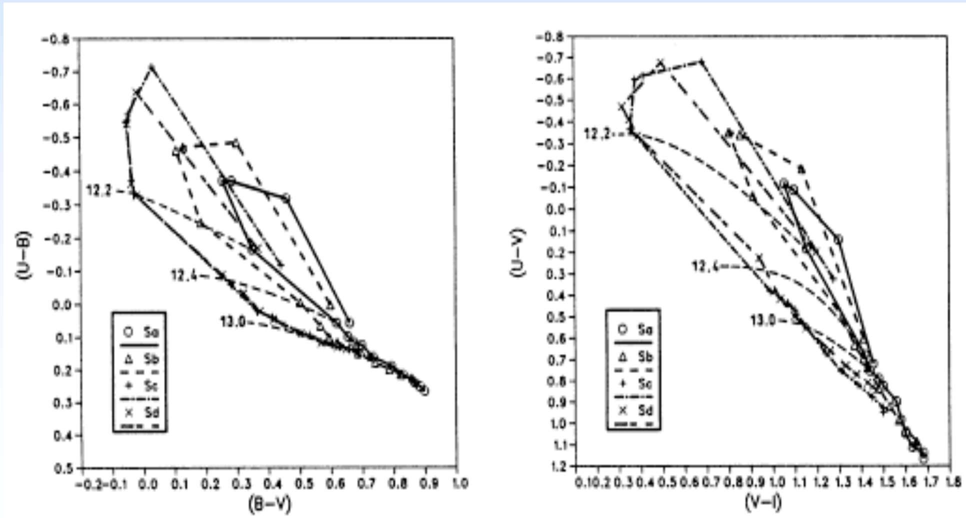
∗ global or nuclear starburst for prograde or retrograde mergers

∗ ~ 1 Gyr after starburst : E + A spectrum

∗ ~ 3 Gyr after starburst : colors of luminous S0s

(Barnes 2002, Hibbard & Mihos 1995, Fritze & Gerhard 1994)





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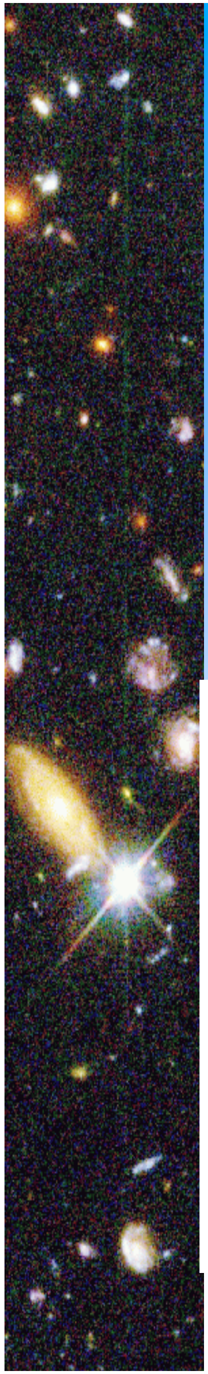
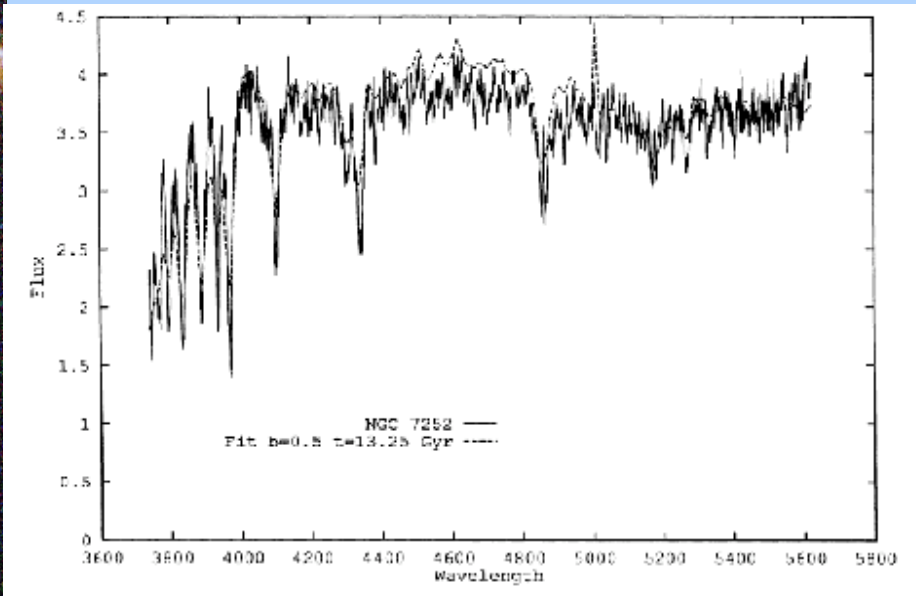


Formation/Transformation of S0s

Major merger : spiral + spiral + starburst
–> E or (luminous) S0

- ~ 1 Gyr after starburst : E + A spectrum
- ~ 3 Gyr after starburst : colors of luminous S0s

(Barnes 2002, Hibbard & Mihos 1995, Fritze & Gerhard 1994)



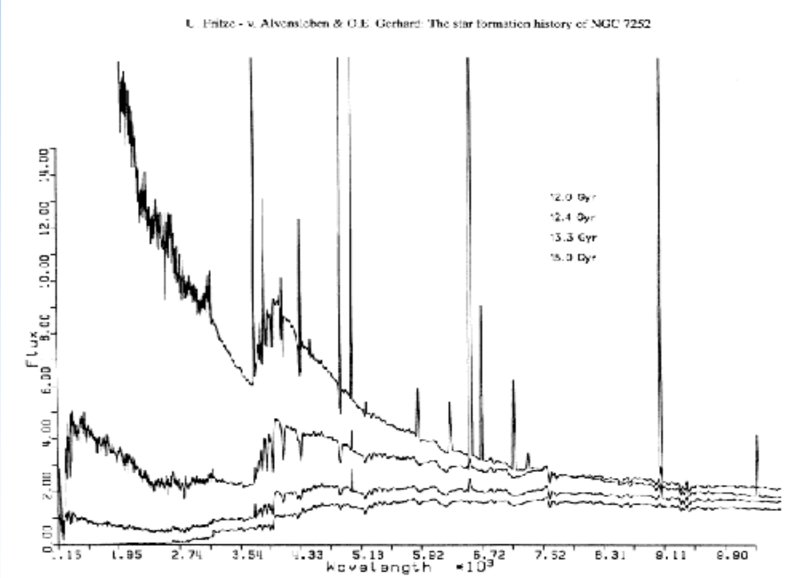
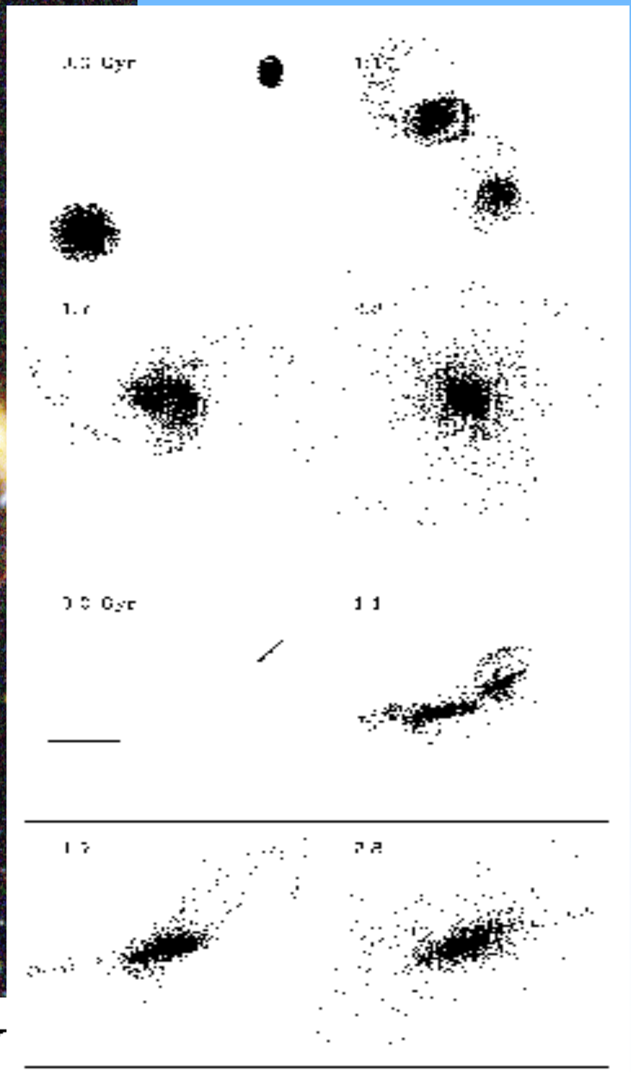


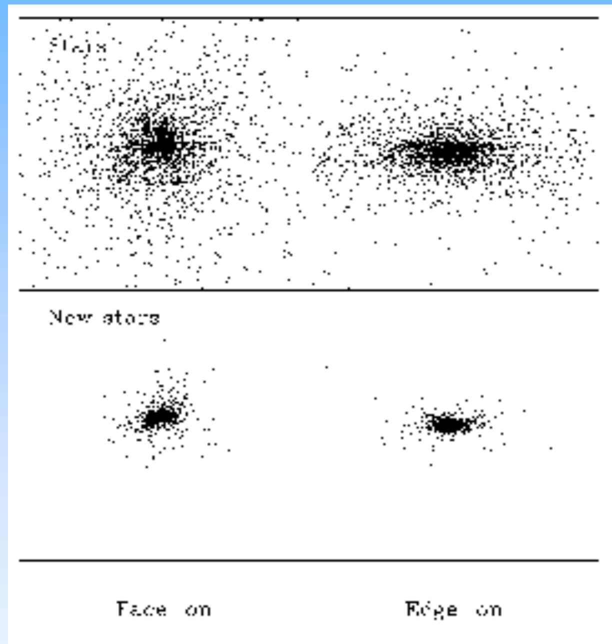
Fig. 2. Time evolution of our synthesized galaxy spectra from the UV to the NIR for our best fit model to NGC 7252

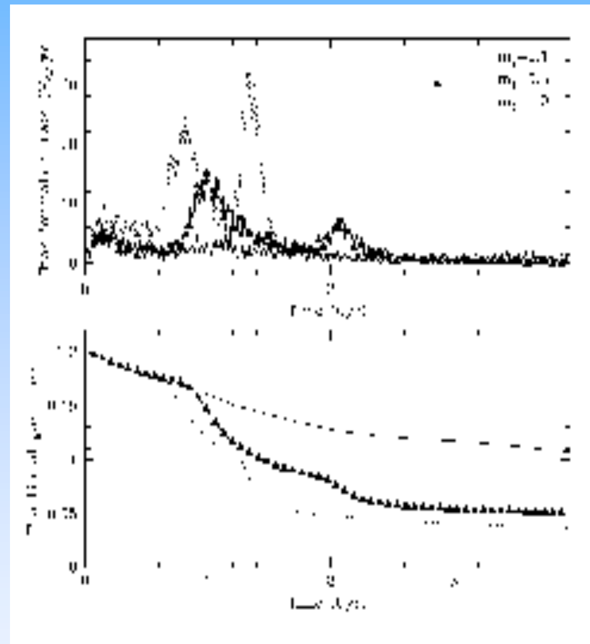
Formation/Transformation of S0s

Minor merger (3 : 1) of 2 gas-rich bulgeless disks

(Bekki 1998)







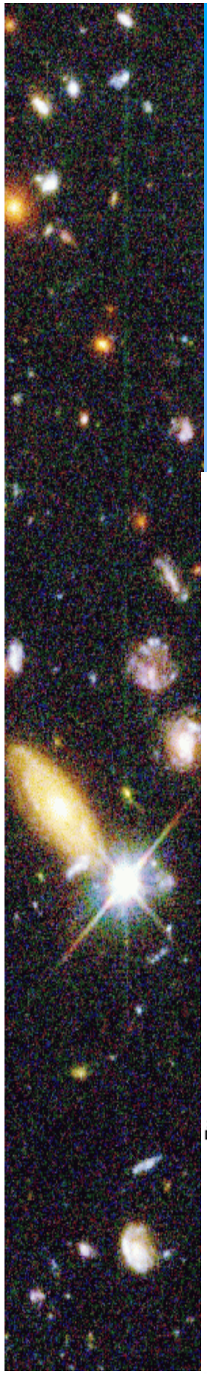
old stars SFR(t) : 2 weak bursts -> 0

new stars G/M(t) < 5%

merger remnant ~S0

after ≤ 3 Gyr

(density profile, B/D, rotation, anisotropy, M/L, ...)

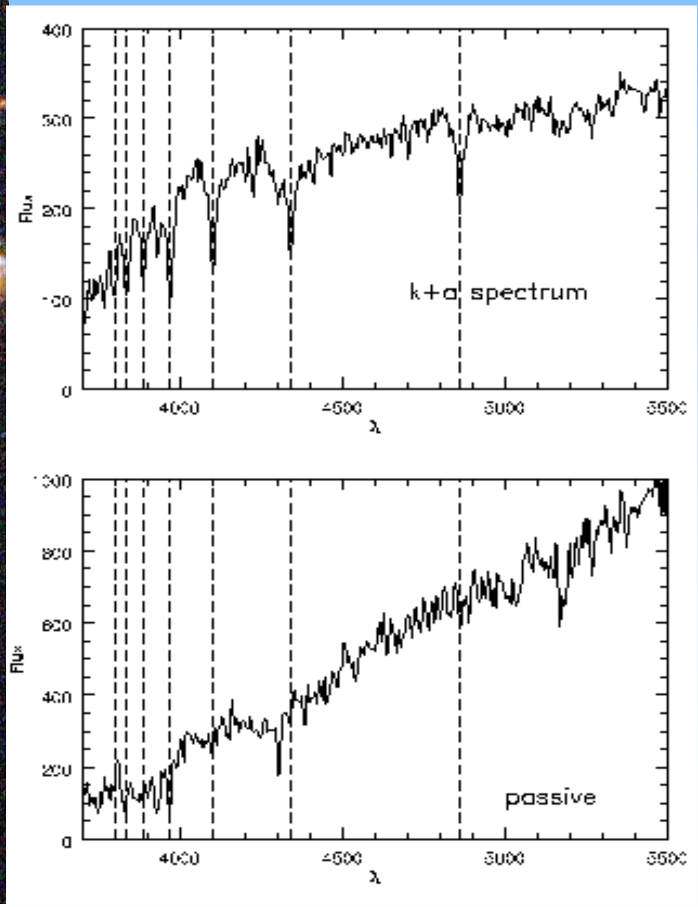


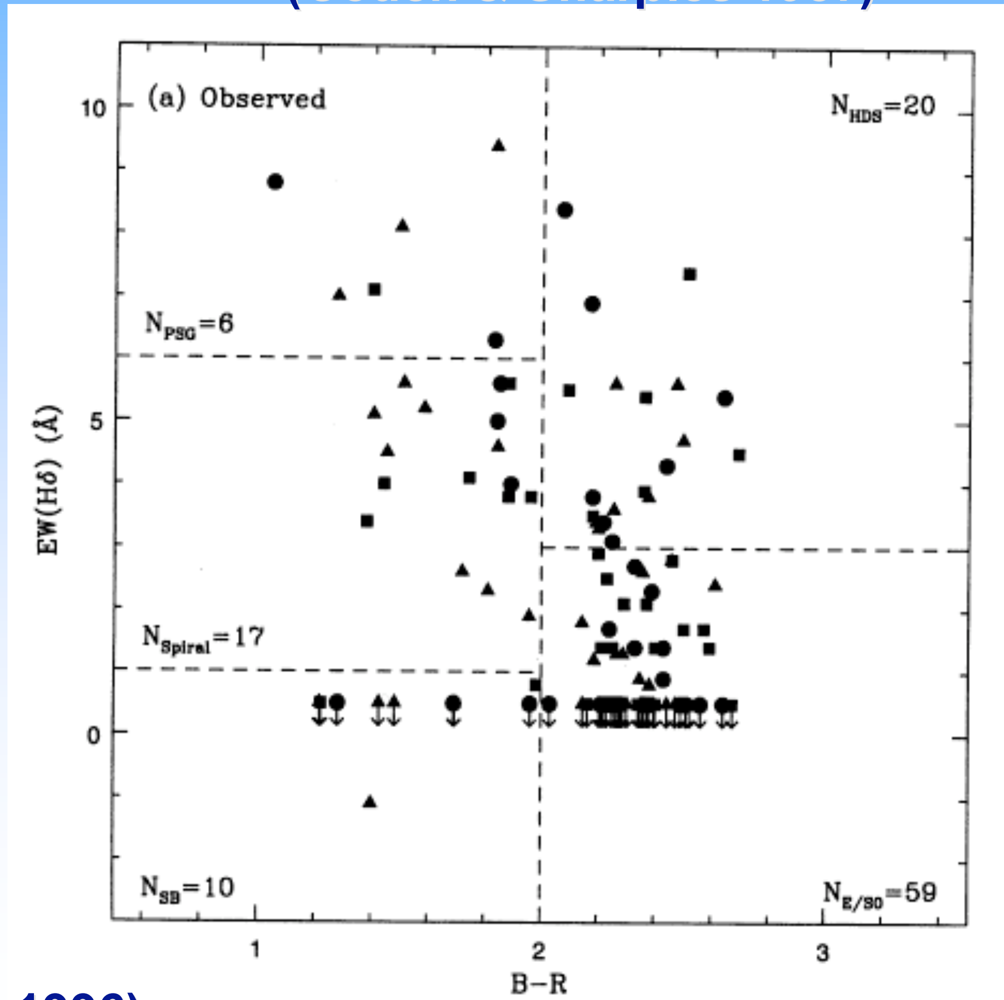
Field Spirals -> Cluster S0s

Spectral Transformation : transition types

5 spectral categories for cluster galaxies :

E+A = k+a ~ Hδ strong (Couch & Sharples 1987)





(Barger et al. 1996)

3 clusters at z=0.3

Field Spirals ➜ Cluster S0s

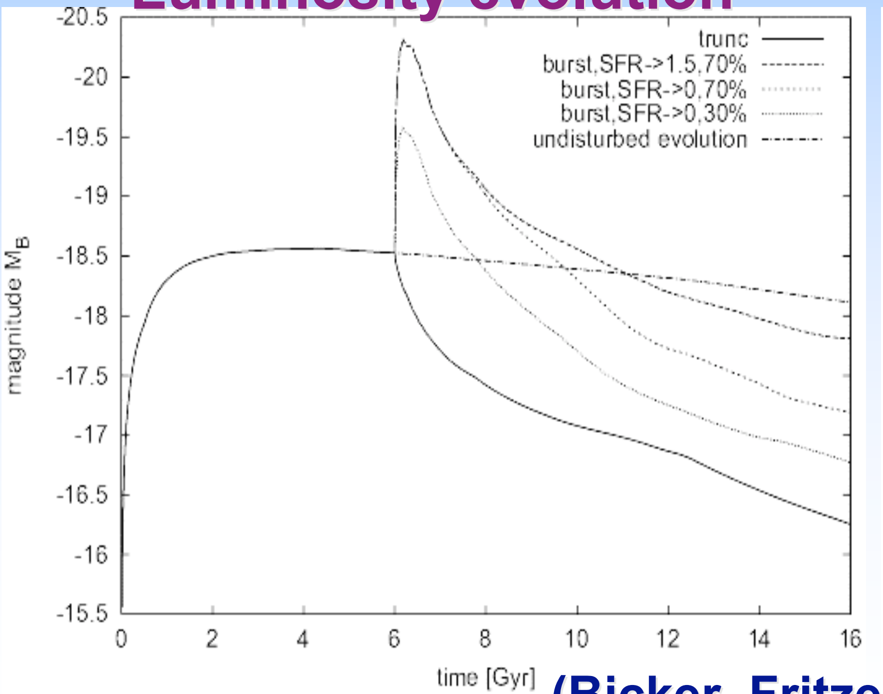
Galaxy Numbers & Morphologies (Kodama & Smail 2001)

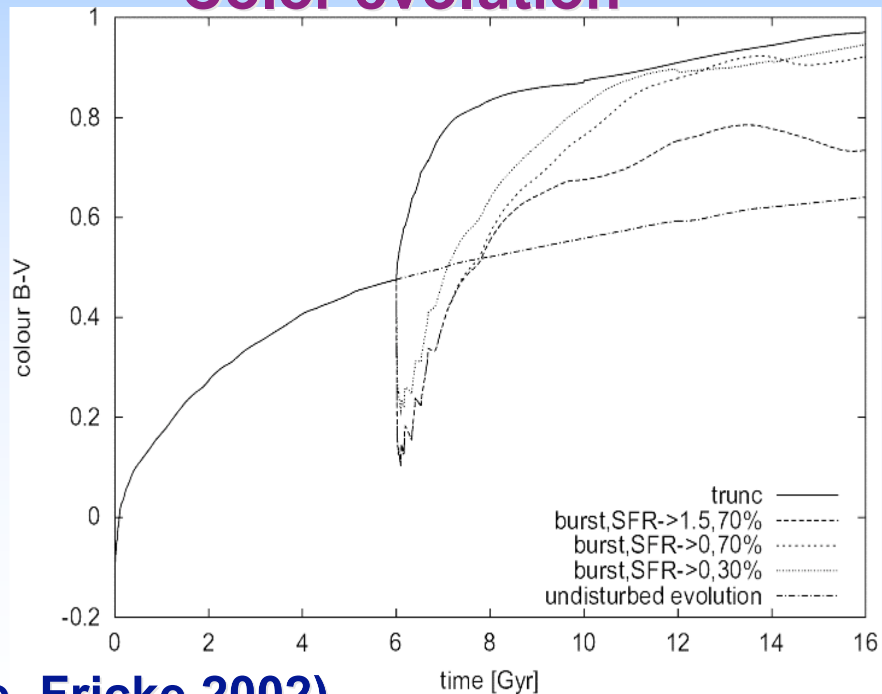
>50% cluster galaxies accreted since z~0.5
most accreted spirals up to Scdm* get transformed into S0s
t_{morph} ~1–3 Gyr *Sd, Sm too faint

Spectrophotometric Aspects (Bicker+02, Shioya+02, 04)

spiral galaxy types ± Starburst + SF truncation/strangulation

Luminosity evolution **Color evolution**





(Bicker, Fritze, Fricke 2002)

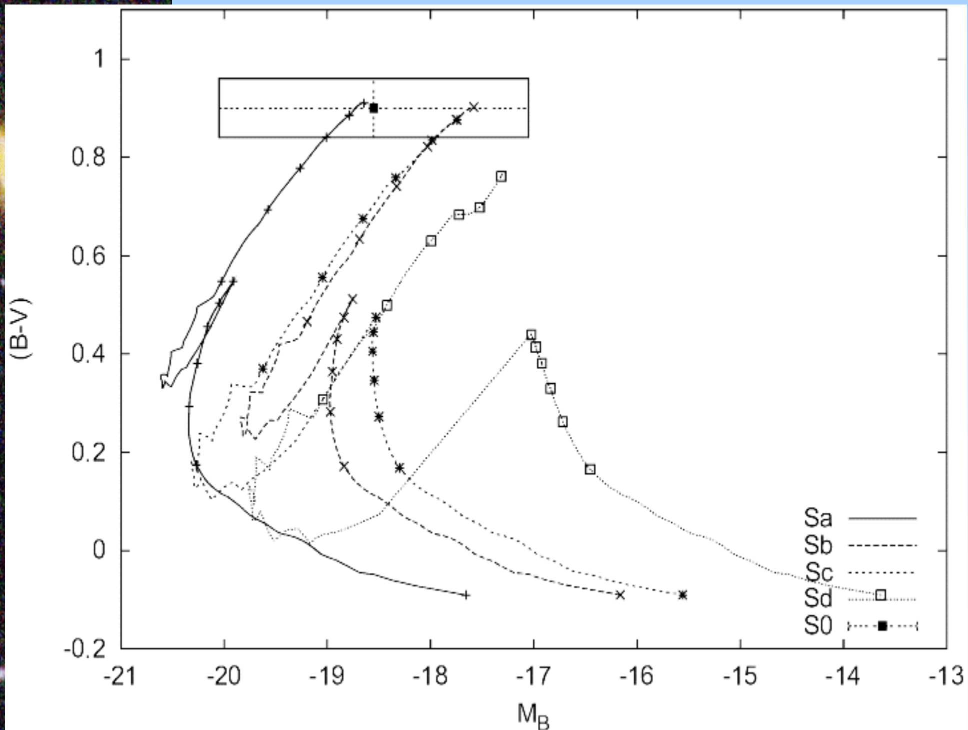
Field Spirals ➜ Cluster S0s

Spectrophotometric aspects (Bicker, Fritze, Fricke 02)

spiral galaxy ± Starburst + SF truncation/strangulation

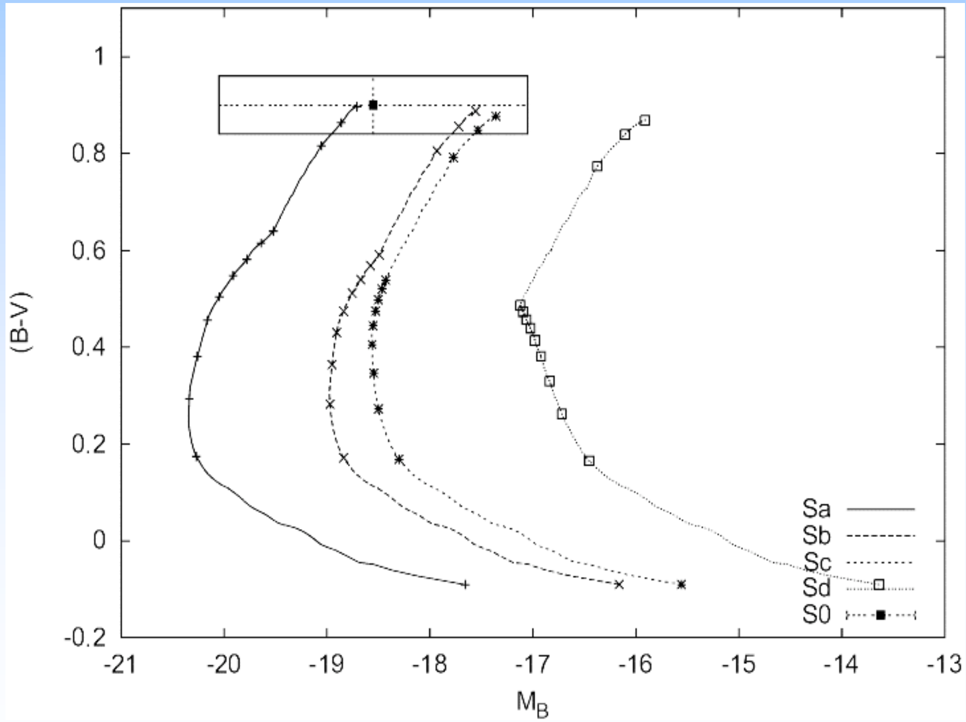
Evolution in Color – Magnitude Diagrams : 1σ box for S0s

Strong starbursts at 6 Gyr



Sa, Sb, Sc ok, Sd too blue

SF truncation at 9 Gyr



Sd too faint

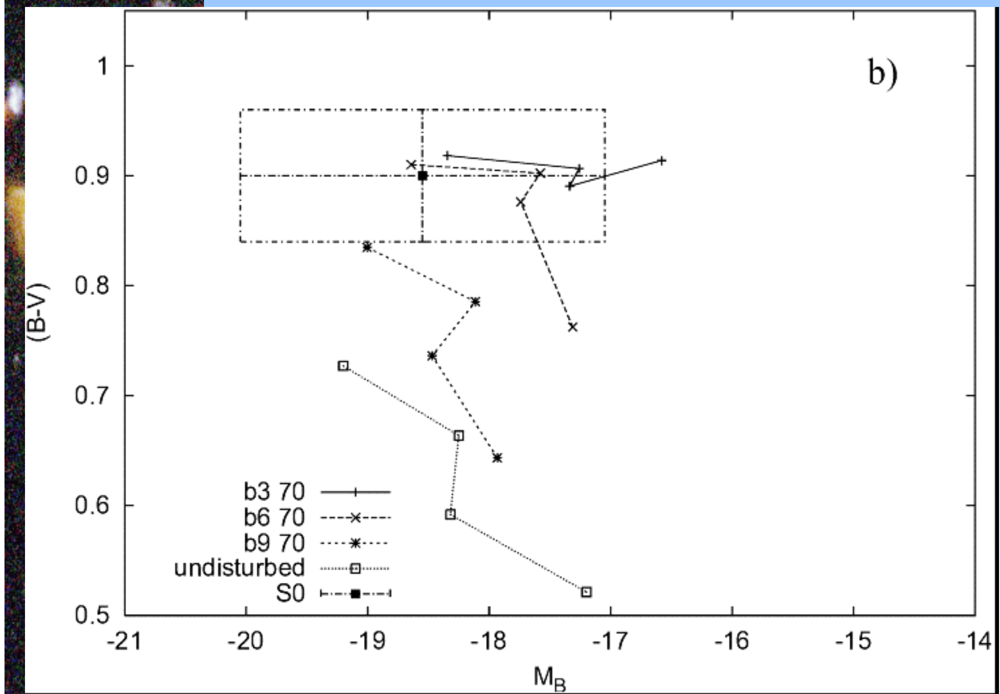
Field Spirals ➜ Cluster S0s

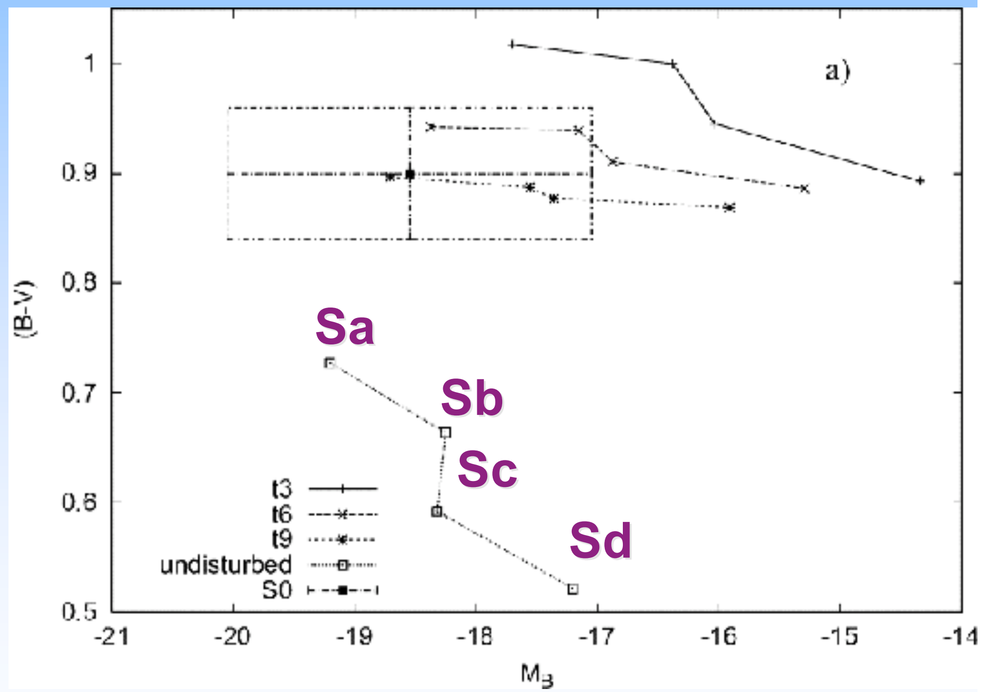
Spectrophotometric aspects (Bicker, Fritze, Fricke 02)

spiral galaxy types ± Starburst + SF truncation/strangulation

Evolution in Color – Magnitude Diagrams : 1 box for S0s

Strong bursts at various ages | **SF truncation at various ages**





Starbursts earlier than 9 Gyr ok

Sa + SF truncation at 3 Gyr : too red

Field Spirals ➜ Cluster S0s

Low-luminosity S0s :

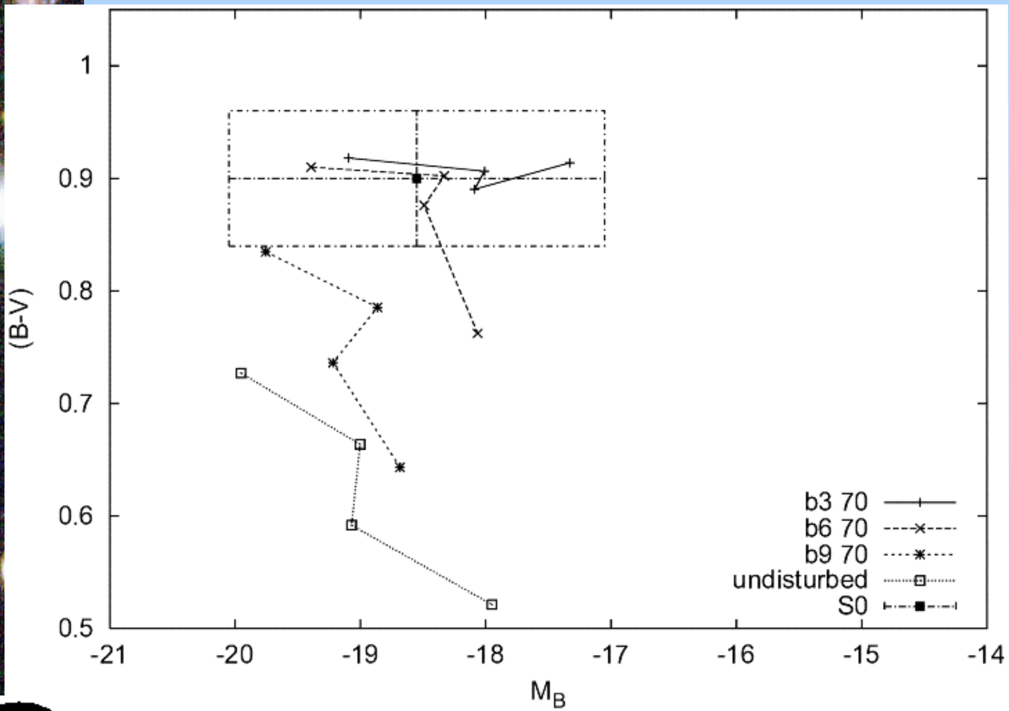
Sa/Sb/Sc with bursts (strong or weak) > 3 Gyr ago

Sa/Sb + SF trunc. at 6 Gyr* < age < 9 Gyr   *gradual ICM build-up

Sc + SF trunc. at ~ 9 Gyr

High-luminosity S0 :

Early-type spiral mergers (Sa)+ bursts at ages < 9 Gyr

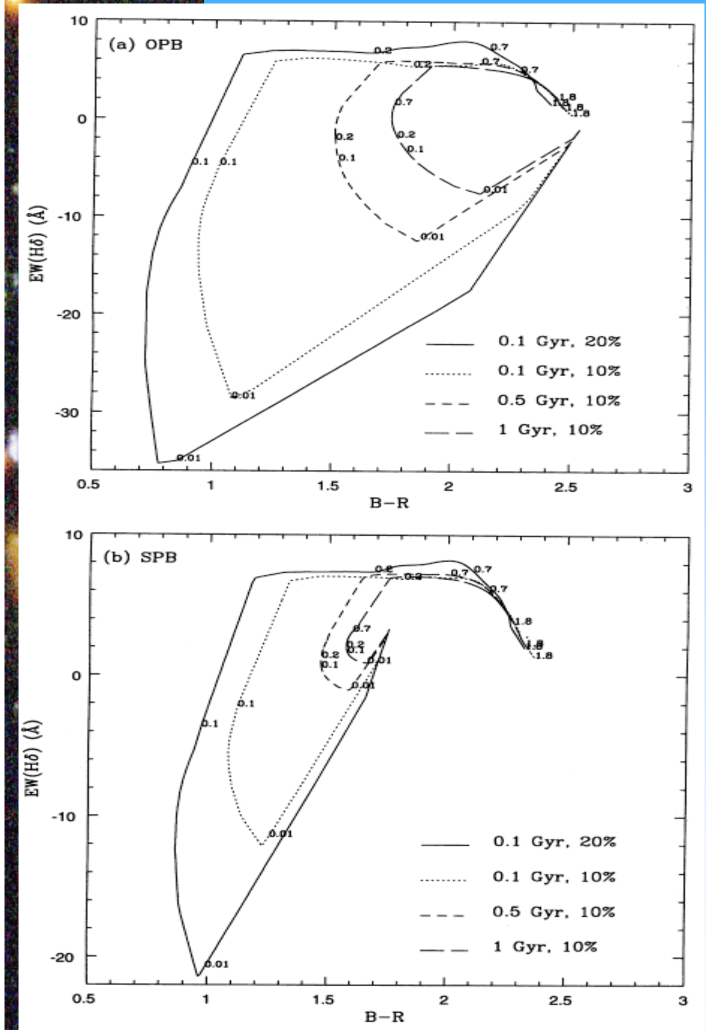


Spiral-spiral mergers + Starbursts

(Bicker, Fritze, Fricke 2002)

Field Spirals ➜ Cluster S0s

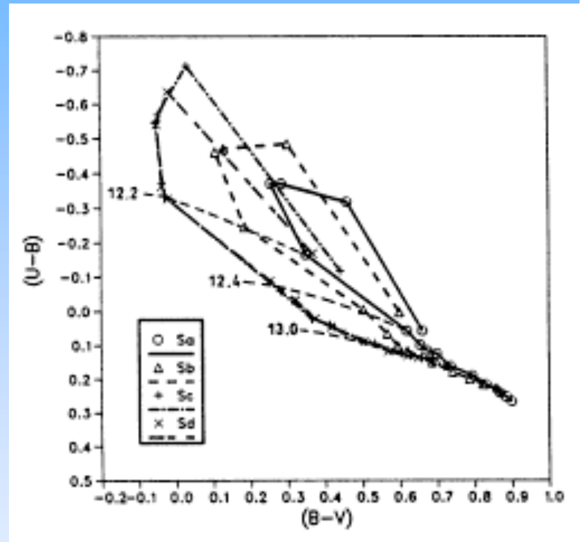
Spectral Transformation Models :



Sp + SF trunc. t<1 Gyr
-> intermed. Hδ -> S0

Sp + SF strang. t>1 Gyr
-> weak Hδ -> S0

Sp + Starburst + SF trunc.
-> strong Hδ -> S0



(Fritze & Gerhard 1994)

(Barger et al. 1996)

E+A ~ k+a ~ Hδ - strong : phase duration ~1.5 Gyr

(Poggianti et al. 1999, Barger et al. 1996)

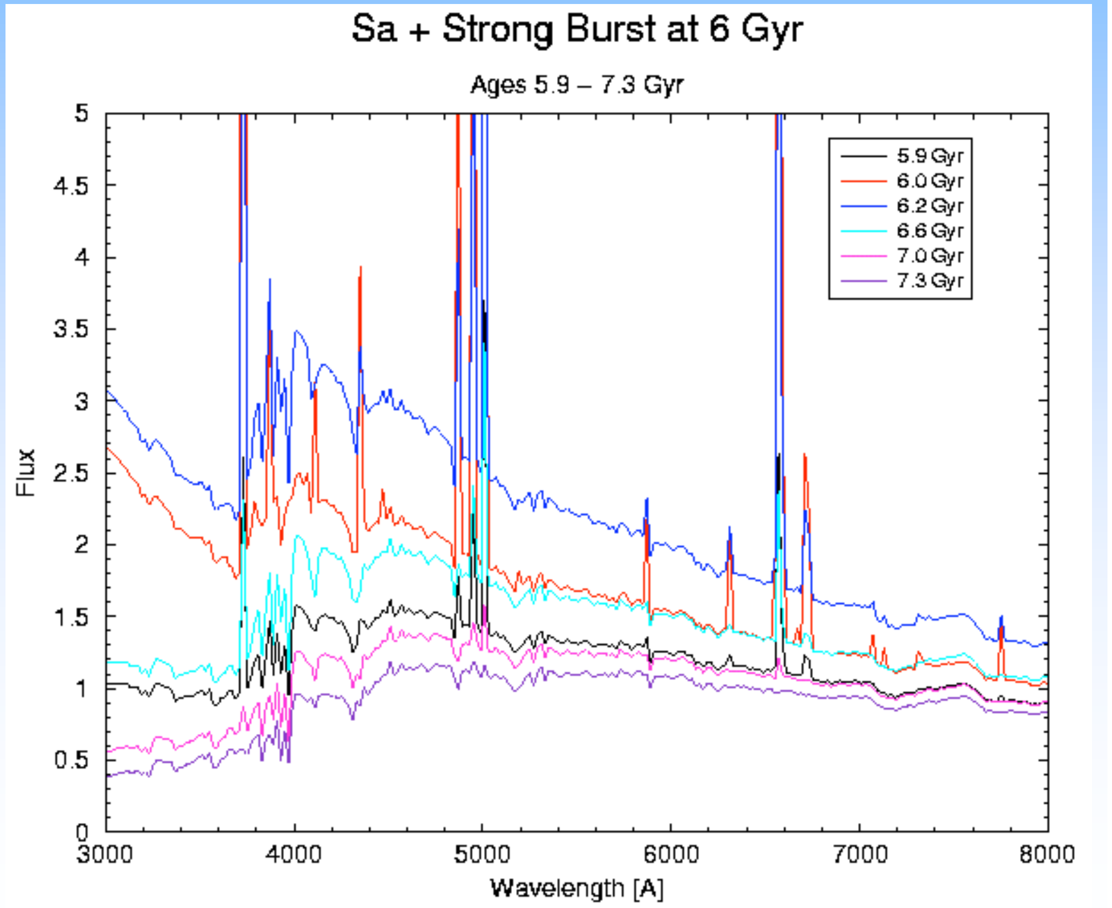
Field Spirals ➜ Cluster S0s : Transition Types

Sa + Sa + strong burst

➜ blue H_δ- strong ➜ red H_δ- strong ➜ luminous S0

(e(a)) (E+A, k+a)

(Tyra & Fritze in prep.)



Field Spirals ➜ Cluster S0s : Transition Types

Sa + strong burst + SF trunc.

➜ H_δ - strong ➜ bright S0

Sa + intermed. burst + SF trunc.

➜ H_δ - intermed. ➜ S0

Sa + SF trunc. on short timescale

(1– 3) 10^8 yr

➜ H_δ - interm. /weak

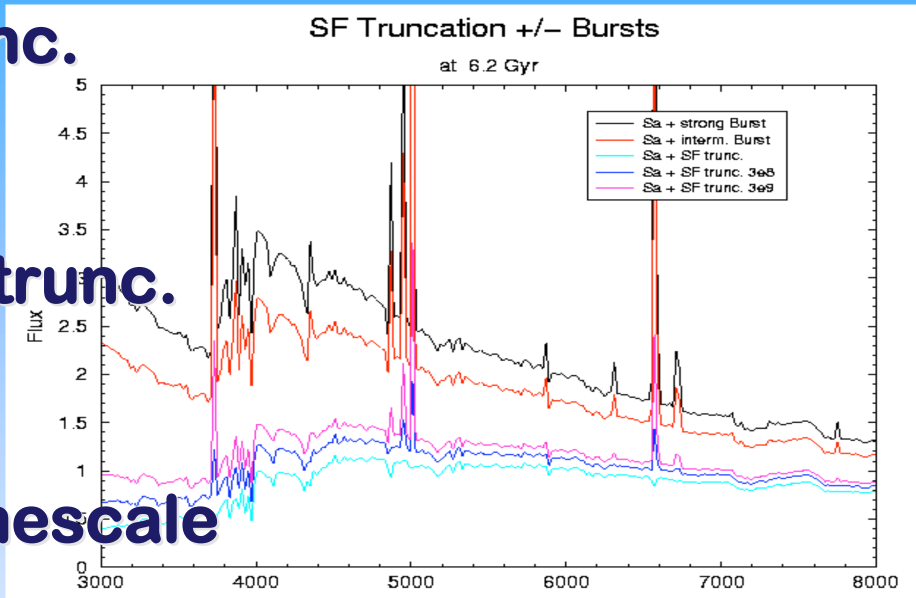
➜ faint S0

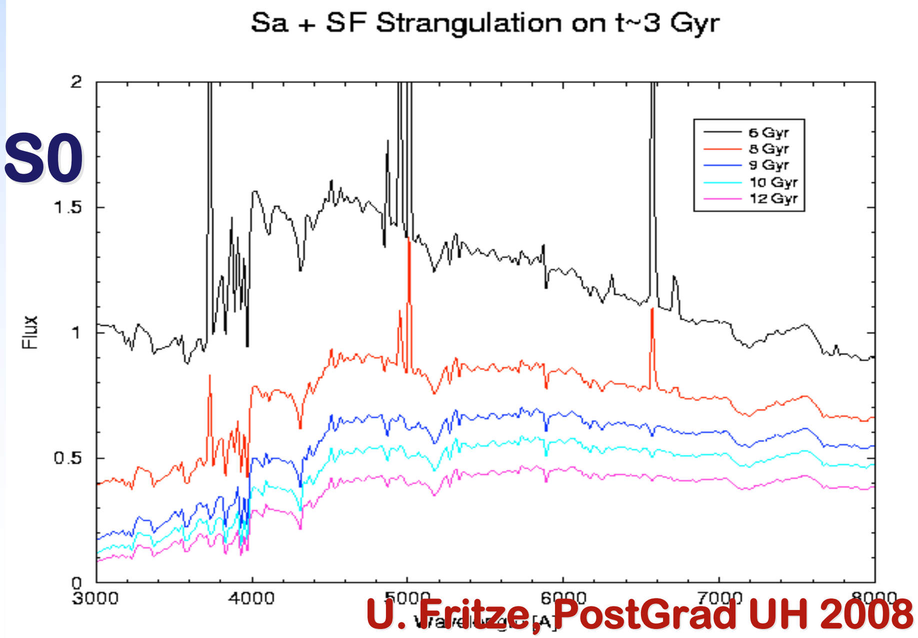
Sa + SF strangulation

10^9 yr

➜ H_δ - weak ➜ faint S0

(Tyra & Fritze in prep.)





Cluster E+A Galaxies

HST: morpological classification: E+A galaxies in clusters :

-5 (E) $\leq$ Hubble Type $\leq$ 3 (Sb),

mostly disk dominated with $0 \leq B/T \leq 0.7$

>50% have significant asymmetry -> recent interaction

(Tran et al. 2003)

➜ t(spectral) < t(morphological)

most Hδ – strong galaxies are regular spheroids

➜ t(spectral) > t(morphological)

(Couch & Sharples 1987)

➜ timescales may depend on type of transformation process ?

diverse properties of E+As :

➜ heterogeneous parent population

➜ more than 1 transformation channel ?

Cluster E+A Statistics

high redshift clusters : E+A & k+a galaxies luminous & massive, starbursts strong $\Delta S/S \sim 0.3$

low redshift clusters : only low luminosity/mass E+A & k+a, starbursts weaker $\Delta S/S \sim 0.1$

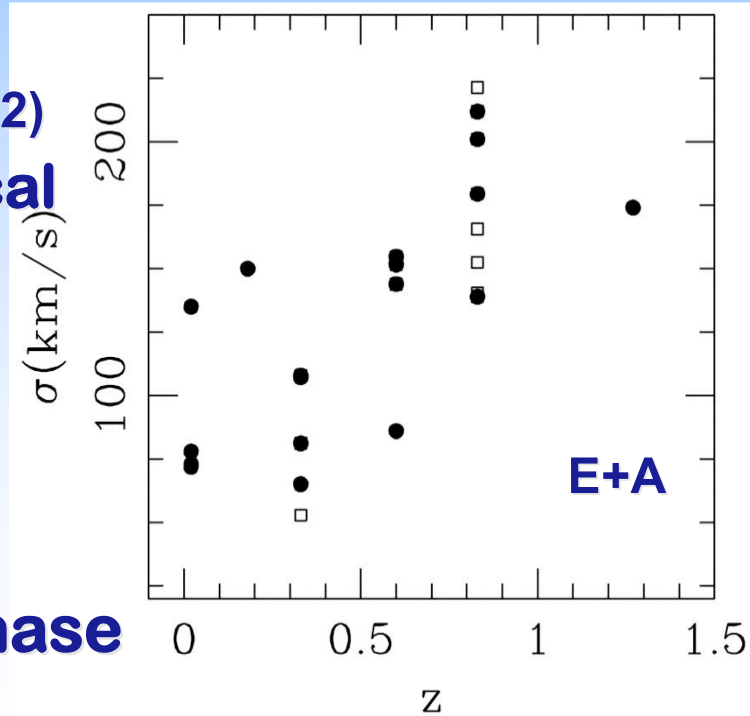
➜ 2-fold **downsizing effect** (also for SFing field galaxies)

(Bower et al. 1999, Cowie et al. 1996)

ISOCAM midIR data for A1689 (z~0.2)

~90 % SF hidden by dust in optical

(Duc et al. 2002)



Lifetime statistics :

➜ 30 – 100% E/S0s have undergone E+A phase

(Tran et al. 2003, Poggianti et al. 2003)

266 E+As from SDSS

(Goto 05)

E+A's have excess of local galaxy density
on scales < 100kpc (=group scales),
not on larger (=cluster) scales,
nor on very large (=Large Scale Structure) scales

➜ E+A related to close companions

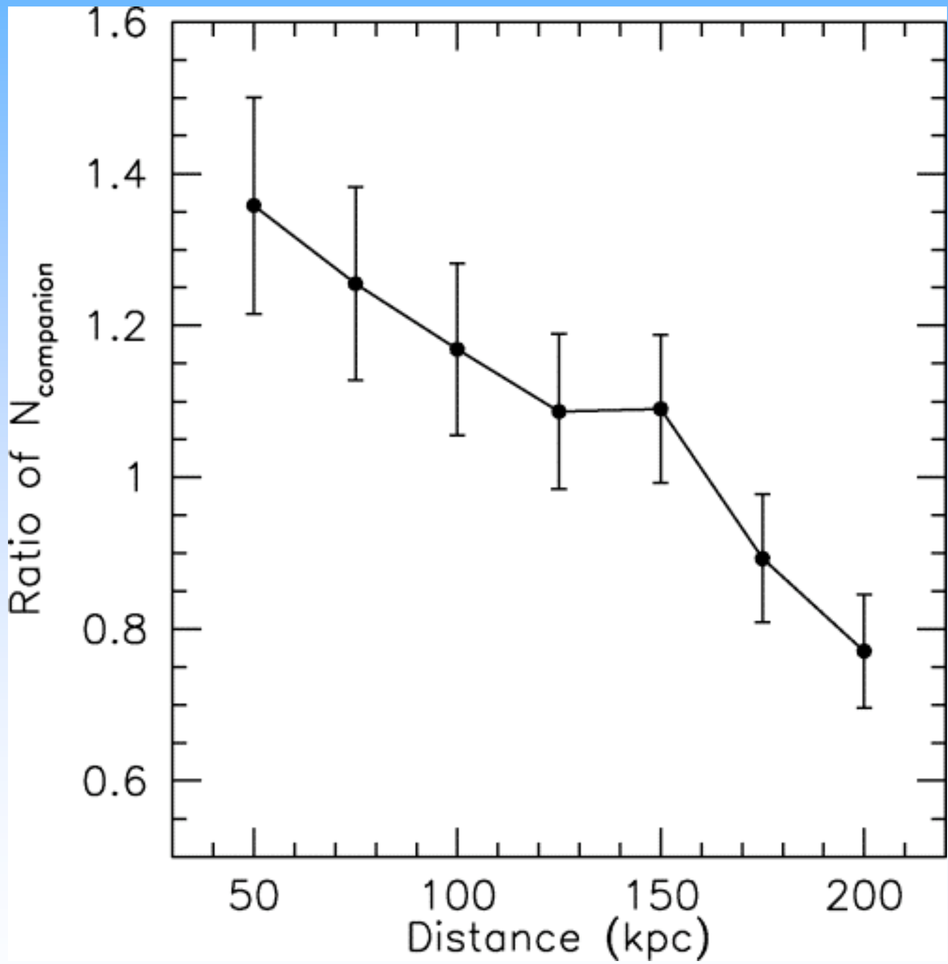
Almost all E+A's have bright compact cores
~ 30 % have dynamically disturbed signatures
or tidal tails

➜ E+A related to (weak?) interaction with companion

Dust plays important role for starburst galaxies,
not any more during E+A – phase

266 E+As from SDSS

(Goto 05)



Field E+A Galaxies

E+A galaxies also exist in the field

E+A galaxy fraction in the field : 2.7±1.1% at $0.3 < z < 1$, $50 \leq \sigma \leq 220$ km/s

E+A galaxy fraction in clusters : 11.0±3.0% at $0.3<z<1$

80% field E+As morphologically irregular

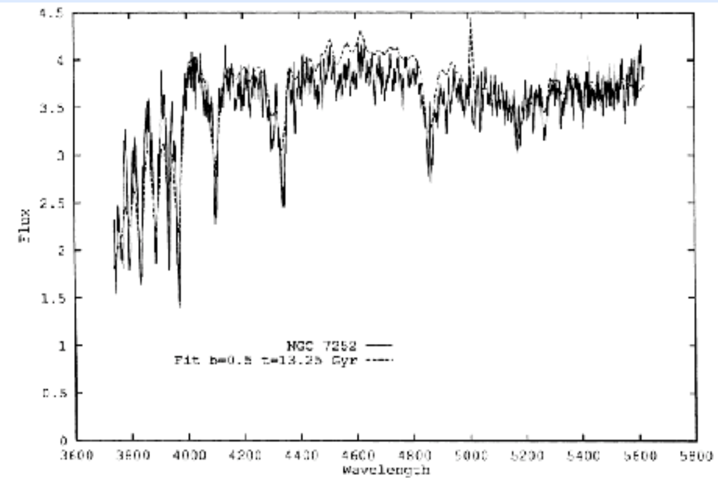
➜ major & minor mergers

4/5 field E+As with WFPC2 imaging show $B/T \leq 0.5$

➜ minor mergers

(Tran et al. 2004)

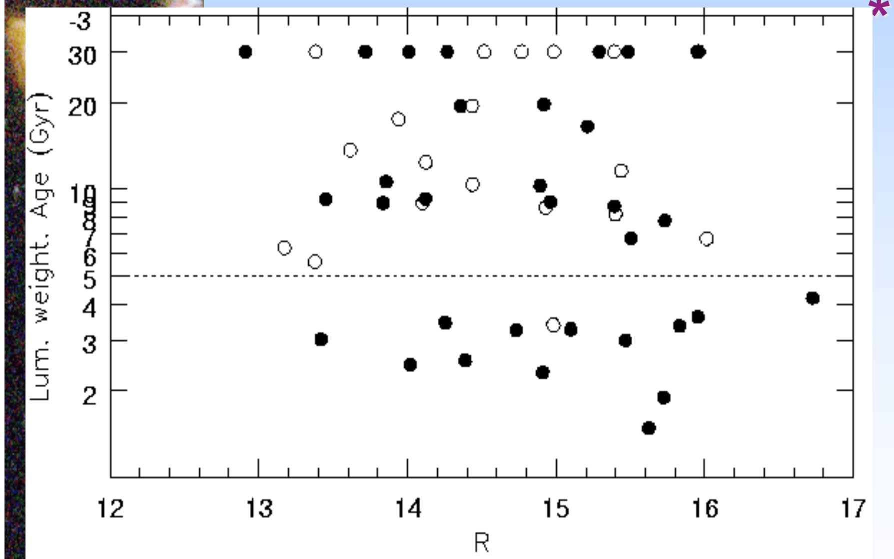
NGC 7252 = field E+A
= major merger
Spectrum : F. Schweizer
(Fritze & Gerhard 1994)

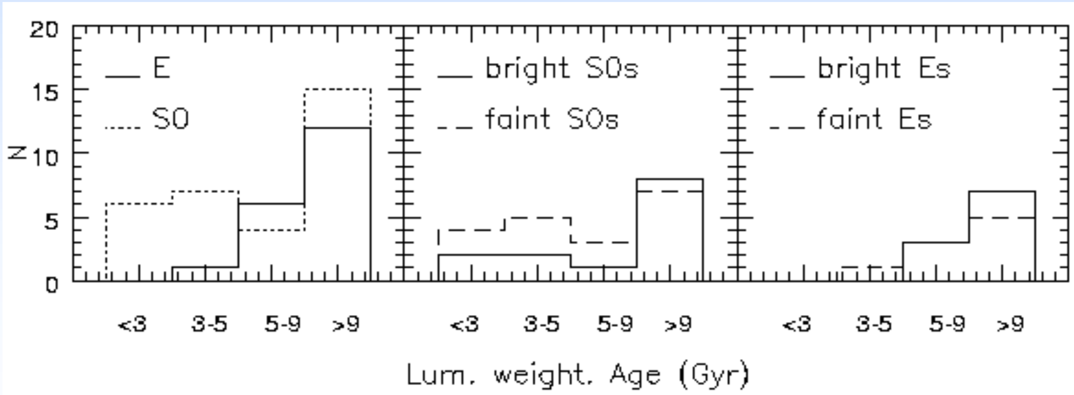


Stellar Population Ages in Cluster S0s

Spectroscopy of 19 Es & 33 S0s in Coma over wide range $-20.5 < M_B < -17.5$ (Poggianti et al. 2001)

* ~ 40% S0s (one of the Es) had significant SF in their central regions during last 5 Gyr
* fraction of S0s with recent SF ↗ with L ↘
* key to series of discrepant results : magnitude limit of sample





also found from optical + NIR photometry in Abell 2218 (z=0.17) (Smail et al. 2001)

Redshift Evolution of the CMR

194 E/S0s in CL1358+62 at z=0.3 (van Dokkum et al. 1998)

scatter* for Es very small, not dependent on R_{cl}

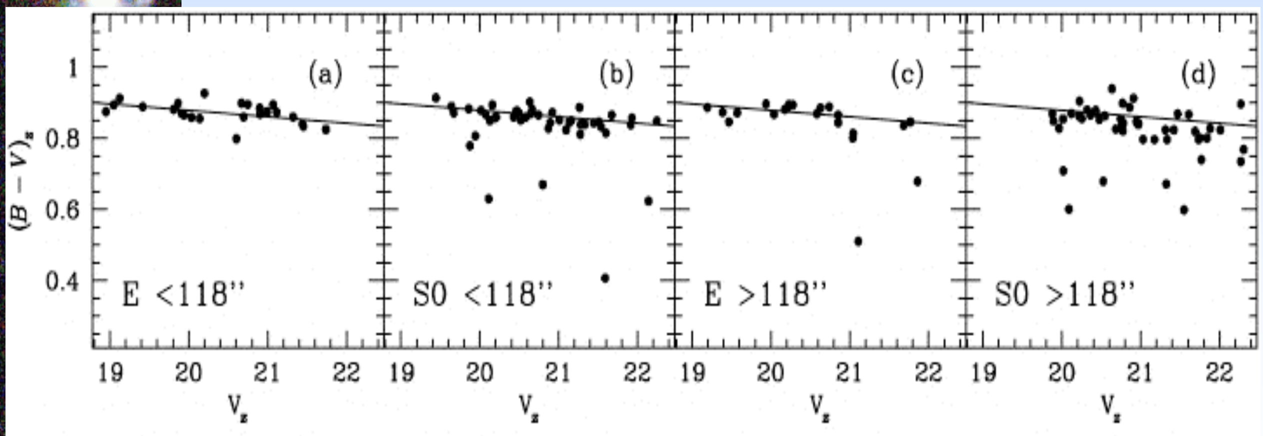
☛ scatter for S0s small at center, larger at larger R_{cl}

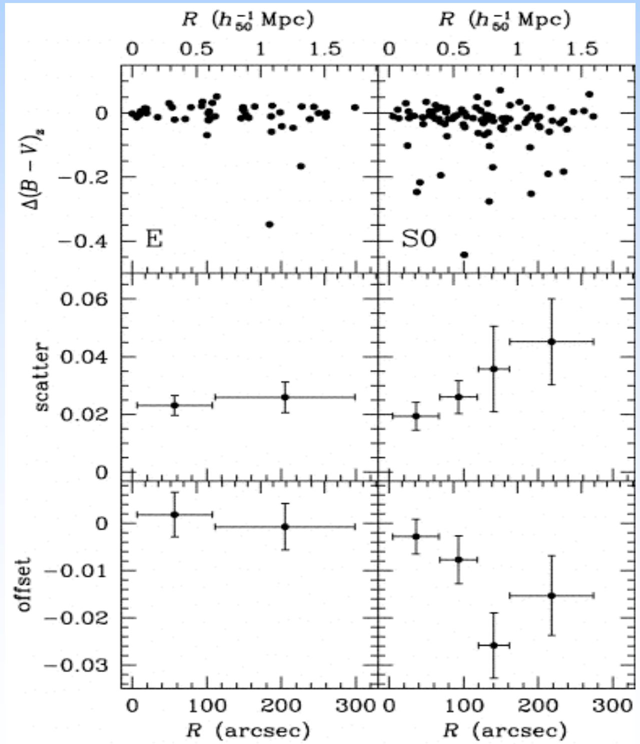
☛ offset of S0s to bluer colors at larger R_{cl}

➜ Es terminate SF well before accretion

➜ S0s stop SF in outer parts of cluster

*scatter <-> age spread





Redshift Evolution of the CMR

Massive Es form before the clusters : ev. in groups
S0s form after cluster virialisation : by transformation

Low luminosity systems : harassment and/or fading

SFR – Galaxy Density Relation

Global <--> local effects

ICM, cluster potential <--> interactions within groups

(Lewis et al. 2002, Gomez et al. 2003, Gerken et al. 2004)

11006 galaxies ($M_b < -19$, $z < 0.1$) from 2dF GRS in 17 clusters

8598 galaxies ($M_r < -20.5$, $z < 0.1$) from SDSS in field, groups, clusters

galaxies out to ~3 R_{vir} in low L_x clusters at z~0.2

$\mu^* := SFR(H\alpha) / L^*$ ↘ with R_{cc} ↗

reaches field galaxy SF level at ~3 R_{vir}

ICM ram pressure not efficient at ~3 R_{vir}

μ^* ↗ with Σ ↘

reaches field galaxy SF level at $\Sigma_{crit} \sim \Sigma\ (3\ R_{vir})$

same for galaxies in rich & poor clusters, groups & field

? what quenches SF in low density environment – group activity?

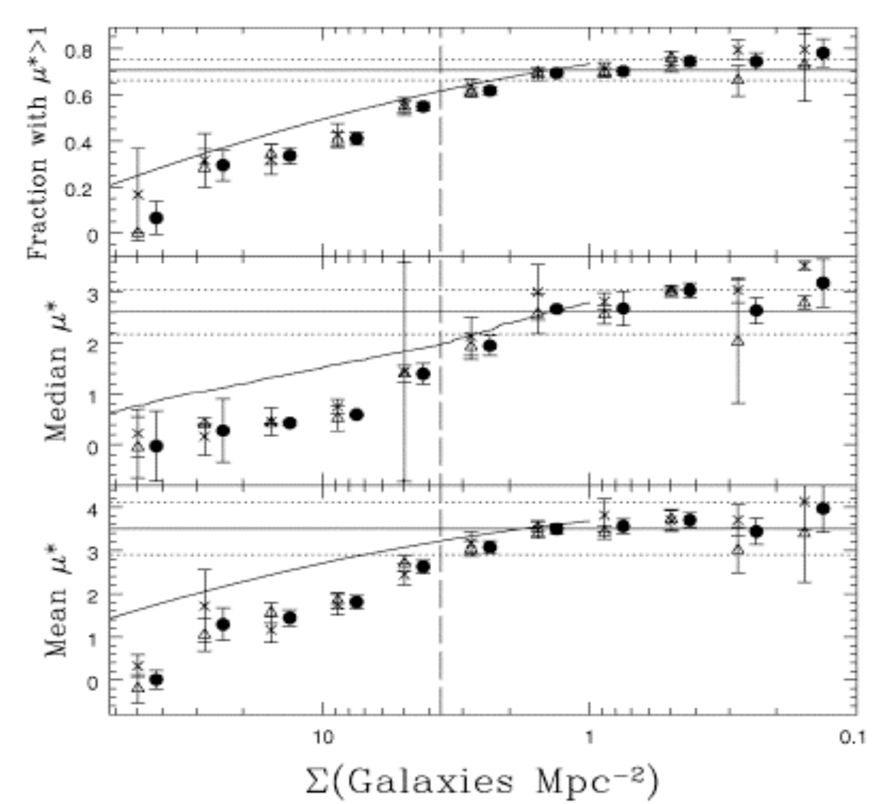
U. Fritze, PostGrad UH 2008

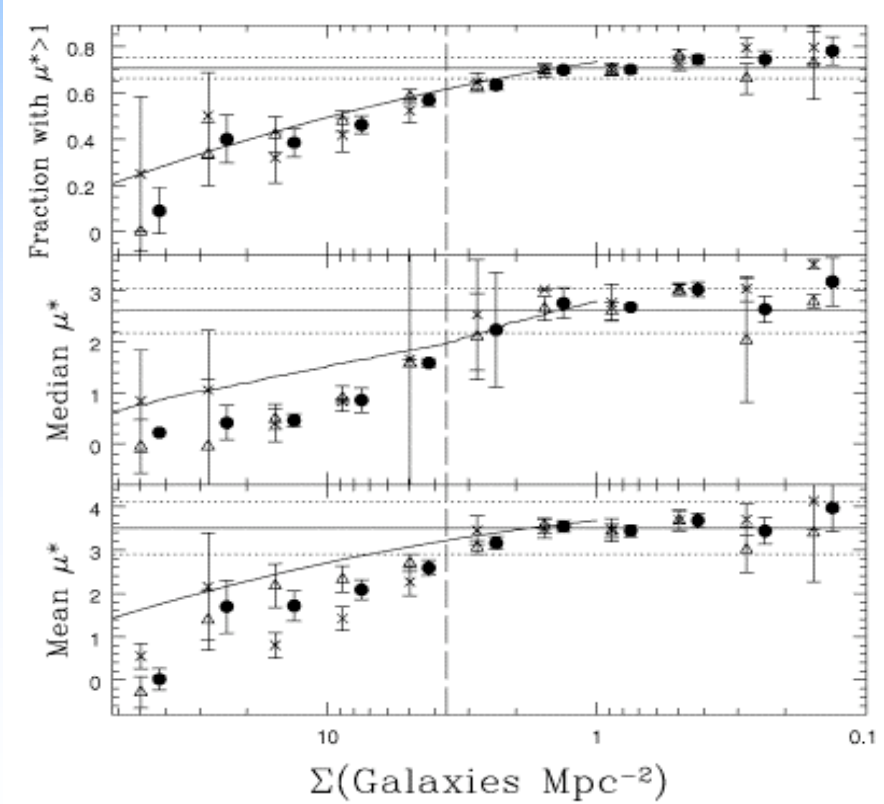
SFR – Galaxy Density Relation

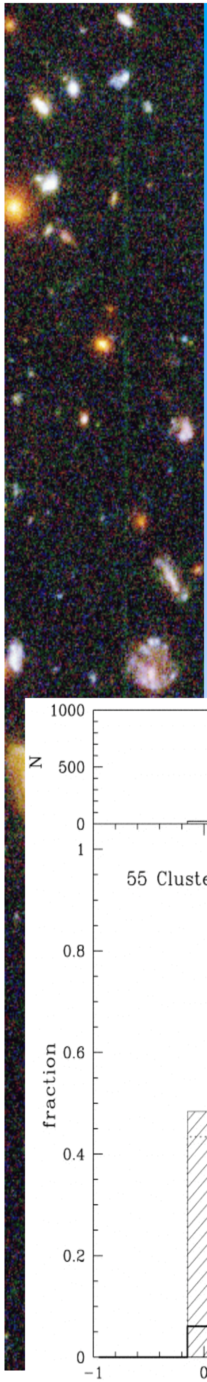
$\mu^* := SFR(H\alpha) / L^*$ ↘ with R_{cc} ↗
reaches field galaxy SF level at ~3 R_{vir}

μ^* ↗ with Σ ↘
reaches field gal. SF level at $\Sigma_{crit} \sim \Sigma(3\ R_{vir})$

same for galaxies in rich & poor clusters, groups & field
(Lewis et al. 2002)







Local Morphology – Density Relation

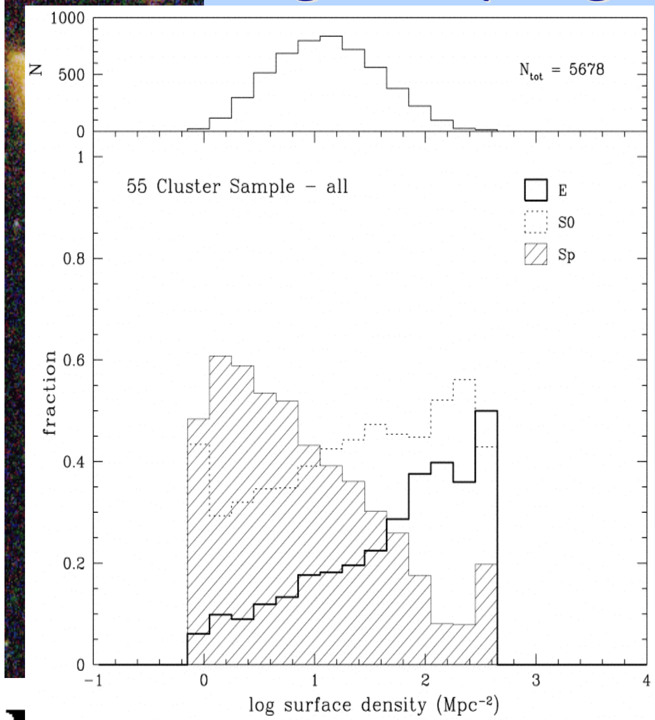
~6000 galaxies in 55 low-redshift rich clusters (Dressler 1980)

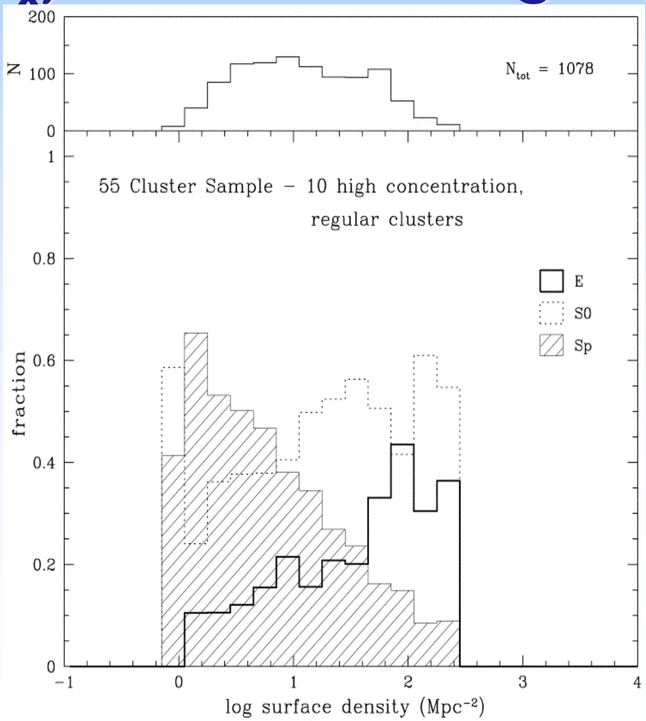
spiral, S0, E fractions correlate with local galaxy surface density

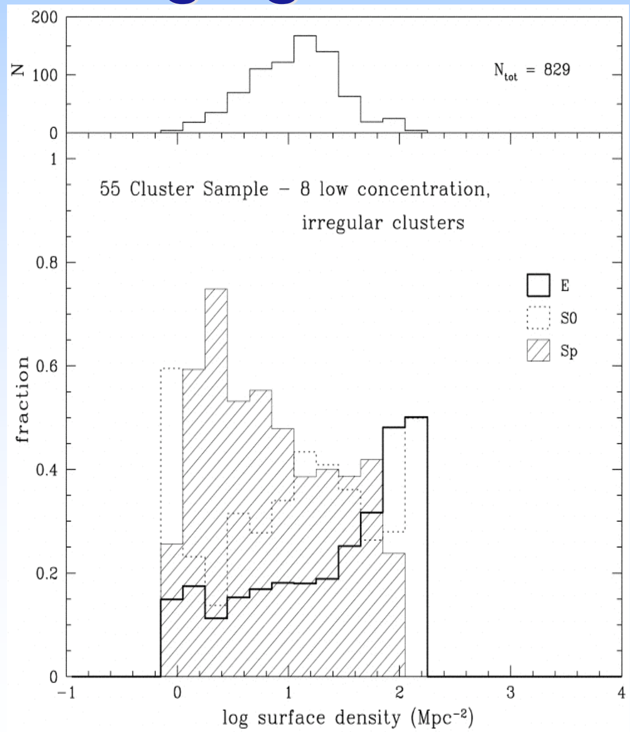
T–Σ relation for regular & irregular clusters

irregular (=low L_X) clusters : no radial segregation of gal. population

regular (=high L_X) clusters : strong radial segregation







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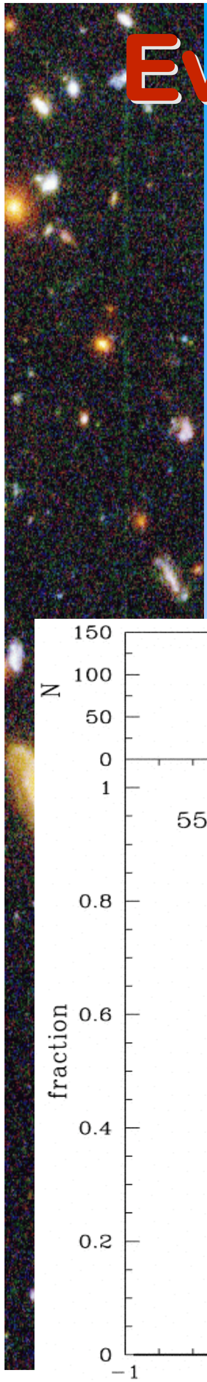


Evolution in Morphology – Density Relation

10 intermediate-redshift (z~0.5) clusters (Dressler et al. 1997)

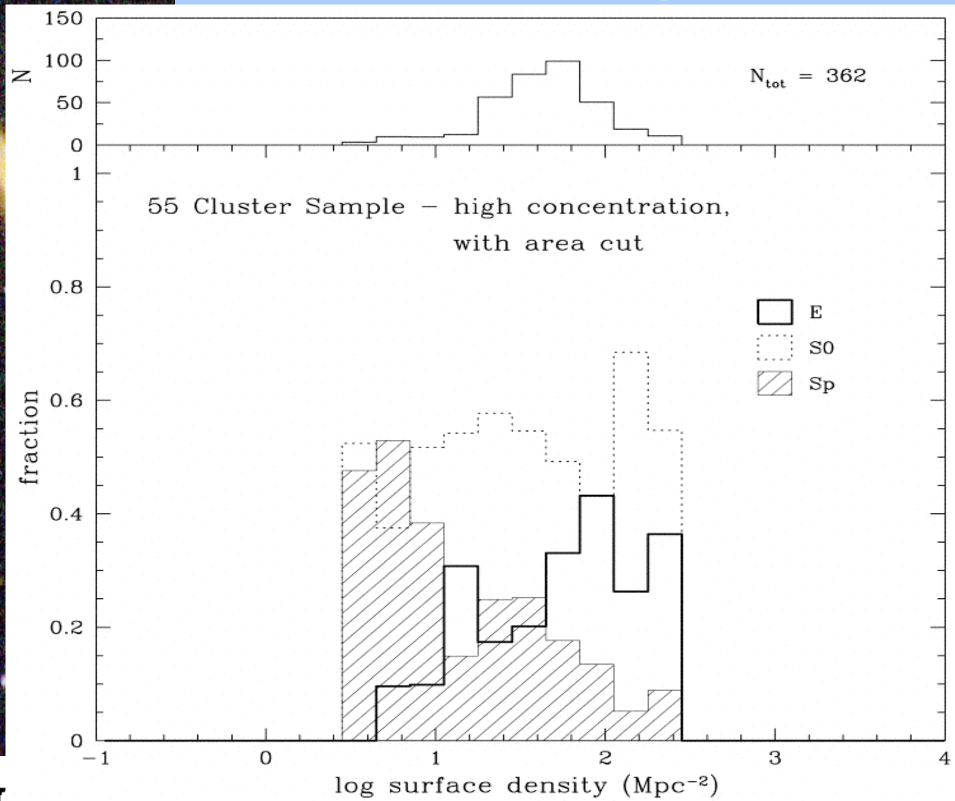
T−Σ relation strong for regular,

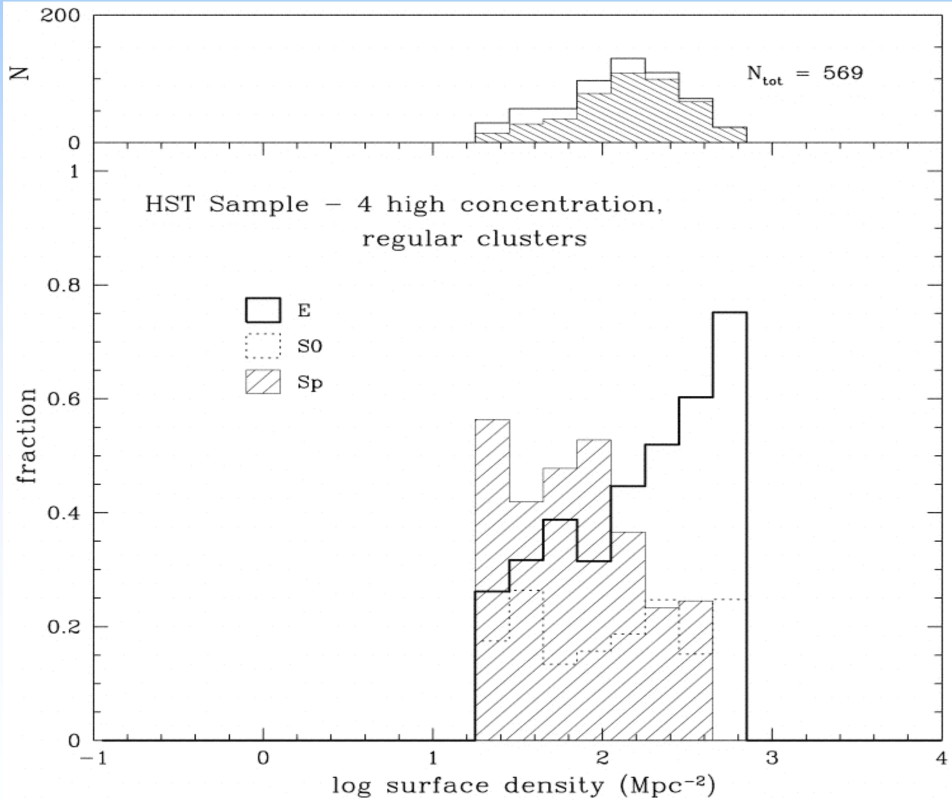
nearly absent for irregular clusters

in all clusters $f_E \sim f_E(\text{local})$, $f_{S0} \leq (1/2-1/3) f_{S0}(\text{local})$,

$f_{Sp} > f_{Sp}(\text{local})$

z~0 high concentration clusters z~0.5





Wrap up: Galaxy Populations in Clusters

Cosmological structure formation & evolution intimately linked with galaxy formation & evolution.

Massive Es form before the clusters, spirals are transformed into S0s & dwarf galaxies as they are accreted by clusters.

A variety of transformation scenarios are at work: harassment, ram pressure, merging within infalling groups. All affect the morphology as well as the spectral properties, timescales may be different.

Recent surprise: transformations already occur at 3 R_{vir} from the cluster centre, local galaxy density effects must be important -- and are also seen in groups and the field.

We still lack a complete census of the relative role of the various transformation channels, timescales, transition stages and their dependence on galaxy/cluster properties.