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ellipticals from $z = 0$ **to** $z = 0.83$ **The evolution and merging history of cluster**

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M. Franx, Van Dokkum, D. Kelson, D. G. Fabricant and G. D. Illingworth

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The evolution and merging history of cluster
ellinticals from $z = 0$ to $z = 0.83$ Figure 1.5 and merging history of clust
ellipticals from $z = 0$ to $z = 0.83$

ellipticals from $z = 0$ to $z = 0.83$
By M. Franx¹, P. G. van Dokkum¹, D. Kelson², D. G. Fabricant³ pticals from $z = 0$ to $z =$, p. G. van Dokkum¹, D. Kelson², I van Dokkum¹, D. Kelson²
And G. D. Illingworth⁴ ¹*Leiden Observatory, PO Box 9513, 2300 RA Leiden, The Netherlands*

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The evolution of galaxies is likely to be complex, involving mergers, starbursts, and
other dramatic changes in morphology and luminosity. The measurement of the evo-The evolution of galaxies is likely to be complex, involving mergers, starbursts, and
other dramatic changes in morphology and luminosity. The measurement of the evo-
lution of the mass function of galaxies is therefore es The evolution of galaxies is likely to be complex, involving mergers, starbursts, and
other dramatic changes in morphology and luminosity. The measurement of the evo-
lution of the mass function of galaxies is therefore es other dramatic changes in morphology and luminosity. The measurement of the evolution of the mass-to-light ratios of galaxies as a function of redshift. The Fundamental Plane relation is uniquely suited to measure the evol lution of the mass function of galaxies is therefore essential. This can be accomplished
by measuring the evolution of the mass-to-light ratios of galaxies as a function of
redshift. The Fundamental Plane relation is uniqu by measuring the evolution of the mass-to-light ratios of galaxies as a function of redshift. The Fundamental Plane relation is uniquely suited to measure the evolution of the mass-to-light ratio of early-type galaxies. We redshift. The Fundamental Plane relation is uniquely suited to measure the evolution
of the mass-to-light ratio of early-type galaxies. We show that the evolution depends
sensitively on cosmology and star-formation histor of the mass-to-light ratio of early-type galaxies. We show that the evolution depends
sensitively on cosmology and star-formation history. We present results on the evo-
lution of the mass-to-light ratio from the Fundamen sensitively on cosmology and star-formation history. We present results on the evolution of the mass-to-light ratio from the Fundamental Plane out to $z = 0.83$. The early-type galaxies in clusters follow a well-defined re lution of the mass-to-light ratio from the Fundamental Plane out to $z = 0.83$. The early-type galaxies in clusters follow a well-defined relation out the highest redshift. The mass-to-light evolution is very slow, and imp early-type galax
The mass-to-ligh
open universe.
One of the m net mass-to-light evolution is very slow, and implies a high mean stellar age in an
en universe.
One of the main uncertainties in the interpretation is morphological evolution.
the voungest early types at low redshift appe

One of the main uncertainties in the interpretation is morphological evolution.
If the youngest early types at low redshift appear as other morphological types at
high redshift, then the study of early-type galaxies at hig One of the main uncertainties in the interpretation is morphological evolution.
If the youngest early types at low redshift appear as other morphological types at
high redshift, then the study of early-type galaxies at hig If the youngest early types at low redshift appear as other morphological types at
high redshift, then the study of early-type galaxies at high redshifts will produce
biased results. We discuss the effects of this 'progeni high redshift, then the study of early-type galaxies at high redshifts will produce
biased results. We discuss the effects of this 'progenitor bias'. We show evidence for
significant morphological evolution for all early t biased results. We discuss the effects of this 'progenitor bias'. We show evidence for significant morphological evolution for all early types (elliptical and S0 galaxies). We find a high fraction of mergers in MS 1054-03,

significant morphological evolution for all early types (elliptical and S0 galaxies).
We find a high fraction of mergers in MS 1054-03, comparable with the fraction of ellipticals. Furthermore, the total fraction of early We find a high fraction of mergers in MS 1054-03, comparable with the fraction of ellipticals. Furthermore, the total fraction of early types in rich clusters decreases from $z = 0$ to $z = 0.83$. These results suggest that ellipticals. Furthermore, the total fraction of early types in rich clusters decreases from $z = 0$ to $z = 0.83$. These results suggest that the set of early types is not a closed set, but evolving. The effects on the deri from $z = 0$ to $z = 0.83$. These results suggest the closed set, but evolving. The effects on the derive ratio is relatively small, due to the small scatter.
The next step will be to extend these studies to be seed set, but evolving. The effects on the derived evolution of the mass-to-light
tio is relatively small, due to the small scatter.
The next step will be to extend these studies to high redshift clusters, and to the
ld

ratio is relatively small, due to the small scatter.
The next step will be to extend these studies to high redshift clusters, and to the field. This work can provide very strong constraints on the mass evolution of galaxie n provide very strong constraints on the mass evo
Keywords: galaxies; clusters; galaxy, formation of

1. Introduction

1. Introduction
One of the important questions in the field of galaxy formation and evolution is that
of the mass evolution of galaxies. Did galaxies form very quickly at high redshift? One of the important questions in the field of galaxy formation and evolution is that
of the mass evolution of galaxies. Did galaxies form very quickly, at high redshift?
Or did galaxies form by the gradual accumulation of One of the important questions in the field of galaxy formation and evolution is that
of the mass evolution of galaxies. Did galaxies form very quickly, at high redshift?
Or did galaxies form by the gradual accumulation of of the mass evolution of galaxies. Did galaxies form very quickly, at high redshift?
Or did galaxies form by the gradual accumulation of smaller building blocks? The
earliest models of galaxy formation assumed that galaxie

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2110 M . Franx and others
when it was found that galaxies have large dark halos, the formation time-scale
increased manyfold. Subsequent theories of galaxy formation allowed for galaxies to when it was found that galaxies have large dark halos, the formation time-scale
increased manyfold. Subsequent theories of galaxy formation allowed for galaxies to
form slowly and at a late moment. In most of these theorie increased manyfold. Subsequent theories of galaxy formation allowed for galaxies to form slowly and at a late moment. In most of these theories galaxies are assembled increased manyfold. Subsequent theories of galaxy formation allowed for galaxies to
form slowly and at a late moment. In most of these theories galaxies are assembled
by the merging of smaller building blocks. Such mergin form slowly and at a late moment. In most of these theories galaxies are assembled
by the merging of smaller building blocks. Such merging has been observed in the
nearby Universe, but the frequency at which it occurs is r 1977). here, but the frequency at which it occurs is relatively low (e.g. Toomre 1977).
Hence, one of the major challenges in current-day astronomy is to measure the mass

1977).
Hence, one of the major challenges in current-day astronomy is to measure the mass
evolution of galaxies, and galaxy clusters; as this will provide an immediate test of
these ideas. Unfortunately, the total masses o Hence, one of the major challenges in current-day astronomy is to measure the mass
evolution of galaxies, and galaxy clusters; as this will provide an immediate test of
these ideas. Unfortunately, the total masses of galax these ideas. Unfortunately, the total masses of galaxies are notoriously difficult to measure. Fortunately, we can use other characteristics to establish mass evolution, these ideas. Unfortunately, the total masses of galaxies are notoriously difficult to measure. Fortunately, we can use other characteristics to establish mass evolution, and these are primarily the circular velocities of g measure. Fortunately, we can use other characteristics to establish mass evolution,
and these are primarily the circular velocities of gas in spiral galaxies, and the velocity
dispersions of stars in early-type galaxies. T and these are primarily the circular velocities of gas in spiral galaxies, and the velocity
dispersions of stars in early-type galaxies. These kinematic indicators are measured
at the scale of the luminous parts of galaxie dispersions of stars in early-type galaxies. These kinematic indicators are measured
at the scale of the luminous parts of galaxies (very large gas discs in spiral galaxies
are generally rare). Hence they cannot provide us at the scale of the luminous parts of galaxies (very large gas discs in spiral galaxies
are generally rare). Hence they cannot provide us directly with information about
the total masses. Fortunately, they are most likely are generally rare). Hence they cannot provide us directly with information about
the total masses. Fortunately, they are most likely related to the halo properties of
galaxies, and merging and accumulation of galaxies is the total masses. Fortunately, they are most likely related to the halo properties of galaxies, and merging and accumulation of galaxies is expected to lead to evolution of these characteristic velocities. laxies, and merging and accumulation of galaxies is expected to lead to evolution
these characteristic velocities.
Another helpful factor is the existence of the Tully–Fisher relation, and the Fun-
mental Plane. The Tully–

of these characteristic velocities.
Another helpful factor is the existence of the Tully-Fisher relation, and the Fun-
damental Plane. The Tully-Fisher relation is a relation between the luminosity, and
rotational velocity damental Plane. The Tully–Fisher relation is a relation between the luminosity, and rotational velocity, and the Fundamental Plane is a relation between surface brightdamental Plane. The Tully–Fisher relation is a relation between the luminosity, and rotational velocity, and the Fundamental Plane is a relation between surface brightness, effective scale length, and velocity dispersion. rotational velocity, and the Fundamental Plane is a relation between surface brightness, effective scale length, and velocity dispersion. Their relatively small scatter in the nearby Universe implies that we do not have to in the nearby Universe implies that we do not have to measure the characteristic velocities for all galaxies, but that we can obtain good insight into galaxy evolution in the nearby Universe implies that we do not have to measure the characteristic velocities for all galaxies, but that we can obtain good insight into galaxy evolution by measuring the evolution of these relations, combine velocities for all galaxies
by measuring the evo
luminosity function.
In practice, the me Iuminosity function.
In practice, the measurement of the kinematic indicators out to high redshift is

hard. In order to obtain reliable rotation curves of spiral galaxies, galaxies need to In practice, the measurement of the kinematic indicators out to high redshift is hard. In order to obtain reliable rotation curves of spiral galaxies, galaxies need to be resolved, and this is hard (but not impossible) at hard. In order to obtain reliable rotation curves of spiral galaxies, galaxies need to
be resolved, and this is hard (but not impossible) at higher redshift. Early results
by Vogt *et al.* (1996) on the Tully-Fisher relati be resolved, and this is hard (but not impossible) at higher redshift. Early results
by Vogt *et al.* (1996) on the Tully-Fisher relation for spiral galaxies have shown
that it is possible to achieve this on small subsampl by Vogt *et al.* (1996) on the Tully–Fisher relation for spiral galaxies have shown
that it is possible to achieve this on small subsamples of galaxies. Here we focus
on the Fundamental Plane of early-type galaxies. It is that it is possible to achieve this on small subsamples of galaxies. Here we focus
on the Fundamental Plane of early-type galaxies. It is easier to work on early-type
galaxies, as the galaxies do not need to be resolved t on the Fundamental Plane of early-type galaxies. It is easier to work on early-type galaxies, as the galaxies do not need to be resolved to measure their central velocity dispersions (e.g. Franx 1993*a*, *b*). Furthermore galaxies, as the
dispersions (e.g
is very small.

2. Passive evolution, or evolution of the M/L ratio from the
Eundamental Plane or evolution of the M/\tilde{E}

Fundamental Plane
|
| We have started a programme to measure the evolution of the Fundamental Plane relation with redshift. Early results can be found in Franx $(1993a, b, 1995)$. The Fun-We have started a programme to measure the evolution of the Fundamental Plane relation with redshift. Early results can be found in Franx (1993*a*, *b*, 1995). The Fundamental Plane is a relation between effective radius relation with redshift. Early results can be found in Fr.
damental Plane is a relation between effective radius I_e , and central velocity dispersion σ of the form

$$
r_{\rm e} \propto \sigma^{1.24} I_{\rm e}^{-0.82}
$$

(see, for example, Djorgovski & Davis (1987), Dressler *et al.* (1987), Jørgensen *et*
el. (1996), and references therein). Its scatter is low, at 17% in r. The implication (see, for example, Djorgovski & Davis (1987), Dressler *et al.* (1987), Jørgensen *et al.* (1996), and references therein). Its scatter is low, at 17% in r_e . The implication of the Fundamental Plane is that the M/L rat (see, for example, Djorgovski & Davis (1987), Dressler *et al.* (1987), Jørgensen *et al.* (1996), and references therein). Its scatter is low, at 17% in r_e . The implication of the Fundamental Plane is that the M/L rat of the Fundamental Plane is that the M/L ratios of galaxies are well behaved (e.g. *Phil. Trans. R. Soc. Lond.* A (2000)

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Evolution of early-type galaxies 2111
Faber *et al.* 1987). Under the assumption that galaxies are a homologous family, the
implied M/L scaling is Faber *et al.* 1987). Under
implied M/L scaling is implied M/L scaling is $M/L \propto r_e^{0.22} \sigma^{0.49} \propto M^{0.24}$.
Such scaling is sufficient for the existence of the Fundamental Plane, and vice versa.

$$
M/L \propto r_e^{0.22} \sigma^{0.49} \propto M^{0.24}
$$
.

 $T_{\rm H}$ \sim $T_{\rm e}$ or \sim $T_{\rm H}$.
Such scaling is sufficient for the existence of the Fundamental Plane, and vice versa.
The cause of the variation in M/L with mass is not well understood, but it is thought
to be Such scaling is sufficient for the existence of the Fundamental Plane, and vice ve
The cause of the variation in M/L with mass is not well understood, but it is thou
to be mainly due to variations in metallicity (see als

to be mainly due to variations in metallicity (see also Renzini $\&$ Ciotti 1993).
The low scatter of the Fundamenal Plane makes it very suitable for the study of evolution of the M/L ratio at higher redshift. The evolution of the M/L ratio at \blacktriangleright a given redshift can be derived from 5-10 galaxies, and the evolutionary signal is evolution of the M/L ratio at higher redshift. The evolution of the M/L ratio at a given redshift can be derived from 5–10 galaxies, and the evolutionary signal is much stronger than the intrinsic scatter. Below we expl a given redshift can be derived from
uch stronger than the intrinsic sc
of M/L as a function of redshift. \bigcup_{a} of M/L as a function of redshift.
(*a*) *Models for the evolution of the* M/L *ratio*

(a) Models for the evolution of the M/L ratio
The luminosity of a coeval stellar population is expected to evolve with time.
nslev (1980) showed that the luminosity evolves like The luminosity of a coeval stellar population is experimently (1980) showed that the luminosity evolves like

$$
L \propto 1/(t - t_{\text{form}})^{\kappa},
$$

where $\kappa = 1.3 - 0.3x$, and x is the slope of the initial mass function (IMF). The Miller-Scalo IMF implies $x = 0.25$, and $\kappa \approx 1.2$. Recent studies indicate that the where $\kappa = 1.3 - 0.3x$, and x is the slope of the initial mass function (IMF). The Miller-Scalo IMF implies $x = 0.25$, and $\kappa \approx 1.2$. Recent studies indicate that the value of κ depends on passband and metallicity (Miller-Scalo IMF implies $x = 0.25$, and $\kappa \approx$
value of κ depends on passband and metallicity
authors find $0.6 < \kappa < 0.95$ for the V band.
The observer measures redshift, and not i lue of κ depends on passband and metallicity (Buzzoni 1989; Worthey 1994). These
thors find $0.6 < \kappa < 0.95$ for the V band.
The observer measures redshift, and not time. In redshift space, the evolution
pends on the f

authors find $0.6 < \kappa < 0.95$ for the V band.
The observer measures redshift, and not time. In redshift space, the evolution depends on the formation redshift of the stellar population z_{form} , and cosmology. The observer measures redshift, and not time. In redshift space
depends on the formation redshift of the stellar population z_{form} ,
For very low values of q_0 , the evolution can be approximated by in M_j and the solid proposition z_{form} ,
s of q_0 , the evolution can be approximated by
 $\ln M/L(z) = \ln M/L(0) - \kappa (1 + q_0 + 1/z_{\text{form}})z$

$$
\ln M/L(z) = \ln M/L(0) - \kappa (1 + q_0 + 1/z_{\text{form}})z
$$

(Franx 1995). Hence the logarithm of the M/L ratio is expected to decrease lin-(Franx 1995). Hence the logarithm of the M/L ratio is expected to decrease linearly with redshift, and the coefficient depends on κ (IMF), q_0 , and z_{form} . The rate at which the M/L ratio evolves is a function (Franx 1995). Hence the logarithm of the M/L ratio is expected to decrease linearly with redshift, and the coefficient depends on κ (IMF), q_0 , and z_{form} . The rate at which the M/L ratio evolves is a function early with redshift, and the coefficient depends on κ (IMF), q_0 , and z_{form} . The rate at which the M/L ratio evolves is a function of several unknown variables, and a direct interpretation of the observed decrease straightforward. direct interpretation of the observed decrease of the M/L ratio may not be very straightforward.
Figure 1*a* shows the expected evolution of the M/L ratio if all galaxies have formed

straightforward.
Figure 1a shows the expected evolution of the M/L ratio if all galaxies have formed
at the same redshift. As can be seen, the evolution depends strongly on the formation
redshift. It is unlikely that gal Figure 1*a* shows the expected evolution of the M/L ratio if all galaxies have formed at the same redshift. As can be seen, the evolution depends strongly on the formation redshift. It is unlikely that galaxies formed in at the same redshift. As can be seen, the evolution depends strongly on the formation redshift. It is unlikely that galaxies formed in such a simple way. For figure 1b we explored models in which galaxies form at a range redshift. It is unlikely that galaxies formed in such a simple way. For figure 1b we
explored models in which galaxies form at a range of redshifts. As a result, scatter
is introduced in the M/L ratio, which increases wi explored models in which galaxies form at a range of redshifts. As a re
is introduced in the M/L ratio, which increases with look-back time. The fact that the relative age difference increases with look-back time. (*b*) *Complex evolution*

 (b) Complex evolution
Even the last model is probably an over-simplification of the formation of early Even the last model is probably an over-simplification of the formation of early types. There is no good reason to assume that all stars in an early-type galaxy formed in a very short burst. A single galaxy may have had a Even the last model is probably an over-simplification of the formation of early types. There is no good reason to assume that all stars in an early-type galaxy formed in a very short burst. A single galaxy may have had a types. There is no good reason to assume that all stars in an early-type galaxy formed
in a very short burst. A single galaxy may have had a complex formation history,
with star formation extending over a long time. The e in a very short burst. A single galaxy may have had a complex formation history, with star formation extending over a long time. The evolution of the M/L ratio will be more complex if such age differences are taken into with star formation extending over a long time. The evolution of the M/L ratio will be more complex if such age differences are taken into account. It is likely that the morphologies of galaxies change as well, for examp will be more complex if such age differences are taken into account. It is likely that
the morphologies of galaxies change as well, for example from spiral, to merger, to
post-starburst galaxy, to early type. This has impo *Phil. Trans. R. Soc. Lond.* A (2000)

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Figure 1. The evolution of galaxies with a simple star-formation history. (a) The luminosity evolution for galaxies with coeval populations. Galaxies which formed recently evolve faster. (b) The evolution of the mean M/L Figure 1. The evolution of galaxies with a simple star-formation history. (a) The luminosity
evolution for galaxies with coeval populations. Galaxies which formed recently evolve faster. (b)
The evolution of the mean M/L The evolution of the mean M/L ratio for a sample of early types which formed at a random time
between $z = 1$ and $z = 3$. The shaded area indicates the scatter in the M/L ratio. The scatter in $\overline{\sigma}$ the relation increases with redshift, as the relative age difference increases with look-back time.

of early types at higher redshifts will be a special subset of the set of early types at of early types at higher redshifts will be a special subset of the set of early types at $z = 0$. If we selecting types at higher and higher redshift, we may be selecting a subsample that is more and more biased towards th of early types at higher redshifts will be a special subset of the set of early types at $z = 0$. If we select early types at higher and higher redshift, we may be selecting a subsample that is more and more biased towards subsample that is more and more biased towards the oldest early types. In short, we may be selecting the oldest galaxies, and find that they are old. The effects of this evolution complicates the interpretation of the resu may be selecting the oldest galaxies, and find that they are old. The effects of this

3. The Fundamental Plane to $z = 0.83$

3. The Fundamental Plane to $z = 0.83$
With modern telescopes and efficient instrumentation, it is possible to measure the
Fundamental Plane out to a redshift of 1. After our first work on Abell 665 (Franx With modern telescopes and efficient instrumentation, it is possible to measure the
Fundamental Plane out to a redshift of 1. After our first work on Abell 665 (Franx
1993a, b. Jorgensen et al. 1999) and CL0024+16 (van Do With modern telescopes and efficient instrumentation, it is possible to measure the
Fundamental Plane out to a redshift of 1. After our first work on Abell 665 (Franx
1993*a*, *b*; Jorgensen *et al.* 1999) and CL0024+16 (v Fundamental Plane out to a redshift of 1. After our first work on Abell 665 (Franx 1993*a*, *b*; Jorgensen *et al.* 1999) and CL0024+16 (van Dokkum & Franx 1996) with the Multiple Mirror Telescope, we started to use the K 1993a, b; Jorgensen *et al.* 1999) and CL0024+16 (van Dokkum & Franx 1996) with
the Multiple Mirror Telescope, we started to use the Keck telescopes to measure
the Fundamental Plane in three clusters: MS 1358+62 at $z = 0.$ the Multiple Mirror Telescope, we started to use the Keck telescopes to measure
the Fundamental Plane in three clusters: MS $1358+62$ at $z = 0.33$, MS $2053-05$ at
 $z = 0.58$, and MS $1054-03$ at $z = 0.83$ (see van Dokkum the Fundamental Plane in three clusters: MS 1358+62 at $z = 0.33$, MS 2053-05 at $z = 0.58$, and MS 1054-03 at $z = 0.83$ (see van Dokkum *et al.* (1998), Kelson *et al.* (2000), and references therein). Figure 2 shows the r $z = 0.58$, and MS 1054-03 at $z = 0.83$ (see van Dokkum *et al.* (1998), Kelson *et al.* (2000), and references therein). Figure 2 shows the resulting Fundamental Planes from $z = 0$ to $z = 0.83$. The figure demonstrates ho al. (2000), and reference
from $z = 0$ to $z = 0.83$.
each redshift interval.
The scatter in the rel om $z = 0$ to $z = 0.83$. The figure demonstrates how well the relation is defined at ch redshift interval.
The scatter in the relation remains low. We find a typical scatter between 15 and $\%$ quite comparable with the sc

each redshift interval.
The scatter in the relation remains low. We find a typical scatter between 15 and
20%, quite comparable with the scatter in nearby rich clusters. The results obtained
by other groups at $z < 0.6$ ag The scatter in the relation remains low. We find a typical scatter between 15 and 20%, quite comparable with the scatter in nearby rich clusters. The results obtained by other groups at $z < 0.6$ agree well with these resu by other groups at $z < 0.6$ agree well with these results (e.g. Bender *et al.* 1998).
4. Evolution of the M/L_B ratio to $z = 0.83$

4. Evolution of the M/L_B ratio to $z = 0.83$
We can derive the evolution of the M/L_B ratio from the offsets of the Fundamental
Plane relation as a function of redshift. A necessary assumption is that early-type We can derive the evolution of the M/L_B ratio from the offsets of the Fundamental
Plane relation as a function of redshift. A necessary assumption is that early-type
galaxies in clusters do not have significant morpholog We can derive the evolution of the M/L_B ratio from the offsets of the Fundamental
Plane relation as a function of redshift. A necessary assumption is that early-type
galaxies in clusters do not have significant morpholog Plane relation as a function of redshift. A necessary assumption is that early-type galaxies in clusters do not have significant morphological evolution between $z = 0$ and $z = 0.83$. We return to this later.

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Figure 2. The evolution of the Fundamental Plane from $z = 0$ to $z = 0.83$. The panels show the Fundamental Planes for the programme clusters. The drawn line is the relation for Coma. The cluster galaxies follow a relation Figure 2. The evolution of the Fundamental Plane from $z = 0$ to $z = 0.83$. The panels show the
Fundamental Planes for the programme clusters. The drawn line is the relation for Coma. The
cluster galaxies follow a relation Fundamental Planes for the programme clusters. The drawn line is the relat
cluster galaxies follow a relation very similar to the relation for the Coma g
difference is the offset, which is mostly due to surface brightness

Figure 3. The evolution of the mean M/L_B ratio, after correction for surface brightness dimming.
The M/L_B ratio decreases slowly with redshift. The drawn lines indicate stellar population
models with formation redshifts Figure 3. The evolution of the mean M/L_B ratio, after correction for surface brightness dimming.
The M/L_B ratio decreases slowly with redshift. The drawn lines indicate stellar population
models with formation redshifts The M/L_B ratio decreases slowly with redshift. The drawn lines indicate stellar population
models with formation redshifts of 2. The shaded area indicates models with a formation redshift
of ∞ . The three panels show models with formation redshifts of 2. The shaded area indicates models with a formation redshift
of ∞ . The three panels show the data and models for three different cosmologies. The models
can provide good fits for op of ∞ . The three panels show the data and models for three different cosmologies. The mode
can provide good fits for open universes, (a) and (c) , but no good fit for a closed universe, $(b$
In the latter case, the IMF

The result is shown in figure 3. The clusters galaxies show a gradual change in The result is shown in figure 3. The clusters galaxies show a gradual change in M/L_B ratio, which can be approximated with a simple curve. The results imply that the star-formation history of early-type galaxies in clust The result is shown in figure 3. The clusters galaxies show a gradual change in M/L_B ratio, which can be approximated with a simple curve. The results imply that the star-formation history of early-type galaxies in clust *Phil. Trans. R. Soc. Lond.* A (2000)

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with the tightness of the Fundamental Plane and colour-magnitude relation at low redshift.

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The evolution of the M/L_B ratio is very slow. It can be well fitted with a model
in which galaxies form at high redshift ($z_{\text{form}} = 2.8$), if $\Omega = 0.3$. It is very difficult
to obtain a good fit for high Ω m The evolution of the M/L_B ratio is very slow. It can be well fitted with a model
in which galaxies form at high redshift ($z_{\text{form}} = 2.8$), if $\Omega = 0.3$. It is very difficult
to obtain a good fit for high Ω models (van The evolution of the M/L_B ratio is very slow. It can be well fitted with a model in which galaxies form at high redshift ($z_{\text{form}} = 2.8$),
to obtain a good fit for high Ω models (van Dokkum
IMF needs to be significantly steeper than Salpeter.
The shape of the Fundamental Plane at high redshift to obtain a good fit for high Ω models (van Dokkum *et al.* 1998). In this case, the IMF needs to be significantly steeper than Salpeter.
The shape of the Fundamental Plane at high redshift is surprisingly similar to t

IMF needs to be significantly steeper than Salpeter.
The shape of the Fundamental Plane at high redshift is surprisingly similar to the
Fundamental Plane at zero redshift. We analysed a sample of 31 early-type galaxies
in The shape of the Fundamental Plane at high redshift is surprisingly similar to the Fundamental Plane at zero redshift. We analysed a sample of 31 early-type galaxies in MS 1358+62 (Kelson *et al.* 2000). This full sample i Fundamental Plane at zero redshift. We analysed a sample of 31 early-type galaxies
in MS $1358+62$ (Kelson *et al.* 2000). This full sample is shown in the panel of figure 2.
The slope of the relation for the early-type g in MS 1358+62 (Kelson *et al.* 2000). This full sample is shown in the panel of figure 2.
The slope of the relation for the early-type galaxies is consistent with the slope at
zero redshift. Accurate morphologies are esse The slope of the relation for the early-type galaxies is consistent with the slope at
zero redshift. Accurate morphologies are essential for this work, as the inclusion
of early type spirals changes the relation drasticall zero redshift. Accurate morphologies are essential for this work, as the inclusion
of early type spirals changes the relation drastically. It is therefore necessary to
obtain imaging with the Hubble Space Telescope (HST) of early type spirals changes the relation drastically. It is the obtain imaging with the Hubble Space Telescope (HST) for this are currently working on large cluster samples out to $z = 0.83$. are currently working on large cluster samples out to $z = 0.83$.
5. Morphological evolution of cluster galaxies

5. Morphological evolution of cluster galaxies
The results of the previous sections have indicated that the evolution of early-type
galaxies in clusters is very slow, and their mean stellar ages very high. We have The results of the previous sections have indicated that the evolution of early-type
galaxies in clusters is very slow, and their mean stellar ages very high. We have
noted, however, that morphological evolution can produc The results of the previous sections have indicated that the evolution of early-type galaxies in clusters is very slow, and their mean stellar ages very high. We have noted, however, that morphological evolution can produc galaxies in clusters is very slow, and their mean stellar ages very high. We have noted, however, that morphological evolution can produce a bias in our results. If early-type galaxies have a spread in ages, then the young early-type galaxies have a spread in ages, then the youngest galaxies will not look like early types at higher redshifts, and will be excluded from the sample.

rly-type galaxies have a spread in ages, then the youngest galaxies will not look
e early types at higher redshifts, and will be excluded from the sample.
We can constrain this effect by studying the morphological evoluti like early types at higher redshifts, and will be excluded from the sample.
We can constrain this effect by studying the morphological evolution of early-type galaxies in clusters. If morphological evolution is significan We can constrain this effect by studying the morphological evolution of early-type galaxies in clusters. If morphological evolution is significant out to $z = 0.83$, then we might expect to find different morphological dis galaxies in clusters. If morphological evolution is significant out to $z = 0.83$, then we might expect to find different morphological distributions at higher redshifts. Such effects have been described before (e.g. Dress might expect to find different morphological distributions at higher redshifts. Such effects have been described before (e.g. Dressler *et al.* 1997), and we present below our new results on the highest redshift cluster s

(*a*) *Observations of MS 1054-03*

(a) Observations of MS $1054-03$
We have taken deep, multicolour images of MS 1054-03 at six pointings with
FPC2 on the HST. The Keck telescope was used to take 200 spectra, aimed to We have taken deep, multicolour images of MS 1054-03 at six pointings with
WFPC2 on the HST. The Keck telescope was used to take 200 spectra, aimed to
be complete to an I magnitude of 22.7 The typical integration time per We have taken deep, multicolour images of MS 1054-03 at six pointings with WFPC2 on the HST. The Keck telescope was used to take 200 spectra, aimed to be complete to an I magnitude of 22.7. The typical integration time pe WFPC2 on the HST. The Keck telescope was used to take 200 spectra, aimed to be complete to an I magnitude of 22.7. The typical integration time per galaxy was 40 min. We were able to measure redshifts of 186 galaxies, a be complete to an I magnitude of 22.7. The typical integration time per galaxy was 40 min. We were able to measure redshifts of 186 galaxies, and of those, 80 were cluster members. Together with data from literature, we 40 min. We were able to measure redshifts of Γ cluster members. Together with data from literation of which 81 lie in the area of the HST images.

(*b*) *Merger fraction*

(b) Merger fraction
We classified the spectroscopically confirmed cluster members, analogous to our
sesification of galaxies in MS 1358+62 (Fabricant et al. 2000). We classified galaxies (σ) *Merger fruction*
We classified the spectroscopically confirmed cluster members, analogous to our
classification of galaxies in MS 1358+62 (Fabricant *et al.* 2000). We classified galaxies
along the revised Hubble We classified the spectroscopically confirmed cluster members, analogous to our classification of galaxies in MS $1358+62$ (Fabricant *et al.* 2000). We classified galaxies along the revised Hubble sequence. We allowed fo classification of galaxies in MS 1358+62 (Fabricant *et al.* 2000). We classified galaxies along the revised Hubble sequence. We allowed for a separate category of mergers. We combined the three classifications from three along the revised Hubble sequence. We allowed for a separate category of mergers.
We combined the three classifications from three of us, and verified that the results
were robust from classifier to classifier. The results We combined the
were robust from $al.$ (1999, 2000).
The main outco The results are presented in van Dokkum *et*
(1999, 2000).
The main outcome of this exercise is the high fraction of mergers in MS 1054-03.
any of these mergers are very luminous. One of the most striking ways to display

al. (1999, 2000).
The main outcome of this exercise is the high fraction of mergers in MS 1054-03.
Many of these mergers are very luminous. One of the most striking ways to display the effect is to show a panel with the 16 brightest galaxies (figure 4). Five out of

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**MATHEMATICAL,
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SCIENCES** Figure 4. Brightest 16 galaxies in MS 1054-03 at $z = 0.83$. These galaxies are spectroscopically confirmed cluster members, and selected on the basis of their rest-frame B luminosity. Five out Figure 4. Brightest 16 galaxies in MS 1054-03 at $z = 0.83$. These galaxies are spectroscopically confirmed cluster members, and selected on the basis of their rest-frame B luminosity. Five out of 16 are classified as merg confirmed cluster members, and selected on the basis of their rest-frame B luminosity. Five out of 16 are classified as mergers. The fraction of mergers remains similar if galaxies are corrected confirmed cluster members, and selected on the basis of their rest-frame B luminosity. Fiven of 16 are classified as mergers. The fraction of mergers remains similar if galaxies are cor for the luminosity brightening. Eac

for the luminosity brightening. Each image has a physical scale of $30h^{-1}$ kpc on a side.
these 16 were classified as mergers. A colour version of figures 4 and 5 can be found
at http://www.strw.leidenuniv.nl/~franx/clus at http://www.strw.leidenuniv.nl/~ franx/clusters. ese 16 were classified as mergers. A colour version of figures 4 and 5 can be found
http://www.strw.leidenuniv.nl/~franx/clusters.
A similar mosaic of the cluster MS 1358+62 at $z = 0.33$ is shown in figure 5. The
sence of

athttp://www.strw.leidenuniv.nl/~franx/clusters.
A similar mosaic of the cluster MS $1358+62$ at $z = 0.33$ is shown in figure 5. The absence of mergers in this lower redshift cluster, and the much more homogeneous colour A similar mosaic of the cluster
absence of mergers in this lower
colour distribution are notable.
The enhancement of peculiar ϵ Sence of mergers in this lower redshift cluster, and the much more homogeneous
lour distribution are notable.
The enhancement of peculiar galaxies in MS 1054-03 could be due to the bright-
ing of low-mass galaxies during a

colour distribution are notable.
The enhancement of peculiar galaxies in MS 1054-03 could be due to the bright-
ening of low-mass galaxies during a starburst. We verified that the merger fraction
remains high if the galaxi The enhancement of peculiar galaxies in MS 1054-03 could be due to the brig
ening of low-mass galaxies during a starburst. We verified that the merger fract
remains high if the galaxies are selected by mass, instead of (bl ing of low-mass galaxies during a starburst. We verified that the merger fraction
mains high if the galaxies are selected by mass, instead of (blue) luminosity.
The optical colours of the mergers are consistent with this r

remains high if the galaxies are selected by mass, instead of (blue) luminosity.
The optical colours of the mergers are consistent with this result. As shown in
figure 6, the mergers are generally red, with a few exception The optical colours of the mergers are consistent with the figure 6, the mergers are generally red, with a few exception of most of the mergers do not show strong emission lines.
These results suggest that the bulk of the These results suggest that the bulk of the stars of the mergers were formed well
fore the mergers do not show strong emission lines.
These results suggest that the bulk of the stars of the mergers were formed well
fore the

of most of the mergers do not show strong emission lines.
These results suggest that the bulk of the stars of the mergers were formed well
before the mergers. Hence the stellar age of the merged galaxies is significantly
d These results suggest that the bulk of the stars of the mergers were formed well
before the mergers. Hence the stellar age of the merged galaxies is significantly
different from the 'assembly age', i.e. the time at which t different from the 'assembly age', i.e. the time at which the galaxy 'was put together'.
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Figure 5. Brightest 16 galaxies in MS 1358+62 at $z = 0.33$, selected in the same way as the galaxies in MS 1054-03. Each image has a physical scale of $30h^{-1}$ kpc on a side Equals 5. Brightest 16 galaxies in MS 1358+62 at $z = 0.33$, selected in the same way as galaxies in MS 1054-03. Each image has a physical scale of $30h^{-1}$ kpc on a side. galaxies in MS 1054-03. Each image has a physical scale of $30h^{-1}$ kpc on a side.
The results are consistent with the hypothesis that the mergers evolve into ellip-

The results are consistent with the hypothesis that the mergers evolve into ellipticals. Their scatter in the colour-magnitude diagram is significantly larger than the scatter for the ellipticals $(0.073 \text{ versus } 0.045 \text{ in rest frame U$ The results are consistent with the hypothesis that the mergers evolve into ellipticals. Their scatter in the colour-magnitude diagram is significantly larger than the scatter for the ellipticals $(0.073 \text{ versus } 0.045 \text{ in rest frame }$ ticals. Their scatter in the colour-magnitude diagram is significantly larger than the scatter for the ellipticals (0.073 versus 0.045 in rest frame U-B). After ageing of the stellar populations, the scatter of the total scatter for the ellipticals (0.073 versus 0.045 in rest frame U-B). After ageing of the stellar populations, the scatter of the total population of mergers + ellipticals will have decreased from 0.054 at $z = 0.83$ to 0.01 stellar populations, the scatter of the total population of mergers + ellipticals will
have decreased from 0.054 at $z = 0.83$ to 0.015 at $z = 0$. Hence a low scatter at $z = 0$
does not mean that all galaxies in the popula have decreased from 0.054 at $z = 0.83$ to 0.015 at $z = 0$. Hence a low scatter at $z = 0$ does not mean that all galaxies in the population are homogeneous and very old: the influence of merging can be small if the star fo \sum_{μ} influ
low. influence of merging can be small if the star formation involved with the merging is
low.
The physical reason for the low star formation is unknown: it is possible that the

low.
The physical reason for the low star formation is unknown: it is possible that the
massive precursor galaxies had already lost their cold gas due to internal processes
(such as super winds or winds driven by nuclear a The physical reason for the low star formation is unknown: it is possible that the massive precursor galaxies had already lost their cold gas due to internal processes (such as super winds, or winds driven by nuclear activ massive precursor galaxies had already lost their cold gas due to internal processes
(such as super winds, or winds driven by nuclear activity). Alternatively, the cluster
environment may play an important role: the cold g (such as super winds, or winds driven by nuclear activity). Alternatively, the cluster environment may play an important role: the cold gas may have been stripped by the cluster X-ray gas. Observations of more clusters ma cluster X-ray gas. Observations of more clusters may shed further light on this effect.
(*c*) *Pair fraction*

Whereas the classifications of galaxies remains a subjective procedure, counting close pairs of galaxies is a very ob jective way to establish whether interactions and

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Figure 6. (a) The colour magnitude diagram for confirmed cluster members of MS 1054-03.
The mergers are indicated by ∞ symbols. They are generally red, although slightly bluer than
ellinticals and S0s. After ageing to Figure 6. (a) The colour magnitude diagram for confirmed cluster members of MS 1054-03.
The mergers are indicated by ∞ symbols. They are generally red, although slightly bluer than
ellipticals and S0s. After ageing to ellipticals and S0s. After ageing to $z = 0$, the scatter in the sample of ellipticals + mergers will be identical to that of ellipticals in nearby clusters. (b) The overdensity of pairs in the outskirts ellipticals and S0s. After ageing to $z = 0$, the scatter in the sample of ellipticals + mergers will
be identical to that of ellipticals in nearby clusters. (b) The overdensity of pairs in the outskirts
of MS 1054-03. The be identical to that of ellipticals in nearby clusters. (b) The overdensity of pairs
of MS 1054-03. There is a clear excess of pairs at small separations of less than
is independent confirmation of the enhanced interactio ō is independent confirmation of the enhanced interaction rate in MS 1054-03.
mergers are enhanced. Furthermore, the distribution of pairs may shed light on the

mergers are enhanced. Furthermore, the distribution of pairs may shed light on the future merging rate in the cluster. We have counted the number of pairs in the outskirts of the cluster, to avoid the high density core. Th mergers are enhanced. Furthermore, the distribution of pairs may shed light on the future merging rate in the cluster. We have counted the number of pairs in the outskirts of the cluster, to avoid the high density core. Th future merging rate in the cluster. We have counted the number of pairs in the outskirts of the cluster, to avoid the high density core. The pair fraction is shown in figure 6b. As we can see, there is an excess of pairs outskirts of the cluster, to avoid the high density core. The pair fraction is shown
in figure 6b. As we can see, there is an excess of pairs at small separations (less
than $10h^{-1}$ kpc). Half of these are classified as in figure 6b. As we can see, there is an excess of pairs at small separations (less than $10h^{-1}$ kpc). Half of these are classified as mergers, the other half not. These may constitute a reservoir of 'future' mergers. It than $10h^{-1}$ kpc). Half of these are classified
may constitute a reservoir of 'future' merger
velocity differences of the galaxies in pairs. velocity differences of the galaxies in pairs.
(*d*) *Evolution of the fraction of early types*

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SCIENCES** The results on MS 1054-03 have demonstrated that the fraction of mergers is high
in at least one cluster. It remains to be seen how typical this result is for other
clusters. At a minimum, the high merger fraction in MS 10 The results on MS 1054-03 have demonstrated that the fraction of mergers is high in at least one cluster. It remains to be seen how typical this result is for other clusters. At a minimum, the high merger fraction in MS 1054-03 shows that late merging can occur, and is likely to produce early-type gala in at least one cluster. It remains to be seen how typical this result is for other clusters. At a minimum, the high merger fraction in MS 1054-03 shows that late
merging can occur, and is likely to produce early-type galaxies which will form a
homogeneous set at low redshift. At a maximum, most or all ea merging can occur, and is likely to produce early-type galaxies which will form a homogeneous set at low redshift. At a maximum, most or all early types in clusters went through a phase of late merging. The merging phase may even be later (i.e. at lower redshift) for galaxies in less massive clusters, a went through a phase of late merging. The merging phase may even be later (i.e. at lower redshift) for galaxies in less massive clusters, and the field. A full description of these effects will have to wait until large sam lower redshift) for galaxies in less massive clusters, and the field. A full description % of these effects will have to wait until large samples of field galaxies and low-mass cluster galaxies have been studied. In the meantime, we can study the morphological fractions in rich clusters to test whether they a Inter galaxies have been studied. In the meantime, we can study the morphological
actions in rich clusters to test whether they are consistent with a gradual evolution.
We take a slightly different approach from that of Dr fractions in rich clusters to test whether they are consistent with a gradual evolution.
We take a slightly different approach from that of Dressler *et al.* (1997). Whereas
those authors focused on the ratio of elliptica We take a slightly different approach from that of Dressler *et al.* (1997). Whereas those authors focused on the ratio of ellipticals to S0s in higher redshift clusters, we study the fraction of early types (i.e. ellipti those authors focused on the ratio of ellipticals to S0s in higher redshift clusters, we study the fraction of early types (i.e. ellipticals plus S0s). This is motivated by the fact that we apply the Fundamental Plane to a study the fraction of early types (i.e. ellipticals plus S0s). This is motifact that we apply the Fundamental Plane to all early types, and by difficulty in separating ellipticals and S0s, especially at high redshift. We s ext that we apply the Fundamental Plane to all early types, and by the practical
ficulty in separating ellipticals and S0s, especially at high redshift.
We show our preliminary results in figure 7. Notice the gradual decli

difficulty in separating ellipticals and S0s, especially at high redshift.
We show our preliminary results in figure 7. Notice the gradual decline in early
type fraction with redshift. Clearly, many clusters will need to b We show our preliminary results in figure 7. Notice the gradual decline in early
type fraction with redshift. Clearly, many clusters will need to be studied to measure
this effect reliably. Nevertheless, the figure indicat type fraction with redshift. Clearly, many clusters will need to be stuthis effect reliably. Nevertheless, the figure indicates that the assum types do not evolve morphologically is not justified by these data. *types* do not evolve morphologically is not justified by these data.
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Figure 7. The fraction of early-type galaxies as a function of redshift (van Dokkum *et al*. 1999, Figure 7. The fraction of early-type galaxies as a function of redshift (van Dokkum *et al.* 1999, and references therein). The filled symbols show X-ray bright clusters. The large symbols show clusters for which we have Figure 7. The fraction of early-type galaxies as a function of redshift (van Dokkum *et al.* 1999, and references therein). The filled symbols show X-ray bright clusters. The large symbols show
clusters for which we have f clusters for which we have full membership information and morphological types. Two clusters have been classified by two groups, and the results are linked. All datasets, including the extensive data by Dressler *et al*. (1997), are consistent with a gradual evolution.

tensive data by Dressler *et al.* (1997), are consistent with a gradual evolution.
A full discussion of the implications will be given elsewhere (van Dokkum & Franx 00). We can estimate roughly how this might effect our F A full discussion of the implications will be given elsewhere (van Dokkum & Franx 2000). We can estimate roughly how this might effect our Fundamental Plane measurement. The results imply that only 60% of early types were A full discussion of the implications will be given elsewhere (van Dokkum & Franx 2000). We can estimate roughly how this might effect our Fundamental Plane measurement. The results imply that only 60% of early types were 2000). We can estimate roughly how this might effect our Fundamental Plane measurement. The results imply that only 60% of early types were in place at $z = 0.83$.
In the simplest models, these 60% would be the oldest 60% surement. The results imply that only 60% of early types were in place at $z = 0.83$.
In the simplest models, these 60% would be the oldest 60% of early types at zero red-
shift. The zero point of the Fundamental Plane for In the simplest models, these 60% would be the oldest 60% of early types at zero redshift. The zero point of the Fundamental Plane for this oldest 60% would be shifted by a value comparable with the scatter in the Fundame shift. The zero point of the Fundamental Plane for this oldest 60% would be shifted
by a value comparable with the scatter in the Fundamental Plane, which is 15% in
the mass-to-light ratio. The gradient would be underesti

the mass-to-light ratio. The gradient would be underestimated by about $0.3 \times z$.
This simple discussion shows that it is essential to use relations with small internal
scatter. The effects of biases are directly proportio This simple discussion shows that it is essential to use relations
catter. The effects of biases are directly proportional to the sc
Fundamental Plane uniquely suited for evolutionary studies. Fundamental Plane uniquely suited for evolutionary studies.
6. Discussion

We have shown that it is possible to determine the Fundamental Plane at intermedi-We have shown that it is possible to determine the Fundamental Plane at intermedi-
ate redshifts, all the way up to $z = 0.83$. The relation is well defined at these redshifts,
with a relatively low scatter less than 20%. We have shown that it is possible to determine the Fundamental Plane at intermedi-
ate redshifts, all the way up to $z = 0.83$. The relation is well defined at these redshifts,
with a relatively low scatter less than 20%. ate redshifts, all the way up to $z = 0.83$. The relation is well defined at these redshifts,
with a relatively low scatter less than 20%. The mean evolution of the M/L_B ratio
is low, at about $\Delta \log M/L_B = 0.4z$ for $\Omega = 0.3$ with a relatively low scatter less than 20%. The mean evolution of the M/L_B ratio
is low, at about $\Delta \log M/L_B = 0.4z$ for $\Omega = 0.3$. This evolution is consistent with
an early star formation epoch for our galaxies, and is d \bigcirc an early star formation epoch for our galaxies, and is difficult to reconcile with a closed universe and normal IMF. We note, however, that the current measurement \bigcirc may be biased, mostly due to the fact that we an early star formation epoch for our galaxies, and is difficult to reconcile with a
closed universe and normal IMF. We note, however, that the current measurement
may be biased, mostly due to the fact that we only use non closed universe and normal IMF. We note, however, that the current measurement
may be biased, mostly due to the fact that we only use non-star-forming red galax-
ies. We may therefore exclude the star-forming progenitors o galaxies.

ies. We may therefore exclude the star-forming progenitors of current-day early-type galaxies.
We have therefore started to study the morphological fractions in our programme clusters. As a first result, we have found a hi We have therefore started to study the morphological fractions in our programme We have therefore started to study the morphological fractions in our programme
clusters. As a first result, we have found a high fraction of mergers in our highest
redshift cluster, MS 1054-03 at $z = 0.83$. The mergers a clusters. As a first result, we have found a high fraction of mergers in our highest redshift cluster, MS 1054-03 at $z = 0.83$. The mergers are generally red. The fraction of mergers is comparable with the number of ellip *Phil. Trans. R. Soc. Lond.* A (2000)

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Evolution of early-type galaxies 2119
consistent with the hypothesis of hierarchical galaxy formation. The relatively old
stellar age of the mergers compared with the young 'assembly age' is consistent with consistent with the hypothesis of hierarchical galaxy formation. The relatively old stellar age of the mergers compared with the young 'assembly age' is consistent with predictions from semi-analytical models (e.g. Kauffm consistent with the hypothesis of hierarchical galaxy formation. The relatively old
gradied are of the mergers compared with the young 'assembly age' is consistent with
gradied models (e.g. Kauffmann 1996).

The results are inconsistent with the hypothesis that all ellipticals are formed and predictions from semi-analytical models (e.g. Kauffmann 1996).
The results are inconsistent with the hypothesis that all ellipticals are formed and
assembled at very high redshift. Nevertheless, many questions remain open. The results are inconsistent with the hypothesis that all ellipticals are formed and
assembled at very high redshift. Nevertheless, many questions remain open. (i) Is
the result for MS 1054-03 typical for high redshift clu the result for MS 1054-03 typical for high redshift clusters? Is the merger fraction higher or lower in the field? It is interesting to note that studies of the field give the result for MS 1054-03 typical for high redshift clusters? Is the merger fraction
higher or lower in the field? It is interesting to note that studies of the field give
high merger fractions and/or pair fractions at in *al.* 1997; Le Fevre *et al.* 1999). It remains to note that studies of the field give high merger fractions and/or pair fractions at intermediate redshift (e.g. Patton *et al.* 1997; Le Fevre *et al.* 1999). It remains to high merger fractions and/or pair fractions at intermediate redshift (e.g. Patton *et al.* 1997; Le Fevre *et al.* 1999). It remains to be seen whether these field mergers are as massive as the mergers found in MS 1054-03 al. 1997; Le Fevre *et al.* 1999). It remains to be seen whether these field mergers are as massive as the mergers found in MS 1054-03. (ii) What is the typical redshift at which the mass of early-type galaxies was half o as massive as the mergers found in MS 1054-C
which the mass of early-type galaxies was hal
the major episode of star formation occur?
More complete studies, of both clusters and t ich the mass of early-type galaxies was half of the current mass? (iii) When dide major episode of star formation occur?
More complete studies, of both clusters and the field, are necessary to answer these estions. We have

the major episode of star formation occur?
More complete studies, of both clusters and the field, are necessary to answer these
questions. We have roughly estimated the effect of morphological evolution on the
evolution of More complete studies, of both clusters and the field, are necessary to answer these questions. We have roughly estimated the effect of morphological evolution on the evolution of the Fundamental Plane. We show that it is questions. We have roughly estimated the effect of morphological evolution on the evolution of the Fundamental Plane. We show that it is proportional to the scatter, which, fortunately, is low. The Fundamental Plane is the which, fortunately, is low. The Fundamental Plane is therefore uniquely suited for evolutionary studies.
Studies are in progress to extend this work to higher redshift, and to the field (e.g. ich, fortunately, is low. The Fundamental Plane is therefore uniquely suited for olutionary studies.
Studies are in progress to extend this work to higher redshift, and to the field (e.g. eu *et al.* 1999: van Dokkum *et*

evolutionary studies.
Studies are in progress to extend this work to higher redshift, and to the field (e.g.
Treu *et al.* 1999; van Dokkum *et al.* 2000). These can be expected to yield results
relatively soon. The new ge Studies are in progress to extend this work to higher redshift, and to the field (e.g. Treu *et al.* 1999; van Dokkum *et al.* 2000). These can be expected to yield results relatively soon. The new generation optical tele Treu *et al.* 1999; van Dokkum *et al.* 2000). These can be expected to yield res relatively soon. The new generation optical telescopes will allow a rapid extension this type of work to larger samples, higher redshifts, a relatively soon. The new generation optical telescopes will allow a rapid extension of this type of work to larger samples, higher redshifts, and lower galaxy masses.
The future observations will be used to determine the e

this type of work to larger samples, higher redshifts, and lower galaxy masses.
The future observations will be used to determine the evolution of the distribution
of circular velocities for galaxies $F(v_c, z)$, and the evo The future observations will be used to determine the evolution of the distribution
of circular velocities for galaxies $F(v_c, z)$, and the evolution of stellar masses locked up
in early-type galaxies $F(M_*, z)$. This require of circular velocities for galaxies $F(v_c, z)$, and the evolution of stellar masses locked up
in early-type galaxies $F(M_*, z)$. This requires accurate observations of the evolution
of the luminosity function and the 'mass re in early-type galaxies $F(M_*, z)$. This requires accurate observations of the evolution
of the luminosity function and the 'mass relations' in the field. The final outcome of
such a programme can be expected to provide stro of the luminosity function and the 'mass relations' in the field. The final outcome of

It is a pleasure to thank the organizers for a stimulating conference.

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