Evolutionary Synthesis Models for Galaxy Transformation in Clusters

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Abstract. The galaxy population in rich local galaxy clusters shows a ratio of one quarter elliptical galaxies, two quarters S0 galaxies, and one quarter spiral galaxies. Observations of clusters at redshift 0.5 show a perspicuously different ratio, the dominant galaxy type are spiral galaxies with a fraction of two quarters while the number of S0 galaxies decreases to a fraction of one quarter (Dressler et al. 1997). This shows an evolution of the galaxy population in clusters since redshift 0.5 and it has been suspected that galaxy transformation processes during the infall into a cluster are responsible for this change. These could be merging, starburst or ram-pressure stripping. We use our evolutionary synthesis models to describe various possible effects of those interactions on the star formation of spiral galaxies infalling into clusters. We study the effects of starbursts of various strengths as well as of the truncation of star formation at various epochs on the color and luminosity evolution of model galaxies of various spectral types. As a first application we present the comparison of our models with observed properties of the local S0 galaxy population to constrain possible S0 formation mechanisms in clusters. Application to other types of galaxies is planned for the future.

Keywords: galaxies:formation, evolution, intersction, starburs, elliptical and lenticular, cD – galaxies: clusters: general

1. Evolutionary Synthesis Model

We use our evolutionary synthesis models based on Tinsley's equations and following the stellar population through the HR diagram (for details see Fritze-v. Alvensleben, Gerhard 1994) using stellar evolution tracks (Geneva), standard IMF (Scalo), one metallicity (1/2 solar) and star formation rate (SFR) specific for each galaxy type (Sandage 1986). This model well describes undisturbed galaxies, in terms of average luminosity, colors (U...K), gas content and metallicity.

To describe the galaxy interaction in clusters we use two scenarios:

– Starburst for merging and tidal interaction of galaxies

– Star Formation Truncation for interaction with the Intra Cluster Medium (ram-pressure-stripping)

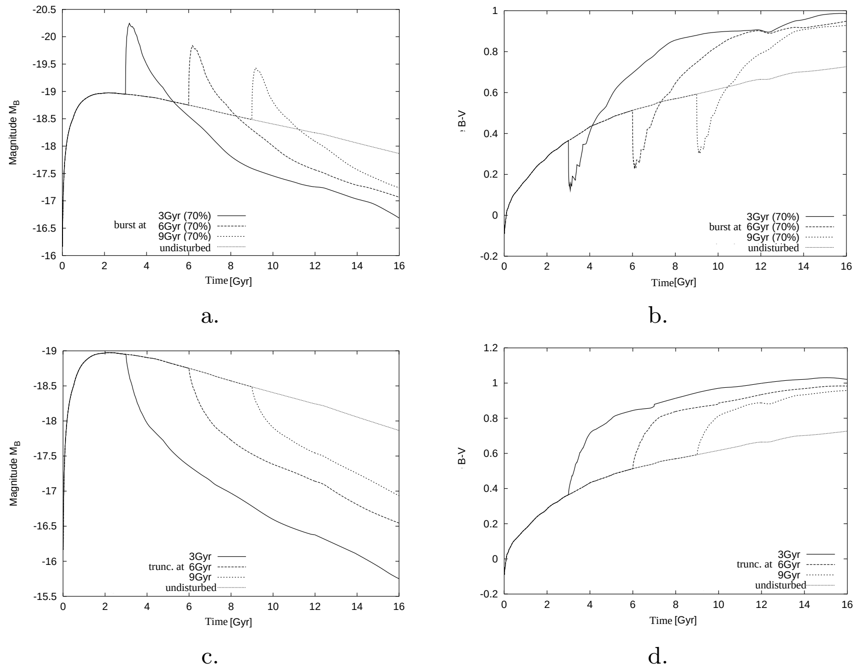


Figure 1. Time evolution of $\mathrm{M_B}$ and $\mathrm{B-V}$ for Sb galaxies with strong bursts and no SF after it (a. and b.) and for Sb galaxies with SF truncation (c. and d.)

In case of the truncation we simply stop star formation at a given point in time. A burst is described by a sudden increase of the SFR followed by an exponential decline to a given value:

Ψ_{max}: max. SFR at the beginning of the burst

τ_{burst}: decline time scale of the burst (typical $\sim 10^8$ yr)

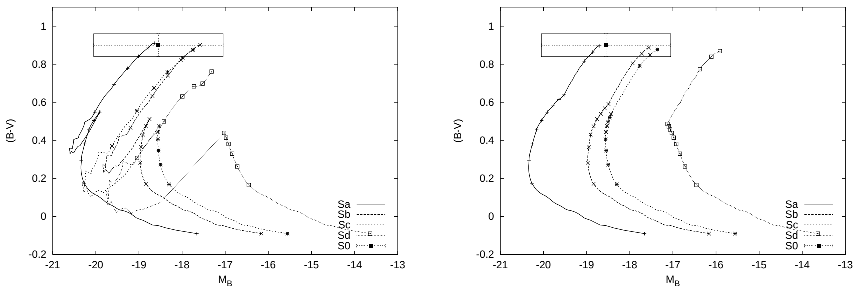
Ψ_{f}: the SFR after the burst (=0 or constant)

The strength of the burst is defined by the fraction of gas which is transformed into stars during the burst. Models produce the time evolution of magnitudes (Johnson UBVRIJHK) and colors for the different scenarios.

2. Models

We compute models for a grid of parameters:

– Galaxy types Sa, Sb, Sc and Sd



a. burst b. truncation

Figure 2. Color-magnitude diagrams for the evolution of spiral galaxies with a.) strong bursts starting at an age of 6 Gyr and b.) star formation truncation after 9 Gyr. The symbols mark timesteps of 1 Gyr.

- Interaction (burst or SF truncation) after 3, 6 or 9 Gyr of undisturbed evolution
- Bursts transform into stars 70%, 50% or 30% of the remaining gas
- SFR after the burst of $\Psi_{\mathrm{f}} = 1.5 M_{\odot} yr^{-1}$ or 0

Fig. 1 show an example of the time evolution of $\mathrm{M_B}$ and $\mathrm{B-V}$ for Sb galaxies with strong (70%) bursts with $\Psi_{\mathrm{f}} = 0$ at 3, 6 and 9 Gyr of evolution (a,b) and for Sb galaxies with SF truncation at the same points in time (c,d). During the bursts the galaxies become more luminous and bluer. But after ~ 2 Gyr the luminosity falls below the luminosity of an undisturbed Sb galaxy, and $\mathrm{B-V}$ becomes redder. In case of SF truncation the luminosity fades immediately and $\mathrm{B-V}$ becomes redder. It is mentionable that the burst models as well as the truncation models reach nearly the same color in $\mathrm{B-V}$ at 4 Gyr after the interaction.

3. S0 Galaxies

As a first application of our models we look at S0 galaxies in clusters. As mentioned in the Abstract, the S0 population evolves significantly from higher redshifts to today.

Fig. 2a shows a color-magnitude diagram for spiral models with a burst at 6 Gyr and $\Psi_{\mathrm{f}} = 0$ after the burst. Spiral galaxies evolve from the lower right to upper left, get brighter and bluer during the burst and fade and redden thereafter towards the observed location of local S0 galaxies as marked by the 1 box. Most tracks end at 12 Gyr (today) in the region of S0 galaxies. Only the Sd galaxies are too blue and slightly too faint. If the burst model is to describe a merger of equal type galaxies, (the mass of the bursting galaxy and) its luminosity is to be increased by a factor 2 (-0.75 in magnitudes). The colors do not change. (The symbols mark time steps of 1 Gyr)

Fig. 2b shows spiral models with SF truncation after 9 Gyr. At first the galaxies evolve like in Fig. 2a. After 9 Gyr the star formation stops and the galaxies get redder and fade. Except for the Sd models all galaxies reach the region of S0 galaxies.

For a detailed study see Bicker et al. 2002.

4. Conclusion

Detailed comparison of photometric evolution models with local cluster S0 properties shows that most of the spirals falling into the cluster over an Hubble time can be transformed into S0 galaxies (Bicker et al. 02):

- The star formation must be stopped after the interaction (truncation or burst with $\Psi_{\mathrm{f}} = 0$) to reach the red colors of S0 galaxies.
- Sd galaxies alone are too faint or too blue. Only in mergers the luminosity can reach the S0 range.
- SF truncation may occur after $\geq$ 6 Gyr, otherwise the galaxies would become too red by today.
- Bursts must occur before $\sim$ 9 Gyr. Thereafter the galaxies would become too blue by today.
- Conclusions are the same for weak and strong bursts.
- Conclusions are the same for all colors (U...K).

These results agree well with spectral analysis of S0 galaxies (Jones et al. 2000). They also found that the progenitors of S0 galaxies in rich clusters are mostly early-type spirals that had their star formation truncated in the cluster environment.

References

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