THE EVOLUTION OF GALAXIES IN THE LAST 10 GYR

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1. Introduction

Rest-frame Strömgren colours are presented for a large number of galaxies in rich clusters between z = 0 and z = 1. Our observations confirm a strong, rest-frame, Butcher-Oemler effect where the fraction of blue galaxies increases from 20% at z < 0.4 to 80% at z = 0.9. After isolating the red objects in each cluster we have compared the mean colour of these old, non-star forming objects with SED models from the literature as a test for passive galaxy evolution in ellipticals. We find good agreement with single burst models which predict an epoch of galaxy formation from z = 2 to 5 (Rakos et al. 1988, 1991; Rakos & Schombert 1993). Although the results demonstrate a great deal of hope for modelling the fine details of colour evolution when our samples are extended into the near- and far-IR, there are reasons to believe that galaxies become, observationally, much more complicated beyond redshifts of 1. The rate of blue colour evolution between 0.6 and 0.9 suggests that by a redshift of 1.5 it will be impossible to tell the difference between galaxies which have completed a single burst at a formation redshift of 2 or ones which are undergoing constant star formation.

2. Classification of Galaxies using Colour Indices

An analysis of colour evolution in ellipticals first requires a separation of star-forming, AGN and other active galaxies from the 'passive' ellipticals. The two colour diagram (uz - vz) versus mz can be used for this purpose. About 140 high resolution, high S/N ratio, spectra of galaxies are available in the literature (Yee & Oke 1978; Gunn & Oke 1975; Kennicutt 1992; De Bruyn & Sargent 1978; Ashby & Houck 1992). Synthetic colours uz, vz, bz and yz have been calculated using these spectra. Figure 1 shows a (uz - vz) versus mz diagram. Starburst galaxies are well separated from ellipticals and Seyfert galaxies. AGN, starburst galaxies and mergers have mz < –0.2 in almost all cases. In general mz is influenced by reddening, metallicity and bimodal distribution of star colours in a galaxy. In any case the intrinsic reddening and the bimodal distribution of colours (blue and red stars) are the only significant contributors.

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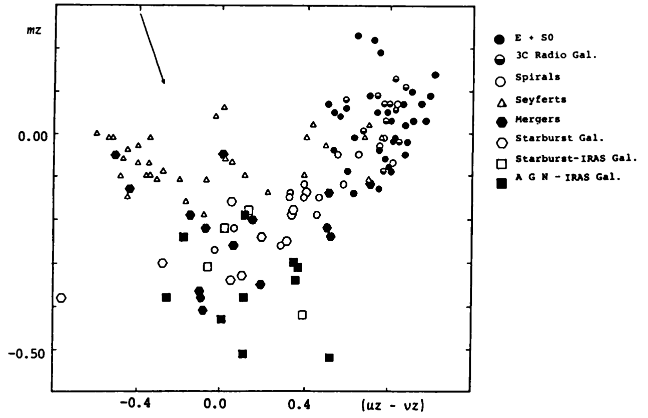

Figure 1.

3. Colour Evolution and Mergers

The rate of interactions increases rapidly with redshift, as rapid as (1 + z) to fourth power (Carlberg 1992). The present day frequency of interaction is estimated by various authors to be between 2% and 5% (solid line in Fig. 2). In Fig. 2 we have plotted the fraction of galaxies with mz < -0.2 in 7 observed clusters as a function of redshift. There is also the measurement for z = 0.37 published by Lavery et al. (1992). We believe that the majority of blue galaxies are mergers. Similar conclusions can be drawn from Fig. 3. It can be shown that the colour index (uz - vz) is simply related to the 4000 Angström break in the galaxies:

$$2.5 \log D = 0.646\,(uz - vz) + 0.245, \quad r = 91\%$$

In Fig. 3 the amplitude of the Break is given as measured by Kimble et al. (1989) for z = 0; Soucail et al. (1988) for z = 0.37 and for 8 different clusters we have measured. The continuous line refers to a 1 Gyr burst model of a galaxy as a function of redshift for the redshift of formation z = 1, published by Bruzual & Charlot (1993). In spite of a high fraction of blue galaxies at a redshift of 1 it seems that at the present time galaxies are results of merging processes at a redshift between 1 and 2.

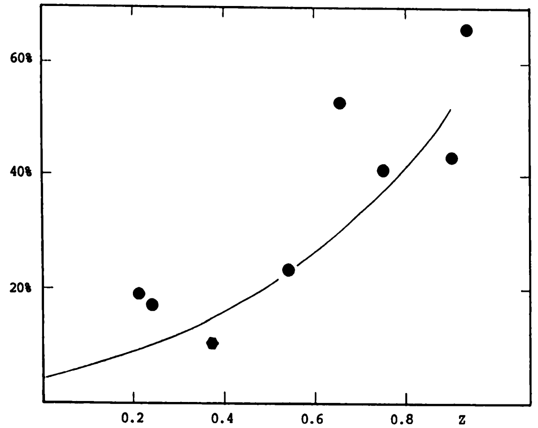

Figure 2.

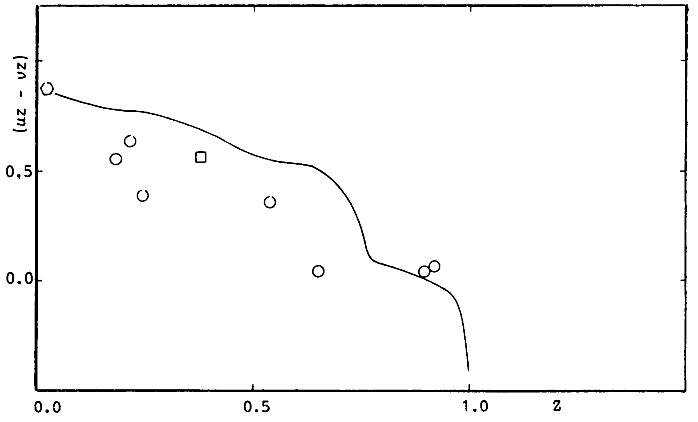

Figure 3.

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