Disturbed Field Elliptical Galaxies: Young or Old?

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Abstract

Elliptical galaxies with morphological signatures of recent merger activity have similar integrated H−K colors as galaxies with no signs of recent merger activity. This constrains the fractional amount of intermediate-age (1 − 3 Gyr) stellar mass to 10 − 15% and is consistent with all the stellar mass being old (T > 10 Gyr) and metal-rich ([Fe/H] $\geq$ −0.3). If these ellipticals were assembled recently, most of their stellar mass was formed at high redshift. We argue that recent merger activity was not accompanied by significant global star formation and that the bluer colors of some of these galaxies are caused by metallicity effects. Evidence is presented for centrally concentrated intermediate-age stellar populations in two galaxies. We suggest that these galaxies have undergone merger driven central star formation events.

1 Do Disturbed Ellipticals Contain Young Stellar Populations?

It is now generally accepted that many elliptical galaxies in low density environments (so-called "field ellipticals") have undergone at least one merger event in the last 5 Gyr. The observational evidence includes the presence of morphological fine structure (e.g. ripples, shells, boxy isophotes) in perhaps 75% of all field ellipticals ([2], [16]), kinematically distinct cores in $\sim$ 30% of ellipticals ([10]), and kinematically unsettled dust in the cores of 60 − 80% of all ellipticals ([21]). Most of these features are thought to be short-lived, suggesting the merger event that created them must have occurred recently. In particular, the dynamical lifetime of the morphological fine structure is estimated to be 2 − 3 Gyr (e.g. [15], [9], [1]).

It remains unclear, however, whether such mergers are inducing significant new star formation or if they are just mixing two or more galaxies in a dissipationless manner. It has been shown that field ellipticals with morphological fine structure tend to have stronger central Hβ absorption ([17]) and bluer large aperture integrated UBV colors ([16]) than elliptical galaxies

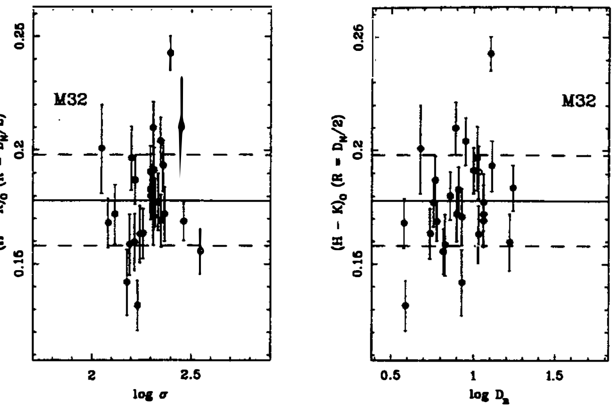

Figure 1: On the left, H–K is plotted against central velocity dispersion, a measure of total mass. On the right, H–K is plotted against log D_N, which correlates with total optical luminosity. Values for log σ and log D_N were taken from [5] and [4], respectively. "Young" ellipticals (as defined in text) are denoted by solid circle (•). The average H–K color and 1σ range are shown by the horizontal solid and dashed lines, respectively. The reddest sample galaxy is NGC 3607, a well-known "dusty" elliptical.

with little or no morphological fine structure. SS92 ([16]) argued that both observations could be explained if these ellipticals had been formed by major disk-disk mergers, roughly 3 – 5 Gyr ago, which resulted in a distributed burst of star formation. In this scenario, the strong Hβ and blue UBV colors are produced by the fading stellar population created by the merger driven star formation event.

If the SS92 hypothesis is correct, the stellar population formed 2 – 3 Gyr ago should include many cool asymptotic giant branch (AGB) stars above the tip of the first-ascent giant branch, as intermediate-age Magellanic Cloud clusters do ([14], [8]). The lack of such stars would point to a different origin for the blue light, perhaps due to metallicity effects.

To constrain the presence of such cool, intermediate-age AGB stars, we have obtained JHK images of 45 field E/S0 galaxies. The presence of such stars should produce distinctive integrated H-K colors. Our sample was mostly drawn from SS92. As such, it spans a range of morphological "fine structure", and thus, probably a range of merger histories. These images were obtained at the KPNO 1.3m using the SQIID multi-band IR imager.

2 Global Population: Old and Metal-Rich

As Figure 1 illustrates, most galaxies in our sample have very similar H–K color, regardless of their morphological state, with no statistically significant correlation between H–K color and mass or luminosity. The "young" ellipticals distinguished by their morphological fine structure and photometric properties (blue UBV colors and/or central Hβ strength) do not have statistically different colors than the rest of our sample. In contrast, M32, a galaxy with a significant extended giant branch population ([6]), clearly stands out on these diagrams.

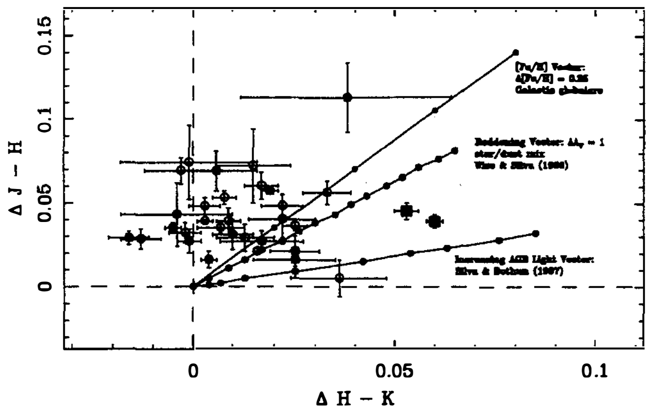

Figure 2: Color differences between a central region (r $\leq$ 0.5 kpc) and an outer annulus (1.0 $\leq$ r $\leq$ 1.5 kpc) are shown. *Positive* color differences are equivalent to *redder* central colors. "Young" ellipticals with signatures of recent merger activity are denoted by solid circle (•). NGC 3610 and NGC 5322 are denoted by large, solid squares.

Only a few galaxies have H–K colors more than 1σ different from the sample mean. Using a very simple model based on combining the light of metal-rich ([Fe/H] $\sim$ −0.3) intermediate-age (T = 2 – 3 Gyr) and old (T $\geq$ 10 Gyr) clusters, we estimate that a H–K color change of 0.02 mag corresponds to a 10 – 15% mass fraction of intermediate-age stars (see [18] for details). Since 0.02 mag is equivalent to the color dispersion of our sample, 10 – 15% is the estimated upper limit mass fraction of intermediate-age stars in any individual sample object. The actual fractions could be much smaller, i.e. our data are consistent with *all* the mass being old (T > 10 Gyr) and metal-rich ([Fe/H] > −0.3) (cf. [7]). Even if these galaxies have been assembled or modified recently, most of their stellar mass must have formed at high redshift.

3 Nuclear Colors: Constraints on Merger Driven Star Formation

Models of disk-disk mergers which account for gas and star formation activity suggest that most star formation is centrally concentrated ([12], [13]). The lack of an intermediate-age stellar population in the center of a "young" elliptical would be consistent with a purely dissipationless merger event. Color differences between a central region (r $\leq$ 0.5 kpc) and an outer annulus (1.0 $\leq$ r $\leq$ 1.5 kpc) for each of our galaxies is shown in Figure 2. *Positive* color differences are equivalent to *redder* central colors. Random errors are denoted by the error bars. Slight PSF differences between photometric bands can create systematic errors with a maximum magnitude of 0.02 mag. Our sample can be sub-divided into two groups. In the first group, galaxies with $\Delta(H - K) \leq 0.025$ mag, the measured color differences are consistent with very small or null H–K color differences. The relative J–H and H–K color differences are larger than seen in the Galactic globular cluster color-metallicity relationship or in our assumed reddening vector. We conclude that these color differences are still metallicity driven, and the coolest first-ascent M giants in these galaxies have properties similar to the M giants seen in the metal-rich Galactic globulars Liller 1 and NGC 6440 ([11]).

In the second group, galaxies with $\Delta(H - K) \geq 0.025$ mag, two galaxies with multiple indicators of recent merger activity stand out: NGC 3610 and NGC 5322. These galaxies have color differences consistent with a significant intermediate-age component (20 - 30% by mass within r = 0.5 kpc) which has been somewhat reddened by dust. Such intermediate-age stellar components are the signature of merger driven central starbursts but they only occur in 5% of our sample.

The apparent lack of central intermediate-age AGB populations in other putatively "young" ellipticals suggests that a significant amount of gas (and thus star formation) was not involved in their merger events, contrary to the SS92 scenario. Thus, it seems unlikely that galaxies akin to modern-day spiral galaxies were involved in these most of these encounters. This issue is discussed more extensively elsewhere ([19]).

4 Origin of the Blue Light

Where then does the blue light seen in many of these disturbed field elliptical galaxies come from? Two metallicity related scenarios suggest themselves.

First, stars injected by the accretion of a less massive companion with either lower mean metallicity or a history of continuous star formation would tend to make the resultant combined galaxy bluer. Dynamical models of such merger events (e.g. [15], [9]) have produced morphological features similar to the fine structure seen in our sample galaxies. The observed optical/near-IR colors allow a large range of accreted mass depending on the assumed stellar populations of the accreted object ([18]). In this context, the observed central Hβ enhancements may be strongly related to the mean age/metallicity and/or horizontal branch morphology of the accreted companion.

A second possibility is that some of these galaxies could have different relative abundance ratios. In particular, it is well-known that in general $[\alpha/\mathrm{Fe}] \approx 0.3$ in ellipticals with luminosities similar to the galaxies in our sample. Indeed, this has been cited as a reason why such galaxies could not be formed from spirals (e.g. [3]). However, some disturbed ellipticals (e.g. NGC 5322) appear to have solar abundance ratios. This would tend to make them bluer than galaxies with enhanced light element ratios. This point is discussed in more detail elsewhere ([18]).

5 Conclusions

1. Our near-IR data are consistent with the conclusion that most (90 - 100%) of the stellar mass in disturbed field ellipticals is old (T $\geq$ 10 Gyr) and metal-rich ([Fe/H] $\geq$ -0.3). The residual mass could be younger and/or more metal-poor.

2. Most recent mergers appear to have been minor and/or involved little or no gas. We argue that the relatively blue colors of these galaxies are caused by metallicity effects, not age effects.

3. Stellar population studies such as our study cannot constrain the assembly epoch of nearby galaxies. However, we have argued that if these disturbed field ellipticals were assembled recently, significant star formation was not involved. In short, the majority of nearby disturbed field ellipticals apparently were not formed by major mergers of objects akin to present-day spirals in the last 5 Gyr.

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