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From Globular Clusters to Tidal Dwarfs: Structure Formation in Tidal Tails

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Abstract. Star clusters can be found in galaxy mergers, not only in central regions, but also in the tidal debris. In both the Eastern and Western tidal tails of NGC 3256 there are dozens of young star clusters, confirmed by their blue colors and larger concentration index as compared to sources off of the tail. Tidal tails of other galaxy pairs do not have such widespread cluster formation, indicating environmental influences on the process of star formation or the packaging of the stars.

1. Introduction

Extended structures resembling young dwarf galaxies are found in tidal debris from galaxy interactions (Mirabel et al. 1992; Duc & Mirabel 1994; Hunsberger, Charlton, & Zaritsky 1996). Star clusters form in abundance in the central regions of interacting galaxy pairs (Schweizer et al. 1996; Miller et al. 1997; Whitmore et al. 1999; Zepf et al. 1999). What physical conditions drive the formation of stars and determine the nature of structure that forms in different environments? Can star clusters also form in tidal debris, how widespread is star formation in the debris, and how similar is it between different tidal environments?

2. HST WFPC2 Images of the Tidal Debris of NGC 3256

The image in Figure 1 is a 1000 second exposure in the F555W filter obtained on 1999 March 24. A F814W image was also obtained. Point sources with $S/N > 3.0$ are indicated, those in the tail with white circles and those out of the tail with white squares. Although this field is crowded with foreground stars due to its low galactic latitude, it is apparent that the numerous point sources are preferentially in the regions containing tidal debris.

The colors, magnitudes, and sizes of these sources allow us to distinguish foreground and background contamination from star clusters in the debris. Figure 2 illustrates that the brighter sources are relatively young star clusters (i.e. hundreds of millions of years old), but some of the fainter ones could be individual stars. The reddest sources are most certainly foreground stars with $-10 < M_V < -7.5$ apparent mostly from WF4. There is an enhancement of

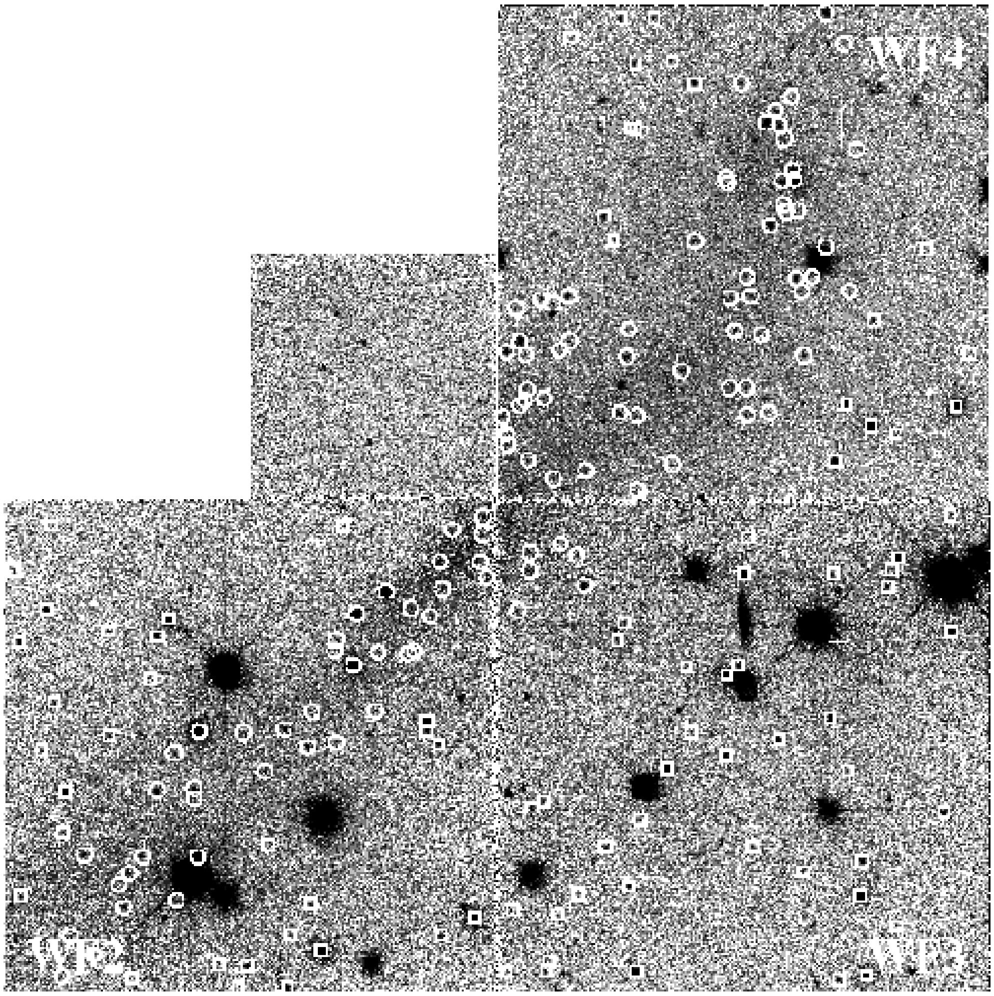

Figure 1. HST WFPC2 image of the Western tail of NGC 3256 taken with the F555W (V–band) filter. The sources within the tail are identified with circles and those outside the tail with squares. Sources were not detected at $S/N > 3$ in the PC region.

point sources with $0 < V - I < 0.8$ and $-12 < M_V < -9$. The relatively large spread of the $V - I$ colors indicates either a range of ages, or non–uniform extinction by dust. The central region of NGC 3256 also has a large number of young clusters that contribute 20% of the total B–band luminosity of the galaxy (Zepf et al. 1999).

In Figure 3, for the Western tail, the $V - I$ color is plotted vs. the concentration index, defined as the difference between V magnitudes measured in a $0.5''$and in a $3''$aperture. The solid circles represent sources in the tail regions while the open circles represent sources in regions outside the tail. Clearly, the sources in the tail are on average larger, indicating that they are not point sources, and bluer. Therefore, we confirm that there are many star clusters in this tail. In the Eastern tail of NGC 3256 we also find a significant number of star clusters, but they are not as abundant as in the Western tail.

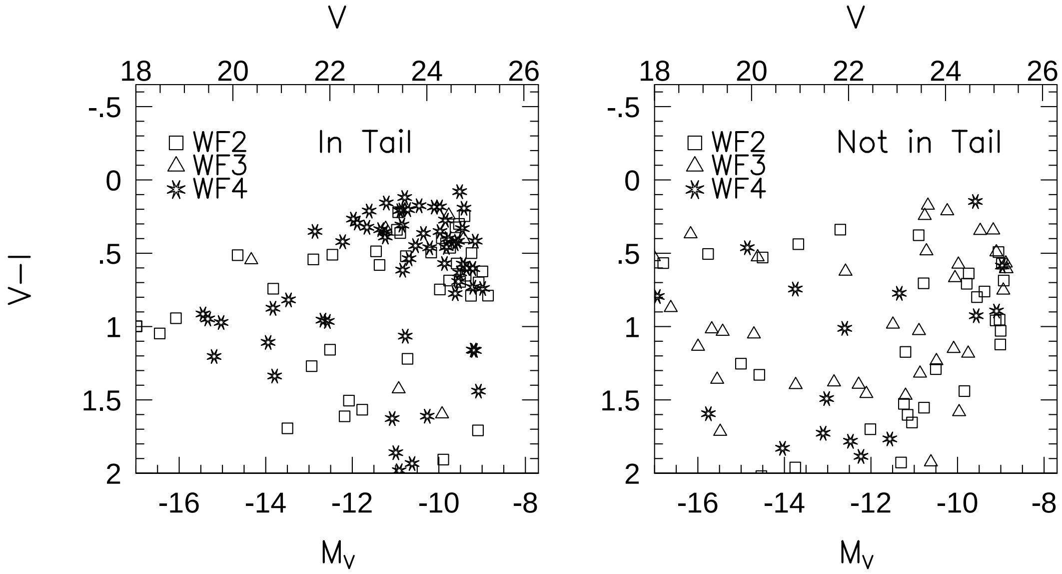

Figure 2. Color Magnitude diagrams for sources in and out of the Western tail of NGC 3256. The $V-I$ color is plotted vs. the absolute magnitude on the lower horizontal scale and vs. the apparent V magnitude on the upper horizontal scale. Sources are included if errors in V are less than 0.25 mag, and if $-0.75 < V-I < 2.0$. Sources from the different WFPC2 chips are indicated by the symbols in the legends. Many of the "in-tail" sources occupy a region in the relatively low luminosity, blue part of the diagram, which is not heavily populated with "out of tail" sources.

3. Environmental Influences on Cluster Formation in Tidal Debris

We have also obtained HST/WFPC2 V and I band images of the tidal debris of three other mergers: NGC 4038/9, "the Antennae", NGC 7252, "Atoms for Peace", and NGC 3921. We detect several cluster candidates in NGC 7252 and NGC 4038/9, and several super star clusters in the debris of NGC 7252 and NGC 3921. However, the debris of the remnant NGC 3256 by far contains the largest number of massive star clusters, both in the Eastern and in the Western tails. Apparently, the conditions in this remnant are more conducive to formation of these clusters.

Clearly, not all tidal debris is equally conducive to the formation of these clusters. NGC 3256 is not distinguished from the other pairs by age or by total H I mass. However, its two tidal tails are the only ones of the eight we have studied that *do not* contain tidal dwarf galaxies. NGC 7252, for example, contains in its Western tail a bright dwarf with prominent patches of star formation, and in its Eastern tail an extended low surface brightness dwarf. In both dwarfs there are point sources with $V-I < 0.5$, indicating that star formation continues well after the merger $\sim$ 750 million years ago (Hibbard & Mihos 1995). Perhaps the formation of small stellar structures (star clusters) and large stellar structures (tidal dwarfs) are mutually exclusive. Detailed comparisons of cluster

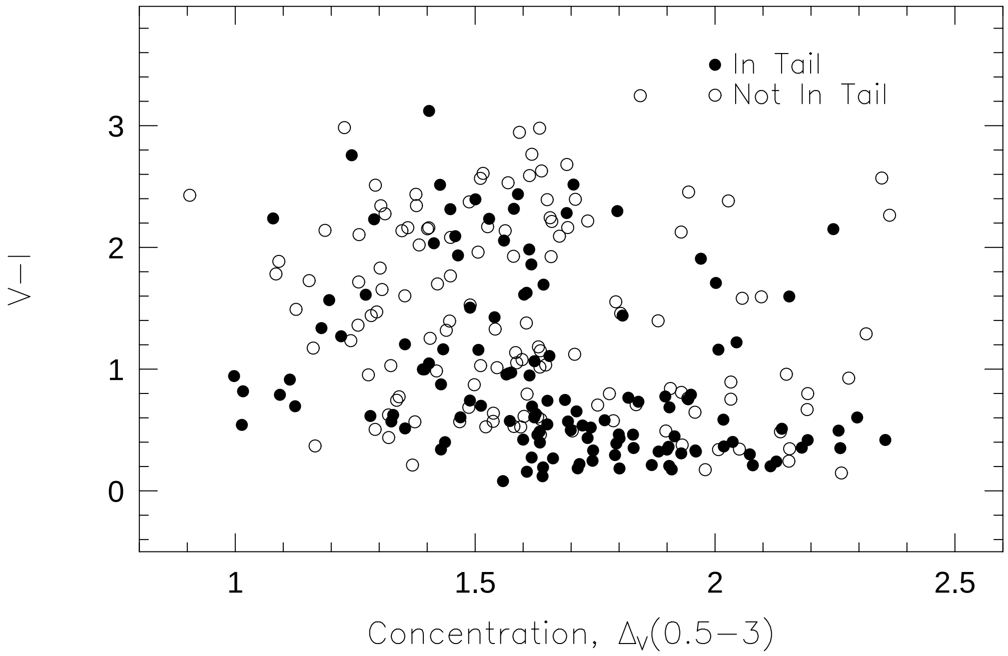

Figure 3. The concentration index is plotted vs. the $V-I$ color for sources in (solid) and out (open) of the Western tail of NGC 3256. The concentration index, $\Delta_V(0.5-3)$, provides a rough measure of cluster size, calculated from the difference in V magnitude between aperture radii of 0.5 and 3.0 pixels.

positions to high resolution 21 cm maps of H I content may also suggest factors that influence the formation and/or the packaging of stars.

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