A Restframe Comparison of Morphological Peculiarities in the Hubble Deep Field - North

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Abstract. A refined version of the asymmetry parameter of Abraham et al. (1996) and a simple concentration index are presented and compared to Abraham et al.'s (1996) C-A algorithm. A set of $z \sim 0.8$ galaxies in the Hubble Deep Field - North is then compared with a sample of local galaxies cosmologically shifted to $z = 0.8$ and "observed" using the HST WFPC-2 through the F814W filter. No significant difference in the peculiarity distribution of these two samples is found. Implications of this and later work are discussed.

1. Introduction

Several recent studies have argued that the number of peculiar objects at high redshift is much higher than it is locally (Forbes et al. 1994, Cowie et al. 1995, Abraham et al. 1996, Driver et al. 1998). The question, however, is whether this is a true evolutionary effect, or if it is simply a result of observational bandpass shifting. It has also been illustrated that galaxies that look perfectly "normal" at optical wavelengths may appear quite "peculiar" at ultraviolet (UV) wavelengths (O'Connell 1997). When observing galaxies beyond $z \sim 1$ through optical filters, one is, in fact, observing in the restframe UV. It is crucial, therefore, to understand the effects of bandpass shifting in order to properly interpret the number density of peculiar galaxies at high redshift.

Before it is possible to say anything about peculiar galaxies, one must first find an objective means of determining peculiarity. Quantitative methods for studying morphology are being developed by several groups (Schade et al. 1995, Abraham et al. 1996, Naim et al. 1997). In this work, I will present a modified version of Abraham et al.'s (1996) Asymmetry and Concentration Indices.

Following a description of the new asymmetry and concentration index algorithms, I will present a comparison of observed $z \sim 0.8$ galaxies from the Hubble Deep Field - North (Williams et al. 1996) to simulations of local galaxies cosmologically shifted to $z = 0.8$. Implications of this comparison and later work will then be discussed.

2. A Refined Asymmetry and a New Concentration Index

Abraham et al. (1996; hereafter, A96) present two new algorithms by which to quantify galaxy morphology. The asymmetry index, A, is a measure of the total flux in the residual image of a galaxy that has been rotated 180° and subtracted from itself. The concentration index, C, is a flux ratio through elliptical apertures at two normalized radii (Abraham et al. 1994). A96 found that galaxies plotted in the log(A)-log(C) plane can be separated into rough morphological classes of E/S0, Spirals, and Irregulars/Mergers.

I have developed a refined version of the A96 Asymmetry parameter, designed to avoid finding artificially high asymmetries due to poor determination of the center of rotation and the region of the galaxy to be included in the asymmetry calculation. The details of the new rotational asymmetry index are presented below. The concentration index used in this work is the ratio of the radii containing 80% versus 20% of the total light. While a direct translation of the A96 concentration index into the r_{80}/r_{20} concentration index has not been derived, the general trend for both algorithms is the same: ellipticals have high concentrations while spirals and irregulars have progressively lower concentrations.

2.1. A Pivoting Minimization

The center of rotation, or pivot point, of the new rotational asymmetry index is determined in the following manner: The image of each galaxy is first convolved with a Gaussian with $\sigma = 0.1r_{1/2}$, to smooth out bright HII regions. The pivot point is then calculated as the intensity-weighted centroid of the pixels brighter than 50% of the maximum of the smoothed image. Once the initial pivot point has been determined, the algorithm steps through two grids of pivot points to find the minimum asymmetry. The first grid is a 5x5 grid centered on the initial pivot point, with a step size of 0.5 pixels. The pivot point corresponding to the minimum asymmetry found in this coarse grid is then used as the center for the second, finer, grid. The second grid is 7x7, with a step size of 0.1 pixels. The final asymmetry for the galaxy is the minimum asymmetry found in the fine grid. This procedure for finding the pivot point provides two improvements: (1) bright regions away from the center of the galaxy will not be mistakenly chosen as the pivot point, and (2) the minimization process will yield the minimum asymmetry, even if the "best" pivot point is not found initially.

2.2. Reaching the Same Edge

The second refinement is in the determination of the area within which the rotational asymmetry is calculated. Rather than using a σ_{sky}-cut, a surface brightness cut is imposed. At high redshift, the surface brightness level is adjusted for cosmological dimming. When one simulates observing a local galaxy at various redshifts, this surface brightness adjustment ensures that the same region of the galaxy is sampled at all redshifts. This guarantees that changes in the asymmetry value are not due to simply observing a different region of the galaxy.

2.3. Comparison with Abraham et al. (1996)

A comparison of Figure 1 with Figure 2 in A96 illustrates the improvements in the asymmetry algorithm. All ellipticals now have low asymmetry values and high concentration indices, as expected. Spirals still show a wide range of both asymmetry and concentration. Included in Figure 1 are four merger candidates from Hibbard & van Gorkom (1996) (large asterisks). Three of the four objects

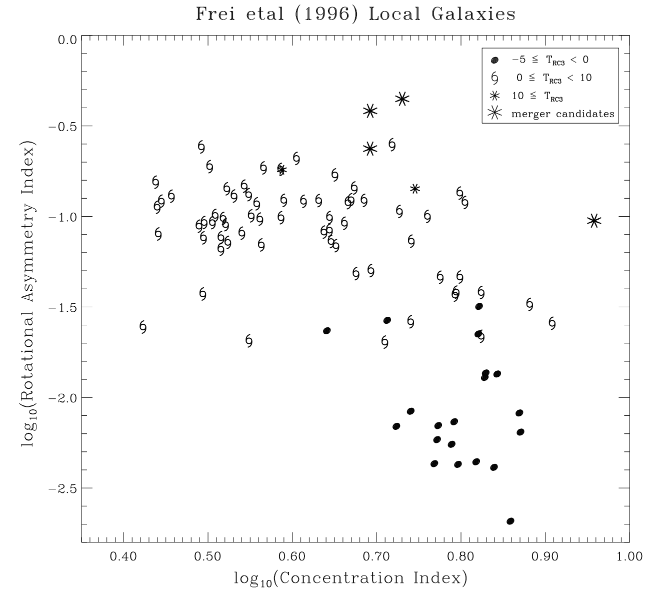

Figure 1. Refined log(Rotational Asymmetry) vs. log(Concentration Index) for local Frei et al. (1996) galaxies. Note that all ellipticals now have low asymmetry values and high concentration indices, as expected. Spirals show a wide range of asymmetry and concentration. Large asterisks mark four merger candidates from Hibbard & van Gorkom (1996).

register asymmetry values higher than the bulk of the rest of the galaxies. The fourth galaxy, NGC 7252, is believed to be a galaxy in its final stages of merger. It is dominated by a very bright, symmetric core. Since the asymmetry index is normalized to the total light of the galaxy, it is not surprising that the faint tidal features do not contribute significantly to the overall asymmetry. It is interesting to note, however, that this galaxy is still significantly more asymmetric than regular ellipticals.

With these improvements in place, let us now consider a comparison of a set of $z \sim 0.8$ galaxies in the Hubble Deep Field - North (HDF-N) with a set of local galaxies cosmologically shifted and “observed” with the WFPC-2 through the F814W filter on HST.

3. A Comparison of Observed to Simulated $z \sim 0.8$ Galaxies

In order to properly interpret the number counts of peculiar galaxies at high redshift, one must understand how the appearance of galaxies is affected by the bandpasses through which they are observed. One way in which to study this effect is to cosmologically shift local galaxies to various redshifts and simulate observing those galaxies through various filters.

I have created simulations of local galaxies taken from the Frei et al. (1996) “Catalog of Nearby Galaxies.” The local images are taken in the B_J and Thuan-Gunn g bands, i.e., roughly B-band. In order to avoid additional uncertainties

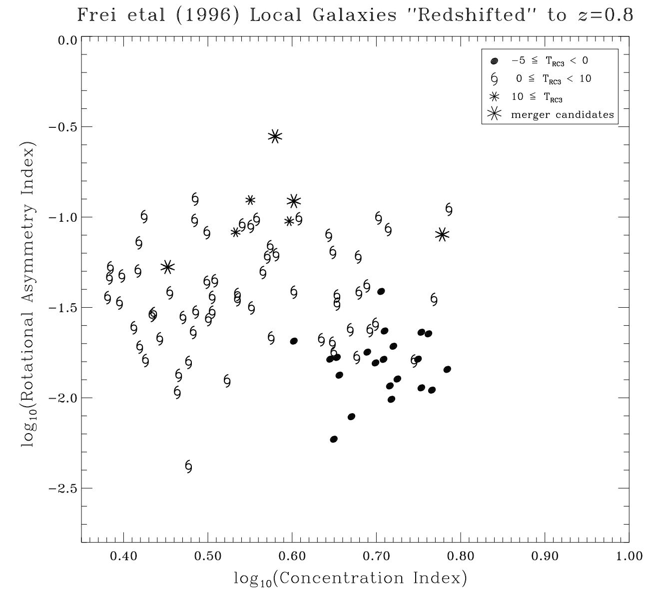

Figure 2. Refined log(Rotational Asymmetry) vs. log(Concentration Index) for "redshifted" local galaxies. Though the absolute value of the indices changes for the "redshifted" sample, asymmetric objects remain reasonably well-segregated from the bulk of the sample.

due to K-corrections, the local images are simulated to be at $z = 0.8$. At this redshift, the HST F814W filter corresponds to the restframe B-band. Direct comparisons can, thus, be made between the simulated and observed galaxies in the HDF-N.

Assuming a cosmology of $H_0 = 75$, $q_0 = 0.5$, the angular size change and surface brightness dimming of each galaxy were calculated and applied. The images were then rebinned and noise was added to simulate observing the "redshifted" galaxies through the F814W filter, as if they were in the HDF-N. As shown in Figure 2, the asymmetric objects in the "redshifted" sample remain reasonably well-segregated.

The rotational asymmetry and concentration indices were then applied to a large sample of objects in the HDF-N for which photometric redshifts have been determined by Connolly (1998) and Fernández-Soto et al. (1999). As was found by A96, a large number of asymmetric objects appears in this sample (Figure 3). If, however, one compares the subset of $z \sim 0.8$ galaxies from the HDF-N to the simulated $z = 0.8$ galaxies, one finds that the two samples have roughly the same distribution. Taking bandpass effects into account, there does not appear to be a significant new population of asymmetric objects at $z \sim 0.8$.

4. Discussion

A major question regarding the apparently large number of peculiar galaxies at high redshift is whether this is largely due to observational bandpass effects. Bandpass shifting certainly does affect the number counts of peculiar galaxies

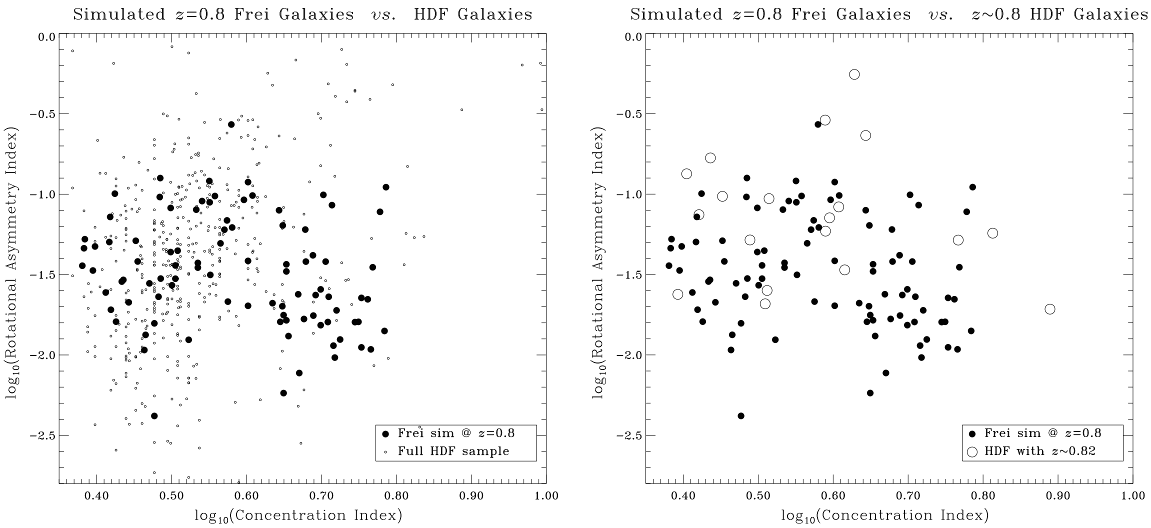

Figure 3. Refined log(Rotational Asymmetry) vs. log(Concentration Index) for the full HDF-N sample from Williams et al. (1996) *(left)* and for a subset of the HDF-N with $z \sim 0.8$ *(right)*. The "redshifted" local sample is overlaid *(filled black dots)*. Though a large number of asymmetric objects are present in the full HDF-N sample, the subset of $z \sim 0.8$ galaxies does not differ substantially from the simulated high-z sample. Note that several of the highest asymmetry objects in the full HDF-N sample are pairs that have been merged into one object.

at high redshift ($z > 1.2$?), but the fraction of the observed peculiar galaxies that are suffering from these effects is still unclear. Based on this work, galaxies at $z \sim 0.8$ (and presumably at $z < 0.8$) do not appear to be significantly more asymmetric than local galaxies. Perhaps, however, this is not unexpected, as one is sampling the restframe B-band, where local observations have shown that galaxies still appear fairly normal.

In subsequent work, I have found that a large number of objects that display high asymmetries have photometric redshift estimates beyond $z \sim 1.2$. At these redshifts, bandpass effects are more likely to play an increasingly significant role. As a step towards understanding the influence of these effects, simulations of local galaxies "redshifted" to $z = 2$ should be compared to the newly available HDF-NICMOS data. If bandpass effects are truly significant, the effect will certainly appear in this comparison.

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