HST OBSERVATIONS OF GIANT ARCS

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Abstract. We discuss HST imaging of eight spectroscopically-confirmed giant arcs, pairs and arclets. Although our HST observations include both pre- and post-refurbishment images, the depth of the exposures guarantees that the majority of the arcs are detected with diffraction-limited resolution. We present the size information on these distant field galaxies in the light of HST studies of lower redshift samples. We suggest that the dominant population of star-forming galaxies at $z \sim 1$ is a factor of 1.5–2 times smaller in size than the equivalent population in the local field. This implies either a considerable evolution in the sizes of star-forming galaxies within the last $\sim$10 Gyrs or a shift in the relative space densities of massive and dwarf star-forming systems over the same time scale.

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1. Introduction

The key to understanding the nature and evolution of the faint field galaxy population may come through morphological studies. Using WFC-1 HST Medium Deep Survey (MDS) data Mutz et al. (1994) studied the scale sizes of galaxy images as a function of redshift. They find only weak evidence for size evolution of spiral disks over the last ~ 3 Gyrs. Unfortunately, the Mutz et al. (1994) sample only probes to $I \sim 21$, corresponding to a median depth of $z \sim 0.2$, and while deeper morphological samples are available (e.g. Glazebrook et al. (1995) and Driver et al. (1995)) these have only statistical redshift information.

Ideally we would like to study the distributions of morphology and size at earlier times to observe the changes in the nature of the faint field population responsible for the steep optical counts. Such a search is hampered, however, by the faintness of these distant galaxies which makes redshift identification extremely time consuming. Thus at high redshift we are constrained to study only the intrinsically brightest and hence possibly least representative objects. Gravitationally lensed features, in particular giant arcs, may offer an alternative approach to study a small sample of "normal" distant galaxies.

If we wish to use the giant arcs to study the scale sizes of distant galaxies we must also discuss the arc detection as a function of intrinsic source size. For the giant arcs used here the high tangential amplification means there should be no bias against finding thick arcs formed from intrinsically large background sources (e.g. Wu & Hammer 1993). However, a bias may exist against identifying the strongly lensed images of compact sources, which appear as multiple, discrete images and are therefore difficult to identify. Hence, we might expect compact sources to be under represented in the current giant arc sample, allowing us to determine only a firm upper limit on the scale size distribution of distant galaxies from the study of the widths of giant arcs.

Using HST we have acquired deep optical imaging at 0.1 arcsec resolution (spatial scales of $\sim 0.5h^{-1}$ kpc) of eight spectroscopically confirmed, high redshift field galaxies which appear as arcs, pairs or arclets in the fields of moderate redshift clusters.

2. Observations and Reduction

Four of the five clusters presented (A370, AC114, Cl0024+16, A2218) were observed with WFC-1 for studies of galaxy evolution in distant clusters (Dressler et al. 1994, Couch et al. 1994). The presence of giant arcs in these fields is purely serendipitous and in some respects reflects the prevalence of such features in these rich, moderate redshift clusters. The fifth cluster

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Cl2244−02 was observed in Cycle-2 to study the arc present in the cluster and these images were retrieved from the STScI archive.

To measure half-light radii (r_{hl}) for the arcs we have chosen to correct for the extended PSF of the WFC-1 images by deconvolving our frames. The frames were therefore processed by deconvolving for 40 iterations of the Lucy-Richardson algorithm using model PSF's created with TINYTIM (Krist 1992). This procedure has been extensively tested by Windhorst et al. (1994), who report that it is adequate for restoring a galaxy's average light profile. To measure the half-light radii of the arcs we extract profiles through the arcs, orthogonal to the local shear direction indicated by the arc's shape. These profiles are effectively one dimensional slices through the source and they must be corrected, by radially weighting the profile to reflect the two dimensional geometry of the source, to give standard half-light radii, with typical measurement errors of $\sim$ 0.1 arcsec. Figure 1 gives half-light radii for the arcs measured from our HST frames. It should be noted that for all arcs, except A5 in A370, we detect the source out to $\gtrsim 3 \times$ the measured half-light radius. To estimate our resolution limit we have analyzed similarly processed stars from our images, showing that the resolution limit of HST is approximately $r_{hl} \sim$ 0.1–0.2 arcsec. Thus HST well resolves all but one arc, Cl2244−02, in our sample.

3. Discussion and Conclusions

The main aim of this study is to gain a first view of the sizes of typical star-forming field galaxies at cosmologically interesting look-back times, back to $z \sim$ 1–2 or from 8 to 11 Gyrs ago (for $h = 0.5$). To do this we must address the possibility that lensing amplification will change the observed source profile. The radial amplification, A_{rad}, of a giant arc depends upon the compactness of the lensing potential (Wu & Hammer 1993). For a lens with an isothermal mass profile the amplification is $A_{rad} = 1$. The majority of giant arcs which have been modeled in detail show that the gross properties of the very central regions of the cluster potential can be characterized by a nearly singular isothermal mass distribution with core radii of $\lesssim 25h^{-1}$ kpc (e.g. Kneib et al. 1993, Smail et al. 1995). With such a small core radius we expect the radial magnification to be $A_{rad} \sim 1$ within 10–20%. Hence we can adopt the radial light profile of the arc as an unmagnified one-dimensional slice through the source.

The half-light radii for our sample are shown in Figure 1. We have chosen to compare our sample with spirals, the dominant local population of star-forming galaxies. We use, therefore, the median size of $r_{hl} \sim 4.4h^{-1}$ kpc taken from the local spiral sample of Mathewson et al. (1992) and a more distant sample analyzed from WFC-1 MDS images by Mutz et al. (1994).

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We plot the variation in apparent angular size of the typical Mathewson disk as a function of cosmology in Figure 1. The observed arc widths follow a smooth progression from the scale lengths observed in the lower redshift samples. However, the distribution of arc widths is apparently incompatible with a non-evolving population of disks with intrinsic half-light radii $r_{hl} \sim 4.4h^{-1}$ kpc, irrespective of the adopted geometry. The mean size of the arc sources is $< r_{hl} >= (2.3 \pm 0.8)h^{-1}$ kpc. Thus the average arc source is a factor of $\sim$ 1.5–2 times smaller than would have been expected from extrapolation of the sizes of local bright star-forming systems, in standard geometries.

To indicate the strength of evolution required to connect the arc source sizes to local spirals we plot on Figure 1 a model, $r_{hl} \propto (1+z)^{-1}$, which Mutz et al. (1994) state is consistent with their observations (also see Im et al. 1995). A more detailed comparison with the Mutz et al. (1994) sample is hampered by the small samples, but what is apparent, however, is the absence of the larger sources ($r_{hl} \gtrsim 5h^{-1}$ kpc) relative to smaller sources in the arc catalogue. As we discussed earlier this cannot be explained by selection effects in the original sample and we must therefore accept that either: 1) large galaxies with very extended star-forming regions are rarer at $z \sim$ 1–2 than they are today or 2) the relative proportions of large and small galaxies has changed between $z \sim 1$ and today. The small number of giant arcs precludes us distinguishing between these alternatives. However, the latter possibility is discussed at length in Driver et al. (1995) and Glazebrook et al. (1995).

These conclusions are similar to those reached by Smail et al. (1993) who used K imaging of a sample of giant arcs, which considerably overlaps that used here, to measure the rest-frame near-infrared luminosities of the sources. They found that the arc sources had sub-K^* luminosities compared to the local field. One explanation for this difference is a lack of massive, luminous galaxies at $z \gtrsim 1$. Alternatively, this result could arise from a change in the relative abundance of dwarf galaxies compared to more massive systems. Thus the distributions of both K luminosities and sizes of $z \gtrsim 1$ field galaxies indicate that dominance of large, massive galaxies is a relatively recent feature of the field population.

The power of using arcs and arclets for studying the evolution of the sizes of faint galaxies comes from the large redshift range probed. As Kneib et al. (1995) show, it is possible, using HST observations of a well-constrained lensing cluster, to study the redshift distribution of very faint galaxies, $R \lesssim$ 26–27, from the shear induced in the galaxy images by the cluster. In principle with deep enough data this technique can be extended to study the distribution of scale sizes as a function of redshift for large samples of very faint galaxies, well beyond the reach of conventional spectroscopy.

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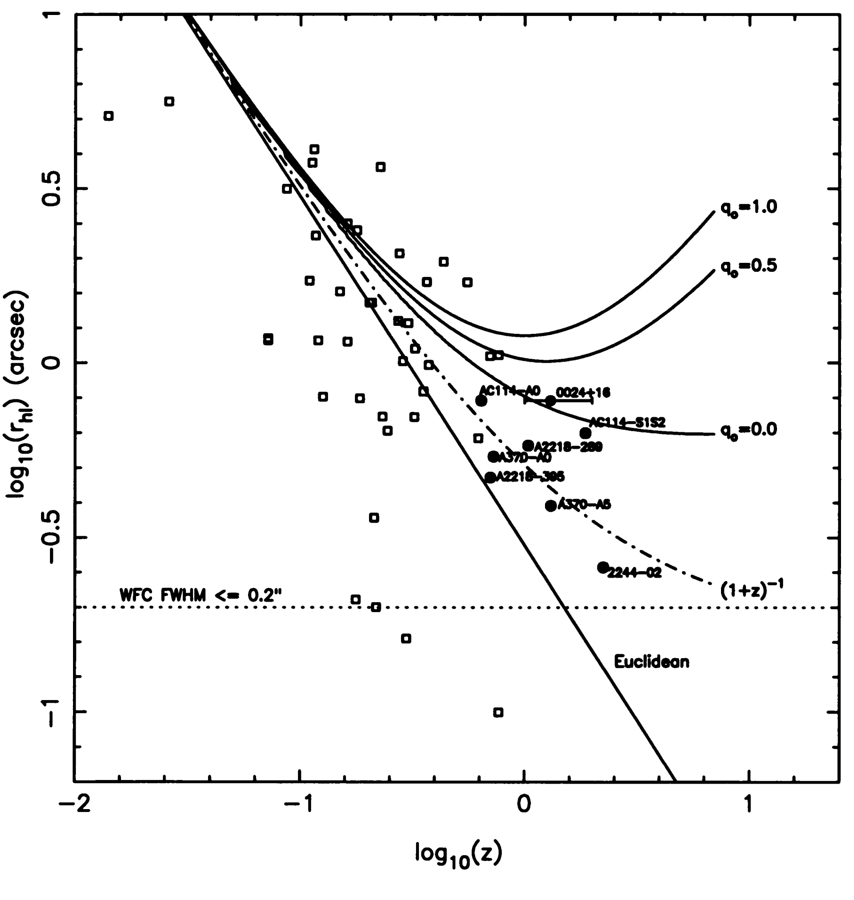

Figure 1. The distribution of observed half-light radii versus redshift for the arc sample (•). We assume no radial magnification by the lensing process. We plot for comparison the half-light radii of a moderate redshift sample (□, Mutz et al. 1994). Finally, we show the observed size of a typical local spiral galaxy from Mathewson et al. (1992), $r_{hl} = 4.4h^{-1}$ kpc, as a function of redshift in different cosmologies and the effect of a scale evolution of the form $r_{hl} \propto (1+z)^{-1}$ in a $q_o = 0.5$ cosmology. The relative dearth of large sources over smaller systems, compared to that expected from a non-evolving population of sources is readily apparent. This plot is adapted from Mutz et al. (1994).

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