

## Evidence for Mergers at $z = 0.7$

In order to address the clustering properties of galaxy cluster populations at high redshift, we acquired deep, high-resolution (FWHM 0.4 arcsec) images of the cluster GHO 0020+0407 (Gunn, Hoessel, & Oke 1986), redshift = 0.7, using the High Resolution Camera (HRCam) on the Canada-France-Hawaii Telescope (see back cover).

This cluster is obviously not a rich, centrally concentrated 'Coma-like' cluster, but is rather irregular and 'Hercules-like'. However, even at the telescope we noticed a striking incidence of close pairs with separations of 1–1.5 arcsec. The extreme distance of this cluster ( $z = 0.698$ ) and the  $(1+z)^4$  cosmological dimming of surface brightness precludes searching for the faint tidal bridges and tails we have previously found for paired 'Butcher Oemler galaxies' (Lavery, Pierce, and McClure 1992) at  $z = 0.4$ . Therefore, we chose to apply a statistical approach to assess the significance of these pairs. It is interesting to note that close pairs are also present in the nearby Hercules Cluster ( $z = 0.036$ ).

We have applied the FOCAS photometry package (Valdes 1982) to these data in order to detect, classify, and catalog the galaxies as objectively as possible. We relied on FOCAS to split galaxies with overlapping isophotes and determine the incidence of true pairs. Nevertheless, every identified galaxy was carefully examined by eye to establish that all members of the photometric catalog are really individual systems. Our photometry appears to be complete to  $R = 26$ . From field galaxy counts of Lilly, Cowie, and Gardener (1991), we estimate an enhancement of galaxies of about a factor of four is seen for this cluster for  $22 < R < 24$ .

Given our FOCAS catalog of galaxy positions and magnitudes, we have constructed a statistical description of subclustering using the angular two-point correlation function,  $w(\theta)$  (Peebles 1980). The estimator we used is given by:

$$w(\theta) = (DD - 2DR + RR)/RR$$

where DD, DR, and RR are the data-data, data-random, and random-random correlations (see Landy and Szalay 1993). The random data sets were constructed with the same number of data points spread uniformly over the field, after eliminating any pairs (random or observed) with separations less than the FWHM of our images. The resulting estimate of the correlation function,  $w(\theta)$ , is shown in Figure 20.

We also present an alternative representation of this result by constructing the distribution of nearest neighbors (Figure 21). This was done by considering each object in the catalog and searching the remaining entries for the nearest neighbor. This distribution was then compared with the mean of 500 trials of equivalent samples of random data.

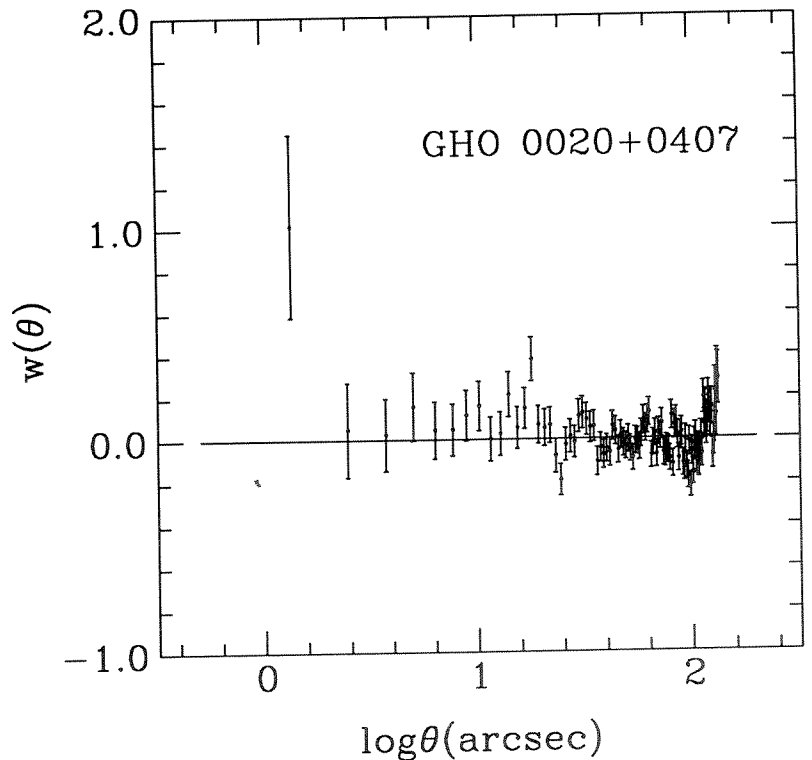


Figure 20: The two-point angular correlation function  $w(\theta)$ , for the galaxies brighter than  $R = 25.5$  and separation larger than 0.4 arcsec in the field of GHO 0020+0407. The errors are assumed to be Poissonian. The mean separation for pairs in the first bin is 1.3 arcsec.

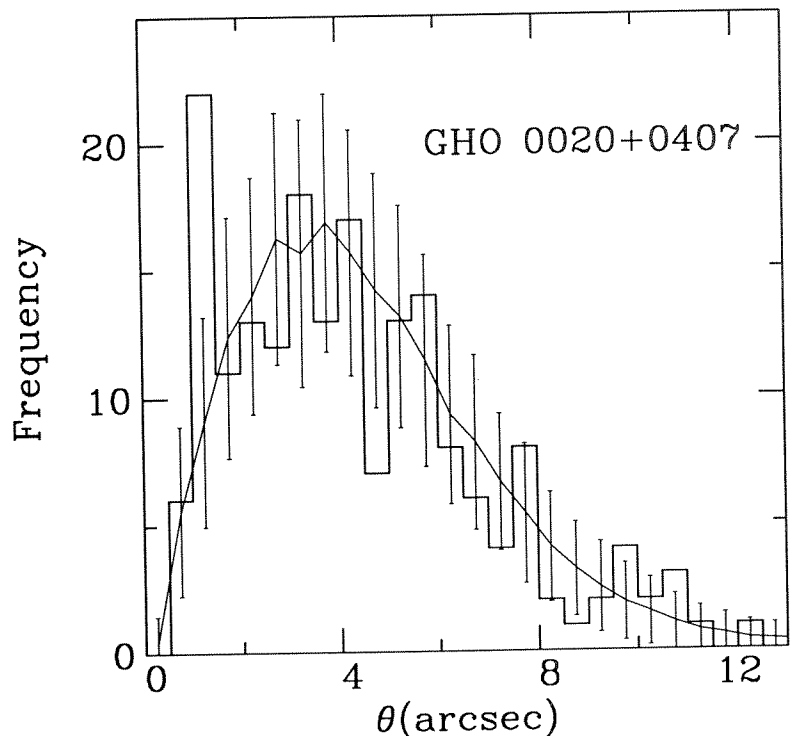


Figure 21: The distribution of nearest neighbors for the galaxies in GHO 0020+0407. The histogram is the observed distribution, while the solid curve and error bars illustrate the mean and 1 standard deviation from 500 random simulations. The enhancement at 1–1.5 arcsec separations is evident, and is significant at 99% confidence.

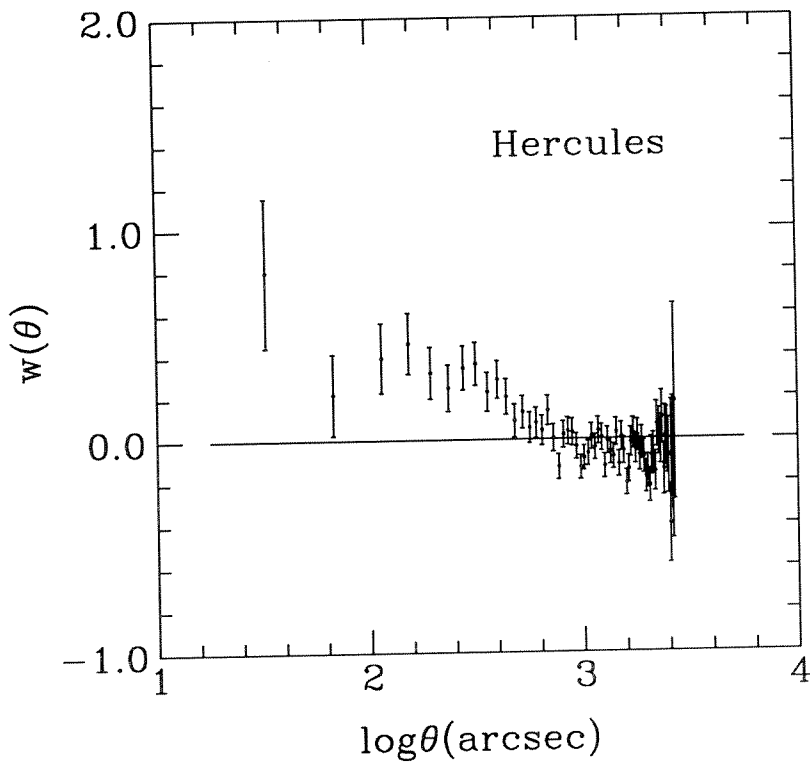


Figure 22: The two-point angular correlation function  $w(\theta)$ , for the galaxies in the field of the Hercules Cluster (from the photometry of Butcher and Oemler 1985). The mean separation for pairs in the first bin is 32.5 arcsec.

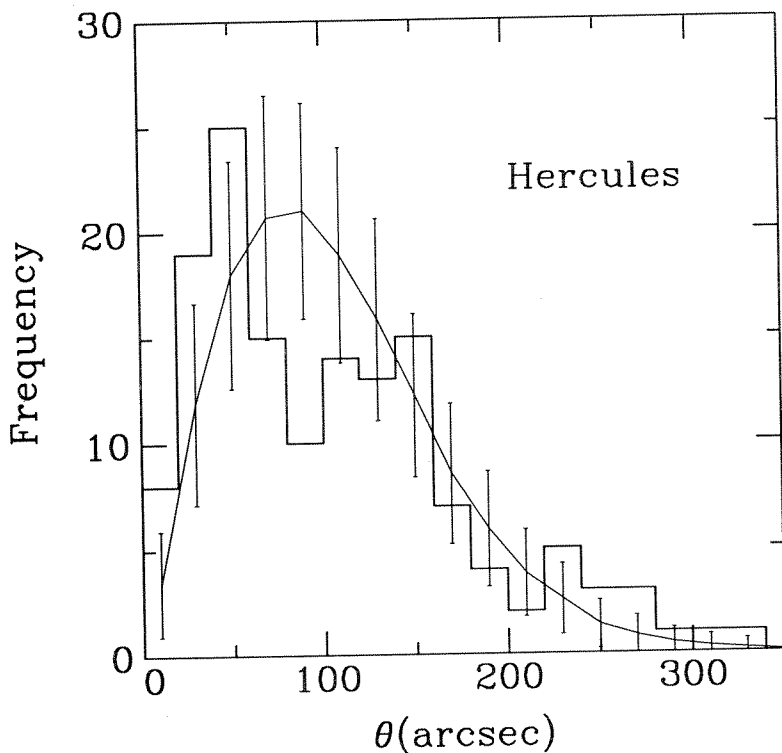


Figure 23: The distribution of nearest neighbors for the galaxies in the Butcher, Oemler (1985) field of the Hercules cluster. The histogram is the observed distribution, while the solid curve and error bars illustrate the mean and 1 standard deviation from 500 random simulations. The enhancement at 50 arcsec and smaller separations is evident.

GHO 0020+0407 bears many of the same characteristics as the well studied Hercules Cluster, both clusters being populated predominately by disk systems, and lacking a central concentration of giant ellipticals. It is well known that the Hercules Cluster has a number of close pairs with morphological distortions indicative of strongly interacting systems. We might ask, therefore, whether Hercules exhibits a statistically significant excess of close pairs, as we found for GHO 0020+0407. Figure 22 shows the angular two-point correlation using the catalog of Butcher & Oemler (1985) for Hercules. We find a similar excess of close pairs!

Our HRCam image from CFHT (FWHM = 0.42 arcsec) of GHO 0020+0407 ( $z=0.698$ ) has been used to examine the statistics of subclustering in this cluster of galaxies. Using both the two-point angular correlation function,  $w(\theta)$ , and the distribution of nearest neighbors, we have quantified the frequency of strong interactions and mergers at  $z=0.7$  (a look-back time of  $\sim 0.4 T_0$ ). We find an enhancement at small separations by nearly a factor of three over what would be expected given a random distribution within the cluster. The typical angular separations are 1 – 1.5 arcsec, corresponding to spatial separations of about 12 kpc, depending on  $H_0$  and  $q_0$ . Given that such close pairs and groups are likely to merge on timescales of about  $< 1$  Gyr, and that the luminosities of some pairs reach up to  $\sim L^*$ , it seems likely that the resulting systems will be identified as elliptical galaxies by  $z=0.3-0.4$ .

The cosmological significance of such strong interactions and mergers in the evolution of rich clusters is obviously still uncertain, but it is very interesting that a similar process appears to be occurring at the present epoch in the Hercules Cluster. Thus we conclude that interactions and mergers in rich clusters are likely related to the dynamical evolutionary state of the cluster at the particular epoch of observations. Albeit, clusters at high  $z$  may be more likely to be in the earlier stages of evolution characterized by the loose subclustered morphology favorable to strong interactions and mergers.

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## Optical Identification of a New Einstein Cross & Discovery of the Deflecting Galaxy

Q1422+231 has been discovered at VLA during a new survey of 1750 flat-spectrum radio sources (from 5 to 8.4 GHz). Radio observations have revealed its very unusual morphology since the source was made by 4 unresolved components within 1.3 arcsec, while flat spectrum radio source generally consists in a single unresolved component.