A MASSIVE CLUSTER OF GALAXIES AT Z \simeq 1

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Abstract. We report the identification of a cluster of galaxies around the high-redshift radio galaxy 3CR184 at z = 0.996. The identification is supported by an excess of galaxies observed in projection in $I$ band images (both in ground-based and HST data), a peak in the redshift distribution comprising 11 galaxies (out of 56 with measured redshifts) in a $\sim 2000$ km s$^{-1}$ velocity interval, and the observation on HST WFPC2 frames of a gravitational arc seen projected at $42h_{50}^{-1}$ kpc away from the central radio galaxy. We thus have strong evidence for the presence of a massive cluster at $z \simeq 1$.

1. INTRODUCTION

Clusters at high redshifts (at $z > 0.8$, say) are poorly known systems, essentially because their identification is a challenging observational task. Indeed, the projected 2D galaxy density on which one can rely to define a cluster at low $z$ is not valid any more at higher redshifts due to the confusion induced by the increasing population of field galaxies. Even though several innovative approaches have recently been advanced to search for high-$z$ cluster from projected data only (Postman et al. 1996, Dalcanton 1996, Pelló 1997), the unambiguous existence of a distant cluster can only be proven if several lines of evidence are combined, including the observation of a projected

excess of galaxies in a surface corresponding to a few typical core radius at
the redshift of the presumed cluster, and the measurement of a significant
overdensity in the redshift distribution of galaxies in order to reduce the
contamination by foreground and background interloper galaxies. In addi-
tion, the detection of X-ray emission, and/or evidence for weak or strong
lensing of background galaxies, provide strong support for the identification
of genuine concentration of mass. Although a number of candidates have
been proposed, only a few clusters (or proto-clusters) of galaxies have been
securely identified at \( z > 0.8 \), with the above criteria fulfilled (Dickinson
1996; Luppino & Kaiser 1996). It is, therefore, of considerable importance
for our knowledge of large scale structures to identify more high redshift
clusters in order to establish the evolution of their physical properties with
look-back time. Extending at \( z \approx 1 \) the correlation between bright radio
galaxies and associated clusters observed at \( z \approx 0.5 \) (Hill & Lilly 1991), we
present here the identification of a cluster around 3CR184 at \( z=0.996 \).

2. OBSERVATIONS

The field around 3CR184 was observed at CFHT in several runs between
1994 Jan. and 1995 Dec. with the Multi-Object-Spectrograph (MOS). Im-
aging in \( I \) band allowed to select object only on the basis of their magnitude
\( (I < 22.2) \) for spectroscopy. Four multi-slit masks with a total of 122 slits
were subsequently designed. The slits were 2'' in width and at least 10''
in length each, and the R300 grism provided a resolution of 23Å between
5000Å and 1μm. 56 objects were identified as galaxies, 26 turned out to be
galactic stars, one was identified as a QSO and 39 remained unidentified.

HST imaging was also conducted with WFPC2 during HST cycle 5.
F814W and F606W images were obtained with a respective total integration
time of 11000s and 6600s, leading to a completeness limit of \( I = 26 \). These
high resolution data revealed a gravitational arc 4.9'' to the North-East of
3CR184 (Deltorn et al. 1997) with \( I = 25 \pm 0.4 \) and \( V - I = 0.3 \pm 0.8 \). The
presence of this gravitational arc close to the central radio galaxy indicates
the proximity of a high concentration of mass.

3. EVIDENCES FOR CLUSTERING

Several estimators have been computed in order to quantify the projected
excess number of galaxies in the vicinity of 3CR184. By way of example
we show in Fig. 1 the density maps computed using the estimator \( D_{\text{proj}} \)
defined in Dressler (1980). Different cuts in color space were applied in
order to maximize the contrast toward distant (\( z \approx 1 \)) galaxies leading to
a maximum excess of \( 10\sigma_{bg} \) above the mean galaxy background (where \( \sigma_{bg} \)}