

# The faint X-ray source population near 3C 295

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**Abstract.** We present a statistical analysis of the Chandra observation of the source field around the 3C 295 galaxy cluster ( $z = 0.46$ ). Three different methods of analysis, namely a chip by chip LogN-LogS, a two-dimensional Kolmogorov-Smirnov (KS) test, and the angular correlation function (ACF) show a strong overdensity of sources in the North-East of the field, that may indicate a filament of the large scale structure of the universe towards 3C 295.

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## 1. Introduction

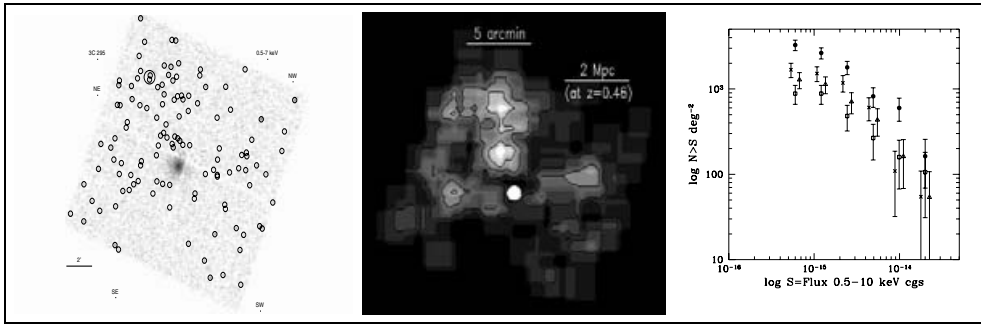
N-body and hydrodynamical simulations show that high redshift clusters of galaxies lie at the nexus of several filaments of galaxies (see e.g. Peacock 1999). Such filaments map out the “cosmic web” of voids and filaments of the large scale structure of the universe. Thus, rich clusters represent good indicators of regions of sky where several filaments converge. The filaments themselves could be mapped out by Active Galactic Nuclei (AGNs), assuming that AGNs trace galaxies.

Cappi et al. (2001) studied the distribution of the X-ray sources around 3C 295 ( $z = 0.46$ ). The cluster was observed with the ACIS-S CCD array for a short exposure time (18 ks). They found a high source surface density in the 0.5 – 2 keV band which exceeds the ROSAT (Hasinger et al. 1998) and Chandra (Giacconi et al. 2002) LogN-LogS by a factor of 2, with a significance of  $2\sigma$ .

In this work an analysis of a deeper (92 ks) Chandra observation of 3C 295 is performed, to check whether the overdensity of such a field in the 0.5 – 2 keV band is real or not, to define the structure of the overdensity, and to extend the above considerations to the 2 – 10 keV band.

## 2. Observation and data reduction

Chandra observed the  $16' \times 16'$  field around the 3C 295 cluster with ACIS-I on May 18, 2001, for 92 ks. The data reduction was carried out using the Chandra Interactive Analysis of Observations software version 2.1.3. All the data analysis has been performed separately in the 0.5 – 2 keV, in the 2 – 7 keV and in the 0.5 – 7 keV bands. An identical analysis was performed for the Chandra Deep Field South (CDFS) in the 0.5 – 2 keV and 2 – 7 keV bands for comparison, and to check our analysis methods. The source detection was carried out using the ‘PWDetect’ algorithm (Damiani et al. 1997). We identified 89 sources in the 0.5 – 2 keV band, 71 sources in the 2 – 7 keV band and 121 sources in the 0.5 – 7 keV band (see fig. 1). The counts in the 0.5 – 2 keV, 2 – 7 keV and 0.5 – 7 keV bands were converted in 0.5 – 2 keV, 2 – 10 keV and 0.5 – 10 keV fluxes using conversion factors appropriate for a  $\gamma = 1.8$  power law spectrum with a galactic absorption toward the 3C 295 field of  $N_H = 1.33 \times 10^{20} \text{ cm}^{-2}$ . Such values take into account the quantum efficiency degradation of the CCD.



Figures 1, 2, 3 (left to right). Figure 1. - The *Chandra* 3C 295 field in the 0.5 – 7 keV band. Circles represent the sources detected; the largest circle indicates an extended source, possibly a group of galaxies. The brightest source in the center of the field is the cluster of galaxies 3C 295. Figure 2. - The density map in the same band. The linear smoothing factor is 1.5 arcmin and the four contour levels indicate source densities of 1.3, 1.8, 2.2 and 2.7 sources per arcmin<sup>2</sup>. Figure 3. - The mean 3C 295 LogN-LogS in the 0.5 – 10 keV band, calculated for each ACIS-I chip separately. Filled circles represent counts for the NE chip, open triangles for the NW, open square for the SW and crosses for the SE.

### 3. Analysis

The following analysis has been performed. The sky coverage has been computed for 3C 295 and CDFS fields. The LogN-LogS in the soft and hard bands for the whole fields have been produced. The LogN-LogS in the soft, hard and whole bands have been produced separately for each ACIS-I chip of the 3C 295 observation (see fig. 3 for the 0.5 – 10 keV band). 3C 295 chip-to-chip and CDFS LogN-LogS have been fitted to evaluate slopes and normalizations (fig. 4 for the 0.5 – 10 keV band). A two dimensional Kolmogorov-Smirnov test has been applied to check whether the sources were uniformly distributed or not. The angular correlation function (ACF) has been computed in order to estimate at which scales the sources in the two fields were clustered. The ACF has been evaluated also for a sample of 8 *Chandra* fields with an exposure time similar to that of 3C 295. The errors associated to the functions (figs. 5 and 6) have been calculated using both Poisson and bootstrap statistics (Barrow, Bhavsar & Sonoda 1984).

### 4. Main results

The following results have been achieved:

3C 295 and CDFS LogN-LogS are in very good agreement both in the soft and hard band, and with the CDFS LogN-LogS by Rosati *et al.* 2002. The 3C 295 LogN-LogS in the soft, hard and broad bands computed separately for each ACIS-I chip show an overdensity of sources in the North-East (NE) chip (fig. 3) which reflects the clustering of sources clearly visible in figs. 1 and 2. The discrepancy between the normalization of the LogN-LogS for the NE and SW chip is 3.2  $\sigma$ , 3.3  $\sigma$  and 4.0  $\sigma$  in the soft, hard and broad band, respectively; fig. 4 shows the normalization vs. slope plot for the broad band.

The two-dimensional Kolmogorov-Smirnov test shows that there is a considerable probability that CDFS sources are uniformly distributed ( $P \sim 15\%$  in the soft and hard bands), while the probability that the 3C 295 sources are uniformly distributed is only a few per cent, and drops below 1% if we consider the 0.5 – 7 keV band.

The angular correlation function of the 3C 295 sources features a strong signal on scales of a few arcmins, and also on lower scales in the 0.5 – 7 keV band (fig. 5). Moreover, the function is above the value found by Vikhlinin & Forman (1995) for a large sample

of ROSAT sources. On the other hand, no signs of a similar behavior is featured by the CDFS and the sample of the 8 Chandra fields (fig. 6).

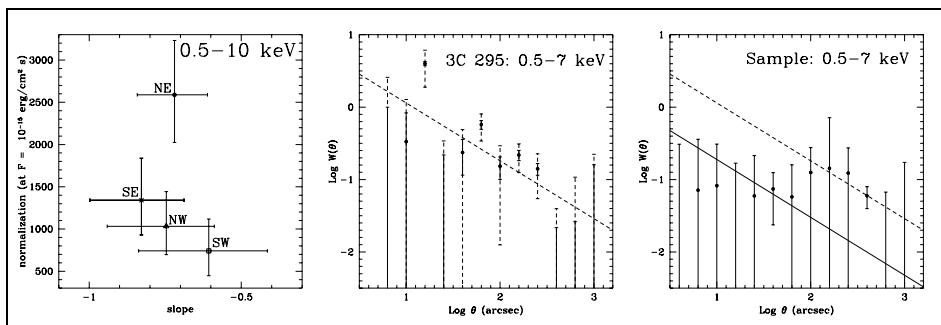
## 5. Discussion

In this work we studied in great quantitative details the excess of sources clearly visible in the upper left corner of the Chandra observation of the 3C 295 galaxy cluster field (see figs. 1 and 2). Since N-body and hydrodynamical simulations show that clusters of galaxies lie at the nexus of several filaments, this excess could represent a filament of the large scale structure of the universe.

Moreover, if the redshift of our sources were the same of 3C 295 ( $z = 0.46$ ), we could compute the galaxy overdensity of the field assuming a spherical distribution. Under these assumption, we obtain a density contrast of  $\sim 70$  which, despite large uncertainties, is intriguingly close to the expected galaxy overdensity of filaments  $\sim 10 \div 10^2$ , and much smaller than the overdensities of clusters of galaxies ( $\sim 10^3 \div 10^4$ ).

Thus, in order to study this candidate filament, further Chandra observations and optical identifications are pursued to obtain the redshift of the sources, to map out the 3C 295 region, and delimiting the filament properties up to scales of 24 arcmin (i.e.,  $\sim 6$  Mpc) from the 3C 295 cluster.

More details on the present work can be found in D'Elia et al., 2004, A&A, submitted.



Figures 4, 5, 6 (left to right). Figure 4. - Results of the power law fits to the four LogN-LogS chips in the broad band; on the x axis is the slope of the power law, y axis the normalization. Symbols refer to chips as in fig. 3. Error bars are the 90% confidence limit. Figure 5. - The 3C 295 angular correlation function (ACF) in the 0.5 – 7 keV band. The dashed line represents the best fit to the data. Solid error bars are Poisson; dashed error bars are bootstrap. Figure 6. - The ACF in the 0.5 – 7 keV band. The solid line is the best fit to these data; the dashed line is the fit to the ACF of 3C 295 (fig. 5). Error bars are bootstrap.

## References

- J.D. Barrow, S.P. Bhavsar & D.H. Sonoda 1984, MNRAS, 210, 19
- M. Cappi et al., 2001, ApJ, 548, 624
- F. Damiani, A. Maggio, G. Micela & S. Sciortino, 1997, ApJ, 483, 350
- G. Hasinger et al., 1998, A&A, 329, 482
- J.A. Peacock, 1999, "Cosmological Physics" (Cambridge: Cambridge University Press)
- P. Rosati et al., 2002, ApJ, 566, 667
- A. Vikhlinin & W. Forman, 1995, ApJ, 455, L109



Alan Dressler shows to journalist Dr. Silvia Rosa-Brusin how much dark matter is there in the universe (*by J.M. Colberg*).



Rachida Sadat and Antonaldo Diaferio at the welcome party (*by J.M. Colberg*).