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Searching for radio sources lensed by the cluster of galaxies CL0024+1654

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The cluster CL0024 + 1654 lies at redshift z= 0.39 and is one of the most optically rich clusters. It also acts as gravitational lens of a blue background (z= 1.65) galaxy; HST images show a spectacular arc system split in multiple images. In 2005, VLA observations with A and C array were requested by Wucknitz and Czoske et al. in order to better resolve its structure and to detect a possible radio halo. These observations could also be useful to search for lensed radio sources. In fact, thanks to gravitational lensing, which provides multiple images and amplication of the fluxs, it is possible to detect faint high redshift radio sources, whose emission is below the level of sensitivity of actual radiotelescopes. In order to identify multiply imaged sources, it is necessary to compare the radio maps with other wavelenghts. In our case this will be optical images of the cluster where it is clear that multiply imaged sources have already been found.
We will present radio maps in L-band of the cluster CL0024, and the results obtained by comparing radio maps with those at different wavelengths.

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1. Cluster of galaxies CL0024+1654

Cl0024 + 1654 is an example of a cluster where estimates of the mass from X-rays studies are smaller than strong lensing mass reconstruction. The discrepancy could be explained by additional sources of energy or pressure that would invalidate the assumption of hydrostatic equilibrium. Also the observed redshift distribution might indicate a merger scenario with a high speed collision of two massive clusters of galaxies (Czoske et al. 2001). An AGN-jet might occur.

2. VLA observations

We calibrated and mapped two data sets from VLA observations at 1.4 GHz that were recorded with 2 IF_S pseudo continuum mode. The first set of data were public observations associated with the central region of CL0024. These observations were made in 1994 with VLA in its B configuration. The total integration time on the source was 20 hours, the half power beam width was $\theta = 3.9$ arcsec. The second set of data were the observations in A configuration requested by Wucknitz et al. The resolution of the A-array is what is needed to resolve the strucure of the cluster and also to identify radio sources with optical ones (fig.1). Data were recorded with 2 IF_S pseudo continuum mode, with bandwiths of 25 MHz at center frequencies of 1.3649 and 1.4351 GHz. Each of these 25 MHz IF_S was further divided into seven spectral channels with a width of 3.125 MHz. In this case the total integration time was 8 hours and $\theta = 1.4$ arcsec. The expected noise level was 11 μJy. Data were processed using the NRAO AIPS package. For each data set the calibration was made in the standard way with the phase variations during the observation calibrated via short observations of the phase reference source. In both cases the whole field was imaged using the task 'IMAGR'. We detected the brightest sources, and the data were calibrated using these and other sources in the sky model. After standard calibration, in order to achieve a better resolution for the inner area of the cluster, we combined the two sets of data in the central part of the field, after substracting the brightest sources. The noise levels we reached were 10.87 μJy (B array), 20.35 μJy (A array), 11.70 μJy (combined data sets).

3. Estimates for the star formation rate from background sources

For an individual star forming galaxy, the star formation rate is directly proportional to its radio luminosity (Condon, 1992). The relation is derived by calculating the synchrotron radio emission from supernova remnants and the thermal emission from HII regions.
Assuming that there are no additional sources of energy due to AGN actvity, deep radio observations are useful to estimate the star formation rate (SFR) of distant sources. It is not clear if the SFR decreases beyond z= 1, we only know that it rises from z= 0 to z= 1. The correlation between SFR and local radio luminosity can be extended to high redshift as well (Haarsma et al., 2000); FIR and radio luminosity seem to correlate at moderate redshift as well (Garrett, 2002). This supports the idea that the radio sub-millimeter spectral index is a redshift indicator for sub-millimeter and radio source population. Taking this for granted, deep radio observations play an important role as estimator of the star formation history of the early Universe.
In the center of the field we detected radio counterparts of background sub-millimiter galaxies

PoS(MRU)138

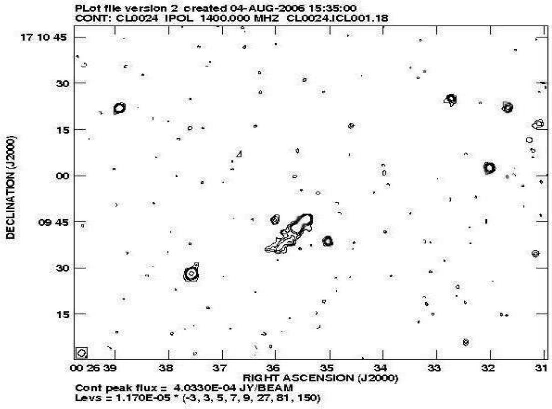

Figure 1: Radio contour map of the inner part of the cluster (combined data set). There is clear evidence for an **AGN-jet** in its centre, which has to be taken into account interpretating the X-ray data. Comparing this map with optical images it is found that there are **no multiply radio sources**

(Smail et al., 2002) and, since our observations are deep enough, for these sources we estimated the star formation rate. We used the radio/sub-mm spectral index as redshift indicator and we converted the observed luminosity of each galaxy $L_{0,\nu}$ at the observing frequency ν and redshift z to the emitted luminosity at 1.4 GHz rest frame frequency, since Condon's relationship uses the emitted source luminosity at $\nu = 1.4$ GHz. Taking into account the lens amplication, from the observed flux we found indications for the SFR in the range $10^2 \div 10^3 \quad M_{\circ} yr^{-1}$.
In our map there are also 13 sources of unknown redshift detected in ISOCAM observations (7 and 15 μm) that are also radio emitting. For these sources the radio/mid-IR spectral index cannot be considered as redshift indicator. They are likely to be background sources lensed by the cluster.

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