H$^i$ gas in the rejuvenated radio galaxy 4C29.30

Yogesh Chandola,$^{1}$* D.J. Saikia$^{1,2}$ and Neeraj Gupta$^2$

$^1$ National Centre for Radio Astrophysics, TIFR, Pune University Campus, Post Bag 3, Pune 411 007, India
$^2$ Australia Telescope National Facility, CSIRO, PO Box 76, Epping NSW 1710, Australia

Accepted. Received

ABSTRACT
We report the results of our observations of H$^i$ absorption towards the central region of the rejuvenated radio galaxy 4C29.30 (J0840+2949) with the Giant Metrewave Radio Telescope (GMRT). The radio source has diffuse, extended emission with an angular size of $\sim$520 arcsec (639 kpc) within which a compact edge-brightened double-lobed source with a size of 29 arcsec (36 kpc) is embedded. The absorption profile which is seen towards the central component of the inner double is well resolved and consists of six components; all but one of which appears to be red-shifted relative to the optical systemic velocity. The neutral hydrogen column density is estimated to be $N(H^i)=4.7\times10^{21} (T_s/100)(f_c/1.0)$ cm$^{-2}$, where $T_s$ and $f_c$ are the spin temperature and covering factor of the background source respectively. This detection reinforces a strong correlation between the occurrence of H$^i$ absorption and rejuvenation of radio activity suggested earlier, with the possibility that the red-shifted gas is fuelling the recent activity.

Key words: galaxies: active – galaxies: nuclei – galaxies: individual: 4C29.30 – radio continuum: galaxies – radio lines: galaxies

1 INTRODUCTION
One of the interesting and important questions in our understanding of active galactic nuclei (AGN) is whether such activity is usually episodic, and if so, the range of time scales of AGN activity. Besides helping to constrain models of episodic activity, this also has wider implications in our understanding of AGN feedback in structure formation and the evolution of galaxies (e.g. Sijacki et al. 2007, and references therein; Nesvadba & Lehnert 2008). In the presently widely accepted paradigm, AGN activity is believed to be intimately related to the ‘feeding’ of a supermassive black hole whose mass ranges from $\sim10^6$ to $10^{10} M_\odot$ (e.g. Marconi et al. 2004). Periodic ‘feeding’ of the supermassive black hole may lead to different cycles of activity.

For radio-loud AGN, an interesting way of probing their history and hence episodic jet activity is via the structural and spectral information of the lobes of extended radio emission. (e.g. Burns, Schwendeman & White 1983; Burns, Feigelson & Schreier 1983; van Breugel & Fomalont 1984; Leahy, Pooley & Riley 1986; Baum et al. 1990; Clarke, Burns & Norman 1992; Junkes et al. 1993; Roettiger et al. 1994; Schoenmakers et al. 2000; Gizani & Leahy 2003; Konar et al. 2006). A very striking example of episodic jet activity is when a new pair of radio lobes is seen closer to the nucleus before the ‘old’ and more distant radio lobes have faded (e.g. Subrahmanyan, Saripalli & Hunstead 1996; Lara et al. 1999). Such sources have been christened as ‘double-double’ radio galaxies (DDRGs) by Schoenmakers et al. (2000). Saikia, Konar & Kulkarni (2006) reported the discovery of a new DDRG J0041+3224 and compiled a sample of approximately a dozen such objects from the literature, including 3C236 (Schilizzi et al. 2001) and J1247+6723 (Marecki et al. 2003; Bondi et al. 2004). The inner doubles in these two sources are compact with sizes of 1.7 kpc and 14 pc respectively, and have been classified as a compact steep spectrum (CSS) and a Gigahertz peaked spectrum (GPS) source respectively. The median linear size of the inner doubles for this sample of DDRGs is $\sim$150 kpc, while the overall median total linear size is approximately a Mpc. In addition to the classic DDRGs, evidence of episodic activity may also be seen as diffuse, steep-spectrum emission from an earlier cycle of activity, in which a young double-lobed radio source may be embedded. An archetypal example of such a source, namely 4C29.30, was studied in detail by Jamrozy et al. (2007).

If the nuclear or jet activity is rejuvenated by a fresh supply of gas one might be able to find evidence of this gas via H$^i$ absorption towards the radio components in the central regions of the host galaxy. Saikia, Gupta & Konar (2007) reported the detection of H$^i$ absorption towards the inner double of the DDRG, J1247+6723. From the available information in the literature, they also suggested that there

* E-mail: chandola@ncra.tifr.res.in (YC), djs@ncra.tifr.res.in (DJS), Neeraj.Gupta@atnf.csiro.au (NG)

© RAS

\[ N(H^i) = 4.7 \times 10^{21} (T_s/100)(f_c/1.0) \text{ cm}^{-2} \]
could be a strong relationship between the detection of HI gas and rejuvenation of radio activity.

We present the results of HI absorption towards the rejuvenated radio galaxy 4C29.30 with the Giant Metrewave Radio Telescope (GMRT). The total flux density of the inner double at 1287 MHz was estimated by Jamrozy et al. (2007) to be 390 mJy when observed with an angular resolution of ~2.6 arcsec, suggesting it to be a suitable source for these observations. We describe some of the basic properties of 4C29.30 (J0840+2949) in Section 2, the observations and analyses in Section 3 and present the results and discussions in Section 4. The conclusions are summarised in Section 5.

2 4C29.30 (J0840+2949)

The radio galaxy 4C29.30 (J0840+2949) is associated with a bright (R ~ 15) host elliptical galaxy (RA 08h40m02.370, DEC +29°49′02″60 in J2000 co-ordinates) at a redshift of 0.064715±0.000133 as listed in the NASA Extragalactic Database from Wegner et al. (2001). The corresponding luminosity distance is 287 Mpc and 1 arcsec corresponds to 1.228 kpc in a Universe with $H_0 = 71$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_m = 0.27$, $\Omega_{\Lambda} = 0.73$ (Spergel et al. 2003). The radio images with arcsec resolution show a double-lobed radio source with two hotspots at the outer edges separated by ~29 arcsec (36 kpc) and a prominent jet towards the south-west (e.g. van Breugel et al. 1986; Parma et al. 1986 and references therein; Jamrozy et al. 2007). In addition there is a diffuse blob of emission towards the south-west (SW blob) with a size of ~40 arcsec (50 kpc) extending beyond the south-western hotspot. These features are all embedded in diffuse extended emission which has an angular scale of ~520 arcsec (639 kpc), which has been shown to be due to an earlier cycle of activity (see Fig. 1). The inner double has an estimated spectral age of $\lesssim$33 Myr, while the diffuse extended emission has an estimated spectral age of $\gtrsim$200 Myr (Jamrozy et al. 2007).

The radio luminosity of the inner double at 1400 MHz is $5.5 \times 10^{24}$ W Hz$^{-1}$, which is significantly below the dividing line of the Fanaroff-Riley classes, while that of the entire source is $7.4 \times 10^{24}$ W Hz$^{-1}$. In some of the DDRGs, the luminosity of the inner double is in the FRI category although its structure resembles that of FRII radio sources (cf. Saikia et al. 2006). van Breugel et al. (1986) have shown the presence of optical line-emitting gas adjacent to the radio jet along a position angle (PA) of $\sim$20° and evidence of the radio jets interacting with dense extranuclear gas. Neutral hydrogen gas has been detected in absorption with an angular resolution of 3.6 arcmin using the Arecibo telescope by Mirabel (1990), although the resolution is somewhat coarse...
Hi gas in rejuvenated radio galaxies

### Figure 2
The GMRT L-band (1332 MHz) image of the inner double from which the spectra have been extracted. The rms in the map is 0.4 mJy beam$^{-1}$ and the contour levels are $1.5 \times (-1, 1, 2, 4, 8, 16, 32)$ mJy beam$^{-1}$. The cross marks the position of the optical galaxy.

### Figure 3
The Hi absorption spectrum (histogram) towards the central component of the radio galaxy 4C29.30 (J0840+2949). The Gaussian components fitted to the absorption profile and the sum of these components i.e. the fit are plotted as dotted and continuous lines respectively. The histogram at the bottom shows the residuals shifted upwards. The arrow marks the systemic velocity as measured from the optical emission lines.

To identify the absorber against any of the main radio components.

The host galaxy of 4C29.30 appears to have merged with a gas-rich galaxy, shows presence of shells and dust (Gonzalez-Serrano, Carballo & Perez-Fournon 1993) and is associated with an IRAS source F08369+2959 (Keel et al. 2005). It is possible that this interaction may have been responsible for the rejuvenated activity seen in this source. At X-ray wavelengths Chandra detects emission from the hot spots in the southwestern radio lobe and also in the counter-lobe (Gambill et al. 2003; Sambruna et al. 2004). Both hotspots have also been detected in observations with the Hubble Space Telescope (Sambruna et al. 2004). Jamrozy et al. (2007) suggest that the X-ray emission from the hotspots consists of a mixture of non-thermal and thermal components, the latter being possibly due to gas which is shock heated by the jets from the host galaxy.

### 3 OBSERVATIONS AND ANALYSES

We observed 4C29.30 (J0840+2949) with the GMRT to search for associated 21-cm absorption towards the nuclear region and possibly from the hotspots of the inner double. The source was observed on 2009 May 05 with a bandwidth of 4 MHz for ∼6 hours including calibration overheads. Approximately 4 hours were spent observing the source. The 4-MHz bandwidth consisted of 128 spectral channels, giving a spectral resolution of ∼7 km s$^{-1}$. The local oscillator and FX correlator system were tuned to centre the baseband bandwidth at 1334 MHz, the red-shifted 21-cm frequency corresponding to $z_{em}=0.0647$. We observed the standard flux density calibrators 3C147 and 3C286 every 3 hours to correct for the variations in amplitudes and bandpass. The compact radio source J0741+312 was observed approximately every 45 minutes for phase calibration of the array.

The data were reduced in the standard way using Astronomical Image Processing System (AIPS) package. After the initial flagging or editing of bad data and calibration, source and calibrator data were examined for baselines and timestamps affected by Radio Frequency Interference (RFI). These data were excluded from further analysis. A continuum image of the source was made using calibrated data averaged over the line-free channels. Due to our interest in absorption towards the compact central source, the imaging was done without any uv cut-off or tapering in the visibility plane. This provided us with the highest possible resolution. This image was then self-calibrated until a satisfactory map was obtained. The self-calibration complex gains determined from this were applied to all the 128 frequency channels and continuum emission was subtracted from this visibility data cube using the same map. Spectra at peak position of the central source, the hotspots of the inner double and the knot in the southern jet were extracted from the cube.

### 4 RESULTS AND DISCUSSION

Our GMRT image of the source (Fig. 2) with an angular resolution of 3.60×2.35 arcsec$^2$ along a position angle of 45.7$^\circ$ and an rms noise of 0.4 mJy beam$^{-1}$ detects the inner double with a peak brightness of 78.9 mJy beam$^{-1}$ for the central component and 74.6 and 71.5 mJy beam$^{-1}$ for the northern and southern hotspots of the inner double. The peak brightness of the knot in the jet towards the south is 15.8 mJy beam$^{-1}$.

The Hi absorption spectrum towards the central component is presented in Fig. 3. Hi absorption has been detected...
clearly towards the core of this rejuvenated radio galaxy. The rms noise in the spectrum is \(\sim 1\) mJy beam\(^{-1}\) channel\(^{-1}\). The absorption profile consists of a number of components all but one of which appear red-shifted relative to the optical systemic velocity. The HI column density, \(N(\text{HI})\), for the different spectral components has been estimated using the relation

\[
N(\text{HI}) = 1.93 \times 10^{18} \frac{T_r}{T_s} \frac{\Delta v}{\Delta v_c} \frac{f_c}{f_p} \text{ cm}^{-2},
\]

where \(T_s, T_r, \Delta v\) and \(f_c\) are the spin temperature, peak optical depth, the full width at half maximum (FWHM) of the Gaussian line profile, and the fraction of background emission covered by the absorber respectively. The estimates have been made assuming \(T_s = 100\) K and \(f_c = 1.0\). The value of \(T_s\) could be significantly greater than 100 K. For example, for the warm neutral medium seen in the Galaxy \(T_s\) ranges from 5000–8000 K (Kulkarni & Heiles 1988). Such high spin temperatures are also expected to arise in the proximity of an active nucleus (Bahcall & Ekers 1969; Holt et al. 2006).

The best fit to the spectrum with six Gaussian components is shown in Fig. 2 and the fit parameters are summarised in Table 1. The sixth component requires confirmation from more sensitive observations. The Table lists the optical heliocentric velocity, \(v_{\text{hel}}\), FWHM of the Gaussian profile, the fractional absorption and the HI column density. The numbers within brackets are the errors on the quoted values. The HI column density integrated over the entire absorption profile is \(4.7 \times 10^{20}\) cm\(^{-2}\).

The HI absorption spectra towards the hotspots and the ‘southern knot’ are shown in Fig. 4. No significant absorption has been detected towards the northern and southern hotspots of the inner double or the ‘southern knot’ indicating a 3-\(\sigma\) upper limits to HI of \(N(\text{HI})=9.5 \times 10^{20}\) cm\(^{-2}\), \(N(\text{HI})=8.3 \times 10^{20}\) cm\(^{-2}\) and \(N(\text{HI})=5.5 \times 10^{21}\) cm\(^{-2}\) respectively, assuming \(T_s=100\) K, \(f_c=1.0\) and \(\Delta v=100\) km s\(^{-1}\). This indicates that the size of the absorber is less than \(\sim 35\) kpc. However, the spectra of the ‘southern knot’ and the northern hotspot show very marginal signs of absorption at \(\sim 1.948 \times 10^{4}\) km s\(^{-1}\) which needs to be confirmed from more sensitive observations.

4.1 HI gas and rejuvenation of AGN activity

Saikia et al. (2007) explored any possible relationship between rejuvenation of radio or jet activity and the occurrence of HI. Unfortunately the number of sources is still small because most of the rejuvenated radio sources have weak radio emission in the central or nuclear region. In the list of DDRGs compiled by Saikia et al. (2006) the two exceptions are 3C236 and J1247+6723, with the flux density within a few kpc of the nuclear region being \(\gtrsim 100\) mJy. The DDRG 3C236 which is a giant radio galaxy with a projected linear size of \(\sim 4250\) kpc shows evidence of star formation and HI absorption against a lobe of the inner radio source (Conway & Schilizzi 2000; Schilizzi et al. 2001; O’Dea et al. 2001). Observations with milliarcsec resolution are required to determine the location of the absorbing clouds in the case of J1247+6723 reported by Saikia et al. (2007). An interesting case is 3C293, which could be classified as a misaligned DDRG, and exhibits absorption features both blue- and red-shifted relative to the systemic velocity (Beswick, Pedlar & Holloway 2002; Beswick et al. 2004), and fast outflowing gas blue-shifted by upto \(\sim 1000\) km s\(^{-1}\) (Morganti et al. 2003; Emonts et al. 2005). The case for 3C258 (J1124+1919) as a rejuvenated galaxy is less clear. Although HI absorbing gas was reported by Gupta et al. (2006) towards the compact central source (e.g. Sanghera et al. 1995), we have not been able to confirm from GMRT observations (Saikia et al., in preparation) the weak extended emission reported by Strom et al. (1990). Another celebrated case is Centaurus A, where the inner double is due to more recent activity while the extended diffuse emission is due to earlier cycles of nuclear activity (Burns et al. 1983; Junkes et al. 1993; Ilana Feain, private communication), and HI absorption is seen towards the central region (e.g. Sarma, Troland & Rippen 2002; Morganti et al. 2008).

While the number of sources is still small, the detection of absorbing HI gas in the rejuvenated galaxies appears to be more frequent than for CSS and GPS objects (Vermeulen et al. 2003; Gupta et al. 2006), and the reported observations of 4C29.30 reinforces this trend. Although the sample size needs to be clearly increased, this trend is unlikely to be due to different source strengths. Considering the GPS objects listed by Gupta et al. (2006), which has the highest HI detection rate of \(\sim 45\) per cent, the median total flux density of the sources at \(\sim 1400\) MHz is \(\sim 2\) Jy. Amongst the rejuvenated galaxies discussed here, the flux densities at \(\sim 1400\) MHz of the entire central source of 3C236, 3C293 and Cen A are comparable to those of the GPS objects, while those of 4C29.30 and J1247+6723 are weaker than the GPS objects listed by Gupta et al. (2006). There should not be any bias because of source strength. Considering the HI column densities (Gupta et al. 2006), the median value for GPS sources is \(\sim 3 \times 10^{20}\) cm\(^{-2}\). The rejuvenated radio
Table 1. Multiple Gaussian fit to the H\textsc{i} absorption spectrum towards the central component (Fig. 3).

| Id. no. | $v_{\text{hel}}$ | FWHM | Frac. abs. | $N(\text{H}^i)_{10^{20}}$ |
|---------|------------------|-------|------------|-----------------|
|         | km s$^{-1}$      | km s$^{-1}$ |            | cm$^{-2}$       |
| 1       | 19383(2)         | 37(5)  | 0.072(0.008) | 5.4(1.4)       |
| 2       | 19457(2)         | 33(3)  | 0.222(0.009) | 16.1(2.0)      |
| 3       | 19490(1)         | 25(3)  | 0.243(0.013) | 13.4(2.1)      |
| 4       | 19519(1)         | 18(2)  | 0.238(0.018) | 9.3(1.6)       |
| 5       | 19549(4)         | 36(11) | 0.062(0.009) | 4.4(2.0)       |
| 6       | 19599(1)         | 14(4)  | 0.065(0.013) | 1.8(1.0)       |

galaxies discussed here have column densities in the range of $\sim 8-50 \times 10^{20}$ cm$^{-2}$.

5 SUMMARY

We have reported the results of 21-cm absorption towards the central component of the rejuvenated radio galaxy 4C29.30 (J0840+2949) using the GMRT. The absorption profile towards the central component is best fitted by six components, all but one of which are red-shifted relative to the systemic velocity of the parent galaxy. The total absorbing neutral hydrogen column density of the gas is estimated to be $N(\text{H}^i)=4.7 \times 10^{21} (\sigma_1/100) (f_e/1.0)^{-1}$ cm$^{-2}$. The largely red-shifted gas may be responsible for fuelling the black hole causing the renewed activity in this source. This may have been triggered by the interaction of the host galaxy of 4C29.30 with a gas-rich galaxy which appears to have merged with it (Gonzalez-Serrano et al. 1993).

No significant absorbing gas is detected towards either the northern and southern hotspots of the inner double, or the knot in the jet towards the south, the 3-$\sigma$ upper limits being $N(\text{H}^i)=9.5 \times 10^{20}$ cm$^{-2}$, $N(\text{H}^i)=8.3 \times 10^{20}$ cm$^{-2}$ and $N(\text{H}^i)=5.5 \times 10^{21}$ cm$^{-2}$ respectively, assuming $T_e=100$ K, $f_e=1.0$ and $\Delta v=100$ km s$^{-1}$. The possible very weak absorption towards the ‘southern knot’ and the northern hotspot needs confirmation from more sensitive observations. The detection of H\textsc{i} gas in this rejuvenated radio galaxy reinforces a possible close relationship between the occurrence of associated H\textsc{i} absorption due to gas clouds and evidence of renewed activity in powerful radio galaxies. Some of these absorbing gas clouds may be responsible for ‘feeding’ the supermassive black hole with a fresh supply of gas to rejuvenate the nuclear radio activity.

ACKNOWLEDGMENTS

YC thanks Aritra Basu, Vishal Gajjar, Nirupam Roy and Sandeep Sirothia for their suggestions during data analysis. We thank the referee for a few helpful suggestions, and the GMRT staff for help with the observations. The GMRT is a national facility operated by NCRA of the Tata Institute of Fundamental Research. This research has made use of the NASA/IPAC extragalactic database (NED) which is operated by the Jet Propulsion Laboratory, Caltech, under contract with the National Aeronautics and Space Administration. We thank numerous contributors to the GNU/Linux group.

REFERENCES

Bahcall J.N., Ekers R.D., 1969, ApJ, 157, 1055
Baum S.A., O’Dea C.P., de Bruyn A.G., Murphy D.W., 1990, A&A, 232, 19
Becker R.H., White R.L., Helfand D.J., 1995, ApJ, 450, 559
Beswick R.J., Pedlar A., Holloway A.J., 2002, MNRAS, 329, 620
Beswick R.J., Peck A.B., Taylor G.B., Giovannini G., 2004, MNRAS, 352, 49
Bondi M., Marchâ, M.J.M., Polatidis A., Dallacasa D., Stanghellini C., Antón S., 2004, MNRAS, 352, 112
Burns J.O., Feigelson E.D., Schreier E.J., 1983, ApJ, 273, 128
Burns J.O., Schwendeman E., White R.A., 1981, ApJ, 271, 575
Clarke D.A., Burns J.O., Norman M.L., 1992, ApJ, 395, 444
Conway J.E., Schilizzi R.T., 2000, in Conway J.E., Polatidis A.G., Booth R.S., Pihlstrm Y.M., eds, EVN Symp. 2000, Onsala Space Observatory, p. 123
Emonts B.H.C., Morganti R., Tadhunter C.N., Oosterloo T.A., Holt J., van der Hulst J.M., 2005, MNRAS, 362, 931
Gambill J.K., Sambruna R.M., Chartas G., Cheung C.C., Maraschi L., Tavecchio F., Urry C.M.; Pesce J.E. 2003, A&A, 401, 505
Gizani N.A.B., Leahy J.P., 2003, MNRAS, 342, 399
Gonzalez-Serrano J.I., Carballo R., Perez-Fournon I., 1993, AJ, 105, 1710
Gupta N., Salter C.J., Saikia D.J., Ghosh T., Jeyakumar S., 2006, MNRAS, 373, 972
Holt J., Tadhunter C., Morganti R., Bellamy M., González Delgado R.M., Tzioumis A., Inskip K.J., 2006, MNRAS, 370, 1633
Jamrozy M., Konar C., Saikia D.J., Stawarz L., Mack K.-H., Siemiginowska A., 2007, MNRAS, 378, 581
Junkes N., Haynes R.F., Harnett J.I., Jauncey D.L., 1993, A&A, 269, 29
Keel W.C., Irby B.K., May A., Miley G.K., Golombek D., de Grijp M.H.K., Gallimore J.F., 2005, ApJS, 158, 139
Konar C., Saikia D.J., Jamrozy M., Machalski J., 2006, MNRAS, 375, 693 (astro-ph/0607660)
Kulkarni S.R., Heiles C., 1988, in Galactic and Extragalactic Radio Astronomy, ed. G. Verschuur & K. Kellerman (Heidelberg: Springer), 95
Lara L., Márquez I., Cotton W.D., Ferlet L., Giovanni G., Marcaide J.M., Venturi T., 1999, A&A, 348, 699
Leahy J.P., Pooley G.G., Riley J.M., 1986, MNRAS, 222, 753
Marconi A., Risaliti G., Gilli R., Hunt L.K., Maiolino R., Salvati M., 2004, MNRAS, 351, 169
Marecki A., Barthel P.D., Polatidis A., Owersianik L., 2003, PASA, 20, 16
Mirabel I.F., 1990, ApJ, 352, L37
Morganti R., Oosterloo T.A., Emonts B.H.C., van der Hulst J.M., Tadhunter C.N., 2003, ApJ, 593, 69
Morganti R., Oosterloo T., Struve C., Saripalli L., 2008, A&A, 485, L5
Nesvadba N.P.H., Lehnert M.D., 2008, in Charbonnel C., Combes F., Samadi R., eds. SF2A-2008: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics (http://proc.sf2a.asso.fr), p. 377
O’Dea C.P., Koekemoer A.M., Baum S.A., Sparks W.B., Martel A.R., Allen M.G., Macchetto F.D., Riley G.K., 2001, AJ, 121, 1915
Parma P., de Ruiter H.R., Fanti C., Fanti R., 1986, A&AS, 64, 135
Roettiger K., Burns J.O., Clarke D.A., Christiansen W.A., 1994, ApJ, 421, 23L
Saikia D.J., Konar C., Kulkarni V.K., 2006, MNRAS, 366, 1391
Saikia D.J., Gupta N., Konar C., 2007, MNRAS, 375, L31
Sambruna R.M., Gambill J.K., Maraschi L., Tavecchio F., Cerutti R., Cheung C.C., Urry C.M., Chartas G., 2004, ApJ, 608, 698
Sanghera H.S., Saikia D.J., Luedke E., Spencer R.E., Foulsham P.A., Akujor C.E., Tzioumis A.K., 1995, A&A, 295, 629
Sarma A.P., Troland T.H., Rupen M.P., 2002, ApJ, 564, 696
Schilizzi R.T. et al., 2001, A&A, 368, 398
Schoenmakers A.P., de Bruyn A.G., Röttgering H.J.A., van der Laan H., Kaiser C.R., 2000, MNRAS, 315, 371
Sijacki D., Springel V., di Matteo T., Hernquist, L. 2007, MNRAS, 380, 877
Spergel D.N. et al., 2003, ApJS, 148, 175
Strom R.G., Riley J.M., Spinrad H., van Breugel W.J.M., Djorgovski S., Liebert J., McCarthy P.J., 1990, A&A, 227, 19
Subrahmanyan R., Saripalli L., Hunstead R.W., 1996, MNRAS, 279, 257
van Breugel W., Fomalont E.B., 1984, ApJ, 282, 55L
van Breugel W.J.M., Heckman T.M., Miley G.K., Filippenko A.V. 1986, ApJ, 311, 58
Vermeulen R.C. et al., 2003, A&A, 404, 861
Wegner G., et al. 2001, AJ, 122, 2893