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# VSOP and VLBI observations of the CSS quasar 3C 309.1

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**Abstract.** We present our most recent results from observations made with VSOP and VLBA at 1.6 GHz, 4.8 GHz and 15 GHz of CSS quasar 3C 309.1. These are a new maps obtained with ∼ 2 times better resolution then the previous ones (1.7 GHz and 5 GHz). 3C 309.1 is one of the most luminous CSS quasars. Compared with the classical core-dominated quasars like 3C 273 it has 20 times higher luminosity. The recent maps obtained by our group reveal an unusually bright complex jet and a weak core that vary in intensity and size. The complex structure of 3C 309.1's jet may be explained by a relativistic helical flow.

## 1. Introduction

The powerfull CSS radio source 3C 309.1 ($L_{178MHz}$=8 × $10^{28} WHz^{-1}$) (Kus et al. 1990) has a stright, steep radio spectrum ($\alpha = 0.69$, $S \propto \nu^{-\alpha}$) between 1 and 10 GHz and overall extent of $\leq 2''$ (Wilkinson 1972); it is identified with relatively bright QSO (V=16.9 mag, z=0.904) (Burbidge & Burbidge 1969). This combination of radio properties is unusual for a source of high intrinsic luminosity. Normally, such luminous steep-spectrum sources are FR II 'classical doubles' (Fanaroff & Riley 1974) whose maximum extent is >100 kpc, whereas asymmetric core-dominated sources with linear sizes similar to 3C 309.1 have very different spectra - often with a high frequency excess. The studies of this quasar (Wilkinson et al. 1984; Kus et al. 1981; Kus et al. 1990; Pearson & Readhead 1984; Akujor & Garrington 1995) by VLBI, MERLIN and VLA reveal a very complicated, complex radio structure. The results presented there indicate no changes in the position of the major features of 3C 309.1's jet but there are changes in the shape and brightness. The observed radio properties of 3C 309.1 can be explained under the assumption of projection of a FR II radio galaxy (Kus et al. 1990).

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## 2. Observations

We observed 3C 309.1 at 1.6 GHz (1997, December 17), 4.8 GHz (1998, May 11) using the *HALCA* (VSOP - VLBI Space Observatory Programme (Hirabayashi et al. 1998)) and at 15 GHz (2002, September 1) using Very Long Baseline Array (VLBA) (Napier et al. 1994). The data were recorded in the

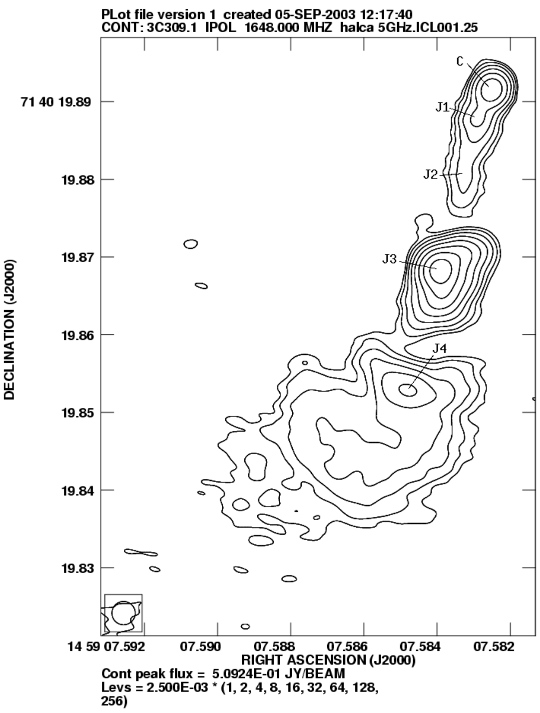


**Fig. 1.** VSOP map of 3C 309.1 at 1.6 GHz.

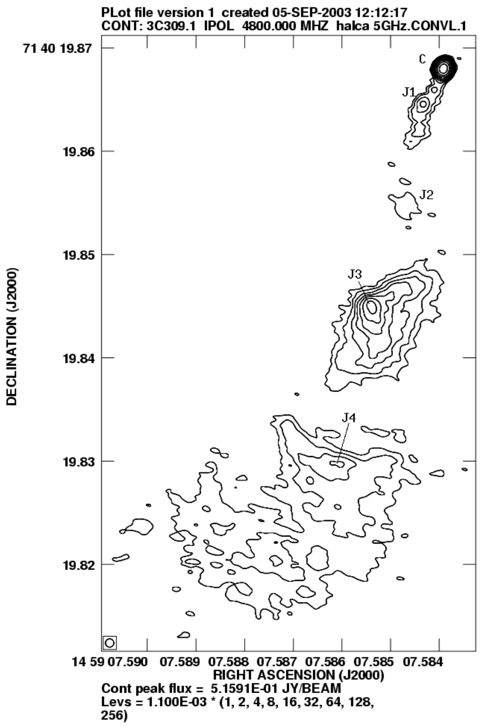


**Fig. 2.** VSOP map of 3C 309.1 at 4.8 GHz.

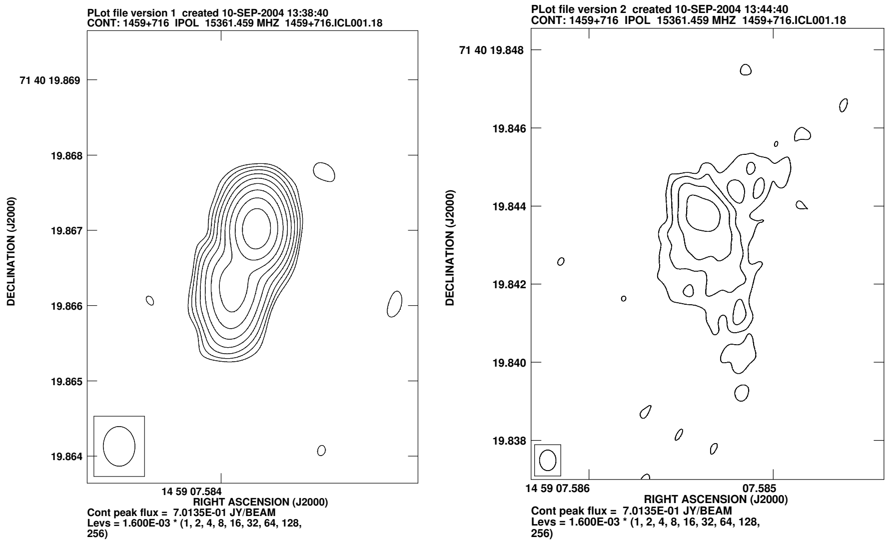


**Fig. 3.** VLBA map of 3C 309.1 at 15 GHz. *Left*: core C. *Right*: 'banana-shaped' bent component J3.

VLBA format (Rogers 1995) and correlated at the VLBA correlator in Socorro (Benson 1995). In both VSOP projects we used all VLBA stations and two European stations (Effelsberg, Germany; Toruń, Poland). The tracking stations in Goldstone (USA) and Tidbinbilla (Australia) were used for the *HALCA* data acquistion. We used AIPS (The NRAO Astronomical Image Processing System) for postprocessing of the correlated data set. The a priori calibration was determined from thw antenna gain and system temperature measuments, including that of the *HALCA* radio telescope (Moellenbrock et al. 2000). We corrected the delay and phase residuals for each antenna and intermediate-frequency (IF) band using the task FRING. To improve the signal-to-noise ratio of solutions we fringe-fitted the *HALCA* data using the source model obtained by imaging the ground-ground VLBI data.

## 3. Results

From the final fringe-fitted VSOP data set, we produced four images (two on each frequency: an image with all data included (hereafter VSOP image) and an image using onlu ground-ground baseline data included. The resulting VSOP images are shown in Figs. 1 & 2. At 15 GHz we were able to detect only core (component C) and 'banana-shaped' component J3. The close-up of those features is shown in Fig. 3 The physical conditions along jet can now be better understood in terms of current AGN models. The derived physical parameters of source components are listed in Tab. 1. We calculated them on the assumption of equipartition and of equal energy in electrons and protons. Minimum internal energy density and equipartition magnetic field have been estimated using well known formulas (Miley 1980). The complex structure of 3C 309.1's jet could be satisfactory explained by a relativistic helical flow (Kus et al. 1990).

| Region | $T_b$ (K) | $B_{eq}$ ($10^{-3}$G) | $u_{min}$ ($10^{-6} erg cm^{-3}$) | $U_{min}$ ($10^{55} erg$) |
|---|---|---|---|---|
| (1) | (2) | (3) | (4) | (5) |
| C | $9.6 \times 10^9$ | 7.5 | 5.3 | 2.4 |
| J1 | $1.3 \times 10^9$ | 8.3 | 6.5 | 5.5 |
| J2 | $3.8 \times 10^8$ | 3.6 | 1.2 | 2.1 |
| J3 | $3.9 \times 10^9$ | 12.0 | 13.3 | 6.6 |
| J4 | $3.2 \times 10^9$ | 6.6 | 4.0 | 4.6 |

**Table 1.** Properties of the 3C 209.1's jet components. Note-Col.(2): Brightness temperature at 1.6 GHz. Col.(3): Magnetic field intensity. Col.(4) Minimum internal energy. Col.(5): Total energy. We assumed $H_0 = 75\ kms^{-1} Mpc^{-1}$ and $q_0 = 0.5$.

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