VSOP/global VLBI observations of 2021+614: Detection of hotspot advance

W. Tschager [a,1] R.T. Schilizzi [b,a] I.A.G. Snellen [c,1]
A.G. de Bruyn [d] G.K. Miley [a,1] H.J.A. Röttgering [a,1]
H.J. van Langevelde [b] C. Fanti [e,f,1] R. Fanti [e,f,1]

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[a] *Leiden Observatory, P.O. Box 9513, 2300 RA Leiden, The Netherlands*
[b] *JIVE, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands*
[c] *Institute of Astronomy , Madingley Rd, Cambridge CB3 OHA, UK*
[d] *NFRA, P.O. Box 2, 7990 AA Dwingeloo, The Netherlands*
[e] *Institute of Radio Astronomy, Via Gobetti 101, 40126 Bologna, Italy*
[f] *Dep. of Physics, Univ. of Bologna, Via Irnerio 46, 40129 Bologna, Italy*

Abstract

We have analysed VSOP and global VLBI data at 5 GHz and VLBA + Effelsberg data at 15 GHz for 2021+614. By identifying the core as being between two bright hotspots, we show that 2021+614 is a compact symmetric object of size $\sim$ 40 pc. From comparison with earlier observations we deduce an apparent age of $\gtrsim$ 450 yr for 2021+614. This provides additional support for the contention that compact symmetric radio objects associated with galaxies are in fact *young* radio sources and the possible precursors of the classical FR I or FR II radio galaxies.

Key words: radio continuum: galaxies, galaxies: evolution, methods: data analysis
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1 Introduction

Extragalactic radio sources have been studied for many years, but it is still unclear how they are formed and evolve. A crucial element in the study of their early evolutionary stage is to identify the young counterparts of *old* FR I/FR II extended objects. Good candidates for young radio sources are those with peaked spectra, Gigahertz Peaked Spectrum (GPS) sources, and Compact Steep Spectrum (CSS) sources, because they are small in angular size as expected for a young source. GPS sources are characterized by a simple convex radio spectrum peaking at a frequency of about 1 GHz and are typically $\lesssim 1$ kpc in size. CSS sources have peaks in their spectra at lower frequencies and have projected linear sizes of < 15 kpc.

Owsianik & Conway (1998) have measured the propagation velocity of the hot spots of 0710+439, a GPS source, to be $0.244\,h^{-1}\,c$. Assuming a constant propagation velocity, this corresponds to an age of 1400 ± 150 yr for this GPS source. Evidence exists that the age of the GPS galaxy 2021+614 is also about 1000 years (Conway et al., 1994; Pearson, 1995). It therefore appears that peaked spectrum sources are indeed young radio sources and are the objects of choice with which to study the initial evolution of extragalactic radio sources. It is obviously of interest to examine these young sources at a number of points along their evolutionary track, and to carry out that investigation at radio wavelengths, with a range of angular resolution, limiting flux density, and observing frequency. As part of this programme, we were granted observing time with VSOP (AO-1) at 5 GHz for a sample of 11 GPS sources. These observations have been complemented by global VLBI observations at 15 GHz.

2 The Sample

The 11 GPS sources in our sample (namely 0108+388, 1404+286, 1622+663, 2021+614, 0248+430, 0552+398, 0615+820, 0636+680, 0646+600, 1333+459 and 1550+582) are all those known in November 1995 with declination, $\delta > 25°$, peak frequency, $\nu_{\mathrm{peak}} \sim 5$ GHz, and peak flux-density, $S_{\mathrm{peak}} \gtrsim 0.5$ Jy. At the time of the 4th EVN Symposium, 5 of the 11 objects had been observed with VSOP and a global ground array, but only 2021+614 has been taken through the complete data reduction procedure. In this contribution, we report on the results of the preliminary data analysis. All objects in the sample were observed with the VLBA and the 100-m Effelsberg radio telescope at 15 GHz to obtain matched beam spectral index data. Here, in addition to the space-VLBI experiment, we present the global VLBI map for 2021+614.

3 The radio galaxy 2021+614

3.1 Optical and radio properties

The optical counterpart of 2021+614 is an elliptical galaxy at redshift 0.2266. It is a highly reddened narrow line radio galaxy most probably with a considerable dust component within the optical object (Bartel et al., 1984a). The asymmetric shape of the [OIII] (λ_0 5007) emission line profile indicates that the nucleus contains clouds with velocity differences of 780 km/sec. Deep CCD imaging by O'Dea et al. (1990) shows that the galaxy has a prominent compact nucleus and two possible companions within 12″. The radio spectrum of 2021+614 has a broad, relatively flat peak centred at about 4 GHz, and falls off at lower and higher frequencies. The flattening of the spectrum at highest radio frequencies indicates the presence of a very compact component. The flux density above the spectral peak shows variability (Aller et al., 1992; Conway et al., 1994).

3.2 The Observations

HALCA observed 2021+614 on 6 November 1997 together with a 15 station ground-based array composed of 10 VLBA and 4 EVN radio telescopes plus the VLA in phased-array mode. The on-source time was 9 hours for the ground telescopes and 6 hours for the satellite. The tracking stations used to downlink the data and relay the local oscillator signal to the satellite were located at the Deep Space Network sites at Goldstone in California (USA) and Tidbinbilla (Australia).

The global VLBI observing run at 15 GHz on 9 October 1998 included the VLBA and the Effelsberg 100-m radio telescope. Both data sets were correlated at the NRAO Array Operating Center in Socorro, NM, USA. The VSOP and global VLBI images at 5 and 15 GHz, respectively, are shown in Fig. 1. The VSOP image was obtained following standard calibration procedures for space-VLBI data reduction as recommended by the AIPS Cookbook (NRAO AIPS package, version Apr98). Self-calibration and mapping were carried out with the Difmap program (Shepherd et al., 1995) applying uniform weighting to the data points. In order to simplify the comparison of the two maps they are restored with a circular 0.5 mas beam. The rms noise in both maps is about $800\,\mu\mathrm{Jy}$/beam.
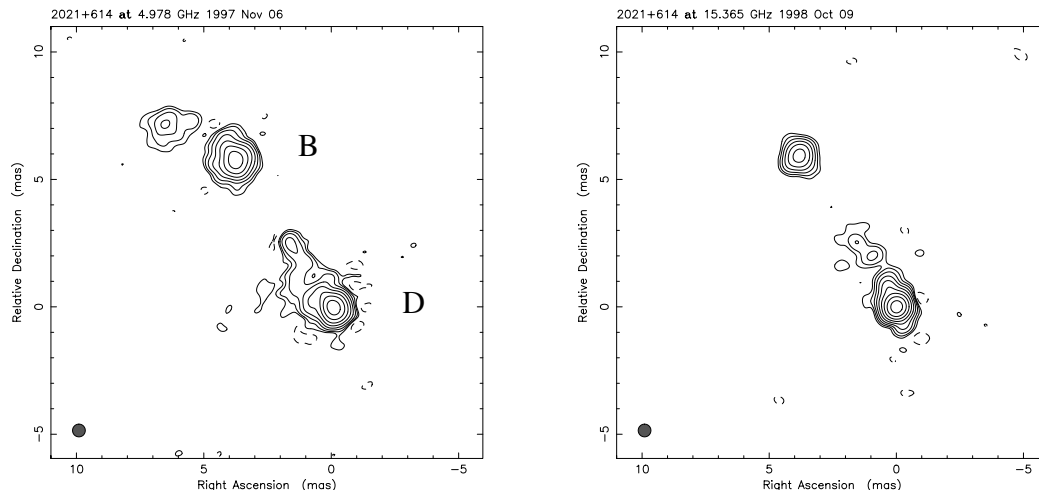
Fig. 1. (left) 5-GHz VSOP image and (right) 15-GHz global VLBI image. Both images are restored with a circular beam of 0.5 mas. Map peaks are 0.7 Jy/beam and 1.33 Jy/beam respectively. Contour levels are drawn at -0.5, 0.5, 1, 2, . . . , 64 % of the map peak.

3.3   Previous VLBI observations

High angular resolution observations of 2021+614 at 2.3, 5 and 8.4 GHz have been published by Wittels et al. (1982), Bartel et al. (1984b), Pearson & Read-head (1988) and Conway et al. (1994). Cawthorne et al. (1993) determined that there is no significant linearly polarised emission from any of the components with upper limits of 5 mJy. The source 2021+614 was also observed by Kellermann et al. (1998) during their 2-cm survey campaign.

4   Discussion

Following Bartel et al. (1984b) we label the components A to D starting from the NE. At the redshift of the object, the overall linear extent is ~ 40 pc. As noted by other investigators, the morphology of 2021+614 is dominated by components B and D. Decomposition of the total radio spectrum on the basis of multi-frequency VLBI by Bartel et al. (1984b) and Conway et al. (1994) makes it clear that the individual component spectra peak at slightly different frequencies causing the overall spectrum between 2 and 10 GHz to be relatively flat for a GPS source. On the basis of D being the most compact component, as well as being variable in flux density (Conway et al., 1994), both groups suggested that it is the site of the nucleus of the galaxy.

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Our VSOP image (Fig. 1, left), however, shows that at the higher resolution provided by the space baselines, a compact component is visible between B and D at the end of an oscillating[2] low brightness jet in the direction of D. We identify this central component as being the core of the radio source. This is confirmed by unpublished observations at 15 and 22 GHz, with similar beamsizes to our VSOP data, by Kellermann et al. and Wilkinson et al. respectively (priv. comm.). Both data sets reveal a compact component in the centre, which is slightly less prominent than in our observations at 5 GHz, thus indicating a flat spectrum with a spectral index of ~ -0.2 ($S \propto \nu^{\alpha}$) between 5 GHz and 22 GHz. This provides strong evidence for a faint, self-absorbed central component. Additional evidence that this is the nucleus comes from its variable flux density at 15 GHz as measured by Kellermann et al. (priv. comm.) in 1994, 1995, 1996 and 1997 and our measurement in 1998 (Fig. 1, right).

A careful analysis of the positions of components B and D by Conway et al. (1994) using model fitting techniques showed that the component separation changed by 69 μas in 4.81 yr, corresponding to an apparent speed of separation of $0.11\,h^{-1}\,c$ ($H_0 = 100\,h\,\mathrm{km\,s^{-1}\,Mpc^{-1}}$, $q_0 = 0.5$). We have made a first order estimate of the separation of B and D ten years after Conway et al.'s observations, and find a rate of separation of ~ 15 μas/yr, (Fig. 2, left) which means that the two components were ejected ~ 450 yr ago assuming constant velocity. With respect to the weak central component at the nucleus the speed of separation is $\sim 0.06\,h^{-1}\,c$. We carried out our model fitting on the 5-GHz global VLBI uv-data set (excluding Earth-HALCA baselines); the resulting best model included 5 components (Fig. 2, right).

5   Conclusions

We confirm that 2021+614 is one of a small group of compact symmetric sources for which speeds of separation can be measured. All have apparent ages of a few hundred to a thousand years, and are thus good candidates for being young sources. In the case of 2021+614 we measure a separation rate of $0.12\,h^{-1}\,c$ between the two dominant components, B and D, and deduce an apparent age of $\sim$450 yr.

Acknowledgments

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[2] During the symposium Steven Tingay argued that the oscillating appearance of the jet could be artificial, due to bad spatial frequency sampling in intermediate regions between Earth-Earth and Earth-HALCA baselines.
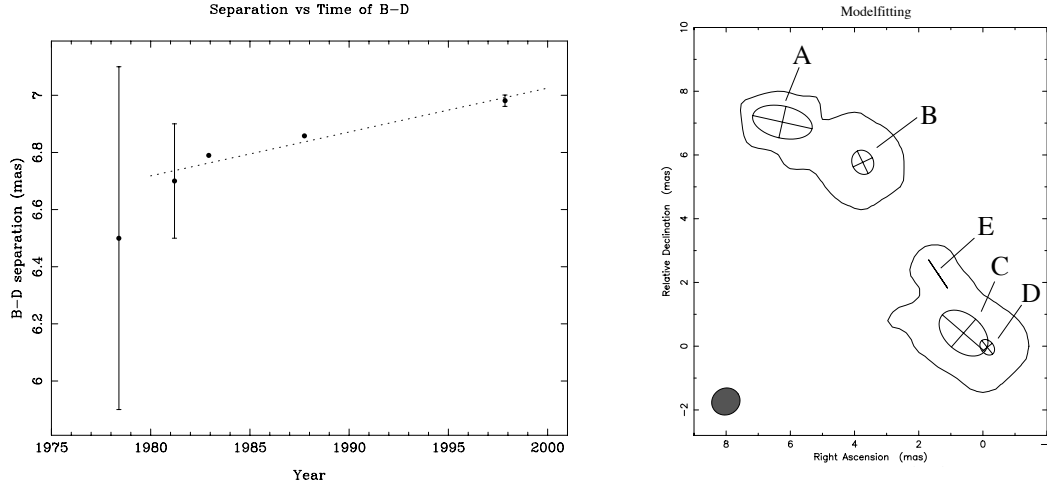
Fig. 2. (left) Separation vs time diagram for components B and D. Component separations at 1978.4 and 1981.2 with 1-σ error bars are from Wittels et al. (1982) and Bartel et al. (1984b), respectively. The 1982.93 and 1987.74 data points (without errors) are from Conway et al. (1994). Our measurement is shown at epoch 1997.85. The error represents an estimate of the maximum uncertainty in separation. The dashed line is a best fit to 4 data points and gives an apparent separation velocity of 15 μas/yr, i.e. $0.12\,h^{-1}\,c$. Fig. 2 (right) The 5-component model used for the determination of the B-D separation.

ments for the 1982.93 and 1987.74 data points in Fig. 2 (left). We gratefully acknowledge the VSOP Project, which is led by the Japanese Institute of Space and Astronautical Science in cooperation with many organisations and radio telescopes around the world.

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