Space VLBI observations of the extremely distant quasars 0201+113 and 0537−286

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There are about 20 radio sources identified to date as high redshift ($z > 3$) quasars that are observable by, and have therefore been proposed for, the VLBI Space Observatory Programme (VSOP, Hirabayashi *et al.* 1998). These are among the most distant and most luminous objects known in the Universe. The goals and other preliminary results of this VSOP project are reported elsewhere (Hirabayashi *et al.* 1998; Gurvits *et al.* 2000; Lobanov *et al.* 2001). Here we present the results of three recent observations.

The quasar 0201+113 (z=3.61, White *et al.* 1993) was observed at both 1.6 and 5 GHz frequencies with the VSOP satellite HALCA and ground-based arrays consisting of small numbers of radio telescopes. The 1.6 GHz observation took place on 31 Jul 1999. The participating ground telescopes were Hartebeesthoek, Mopra, Noto and Tidbinbilla. The 5 GHz data were obtained on 10 Aug 1998, together with the Australia Telescope Compact Array (ATCA) and Sheshan. The data were recorded in S2 format, correlated at the DRAO correlator in Penticton (Canada), and post-processed with the AIPS and Difmap programs.

There is a damped Lyα system in the direction toward this source at $z = 3.388$. The inferred H I column density is $N_{\rm H} = 10^{21.4}$ cm^{-2} (White *et al.* 1993). This is the most distant Lyα system in which the redshifted H I 21 cm line was detected in absorption (de Bruyn *et al.* 1996; Briggs *et al.* 1997). At 1.6 GHz with the VLA, Stanghellini *et al.* (1990) found a faint secondary component at $2''$ to the South of the core of this quasar.

Our data at 1.6 GHz show a resolved source, with no extended structure. The source brightness distribution is consistent with a single elliptical Gaussian component (0.9 Jy flux density, 3.1 mas $\times$ 0.2 mas angular size (FWHM), -33° major axis position angle). At 5 GHz, despite the small number of participating telescopes and the missing short baselines, an image of the source could be made (Fig. 1a). The position angle of the "jet" component located at 0.9 mas N-NW from the core (in PA=-20°) is consistent with earlier ground-only VLBI images of slightly poorer resolution (8.4 and 15 GHz images in the USNO Radio Reference Frame Image Database, *http://maia.usno.navy.mil/rorf/rorf.html*). The flat-spectrum southern component, the "core" appears resolved and somewhat extended in the image. However, the reliability of the fine details is constrained by the small array of radio telescopes. According to our result, there seems a large ($\sim 160^\circ$) misalignment between the arcsecond- (Stanghellini *et al.* 1990) and mas-scale extended structure of this source.

The quasar 0537−286 (z=3.104, Osmer *et al.* 1994) was observed at 5 GHz with HALCA and four ground telescopes (the ATCA, Hartebeesthoek, Hobart and Mopra) on 1 Oct 1999. This quasar is a prominent X-ray source observed first by the Einstein Observatory (Worral *et al.* 1987). Siebert *et al.* (1996), based on ASCA and pointed ROSAT observations, found that there is no evidence for absorption in excess of the

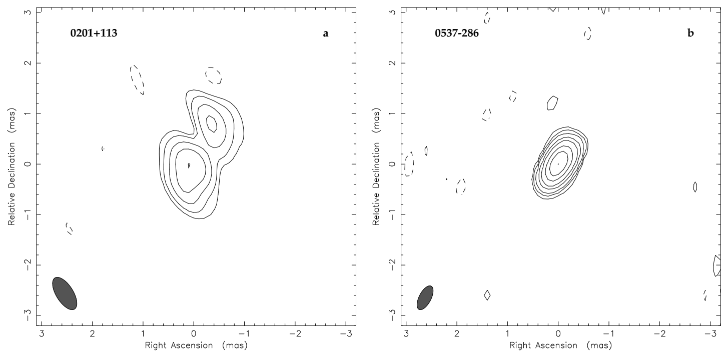

FIGURE 1. Uniformly weighted 5 GHz VSOP image of **(a)** 0201+113 and **(b)** 0537−286. Contour levels are at **(a)** −4, 4, 10, 25, 50 and 99% of the peak brightness (145 mJy/beam) and **(b)** −0.5, 0.5, 1, 2, 5, 10, 25, 50 and 99% of the peak brightness (726 mJy/beam). Restoring beam is **(a)** 0.73 mas × 0.34 mas at PA=32° and **(b)** 0.52 mas × 0.24 mas at PA=−27°.

Galactic value. A re-analysis later by Cappi *et al.* (1997) led to marginal evidence for excess absorption, giving $N_{\rm H} = 10^{20}$ cm^{-2} HI excess column density. Wright *et al.* (1978) estimated the same value from optical spectroscopy of the absorption line system towards 0537−286 at $z = 2.976$.

At the time of the 5 GHz VSOP-VLBA Pre-launch Survey (VLBApls, June 1996, Fomalont *et al.* 2000), the correlated flux density of 0537−286 on the shortest baselines of 2 Mλ was 0.5 Jy. By the time of our VSOP observation (40 months later), the source flux density has apparently increased dramatically (0.95 Jy and 0.6 Jy on the shortest and longest baselines respectively), as well as the "compactness" of the source (i.e. the ratio between the 150 Mλ and the short-spacing correlated flux density). Our image (Fig. 1b) displays no visible structural pattern although the source is resolved. A single elliptical Gaussian model with a flux density of 0.95 Jy, angular size of 0.22 mas × 0.14 mas (FWHM) and major axis position angle of −72° fits well to the visibility data. The rest-frame brightness temperature of the source is 6.2×10^{12} K, thus well exceeding the inverse Compton limit (Kellermann & Pauliny-Toth 1969). If we assume Doppler boosting, the corresponding Doppler factor is $\delta \sim 10$.

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