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EVN–MERLIN/Global observations of the Gravitational Lens MG 2016+112

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Abstract. We present preliminary results from recent observations of this gravitational lens system, made using MERLIN and an EVN/Global array including the 305 m Arecibo telescope.

1. Introduction

The gravitational lens system MG 2016+112 was discovered by Lawrence et al (1984). VLA and MERLIN observations have shown that there are 3 regions of emission (A,B,C) within an area of 4". The integrated radio spectrum peaks in the range 1 to 5 GHz. A and B are associated with two AGN images at z=3.273, produced by the gravitational field of a lensing galaxy 'D' (z=1.01; Schneider et al, 1985) located close to the centroid of A, B and C. Previous VLBI observations (e.g. Garrett et al, 1996) reveal that both A and B images exhibit similar 2-component structures, whilst region C breaks up into at least 4 distinct components, aligned along a gently curving arc of length 200 mas. Nair & Garrett (1997) developed a number of models for this system.

Koopmans et al (2002) have recently made new models of the lens galaxy potential in this system, and the results suggest that C is a region of very high magnification. It is presumed that this region contains the "merging images" of (almost) another 2 images of the same double source, making this system a (nearly) 4-image "quad" system. However, the exact details of the relationship between images A and B, and their partial counterparts in region C remain unclear.

Following the incorporation of Arecibo Observatory as an Associate Member of EVN, we have made highly sensitive VLBI observations of MG 2016+112 at λλ6 and 18cm, using MERLIN, EVN, VLBA, phased-VLA, the 305 m Arecibo telescope (and the 70 m DSN antennas at Robledo and Goldstone at λ18cm) The aim of these observations is to make a high-resolution spectral analysis of the components in region C. The λ18cm observations took place only recently (25 February, 2002) and have not yet been analysed.

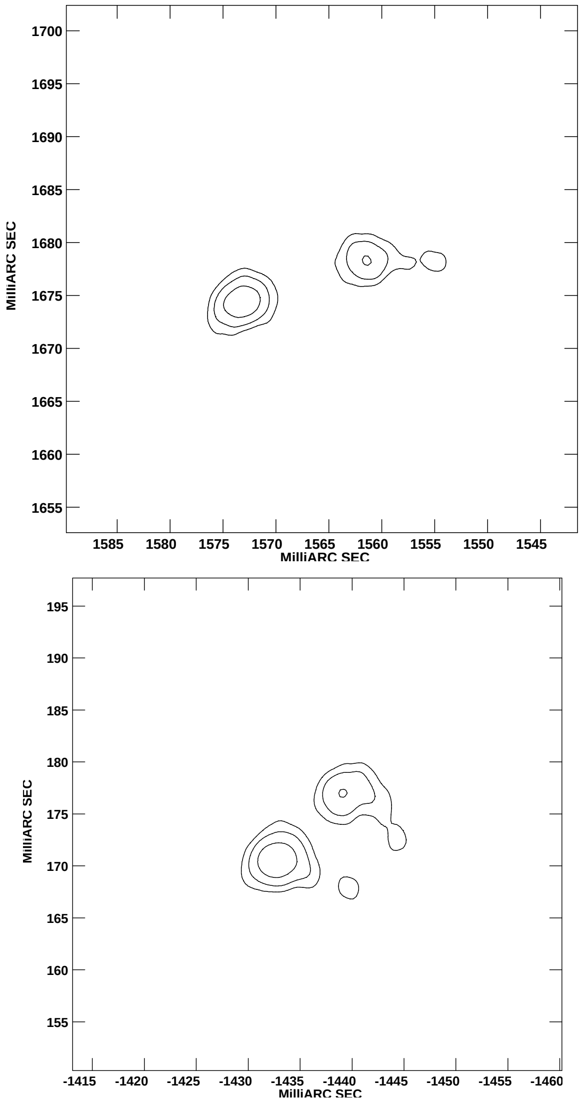

Fig. 1. Global 5 GHz maps of MG 2016+112 at 3 mas resolution; contours at 2^n x 0.6 mJy/beam: **(top)** image A, peak 3.9 mJy/beam; **(bottom)** image B, peak 4.2 mJy/beam

2. Observations and Preliminary Results

Global VLBI observations at λ6cm (together with MERLIN) were made on 17 November 2001, using a total of 18 antennas - EVN(6), VLBA(10), phased-VLA and Arecibo. Two 8 MHz channels of data were recorded for both RHC and LHC polarisations, with a total recorded bit-rate of 128 Mb/s. We performed phase-referencing

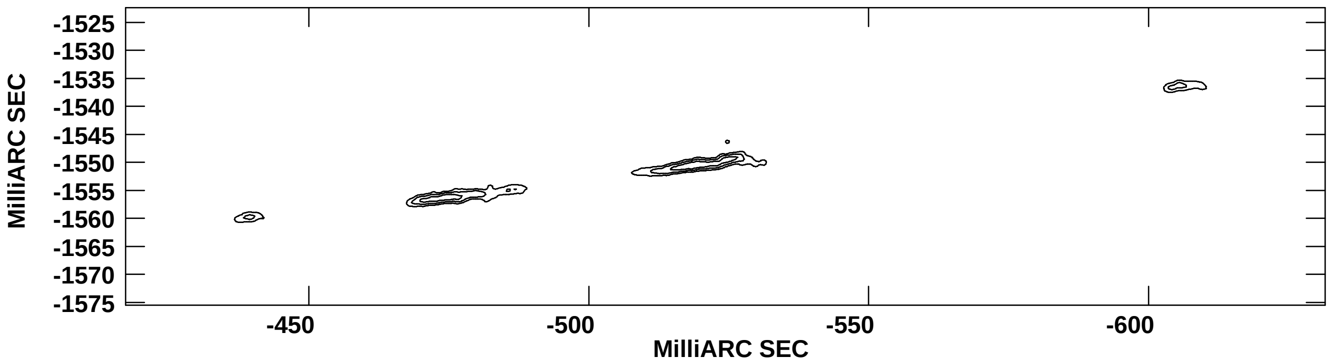

Fig. 2. Global 5 GHz image of MG 2016+112 region C, beam 1 x 1 mas, contours at 2^n x 0.2 mJy/bm, peak 1.43 mJy/bm

w.r.t the calibrator 2029+121, with a duty cycle of 6 mins (7 whilst Arecibo was tracking). Correlation at a single position (between A, B and C) was performed at the VLBA correlator. In order to preserve a sufficiently wide field of view, the visibility function was produced with 1s time resolution and 500kHz frequency resolution. All 18 antennas gave fringes ! Further analysis was done in AIPS.

Amplitude calibration was performed by first applying the antenna radiometry and gain curves provided, mapping the calibration source 2029+121, then deriving and applying corrections for each antenna. Calibration of the IF relative phases was also determined on 2029+121. After re-fringing 2029+121 (with a source model) the antenna solutions were interpolated and applied to the MG 2016+112 data, and phase-referenced maps of the A,B and C regions were made using IMAGR with 3 fields. A few iterations of phase self-calibration were also used before producing the hybrid maps of A and B (Fig 1) and region C (Fig 2).

Images A and B both exhibit the double structure of the background source. The map of region C shows the 4 components seen in previous VLBI maps, stretched out along a gently curving arc. It is remarkable how thin these components are, perpendicular to their extension, and this supports the idea that this is a region of very high magnification by the lens - perhaps as high as 300 according to Koopmans et al (2002). The long, thin nature of the components in region C can be seen directly in the visibility data. We re-referenced the data to a position centred in region C, and averaged over the 8 MHz bands and for 1 minute, to produce a region C visibility function with a small field of view to eliminate the responses of images A and B. In Fig 3 we plot this visibility function against u,v position angle (for Effelsberg, Arecibo and VLBA antennas only). There is a clear response of ca. 45 mJy on all baselines, but only when they are oriented perpendicular to the arc in PA 10° or −170° (80° and −100° in Fig 3).

It is tempting to identify the 4 components in region C as 2 further images of the background double source, but spectral and image parity considerations appear to rule this out for any plausible model for the lens. In the model of Koopmans et al (2002) the background source straddles

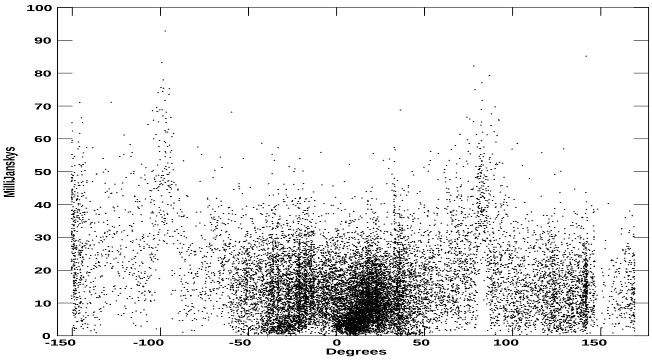

Fig. 3. Plot of MG 2016+112 region C visibility amplitude against (90° – u,v position-angle)

the line dividing regions producing 2 and 4 images; the inner 2 components in C are very highly magnified images of a flat spectrum extension ("core"?) to the NW in A and B, whereas the outer 2 components correspond to faint, but highly magnified, emission from a "counter-jet", not visible in A and B. The clear gap between the 2 inner components suggests that whatever is being imaged is a discrete object.

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