VERA Monitoring of OJ 287 in 2010-2013

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Introduction & Observations

OJ 287 is known to show a strong variability across a wide range of wavelengths. Recent γ-ray monitoring by Fermi revealed the high activity of OJ 287 in 2011 and 2012. In this poster, we present a kinematic study of the pc-scale radio jet in OJ 287 during γ-ray flares to explore the relation between pc-scale radio jet activity and γ-ray emission. VLBI monitoring observations were carried out roughly every two weeks, with the VLBI Exploration of Radio Astrometry (VERA) telescope array from 2010 November to 2012 September. We estimated the position and flux density of each component by fitting three Gaussians (C, J1, J2). We also collected the Fermi-LAT data (γ-ray) from 2010 November 1 to 2012 October, the KANATA data (optical). We constructed the γ-ray light curve of OJ 287 with 1-week time bins and a power-law model with the photon index fixed to the value obtained during 2010 November–2012 October.

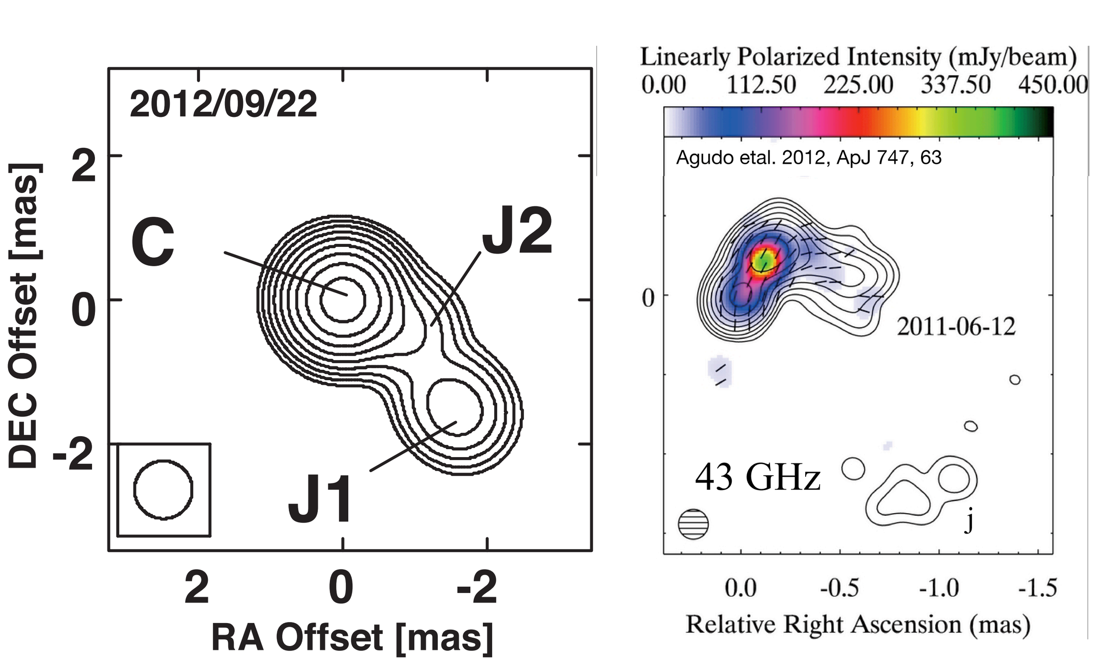


Fig.1 The core-jet structure is represented by the three components described above: C, J1 and J2. The components C and J1 can be identified as 'C' and 'j' of the VLBA 43-GHz images by Agudo et al. (2012).

Radio, Gamma-ray & Optical Light Curves

The 22-GHz VERA light curve of OJ 287 reveals obvious increasing activities in 2011 May, 2011 October, 2012 March and 2013 March. In this period, two pronounced γ-ray flares in OJ 287 are detected by Fermi LAT. The two γ-ray flaring events seem to occur close in time with the second and third radio increasing events, unlike the previous γ-ray flaring events in 2009 (Agudo et al. 2011, ApJ, 726, L13) when the γ-ray flare preceded the millimeter radio counterpart by three months.
The optical light curves at V- and R-bands with the KANATA reveal two increasing activities in 2012 March and 2013 March, and the fact indicates some connection between radio and optical flares in 2012 March and 2013 March. EVPA obtained by KANATA is stable around 150 degree, although time variation of EVPA at R-band has been reported (Bozhilov et al. 2014, MNRAS, 439, 639).

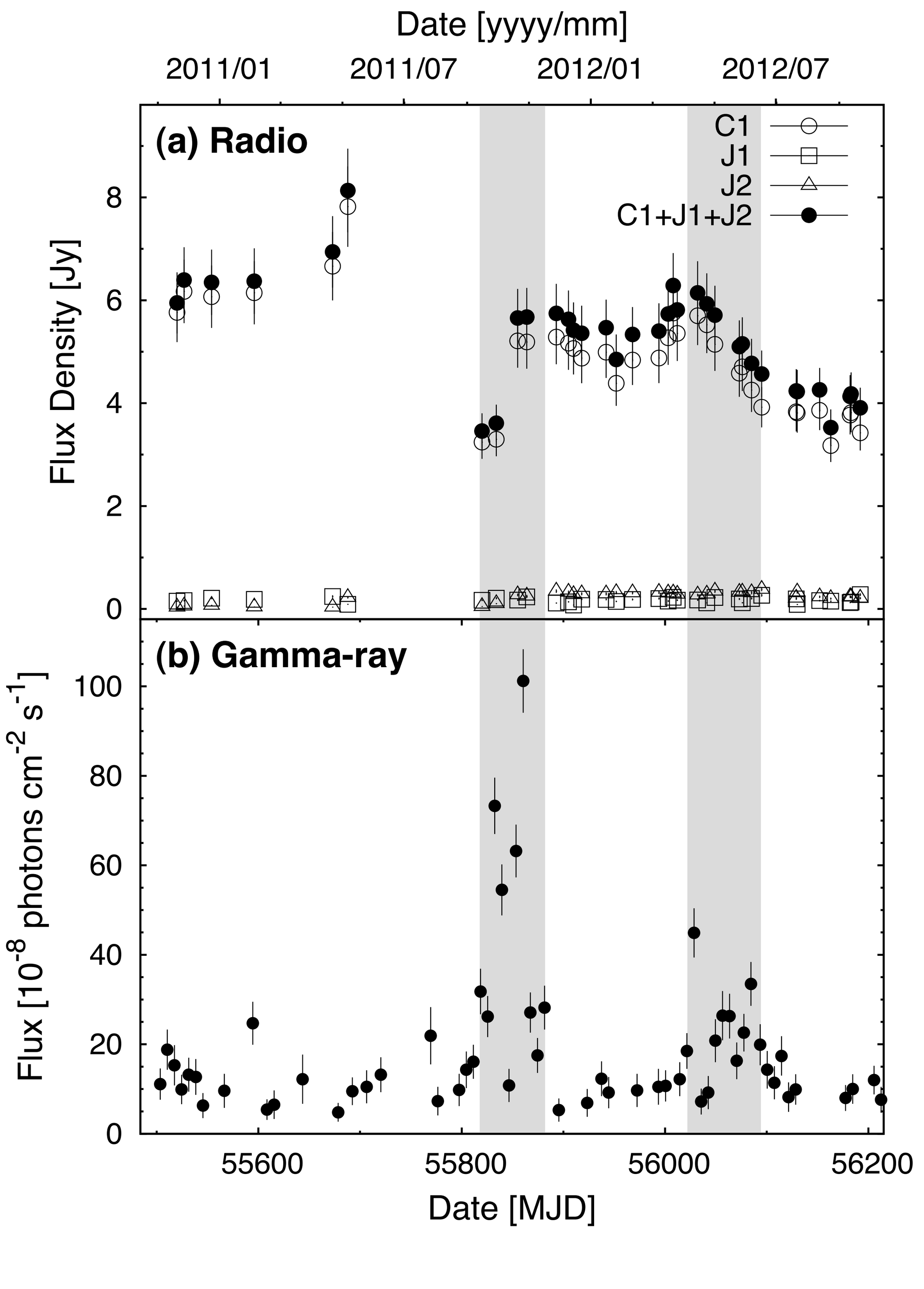


Fig.2 Light curves of 22-GHz radio and γ-ray of OJ 287. Grey rectangles represent the periods of the γ-ray flaring event at a 1×10^{-6} photons cm^{-2} s^{-1} reported by Fermi LAT.

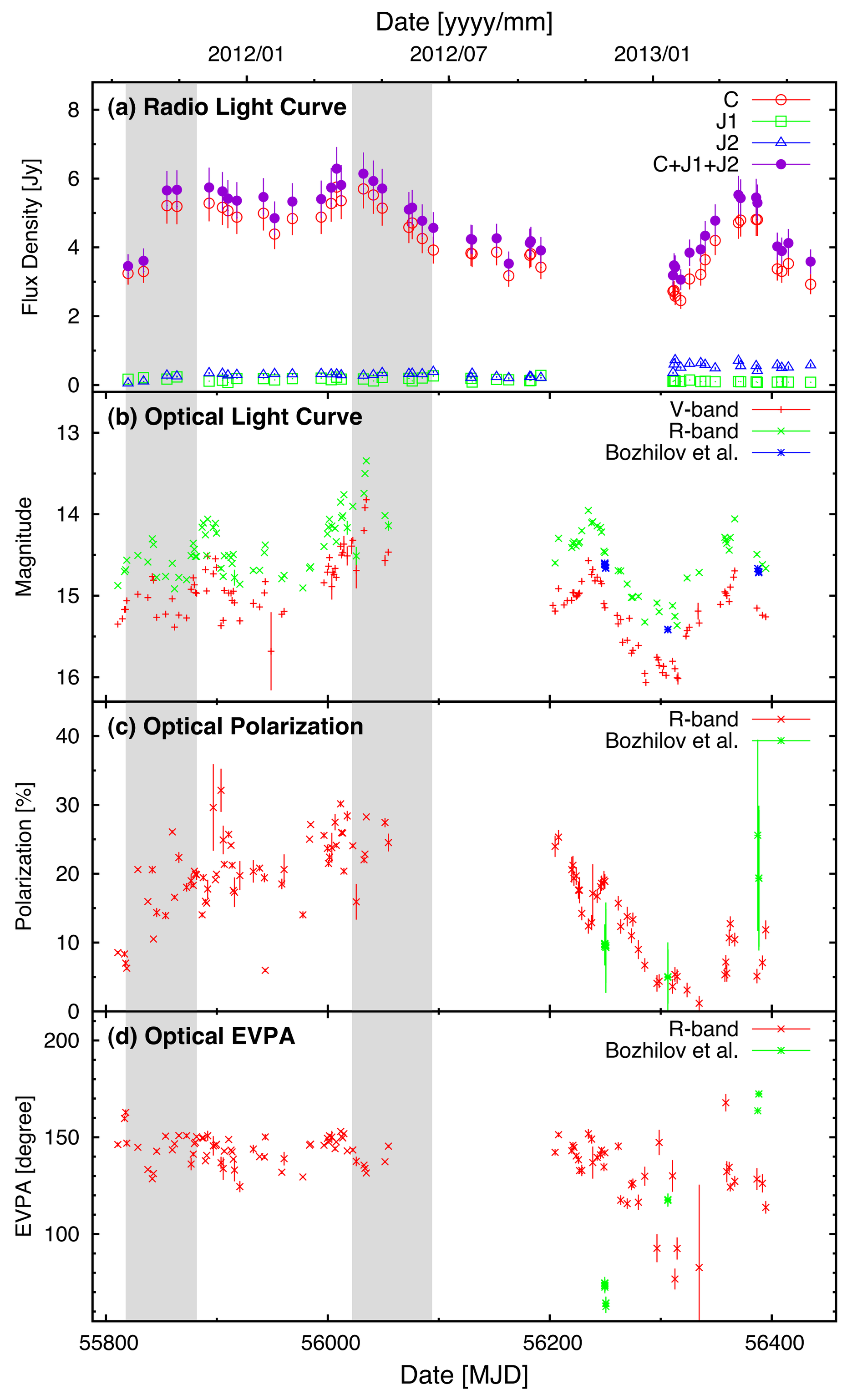
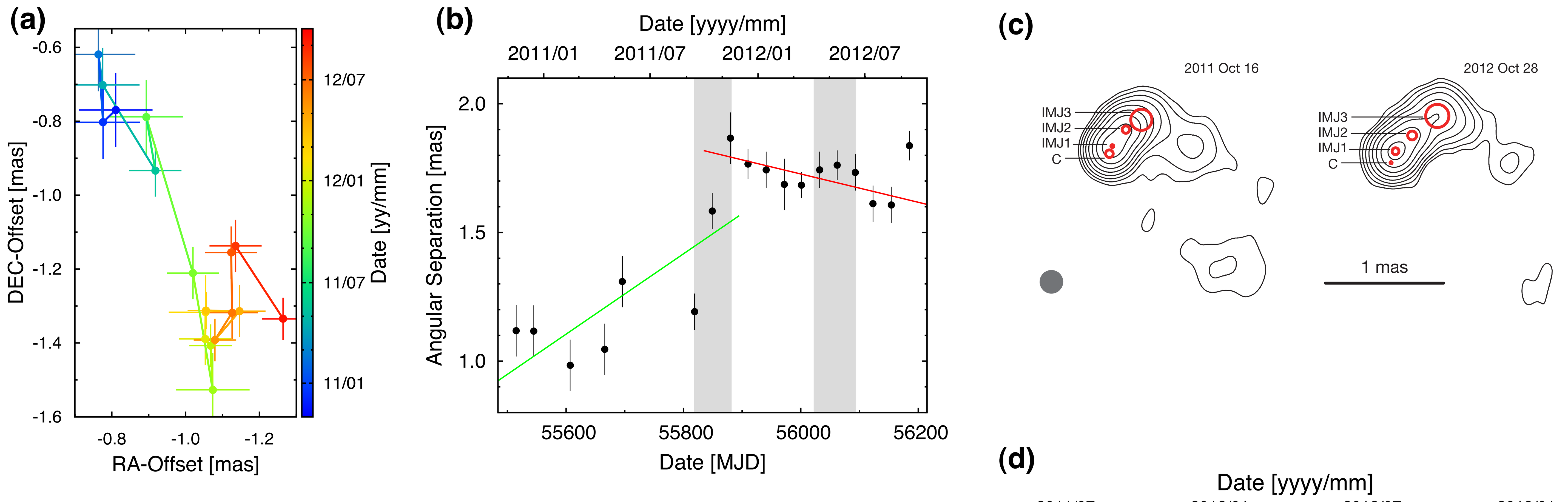


Fig.3 Variations of observational parameters of OJ 287. Grey rectangles represent the periods of the γ-ray flaring event at a 1×10^{-6} photons cm^{-2} s^{-1} reported by Fermi LAT.

Jet Motion

From 2010 November to 2012 September, the relative motion was seen toward the South-West direction, in agreement with the previous 43-GHz VLBA images. The motion of J1 sharply changed direction to backward in 2011 November, just after the second radio flare. From 2010 November to 2012 September, the relative motion was seen toward the South-West direction, in agreement with the previous 43-GHz VLBA images. The motion of J1 sharply changed direction to backward in 2011 November, just after the second radio flare. The apparent average radial velocity from 2010 November to 2011 November is estimated using a linear fit, giving (0.57±0.09) mas yr^{-1}, which corresponds to an apparent superluminal speed of (11±2) c. The apparent inward motion is (−0.2±0.1) mas yr^{-1}, which corresponds to (−4±2) c. The relative motion between C1 and J1 could be affected by uncertainties in the position or wobbling behavior of either C1 or J1, or both. Here we propose the senario that the temporary positional shift due to an unresolved emerging jet component and the core component. No newborn jet component was found in the 22-GHz VERA images, but the relative position of J1 from 2011 November to 2012 August moved backward and forward along a line at a PA of ~ −20 degree, nearly parallel to the direction of the innermost jet components IMJ1, IMJ2 and IMJ3 at 43 GHz. If the apparent inward motion of J1 is due to a highly curved trajectory, the flux density of J1 would show time variability due to a Doppler factor variation of geometrical origin. Our radio light curve of J1, however, indicates a constant flux density of J1 during the inward motion. Thus, there is no observational evidence of a highly bent motion of J1.



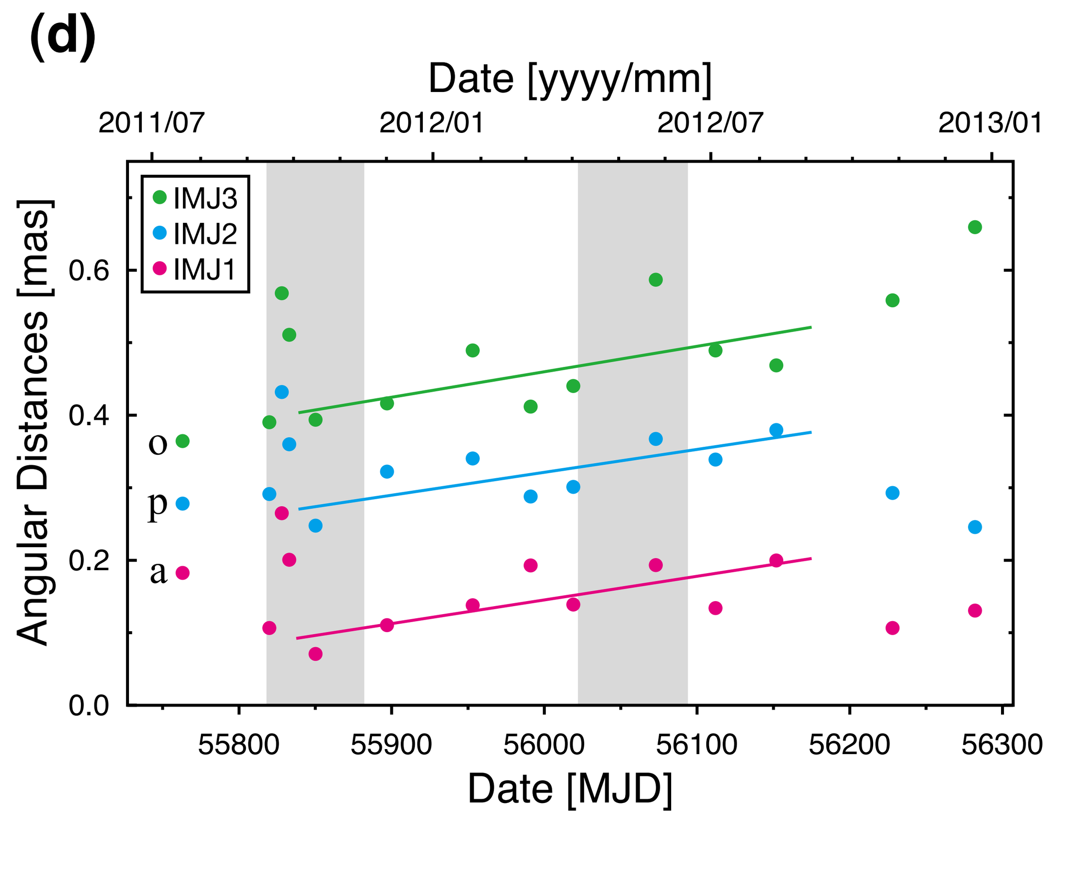


Fig.4 (a) Relative motion of the jet component J1 with respect to the core component C1. (b) Time variation of the angular separation between the components C1 and J1, The two lines represent a weighted rectilinear fit to the data points from 2010 November to 2011 November (green line) and from 2011 November to 2012 August (red line). Results of the rectilinear fits are shown in Table 2. The γ-ray flaring periods are indicated with gray rectangles. Each point in (a) and (b) is monthly averaged, with the exception of January, March, June, July and August in 2011. (c) VLBA images of OJ 287 at 43 GHz on 2011 October 16 and 2012 October 28, convolved with a circular Gaussian beam size (FWHM) of 0.2 mas. Contours start at 14 mJy $beam^{-1}$ (typical 3 σ level), increasing by a factor of 2. Red circles indicate circular Gaussian models. (d) Time variation of the angular distances of IMJ1, IMJ2 and IMJ3 from C at 43 GHz. Each color line represents a rectilinear fit to the color data points from 2011 October to 2012 August, when the inward motion was seen. Component 'a' of Agudo+ (2012) does not agree with the extrapolation of IMJ1, and a new jet could be identified as IMJ1 in 2011 October.