New look at old friends:
EVN imaging of prominent radio-loud active galactic nuclei with extremely large radio–optical positional offsets

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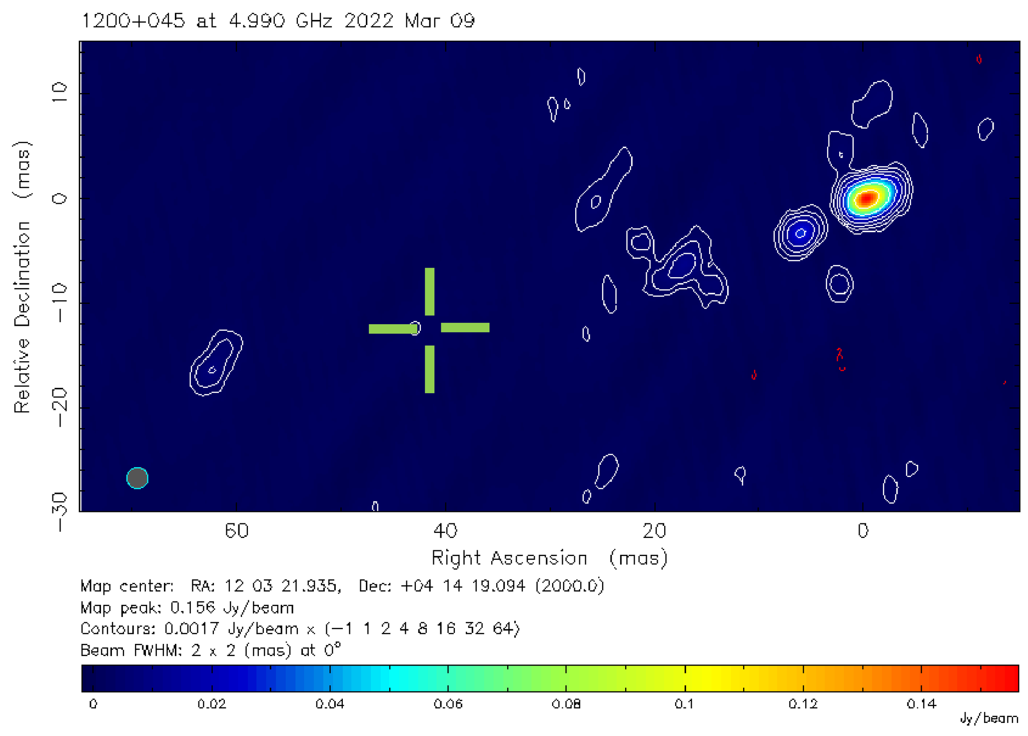
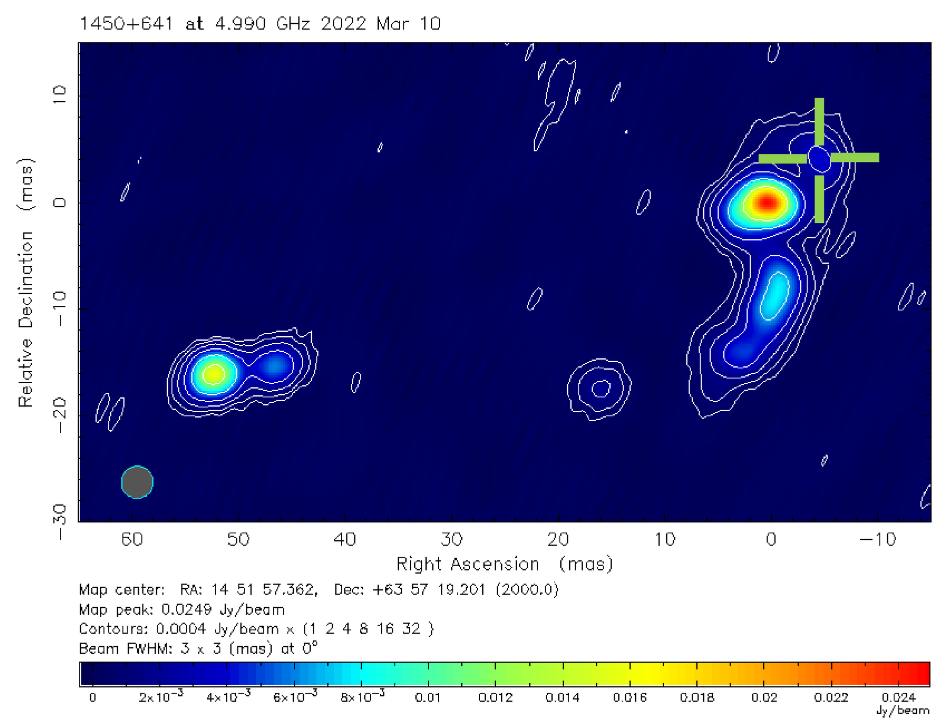
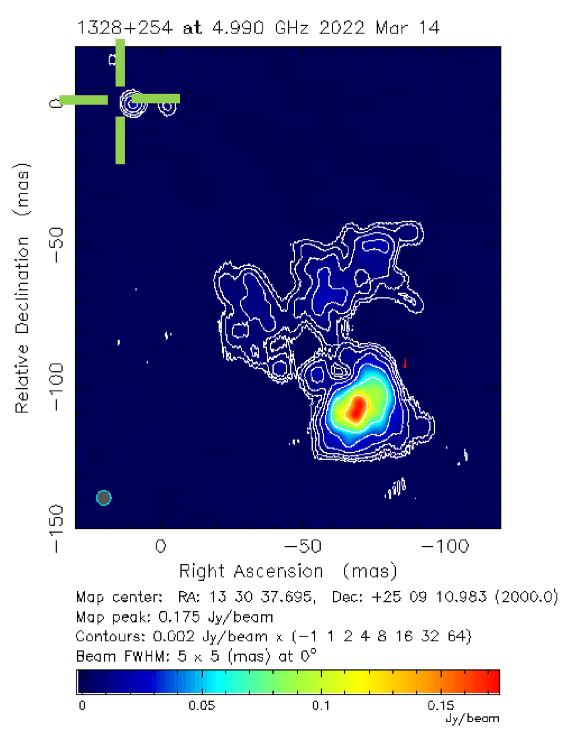
When comparing modern fundamental **reference frames** in the **radio** (ICRF) and **optical** (*Gaia*), a couple of bright radio reference sources appear to have very **large radio–optical offsets**, from tens up to hundreds of milliarcseconds. The amount of these positional misalignments exceeds the uncertainty of each individual technique by at least an order of magnitude. In most cases, complex and extended radio structure and its time variability, and thus the difficulty in pinpointing the true location of the central engine, is responsible for the large apparent offsets. Sometimes distant parts of the radio structure are not properly detected due to a lack of shorter interferometer baselines. For our 5-GHz **EVN and e-MERLIN experiment** (ET048, PI: O. Titov), we selected 10 bright radio-loud active galactic nuclei with extremely large radio–optical offsets. **Sensitive imaging** involving a wide range of projected baseline lengths, as well as **phase-referencing to nearby sources** shed light on the possible causes of positional inconsistencies. Here we show results for 3 selected sources from this project.



PKS 1200+045 (J1203+0414) is a bright peaked-spectrum radio quasar at redshift z=1.224. Its radio structure extended to ~60 mas (0.5 kpc projected size) is consistent with earlier VLBI images. It was not clear whether its compact radio structure can be classified as a core–jet [1,2] or a **compact symmetric object** CSO; [1]). The *Gaia* **optical position marked by a cross** in the image differs significantly from the radio peak position [3,4], lending support for the CSO classification. It is one of the typical causes of radio–optical offsets becuse *Gaia* basically pinponts the accretion disk emission from around the central supermassive black hole, often invisible in the radio, while the radio emission peak is associated with a bright hot spot in a lobe [5].

TXS 1450+641 (J1451+6357) is a quasar with unknown redshift. Because of its complex radio structure dominated by two bright features [6], it was once considered but then refuted as a CSO candidate [7]. Indeed, the ***Gaia*** **optical position** is not in between two main features but **close to the western one**, although there is a clear offset from the radio brightness peak. The interpretation of this apparently **peculiar structure** which may involve a turning or bending jet is beyond the scope of this astrometric study. Note that an earlier VLBI image at the same frequency (5 GHz) shows the easternmost component as the brigtest one [6]. This reminds us the fact that VLBI astrometric positions can sometimes be influenced by dramatic changes in the brightness distribution of the sources [8].





PKS 1328+254 (J1330+2509, alias **3C 287**) is a bright steep-spectrum quasar (z=1.055) extensively studied from the early years of VLBI [9–11], until before 2000 [12]. The **extended and complex radio structure** seen in the south-western part of our image was originally interpreted as a helical jet shaped by precession. This, and the identification of the radio core inside were later questioned by several authors [12,13]. Intriguingly, the VLBI astrometric position of 3C 287 was **displaced by ~130 mas within a very short time**, between 2014 and 2017 [8]. It was interpreted as caused by a sudden *brightening of a new component in the north-eastern direction* [8]. Unfortunately, modern VLBI imaging data were not available in the archives for verifying this scenario. In our new EVN image, we do **detect this putative component for the first time**, even though its present-day flux density (~20 mJy) is not particularly large. Most notably, the *Gaia* optical position in the phase-referenced image is close the this component which might have gone through a huge radio outburst in the mid-2010's. In any case, in the light of new astrometric and imaging VLBI data, the time has arrived for revisiting 3C 287.

References:
[1] Liu X. et al. 2007, *A&A* **470**, 97
[2] Cui L. et al. 2010, *A&A* **518**, 23
[3] Makarov V. et al. 2017, *ApJL* **853**, L30
[4] Petrov L.,Kovalev Y.Y. 2017 *MNRAS* **467**, L71
[5] Krezinger M. et al. 2020, *MNRAS* **496**, 1811
[6] Helmboldt J.F. et al. 2006, *ApJ* **658**, 203
[7] Tremblay S.E. et al. 2016, *MNRAS* **459**, 820
[8] Titov O. et al. 2022, *MNRAS* **512**, 874
[9] Fanti C. et al. 1985, *A&A* **143**, 292
[10] Fanti C. et al. 1989, *A&A* **217**, 44
[11] Fanti R. et al. 1990, *A&A* **231**, 333
[12] Paragi Z. et al. 1998, *A&A* **338**, 840
[13] Kellermann K.I. et al. 1998, *AJ* **115**, 1295

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