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THE BORDEAUX OBSERVATORY IVS ANALYSIS CENTER

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Abstract. This paper reports about VLBI activities that are conducted in the framework of the International VLBI Service for Geodesy and Astrometry (IVS) at Bordeaux Observatory. The IVS is a international collaboration of 37 institutions around the world that support astrometric and geodetic VLBI observing programs for research in Earth science and reference systems. The activities developed in Bordeaux focus primarily on the maintenance, extension and improvement of the International Celestial Reference Frame (ICRF). This includes regular VLBI imaging of the ICRF sources and evaluation of their astrometric suitability, as well as the monitoring of the temporal evolution of their astrometric coordinates. In addition, we also develop VLBI observing programs aimed at densifying the ICRF and are involved in VLBI software development for multi-technique data combination at the raw observation level with the GINS software.

1 Introduction

The Very Long Baseline Interferometry (VLBI) technique is unique in providing positions of extragalactic radio sources with sub-milliarcsecond (mas) accuracy and ultra-high resolution images of their brightness distributions. This astrometric capability led to the construction of the International Celestial Reference Frame (ICRF), now comprising 717 extragalactic objects distributed over the entire sky, which was adopted as the IAU fundamental celestial reference frame in 1998 (Ma et al. 1998, Fey et al. 2004). VLBI is also the only technique that is able to measure accurately all components of the Earth's orientation (polar motion, nutation and the Earth's rotation rate). Additionally, it contributes to establishing and maintaining the International Terrestrial Reference Frame (ITRF) and to deriving plate tectonic motions (Boucher et al. 2004).

International collaborations are essential in organizing VLBI experiments since the technique requires simultaneous observing with radio telescopes located on several continents to create interferometer baselines that are thousands of kilometers long. There are two major VLBI networks dedicated to astrophysics, the European VLBI Network (EVN) and the US Very Long Baseline Array (VLBA), both of which are opened to the worldwide scientific community based on peer-reviewed proposals. In addition, regular astrometric and geodetic VLBI observations are conducted under the coordination of the International VLBI Service for Geodesy and Astrometry (IVS) to monitor the Earth's rotation and to maintain the celestial and terrestrial frames. In the sections below, we describe the IVS organization and the contribution of Bordeaux Observatory to this service.

2 The International VLBI Service for Geodesy and Astrometry (IVS)

The International VLBI Service for Geodesy and Astrometry (IVS) is an international collaboration of organizations which operate or support VLBI. Its primary role is to provide a service to coordinate geodetic and astrometric VLBI observing programs, to analyze the data that are acquired through these programs, and to make the resulting VLBI products (celestial frame, Earth orientation, and terrestrial frame) publicly available to the scientific community for research in these areas. IVS promotes research and development activities in all aspects of geodetic and astrometric VLBI, including technology, observing strategies, and refinements of physical models (troposphere, source structure), for improving the accuracy of the VLBI data and products. The objective of IVS is also to integrate VLBI into a global Earth observing system that includes also satellite geodetic techniques such as SLR (Satellite Laser Ranging) and the GPS and DORIS positioning systems.

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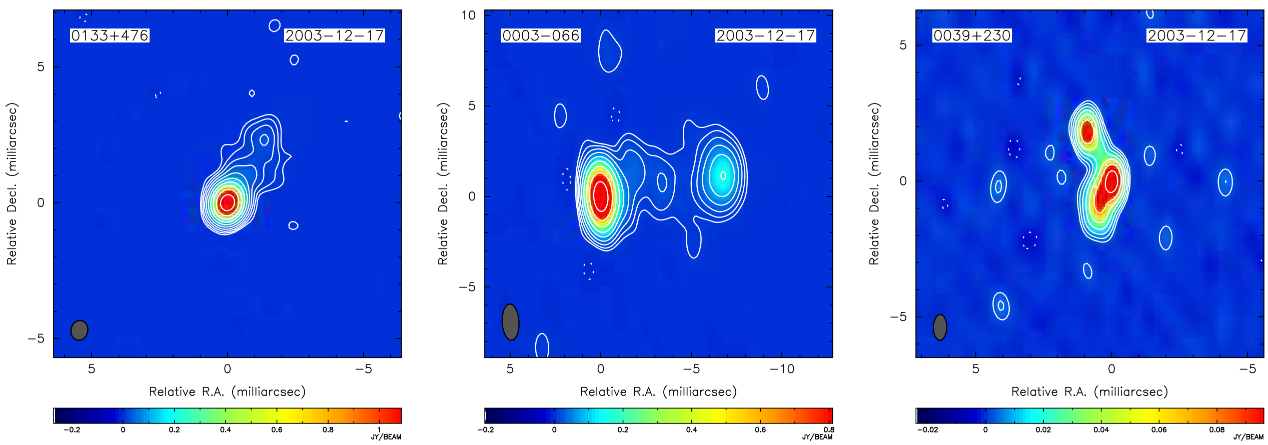

Fig. 1. A sample of VLBI images at 8.6 GHz (X band) for three ICRF sources observed on 2003 December 17. The brightness distribution of these three sources show an increasing complexity (from 0133+476 to 0003−066 and to 0039+230) which produces increasing structural effects in the VLBI measurements, as shown in Fig. 2.

The IVS internal organization comprises several types of components: 1) *Network Stations* that acquire raw VLBI data; 2) *Operations Centers* that coordinate routine operations of one or more groups of network stations; 3) *Correlators* that process the raw VLBI data recorded by the stations; 4) *Data Centers* that are repositories for the IVS observing schedules, data and products; 5) *Analysis Centers* that regularly analyze the VLBI measurements to monitor the Earth's rotation and to maintain and improve the celestial and terrestrial frames; and 6) *Technology Development Centers* that are engaged into hardware and/or software developments to improve the VLBI technology. The IVS *Coordinating Center* is responsible for coordination of both the day-to-day and long-term activities of the IVS, consistent with the policy established by the Directing Board. Altogether, the IVS consists of 74 permanent components, representing 37 institutions in 17 countries. For further details on the IVS organization, see the IVS web site at `http://ivscc.gsfc.nasa.gov`.

3 IVS Analysis Activities at Bordeaux Observatory

The VLBI group at Bordeaux Observatory joined IVS in 1999 – at the time IVS was established – with the goal of developing VLBI analysis activities primarily connected to the celestial reference frame (Charlot et al. 2000). Accordingly, we became an IVS Analysis Center and are now engaged in the three IVS tasks described below.

3.1 VLBI imaging of the ICRF sources

A major limitation in the accuracy of the ICRF is caused by the extended brightness distribution of the observed radio sources which are only imperfect fiducial points in the sky on VLBI scales. Although they all have a very compact VLBI core, a large portion of these sources also possess extended jets with radio emission that varies in time and frequency (Fey & Charlot 1997, 2000). As shown by Charlot (1990), these extended structures may introduce significant effects in the VLBI measurements, hence making such sources unsuitable for the realization of a celestial frame of the highest quality. For this reason, it is desirable to image all ICRF sources on a regular basis so that the most compact sources may be recognized and used in the definition of the celestial frame.

We have now produced about 400 VLBI images of ICRF sources at X and S band (8.6 and 2.3 GHz) based on data acquired with the VLBA and up to 10 geodetic telescopes. This task is shared between Bordeaux Observatory and the US Naval Observatory. A sample of images for three ICRF sources is shown in Fig. 1. 0133+476 shows a weak jet emerging from the source core, while 0003−066 exhibits a more pronounced jet with a secondary component 6 mas away from the core. 0039+230 has complex emission with two VLBI components of comparable intensity. As discussed below, the three sources produce increasing VLBI structural effects. Our rapidly-growing VLBI image database will be important not only for IVS but also for studying the long-term radio source evolution.

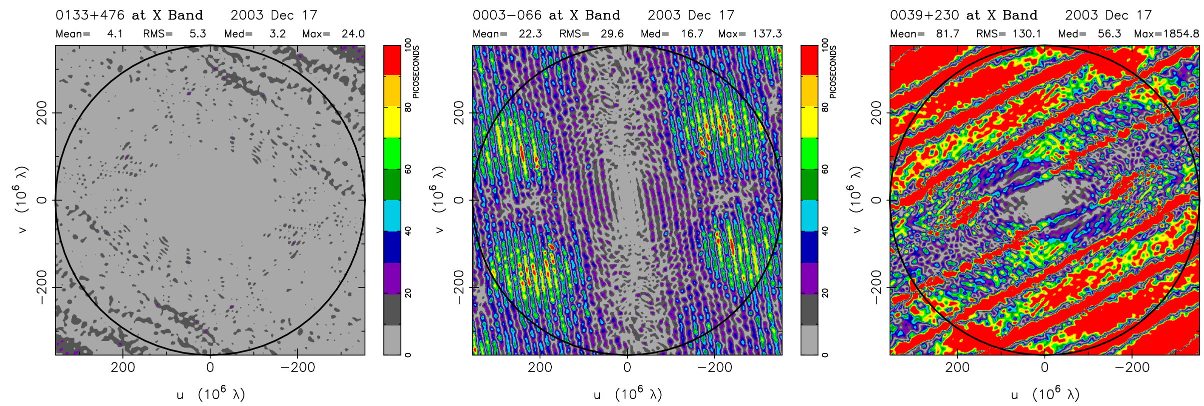

Fig. 2. VLBI structural delay effects at X band for the three ICRF sources for which images are shown in Fig. 1. The structural delay is plotted as a function of the length and orientation of the VLBI baseline projected onto the sky, expressed in millions of wavelength. The color scale is identical in each panel and ranges from 0 to 100 picoseconds (ps). All structure corrections larger than 100 ps are plotted as red. The circle drawn in each panel has a radius equal to one Earth diameter, corresponding to the longest baselines that can be theoretically observed with Earth-based VLBI. The mean, rms, median and maximum values of the structure corrections within this circle are indicated above each panel.

3.2 Evaluation of the astrometric suitability of the ICRF sources

The expected effects of intrinsic source structure on VLBI delay measurements depend on the exact form of the spatial brightness distribution relative to the coordinates of the VLBI baseline vector projected onto the plane of the sky (Charlot 1990). In order to categorize the sources, Fey & Charlot (1997) introduced a "structure index" which defines the astrometric source quality according to the magnitude of the structural effects, calculated for all projected VLBI baselines that could be possibly observed with Earth-bound VLBI. The structure index ranges from 1 to 4, with values of 1 and 2 pointing to excellent and good astrometric suitability, while values of 3 and 4 point to poor and extremely poor suitability, respectively.

By using VLBI images produced by USNO and ours, we have derived structure indices for a large portion of the ICRF (557 sources at X band and 459 sources at S band). Based on this indicator, it is found that roughly 40% of the ICRF sources have excellent or good astrometric suitability (i.e. structure indices of 1 or 2). Figure 2 plots our results for the three ICRF sources for which VLBI images are shown in Fig. 1. The three sources are found to have structure indices of 2, 3 and 4, respectively. The increasing value of the structure index for the three sources is reflected by the increasing structural effects seen in the plots of Fig. 2.

Because of source structure evolution, the structure index may vary with time, hence it is necessary to recalculate its value on a regular basis as new maps are available. In our data base, structure indices are available for up to 20 epochs for the most-intensively observed sources. Up-to-date structure indices are mandatory to identify the proper sources to schedule in astrometric and geodetic IVS observing programs.

3.3 Monitoring the source position stability

As noted above, most of the VLBI extragalactic sources that realize the ICRF show a core-jet morphology, i.e. they comprise a compact core and a one-sided jet which contains material out-flowing at relativistic speed. On VLBI scales, synchrotron-emitting blobs typically emerge from the core on scales of months to years and they move further down the jet with angular velocities up to 1 mas/yr until they fade out. As a result, the centroid of the overall radio emission is displaced with time, hence causing instabilities in the estimated source positions.

It is important to identify such instabilities as these affect the quality and stability of the celestial reference frame. For this identification, we have developed an analysis strategy which consists in estimating monthly VLBI source positions. The data used for this investigation are the bi-weekly IVS sessions that are dedicated to monitoring the Earth's orientation. The astrometric source positions are derived with the JPL VLBI estimation software MODEST (Sovers & Jacobs 1996). See Charlot et al. (2004) for an example of our results. The aim of this monitoring is also to determine whether source position instabilities are entirely connected to the evolution of their structures by comparison with our source maps or whether other causes may exist.

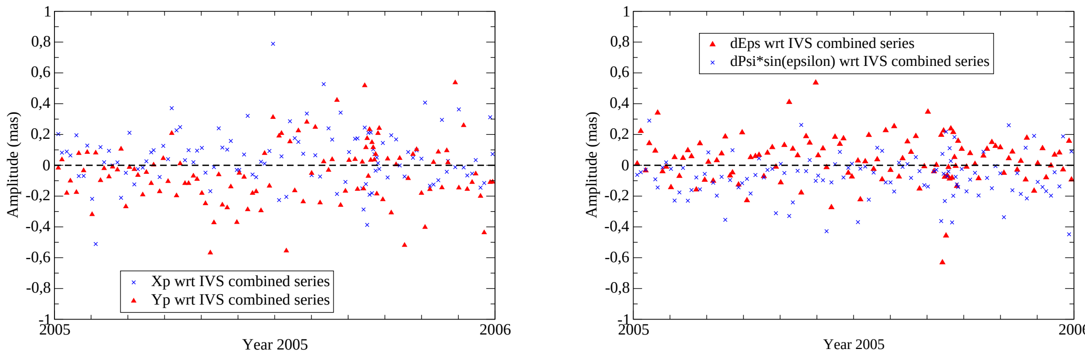

Fig. 3. Polar motion (X_p, Y_p) and nutation offsets ($d\epsilon$, $d\psi \sin \epsilon$) derived from analysis of the 2005 bi-weekly IVS sessions with the GINS software. The results are reported with respect to the corresponding values in the IVS combined series.

4 VLBI Research and Developments

Apart from the regular IVS analysis activities described in the previous section, we are also developing a VLBI observing program to densify the ICRF using the EVN and additional geodetic radio telescopes. Altogether, 150 new sources have been observed since 2000. The sources were selected on the basis of their sky location in order to fill the "empty" regions of the frame and compactness to limit structural effects in the astrometric measurements. As reported by Charlot et al. (2005), all 150 new sources have been successfully detected and the precision of the estimated coordinates in right ascension and declination is better than 1 mas for most of the sources. In the future, we plan to target further VLBI experiments to searching candidate radio/optical sources for linking the ICRF and the optical frame that will be built by the GAIA space astrometric mission.

Additionally, we are involved in a project aimed at combining all VLBI and space geodetic data in a consistent analysis using the GINS software (developed by the CNES) to unify the reference frames and the Earth Orientation Parameters (EOP) estimation. In this project, the VLBI data are analyzed in Bordeaux, while the satellite geodetic data are processed either in Toulouse (for GPS and DORIS) or Grasse (for SLR), with the final combination produced at Paris Observatory. We are in charge of validating the VLBI part of GINS and developing operational VLBI analyzes targeted to this multi-technique combination. Our current VLBI-only EOP results indicate agreement at the 0.2 mas level with the IVS combined series (Fig. 3). In the future, GINS may eventually replace the MODEST software and be integrated into our regular IVS activities.

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