Report for 2014 from the Bordeaux IVS Analysis Center

Patrick Charlot, Antoine Bellanger, Romuald Bouffet, Géraldine Bourda, Arnaud Collioud, Alain Baudry

Abstract This report summarizes the activities of the Bordeaux IVS Analysis Center during the year 2014. The work focused on (i) the regular analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package, also producing a 12-year long solution (2002—2013); (ii) the systematic VLBI imaging of the RDV sessions and calculation of the corresponding source structure index and compactness values; (iii) the investigation of the correlation between astrometric position instabilities and source structure variations, and (iv) the continuation of activities to identify and monitor optically-bright radio sources suitable as transfer sources to align the International Celestial Reference Frame (ICRF) and the future Gaia frame. Also to be mentioned is the organization of a workshop on gravitation, reference systems, astronomy, and metrology, and participation in the IAU Working Group Meeting on the next ICRF realization.

1 General Information

The *Laboratoire d'Astrophysique de Bordeaux (LAB)*, formerly Bordeaux Observatory, is located in Floirac, near Bordeaux, in the southwest of France. It is funded by the University of Bordeaux and the *Centre National de la Recherche Scientifique (CNRS)*. VLBI activities are primarily developed within the *Métrologie de l'espace, Astrodynamique, Astrophysique (M2A)* team.

Laboratoire d'Astrophysique de Bordeaux

Bordeaux Analysis Center

IVS 2014 Annual Report

The contribution of the Bordeaux group to the IVS has been mostly concerned with the maintenance, extension, and improvement of the International Celestial Reference Frame (ICRF). This includes regular imaging of the ICRF sources and evaluation of their astrometric suitability, as well as developing specific VLBI observing programs for enhancing the celestial frame.

In addition, the group is in charge of the VLBI component in the multi-technique GINS software package [1] as part of a collaborative effort within the French *Groupe de Recherches de Géodésie Spatiale (GRGS)* to combine VLBI and space geodetic data (SLR, GPS, and DORIS) at the observation level. This effort involves institutes in Toulouse, Nice, and Paris.

2 Description of Analysis Center

The Bordeaux IVS group routinely analyzes the weekly IVS-R1 and IVS-R4 sessions with the GINS software package. During the past year, weekly normal equations for all such sessions in 2014 (with six-hour EOP resolution) were produced and integrated in the multi-technique solutions derived by the GRGS. In addition, we produced a solution that includes all IVS-R1 and IVS-R4 sessions from 2002 to 2013. The motivation for setting up this 12-year long VLBI solution was to obtain multi-technique results derived from combining all space geodetic data at the observation level in the framework of the ITRF2013 preparation.

The group is also focused on imaging the ICRF sources on a regular basis by systematic analysis of the data from the RDV sessions which are conducted six times a year. This analysis is carried out with the AIPS and DIFMAP software packages. The aim of such reg-

ular imaging is to characterize the astrometric suitability of the sources based on the so-called "structure index" and to compare source structural evolution and positional instabilities. Such studies are essential for identifying sources of high astrometric quality, which is required, e.g., for the future Gaia link.

3 Scientific Staff

During the past year, there were no changes in the IVS staff. In all, six individuals contributed to one or more of our IVS analysis and research activities during 2014. A description of what each person worked on, along with the time spent on it, is given below.

- Patrick Charlot (20%): researcher with overall responsibility for Analysis Center work and data processing. His interests include the ICRF densification, extension, and link to the Gaia frame, studies of radio source structure effects in astrometric VLBI data, and astrophysical interpretation.
- Antoine Bellanger (100%): engineer with a background in statistics and computer science. He is tasked to process VLBI data with GINS and to develop procedures and analysis tools to automate such processing. He is also the M2A Web master.
- Romuald Bouffet (30%): Ph. D. student from the University of Bordeaux whose thesis is focused on the study of the relationship between radio source structure and position instabilities. He is using astrometric data and VLBI images from IVS sessions.
- Géraldine Bourda (50%): astronomer in charge of developing the VLBI part of GINS and responsible for the analysis results derived from GINS. She is also leading a VLBI observational program for linking the ICRF and the future Gaia optical frame.
- Arnaud Collioud (100%): engineer with a background in astronomy and interferometry. His tasks are to image the sources in the RDV sessions using AIPS and DIFMAP, to develop the Bordeaux VLBI Image Database and *IVS Live* tool, and to conduct simulations for the next generation VLBI system.
- Alain Baudry (10%): radioastronomy expert with specific interest in radio source imaging and astrometric VLBI. He is a Professor Emeritus and is working part time as a co-investigator for developing upgrades of the ALMA mm/submm array.

4 Analysis and Research Activities in 2014

As noted above, a major part of our activity consists of imaging the sources observed during the RDV sessions on a systematic basis. During 2014, two such sessions were processed (RDV92 and RDV94), resulting in 337 VLBI images at either X- or S-band for 150 different sources. The imaging work load has been shared with USNO since 2007 (starting with RDV61); the USNO group processes the odd-numbered RDV sessions while the Bordeaux group processes the even-numbered ones. The VLBI images are used in a second stage to derive structure correction maps and visibility maps along with values for structure indices and source compactness (see [2, 3] for a definition of these quantities) in order to assess astrometric source quality. All such information is made available through the Bordeaux VLBI Image Database (BVID)[1]. At present, the BVID comprises a total of 4,007 VLBI images for 1,170 different sources (with links to an additional 6,775 VLBI images from the Radio Reference Frame Image Database of USNO) along with 10,572 structure correction maps and as many visibility maps.

In addition to such regular imaging, studies aimed at characterizing correlations between astrometric position instabilities and source structural variations have been pursued. As indicated in our 2013 IVS report, although a link between the two phenomena was found, a fraction of the sources shows a negative correlation. Investigating further such discrepancies, a number of explanations have been put forward: (i) misidentification of the core component over the epochs in the successive VLBI maps, (ii) imprecision in the VLBI core location (e.g. due to blended VLBI components in the inner part of the jet), (iii) effects of the S-band data, not considered in this study, (iv) inadequacy of the brightness centroid motion to match astrometric instabilities, (v) opacity variations affecting the VLBI core position along the jet, and (vi) precession effects (due to the rotation of the central black hole) or orbital motion (due to the presence of a binary black hole system) causing true VLBI core displacement. Focusing on the latter and taking an additional step, we developed simulations of jets affected by such physical phenomena (precession and the presence of a binary black hole). Preliminary results indicate that the resulting trajecto-

[1] The Bordeaux VLBI Image Database may be accessed at http://www.obs.u-bordeaux1.fr/BVID.

ries on the sky show oscillations whose amplitude and time scale are in agreement with those observed in actual sources, hence giving credence to these considerations.

Another major activity of the group is the identification and characterization of appropriate radio sources to align the ICRF and the future Gaia optical frame. To this end, two complementary directions are being followed: (i) the identification and monitoring of such sources within ICRF2 and (ii) the search for additional sources (outside of ICRF2) to increase the pool of transfer sources. As noted in our 2012 IVS report, the examination of ICRF2 led to the identification of 195 transfer sources. Following our proposal, most of these sources were inserted into IVS programs and are now observed on a regular basis. During the past year, the work has consisted of assessing the time coverage of these sources, in collaboration with the IVS Coordinating Center, with the aim of getting one epoch per month, similar to the overall Gaia time coverage. Additionally, some of the transfer sources from the other set (the non-ICRF2 sources) were inserted into Deep Space Network sessions through a collaboration with the Jet Propulsion Laboratory. These sources are much weaker and require large antennas for detection. Observations to characterize potential transfer sources in the southern hemisphere are also soon to be initiated following acceptance of a proposal by the Australian Long Baseline Array.

Most of this work (source imaging, assessment of structural effects, identification of Gaia transfer sources, etc.) naturally fits within the tasks of the IAU Working Group on the next ICRF realization which was set up at the 2012 IAU General Assembly. Both G. Bourda and P. Charlot are members of this Working Group and as such contributed to the two meetings of the Working Group held during the past year (7 March 2014 in Shanghai and 14 October 2014 in Luxembourg).

5 Dissemination and Outreach

A workshop on gravitation, reference systems, astronomy, and metrology was hosted by the Bordeaux group on 3-4 April 2014 as part of the five-year planning exercise for French astronomy. During the workshop, P. Charlot gave a talk on the next generation VLBI system, putting emphasis on the need to set up a VGOS antenna in Tahiti. The planning exercise concluded with a one-week long meeting covering all fields of astronomy that took place in the fall of the 2014.

The *IVS Live* Web site [4], dedicated to monitoring IVS sessions and viewing VLBI images of the observed sources, was updated on a regular basis during 2014. It now includes 6,335 IVS sessions (with 71 stations participating) and 1,799 sources. Monitoring of the connections indicates that there were 1,017 visits from around the world (47 countries, 277 locations) during 2014, with 70% originating from different individuals. On the other hand, the Bordeaux VLBI Image Database was accessed from 77 different locations in 27 countries. In all, there were 629 connections, with about one-third originating from different individuals.

6 Outlook

Our plans for the coming year are focused on moving towards operational analysis of the IVS-R1 and IVS-R4 sessions with the GINS software package. Imaging of the RDV sessions and evaluation of the astrometric suitability of the sources will continue along the lines described in this report. Dissemination activities include upgrading the BVID by implementation of a new user interface. Of the most importance are our observing programs in cooperation with IVS and other groups to search and monitor Gaia transfer sources both in the northern hemisphere and in the southern hemisphere. The aim is to finalize the source list by 2016, in time for the first release of the Gaia catalog. Finally, we expect to contribute to the work towards the next realization of the ICRF in accordance with the plans of the IAU Working Group in charge of this task. This includes participation in the upcoming meetings of the Working Group, among which is the one to be held during the IAU General Assembly this summer in Hawaii.

Acknowledgements

We would like to thank the *Observatoire Aquitain des Sciences de l'Univers (OASU)* for supporting IVS activities in Bordeaux.

References

1. Bourda, G., Charlot, P., Biancale, R.: 2007, GINS: A New Tool for VLBI Geodesy and Astrometry, 18th EVGA Working Meeting, Eds. J. Böhm, A. Pany, and H. Schuh, IGG Vienna, p. 59–63.
2. Fey, A. L., Charlot, P.: 1997, VLBA Observations of Radio Reference Frame Sources. II. Astrometric Suitability Based on Observed Structure, ApJS, 111, 95–142.
3. Charlot, P.: 2008, Astrophysical Stability of Radio Sources and Implication for the Realization of the Next ICRF, 5th IVS General Meeting, St Petersburg, Eds. A. Finkelstein and D. Behrend, p. 345–354.
4. Collioud, A.: 2011, IVS Live: All IVS on your deskstop, Proceedings of the 20th Meeting of the European VLBI Group for Geodesy and Astronomy, Eds. W. Alef, S. Bernhart, and A. Nothnagel, Universität Bonn, Institut für Geodäsie und Geoinformation, Schriftenreihe 22, p. 14–18.