The Fundamental Reference Image Data Archive (FRIDA)

Christopher DiLullo[1,2], Remington Sexton[1], Phillip Cigan[1]

Abstract The Fundamental Reference Image Data Archive (FRIDA) is a web-accessible archive of images of $\sim$ 4000 extragalactic sources made available through the United States Naval Observatory (USNO) as part of its mission as an IVS Analysis Center for Source Structure. Imaging is a critical component to monitoring efforts which aim to understand the astrometric variability of International Celestial Reference Frame (ICRF) sources. Due to the highly variable nature of AGN and the capability of Very Long Baseline Interferometry (VLBI) to resolve small scale structure, if this structure is either not accounted for or not well understood, it can affect the precision of astrometric measurements. Imaging an ICRF source at multiple epochs is crucial to understanding how its structure varies, since bright components can be monitored with both photometric and morphological techniques. USNO has been consistently imaging sources since 1994 and currently supports FRIDA via monthly dedicated imaging observations using the Very Long Baseline Array (VLBA) at S-, X-, and K-bands (2.3, 8.4, and 24 GHz, respectively). A calibration and imaging pipeline has been developed using the Common Astronomical Software Application (CASA). A major overhaul of both the imaging pipeline and the FRIDA user interface is underway.

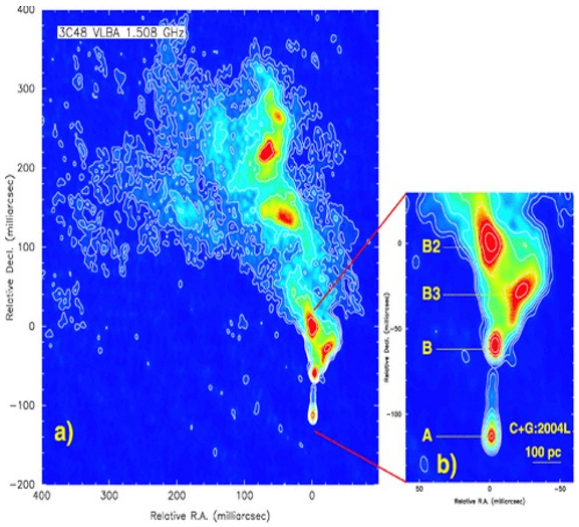
Keywords Imaging, AGN, Celestial Reference Frame

1. United States Naval Observatory
2. Computational Physics, Inc.

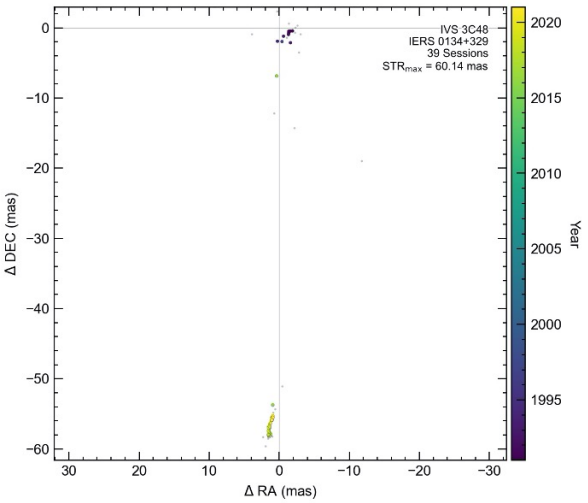
1 Introduction

The three realizations of the International Celestial Reference Frame (ICRF, ICRF2, and ICRF3) all rely on high precision measurements of extragalactic sources (AGN) using Very Long Baseline Interferometry (VLBI). The frames consist of "defining sources", which define the axes of the frame, and "densifying sources", which serve to fill in the frame in order to provide astrometric reference points across the sky. The astrometric measurements which are used to build the ICRF simply measure the position of the brightest point in each observed field and report that position as the position of the source. However, complications arise when one considers both frequency-dependent effects such as core shift, which is a shifting of the VLBI core position with frequency, and time-dependent effects such as AGN variability. Astrometric measurements are limited in what they can make possible to deduce about the underlying astrophysical origins of such variability. In fact, monitoring of ICRF sources through imaging is the only way to understand the relationship between apparent source position and extended structures. This relationship may be frequency- and time-dependent and is not obvious from regular geodetic-mode observations. An example of AGN astrometric variability is shown in Figure 1.

The United States Naval Observatory (USNO) has been imaging ICRF sources for the past two decades as part of its mission as an IVS Analysis Center for Source Structure. USNO hosts the Fundamental Reference Image Data Archive (FRIDA), formerly known as the Radio Reference Frame Image Database (RRFID), which is a web-based data archive of VLBI images of ICRF sources. These images are mainly produced with



(a) 1.5-GHz image of 3C48. *An, T. et al. (2009)*



(b) Astrometric offset of 3C48 from official ICRF3 position. *Cigan, P. et al. (submitted)*

Fig. 1: (a) L-band (1.5 GHz) image of 3C48 showing multiple bright spots along the jet. These spots can brighten and dim over time, leading to variable astrometric positions for 3C48. The ICRF position was previously reported as the location of component B2 but was changed to B after it became brighter than B2. Neither represents the position of the galaxy core, which is component A. (b) Astrometric offsets of 3C48 from the official ICRF3 position set to the origin of the axes. There was a 60 mas jump in 2019 after a flare occurred.

data from the Very Long Baseline Array (VLBA); however, there are a few images of far southern declination sources obtained using international telescope arrays. The VLBA is mainly used today due to its excellent performance and the time allocation agreement between USNO and the National Radio Astronomy Observatory (NRAO).

The purpose of FRIDA is to serve the astronomical community as a central database for high-quality VLBI images of ICRF sources. FRIDA is intended to be a complementary database to the Bordeaux VLBI Image Database[1] (BVID), which offers images and source structure maps of ICRF sources. We are currently redesigning FRIDA to offer an improved user interface to enhance accessibility to these data and are working to offer more data products besides just images, such as raw and calibrated visibility data in multiple data formats as well as source CLEAN components. A VLBI calibration and reduction pipeline written in the Common Astronomical Software Applications (CASA) package has been developed and was presented in Hunt et al. 2021. This pipeline is also undergoing new development with plans for future public release.

[1] https://bvid.astrophy.u-bordeaux.fr/

2 Calibration and Imaging Pipeline

The CASA calibration and imaging pipeline takes in raw data in FITS-IDI format and produces calibrated visibility data and images. This pipeline was originally presented in Hunt et al. 2021 and used to image ICRF3 sources. USNO has been further developing the pipeline to improve its robustness, radio frequency interference (RFI) flagging, and data quality checking capabilities. The current version of the pipeline first converts the raw data into a CASA Measurement Set. It then undergoes an automated RFI flagging procedure, and *a priori* antenna-based calibration tables are created based on information stored in the raw FITS-IDI file. The data are then phase-calibrated using the CASA task **fringefit** to solve for both the static instrumental delays and time-dependent fringe solutions. A bandpass solution is then computed using the brightest sources in the observation. Once the data have fin-

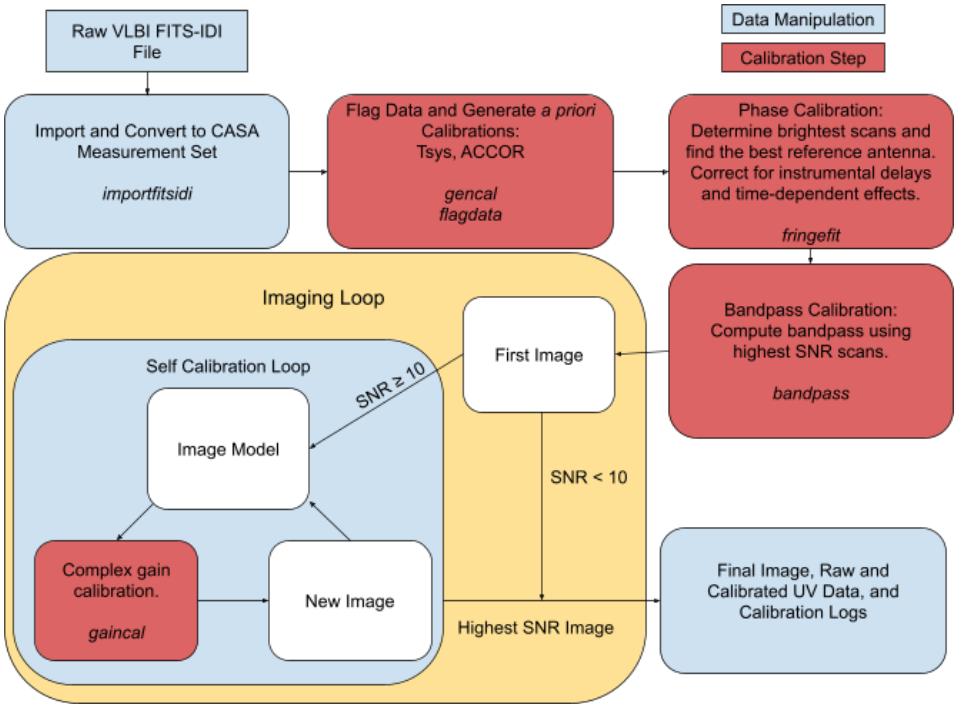


Fig. 2: Flowchart describing the major steps of the calibration and imaging pipeline.

ished being calibrated, the final step is to image each source in the observation using the standard CLEAN algorithm. To achieve this, data from each source are passed into an imaging loop that first tries to create a conservative image that only includes the brightest components. If the initial image has an SNR ≥ 10, self calibration is attempted to improve image quality. The image with the highest SNR after this process is then saved. A flowchart of the major steps in the pipeline is shown in Figure 2.

3 New FRIDA User Interface

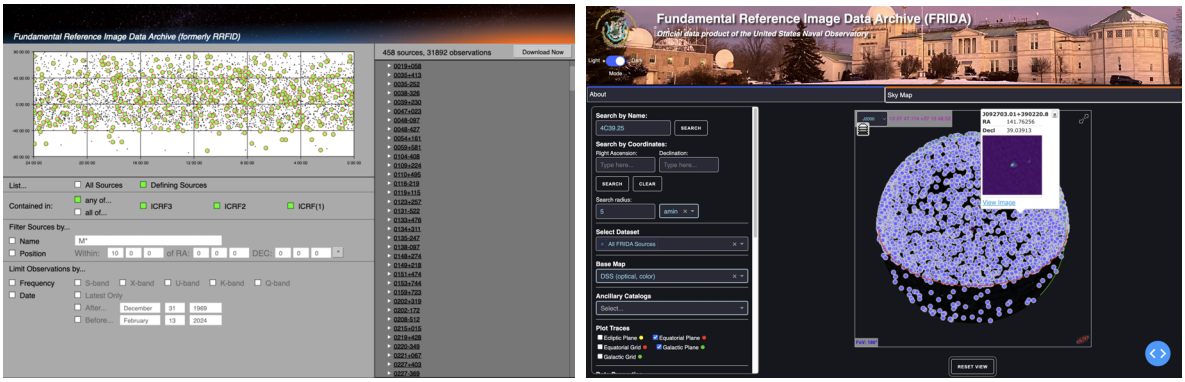
USNO has been working to overhaul the user interface for FRIDA. This refresh will improve user experiences and allow FRIDA to serve the community as a powerful scientific resource. FRIDA will offer both raw and calibrated data in UVFITS and HDF5 formats, final images, clean components, and synthesized beam PSFs for recent VLBA observations of ICRF sources. Every source in the catalog will be cross-referenced through SIMBAD[2], which allows for quick and easy access to multi-band information. The sources are projected onto an interactive sky map that uses the Aladin Lite[3] applet produced by Strasbourg astronomical Data Center (CDS). The sky map supports a multitude of base maps for showing the sky at different wavelengths.

Screenshots of the current FRIDA and the alpha-version of the new FRIDA web interface are shown in Figure 3. The new website is expected to be public by summer 2024 and can be found through the USNO Celestial Reference Frame Department website at https://crf.usno.navy.mil/FRIDA.

4 Summary

The Fundamental Reference Image Data Archive (FRIDA) is an archive of VLBI images of ICRF sources. USNO maintains FRIDA as part of its mission as an IVS Analysis Center for Source Structure.

[2] https://simbad.u-strasbg.fr/simbad/sim-fbasic
[3] https://aladin.cds.unistra.fr/AladinLite/



(a) (b)

Fig. 3: (a) The current FRIDA website. (b) An alpha-version of the new FRIDA website. The new UI includes an interactive sky map and will offer source cross-referencing via SIMBAD.

Currently, FRIDA has images of ∼4000 sources with plans to add a few hundred images each month. These images will come from VLBA observations under the time allocation agreement between USNO and NRAO. A calibration and imaging pipeline for VLBA data in CASA has been developed and is being further improved to support enhanced data products for FRIDA. Finally, the website for FRIDA is currently undergoing a complete overhaul which will result in a more modern UI that enhances accessibility to these products.

References

1. Ma, C. et al. “The international celestial reference frame as realized by very long baseline interferometry”, *The Astrophysical Journal*, 116.1 (1998): 516
2. Fey, A. L. et al. “The second realization of the international celestial reference frame by very long baseline interferometry”, *The Astrophysical Journal*, 150.2 (2015): 58
3. Charlot, P. et al. “The third realization of the international celestial reference frame by very long baseline interferometry”, *Astronomy & Astrophysics*, 644 (2020): A159
4. Hunt, L. R. et al. “Imaging Sources in the Third Realization of the International Celestial Reference Frame”, *The Astronomical Journal*, 162.3 (2021): 121
5. Högbom, J. A. “Aperature synthesis with a non-regular distribution of interferometer baselines”, *Astronomy and Astrophysics Supplement*, Vol. 15 (1974), p. 417