USNO Analysis Center for Source Structure

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Abstract This report summarizes the activities of the United States Naval Observatory Analysis Center for Source Structure during the 2023 and 2024 calendar years.

1 Introduction

The Analysis Center for Source Structure is supported and operated by the United States Naval Observatory (USNO). It was accepted by the IVS as a "Special Associate Analysis Center" in January 2000, with the charter to provide products directly related to the IVS determination of the "definition and maintenance of the celestial reference frame." These products are to include radio images of International Celestial Reference Frame (ICRF) sources, intrinsic structure models derived from the radio images, and an assessment of the astrometric quality of the ICRF sources based on the radio images.

The primary service that the Analysis Center for Source Structure provides to the IVS is to image ICRF sources at Very Long Baseline Interferometry (VLBI) scales and make these images accessible via a web-based user interface. The earliest version of the interface was named the Radio Reference Frame Image Database (RRFID) and began in mid-1996. It mainly contained data from the "Research and Development with the VLBA" (RDV) sessions, which are sessions combining the Very Long Baseline Array (VLBA) with other IVS geodesy antennas. USNO images the RDV sessions jointly and in collaboration with the University of Bordeaux. In 2017, RRFID was renamed to the Fundamental Reference Image Data Archive (FRIDA)[1], and a new user interface was released in 2022.

FRIDA is an archive of radio images of ICRF sources hosted by USNO to support this mission. FRIDA currently contains images of ∼4000 sources spanning 30 years and covering five frequency bands: S (2.3 GHz), X (8.4 GHz), U/Ku (15 GHz), K (24 GHz), and Q (43 GHz). These data are from a combination of RDV sessions as well as sessions using only the VLBA. USNO supports FRIDA through monthly geodetic-style observations using the VLBA at S/X- and K-bands. These observations are calibrated and imaged using an automated pipeline that utilizes the Common Astronomy Software Applications (CASA) package. This pipeline was originally authored by Lucas Hunt[2], but as of 2023 its development is managed by Christopher DiLullo.

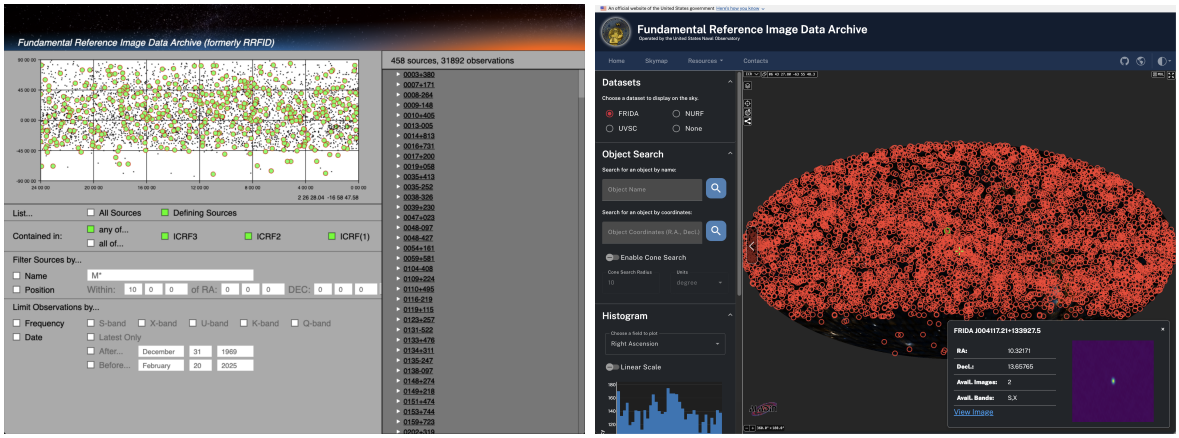
During the years 2023 – 2024, USNO has further developed its CASA-based calibration and imaging pipeline and has begun a modernization effort for both the FRIDA website user interface and the underlying database.

* At NSF as of June 2024

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

[1] https://crf.usno.navy.mil/FRIDA

[2] Now at NRAO.



(a) Current FRIDA interface.

(b) New FRIDA interface.

Fig. 1: Comparison between the original FRIDA sky map interface and the new one.

2 Analysis Center for Source Structure Operation Updates

2.1 New FRIDA User Interface

Even though the FRIDA website was only launched in 2022, the design of its user interface is dated, and challenges with respect to the accessibility of the data have been identified. Beginning in late 2023, the decision was made to completely rewrite the website using the modern web development framework Angular while adhering to current best practices. The new website will allow users to easily access the data in FRIDA as well as interact with the images on the web within interactive Plotly frames. The new FRIDA website is expected to go live during the second half of 2025.

The Aladin Lite applet, created by the Strasbourg Astronomical Data Center (CDS), is used to create an interactive sky map which can display various background sky maps and data catalogs on top of the FRIDA catalog. This is a powerful tool for quickly identifying sources in FRIDA that also are in other catalogs such as Gaia. Performing cone searches around an object is also possible, which makes the new FRIDA useful in finding strong astronomical calibrator sources near an object of interest. The Sesame[3] name resolver enables the users to search for objects using more than just ICRF, IVS, or IERS names. Figure 1 compares the old and new FRIDA sky map pages. The new image viewer page can be seen in Figure 2.

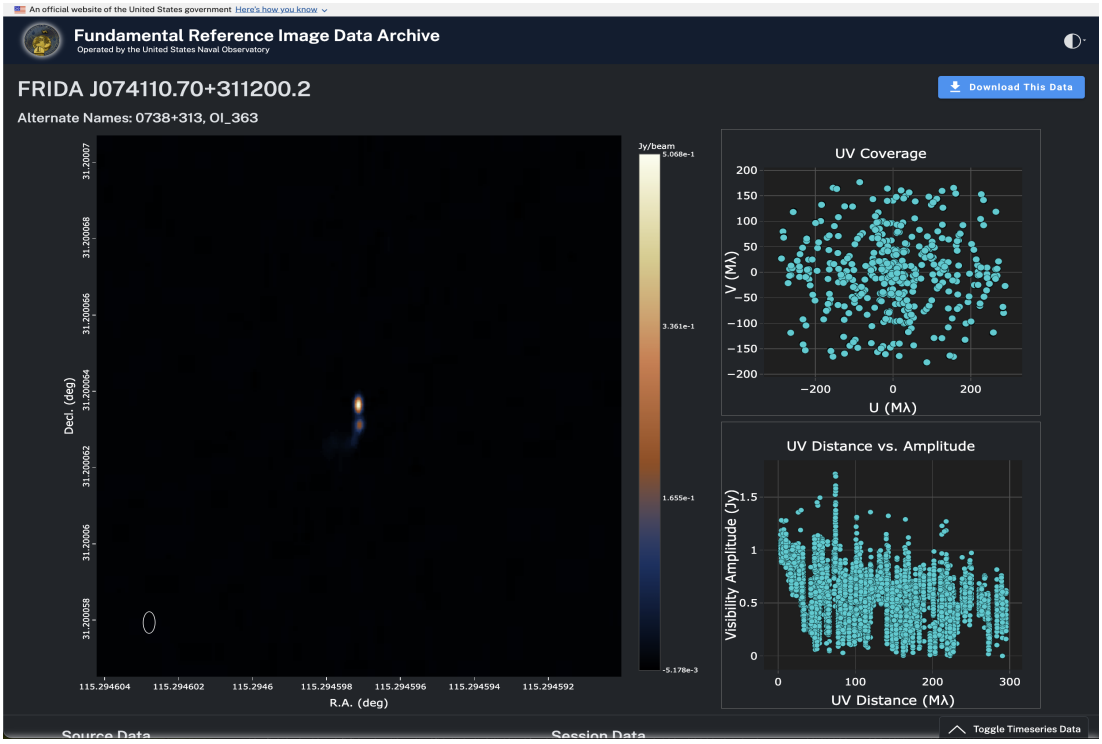
Other USNO projects will also now fall under the FRIDA umbrella, and their associated data will be hosted on the website. The main subsidiary projects are the NRAO/USNO Reference and Flux-density (NURF) survey and the USNO VLBI Spectroscopic Catalog (UVSC). These are projects separate from the core mission of the Analysis Center for Source Structure, but they fall in the greater mission of USNO to help monitor and maintain the ICRF.

2.2 CASA Pipeline and VLBA Imaging

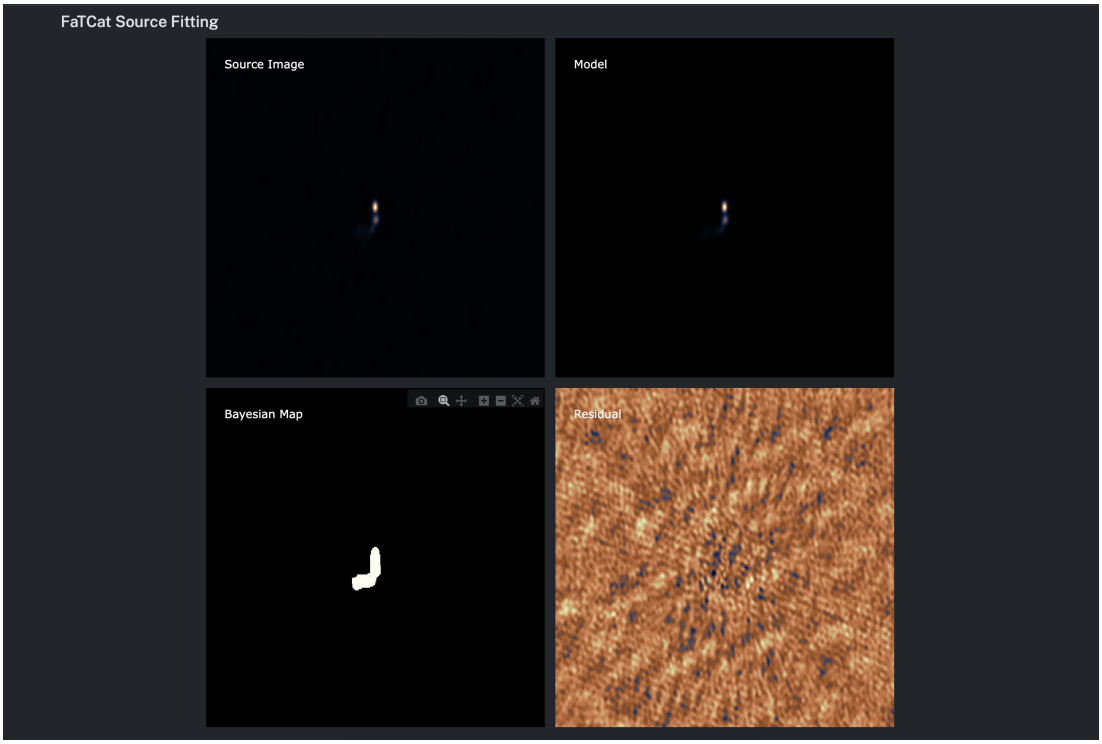
The calibration and imaging pipeline written for CASA has been largely refactored and almost entirely rewritten to improve its robustness and output data quality. As of 2023, the pipeline is now hosted on an internal GitLab server and is version controlled. In 2024, efforts were made to convert the pipeline from a collection of scripts to an installable Python package. The Analysis Center for Source Structure plans to submit the pipeline for internal code review in order to make it publicly accessible.

The performance of the pipeline depends on the hardware on which it is being run and how large the input dataset is. It typically takes about 18–20 hours to complete calibration and imaging of a single 24 hour long geodetic-style observation at S/X-bands on the

[3] `https://cds.unistra.fr/cgi-bin/Sesame`



(a) New FRIDA image page display.



(b) FRIDA FaTCat source fitting.

Fig. 2: Screenshots of the updated image viewer page on the new FRIDA website. (a) An image of 0738+313 with associated (u,v)-coverage and amplitude versus (u,v)-radius plots. (b) FRIDA FaTCat source fitting images.

server node used by the Analysis Center for Source Structure. This speed allowed for a large backlog of data to be processed quickly in the last quarter of 2024.

During 2023 and 2024, USNO supported monthly 24-hour long geodetic-style observations at S/X- and K-bands, project codes UG- and UD-, respectively. These observations are made possible by the timesharing agreement between USNO and the National Science Foundation (NSF) for 50% of the operational costs of the VLBA for 50% of the observing time. These sessions were not imaged until late in 2024 after the rewrite of the calibration and imaging pipeline was complete. Once the pipeline was in an operational state, they were all imaged and added to the new FRIDA database. These data will be available when the new FRIDA website is released. The addition of these observations brings the current source count in FRIDA to 5041, a $\sim$25% increase from the current publicly available FRIDA database.

2.3 The FRIDA Flux and Time-series Catalog (FaTCat)

The FRIDA Flux and Time-series Catalog (FaTCat) is a catalog of fluxes and source model components of FRIDA sources. It was created using a novel Bayesian search algorithm to identify likely real emission in the FRIDA images and the source fitting package *PyBDSF* to extract flux from source model components. The source models and Bayesian masks will be available for download on the new FRIDA website. FaTCat is the main focus of a paper expected to be published in 2025 (DiLullo et al., in prep). An example of the FaTCat source fitting can be seen in Figure 2.

3 Conclusion and Future Plans

The work carried out during 2023–2024 focused on completely overhauling the current outdated FRIDA website and improving the CASA-based calibration and imaging pipeline. These efforts have been largely successful, and the USNO Analysis Center for Source Structure is excited to release the new version of FRIDA in 2025. The FRIDA Flux and Time-series Catalog will also be released in 2025 with the release of the new FRIDA website. This catalog will contain important information about each of the FRIDA sources such as flux and number of components and will allow for the community to more easily study time- and frequency-dependent effects. The study of such effects is the main purpose of imaging ICRF sources.

In the coming year, the Analysis Center for Source Structure will begin to work on developing a CASA-based pipeline to image the RDV sessions. USNO has stopped imaging the RDV sessions in the past few years as staffing changes have led to disruptions in its ability to properly calibrate and image these more complex observations. Given that the RDV sessions now have a monthly cadence beginning in 2025 and these sessions offer improved angular resolution which can resolve smaller scale structure in the jets of ICRF sources, building out a well-documented and automated way to calibrate and image these sessions is a top priority for the Analysis Center.

FRIDA should be updated on a monthly cadence in the future with a few hundred images added at a time. As this becomes more operationally routine, the Analysis Center for Source Structure plans to turn its attention to deriving source structure corrections which can be derived from the images. Intrinsic source structure, if left uncorrected, will create an uncertainty floor in the astrometry of these sources and add uncertainty to EOP values derived from uncorrected delay offsets. Next generation analyses should aim to account for source structure through corrections derived from imaging.

4 Staff

The staff at the USNO Analysis Center for Source Structure during 2023 – 2024 consisted of Christopher DiLullo, Megan Johnson, Phil Cigan, Remington Sexton, David Gordon, Christopher Dieck, and Seth Bruzewski. Christopher DiLullo joined USNO in March 2023 and took over the CASA pipeline development after Lucas Hunt went to NRAO. Remington Sexton is leading the web development of the new FRIDA website. Megan Johnson left USNO in June of 2024 and is now at the National Science Foundation. Seth Bruzewski joined in November 2023.

Acknowledgements

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