Multi-epoch VLBI Images to Study the ICRF-3 Defining Sources in the Southern Hemisphere

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Abstract

The third realisation of the International Celestial Reference Frame (ICRF-3) is based on high precision Very Long Baseline Interferometric (VLBI) measurements of positions of 4536 extragalactic radio sources. This includes the 303 defining sources which determine the orientation of the frame axes. These reference sources often show extended emissions on milliarcsecond scales that can vary with time, frequency and baseline projection. The effect of source structure on astrometric VLBI positions can be significant and it is therefore important to map the structures of these sources on a regular basis. However, due to the limited number of radio telescopes in the south, it has always been difficult to run dedicated imaging programmes and to monitor source structure, especially for sources below -30° declination.

We present results from our efforts to image and monitor the intrinsic source structures of ICRF sources using ongoing astrometric and geodetic VLBI observations in the south.

Background Information

- The current realization of the International Celestial Reference Frame, the ICRF-3 [1] was adopted by the IAU in September 2018.
- The ICRF-3 is based on high precision Very Long Baseline Interferometric (VLBI) measurements of positions of extragalactic radio sources.
- The ICRF-3 catalog contains 4536 sources including the 303 defining sources.
- The ICRF-3 made significant improvements in the south, however the south has not yet reached parity with the north and much work remains to be done.

Source Density in the ICRF-3

- The ICRF-3 below -30° declination is weak.

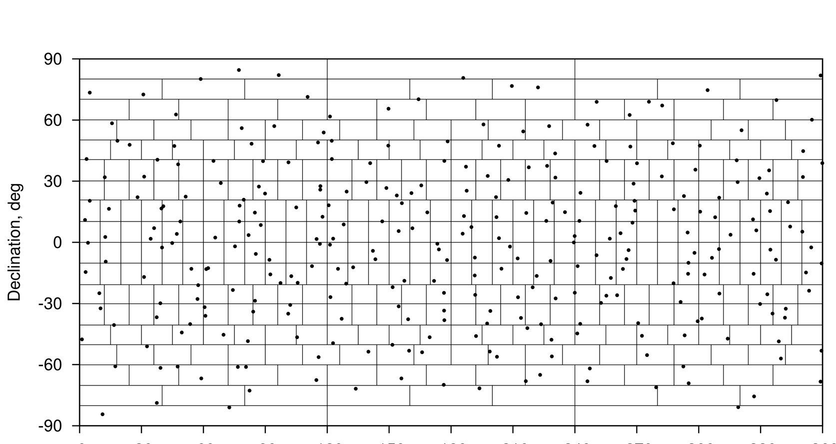

Figure 1: ICRF-3 defining source distribution using 406 equal-area cells.

- Despite efforts to improve the south, there still remains a significant hemisphere disparity in source distribution and density.
- In figure 1, we present the distribution of the ICRF-3 defining sources using a method of subdividing a spherical surface into equal-area cells [2].
- It is clear that we still need more sources in the south and that we also need to improve the spatial coverage, especially for declination south of -30°.

Radio Source Structure

Radio-loud quasars making up the ICRF-3 may exhibit significant structure which:

1. can vary with time, frequency and baseline projection on timescales of months to years (e.g. figure 2).
2. Can have serious effect on geodetic and astrometric measurements.

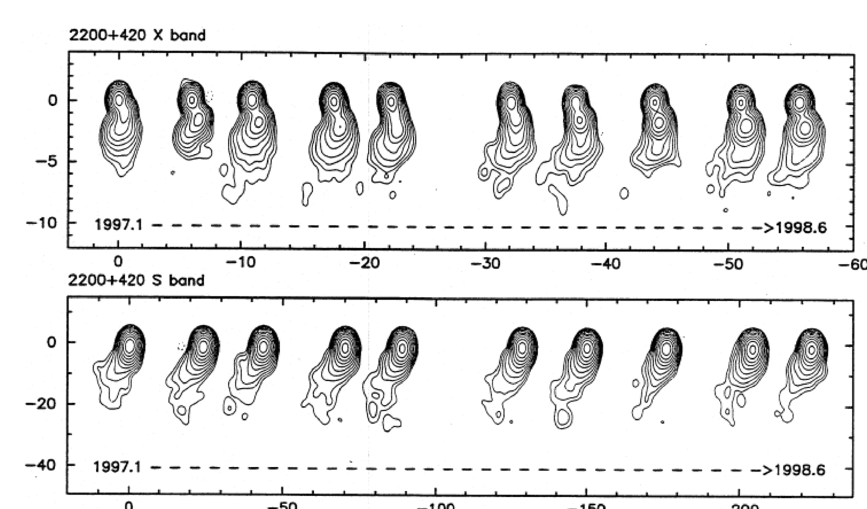

Figure 2: Time and frequency-dependent source models of ICRF source 2200+420 at S/X band. The scale is in milli-arcseconds [5].

- Multi-epoch source maps are essential to assess the astrometric suitability of the CRF sources.

Need for an Imaging Program in the South

- Dedicated multi-epoch VLBI campaigns to map and monitor source structure in the south have proven difficult to obtain.
- We identified 124 sources (37 ICRF-2 defining sources) in the far-south (below -45°), with no VLBI images (e.g. figure 3).

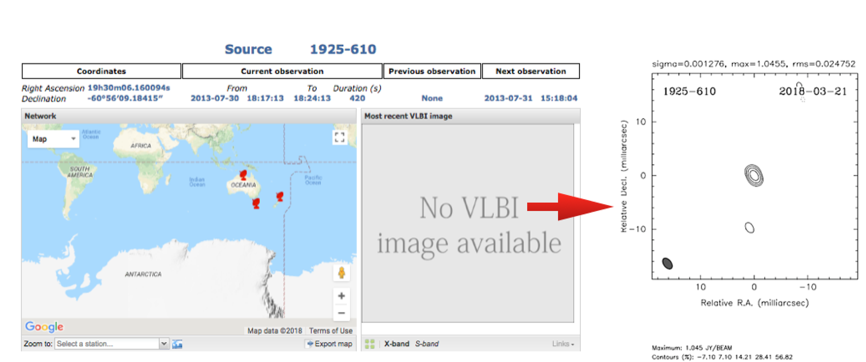

Figure 3: Example of an ICRF-3 defining source in south for which no imaging results was available before. A contour plot of the first VLBI imaging of this source, from existing CRDS sessions, is shown on the right.

Optimization of CRDS Observations

- We selected the Celestial Reference Frame Deep South (CRDS) geodetic VLBI sessions and optimized it for VLBI imaging [3].
- Since January 2018, we increased the of the CRDS sessions from 256 Mbps to 1 Gbps and we also optimized the scheduling for both geodesy and imaging.
- The higher data rates and improved scheduling results in more sources per sessions and improved uv-coverage for imaging.

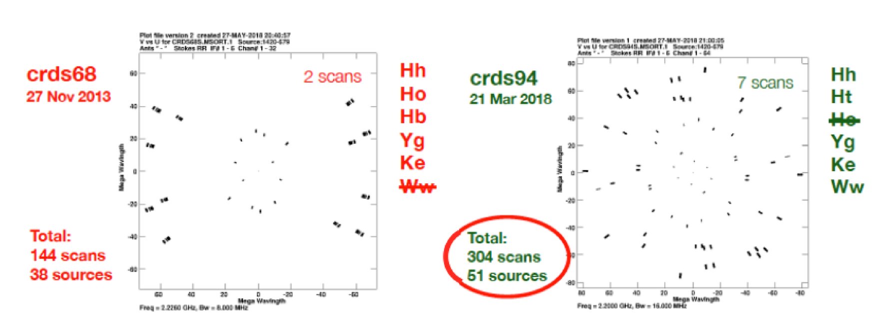

Figure 4: Improvement in number of scans per source thus better uv-coverage helps for a better imaging.

- In figure 4, we show uv-coverage comparison between an old and a new CRDS session.

Results

- We have shown that CRDS sessions can be used to successfully image intrinsic structures of ICRF sources [4].
- So far, CRDS-63, 66 and 68 from 2013 and CRDS-94 from 2018 have been used to produce maps of ICRF sources in the south.
- There are 5-6 CRDS sessions per year with 4-6 participating antennas in every session.
- In figure 5, we show multi-epoch maps for a representative sample of our sources imaged using CRDS data at X-band.
- Some ICRF sources were imaged for the first time using data from CRDS sessions. These images were used in selecting defining sources for the ICRF-3.

VLBI Images from CRDS Sessions

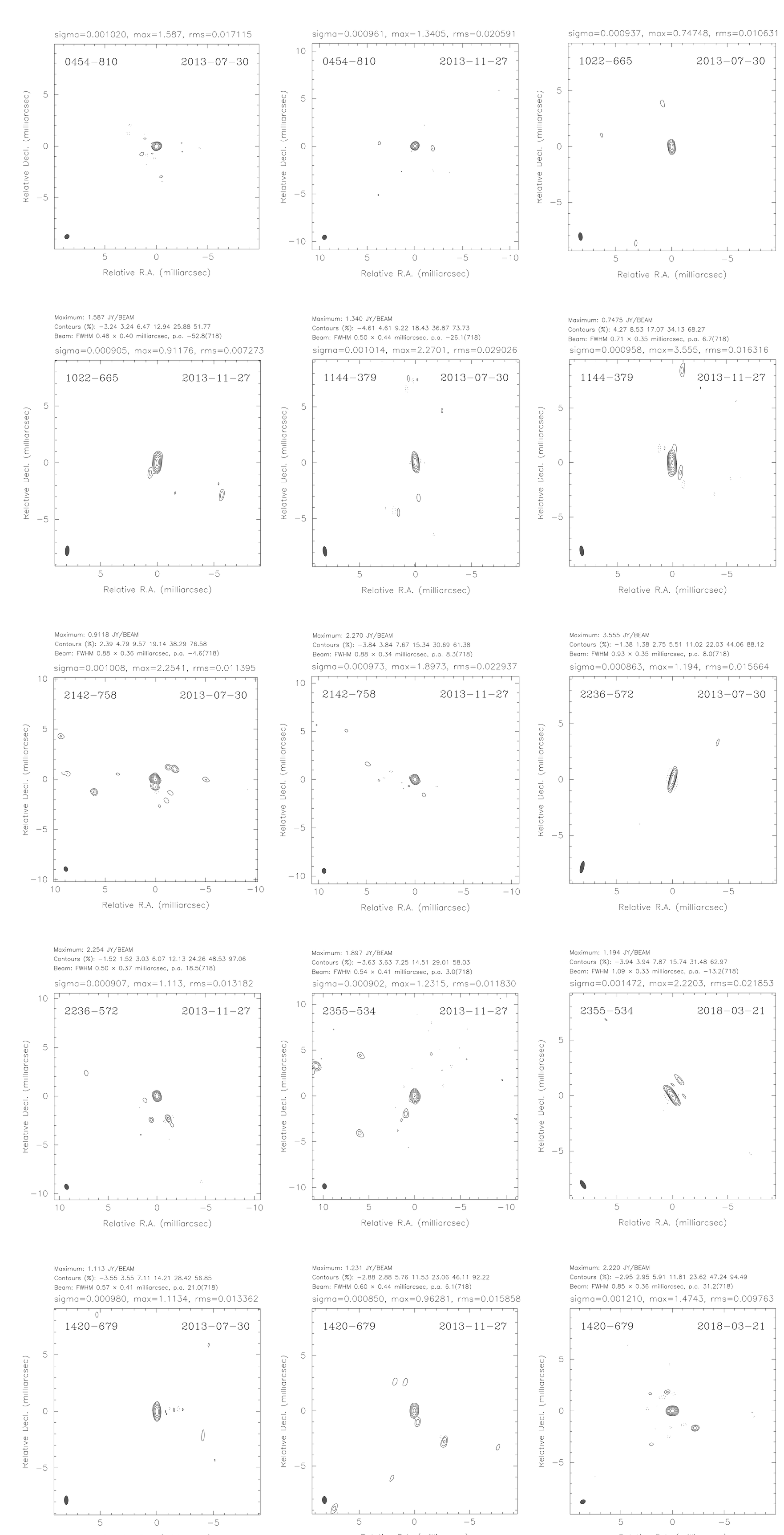

Figure 5: Contour plots of sample ICRF-3 defining sources 0454-810, 1022-665, 1144-379, 2142-758, 2236-572, 2355-534, and 1420-679. North is up and East is to the left.

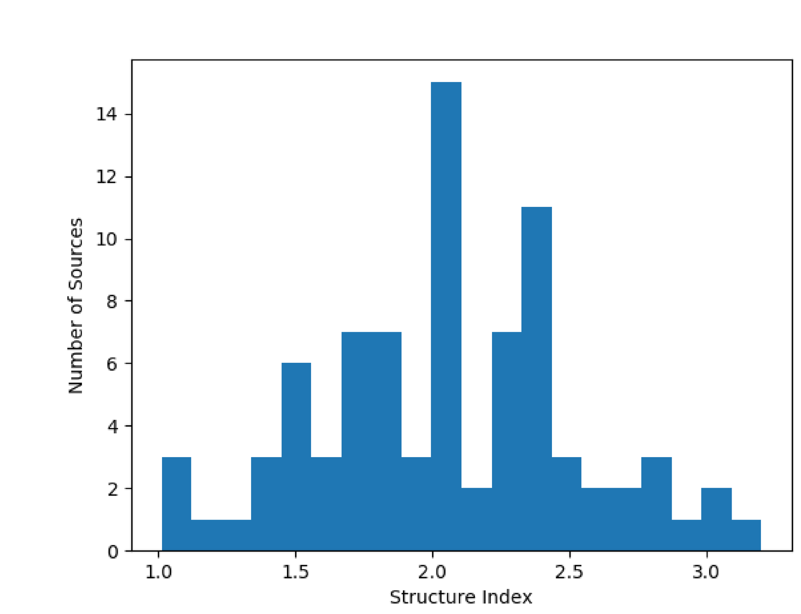

Figure 6: Structure index distribution of the ICRF-3 defining sources imaged using CRDS sessions. Some sources have been imaged at three-epochs.

- Structure Index (SI, [6]) was calculated for astrometric quality assessment of the sources (Figure 6).
- SI=1 (very good), 2 (good), 3 (use with caution) and 4 (not recommended for use).

Conclusions

- CRDS sessions prove to be valuable for structure analysis of ICRF sources.
- The ICRF-3 defining sources need to be evaluated and monitored on a regular basis.
- CRDS VLBI imaging results can be used for source selection prior to any geodetic and astrometric observation in the south.

Future Work

- In figure 7, we present a HEALPix sky distribution plot of the ICRF-3 sources. White patches indicate areas with no sources.
- New potential sources are being added to the CRDS sessions for imaging and astrometric quality assessment.

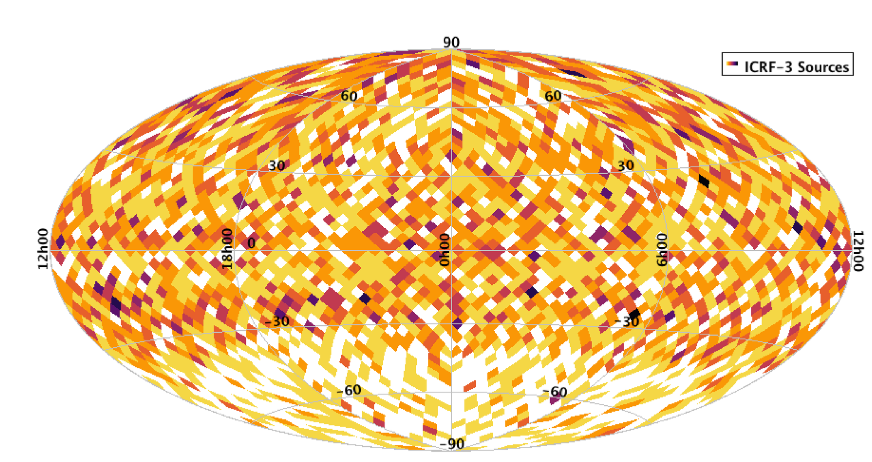

Figure 7: ICRF-3 source distribution using HEALPix (N_{side}=4). New sources are needed in south.

- Automation of the calibration and imaging to handle the large volumes of data.
- Increase the number of ICRF-Gaia Celestial Reference Frame link sources in south.

References

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[6] Charlot P., 1990, *AJ*, 99, 1309-1326

Acknowledgements

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