The Celestial Reference Frame at K-band (24 GHz)
and Future Roadmap

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Abstract

The K-band AstroGeo collaboration was launched in 2013 with the aim of building a K-band astrometric catalogue using VLBI astrometric and imaging observations of Active Galactic Nuclei (AGN) at 24 GHz, initiated in 2002 by Lanyi et al. 2010 [1] and Charlot et al. 2010 [2]. The efforts of the collaboration to increase the source density, sky coverage, and improve the astrometric accuracy of the K-band catalogue led to the adoption of the K-band astrometric catalogue in 2018 as part of the third realisation of the International Celestial Reference Frame, the ICRF3 (Charlot et al. 2020 [3]). Since its incorporation into ICRF3, the K-band Celestial Reference Frame has been significantly expanded.

As of January 2024, the frame consists of 1315 relatively uniformly distributed sources - comparable to the number of regularly observed S/X-band sources - derived from 161 observing sessions and more than 2.57 million observations. For sources that overlap with the standard S/X-band frame, the median precision of the K-band frame is now comparable to that of the S/X-band frame. This development also highlights the growing potential of K-band geodesy. This contribution presents the forward-looking roadmap of the K-band collaboration aimed at continuously improving the observational quality and frame accuracy.

The K-band Celestial Reference Frame

The celestial angular coordinates (RA, Dec) of 1315 active galactic nuclei are derived from VLBI measurements at 24 GHz (1.2 cm). **The agreement with the S/X solutions is in the part-per-billion level.** Recent efforts have reduced the astrophysical systematics for K-band compared to S/X.

Applications

High-accuracy Celestial Reference Frames (CRFs) are useful for many applications such as determining the Earth's orientation in space, studying the motion of tectonic plates, the alignment of radio and optical reference frames, studies of Galactic aberration, satellite tracking and orbit determination, Deep-Space navigation, alignment of the planetary ephemerides, and as phase reference calibrators for VLBI imaging of weak and extended sources and measurements of parallaxes and proper motions.

Of particular importance is its contribution to the **Global Geodetic Reference Frame (GGRF), which is the subject of a recently adopted United Nations resolution for sustainable development.**

Motivation for higher frequencies

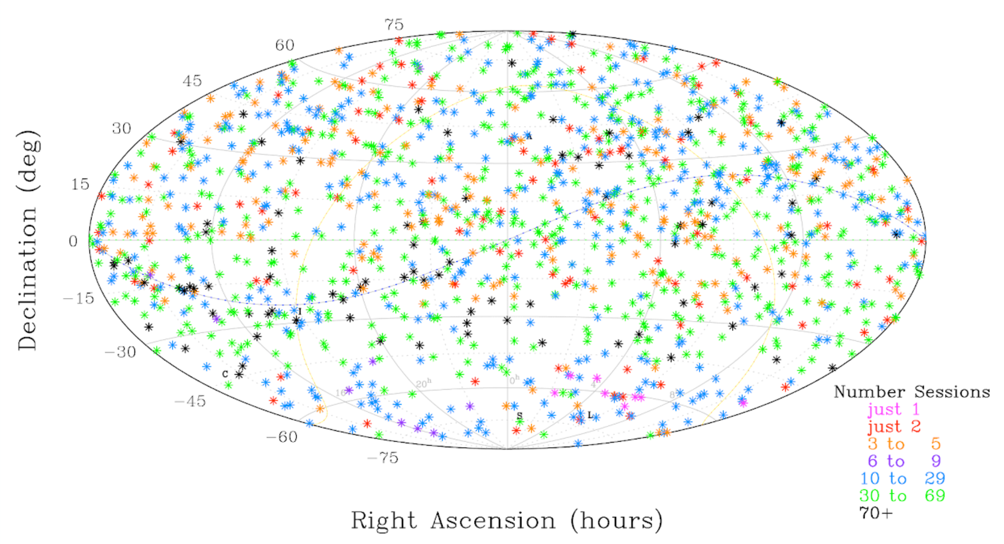
To allow data from multiple independent data sets to be compared: mitigate systematic errors, improve accuracy and redundancy of measurements, ensure reliability and robustness of the reference frame.

To realize the potential advantages of higher frequencies: improvement in angular resolution, more compact source morphology and reduced core-shift effect. Allow observations closer to the Sun and Galactic Plane.

To meet the demands of modern VLBI systems: next-generation instruments are not expected to have dual S/X capability, these bands face increasing Radio Frequency Interferences (RFI).

To serve as a crucial resource for astronomical VLBI observations at higher frequencies: enhance the precision and effectiveness of phase-referencing and differential astrometry VLBI observations at K-band.

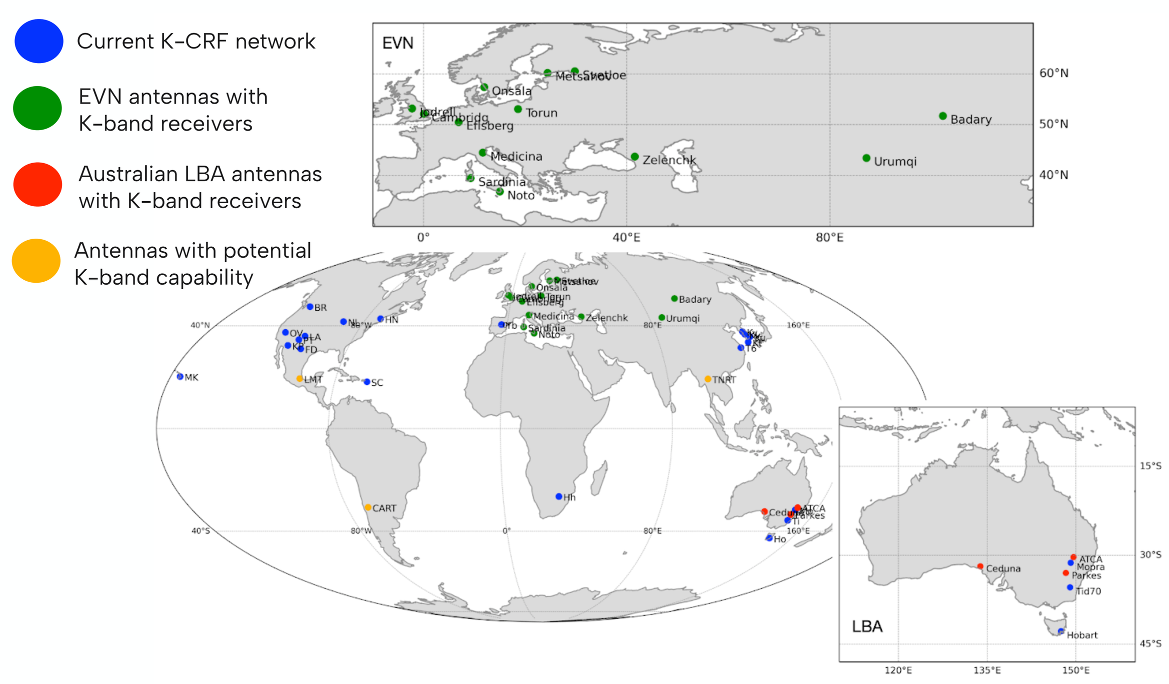
K-band Catalog



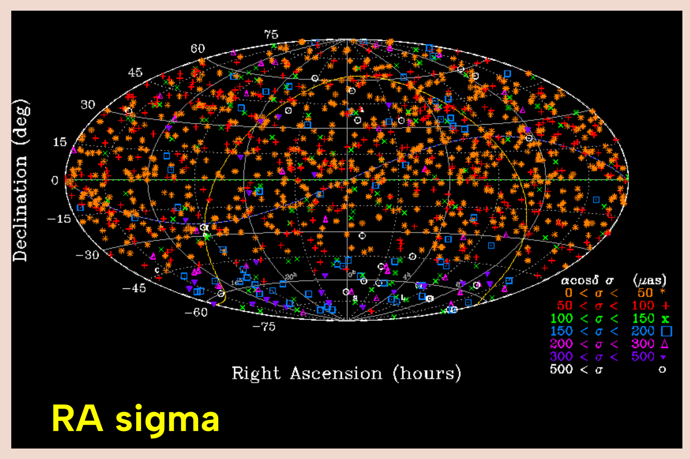
The sky distribution of the 1315 sources (AGN) in the current K-CRF astrometric catalogue (Jan. 2024 astrometric solution, D. Gordon, USNO), colour-coded by the number of sessions each source was observed in. The median number of sessions is 27.

K-band Networks

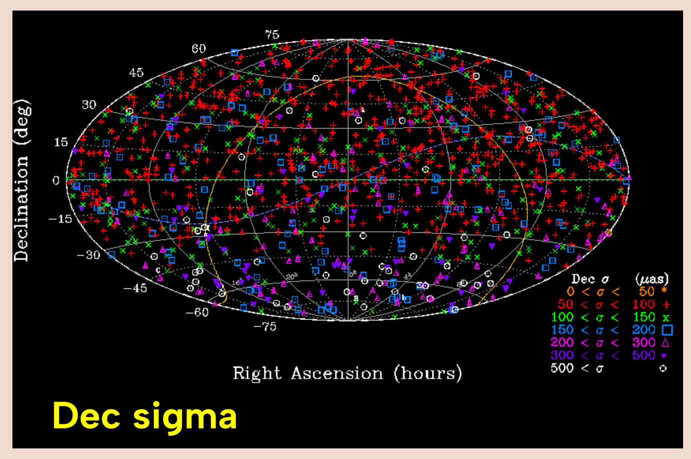
Worldwide distribution of radio telescopes and networks that are or will be potentially equipped with K-band receivers.



K-band Celestial Reference Frame



RA* (arc) precision: Median sigma is 52 µas for 1315 sources. Median is 190 µas for Dec < -45 deg.



Dec precision: Median sigma is 91 µas for 1315 sources. Median is 324 µas for Dec < -45 deg.

Comparing K-band (2024/01/19) to the ICRF3-S/X (Charlot et al., 2020 [3]), after removing sources with sigma > 2 mas and 57 outliers > 5-sigma leaves 1175 common sources. wRMS agreement is 112/ 162 µas in RAcosDec and Dec, respectively. It is expected that **more North-South baseline data will help to reduce systematic errors.**

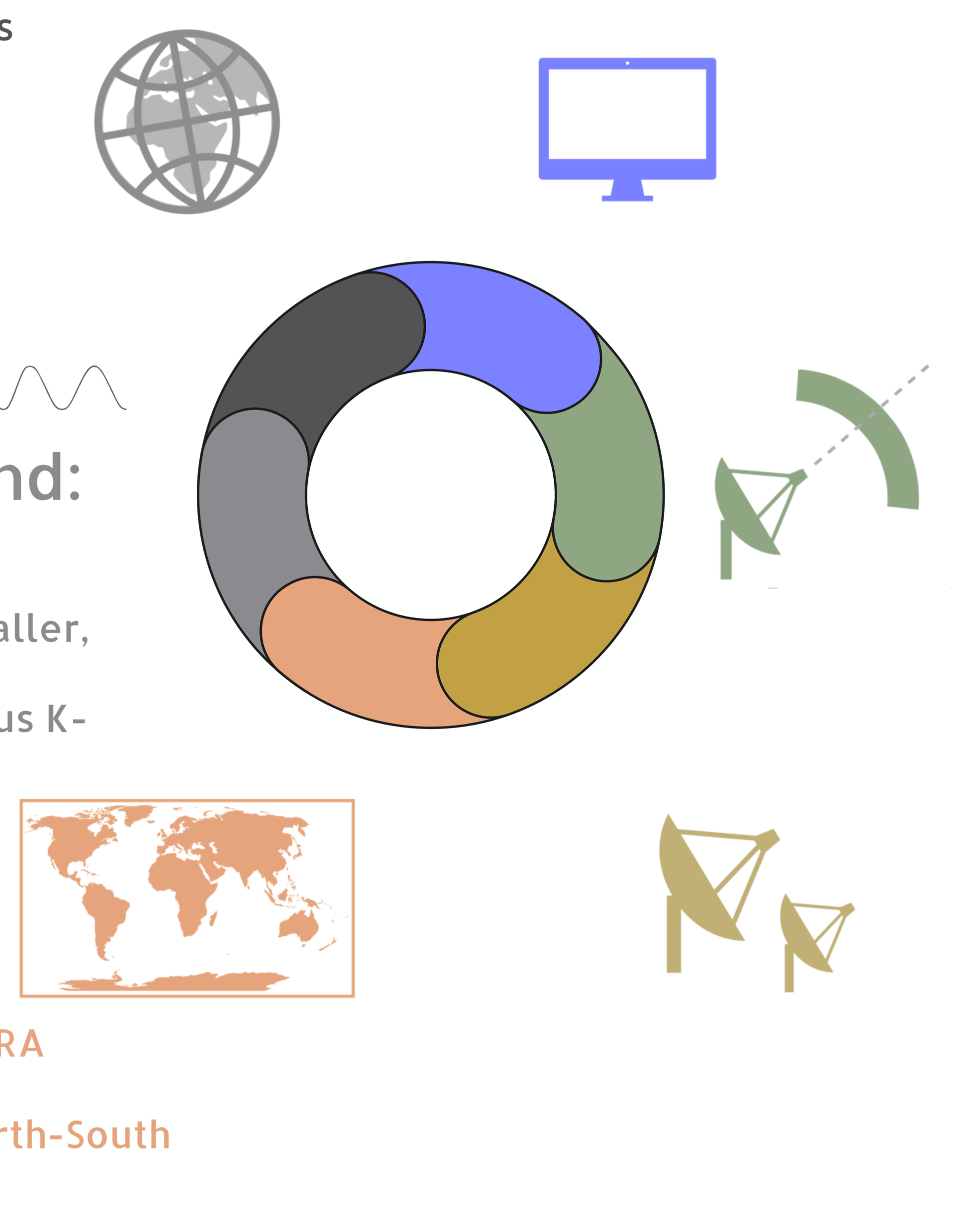
Future Roadmap for the K-band AstroGeo Collaboration

The K-band AstroGeo Collaboration seeks to improve the products continually. To that end, we have several initiatives underway to improve the various aspects of our work. In addition, we are working to increase the number of operationally available K-band products.

K-band AstroGeo website: https://sites.google.com/sarao.ac.za/k-bandastrogeovlbi/home

Products:

- Merge high-frequency astrometric/geodetic VLBI efforts into one service
- Make K-band VLBI products available to the community (astrometric/ geodetic/ astronomical)



Optimal Frequency Band:

- K-band needs dual-band X/K for ionosphere calibration
- Q & W-band ionosphere effect smaller, but sources weaker
- Tri-band receivers for simultaneous K-Q-W CRF using Frequency Phase Transfer technique

Geometry:

- Precision much worse in Dec than RA direction
- Need more Southern stations & North-South baselines
- Add EVN stations to improve uv-coverage

Analysis:

- Compare results from independent geodetic VLBI analysis software packages
- Troposphere: refine the elevation-dependent weighting used in our geodetic analysis
- Improve Ionosphere calibration
- Correction of source structure effects and its variation over time (de Witt et al. 2023 [4])

Ionospheric Calibration:

- Equip all 10 VLBA stations with GNSS receivers
- JPL 3-D ion cals, 15 minute resolution JPL R&D 15-min temporal resolution GNSS calibrations and 3D modelling (Soja et al. 2019 [5])
- JPL broadband receiver (8-36 GHz) for X/K (Kooi et al. 2023 [6])

Sensitivity:

- Upgrade to higher data rates, up to 8 Gbps
- Add additional antennas, e.g. LMT 50-m to VLBA ~double sensitivity baselines
- Wider bandwidth: JPL broadband receiver ~factor of three increase in sensitivity

References

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