



Current Celestial Reference Frame Status at X/S and K Bands



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Outline



- Current X/S Band (8.6/2.3 GHz) Status
- Current K Band (24 GHz) Status
- X/S and K Band Precision Improvements Over ICRF3
- Importance of the VLBA to the ICRF
- Sgr A* in ICRF3 frame at K band



Current X/S Band Status



ICRF3-SX used data through March 2018. Now have 4+ additional years of VLBA and IVS X/S sessions.

ICRF3-SX:

4536 sources, 13.2 million obs.



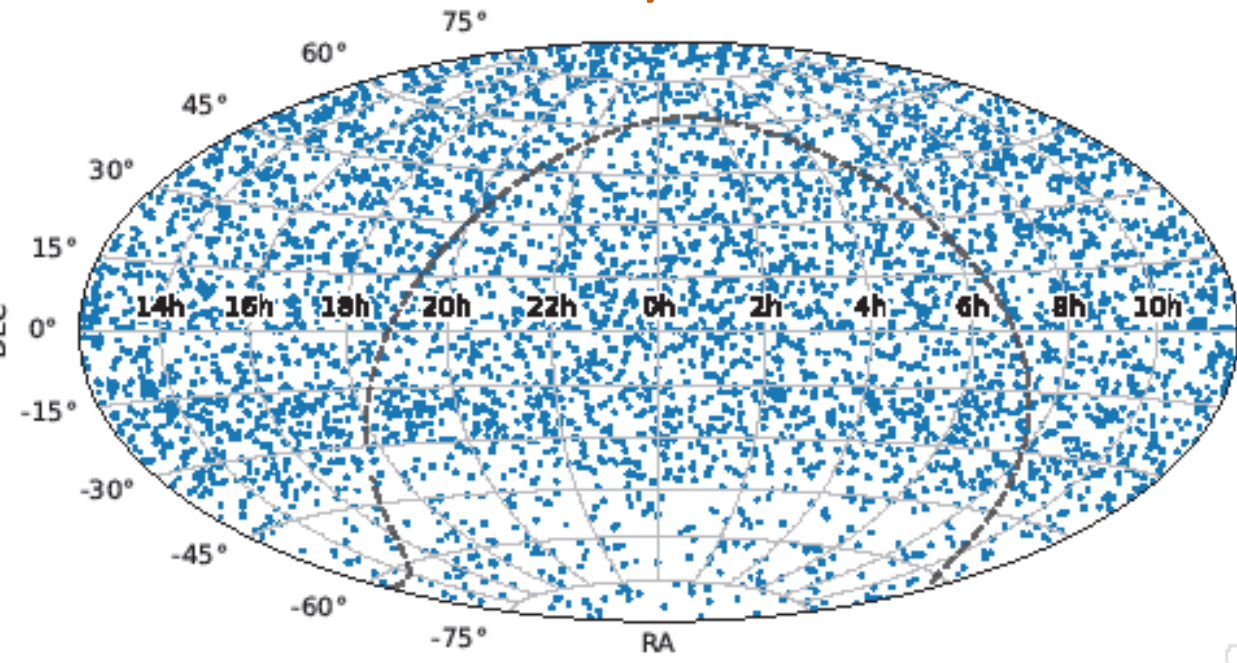
XS-22July03 Solution:

5518 sources, 17.1 million obs.

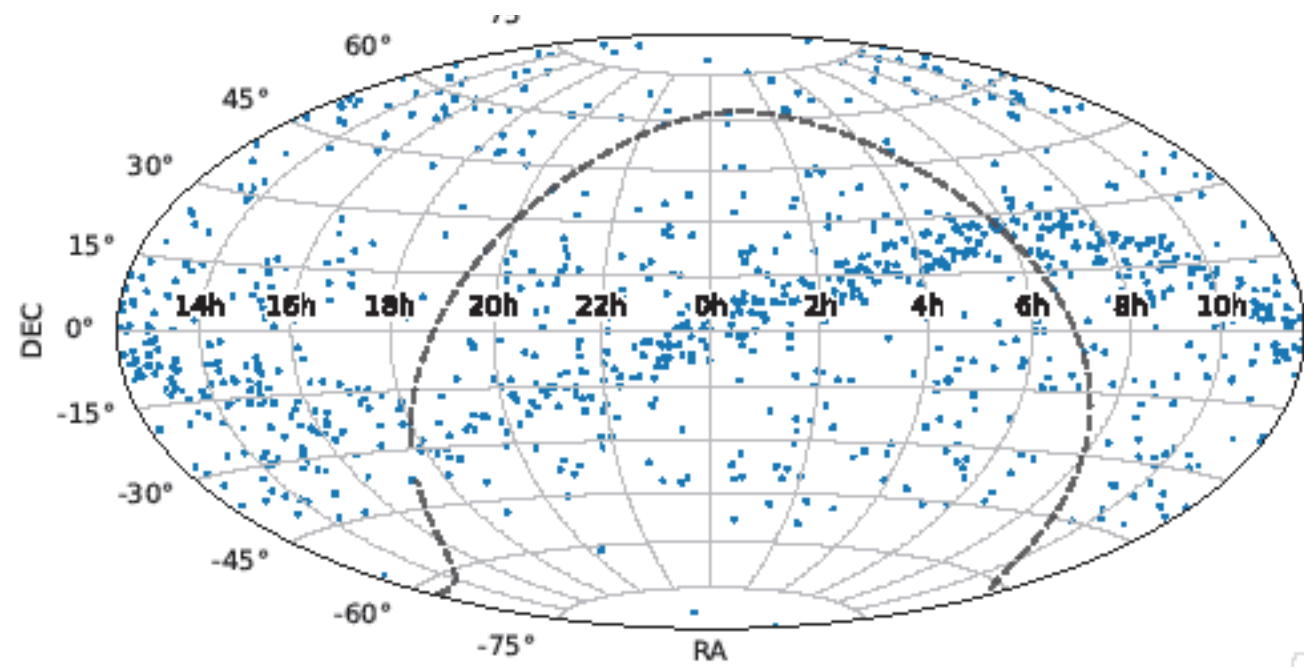
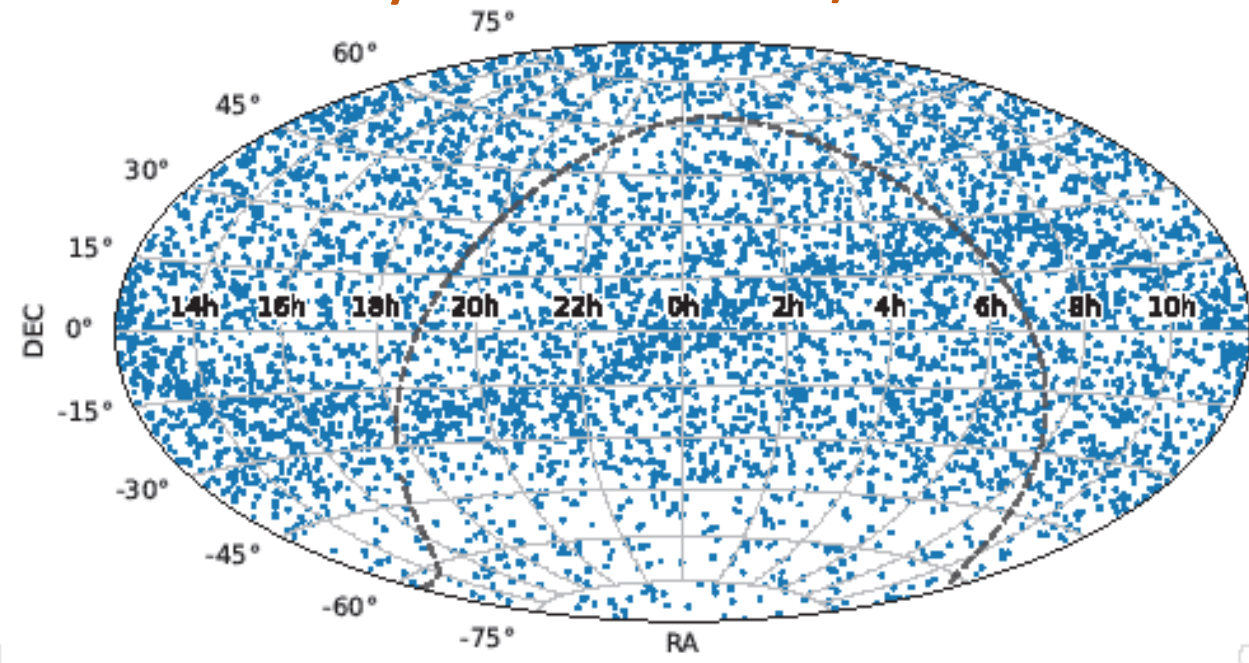
22% more sources, 30% more obs.

- Monthly VLBA 2 Gb/sec X/S astrometry and bi-monthly RDV 512 Mb/s sessions have added ~830 additional X/S sources since ICRF3, ~half being within 7° of the ecliptic. Run under the USNO's VLBA time allocation.
- AOV/AUA/CRF/CRDS IVS sessions have added ~150 X/S sources, some in the far-south.

ICRF3-SX: 4536 X/S Sources



2022July03 Solution: 5518 X/S Sources



**2022July03 Solution:
983 X/S sources added since ICRF3**



Current K Band Status



ICRF3-K used data through May 2018. K-band has since matured now with 4+ additional years of VLBA and HARTRAO-HOBART26 sessions.

ICRF3-K:
824 sources, 0.48 million obs.

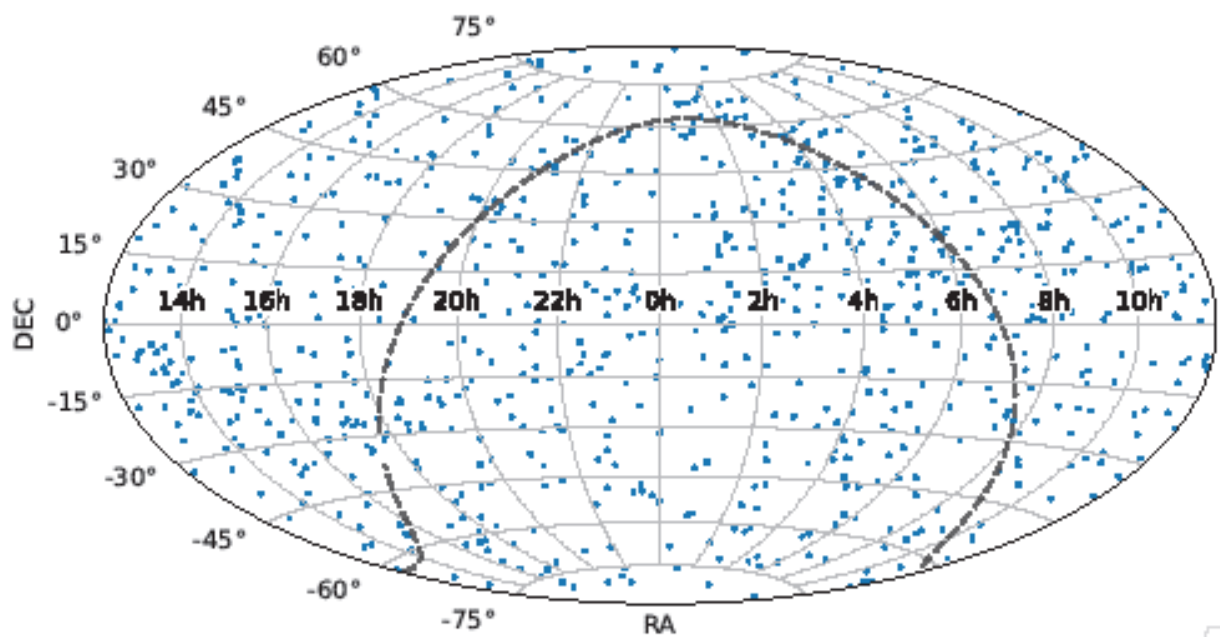


K-22July05 solution:
1035 sources, 1.89 million obs.
25% more sources, 3.9X obs.

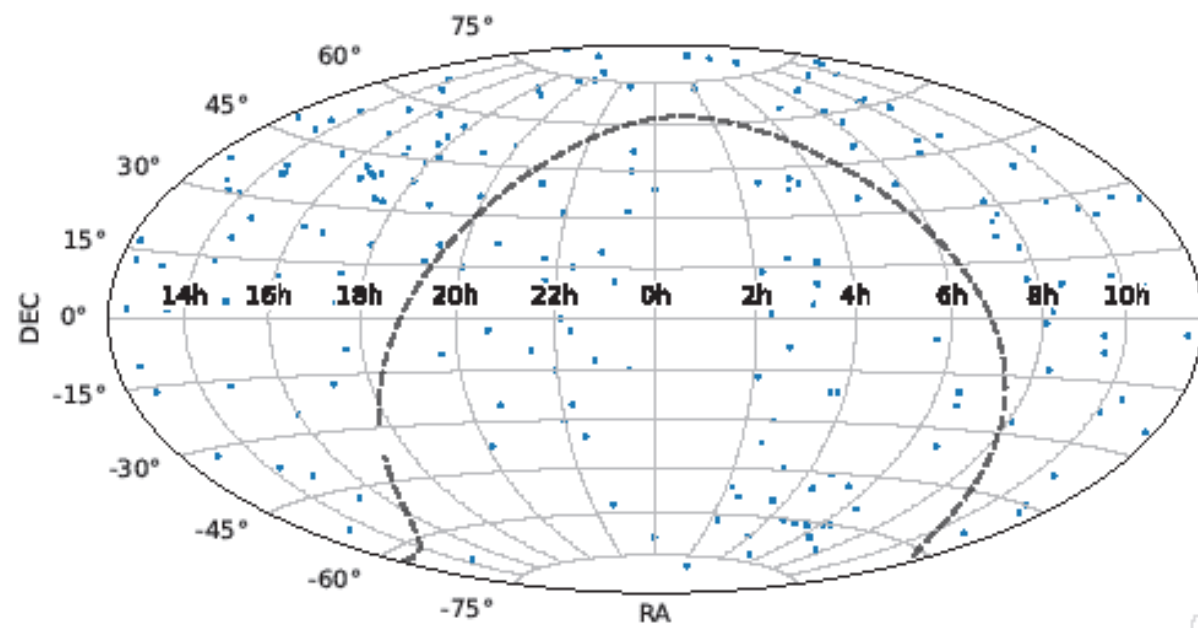
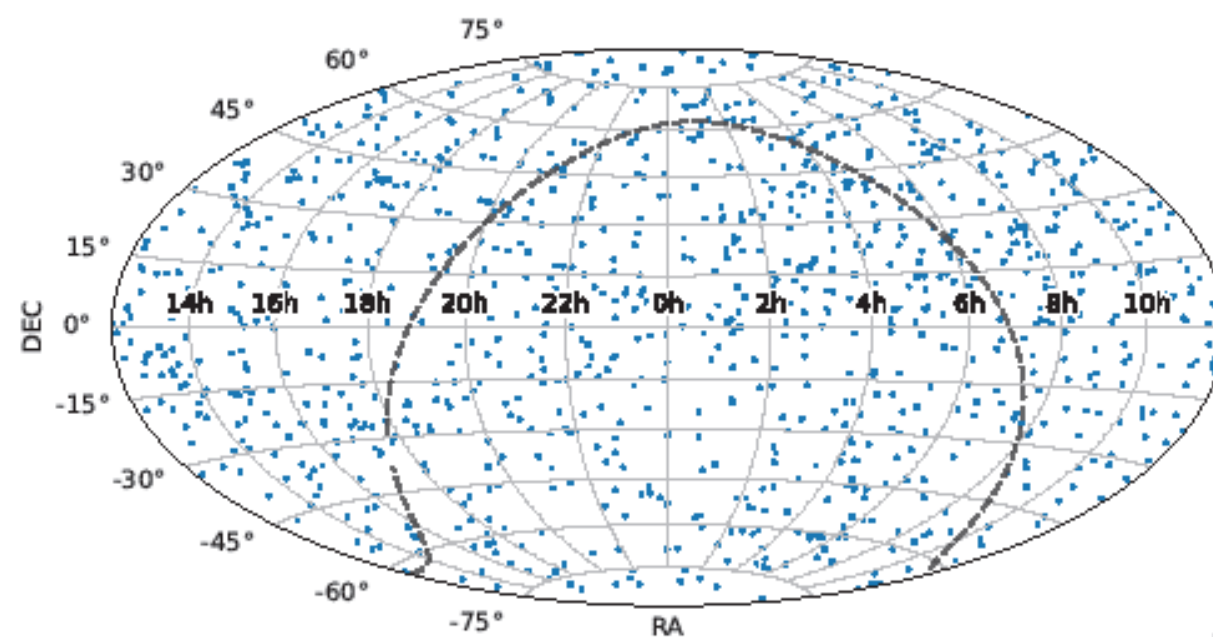
- Monthly K-band VLBA 2 Gb/sec or 4 Gb/sec astrometry sessions have added **183** additional K-band sources. Run under the USNO's VLBA time allocation.
- HARTRAO-HOBART26 sessions have added **28** sources south of -46° declination. (Unfortunately no data since February 2021.)

913 sources observed by the VLBA. **328** sources observed by HARTRAO-HOBART26. **206** sources observed in both networks, -46° to $+39^\circ$ declination.

ICRF3-K: 824 sources



K-22July05: 1035 K-band sources



**K-22July05 solution:
211 K-band sources
added since ICRF3**



Precision Has Improved Over ICRF3



ICRF3-SX: 4535* sources

**Median scaled errors:
RA/Dec 127/218 μ asec**



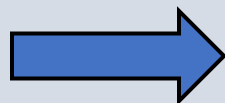
X/S-22July03: Same 4535* sources

**Median scaled errors:
RA/Dec 95/160 μ asec,
~25% improvement**

*3C48 excluded
due to large
position jump.

ICRF3-K: 824 sources

**Median scaled errors:
RA/Dec 73/134 μ asec**



K-22July05: Same 824 sources

**Median scaled errors:
RA/Dec 45/79 μ asec,
~40% improvement**



K vs. X/S RA/Dec Median Scaled Errors for Common Sources*

<u># Sources</u>	<u>ICRF3-K</u>	<u>ICRF3-SX</u>
793	72.0/132.6 μ as	62.6/86.8 μ as

RA/Dec noise floors:
 X/S-band: 30/30 μ as
 K-band: 30/50 μ as

<u># Sources</u>	<u>K-22Jul05</u>	<u>ICRF3-SX</u>
999	47.6/81.0 μ as	51.8/67.9 μ as

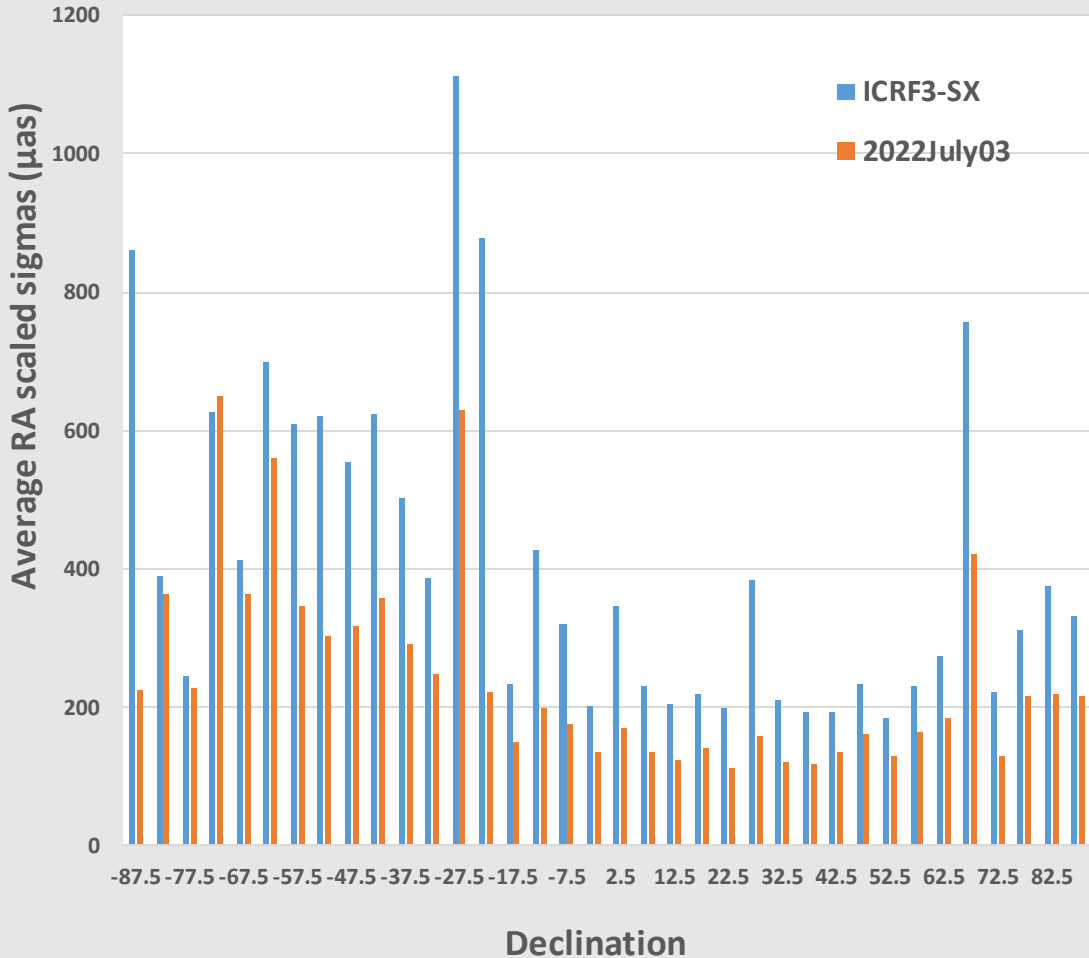
K-band has higher declination noise floor due to more limited N-S extent of the VLBA compared to IVS X/S networks.

<u># Sources</u>	<u>K-22Jul05</u>	<u>XS-22Jul03</u>
1014	47.9/81.5 μ as	46.5/58.7 μ as

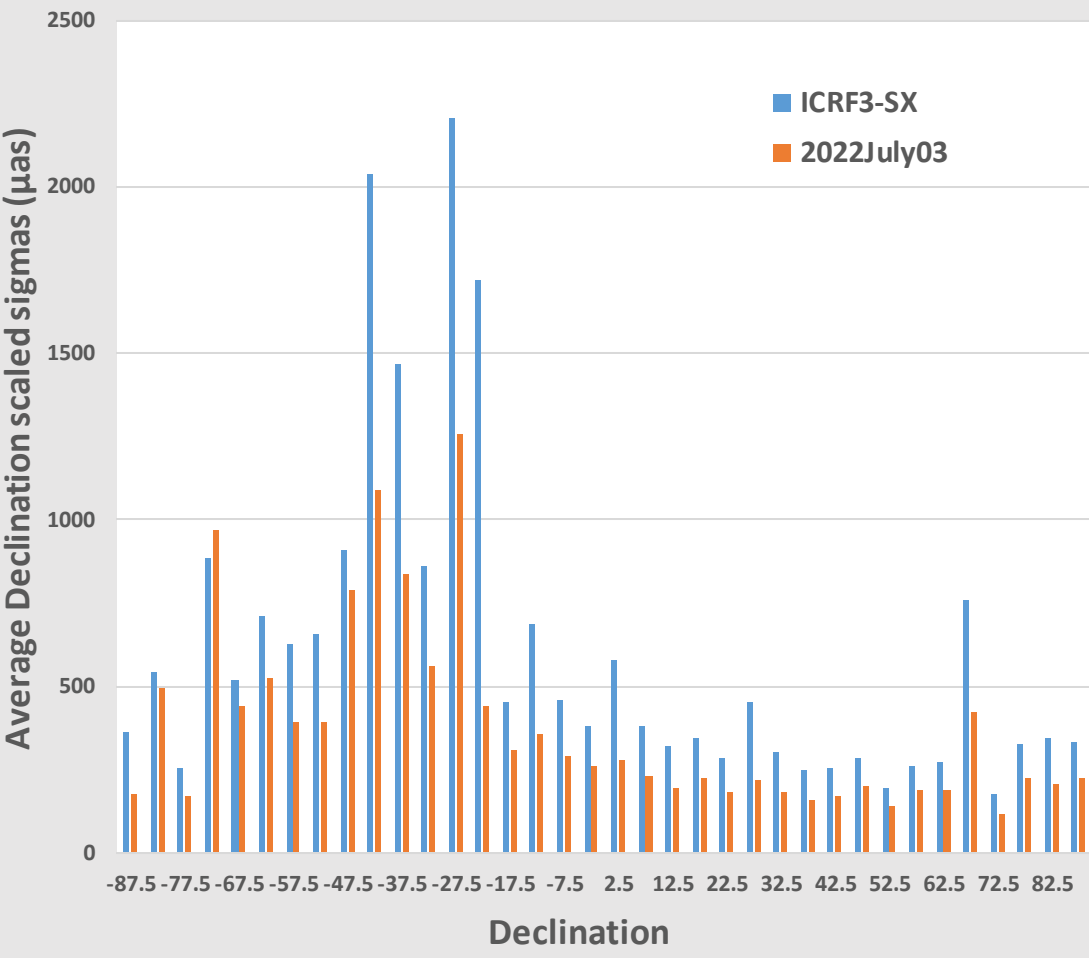
*For sources with at least 10 observations.

Average X/S scaled errors for 4535 common sources in 5° declination bins.

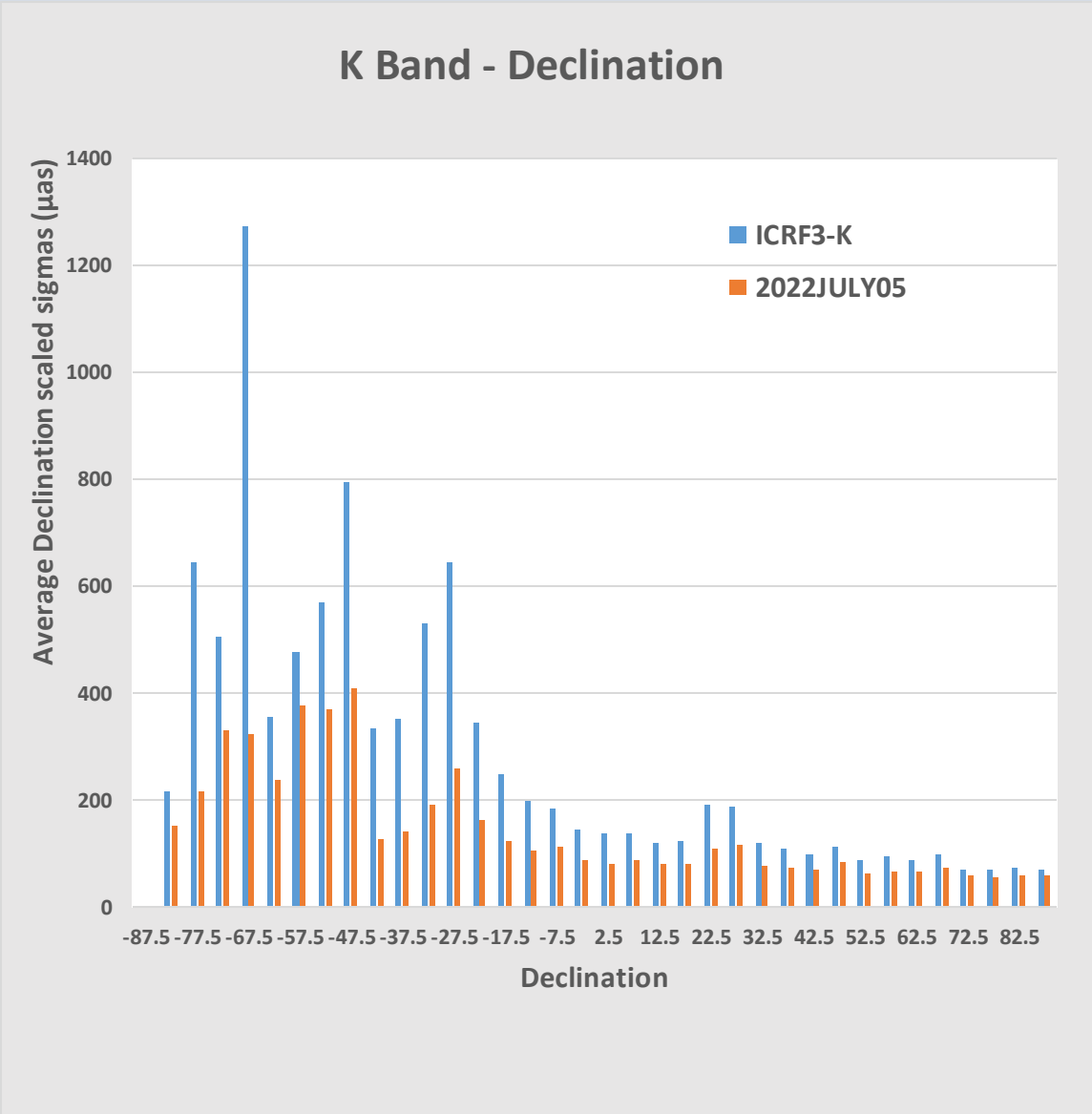
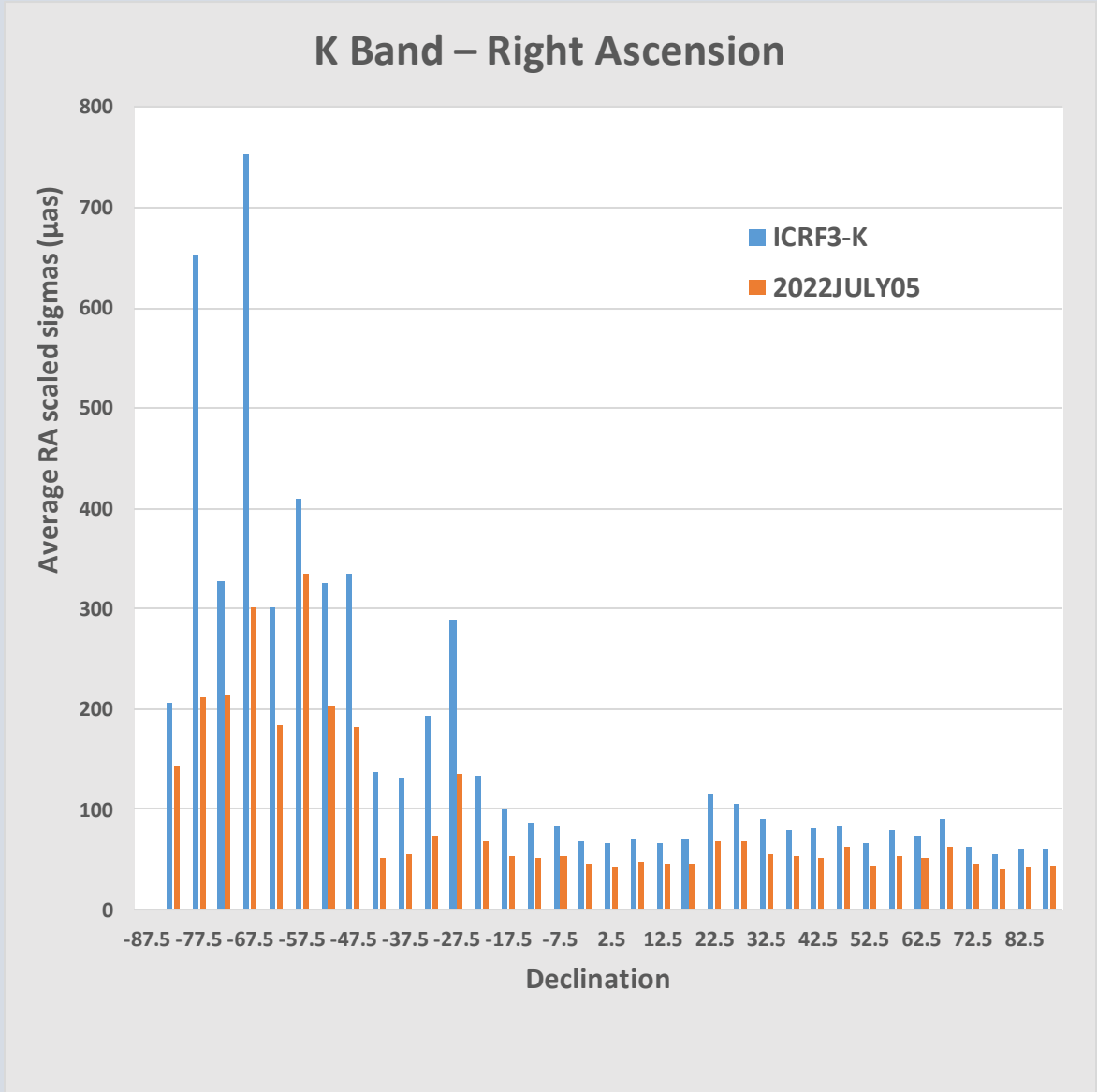
X/S Band – Right Ascension



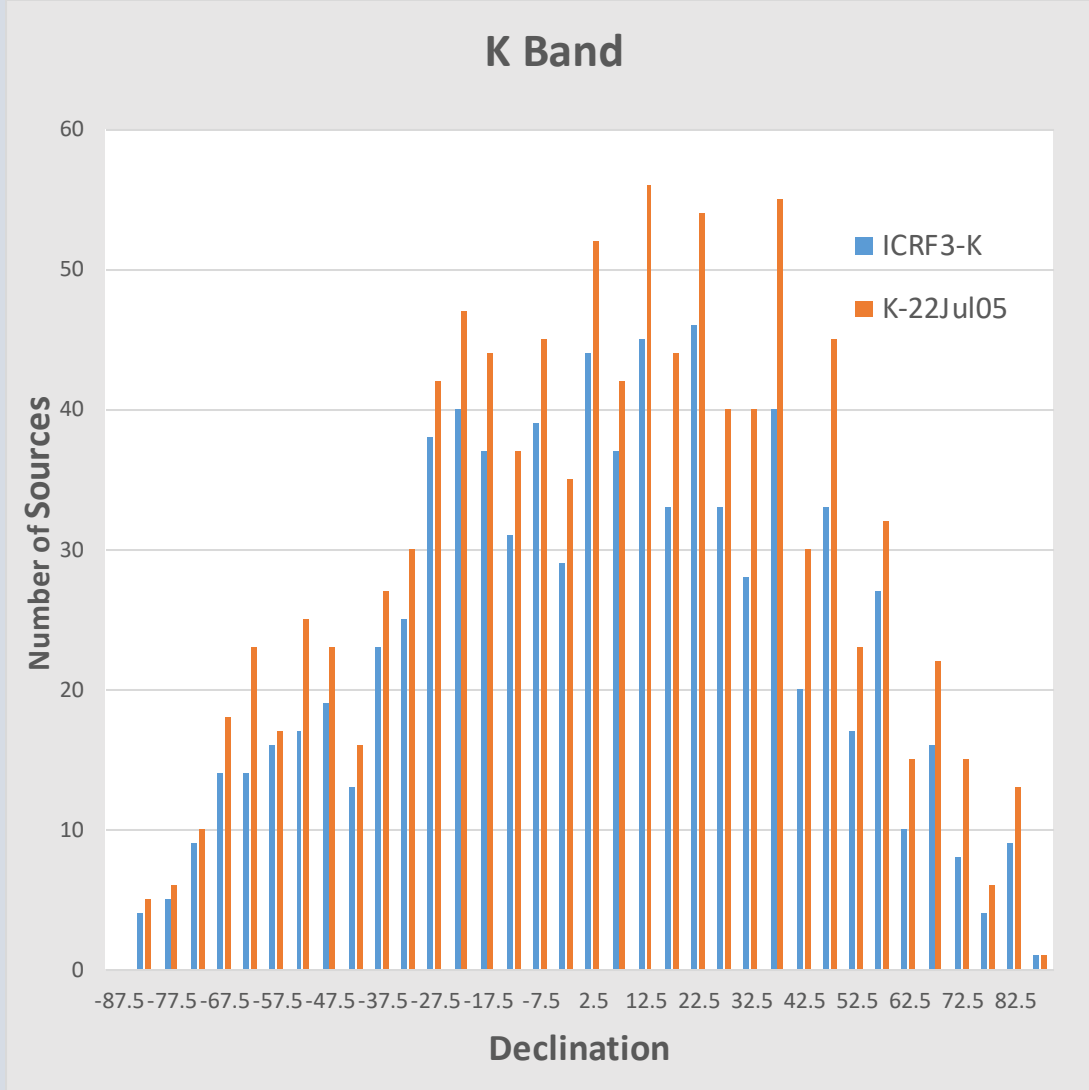
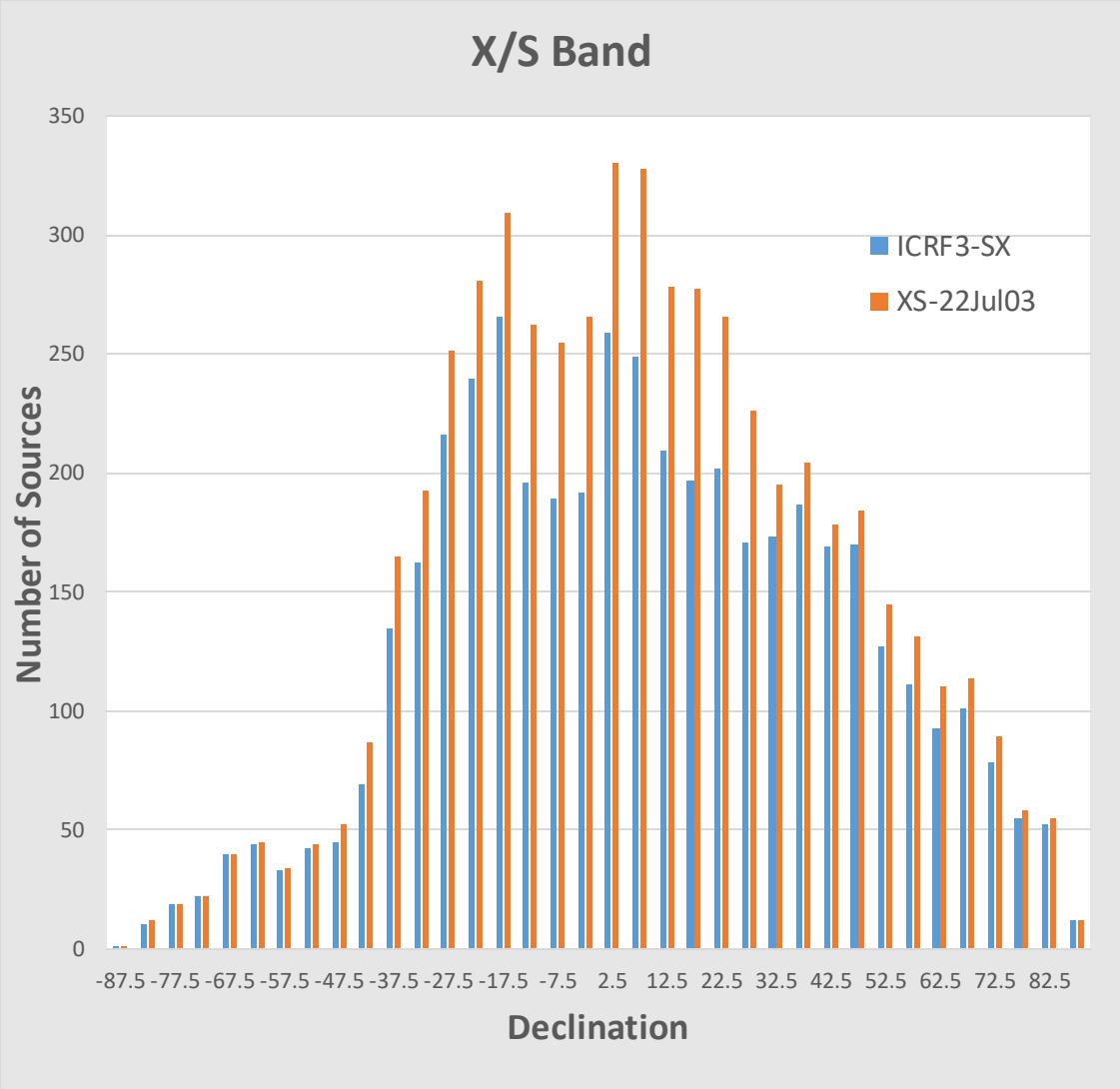
X/S Band - Declination



Average K band scaled errors for 824 common sources in 5° declination bins.



Numbers of sources in 5° declination bins in ICRF3 vs. latest solutions. Source distribution is clearly asymmetric at X/S band but much more symmetric at K-band (though many fewer total sources).





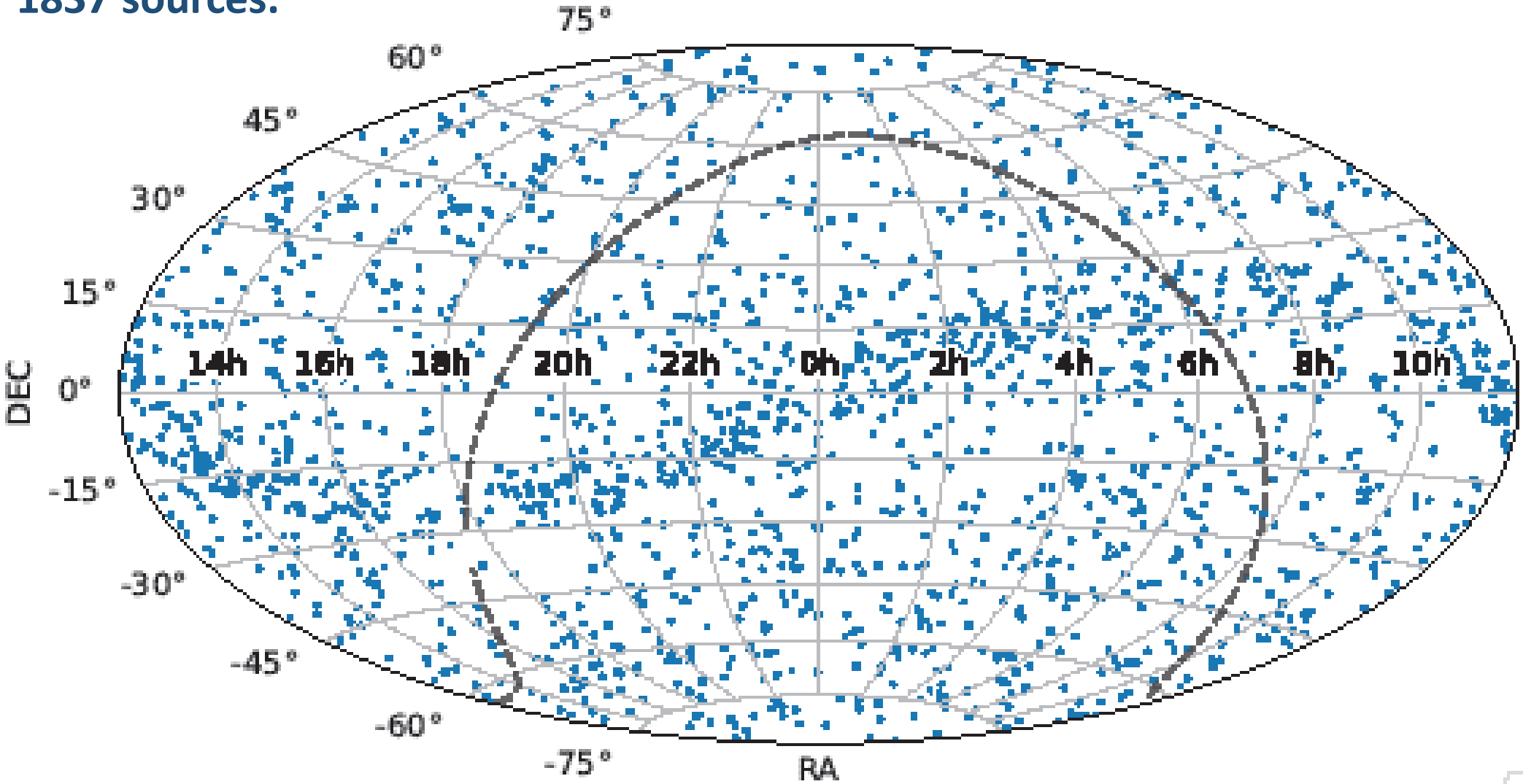
Impact of the VLBA at X/S Band

Total X/S Sources (IVS + VLBA sessions):	5518 sources => 100%
X/S Sources observed on the VLBA: (down to -53° 11')	5287 sources => 96%
X/S Sources observed <u>only</u> in IVS sessions:	231 sources => 4%
X/S Sources observed <u>only</u> on the VLBA: (~22% of the data is from the VLBA)	3681 sources => 67%
X/S Sources observed in IVS sessions (<u>No VLBA</u>): (~78% of the data is from IVS)	1837 sources => 33%

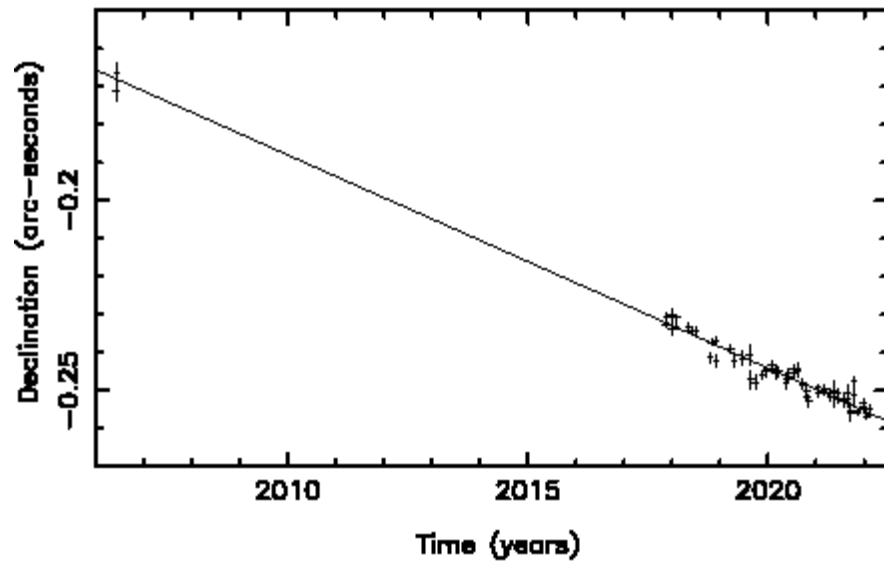
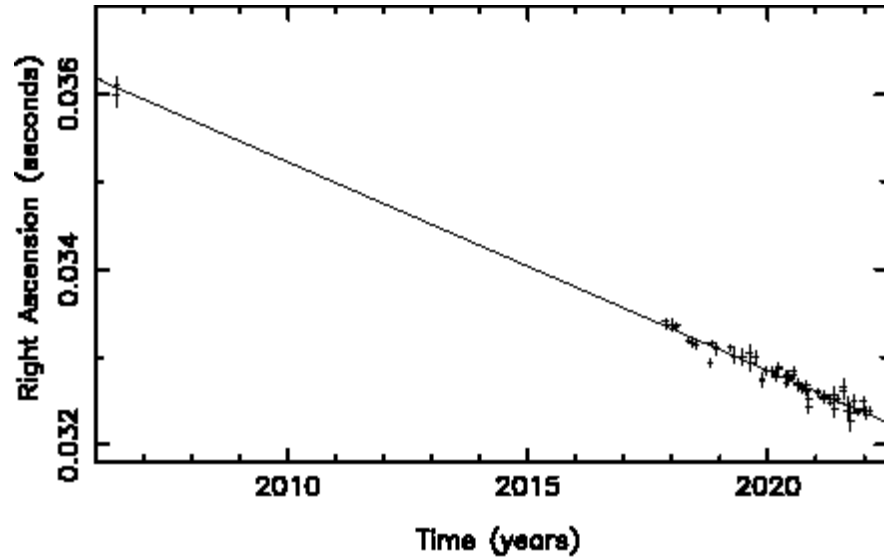
IVS* = all IVS non-VLBA observations; i.e., RV/RDV's count as VLBA obs.

X/S sources observed in
IVS (non-VLBA) sessions,
1837 sources.

This is the ICRF-SX if the VLBA did not exist!



Sgr A* Absolute Astrometry at K Band



Sgr A* has been observed at K-band to locate it in the ICRF3 frame. Its ICRF3 position as a function of time:

$$\text{RA} = 17^{\text{h}}45^{\text{m}}40^{\text{s}}.034047 + (-0^{\text{s}}.000238492) \times (\text{yr}-2015.0)$$

$$\text{Dec} = -29^{\circ}00'28''.021597 + (-0''.005587) \times (\text{yr}-2015.0)$$

Proper Motion:

$$\text{RA velocity} = -3.129 \pm 0.042 \text{ mas/yr}$$

$$\text{Dec velocity} = -5.587 \pm 0.076 \text{ mas/yr}$$

$$\Rightarrow 6.40 \pm 0.09 \text{ mas/yr @ } 209.25^{\circ} \pm 0.7^{\circ} \text{ position angle}$$

2006 observations from the original processing of the Galactic Plane Survey sessions (Petrov et al, 2011, AJ, 142,35).

Paper by D. Gordon, A. deWitt and C.S. Jacobs in preparation.

Summary:

X/S: 5518 sources in unofficial ICRF3-SX+ catalog.

- **22% more sources, 30% more data than ICRF3-SX.**
- **25% improvement in scaled errors for the ICRF3-SX sources.**
- **~400 additional ecliptic sources.**
- **96% of the sources have been observed on the VLBA.**
- **67% of the sources have been observed ONLY on the VLBA.**
- **VLBA accounts for only 22% of the total X/S data.**

K: 1035 sources in unofficial ICRF3-K+ catalog.

- **25% more sources, 290% more data than ICRF3-K.**
- **~40% improvement in scaled errors for the ICRF3-K sources.**
- **99.5% of the observations are from the VLBA.**
- **Source distribution is fairly even between the northern and southern hemispheres.**
- **Sgr A* located in ICRF3 frame as a function of time using absolute astrometry.**

More info:

Latest X/S and K band source catalogs:

<https://crf.usno.navy.mil/quarterly-vbli-solution>

X/S images from VLBA X/S sessions by Lucas Hunt at USNO (FRIDA).

<https://crf.usno.navy.mil/FRIDA>

K-band images by Alet deWitt (SARAO).

[de Witt et al., The Celestial Reference Frame at K-band: Imaging. I. First 28 Epochs of K-band Images, AJ, 2022, in review.](#)

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- The research was carried out in part at the Jet Propulsion Laboratory, California Institute of Technology, under a contract with the National Aeronautics and Space Administration (80NM0018D0004). Copyright © 2022 All Rights Reserved.

Backup slides

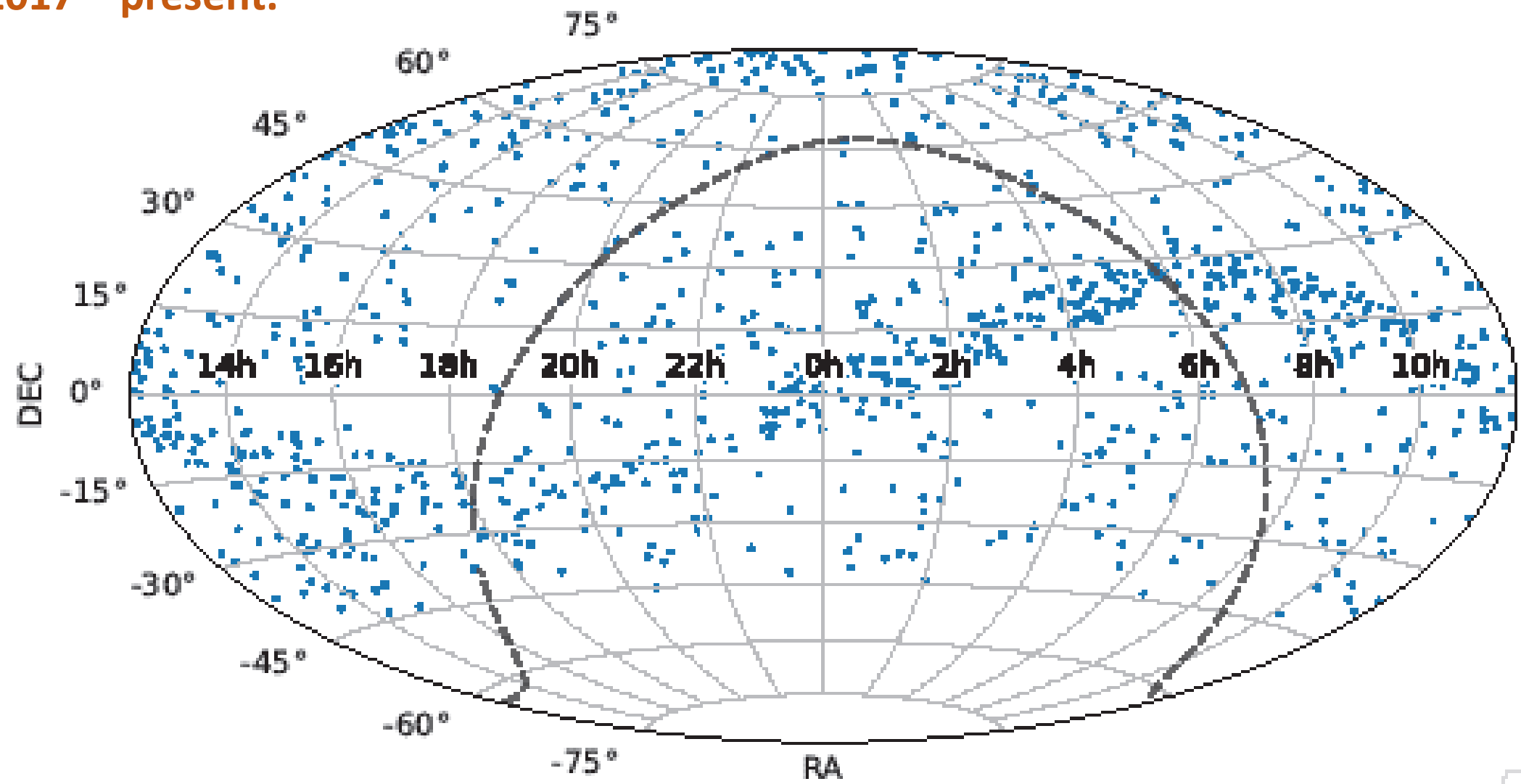


Impact of the USNO VLBA time allocation

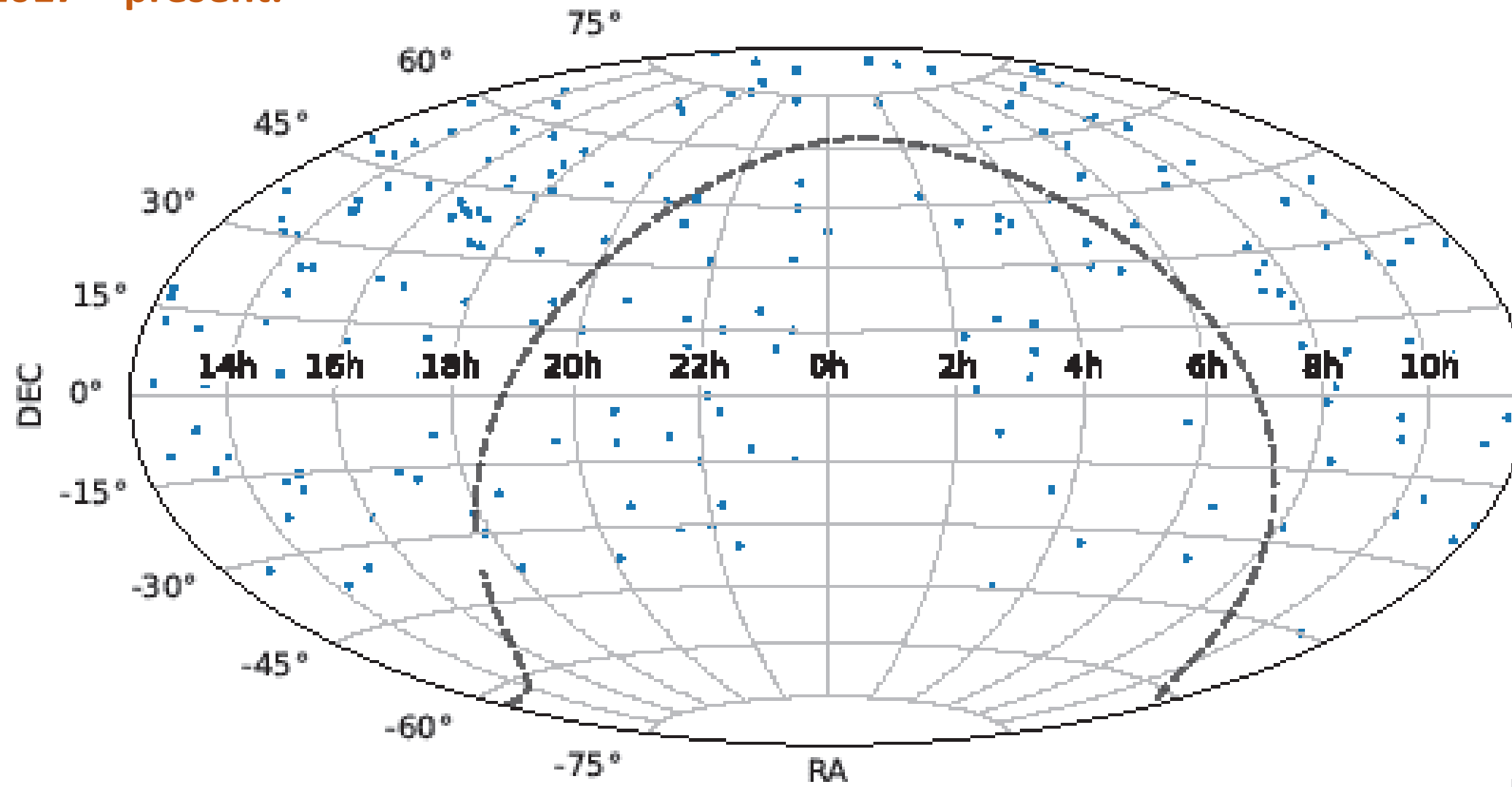
USNO began funding 50% of VLBA operations and receiving up to 50% of the observing time in 2017. This has enabled a significant improvement and expansion of the ICRF at X/S and K bands.

- **X/S band:** Approximately monthly or twice monthly X/S astrometry and 6 yearly RDV sessions since January 2017, adding **1010** X/S sources and greatly improving the precision of ~3000 lesser observed (non IVS) sources. In particular the number of ecliptic sources has been approximately doubled. Without these USNO time allocation sessions, there would be only 4508 X/S sources and the median scaled errors would be ~twice as large.
- **K band:** Approximately monthly K band astrometry sessions since January 2017, adding **211** sources. Without these USNO time allocation sessions, there would be only 824 K band sources and the median scaled errors would be ~50 times larger.

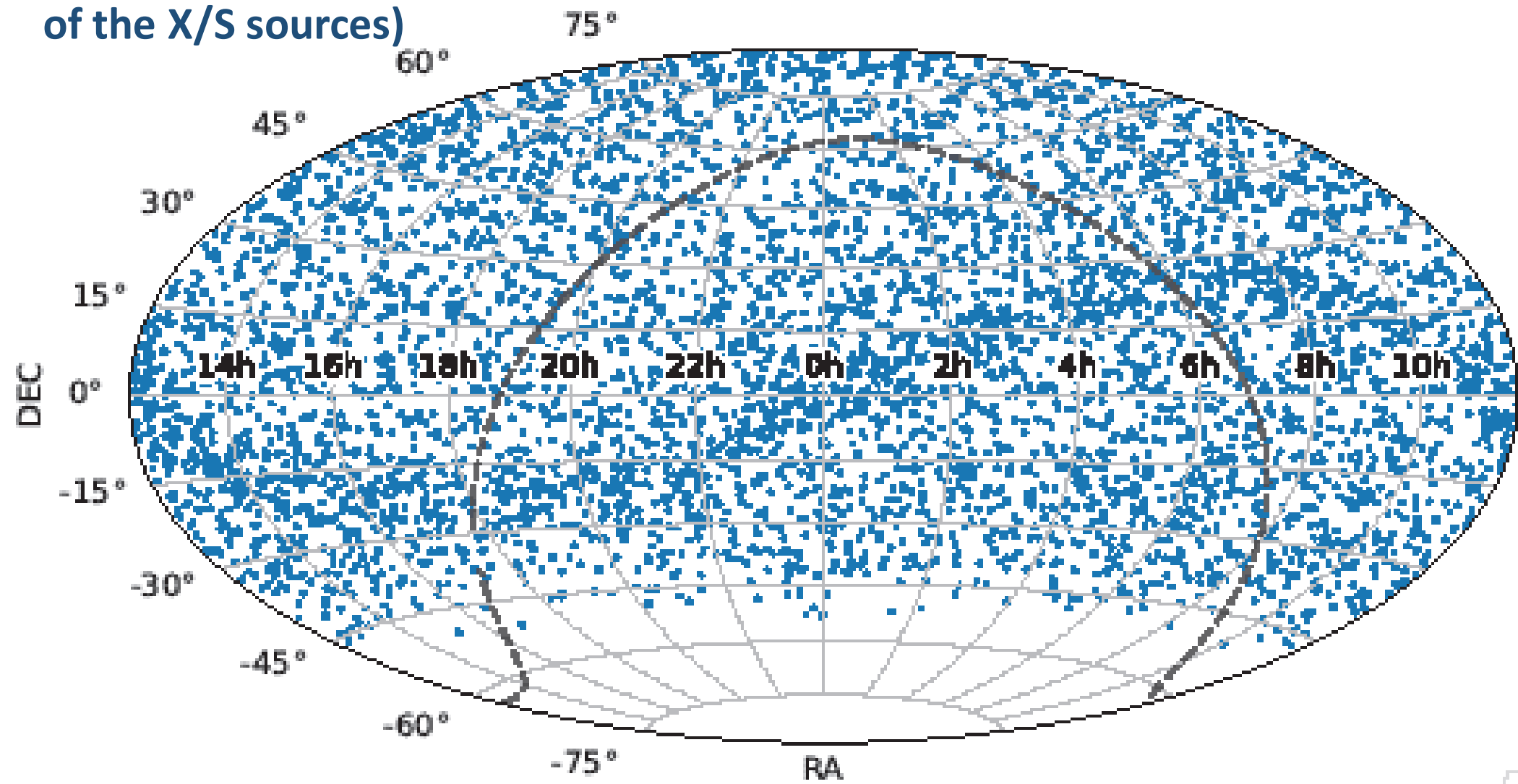
1010 X/S sources added via
USNO VLBA time allocation,
2017 – present.

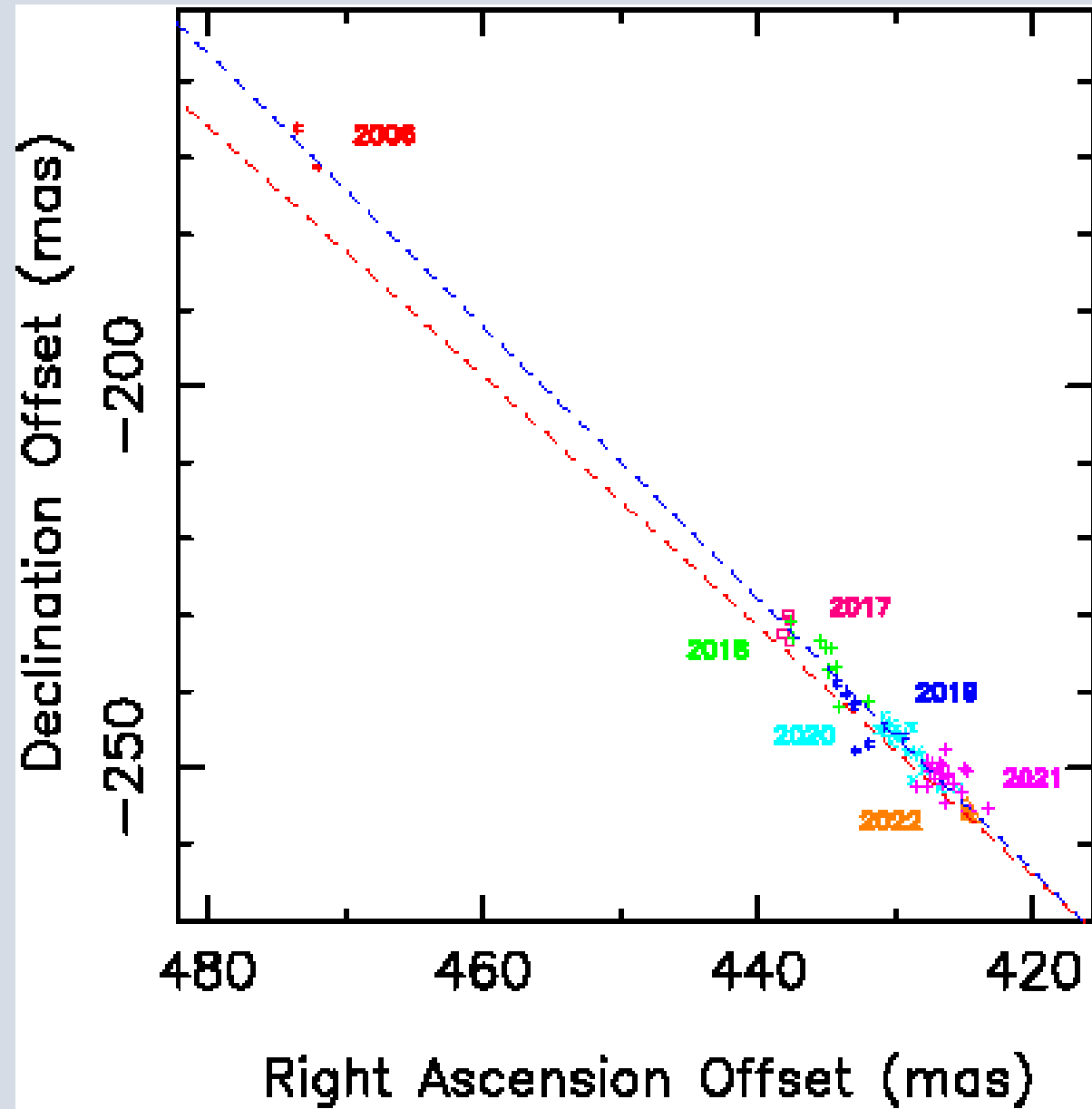


211 K band sources added via
USNO VLBA time allocation,
2017 – present.



All X/S sources observed on
the VLBA (5287 sources – 96%
of the X/S sources)





Sgr A* K-band positions color-coded by time.

Positions are offset from
 $17^{\text{h}} 45^{\text{m}} 40^{\text{s}}, -29^{\circ} 00' 28''$

Blue dotted line = fit to Sgr A* positions
Red dotted line = direction of galactic plane