



# ICRF3, the new realization of the International Celestial Reference Frame

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# Outline

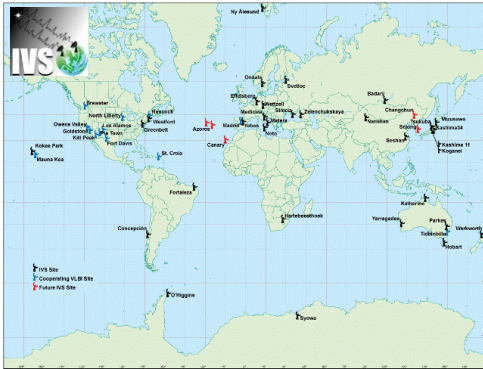
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- Data sets used for ICRF3
- Modeling and analysis configuration
- Overview of ICRF3 and its properties
- Comparison between frames (ICRF2, Gaia-CRF2,...)
- Adoption of ICRF3 by IAU

# Data sets for ICRF3

ICRF3 is a **three-frequency frame**: S/X band, K band and X/Ka band

**IVS**



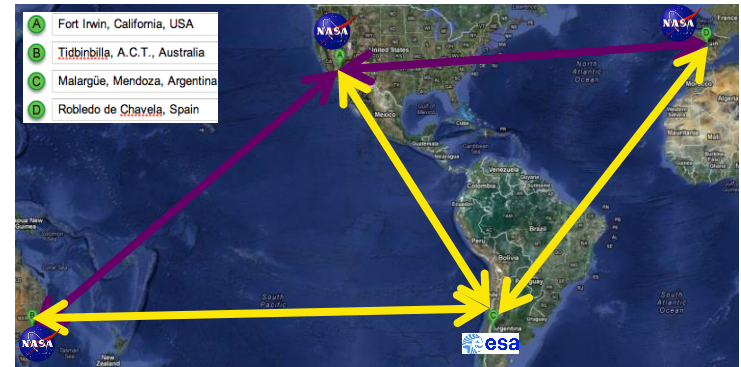
S/X band

**VLBA**



S/X band and K band

**DSN + ESA**



X/Ka band

	Total nb of sessions	Number of sessions per network					Data span
		IVS	VLBA	Ht-Ho	DSN	ESA	
S/X	6362	6206	184 (*)				1979-2018
K	56		40	16			2002-2018
X/Ka	167				167	18 (**)	2005-2018

(\*) 128 joint VLBA-IVS and 56 VLBA-only sessions

(\*\*) Joint DSN-Malargue sessions



# Modeling and analysis configuration

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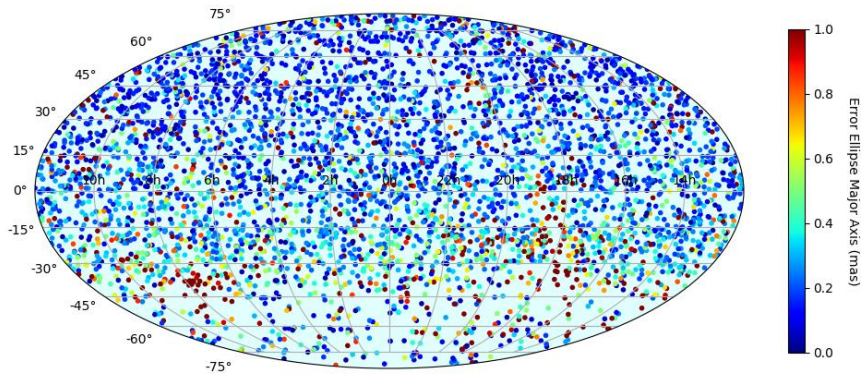
- Adhere to IERS conventions (2010)
- Ionospheric corrections (K band data) using TEC maps from GPS
- Celestial frame
  - All sources treated as global parameters
  - SX frame aligned onto ICRF2 using the 295 ICRF2 defining sources
  - K and XKa frames aligned onto SX frame using ICRF3 defining sources
- Terrestrial frame and EOP
  - Terrestrial frame aligned onto ITRF2014
  - Station coordinates treated as global parameters
  - EOP estimated per session
- Galactocentric acceleration correction of  $5.8 \mu\text{as/yr}$  applied (estimated from the SX data) – Positions given for epoch 2015.0
- Rescaling of formal position uncertainties
  - Multiplicative factor of 1.5 applied to SX and K band coordinate errors
  - $30 \mu\text{as}$  added in quadrature to  $\alpha^*$  and  $\delta$  errors ( $50 \mu\text{as}$  for  $\delta$  at K band)



# ICRF3-SX vs ICRF2

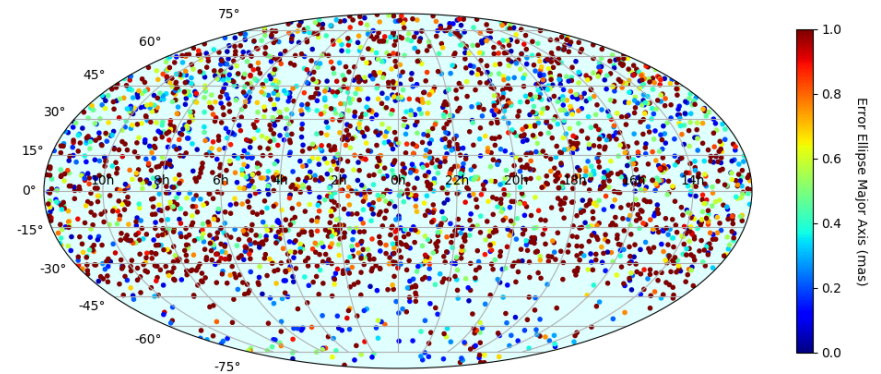
4536 sources

ICRF3X

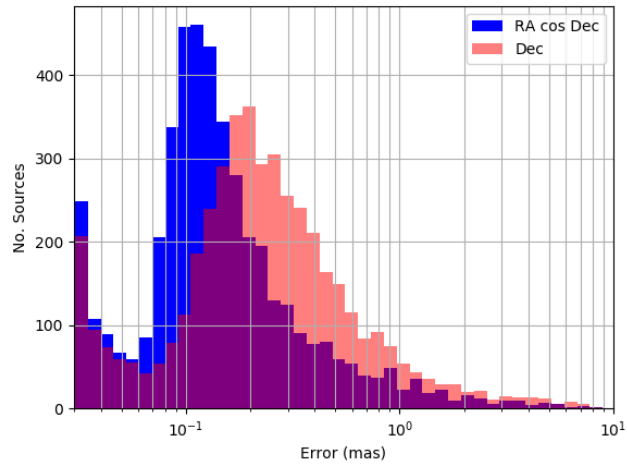


3414 sources

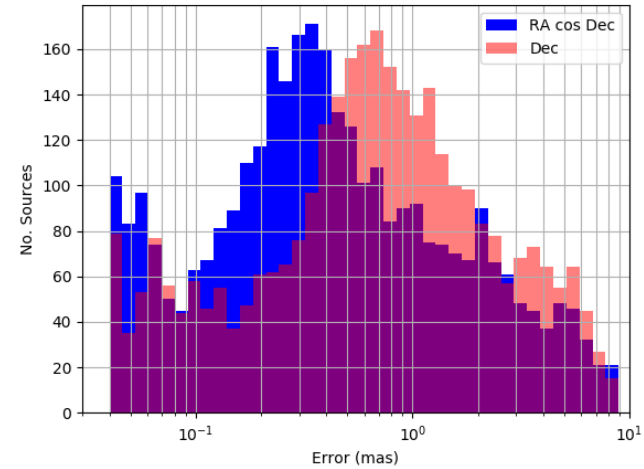
ICRF2



ICRF3X

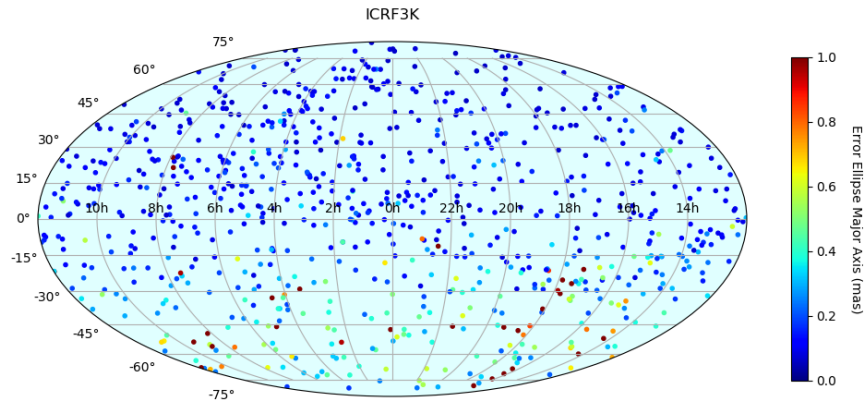


ICRF2

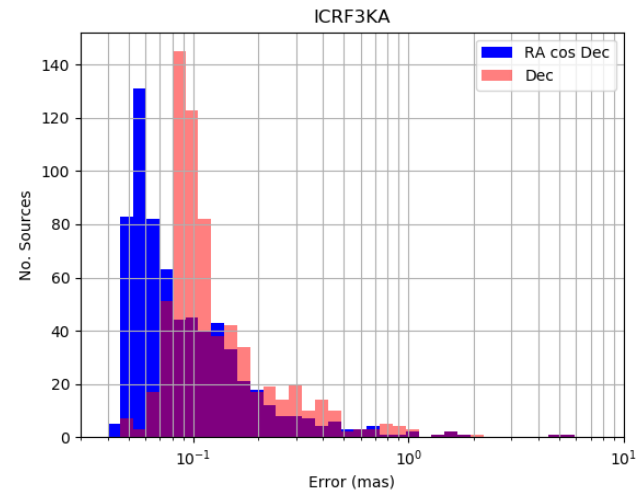
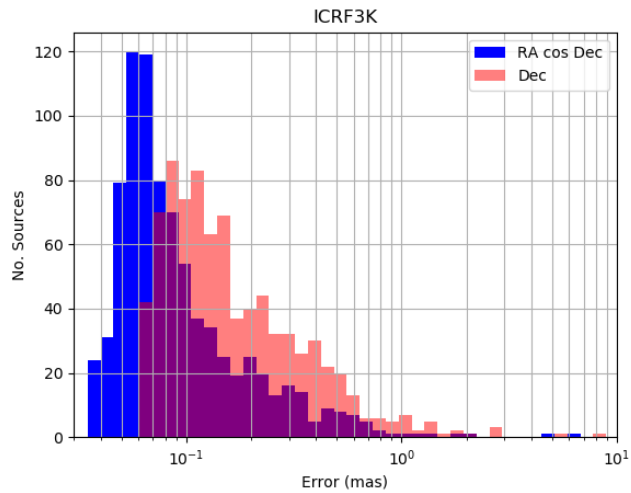
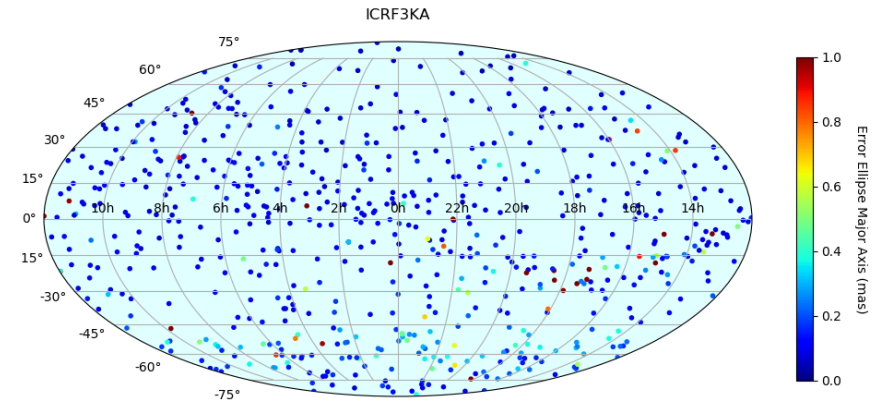


# ICRF3-K and ICRF3-XKa

824 sources



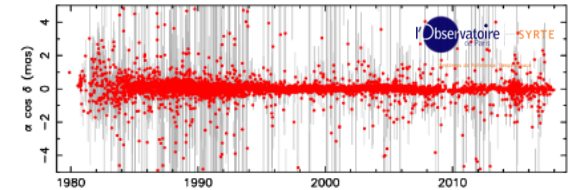
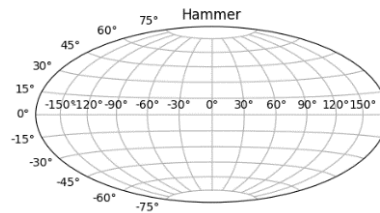
678 sources





# Selection of defining sources

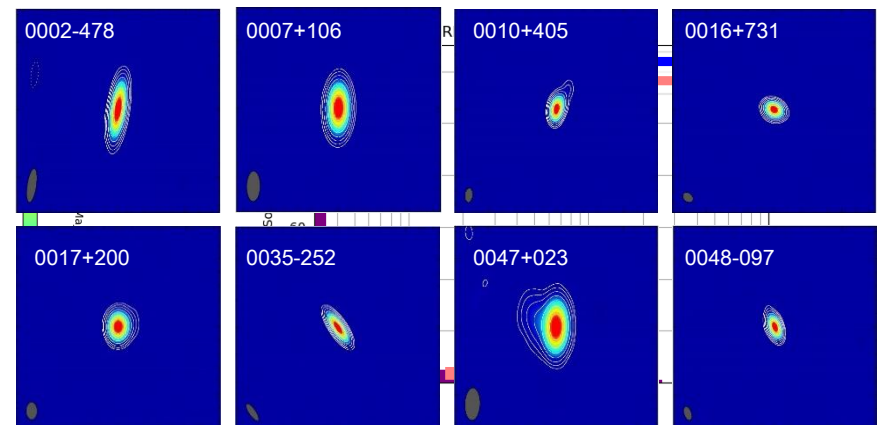
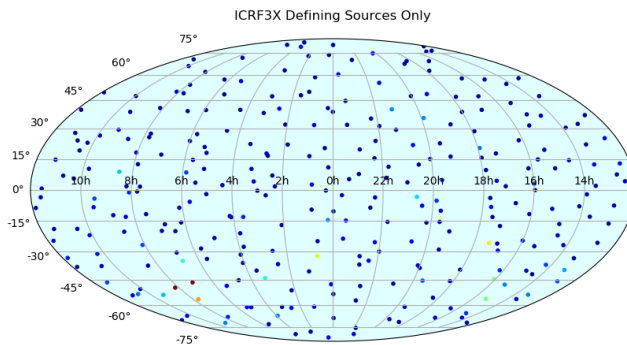
- Celestial sphere sub-divided into 324 sectors of equal area



- Most stable and compact source in each sector selected as defining source



- **303 defining sources identified** (72% with good or excellent astrometric quality)



# Model for comparing frames

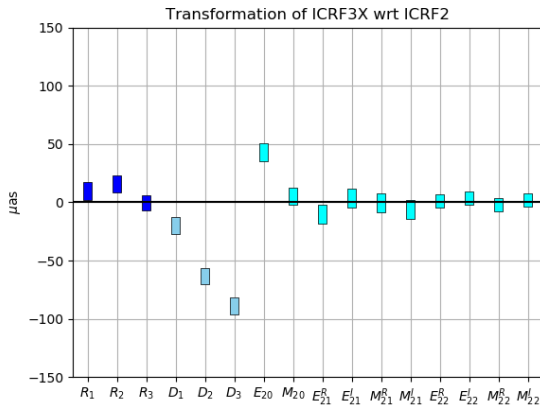
$$\begin{aligned}
 \Delta\alpha \cos \delta &= \underbrace{R_1}_{\text{Rotations}} \cos \alpha \sin \delta - \underbrace{R_2}_{\text{Rotations}} \sin \alpha \sin \delta - \underbrace{R_3}_{\text{Rotations}} \cos \delta - \underbrace{D_1}_{\text{Glide}} \sin \alpha + \underbrace{D_2}_{\text{Glide}} \cos \alpha \\
 &+ \underbrace{a_{20}^M}_{\text{Quadrupole}} \sin 2\delta \\
 &+ \left( \underbrace{a_{21}^{E, \text{Re}}}_{\text{Quadrupole}} \sin \alpha + \underbrace{a_{21}^{E, \text{Im}}}_{\text{Quadrupole}} \cos \alpha \right) \sin \delta \\
 &- \left( \underbrace{a_{21}^{M, \text{Re}}}_{\text{Quadrupole}} \cos \alpha - \underbrace{a_{21}^{M, \text{Im}}}_{\text{Quadrupole}} \sin \alpha \right) \cos 2\delta \\
 &- 2 \left( \underbrace{a_{22}^{E, \text{Re}}}_{\text{Quadrupole}} \sin 2\alpha + \underbrace{a_{22}^{E, \text{Im}}}_{\text{Quadrupole}} \cos 2\alpha \right) \cos \delta \\
 &- \left( \underbrace{a_{22}^{M, \text{Re}}}_{\text{Quadrupole}} \cos 2\alpha - \underbrace{a_{22}^{M, \text{Im}}}_{\text{Quadrupole}} \sin 2\alpha \right) \sin 2\delta, \\
 \Delta\delta &= -\underbrace{R_1}_{\text{Rotations}} \sin \alpha + \underbrace{R_2}_{\text{Rotations}} \cos \alpha - \underbrace{D_1}_{\text{Glide}} \cos \alpha \sin \delta - \underbrace{D_2}_{\text{Glide}} \sin \alpha \sin \delta + \underbrace{D_3}_{\text{Glide}} \cos \delta \\
 &+ \underbrace{a_{20}^E}_{\text{Quadrupole}} \sin 2\delta \\
 &- \left( \underbrace{a_{21}^{E, \text{Re}}}_{\text{Quadrupole}} \cos \alpha - \underbrace{a_{21}^{E, \text{Im}}}_{\text{Quadrupole}} \sin \alpha \right) \cos 2\delta \\
 &- \left( \underbrace{a_{21}^{M, \text{Re}}}_{\text{Quadrupole}} \sin \alpha + \underbrace{a_{21}^{M, \text{Im}}}_{\text{Quadrupole}} \cos \alpha \right) \sin \delta \\
 &- \left( \underbrace{a_{22}^{E, \text{Re}}}_{\text{Quadrupole}} \cos 2\alpha - \underbrace{a_{22}^{E, \text{Im}}}_{\text{Quadrupole}} \sin 2\alpha \right) \sin 2\delta \\
 &+ 2 \left( \underbrace{a_{22}^{M, \text{Re}}}_{\text{Quadrupole}} \sin 2\alpha + \underbrace{a_{22}^{M, \text{Im}}}_{\text{Quadrupole}} \cos 2\alpha \right) \cos \delta
 \end{aligned}$$

Mignard & Klioner (2012)

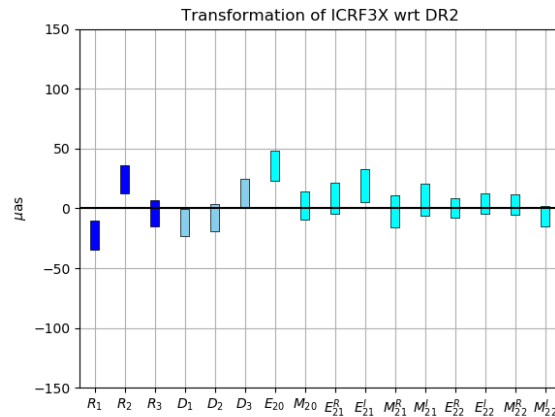


# Deformations between frames

## ICRF3-SX vs ICRF2

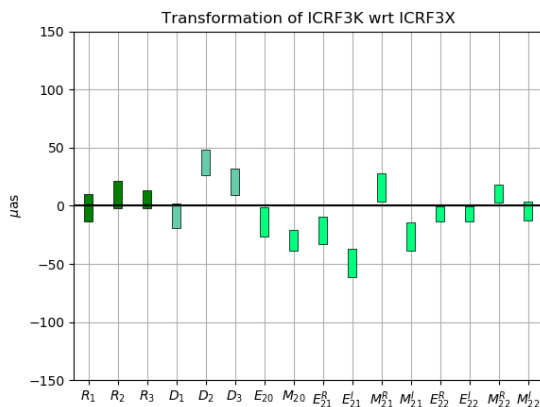


## ICRF3-SX vs Gaia-CRF2

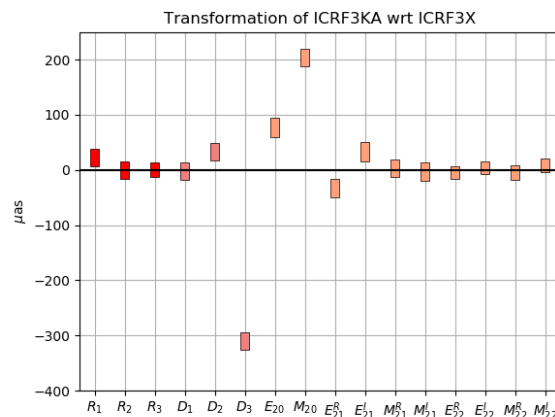


- ICRF3-SX deformed with respect to ICRF2 because Galactic aberration was not modeled in ICRF2
- No deformations between ICRF3-SX and Gaia CRF2

## SX vs K



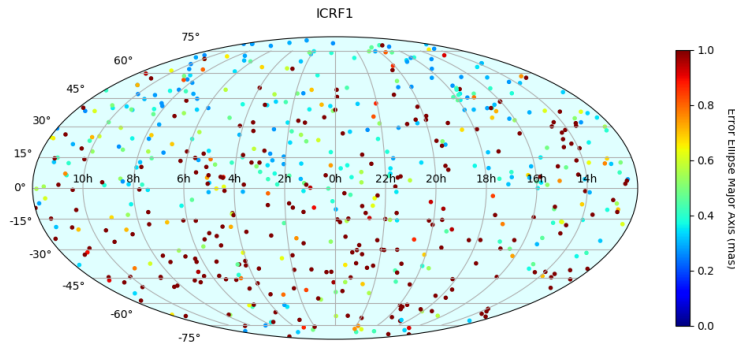
## SX vs XKa



- ICRF3-SX very consistent with ICRF3-K
- ICRF3-XKa significantly deformed (D3, E20, M20) because of the limited geometry of the network

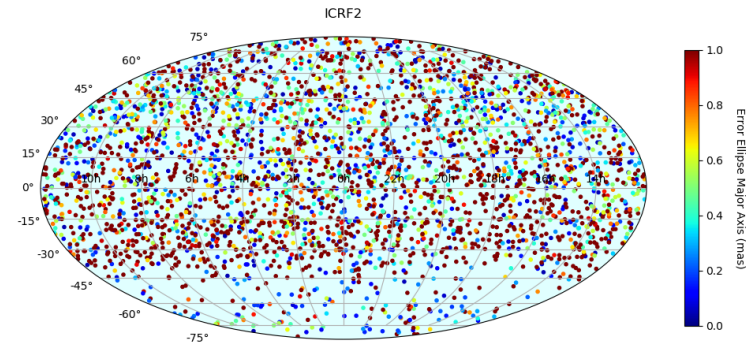
# From ICRF1... to ICRF3

## ICRF1 (1997)



608 sources

## ICRF2 (2009)

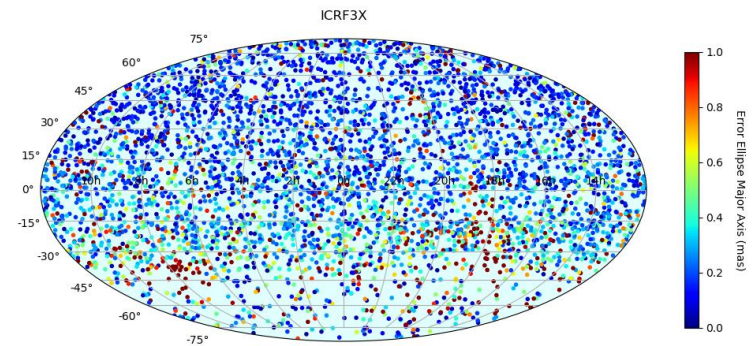


3414 sources

## Main features of ICRF3

- Median position error decreased by a factor of 3.5 compared to ICRF2
- 4536 sources (35% more than in ICRF2)
- 3-frequency positions for 600 sources
- No deformations wrt Gaia-CRF2

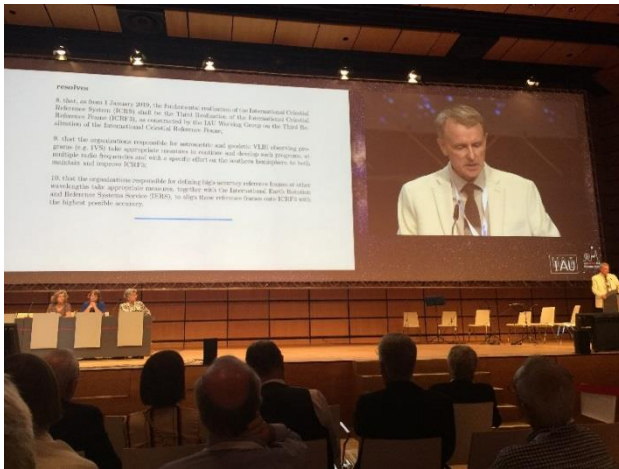
## ICRF3 (2018)



4536 sources

# Adoption of ICRF3 by IAU

ICRF3 was adopted by the IAU at the XXX IAU General Assembly on 30 August 2018



ICRF3 has replaced ICRF2 as the fundamental celestial reference frame since January 1, 2019

*A paper on ICRF3 is being prepared (Charlot et al. 2019, A&A)*

# Thank you for your attention

