Evaluate the ICRF3 Axes Stability via Extragalactic Source Position Time Series

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12th IVS General Meeting, March 28 – April 1, 2022

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01 What is the ICRF axes stability?

Celestial reference frame instability

- Non-rotating of the axes is one of the crucial points for the International Celestial Reference System (ICRS) concept.
- Extragalactic sources show astrometric instability as seen from source coordinate time series (Feissel-Vernier 2003), images (structure index; Fey & Charlot 1997), light curves (Shabala et al. 2014, Taris et al. 2018), closure quantities (Xu et al. 2020).
- The axes orientation may vary, i.e., CRF instability
    - a common issue for all kinds of extragalactic celestial frames!
    - perturbing the nutation estimates (Lambert et al. 2008)
- Selecting suitable defining sources to mitigate the deficiency, e.g., Feissel-Vernier 2003, 2006; Arias & Bouquillon 2004; Lambert et al. 2009.
- Gattano & Charlot (2018) found that the source position showing a stable behavior is likely to become unstable within a longer time span.
- A regular monitoring of the astrometric behavior of sources and the axes stability of the ICRF is required!

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02 How to evaluate ICRF axes stability?

Evaluate ICRF axes stability

- The ICRF1 axes are stable at 20 μas and it is 10 μas for ICRF2.

- Three methods
  - (IRCF1 case) orientation agreement between yearly CRFs
    - From successive realizations of IERS CRS (Arias et al. 1995)
    - Based on averaged source positions (Feissel-Vernier 2003)
  - (ICRF2 case) orientation agreement between ICRF2 and ICRF1-Ext.2 using various subsets of sources

  → Scatter

  - Global spin of CRF derived from apparent motions of defining sources

  → Linear trend

- Our results suggest that the axes of the ICRF3 are stable at approximately 10 μas–20 μas during 1979.6–2021.0.

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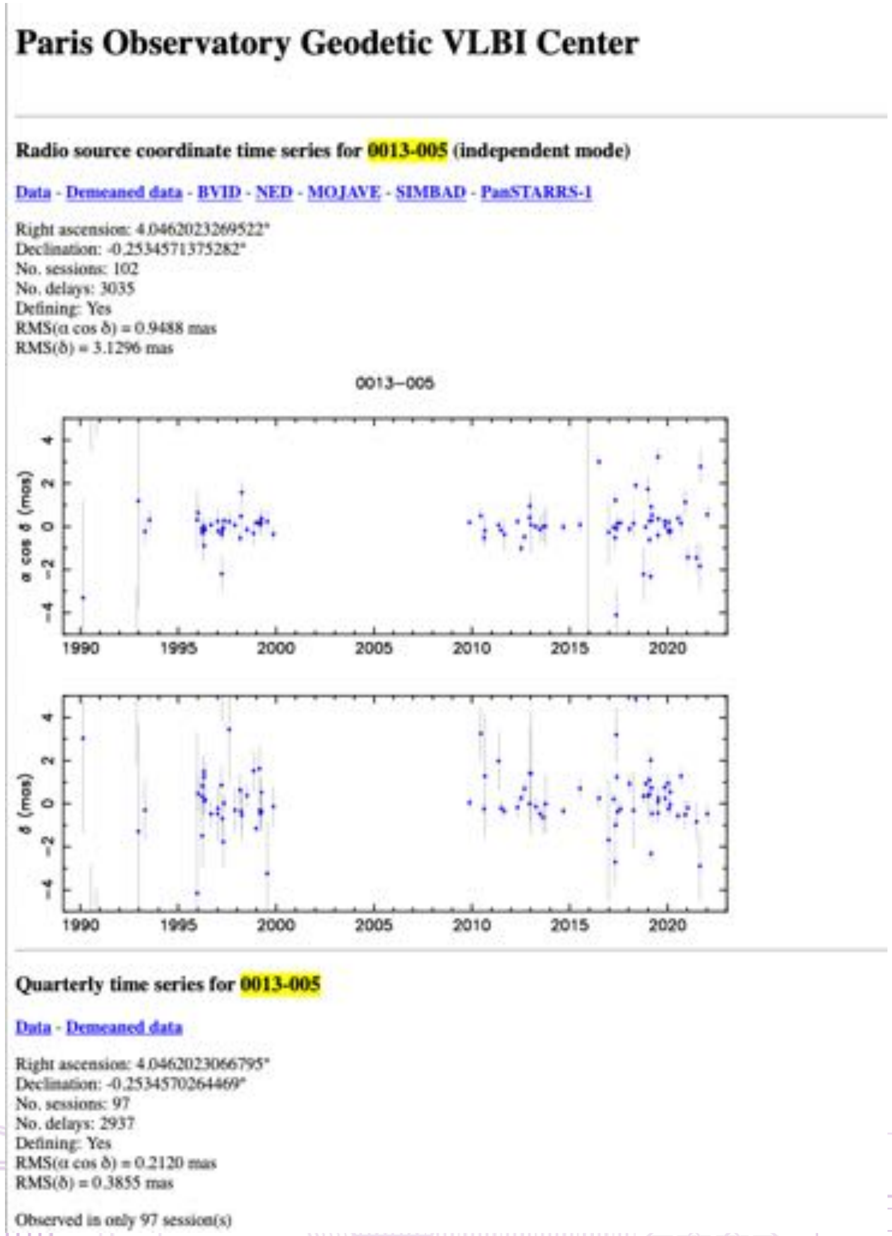
03 How to produce source coordinate time series?

Generate source coordinate time series

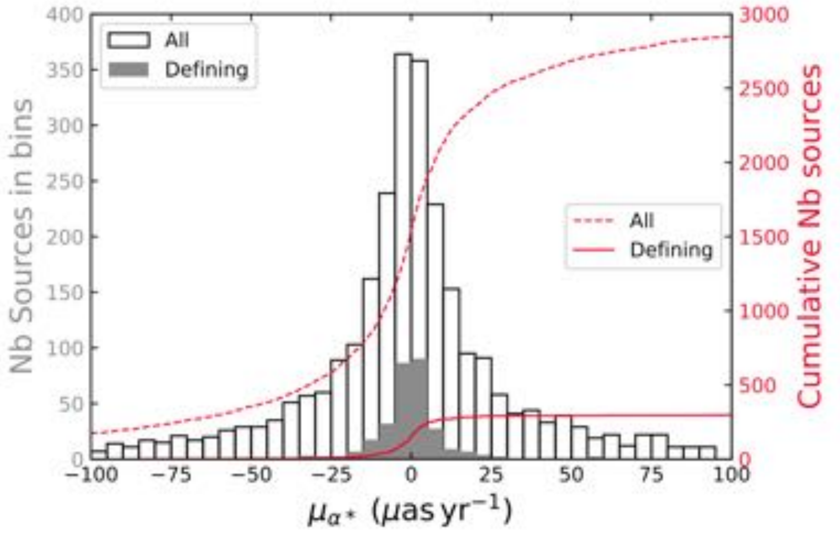
- First proposed by Eubanks (IERS TN 23), then used in Feissel-Vernier (2003, derived by Alan Fey) and others

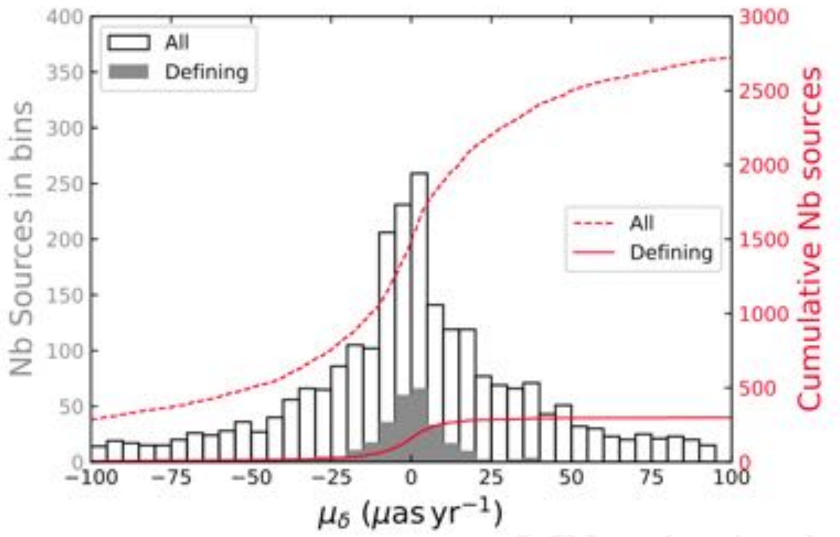
- We used a similar but slightly improved method
    - Divided sources (defining + non-defining separately) into ten subsets with nearly identical and uniform sky distribution
    - Downgraded source positions in each subset as ”arc” parameter, and ran 10 separate global solutions
    - Collected source coordinate time series from each solution

- Source coordinate time series product can be also found at OPAR (http://ivsopar.obspm.fr/radiosources/index.php)



Source apparent proper motion (APM)





Distribution of APM

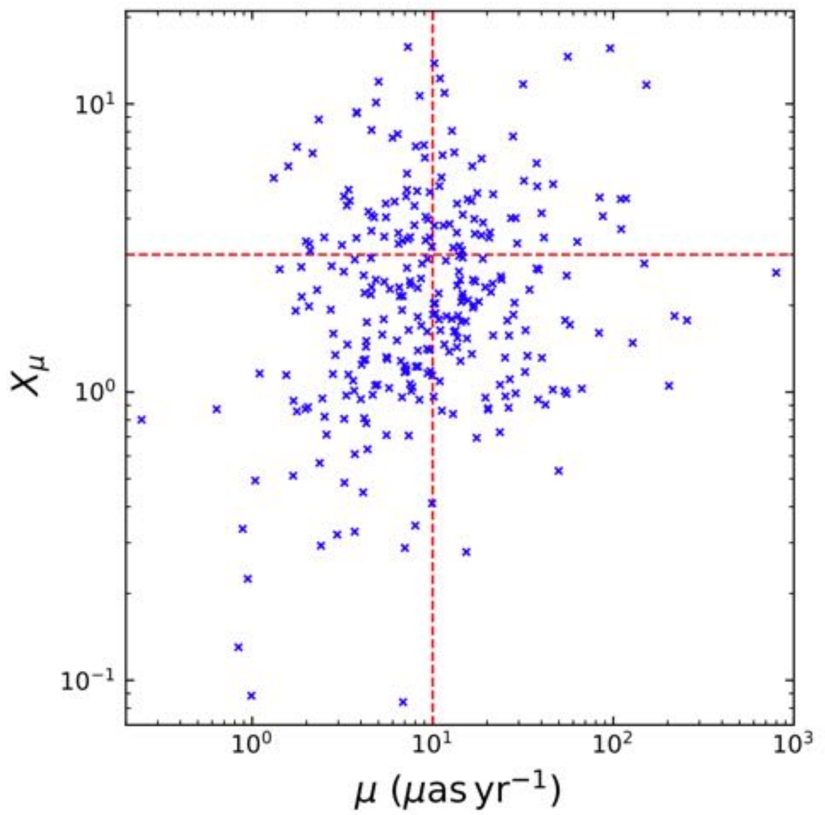
Mean values (μas yr^{-1})

	RA	Dec
All 3034 sources	−0.36	0.26
299 defining	−0.57	−0.33

Significance of APM

Approximately 16% of the ICRF3 defining sources showed both μ > 10 μas yr^{-1} and X_{μ} > 3

For ICRF3 defining sources



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04 What results do we obtain?

ICRF3 axes stability inferred from global spin

- From a least-squares fit

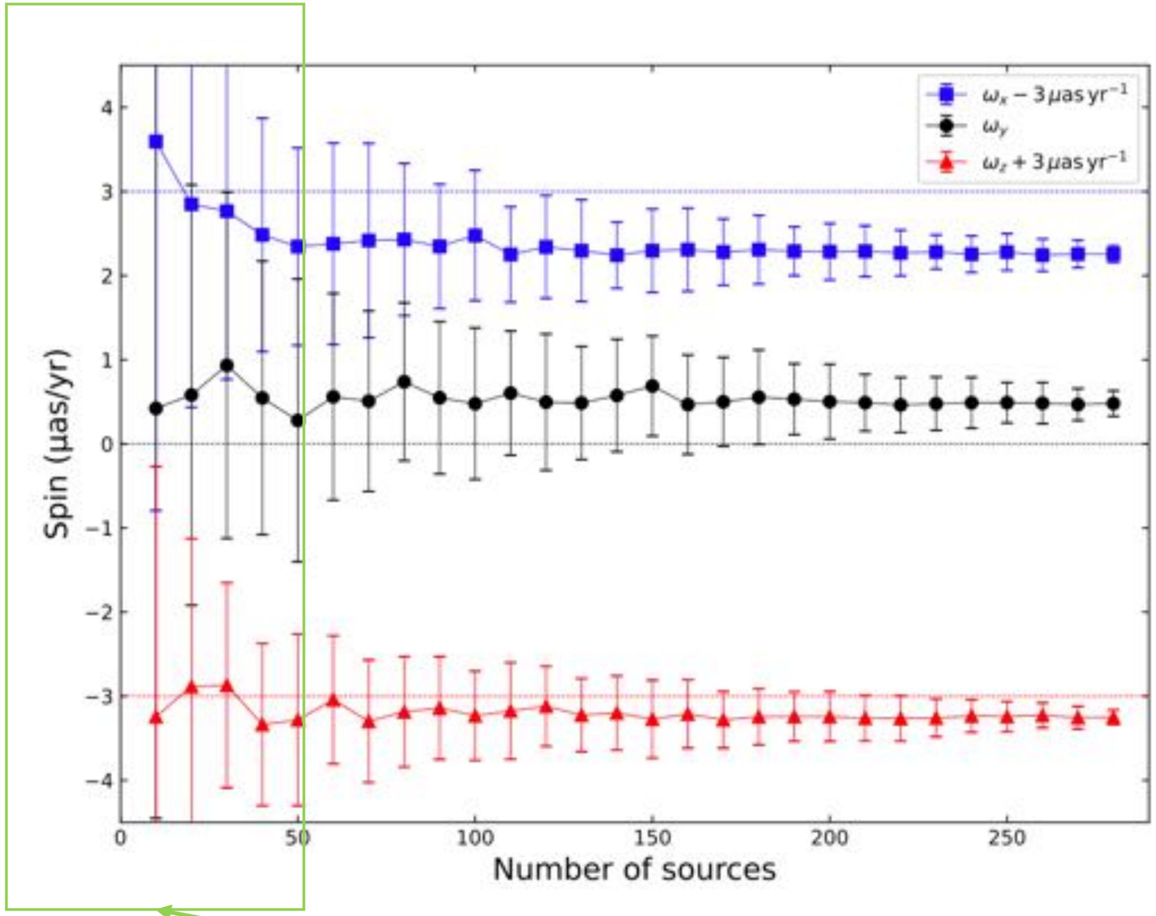
$$\omega_x = -0.73\ \mu\text{as yr}^{-1} \pm 0.27\ \mu\text{as yr}^{-1},$$
$$\omega_y = +0.48\ \mu\text{as yr}^{-1} \pm 0.31\ \mu\text{as yr}^{-1},$$
$$\omega_z = -0.25\ \mu\text{as yr}^{-1} \pm 0.21\ \mu\text{as yr}^{-1}.$$

- From bootstrap resampling (for a reasonable uncertainty)

$$\omega_x = -0.71\ \mu\text{as yr}^{-1} \pm 0.42\ \mu\text{as yr}^{-1},$$
$$\omega_y = +0.51\ \mu\text{as yr}^{-1} \pm 0.57\ \mu\text{as yr}^{-1},$$
$$\omega_z = -0.24\ \mu\text{as yr}^{-1} \pm 0.36\ \mu\text{as yr}^{-1}.$$

- Dependency on number of the ICRF3 defining sources 👉
    - $N_{def} \geq 50$
- Considering data span of ~40 yr and formal uncertainty

=> orientation variation of the ICRF3 ~ 10 – 20 μas



variations

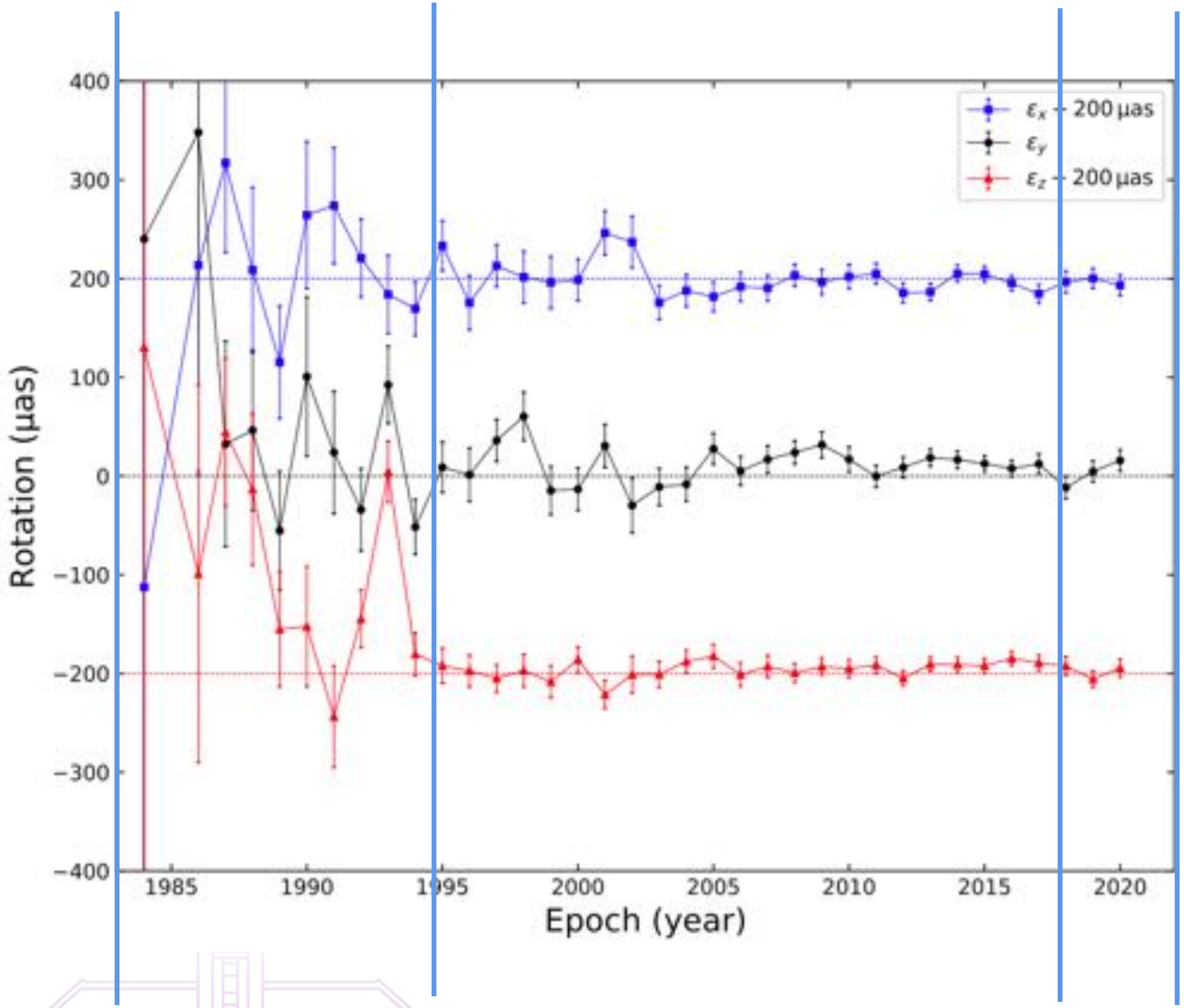
ICRF3 axes stability inferred from yearly representations

Based on coordinate time series (shown)

Weighted the coordinate time series within one year to obtain the yearly averaged positions for the ICRF3 defining sources.

Based on global VLBI solution

- Truncated VLBI data to a certain year N (i.e., 1979 - N) and ran global solutions
- obtained consistent results

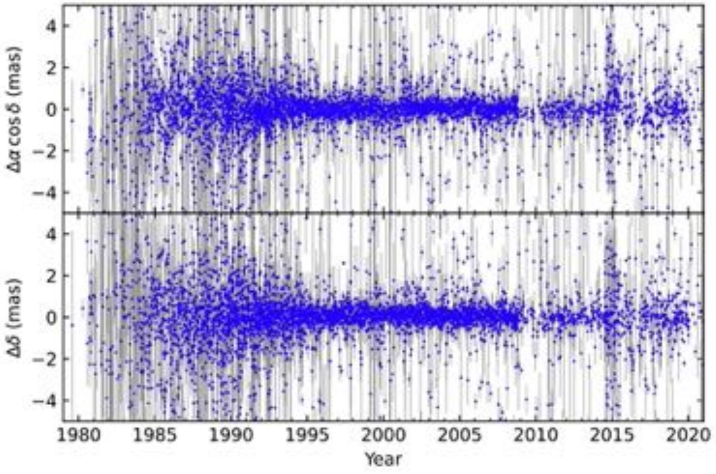


WRMS

13 µas
11 µas
3 µas
16 µas
13 µas
11 µas
17 µas
7 µas
6 µas

Influence from source astrometric instability

Observed



Simulation of 0552+398

Gaussian + Markovian characteristics

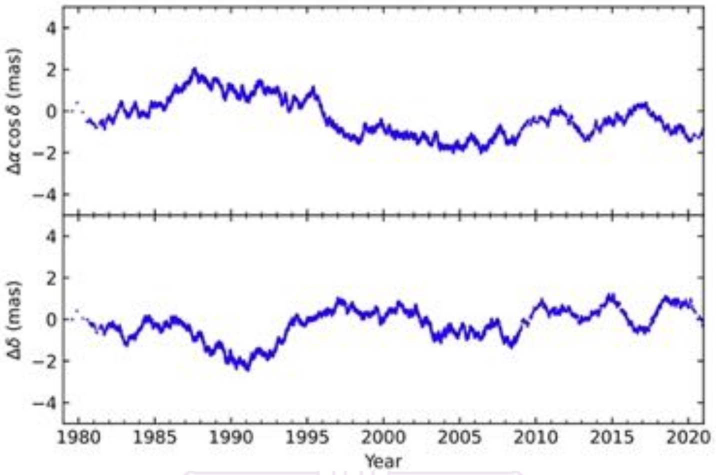
$$\begin{bmatrix} \Delta\alpha_*(t_i) \\ \Delta\delta(t_i) \end{bmatrix} = e^{-\Delta t_i/\tau_{\rm cor}} \begin{bmatrix} \Delta\alpha_*(t_{i-1}) \\ \Delta\delta(t_{i-1}) \end{bmatrix} + \begin{bmatrix} g_i^{\alpha_*} \\ g_i^{\delta} \end{bmatrix}$$

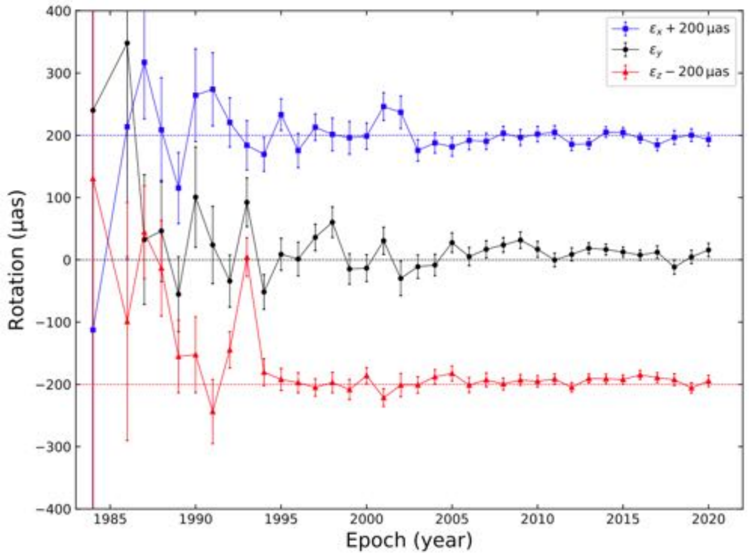
$$\sigma_i = \sigma_{\rm var}\sqrt{1-\exp(-2\Delta t_i/\tau_{\rm cor})}.$$

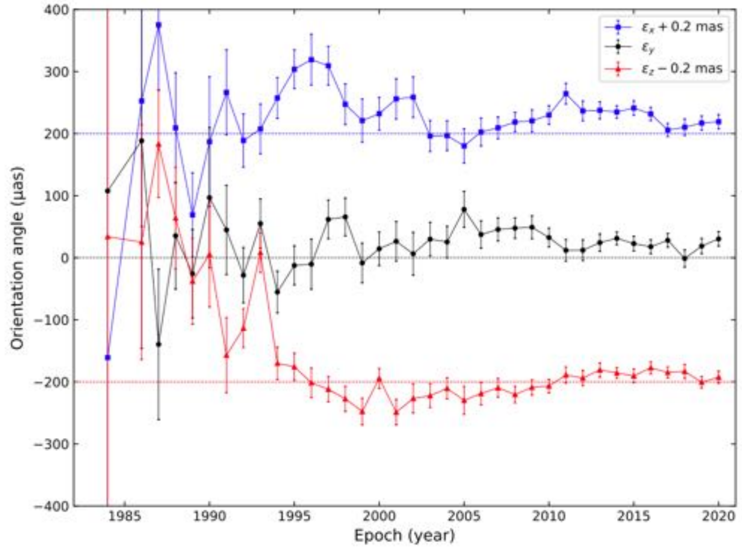
Degrade ICRF3 stability if

$\sigma_{var} \geq 3$ mas, assumed that $\tau_{cor} = 5$ yr

Simulated
($\sigma_{var} = 3$ mas, $\tau_{cor} = 5$ yr)







Summary

We evaluate the ICRF3 axes stability based on source coordinate time series.

We found：

1. The global spin is no higher than 0.8 μas yr^{-1} for each ICRF3 axis with an uncertainty of 0.3 μas yr^{-1}.

2. The axes orientation of the yearly celestial frame becomes more stable as time elapses, with a standard deviation of 10 μas–20 μas for each axis.

Conclusions：The axes of the ICRF3 are stable at approximately 10 μas–20 μas during 1979.6–2021.0 and the axes stability does not degrade after the adoption of the ICRF3.

For more details, please see Liu et al., A&A 659, A75 (2022).

Thanks for your attention!

诚耀百廿 雄创一流