Is It Possible To Bring the Gaia-CRF2 Into the VLBI Data Reduction?

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Outline

- Motivation
- Implementation of Gaia-CRF in VLBI solution
- Comparison of VLBI solutions
- Concluding remarks

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Motivation

- VLBI can determine the celestial reference frame (CRF) , Earth orientation parameters (EOP), and terrestrial reference frame (TRF) simultaneously
    - north-south VLBI network asymmetry leads to large scale (declination-dependent) systematics
    - also some possible unknown dependency between TRF and CRF
- Gaia is a unique instrument that is principally able to build a CRF on itself
    - free of declination-dependent systematics
    - precision of DR2 is comparable to ICRF3, but we can expect a better precision (positional error) and accuracy (lower systematics) in the future release
- If considering Gaia-CRF in the VLBI analysis
    - A possible way for radio-optical reference frame tie?
    - Any new information to the nutation/UT1?
    - An interesting option for VLBI data analysis?

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Geodetic/Astrometric VLBI analysis

- Taking Calc/Solve@GSFC for example: Least square method
  - $\tau_{\text{obs}} = \tau_{\text{mod}} + \epsilon \Rightarrow \tau_{\text{obs}} - \tau_{\text{mod}} = \frac{\partial \tau}{\partial \vec{x}} \cdot \Delta \vec{x} + \epsilon$
  - Normal equation: $N \Delta \vec{x} = \vec{b}$

- Due to degeneracies amongst CRF, TRF, and EOP, special constraint equations should be added to normal equation.

- Maintenance of the reference frame
  - No-Net-Rotation (NNR) constraint to position of radio sources (also possible for proper motion but not used)
  - No-Net-Translation (NNT) and No-Net-Rotation (NNR) constraint to station positions and velocities

NNR constraint on radio source positions

- NNR constraint equation of CRF
  - $\sum_i \Delta\vec{s}_i \times \vec{s}_{i,0} = \vec{0}$
  - Average rotation for a special ensemble of radio sources to be 0
- Rewrite the equation as
  - $\vec{s}_i = \vec{r}, \Delta\vec{s}_i = \Delta\alpha \cos\delta \cdot \vec{p} + \Delta\delta \cdot \vec{q}$
  - $\vec{p} = (-\sin\alpha, \cos\alpha, 0)^{\mathrm{T}}, \vec{q} = (-\sin\delta\cos\alpha, -\sin\delta\sin\alpha, -\cos\delta)^{\mathrm{T}}, \vec{r} = (\cos\delta\cos\delta, \cos\delta\sin\delta, \sin\delta)^{\mathrm{T}}$
  - $\Rightarrow \sum_i -\Delta\alpha_i \cos\delta_i \cdot \vec{q}_i + \Delta\delta_i \cdot \vec{p}_i = \vec{0}$
- State-of-art VLBI solution
  - ICRF3 (S/X) positions of 303 defining sources

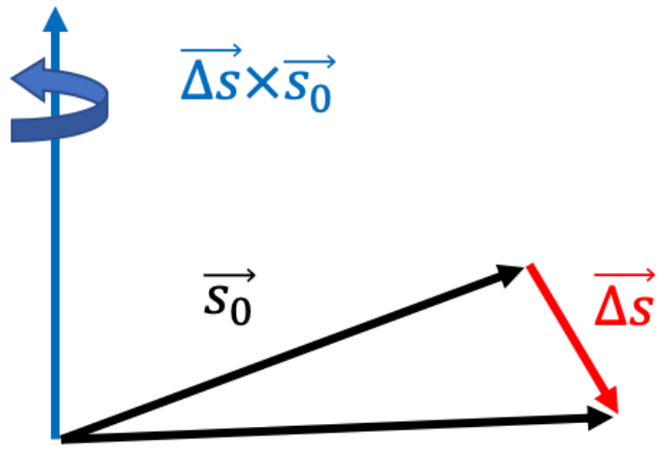

Fig. 1 Rotation needed to align the adjusted position to a priori position

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- State-of-art VLBI solution
  - ICRF3 (S/X) positions of 303 defining sources => Gaia DR2 position?

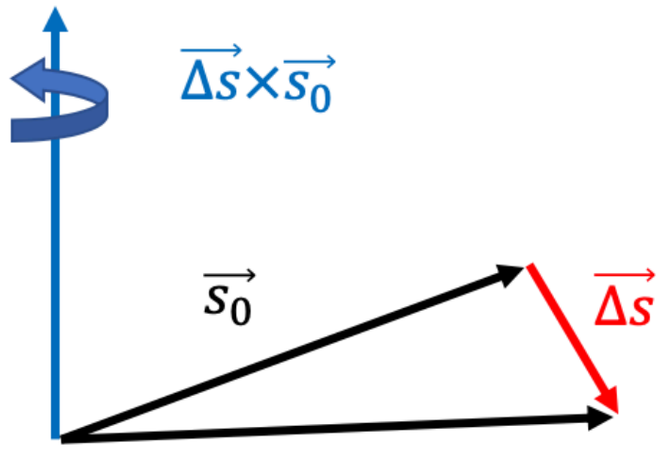

Fig. 1 Rotation needed to align the adjusted position to a priori position

Gaia-CRF2

- 250 common sources between Gaia DR2 IERS subset and ICRF3 defining source set

- Most precise position in the ICRF3 but not in the Gaia DR2

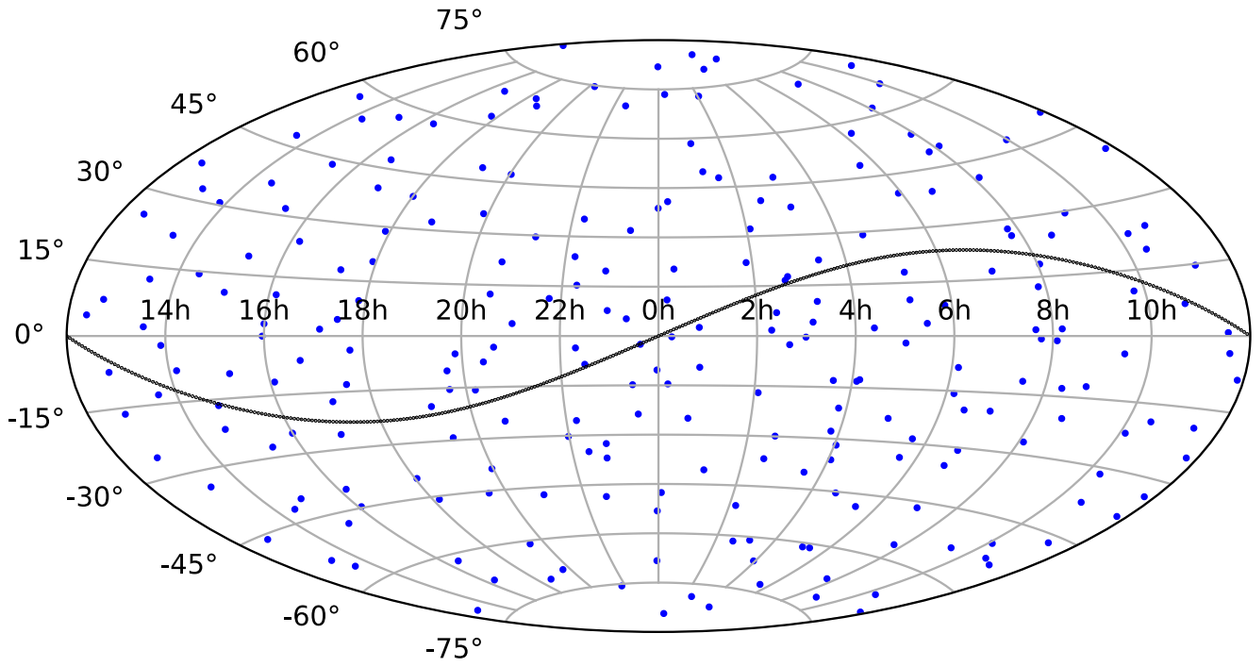

Fig. 2 Distribution of 250 sources

Interesting sources

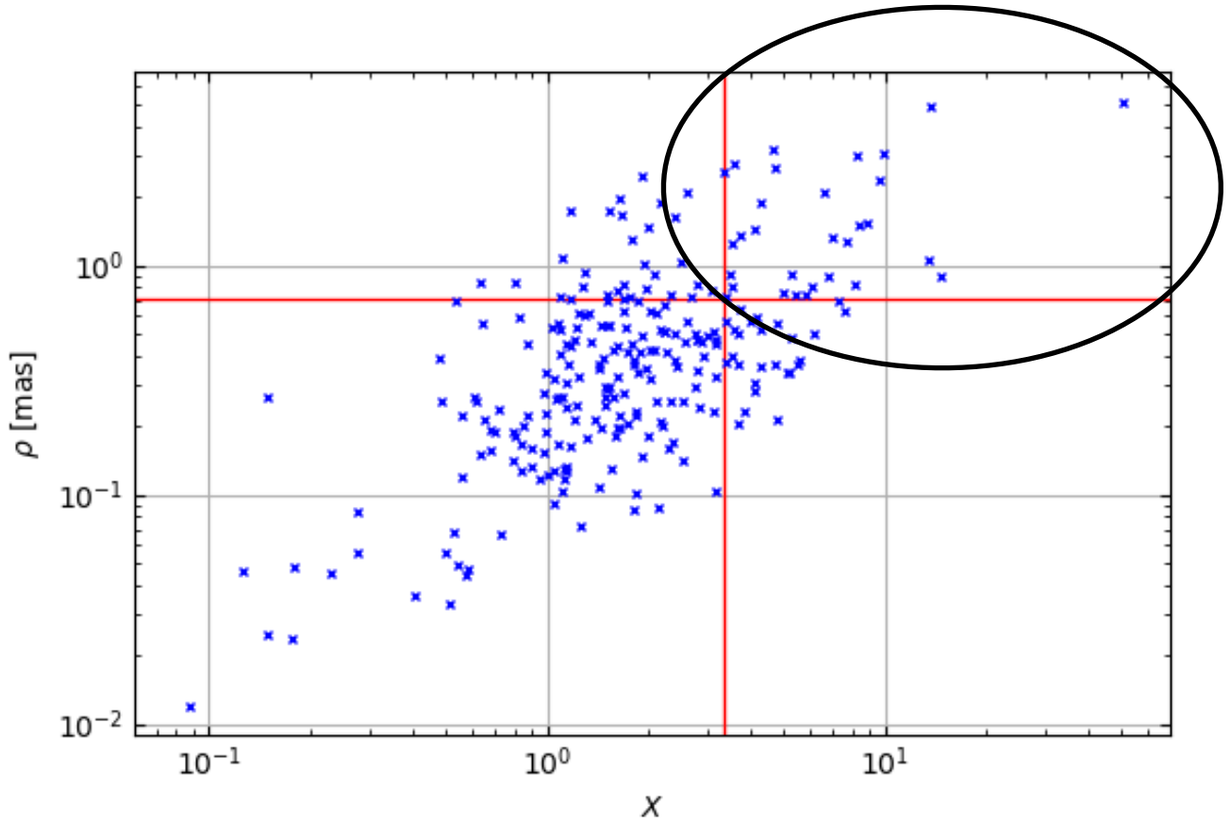

Fig. 3 Angular separation ρ and normalized separation X

iers_name	ra	dec	rho	X
	deg	deg	mas	
0010+405	3.38	40.86	1.332	6.98
0013-005	4.05	-0.25	1.244	3.54
0235-618	39.22	-61.60	1.449	4.12
0305+039	47.11	4.11	4.943	13.70
0312+100	48.84	10.21	3.105	9.86
0615+820	96.51	82.04	0.820	8.22
0642-349	101.11	-34.99	0.911	5.28
0743-006	116.48	-0.74	1.054	13.43
0749+540	118.26	53.88	0.889	6.85
0818-128	125.24	-12.98	2.333	9.60
...	...	...	...	...
1642+690	250.53	68.94	2.803	3.61
1730-130	263.26	-13.08	0.760	4.98
1806-458	272.49	-45.88	2.077	6.58
1908+484	287.44	48.58	2.560	3.35
1921-293	291.21	-29.24	1.273	7.73
2209+236	333.02	23.93	0.723	3.39
2214+350	334.08	35.30	0.812	6.13
2254+074	344.32	7.72	1.490	8.34
2325-150	351.95	-14.80	1.869	4.31
2331-240	353.48	-23.73	0.752	5.44

Length = 30 rows

- Outliers for reference frame construction
- interesting objects for astrophysical studies

Global difference between Gaia DR2 and ICRF3 S/X

- Vector spherical harmonics (VSH) of degree-1

- Rotation

$$\Delta\alpha^* = -R_x \cos\alpha \sin\delta - R_y \sin\alpha \sin\delta + R_z \cos\delta$$
$$\Delta\delta = +R_x \sin\alpha - R_y \cos\alpha$$

- Dipole or Glide

$$\Delta\alpha^* = -D_x \sin\alpha + D_y \cos\alpha$$
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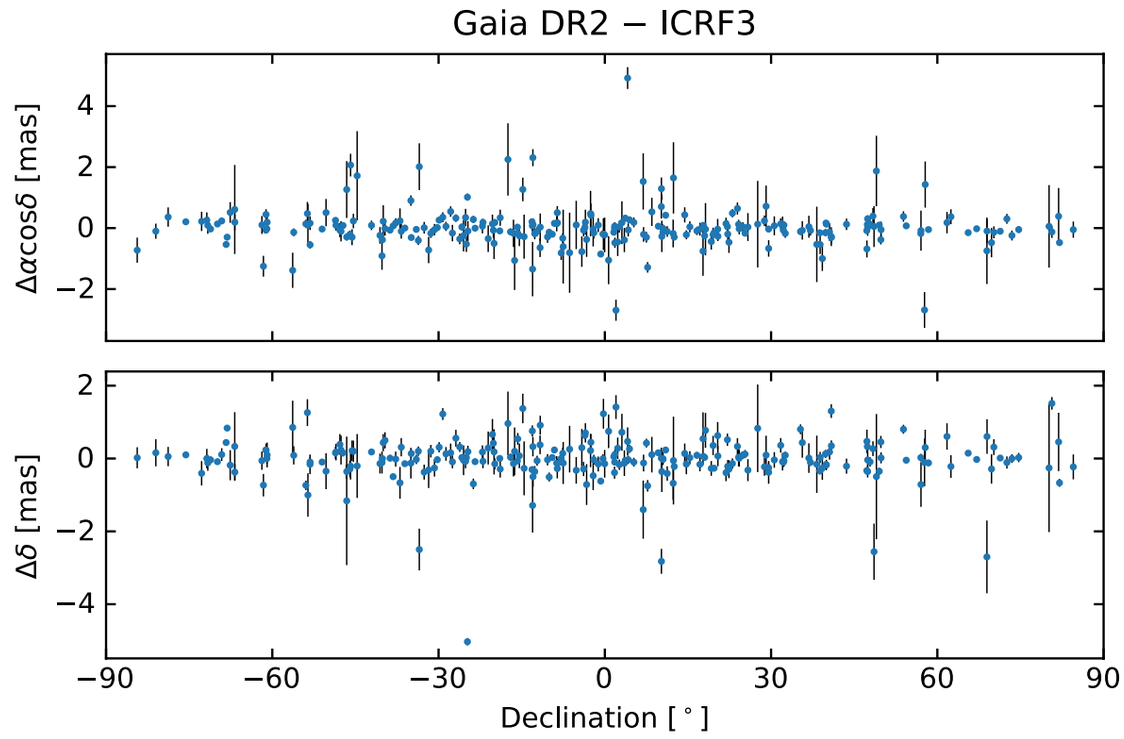

Fig. 4 ICRF3—Gaia DR2 for 250 sources

N	Rotation (μas)			Dipole (μas)		
	x	y	z	x	y	z
250	−74 ± 32	−16 ± 31	−9 ± 35	+47 ± 31	−48 ± 32	−47 ± 32
2820	−26 ± 32	+32 ± 30	+41 ± 28	+32 ± 30	−37 ± 28	−30 ± 30

Table 1 VSH parameters of ICRF3—Gaia DR2

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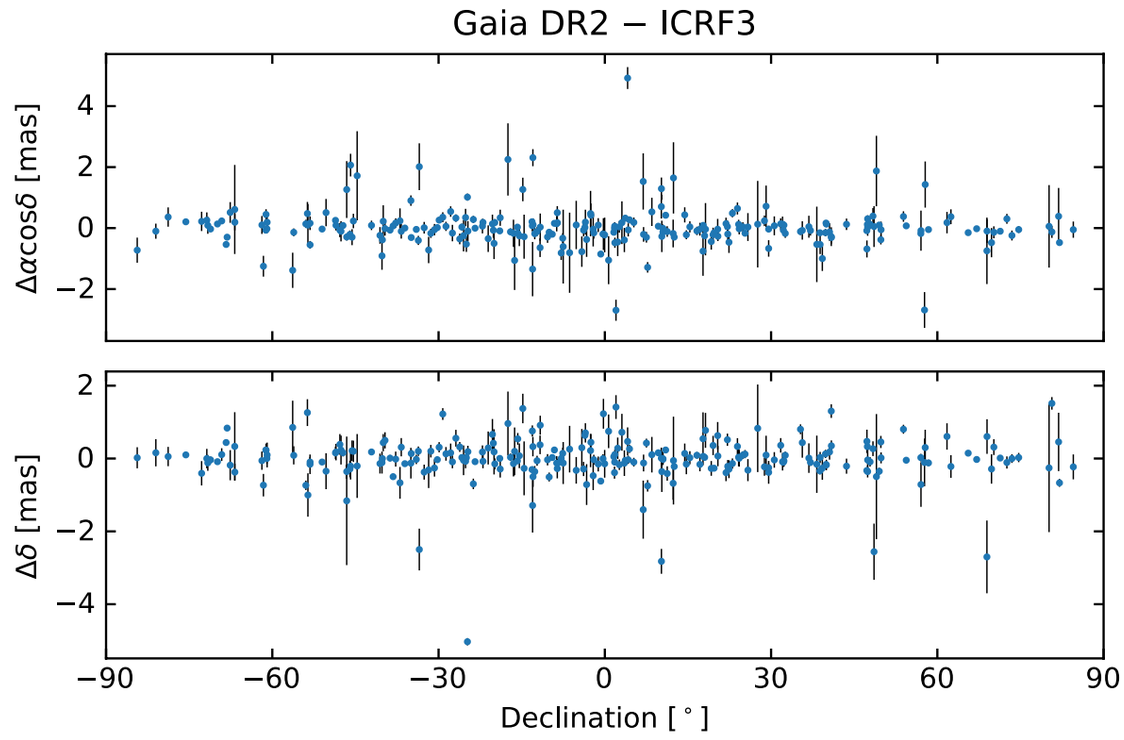

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Solution configuration

- Test on
  - different a priori source position (ICRF3 S/X or Gaia DR2)
  - adjusting or fixing positions of defining source
- VLBI solutions @SYRTE/Paris Observatory

Table 2 VSH Configuration of VLBI solutions

Label	Name	A priori catalog	Defining Source position	NNR rad	Post-fit rms ps	Reduced-χ^2
A	gcrf250	Gaia DR2	adjusted	10^{-10}	26.37	1.19
B	icrf250	ICRF3 SX	adjusted	10^{-10}	26.37	1.19
C	gcrf250-fix	Gaia DR2	fixed	10^{-10}	28.03	1.34
D	icrf250-fix	ICRF3 SX	fixed	10^{-10}	26.44	1.20

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Only changing a priori positions of radio sources

Fig. 5 Positional difference vs. R.A.

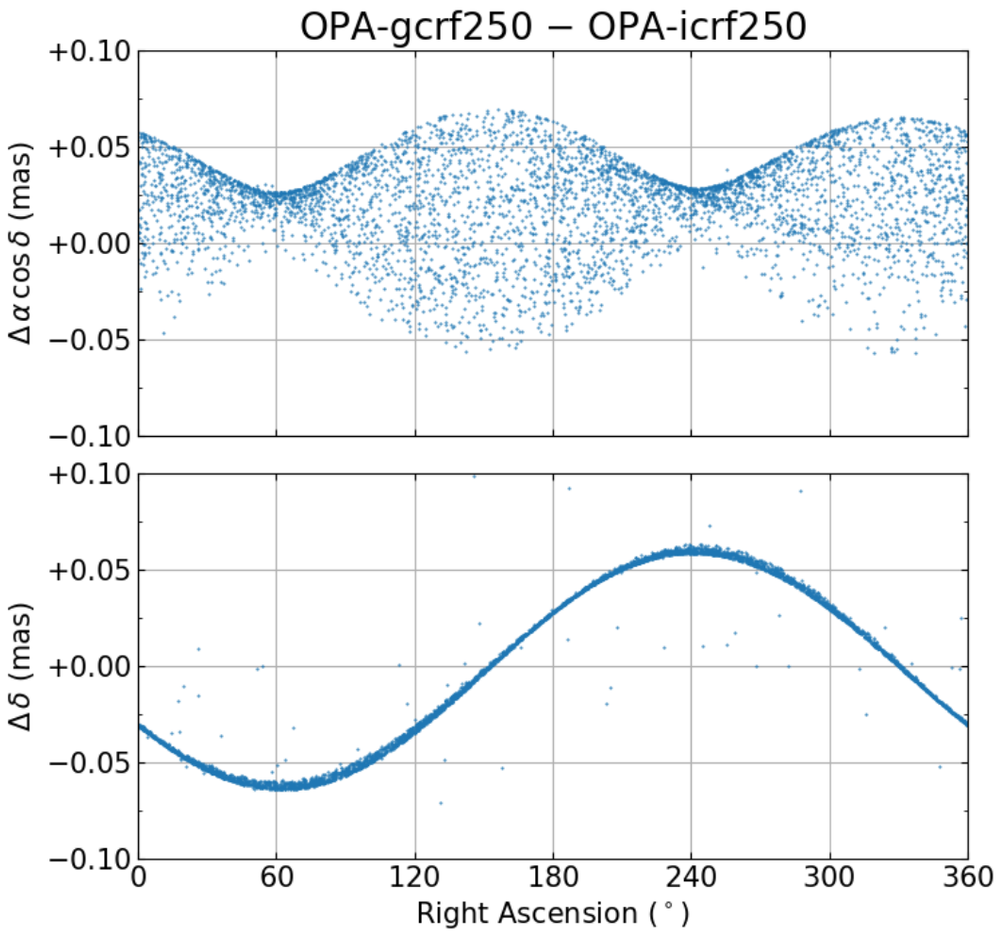
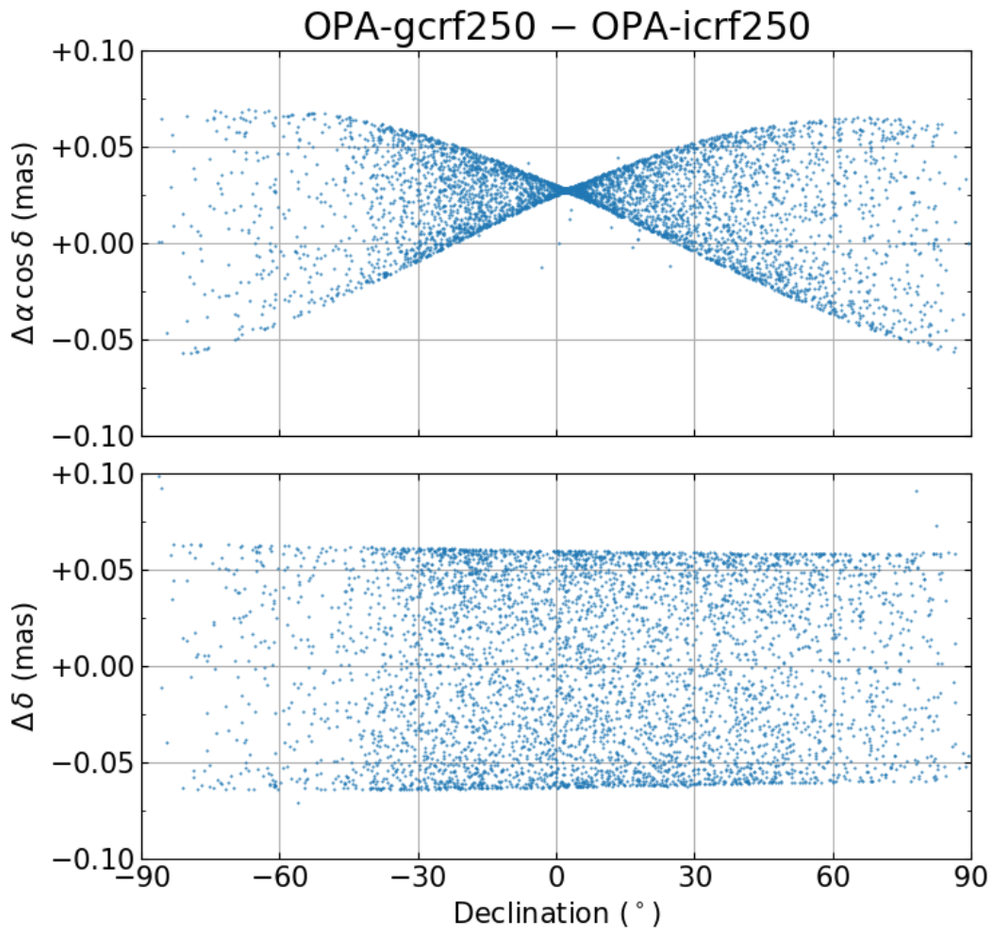


Fig. 6 Positional difference vs. decl.



Rotation (μas): $R_x \sim -54, R_y \sim +29, R_z \sim +27$

No dipole found

Only changing source positions

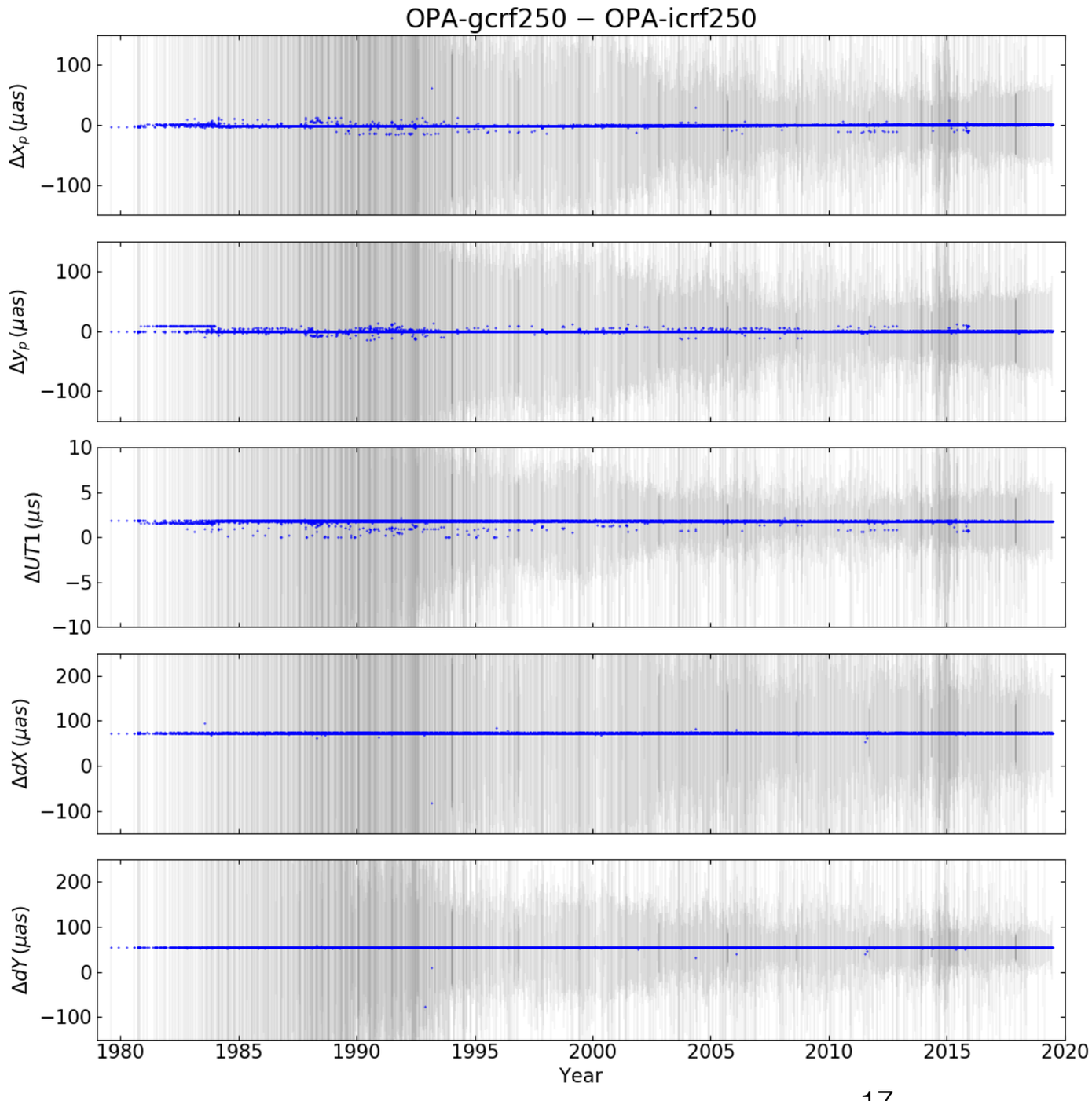


Fig. 7 EOP differences.
From top to bottom:
polar motion (x_p and y_p);
UT1;
Nutation offset (dX and dY)

No influence on polar motion

$R_z \sim +27\mu as$

$R_y \sim +29\mu as$?

$R_x \sim -54\mu as$

Fixing defining source positions

Fig. 8 Positional difference vs. R.A.

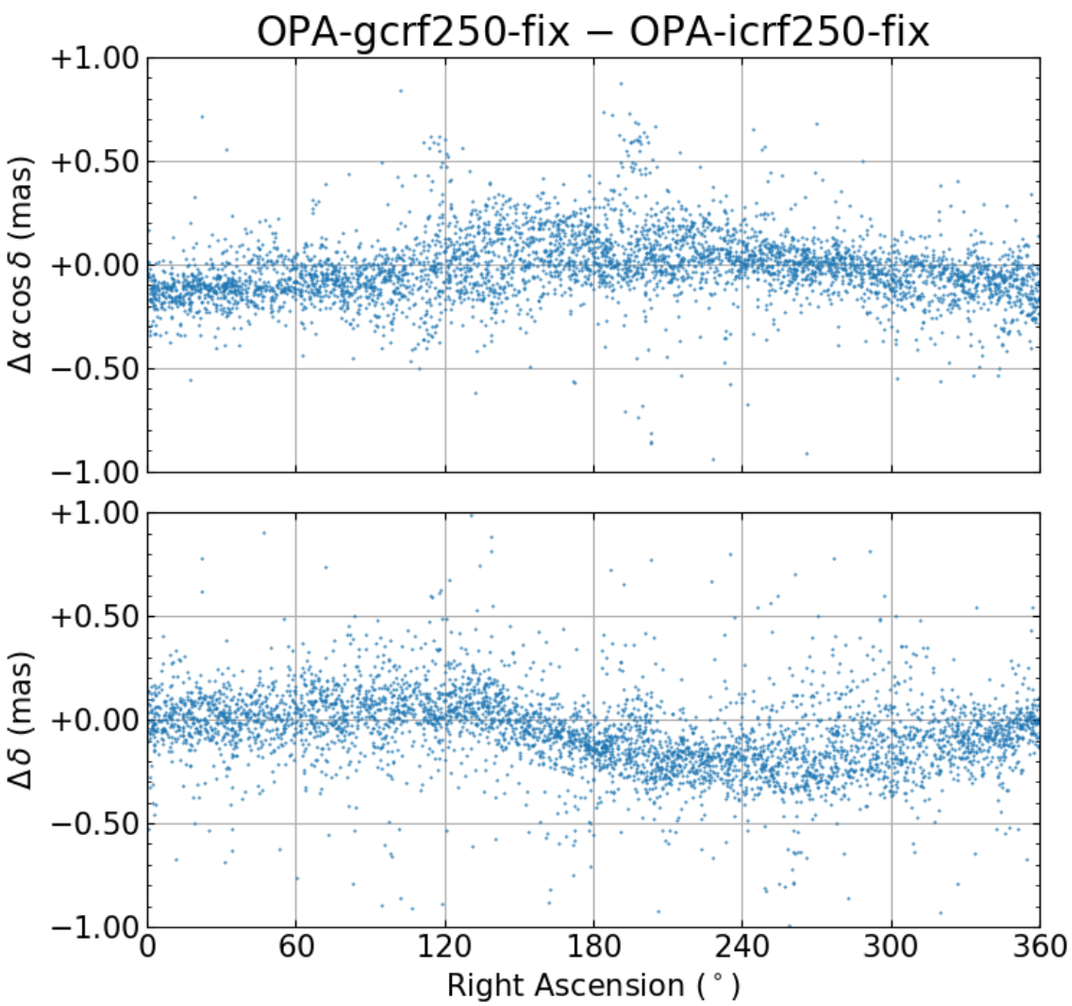
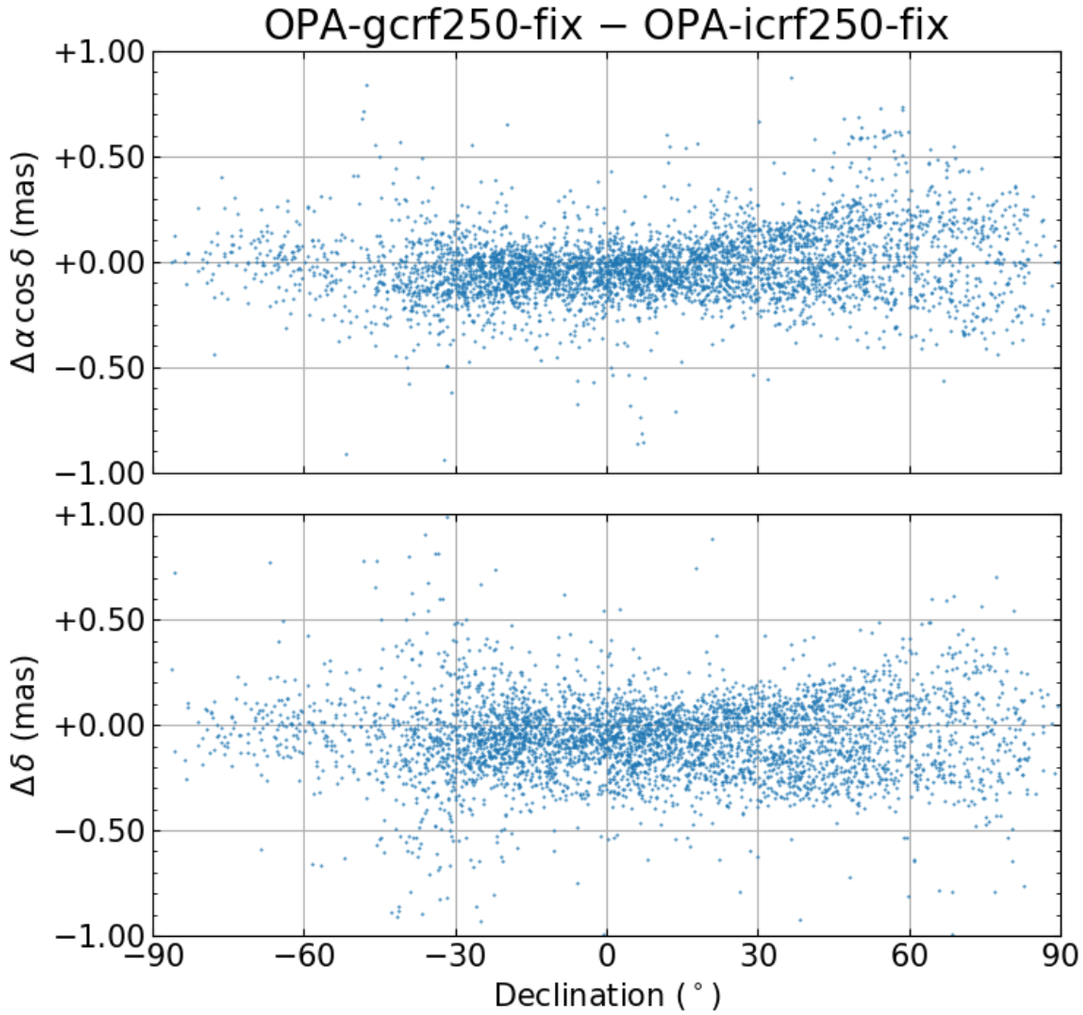


Fig. 9 Positional difference vs. decl.



Rotation (μas): $R_x \sim +148, R_y \sim -87, R_z \sim -17$

Dipole (μas): $D_x \sim +86, D_y \sim -104, D_z \sim -95$

Fixing defining source positions

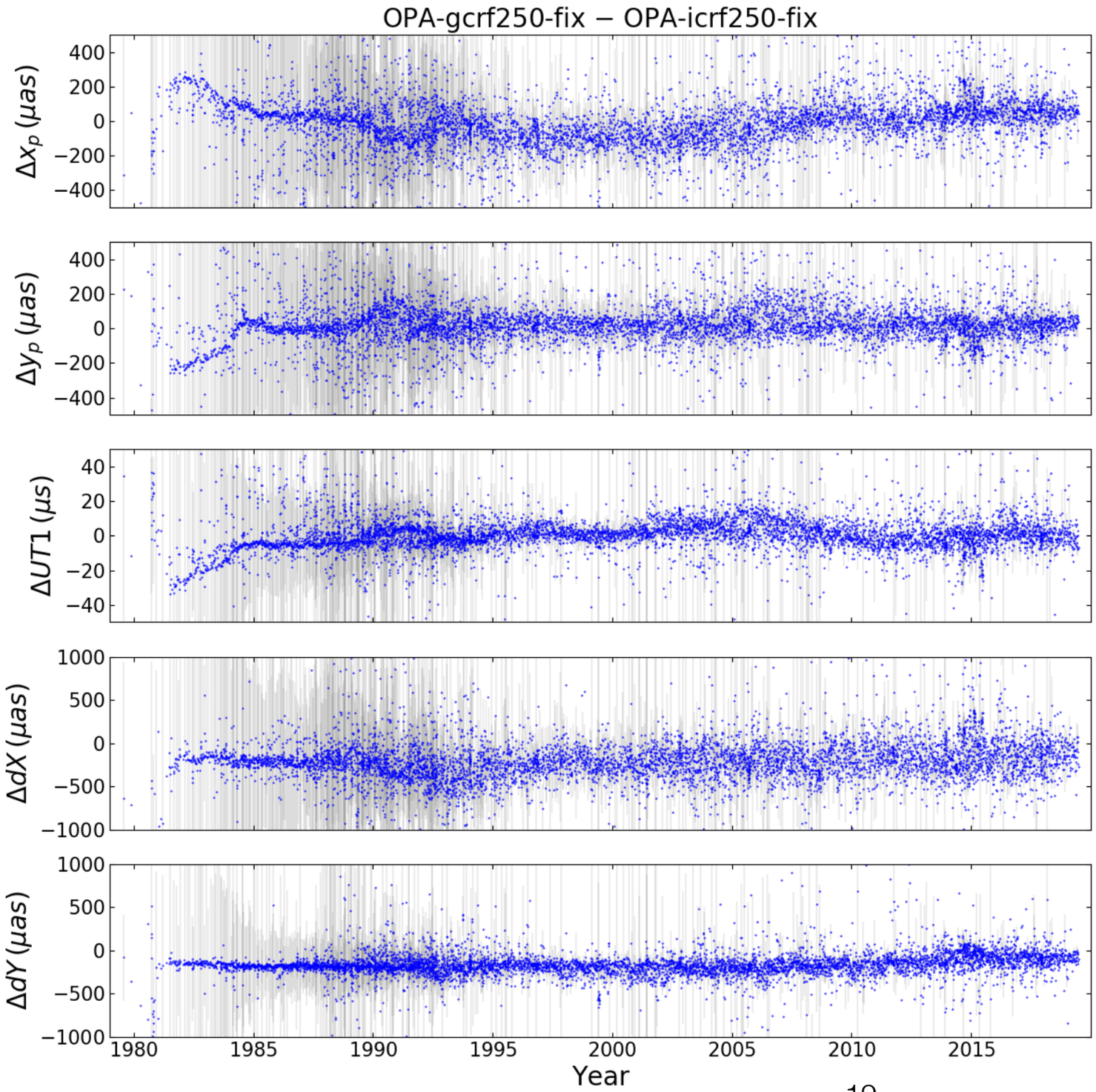


Fig. 10 EOP differences.
From top to bottom:
polar motion (x_p and y_p);
UT1;
Nutation offset (dX and dY)

Irregular offset

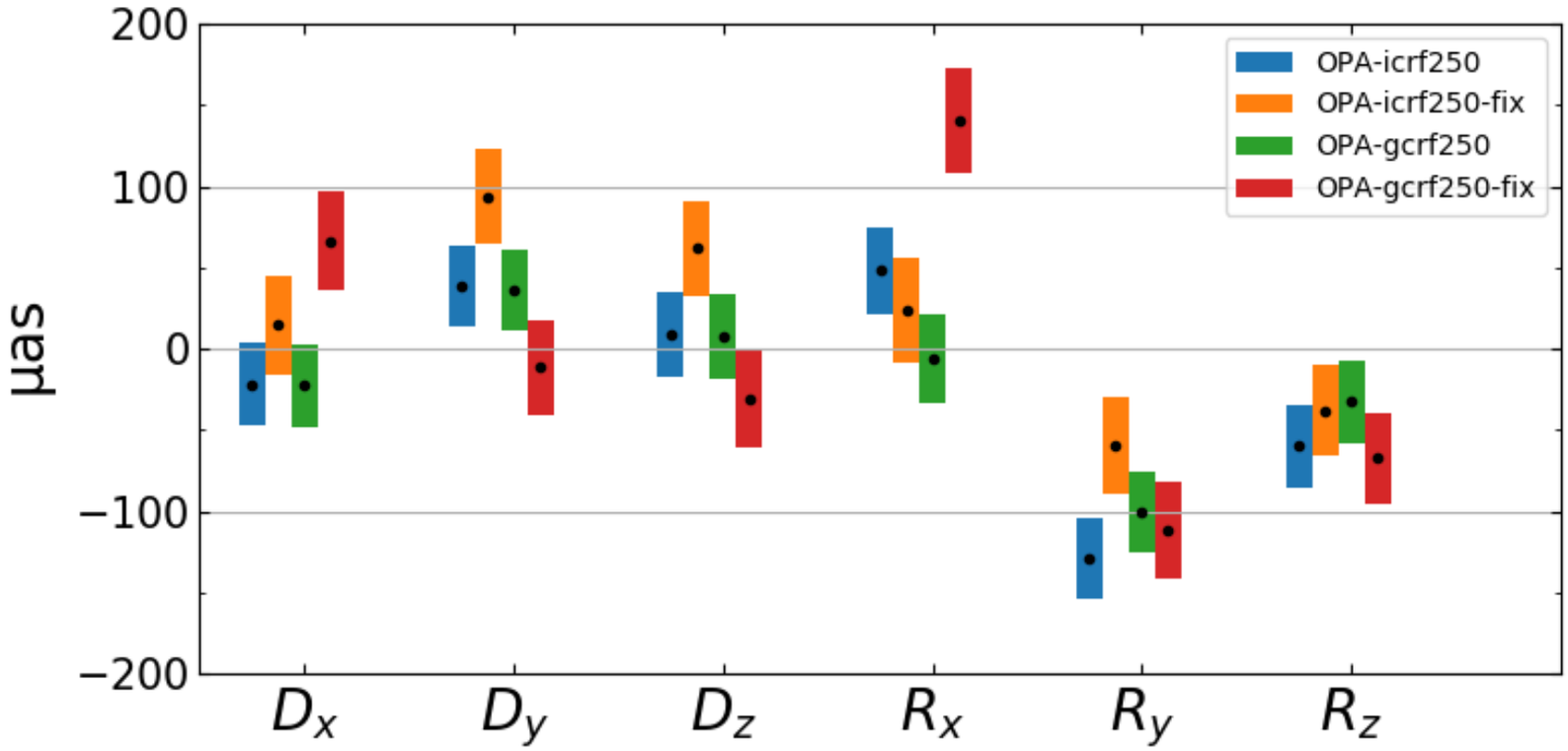
$R_z \sim -95\mu as$

$R_y \sim -87\mu as?$

$R_x \sim +148\mu as$

Comparison with Gaia DR2

Fig. 11 VSH parameters between solutions and Gaia DR2



- Rotation generally agrees with each other

- Fixing defining source position to Gaia DR2 (*OPA-gcrf250-fix*) reduces the dipole with Gaia DR2 than fixing to ICRF3 positions (*OPA-icrf250-fix*)

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Concluding remarks

- We present a possible method to analyze VLBI observations within the frame of Gaia-CRF2
- We found
    - taking ICRF3 or Gaia DR2 positions as a priori &adjusting the celestial frame introduces only orientation and corresponding offsets in UT1/Nutation
    - fixing defining source position to Gaia DR2 bring the estimated source position closer to Gaia DR2 in terms of dipole. However, it is a bad choice. We should better fix them to the ICRF3.
- Outlooks
    - Choose a suitable set of radio sources for radio-optical frame tie
    - Also consider the proper motion of Gaia DR2?