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Selection of sources to construct a more uniform reference frame

— *The preliminary results*

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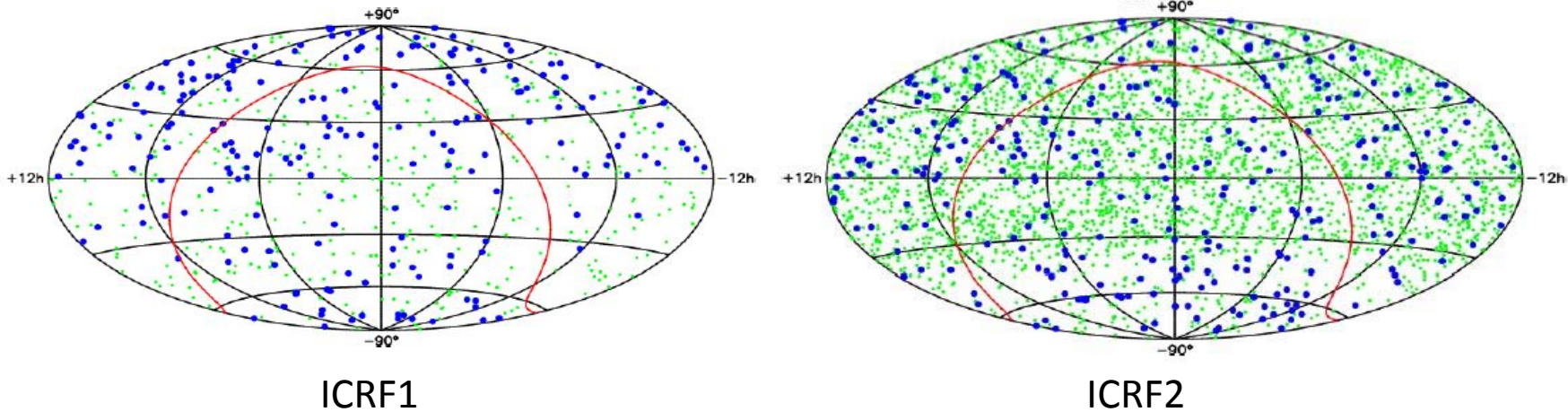
Outline

- The homogeneity of the source distribution
- Data and analysis strategy
- Selection of the radio sources



The ICRF realized by the radio sources

- ◆ ICRF1: January 1998
- ◆ ICRF2: January 2010 *as fundamental reference frames*



The ICRF2 has achieved:

- ◆ More uniform distribution of the defining sources.
- ◆ Improving the source position uncertainty (from 250 μ as to 40 μ as for noise floor).
- ◆ Elimination of large systematic error at the level of 0.2 mas.



The ICRF3

- ◇ The inertial ICRF3
 - ◇ No global rotation
 - ◇ No acceleration
 - ◇ VLBI realized a quasi-inertial frame with origin at the Solar system barycenter (SSB)

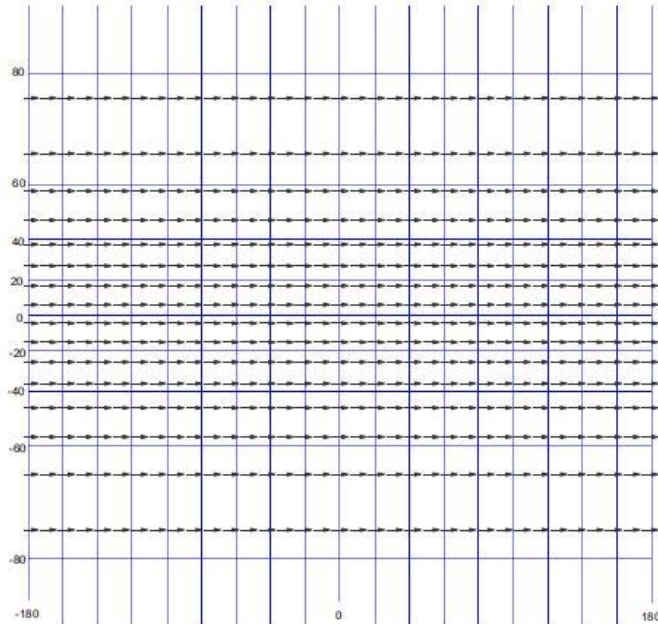
- ◇ The path to the future
 - ◇ Higher frequency
 - ◇ More south hemisphere sources for uniform special coverage
 - ◇ Higher and more uniform accuracy for all sources
 - ◇ Competitive accuracy with Gaia
 - ◇ Prepare for optical-radio frame link

- ◇ Adopt in the IAU GA 2018?

cf: Jacobs 2013, Journées 2013 presentation, Paris

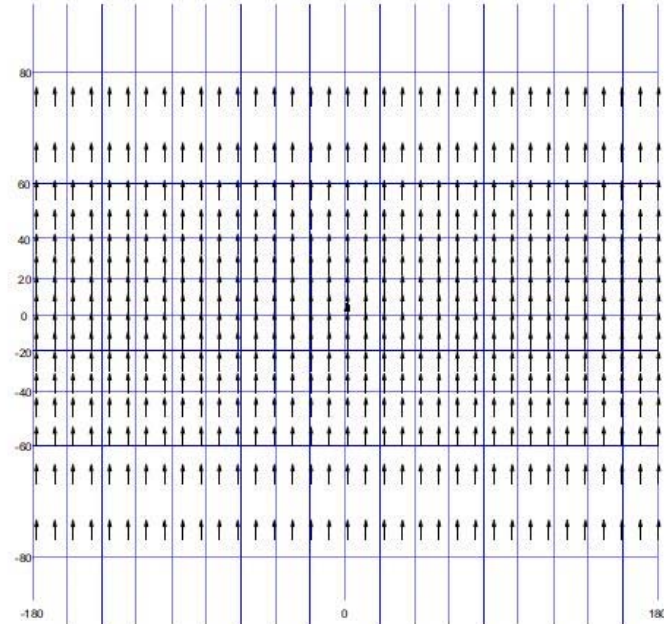


Description of the homogeneity of source distribution



(a) Rotation

$$\mathbf{V}^R = \mathbf{R} \times \mathbf{u}$$



(b) Glide

$$\mathbf{V}^G = \mathbf{u} \times (\mathbf{G} \times \mathbf{u}) = \mathbf{G} - (\mathbf{G} \cdot \mathbf{u}) \mathbf{u}$$

Topologically orthogonal to each other.



Source distribution

- ◆ Calculate glide proper motion
 - ◆ Is there global rotation hidden in the glide (dipole) pattern
 - ◆ If the distribution is uniform

Glide

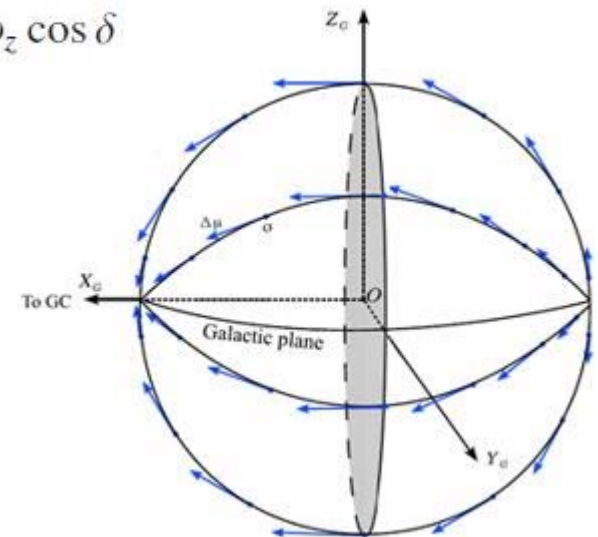
$$\begin{aligned}\Delta\mu_\alpha \cos \delta &= -d_1 \sin \alpha + d_2 \cos \alpha, \\ \Delta\mu_\delta &= -d_1 \cos \alpha \sin \delta - d_2 \sin \alpha \sin \delta + d_3 \cos \delta,\end{aligned}$$

- ◆ Fit the proper motion field to global rotation equations

Rotation

$$\begin{aligned}\Delta\mu_\alpha \cos \delta &= -\omega_x \cos \alpha \sin \delta - \omega_y \sin \alpha \sin \delta + \omega_z \cos \delta \\ \Delta\mu_\delta &= +\omega_x \sin \alpha - \omega_y \cos \alpha,\end{aligned}$$

- ◆ Example for the ICRF source distribution

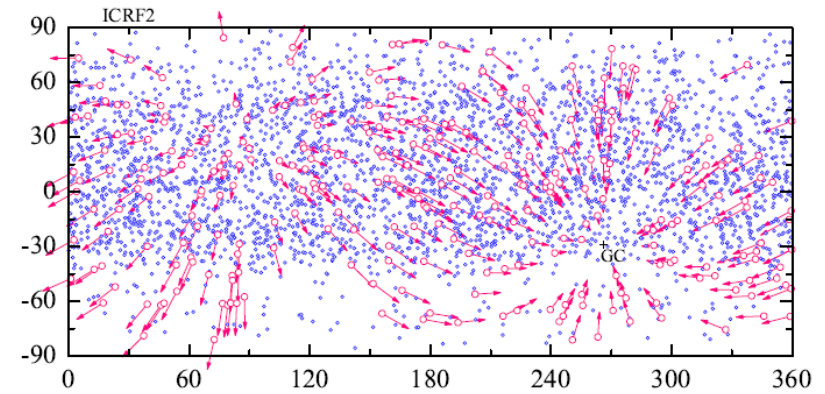
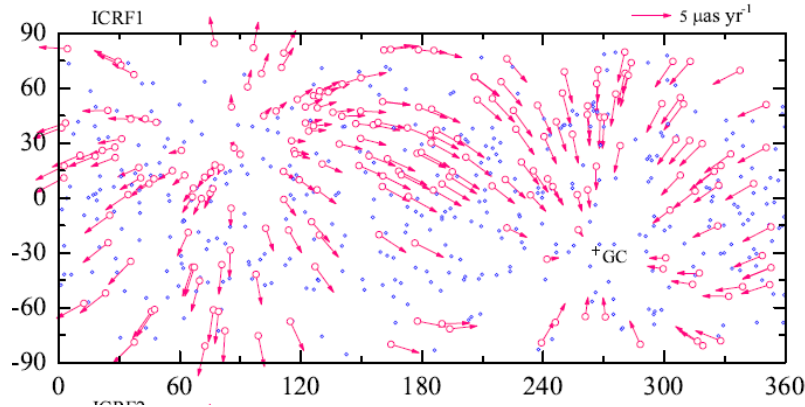


cf: Liu, Capitaine, Malkin et al. (2012) A&A



Source distribution

- Galactic aberration – Glide apparent proper motion



The magnitude of the dipole $A = \frac{\omega_0 V_0}{c} \approx 5 \mu\text{as yr}^{-1}$

- Results of the Global rotation fitted to the theoretical proper motions

Catalog	No.	ω_{X_G}	ω_{Y_G}	ω_{Z_G}	ω_{tot}	θ
ICRF1 def	212	$+0.03 \pm 0.08$	$+0.73 \pm 0.08$	-0.82 ± 0.09	1.09 ± 0.14	$-48^\circ.3$
ICRF1	608	-0.01 ± 0.05	$+0.15 \pm 0.05$	-0.18 ± 0.05	0.23 ± 0.09	$-50^\circ.2$
ICRF2 def	295	-0.01 ± 0.07	$+0.26 \pm 0.07$	$+0.15 \pm 0.07$	0.30 ± 0.12	$+30^\circ.0$
ICRF2	3414	-0.00 ± 0.02	$+0.51 \pm 0.02$	-0.74 ± 0.02	0.90 ± 0.03	$-55^\circ.4$
uniform	2500	$+0.00 \pm 0.02$	$+0.00 \pm 0.02$	$+0.00 \pm 0.02$	0.00 ± 0.03	---

With uniform distribution, the global rotation should be zero.

Source distribution index



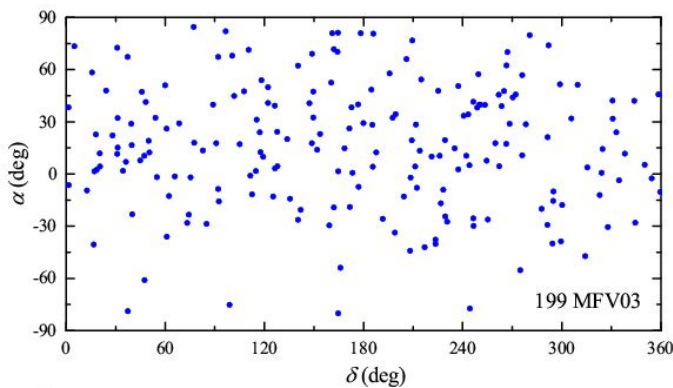
- ◇ The amplitude of global rotation fitted from glide proper motion can be used to characterize uniformity of source distribution on the sky

- ◇ Several choices
 - ◇ 295 ICRF2 defining sources (Fey et al. 2009)
 - ◇ 199 MFV03 selected sources (Feissel-Vernier 2003)
 - ◇ 247 MFV06 selected sources (Feissel-Vernier et al. 2006)
 - ◇ 269 LG09 selected sources (Lambert & Gontier 2009)

- ◇ Dipole
 - ◇ Coordinates of the apex: $(\alpha = 0, \delta = 0)$
 - ◇ Amplitude: $A = 5 \mu\text{as yr}^{-1}$

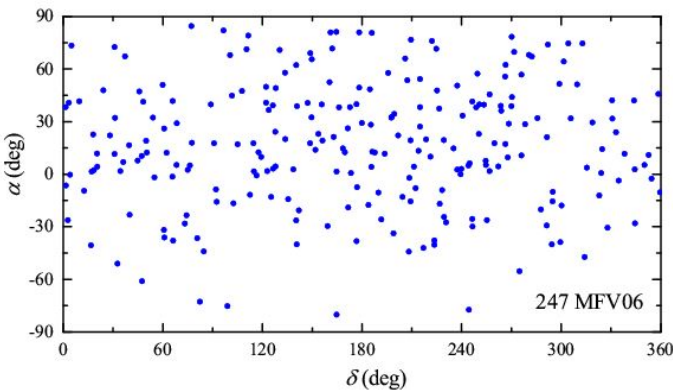


Source distribution index



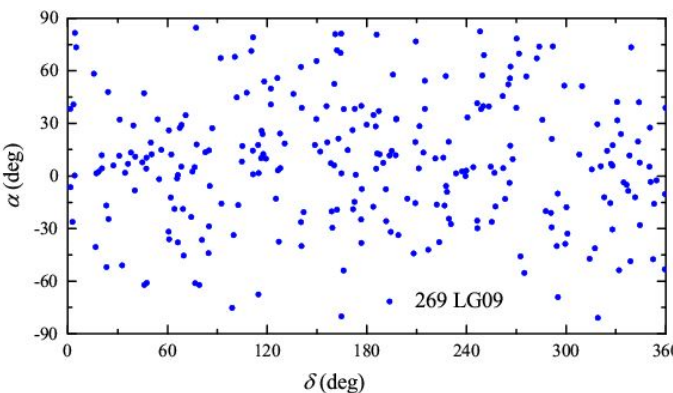
199 MFV03 sources
 $\omega = 1.792 \mu\text{as yr}^{-1}$

295 ICRF2 defining:
 $\omega = 0.154 \mu\text{as yr}^{-1}$



247 MFV06 sources
 $\omega = 1.842 \mu\text{as yr}^{-1}$

212 ICRF1 defining:
 $\omega = 0.989 \mu\text{as yr}^{-1}$



269 LG09 sources
 $\omega = 0.886 \mu\text{as yr}^{-1}$



The data for radio sources

- ◆ Coordinate series from 1979-2015 (IVS analysis center at Paris)
- ◆ For non-defining sources, only sources with 50 more sessions are selected
- ◆ Only post 1990 data are used
- ◆ Various parameters are estimated for each source
 - ◆ LSQ derived motion (proper motion)
 - ◆ RMS, WRMS
 - ◆ Slope for Yearly mean coordinates (with more than 3 observation)
 - ◆ Allan variance for Yearly mean coordinates

Source ID: (e.g., 0923+392, 4C 39.25, 3C 273)

Display series longer than

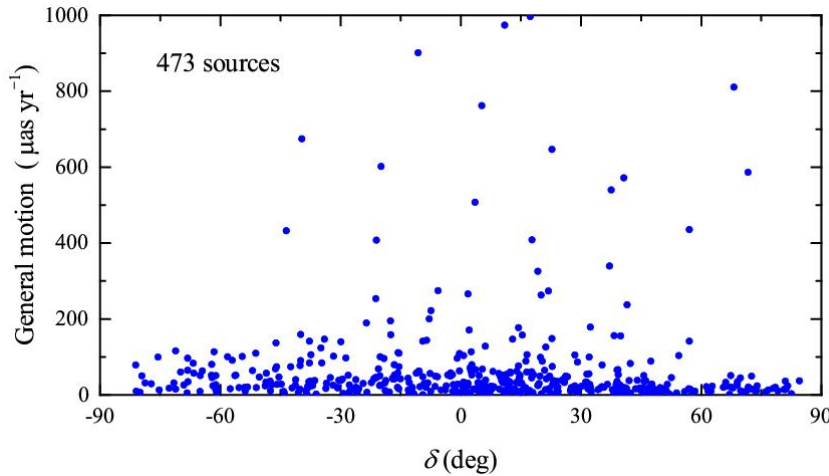
0000-197 0000-199 0001+459 0001-120 0002+051 0002+200 0002+541 0002-170 0002-478 0003+123 0003+340
0003+380 0003-066 0003-302 0004+240 0005+114 0005+568 0005+683 0005-239 0005-262 0006+061 0006+397
0006-363 0007+106 0007+171 0007+439 0007-048 0007-325 0008+704 0008-222 0008-264 0008-300 0008-307
0008-311 0008-421 0009+081 0009+467 0009+655 0009-148 0010+336 0010+405 0010+463 0010-155 0010-401
0011+189 0011-046 0012+319 0012+610 0012-184 0013-005 0013-184 0014+813 0015+529 0015-054 0015-280
0016+731 0017+200 0017+257 0017-307 0018+715 0018+729 0019+058 0019+451 0019-000 0020+446 0021+243
0021+464 0021-084 0022+390 0022-044 0022-227 0022-423 0023-263 0024+092 0024+224 0024+348 0024+597
0024-114 0025+197 0026+048 0026+346 0026-015 0027+056 0027+703 0027-024 0027-426 0028-396 0029-147
0032+276 0032+612 0033+142 0033+143 0033-088 0034+078 0034+108 0034-220 0035+121 0035+238 0035+367
0035+413 0035+503 0035-024 0035-037 0035-252 0036-099 0036-191 0036-216 0037+139 0037+487 0037-329
0037-593 0038+133 0038+319 0038-020 0038-326 0039+230 0039+568 0040+098 0041+677 0042+186 0043+246
0043-268 0043-392 0044+387 0044+566 0045+243 0046+063 0046+316 0046+511 0046+861 0046-315 0047+023
0047-051 0047-579 0048+447 0048-071 0048-097 0048-427 0049+437 0050-287 0051+291 0051+679 0051+706
0051-077 0052-125 0052-201 0054+161 0054-006 0055+060 0055+300 0055+329 0055-059 0055-328 0055-340
0056+579 0056-001 0056-572 0057+334 0057+678 0057-338 0058+058 0058+498 0059+163 0059+581 0059-287
0100-270 0102+480 0102+511 0102-245 0103+127 0103+253 0103+337 0103-021 0104+195 0104-035 0104-275

- ◆ 473 sources including
 - ◆ 295 defining sources
 - ◆ 178 non-defining sources with more than 50 sessions
- ◆ Northern hemisphere: 280 sources
- ◆ Southern hemisphere: 193 sources



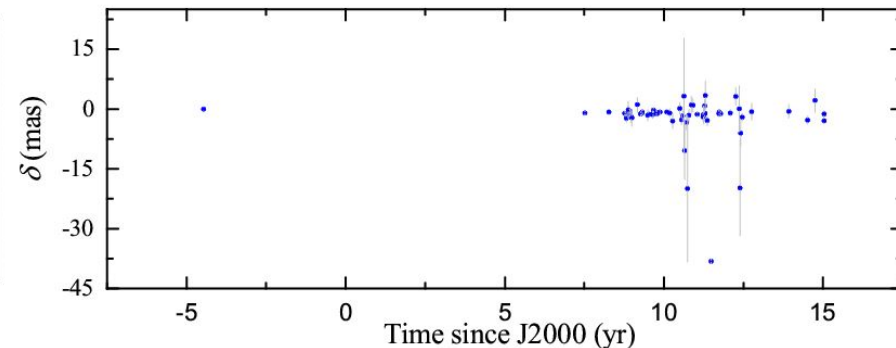
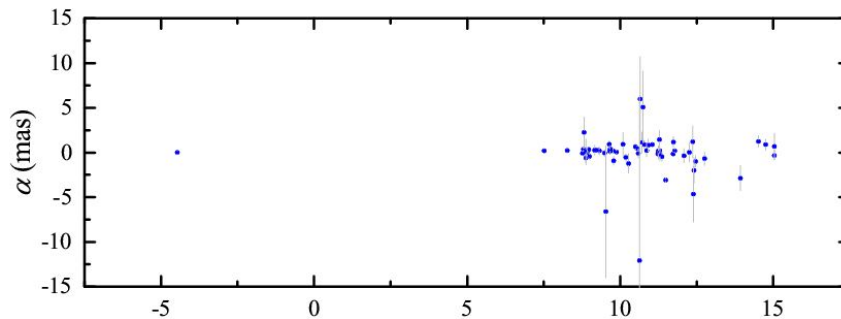
Slope of coordinates

- ◆ Parameters are not strictly correlated
- ◆ The slope of α and δ are derived from weighted squares fit
- ◆ Some large motion are found for defining sources, e.g.



Defining source 1456+044

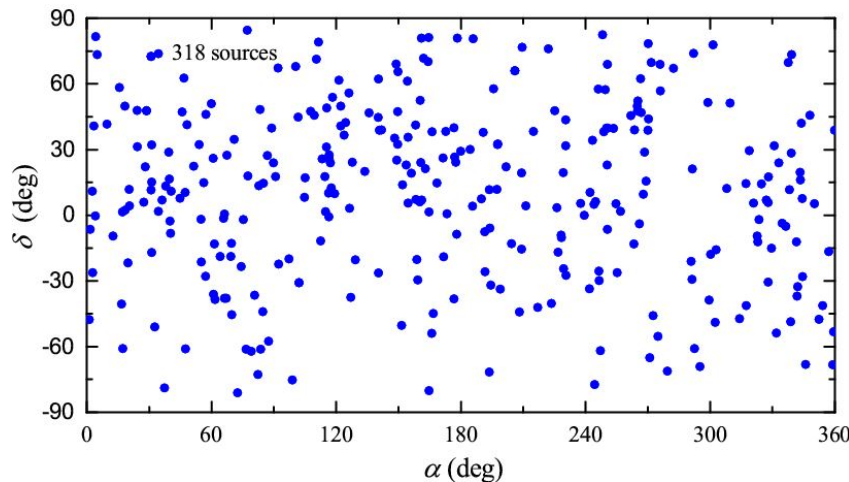
1456+044: $Z = 0.391547$



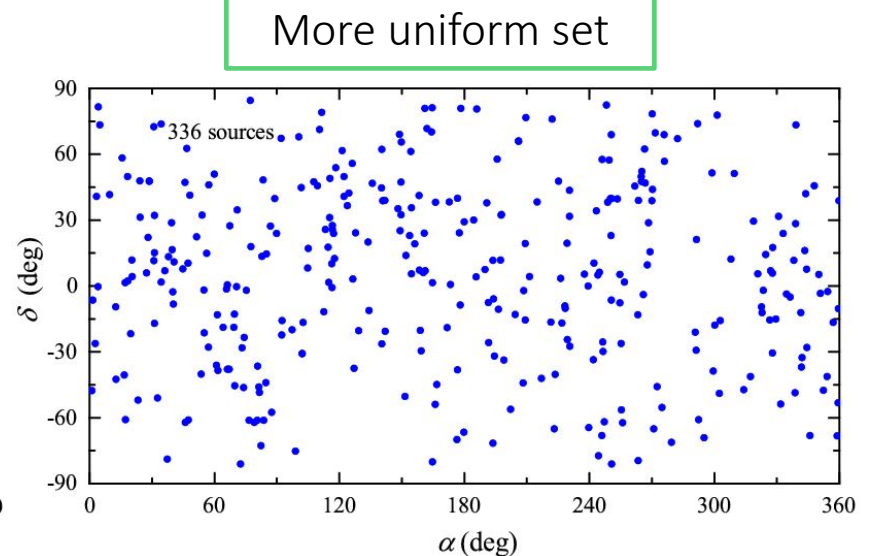


Selection of sources based on “proper motion”

- ◆ Select sources with motion $\mu < 50 \mu\text{as yr}^{-1}$
 - ◆ 318 sources with mean declination = 10.54°
- ◆ For more homogeneous distribution we change the restrictions
 - ◆ Northern hemisphere: $\mu < 40 \mu\text{as yr}^{-1}$
 - ◆ Southern hemisphere: $\mu < 60 \mu\text{as yr}^{-1}$
 - ◆ 336 sources with mean declination = 5.12°



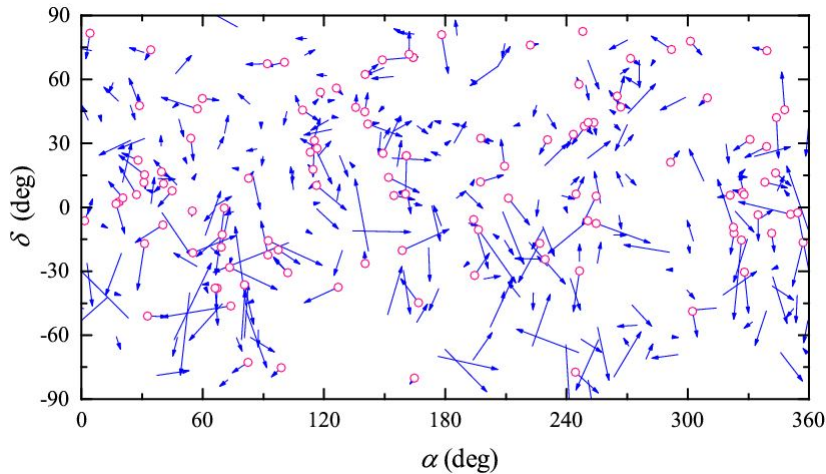
$$\omega = 1.169 \mu\text{as yr}^{-1}$$



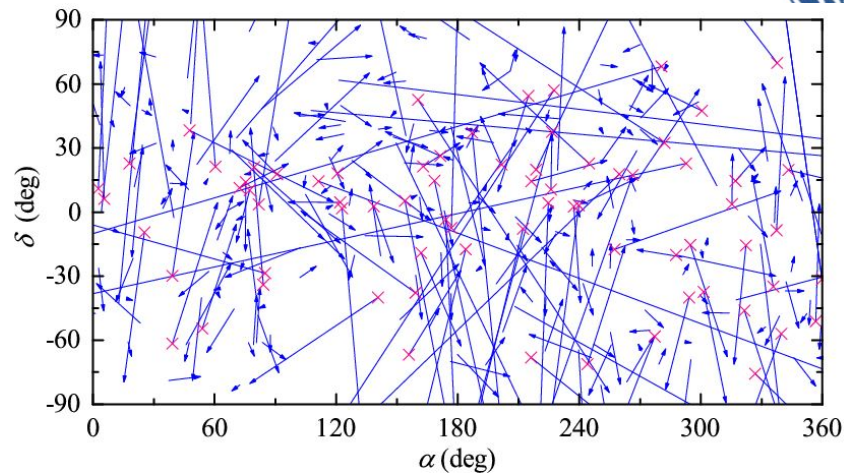
$$\omega = 0.668 \mu\text{as yr}^{-1}$$



New list vs ICRF2 defining sources



336 new sources



295 ICRF2 sources (more uniform set)

◆ Fit the apparent motion of sources to global and glide simultaneously

sources	r_1	r_2	r_3	r	g_1	g_2	g_3	g
295 ICRF2	1.95	-17.1	1.12	17.2	-2.58	-2.45	-2.90	4.59
318 set	-0.17	-0.15	0.59	0.63	-0.02	-2.31	-4.06	4.68
336 set	-0.42	-0.25	0.85	0.98	-0.18	-2.89	-4.42	5.28

unit: $\mu\text{as yr}^{-1}$

Summary



- ◇ Possible way to evaluate the homogeneity of sky distribution
 - ◇ Balance between homogeneity and stability
 - ◇ More parameters to be tested to find a best criterion
-

Thank you for attention!



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