Towards the ICRF3: Comparing USNO 2016A VLBI Global Solution to Gaia and ICRF2

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Outline

- *Introduction*
- *USNO 2016A Global Solution*
  - *Comparison to ICRF2*
  - *Comparison to GAIA DR1*
- *Results*
- *Future Prospects*
- *Conclusions*

International Celestial Reference Frame (ICRF)

- *A brief history…*
  - *The first realization (ICRF1) adopted by IAU on 1 January 1998 as the fundamental celestial reference frame replacing FK5 optical frame (Fricke+ 1988)*
  - *ICRF1 contained Very Long Baseline Interferometry (VLBI) positions of a total of 608 compact radio sources*
    - *Geodetic/astrometric data obtained from August 1979 through July 1995*
    - *Simultaneous observations made at S- and X-bands using a dichroic*
    - *212 "defining" compact radio sources independent of equator, equinox, ecliptic, and epoch*
  - *2 extensions added another 109 sources (Fey+ 2004)*
    - *Some sources from the VLBA Calibrator Survey (VCS) (Beasley+ 2002)*

Spatial distribution of ICRF1

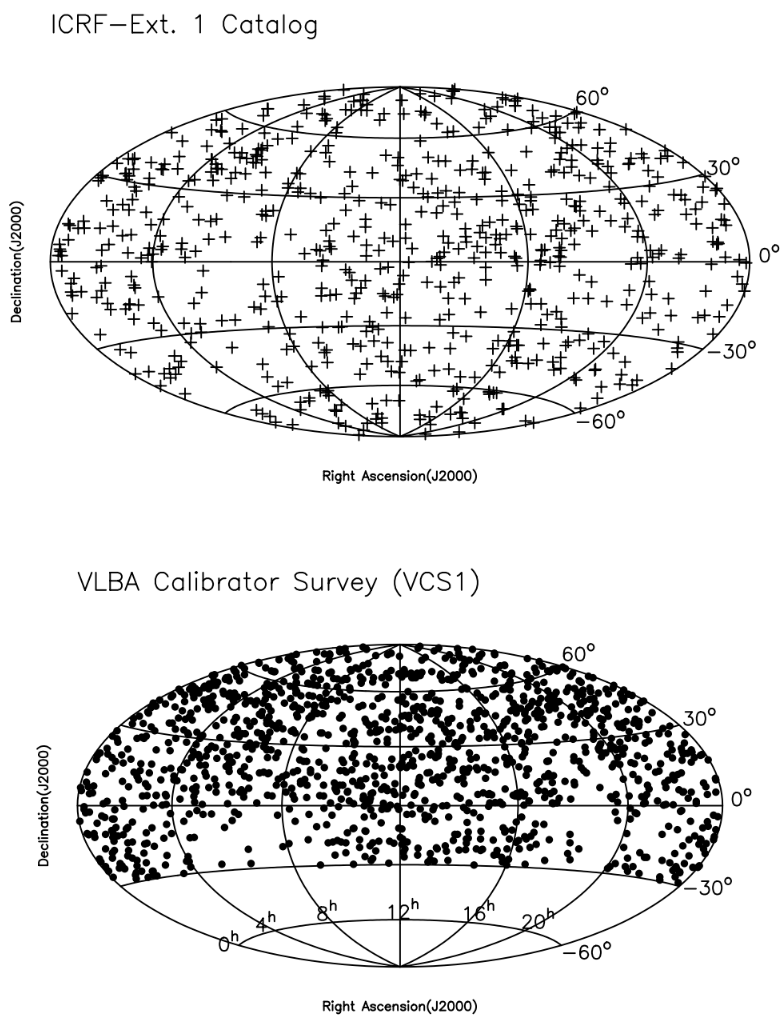


FIG. 1.—Equal-area projection of celestial distribution of ICRF-Ext. 1 (667 sources, *top*) and VCS1 catalogs (1332 sources, *bottom*).

Beasley+ 2002

Introduction

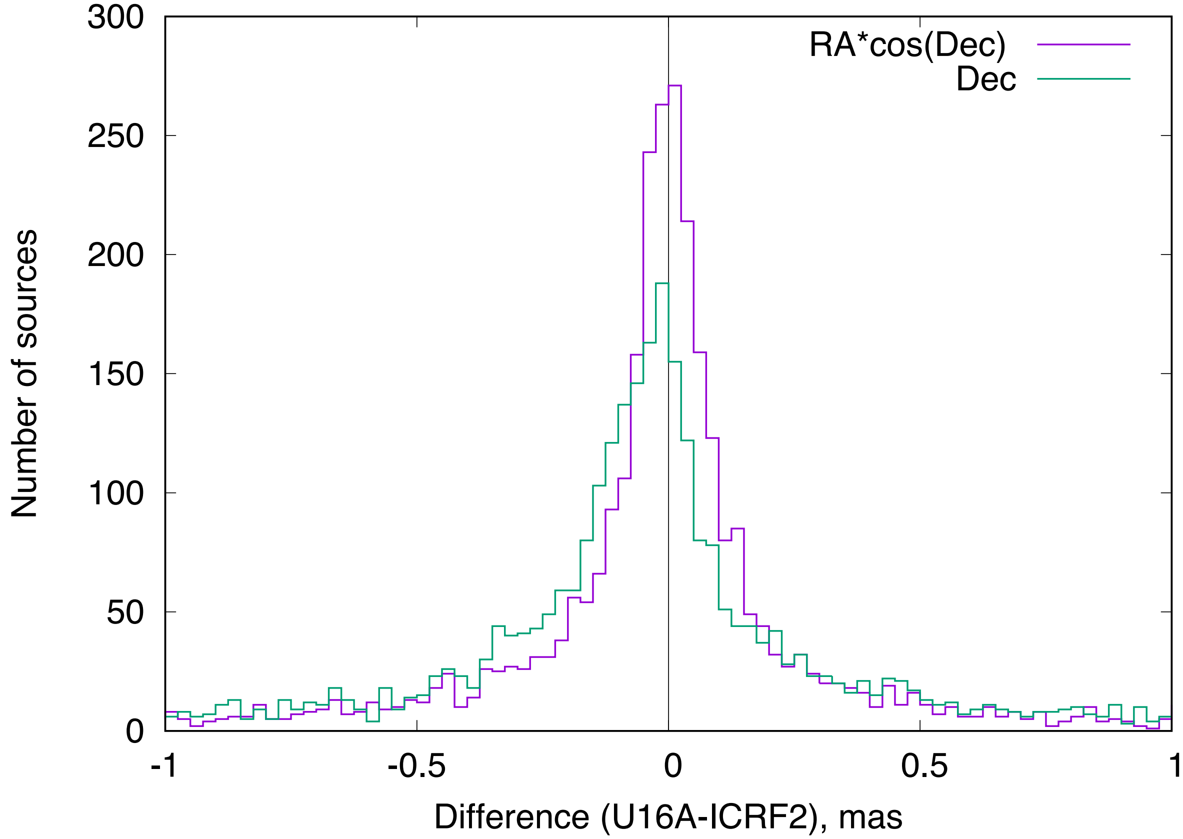
- Current International Celestial Reference Frame, ICRF2 (Fey et al. 2015)
  - Radio Astrometry catalog of 3414 radio loud quasars, Active Galactic Nuclei (AGN)
    - 295 Defining Sources
    - 2197 VLBA Calibrator Survey (VCS) sources
    - 922 non-VCS sources
  - Accuracy floor of ~40 μas for the whole dataset
  - Not all sources have same astrometric quality!
    - VCS sources only observed 1 time!
    - Wide range of accuracies

USNO 2016A (U16A) Solution

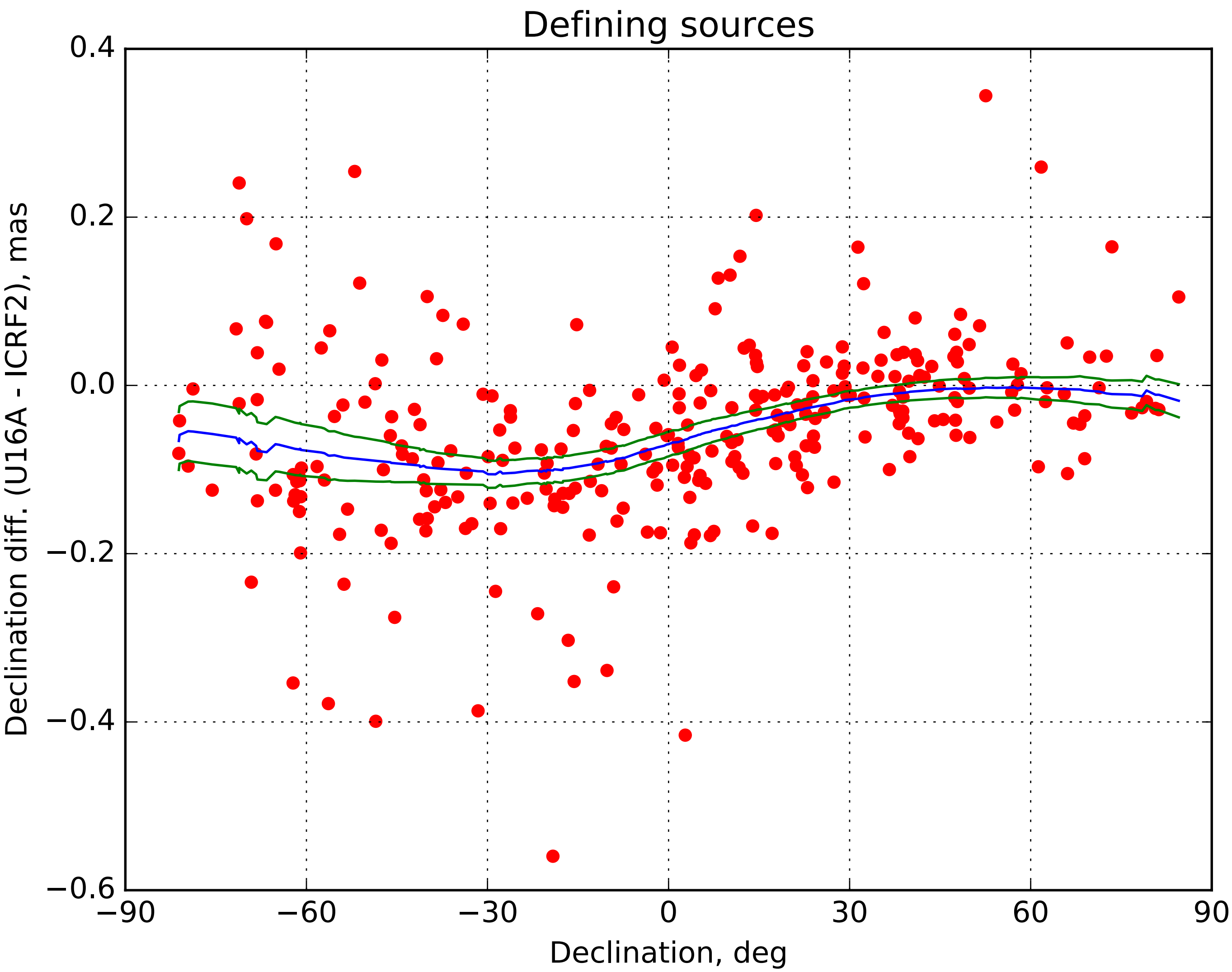
- Global solution includes data from the onset of VLBI in August 1979 through the present
- VLBI observations at 13 and 3.6 cm simultaneously
  - Accurate calibration of Earth's ionosphere
  - Least-squares analysis over multiple channels in each band for precise group delay
  - CALC/SOLVE software used for source position derivation (see Ma et al. 1986)
- U16A solution contains 4129 sources
  - 295 defining sources
  - 2195 VCS sources
  - 921 non-VCS sources
  - 718 new sources

U16A Compared to ICRF2

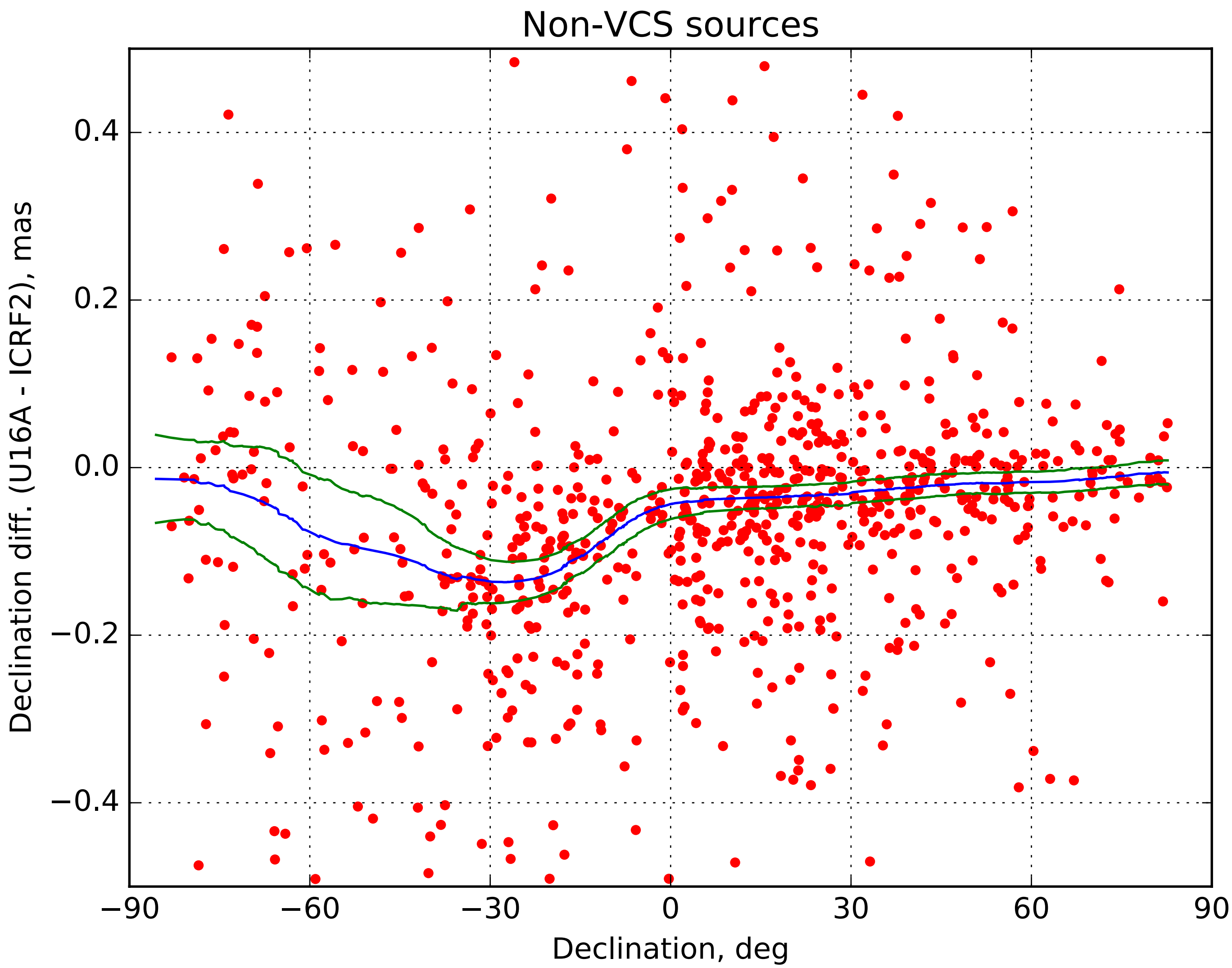
- *Improved astrometric accuracy over ICRF2*
  - *Increased number of observations for VCS sources*
  - *Offsets of 0.1 mas*



U16A Compared to ICRF2

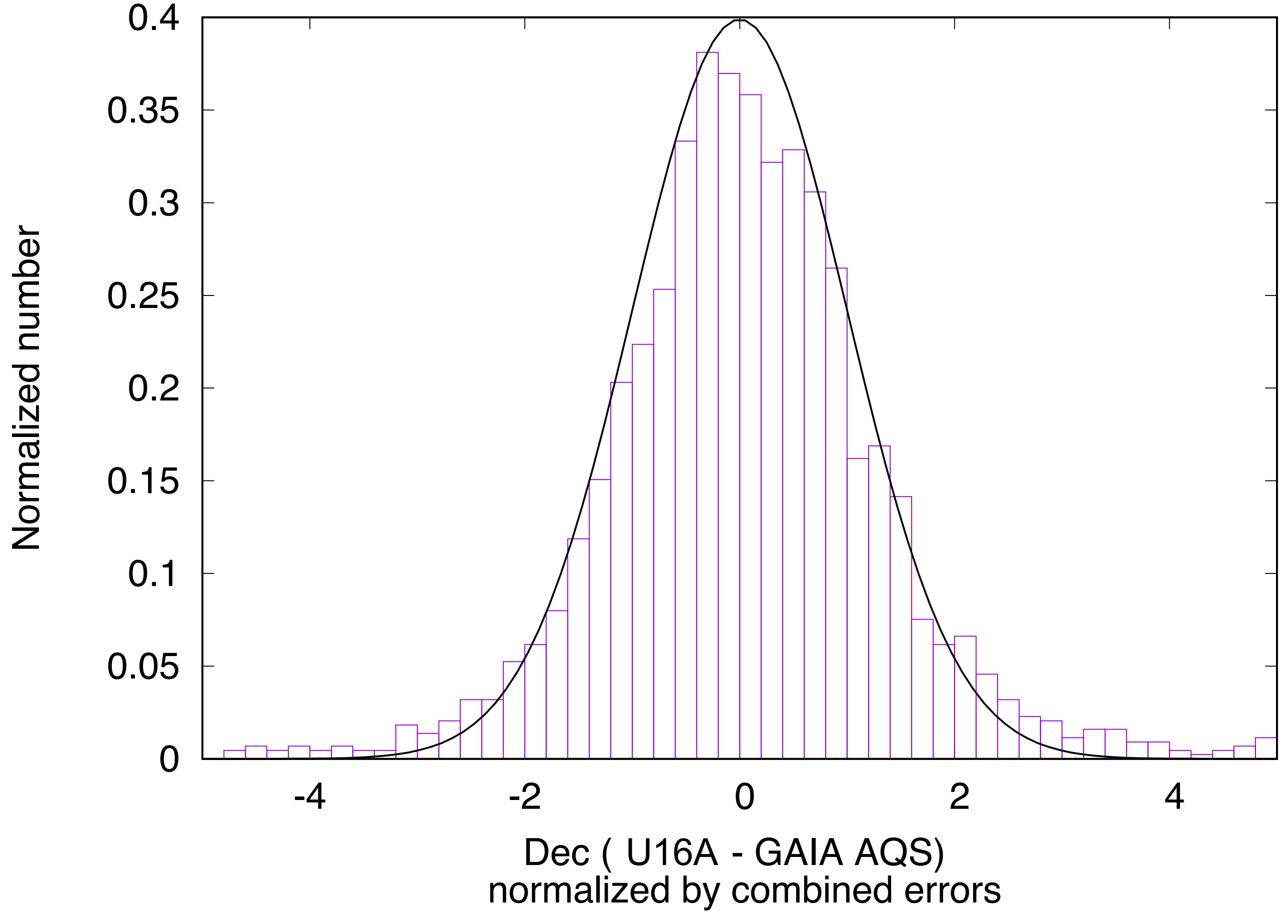


U16A Compared to ICRF2



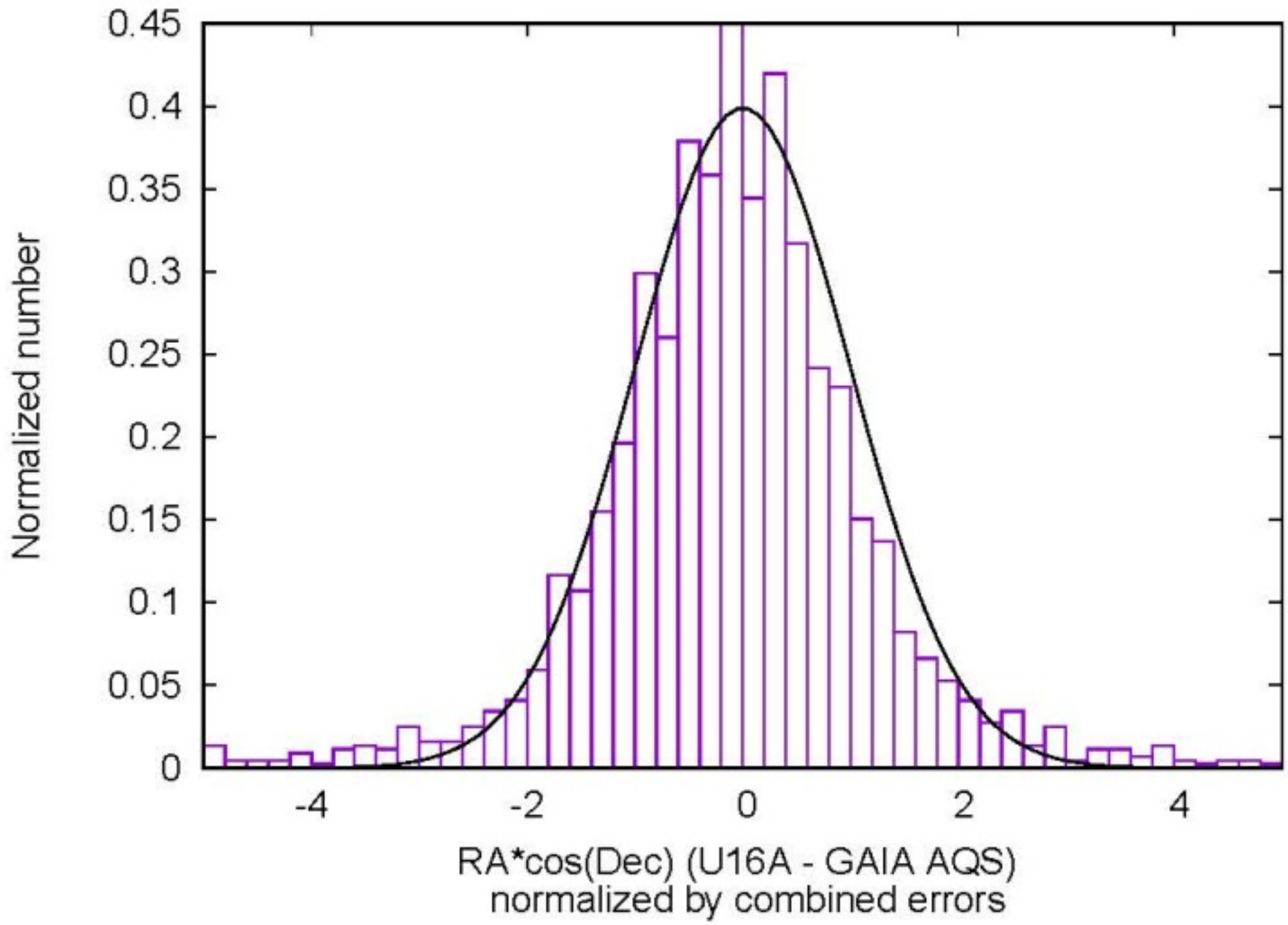
U16A Compared to Gaia

- *Using Gaia Auxiliary Quasar Solution (AQS; Mignard+ 2016) to understand offset between U16A and ICRF2*



U16A Compared to Gaia

- ***Using Gaia AQS to understand offset between U16A and ICRF2***

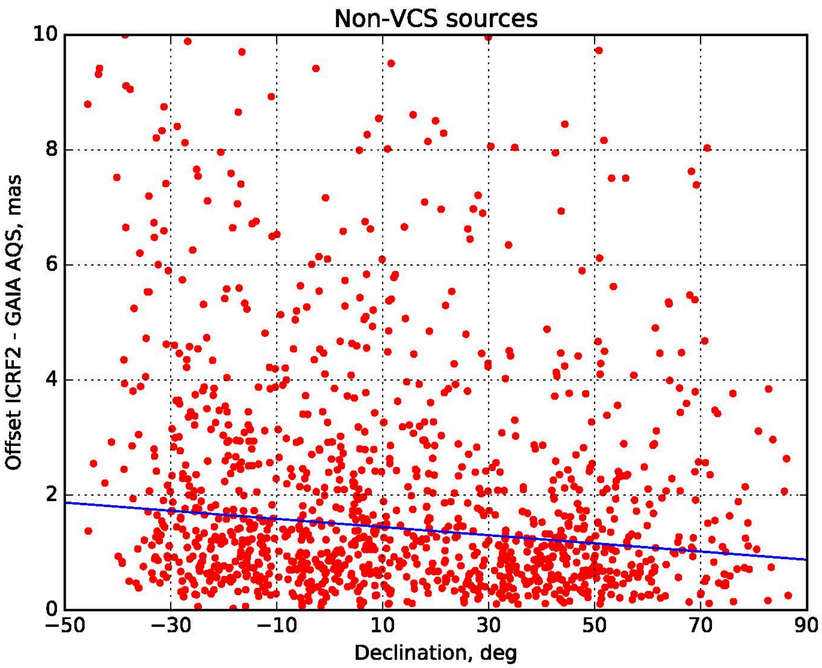


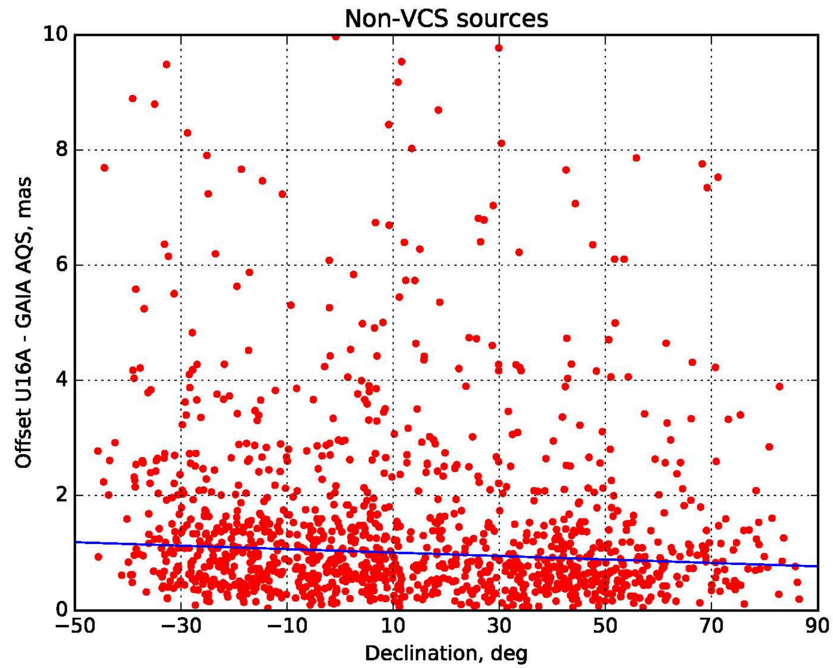
Results

		262 defining		1289 VCS		640 Non-VCS		**2191 sources**	
U16A-Gaia AQS	RA*cos(Dec)	-104	(-277, 12)	-108	(-169, -27)	-171	(-254, -83)	**-121**	**(-173, -76)**
	Dec	77	(11, 148)	-32	(-90, 30)	36	(-11, 91)	**13**	**(-31, 48)**
	Absolute Offset	584	(489, 652)	1009	(938, 1073)	897	(796, 991)	**916**	**(865, 961)**
ICRF2-Gaia AQS	RA*cos(Dec)	-84	(-199, 10)	-4	(-109, 98)	-113	(-221, -39)	**-62**	**(-124, 3)**
	Dec	135	(88, 236)	25	(-74, 86)	108	(30, 176)	**69**	**(29, 111)**
	Absolute Offset	601	(491, 666)	1346	(1325, 1551)	950	(818, 1034)	**1159**	**(1097, 1225)**

Table 3. Median differences in position in the sense U16A-Gaia AQS and ICRF2-Gaia AQS, in μas, with bootstrap BC_a confidence intervals with 95% coverage.

Results

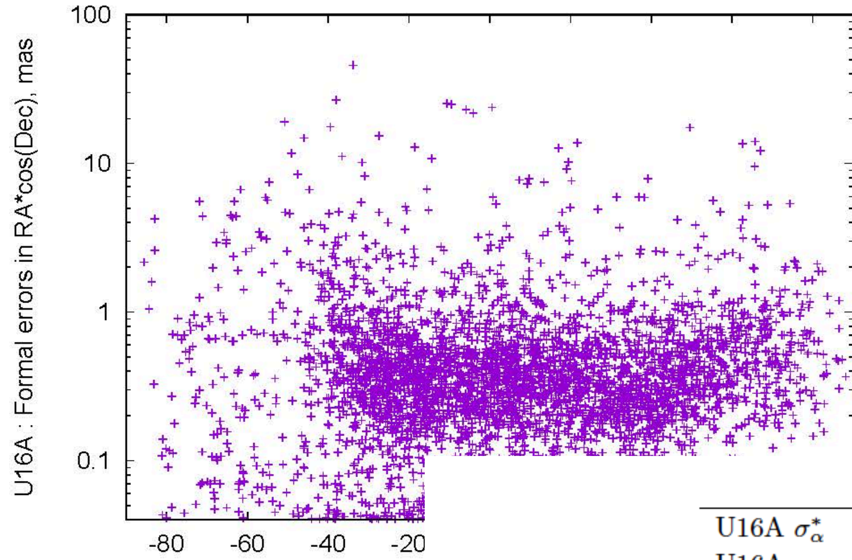


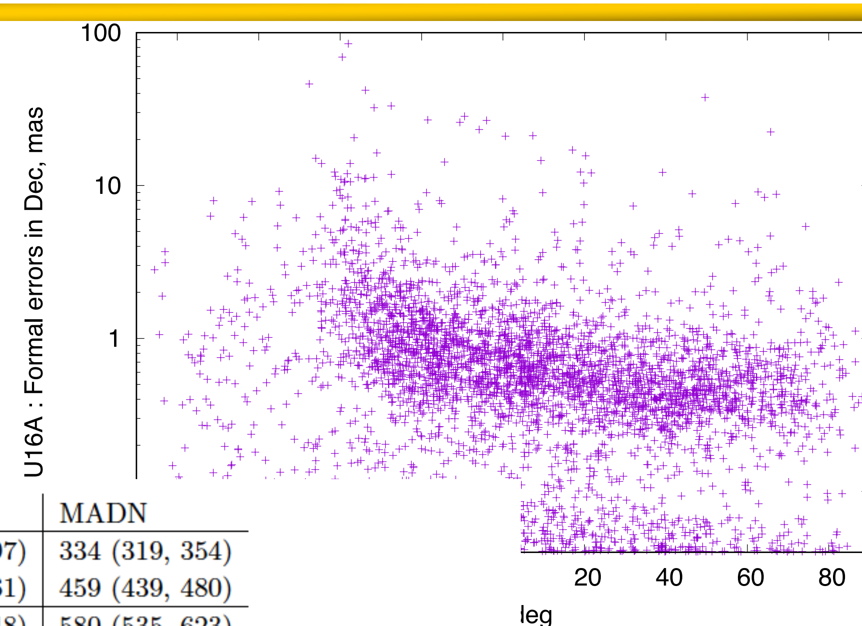


	262 Defining	1289 VCS	640 Non-VCS	**2191 sources**
Offset U16A - Gaia AQS	0.51 (-0.83, 1.90)	-3.00 (-4.44, -1.59)	-1.75 (-3.39, -0.29)	**-1.49 (-2.40, -0.59)**
Offset ICRF2 - Gaia AQS	0.29 (-1.09, 1.75)	-7.09 (-9.54, -4.75)	-1.87 (-3.51, -0.35)	**-2.39 (-3.63, -1.19)**

Table 5. The slope of the absolute offsets with the declination, in μas.deg^{-1}. The slope and the 95% coverage confidence intervals (indicated between parenthesis) are determined with the Thiel-Sen method (Theil 1950; Sen 1968).

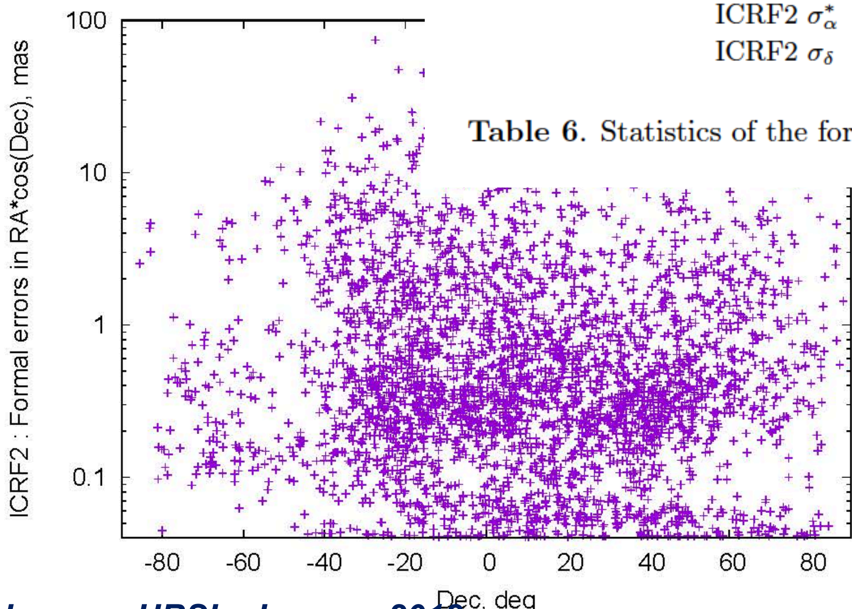
Results

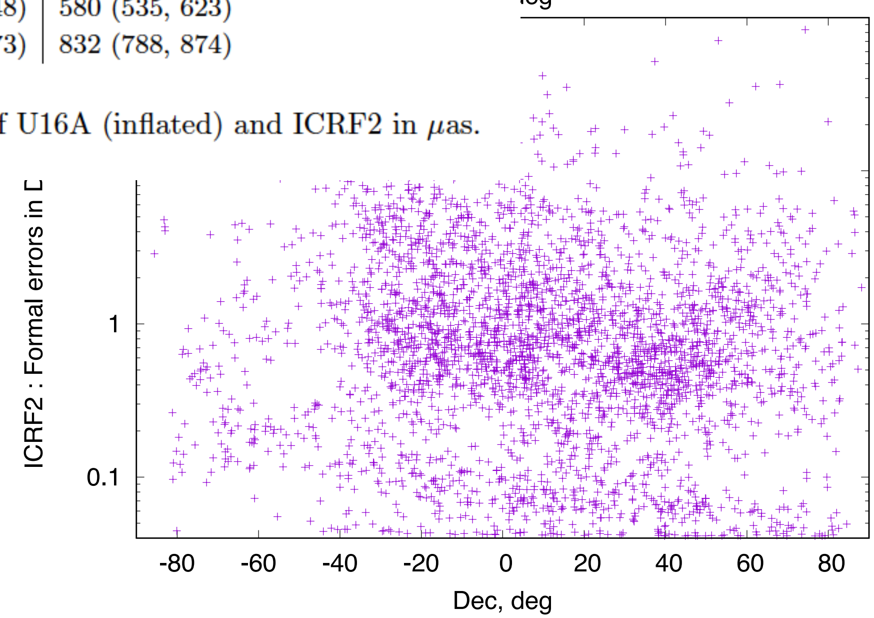




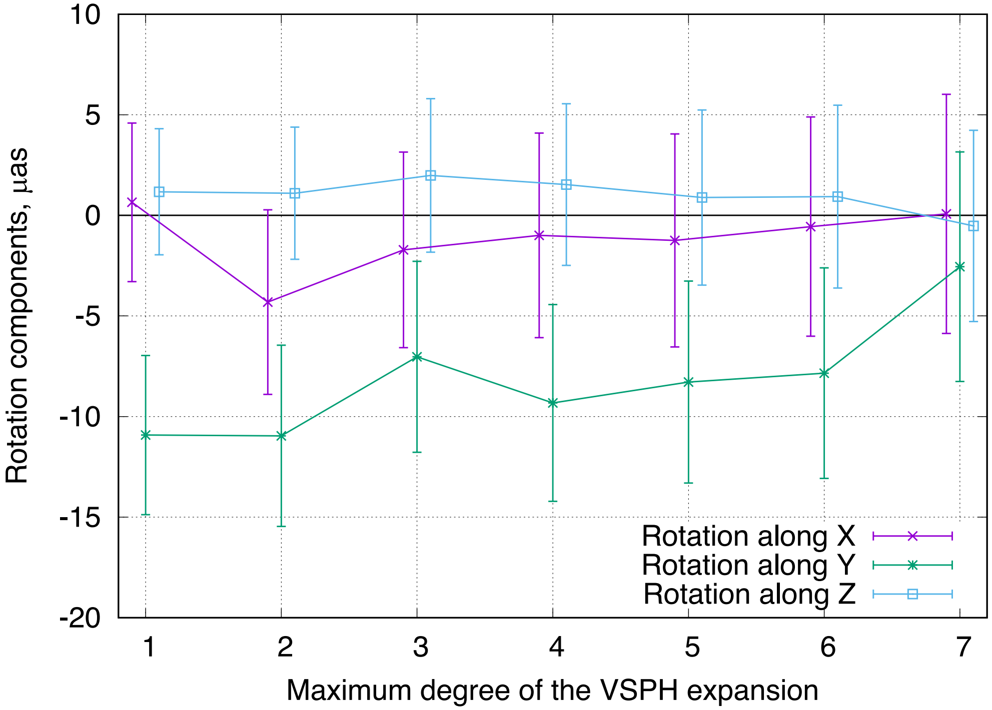
	median	MADN
U16A σ_α^*	386 (373, 397)	334 (319, 354)
U16A σ_δ	548 (530, 561)	459 (439, 480)
ICRF2 σ_α^*	511 (479, 548)	580 (535, 623)
ICRF2 σ_δ	739 (705, 773)	832 (788, 874)

Table 6. Statistics of the formal errors of U16A (inflated) and ICRF2 in μas.

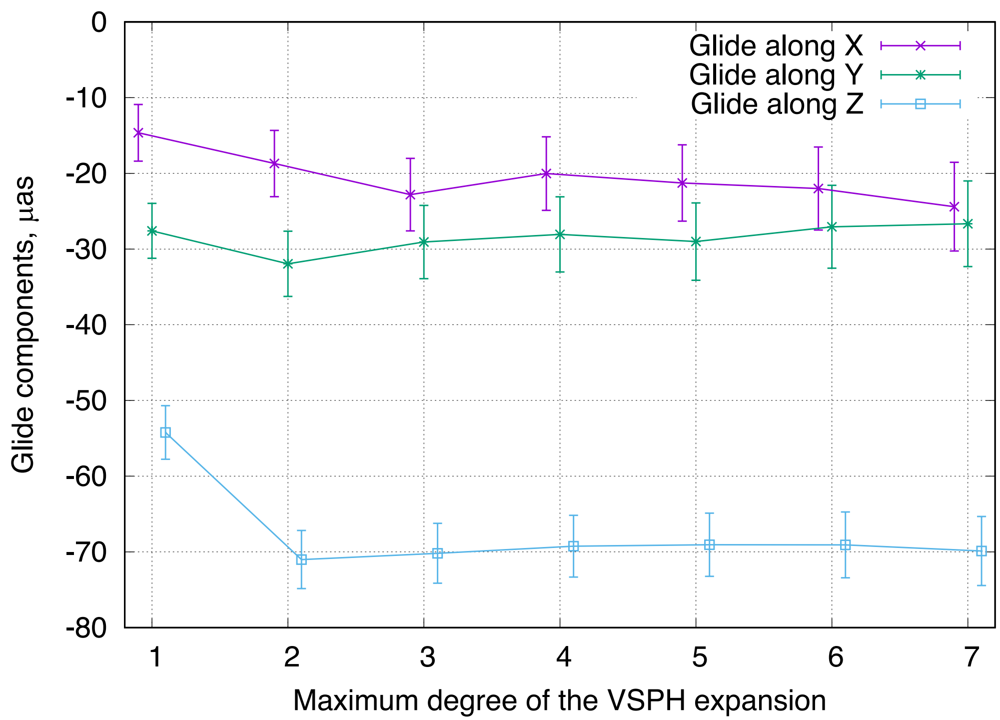




Results



Rotation components, µas
Maximum degree of the VSPH expansion
Rotation along X
Rotation along Y
Rotation along Z
10
5
0
-5
-10
-15
-20
1
2
3
4
5
6
7



Glide components, µas
Maximum degree of the VSPH expansion
Glide along X
Glide along Y
Glide along Z
0
-10
-20
-30
-40
-50
-60
-70
-80
1
2
3
4
5
6
7

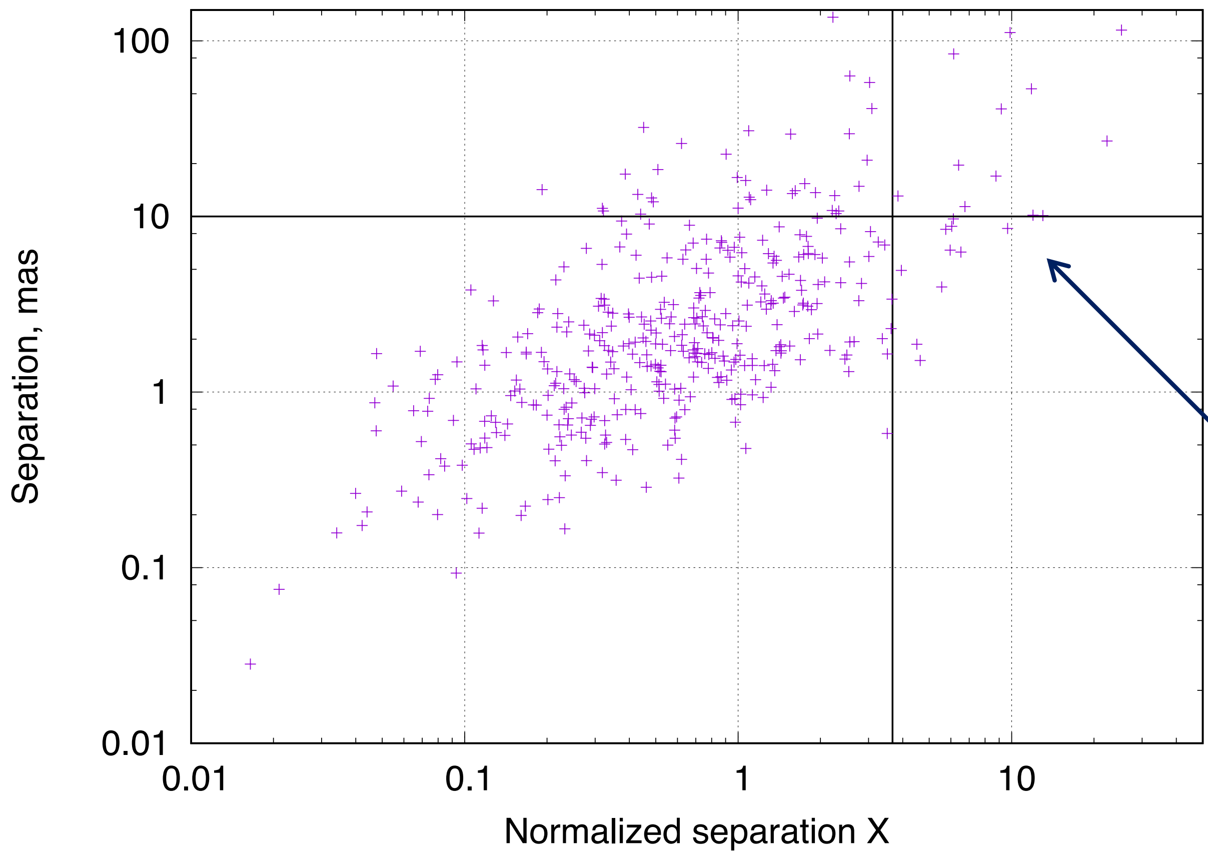
Results

	l_{max}	$N_{sources}$	Rotation			Glide		
			x	y	z	x	y	z
U16A - ICRF2	2	2433	-4 ± 5	-11 ± 5	1 ± 3	$\mathbf{-19 \pm 4}$	$\mathbf{-32 \pm 4}$	$\mathbf{-71 \pm 4}$
U16A - GAIA AQS	1	1794	-35 ± 14	$\mathbf{-53 \pm 12}$	-3 ± 13	-28 ± 13	$\mathbf{61 \pm 13}$	$\mathbf{77 \pm 12}$
ICRF2 - GAIA AQS	1	1728	-46 ± 17	$\mathbf{-57 \pm 15}$	14± 16	-22 ± 16	$\mathbf{88 \pm 16}$	$\mathbf{153 \pm 14}$

Table 7. Components of the global rotation and glide between the catalogs, in μas. The bold font denote the values with a 3-sigma significance.

New Sources Compared to Gaia

- ***Out of 718 new sources in U16A, 415 matches within 150 mas of Gaia sources***

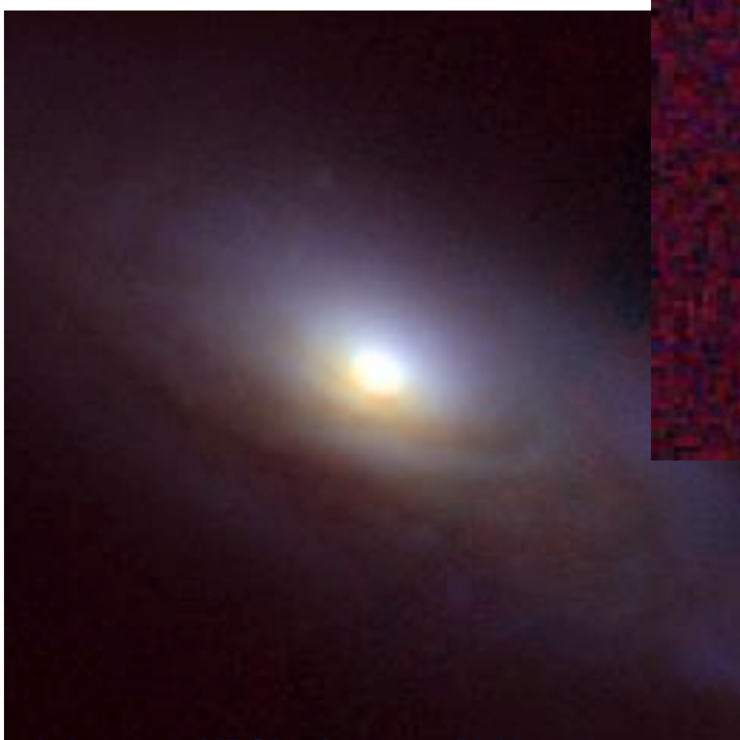


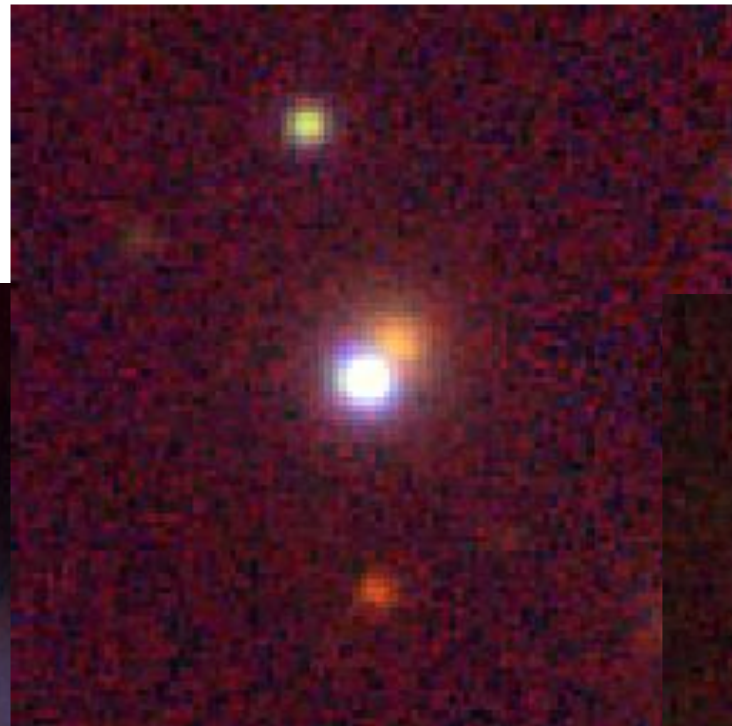
22 outliers

New Sources Compared to Gaia

- *PanSTARRS DR1 images can help explain offset sources*

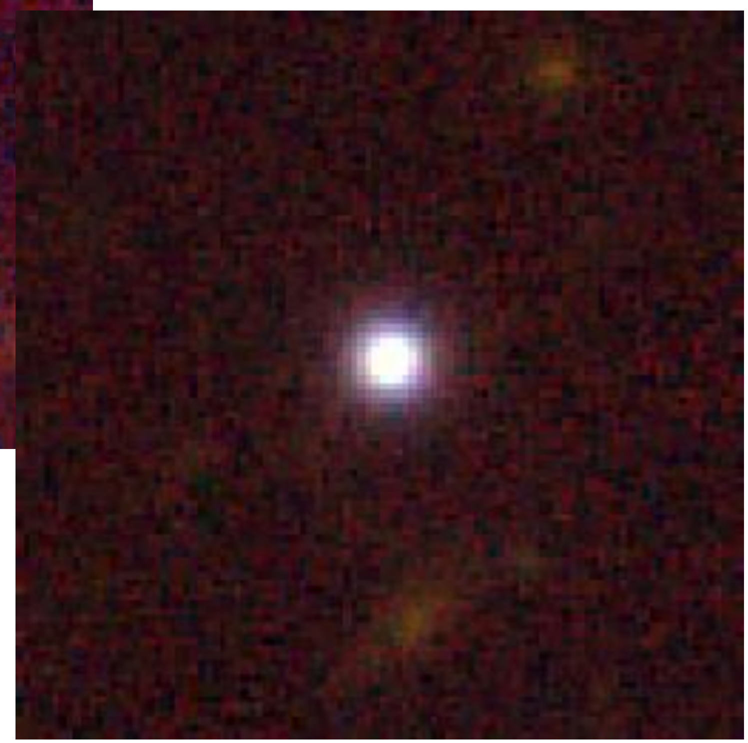
Extended Source
Offset = 948 mas





Double Source
Offset = 27 mas

No Discernable Feature
Offset = 309 mas



Future Prospects

- ***ICRF3 will debut at upcoming IAU general assembly***
- ***Going forward with VLBA…***
  - ***Radio astrometry measurements key to maintaining ICRF***
  - ***Source structure studies currently underway***
  - ***Higher frequencies, i.e., Ka-band, allow for more compact source structure detections***
  - ***Wide bandwidth capabilities could transition to more accurate phase delay measurements***

Conclusions

- *U16A has source position offsets of ~0.1 mas when compared to ICRF2*
- *U16A global solutions are statistically more inline with Gaia than ICRF2*
- *Systematic differences between ICRF2 and U16A? Those might be caused by observations from some of the AUST stations, from 2010 onwards*
- *718 new radio sources in U16A*
  - *Gaia contains 415 matches within 150 mas; 22 of these are outliers*
  - *10 out of 22 optical-radio offset sources can be explained when compared to PanSTARRS optically resolved images*
- *Future prospects for potentially higher frequencies and wide bandwidth capabilities on VLBA*