Le futur repère de référence céleste international ICRF3 et la synergie avec Gaia

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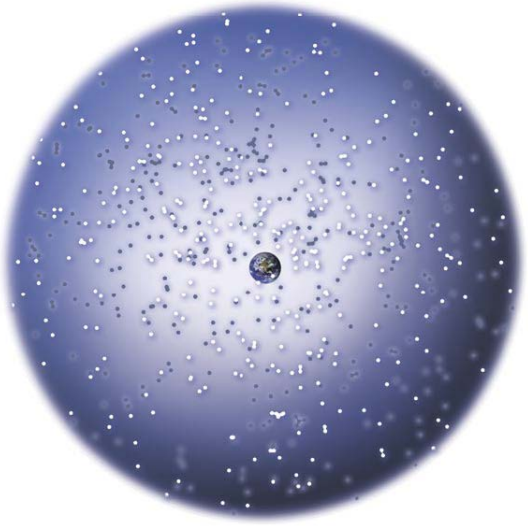
Outline

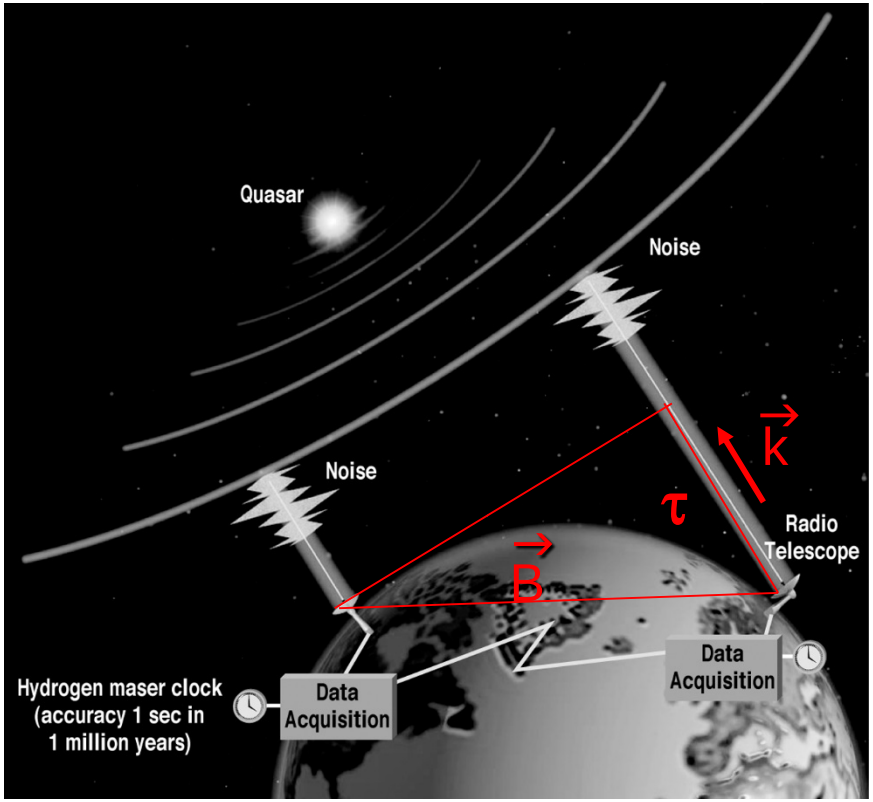
- Introduction
  - ICRF and ICRF2
  - Towards ICRF3
- Construction of ICRF3
  - Status of observations
  - Questions and issues to be addressed
- Synergy with the Gaia frame
  - Comparison ICRF3 / Gaia DR1
  - AGN astrophysics
- Summary

Celestial frames: a brief history

- Until 1997
  - IAU fundamental celestial reference frame based on star positions measured by optical astrometry
  - Last realization: FK5 catalog, consisting of 1535 stars brighter than magnitude 7.5
- Since 1998
  - IAU fundamental celestial reference frame based on quasars
  - Located at cosmological distances, hence no proper motions, and highly compact
  - Position measured by VLBI (Very Long Baseline Interferometry) with mas accuracy
  - ICRF (International Celestial Reference Frame) adopted by IAU in 1997, in use from 01/01/1998 to 31/12/2009
  - ICRF2 adopted by IAU in 2009, replaced ICRF on 01/01/2010

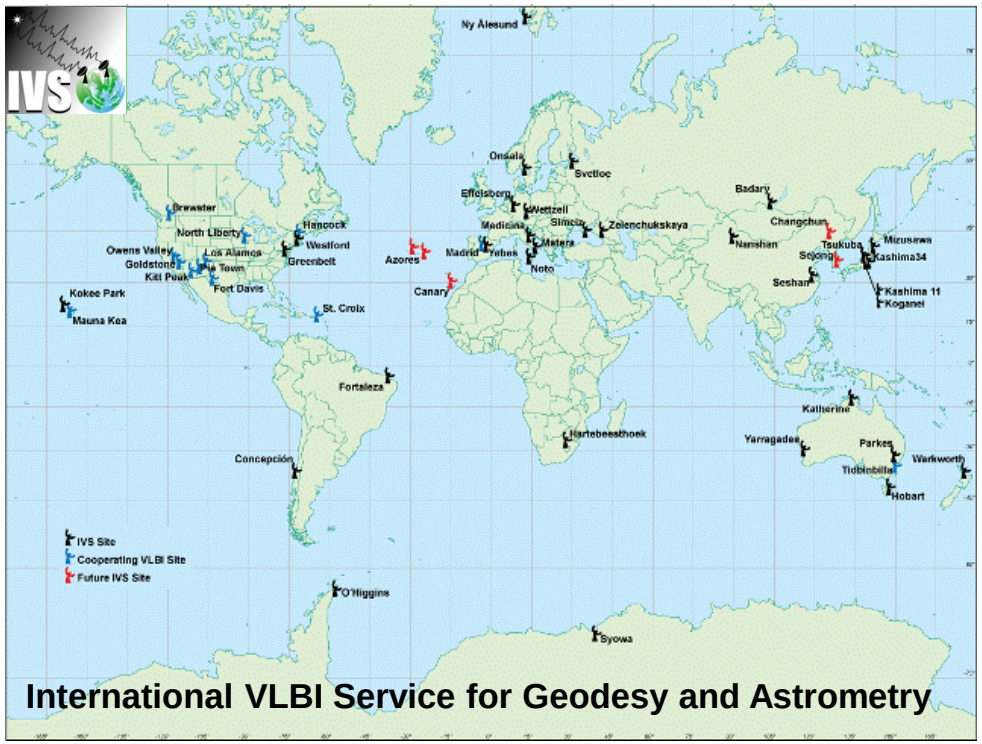


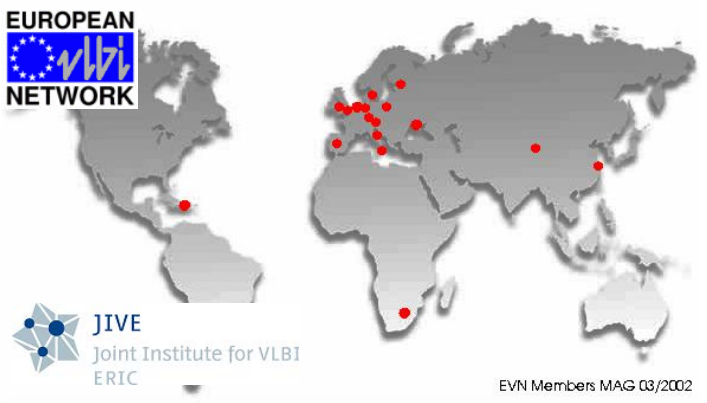
VLBI principle



- VLBI delay τ measured with a precision of 10 ps (3 mm)
- 6000+ VLBI sessions carried out since 1979, each 24-hour long
- 2 to 20 radiotelescopes used in each session
- > 10 millions VLBI delay measurements acquired

VLBI networks: IVS, EVN, VLBA





Very Long Baseline Array (VLBA)

Applications of ICRF

- Underlies every position determination in astronomy
  - Extragalactic and Galactic objects
  - But also Solar System objects: ephemerides tied to ICRF
- Knowledge about the Earth
  - Rotation, precession/nutation
  - Plate tectonic motions
  - Earth's interior (liquid and solid core)
- Spacecraft navigation
  - Measurement of spacecraft positions relative to angularly-close quasars
  - Corrections of trajectories
- AGN astrophysics

ICRF and ICRF2

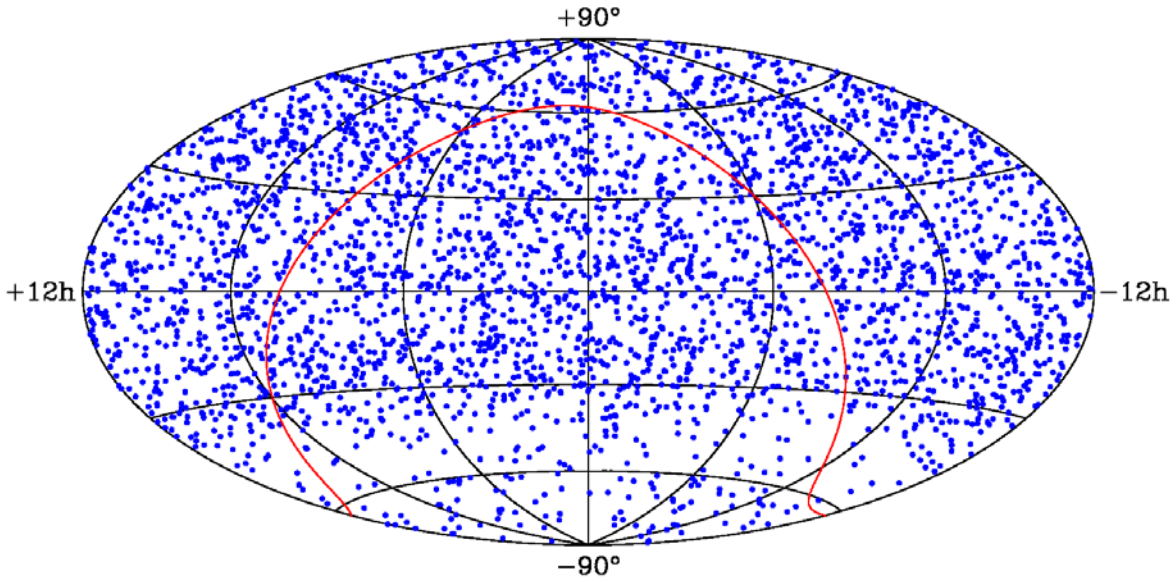
ICRF=International Celestial Reference Frame

- Based on positions of extragalactic radio sources measured by VLBI
- Observations acquired from various VLBI programs mostly run by the IVS (International VLBI Service for geodesy and astrometry) and VLBA

	ICRF	ICRF2
Frequency (GHz)	8.4 / 2.3	8.4 / 2.3
Nb of observations	1.6 Million	6.5 Million
Time range of obs.	1979-1995	1979-2009
Nb of sources	609	3414
Nb of defining sources	212	295
Noise floor (μas)	250	40
Adoption by IAU	1997	2009

ICRF2

ICRF2 is the official celestial reference frame of the IAU in use since January 1, 2010



Note: ICRF2 includes data from the VLBA Calibrator Survey (VCS), a series of 6 multi-session S/X band astrometry campaigns

Towards ICRF3

- IAU Working Group formed in 2012 to build ICRF3 for presentation at IAU 2018 General Assembly
- Main goal: produce state-of-the-art VLBI reference frame to serve as reference for aligning the Gaia frame, allowing comparison of optical and radio positions at < 100 µas
- Organization of the work
  - 2012-2015: focus on the observing programs, i.e. acquiring proper new VLBI data
  - 2015-2018: focus on building the frame
- New feature: observations not only at S/X band (2.3/8.4 GHz) but also now at K band (24 GHz) and X/Ka band (8/32 GHz)

ICRF3 Working Group

P. Charlot (Chair, LAB)	A. L. Fey	Z. Malkin
E. F. Arias (BIPM)	R. Gaume	A. Nothnagel
D. Boboltz	D. Gordon	M. Seitz
J. Boehm	R. Heinkelmann	E. Skurikhina
S. Bolotin	C. Jacobs	J. Souchay (SYRTE)
G. Bourda (LAB)	S. Lambert (SYRTE)	O. Titov
A. de Witt	C. Ma	

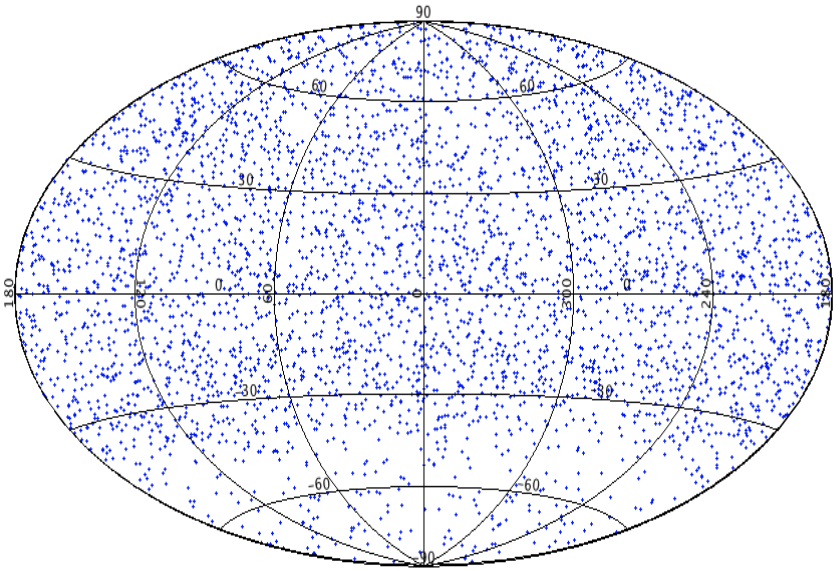
2012-2015: WG chaired by C. Jacobs
2015-2018: WG chaired by P. Charlot

Timeline for ICRF3

- 2016 September 01
  - Prototype ICRF3 catalogs made by different members of the WG
  - Including data up to 30 April 2016
- 2017 June 30
  - Second round of catalogs
  - Including data up to 30 April 2017
- 2017 October 15
  - Decide on final ICRF3 configuration
- 2018 January 01
  - Produce final ICRF3
- 2018 (January-June)
  - Extensive checks of ICRF3
  - Prepare IAU resolution, write Technical Note and ICRF3 paper
- 2018 August: presentation of ICRF3 at IAU GA for adoption

Status of observations: S/X band

4262 sources at S/X band (2.3/8.4 GHz)



Errors vs number of observations

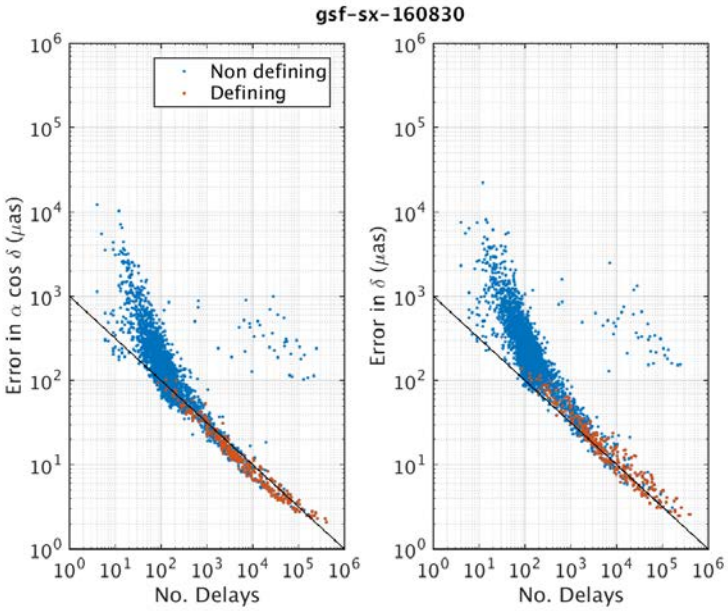
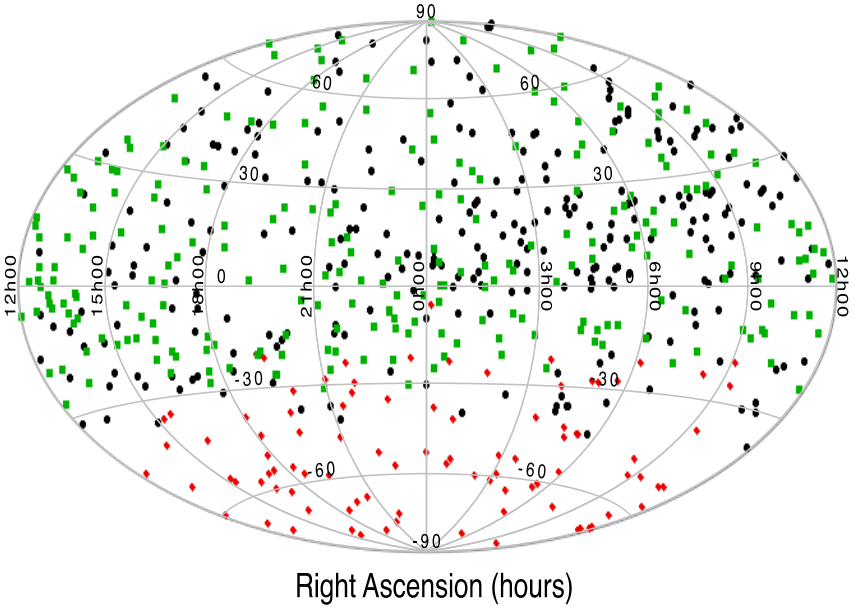


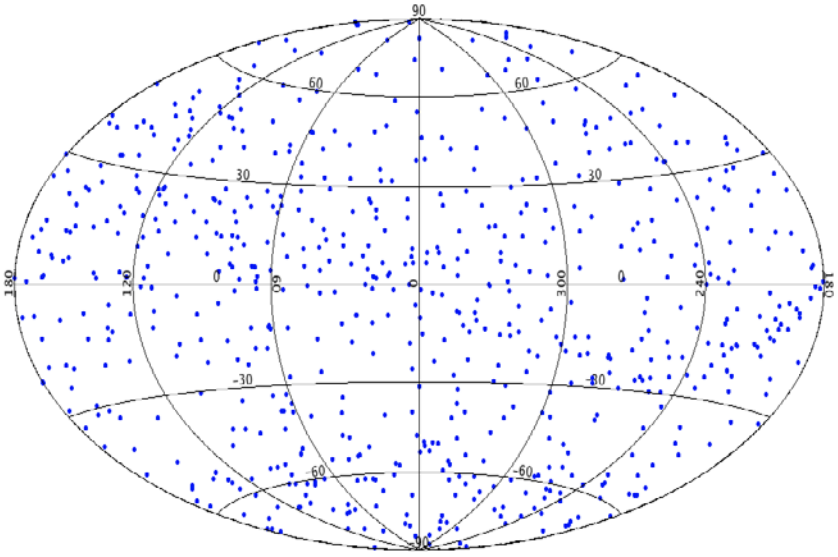
Figure courtesy of Lambert and Arias

Status of observations: higher radio frequencies

769 sources at K band (24 GHz)

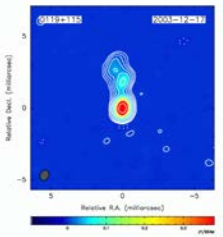


668 sources at X/Ka band (8.4/32 GHz)



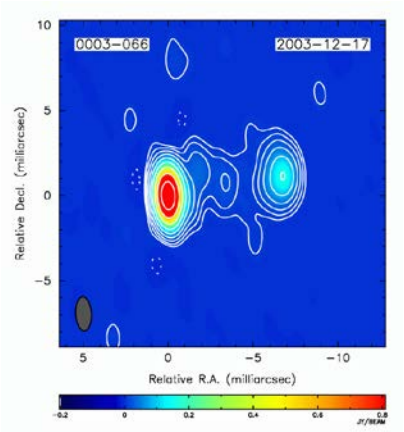
Questions being addressed for ICRF3

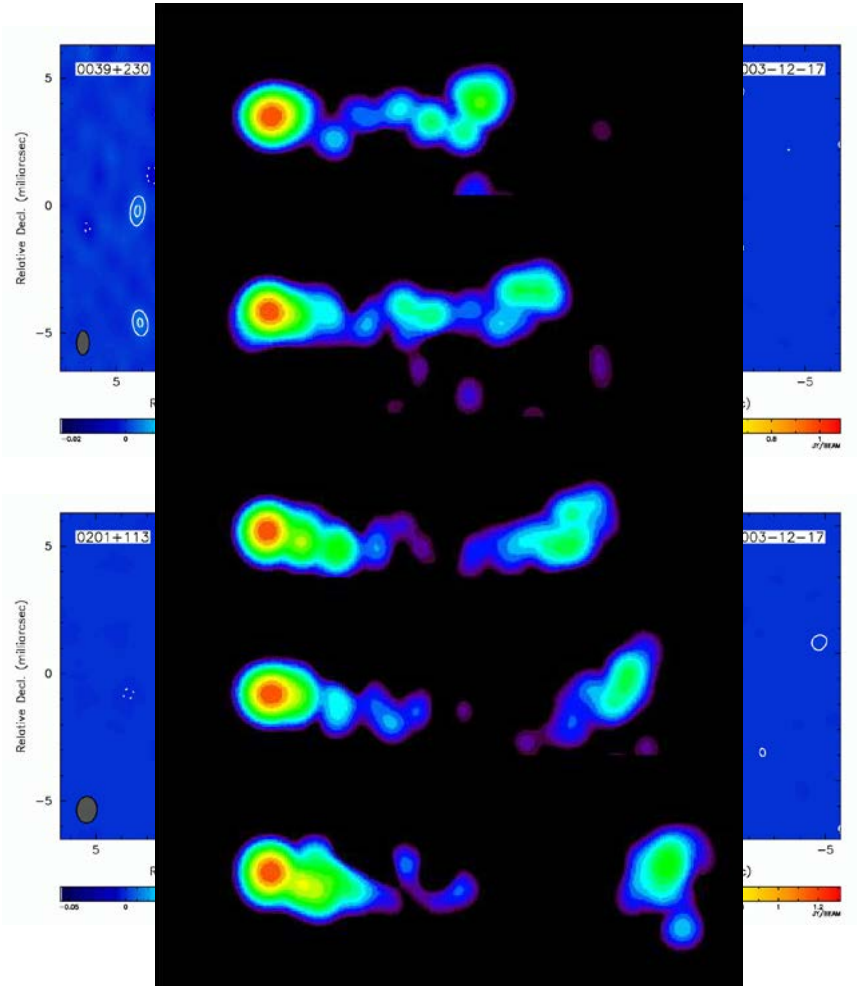
- Identification of a list of transfer sources from ICRF2 to ICRF3 to maintain the orientation of the frame
  - Default list = 295 ICRF2 defining sources, but may be adjusted
- Treatment of Galactic aberration:
  - Magnitude: ~ 5 μas/yr → 100 μas after 20 years
  - IVS Working Group on Galactic aberration (formed October 2015) to make recommendation on dealing with this effect.
- Identification of ICRF3 defining sources
  - Primary criteria: source structure index + position stability
  - Optical brightness as secondary criterion

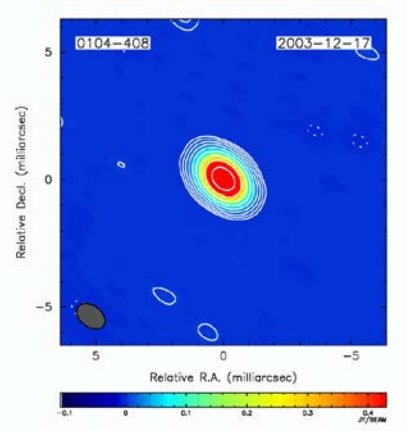


- Decision on whether ICRF3 should be single-frequency, multi-frequency or combined

Source morphology on VLBI scales







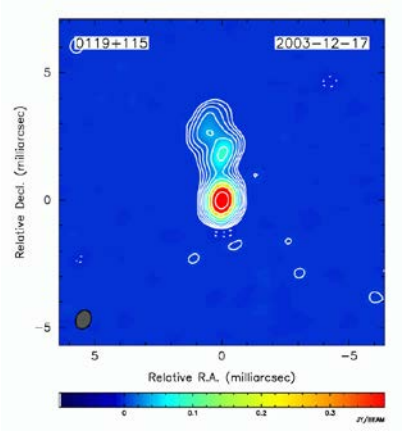
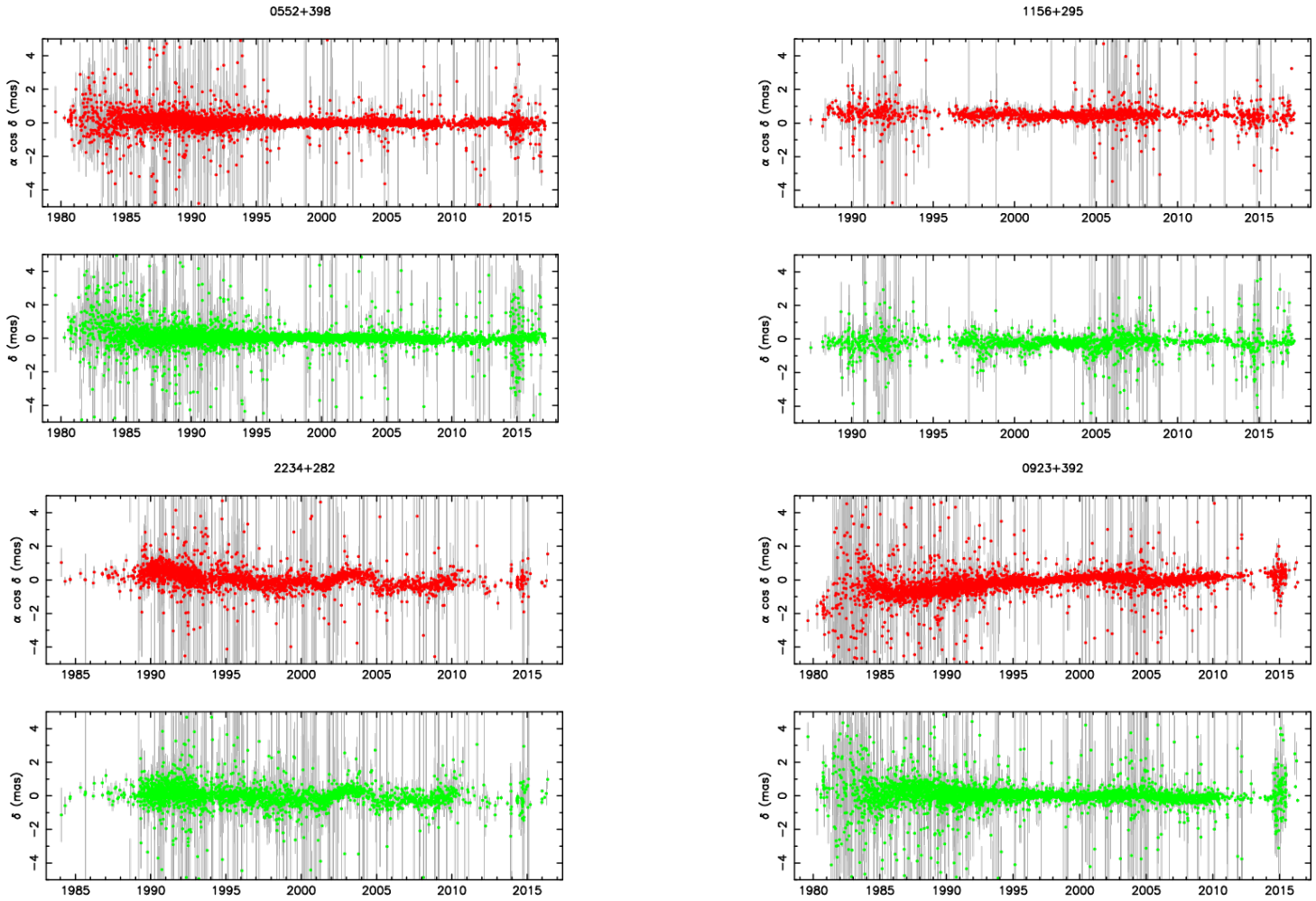


Image courtesy of NRAO/AUI

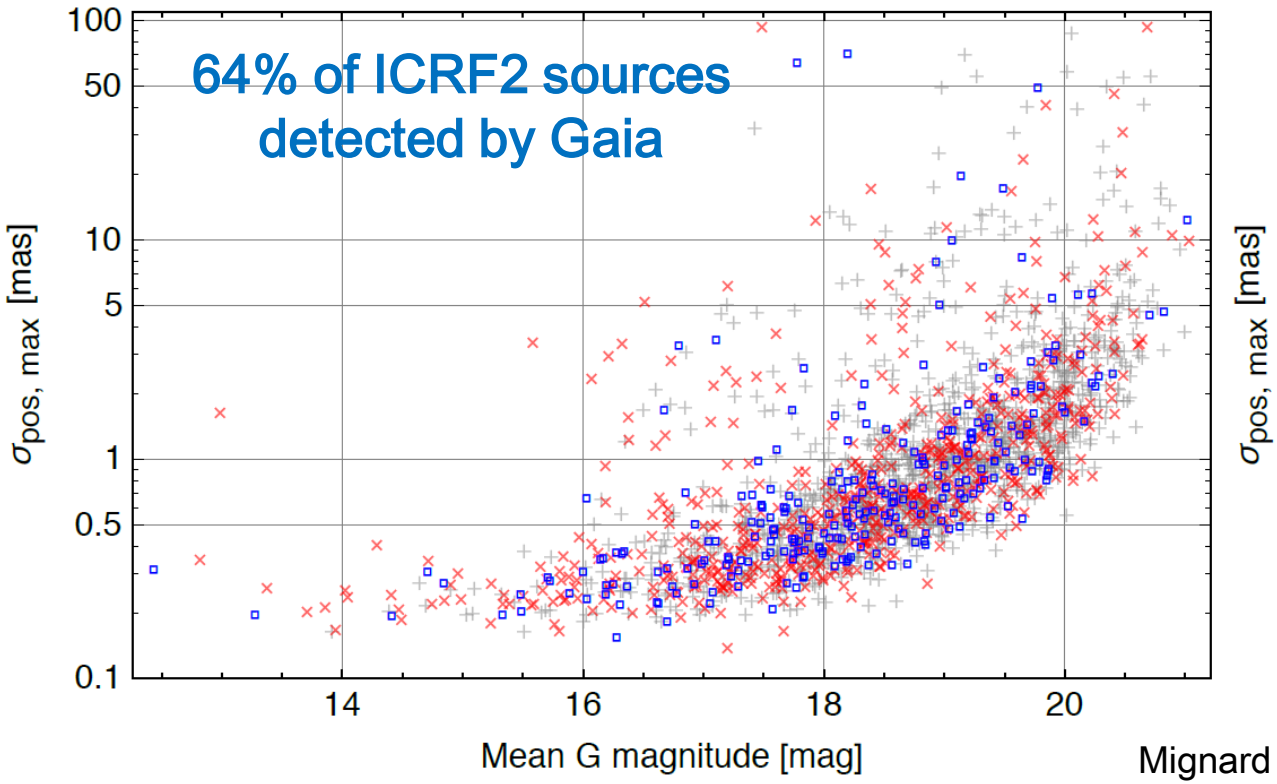
Source position stability



Figures courtesy of OPAR IVS Analysis Center

Gaia position uncertainty

2191 ICRF2 quasars



Floor of
0.25 mas

Mignard et al. (2016)

Defining sources Non-VCS sources VCS sources

Comparison between the two frames

$$\Delta\alpha = A_1 cos\alpha\, sin\delta + A_2\, sin\alpha\, sin\delta - A_3 + D_\alpha(\delta - \delta_o)$$

$$\Delta\delta = -A_1\, sin\alpha + A_2\, cos\delta + D_\delta(\delta - \delta_o) + B_\delta$$

Comparison between ICRF3 S/X prototype catalog and Gaia DR1

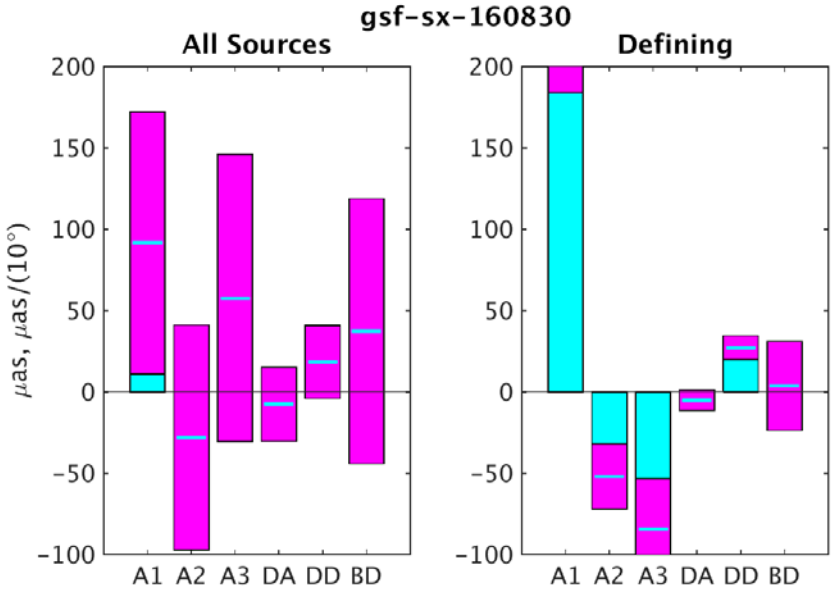
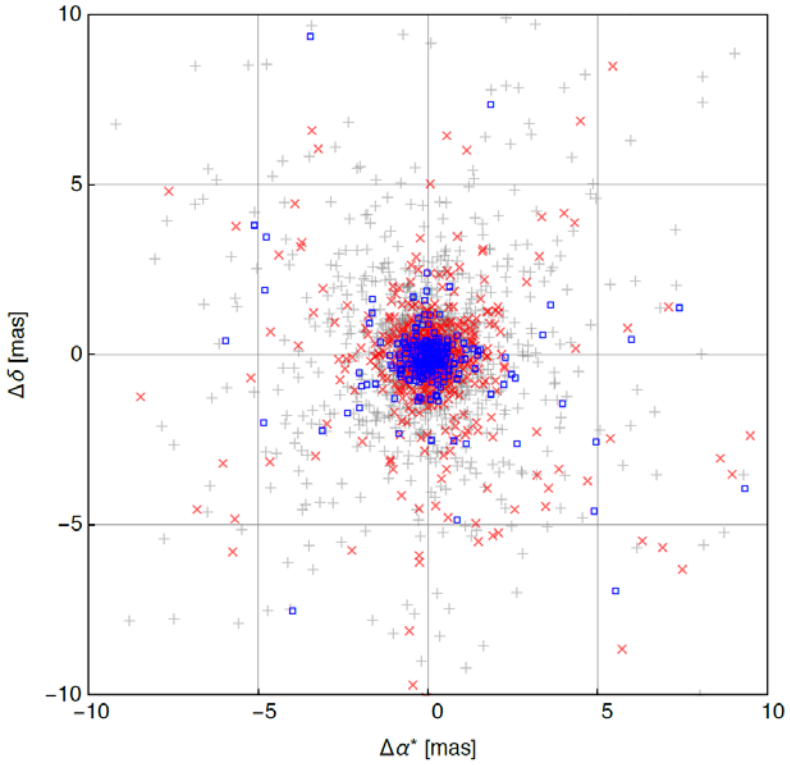
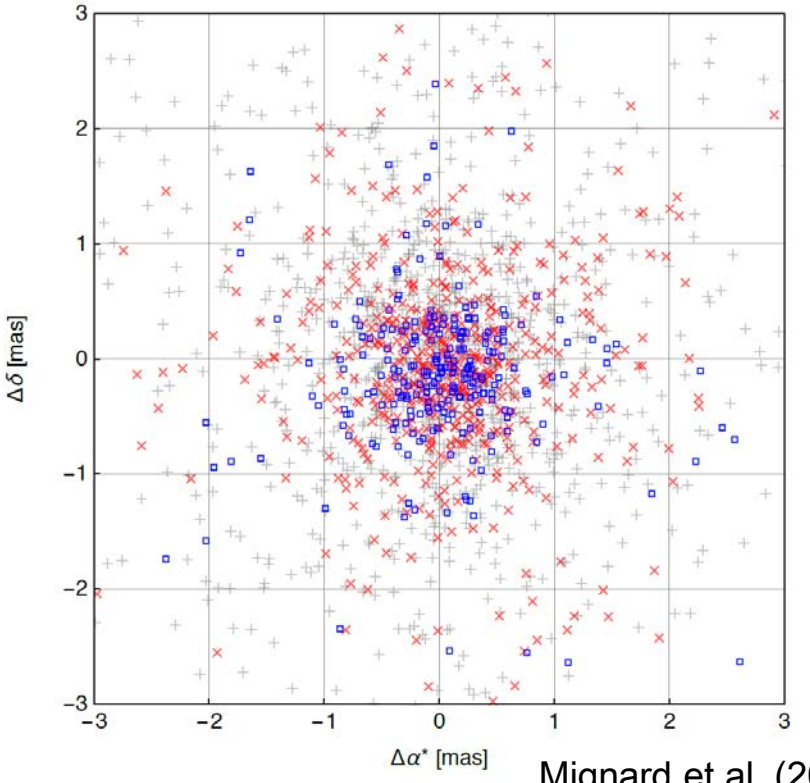


Figure courtesy of Lambert and Arias

Optical-radio position differences

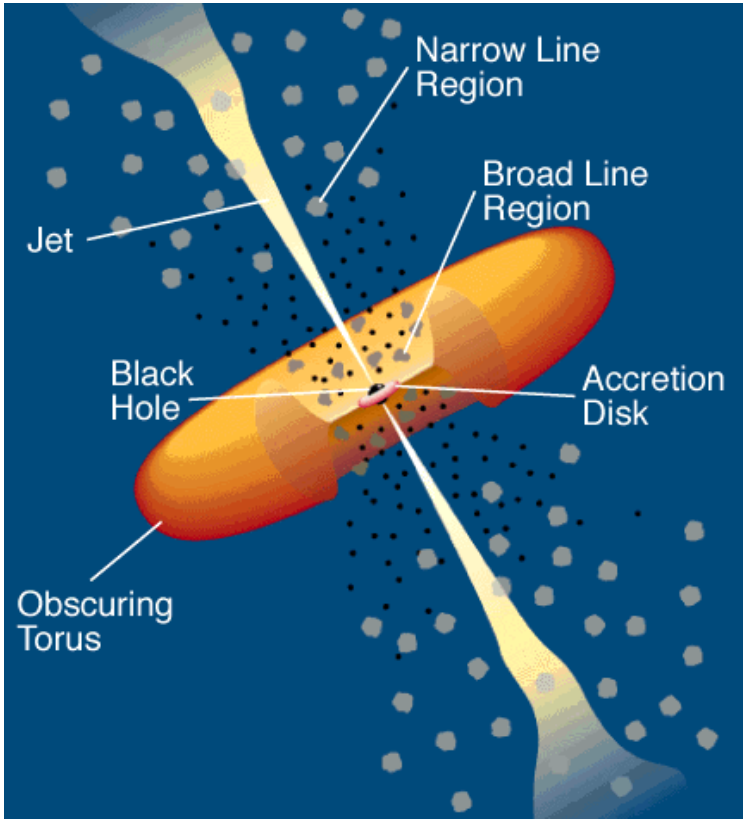




Mignard et al. (2016)

Defining sources Non-VCS sources VCS sources

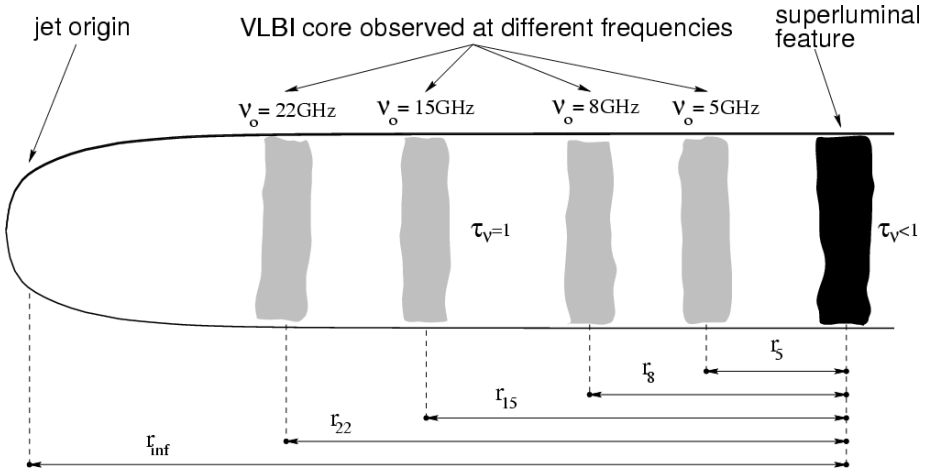
AGN astrophysics



Urry and Padovani (1995)

« Core shift » in AGN

- Radio emission originates from the jets
- Optical emission originates from the accretion disk and/or jets



Lobanov (1996)

Summary

- Preparation for ICRF3 going well, on time for IAU 2018

	ICRF	ICRF2	ICRF3
Frequency (GHz)	8.4 / 2.3	8.4 / 2.3	tbd
Nb of observations	1.6 Million	6.5 Million	> 10 Million
Time range of obs.	1979-1995	1979-2009	1979-2017
Nb of sources	609	3414	4000-5000
Nb of defining sources	212	295	tdb
Noise floor (μas)	250	40	?
Adoption by IAU	1997	2009	2018

- ICRF3 will have a larger number of sources, be more accurate and have a more uniform precision in position compared to ICRF2
- Comparison of ICRF3 and Gaia positions at the few 10 μas may provide insights into the AGN geometry