



Aligning VLBI and Gaia Extragalactic Celestial Reference Frames

On the basis of which sources?

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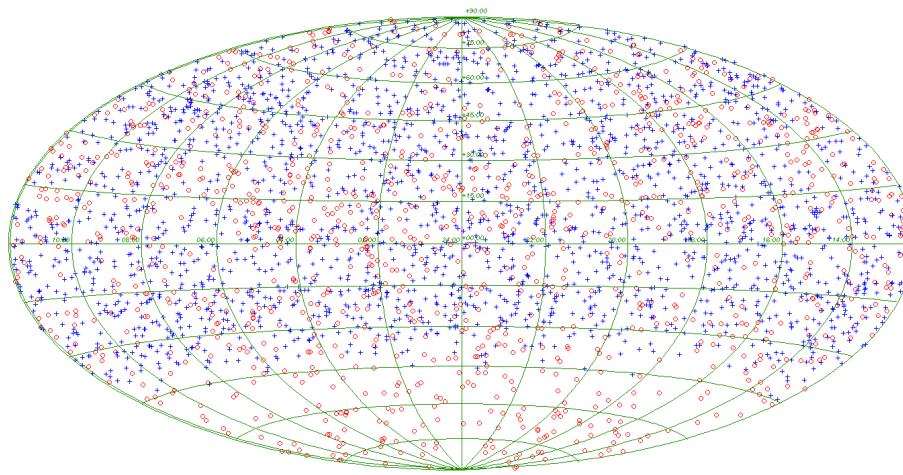
FRANCE



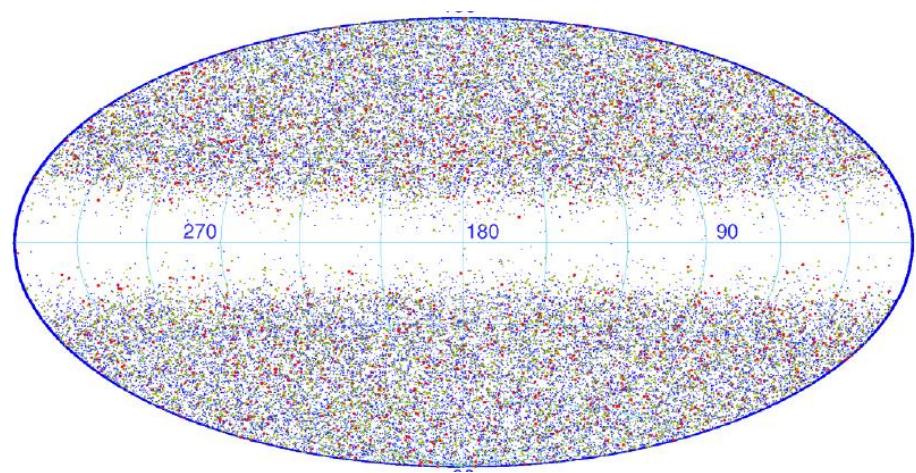
Motivation – 1

2021: Two extragalactic celestial reference frames will coexist

VLBI – Radio



Gaia – Optical



ICRF2

3 414

@ best 60 μ as

of objects

Position accuracy

GCRF

~10 000 – 20 000

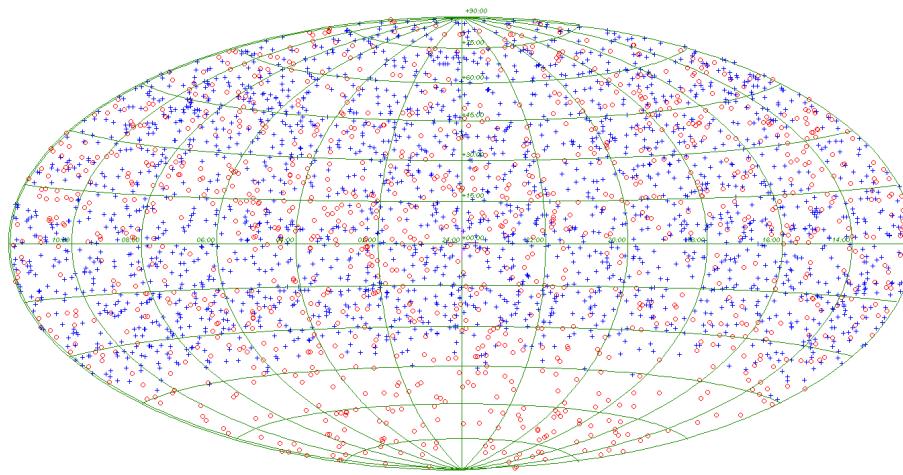
~70 μ as @ G=18
~200 μ as @ G=20

[Lindegren et al. 2008](#)

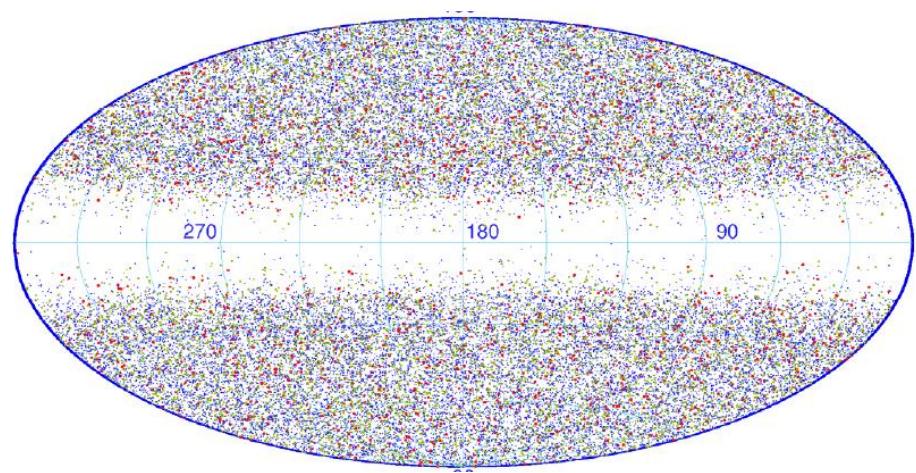
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GCRF

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~110 μ as @ G=18
~450 μ as @ G=20

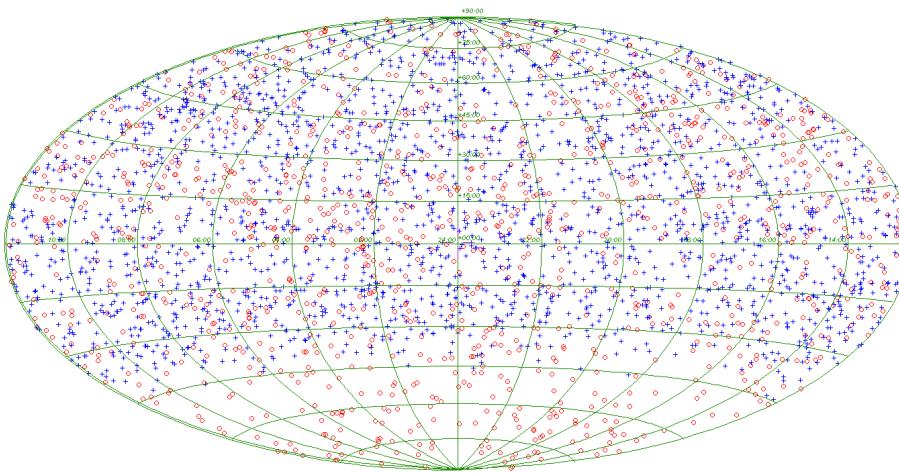


Problems revealed during commissioning phase → *Re-assessment of astrometry* (Mignard, EGSG 2014: Based on Gaia performance page maintained by J. de Bruijne)

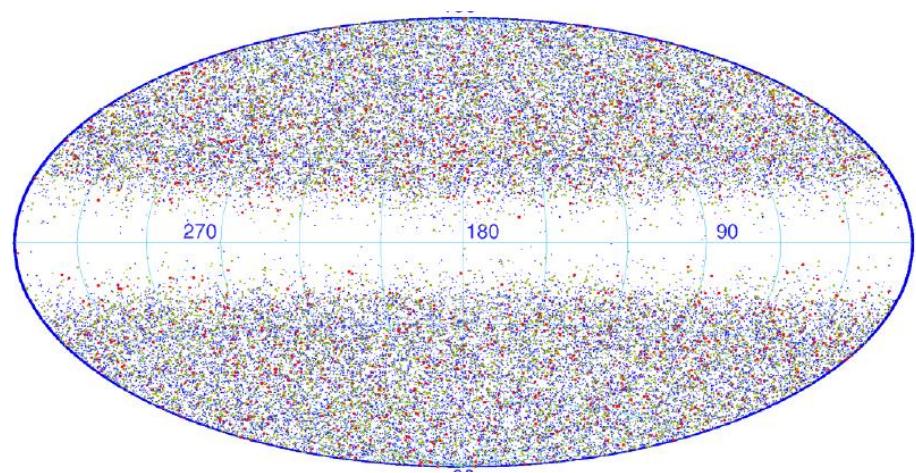
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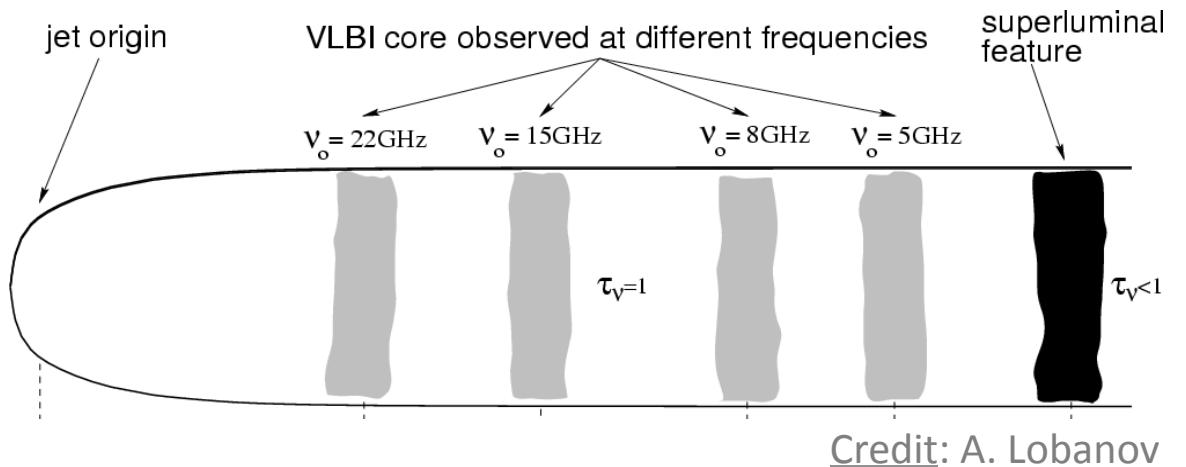
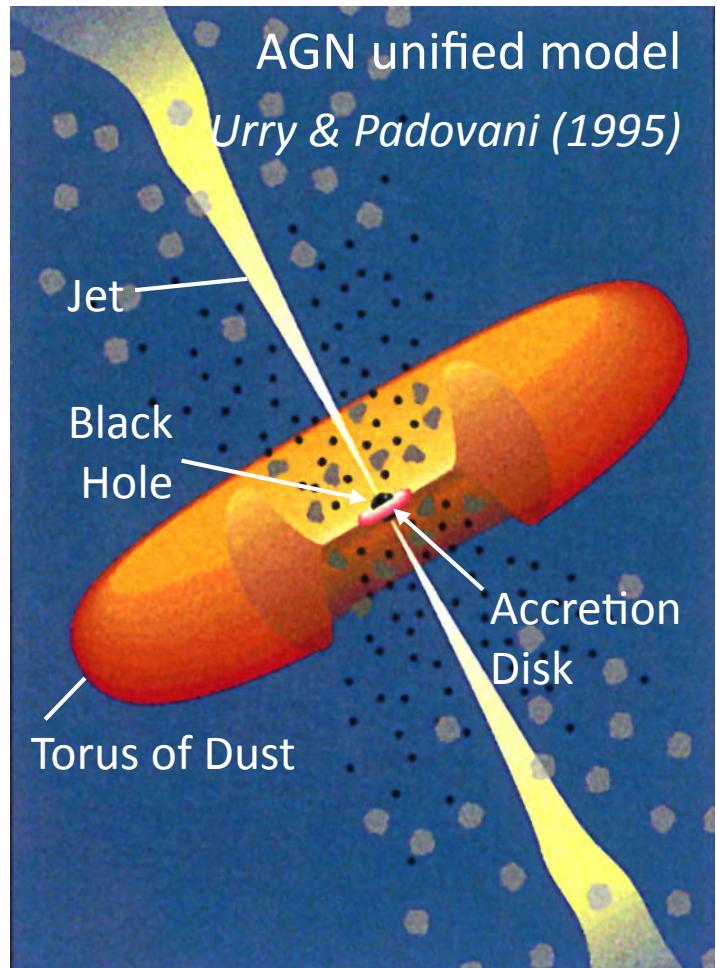
~10 000 – 20 000

~110 μ as @ G=18

Alignment of the two frames is mandatory to ensure consistency of the measured optical and radio positions for any celestial object

Motivation – 2

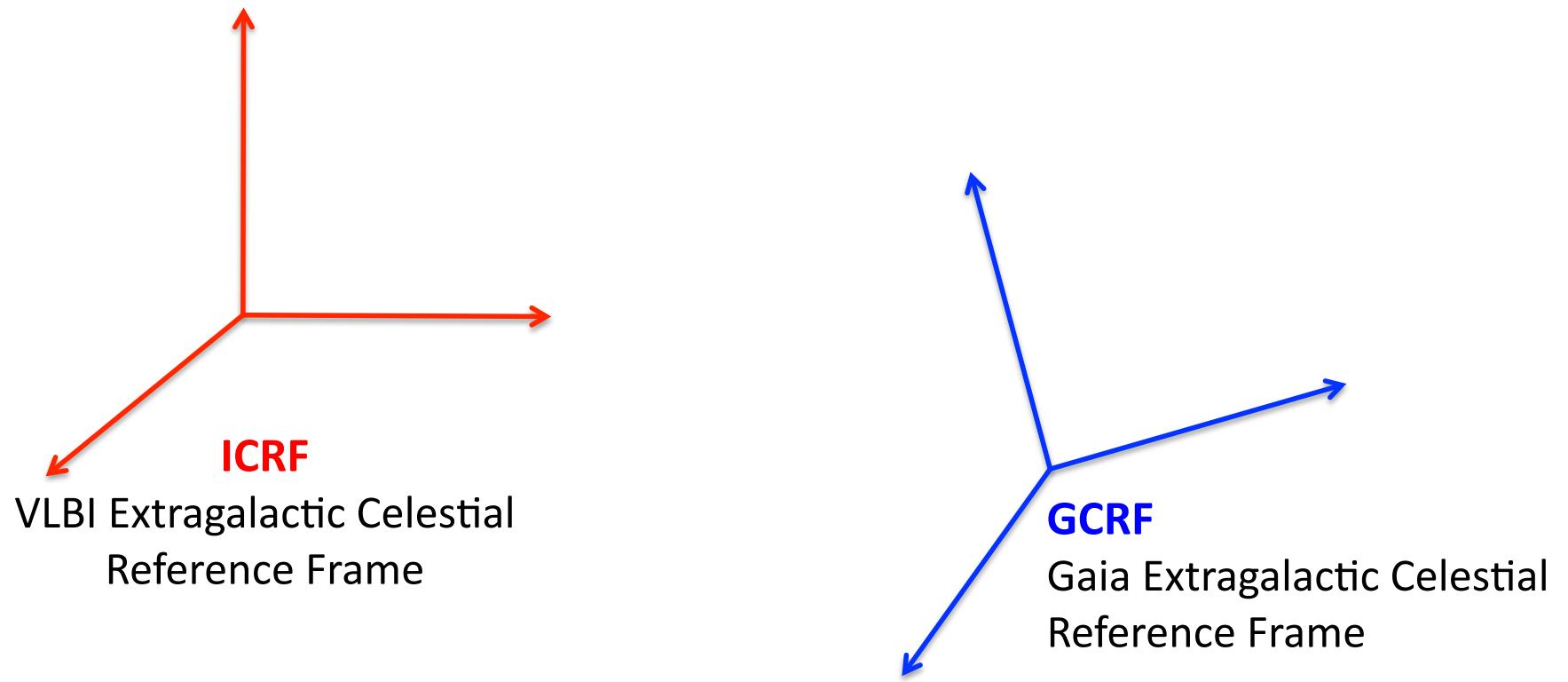
Astrophysics: probe AGN geometry and physics



Expected shift between the optical and radio emission regions: up to 100-200 μ as (theory; e.g. Kovalev et al. 2008)

Comparison of the optical and radio positions to a few tens of μ as may permit to detect directly these shifts and reveal clues about AGN physics

Frames Alignment – Theory

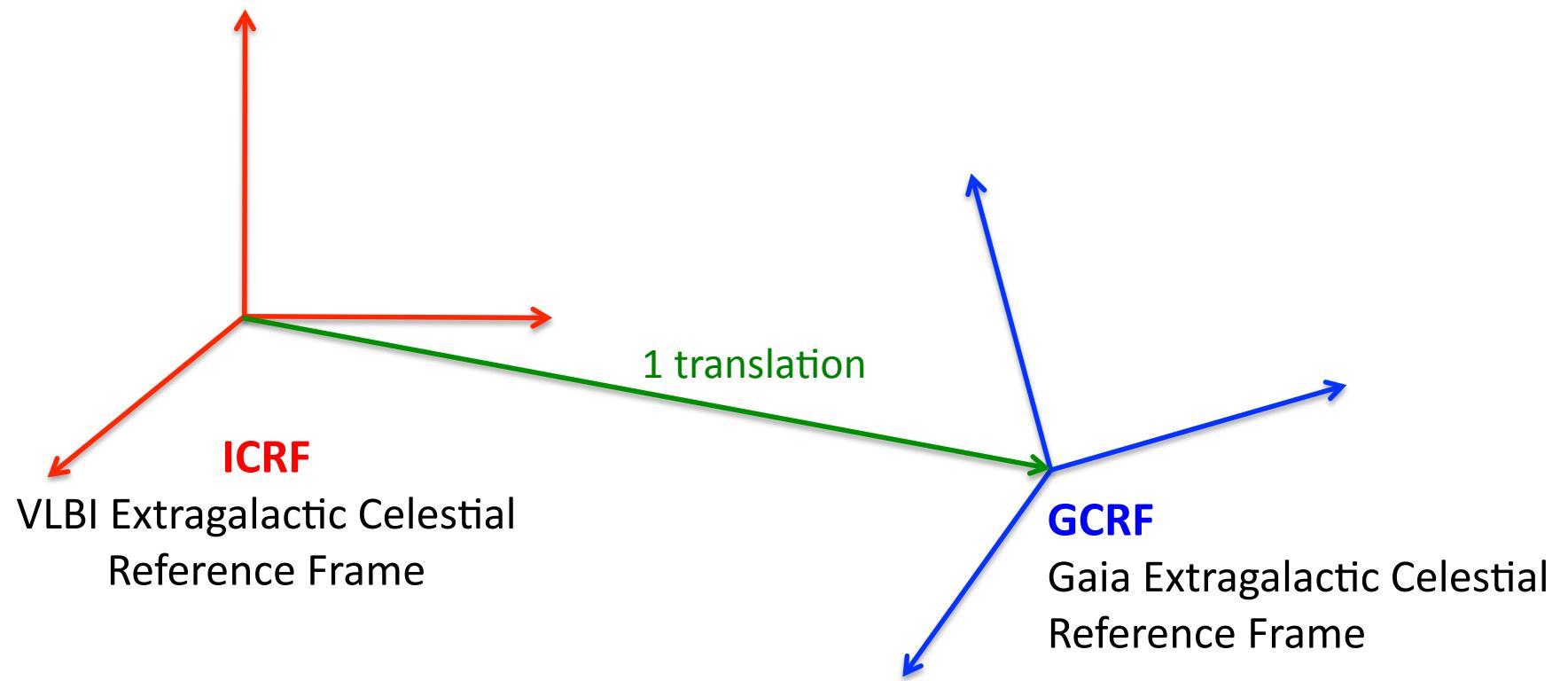


VLBI = Very Long Baseline Interferometry

ICRF = International Celestial Reference Frame

GCRF = Gaia Celestial Reference Frame

Frames Alignment – Theory

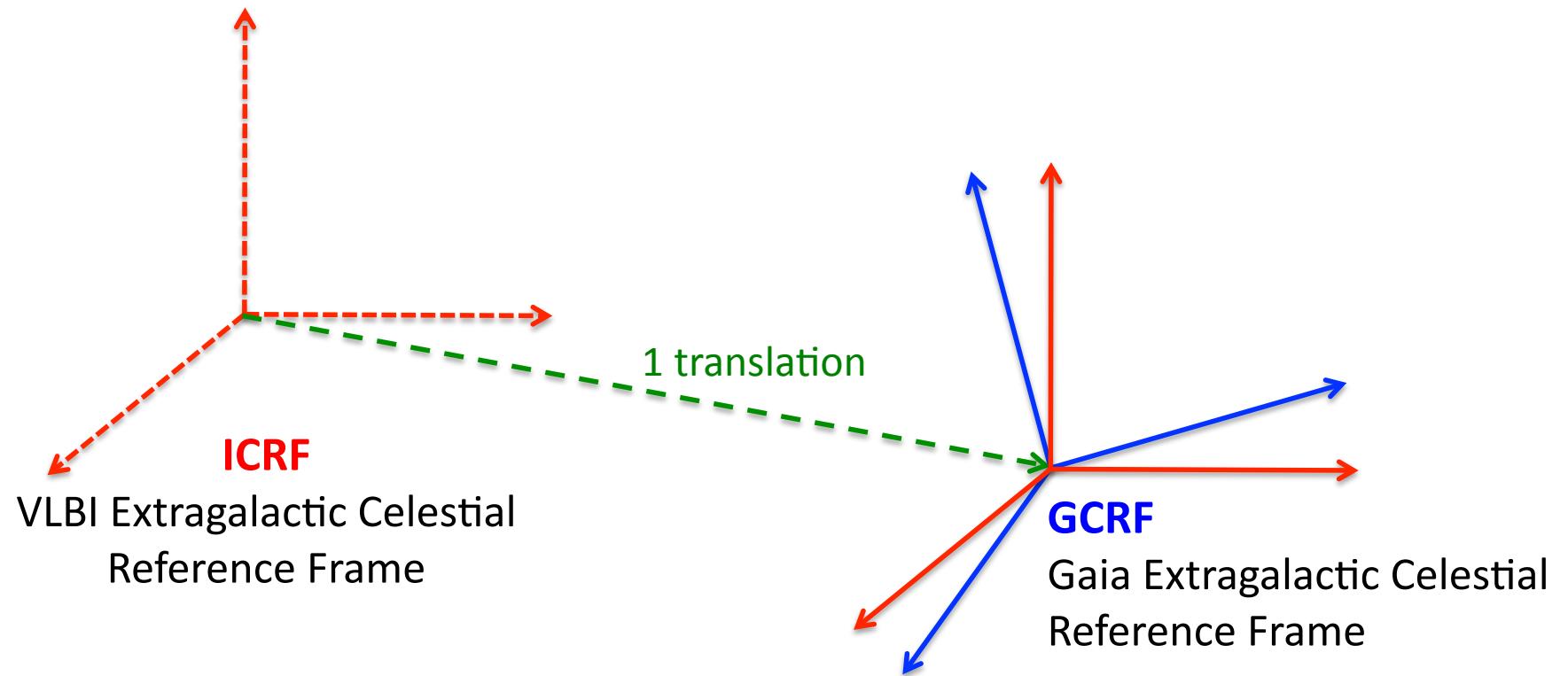


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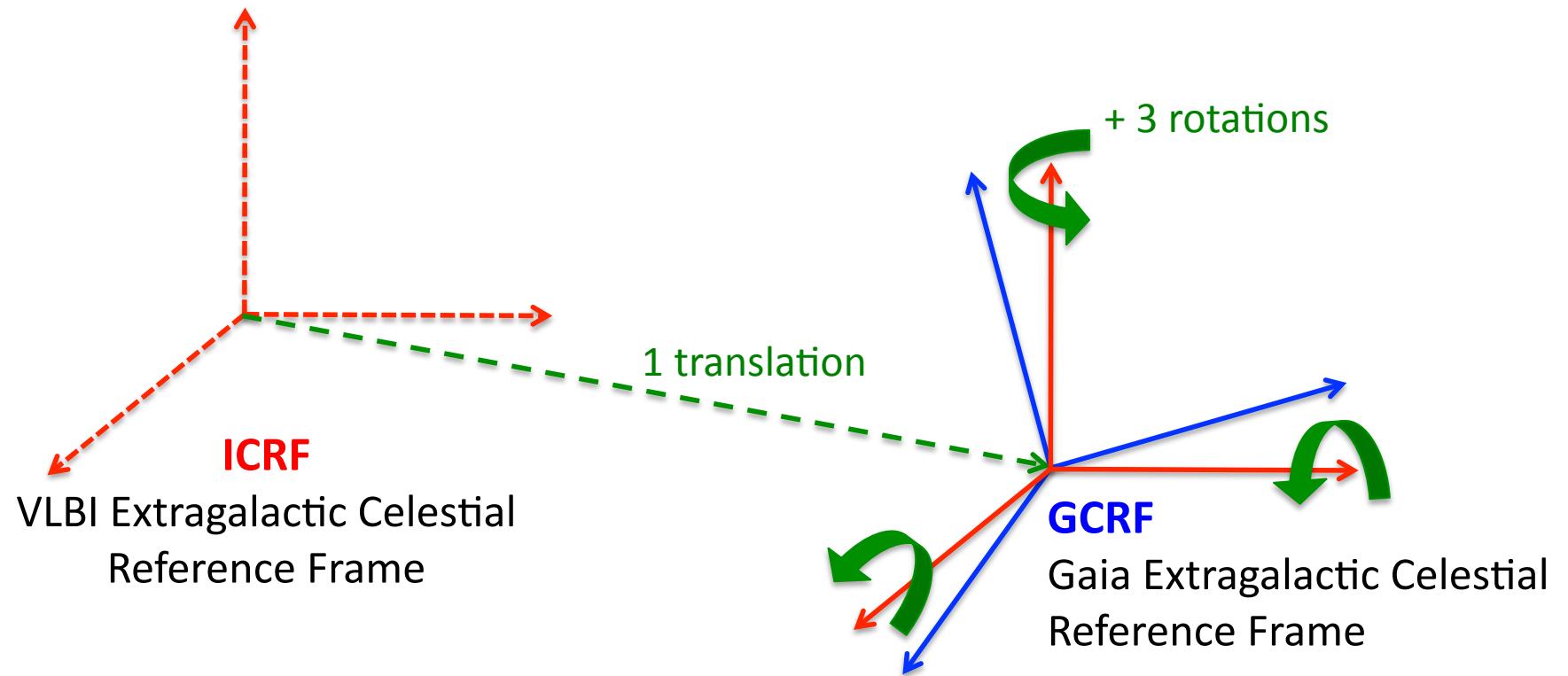


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Frames Alignment – Theory



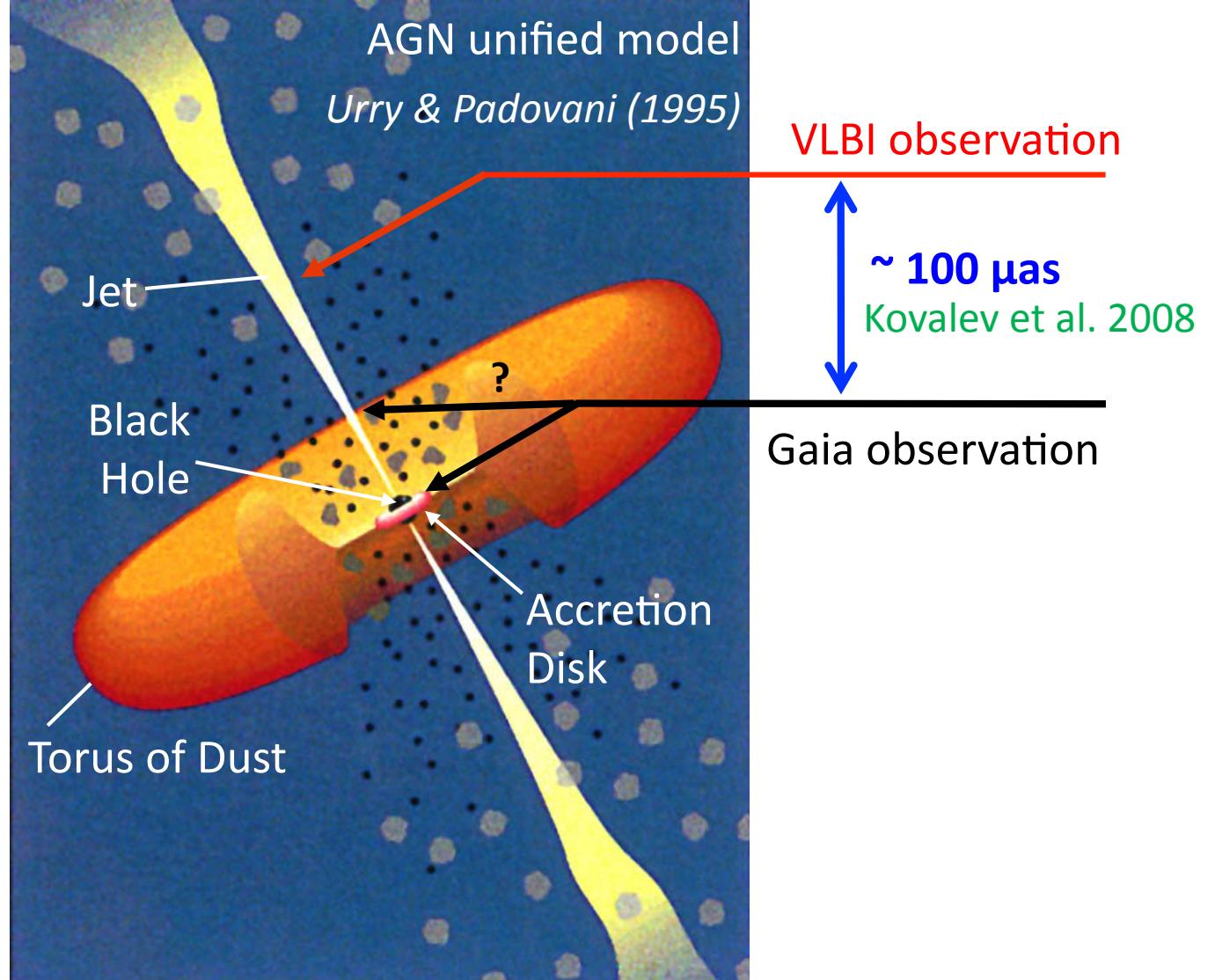
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Frames Alignment – Real life

- VLBI & Gaia observations will not probe the same regions
- Interesting for astrophysical purposes: e.g. constraining the physical properties of AGNs
- BUT:
Will this be visible?
Will this be annoying for the link?



Frames Alignment – Real life

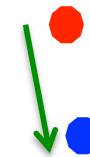
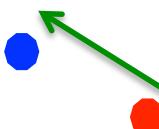


VLBI quasars
Gaia QSOs

IF we have enough accuracy,
this phenomenon is “visible”



IF this core-shift is **statistically** “well distributed” (in every direction and amplitudes), it should vanish in the alignment process...



BUT problems can occur:

IF these shifts are generally speaking much bigger than expected
IF the “shift directions” are biased...

Frames Alignment – How linking @ best?

Enough transfer sources

→ How many?

Homogeneous sky coverage

→ Southern surveys on their way (ICRF3 WG)

High accuracy & stability in positions @ both wavelengths

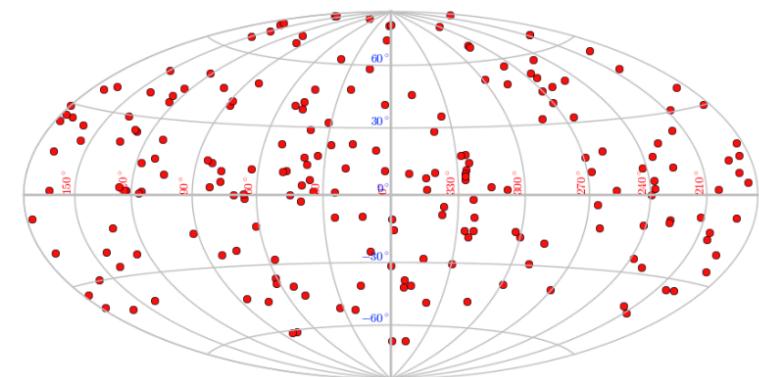
→ Object **morphology & variability** are important in this respect

→ Idea of monitoring during Gaia mission...

How minimizing core-shifts?

Transfer sources selection – 1

- Requirements
 - Several hundreds of common sources
 - With a uniform sky coverage
 - Accurate Gaia positions → Optically-bright (Magnitude ≤ 18)
 - Accurate VLBI positions → Good astrometric quality (*e.g. no structure*)
- Situation in 2007
 - Only 70 ICRF sources match the criteria ([Bourda et al. 2008](#))
- ICRF2 current situation
 - 195 ICRF2 transfer sources identified
 - IVS proposal ([Bourda & Charlot 2012](#))
 - 4 categories identified
 - Recommendations given
 - IVS regular observations since 2012



ICRF2 Transfer sources

1. Optical properties:

- 72% observable with Gaia
 - $0 < \text{mag} \leq 20$ from LQAC2
 - $\text{mag} \leq 18$
- Half of which optically-bright
- **1264 sources suitable**

174 ICRF2 defining, 438 ICRF2 non-defining, 632 VCS only

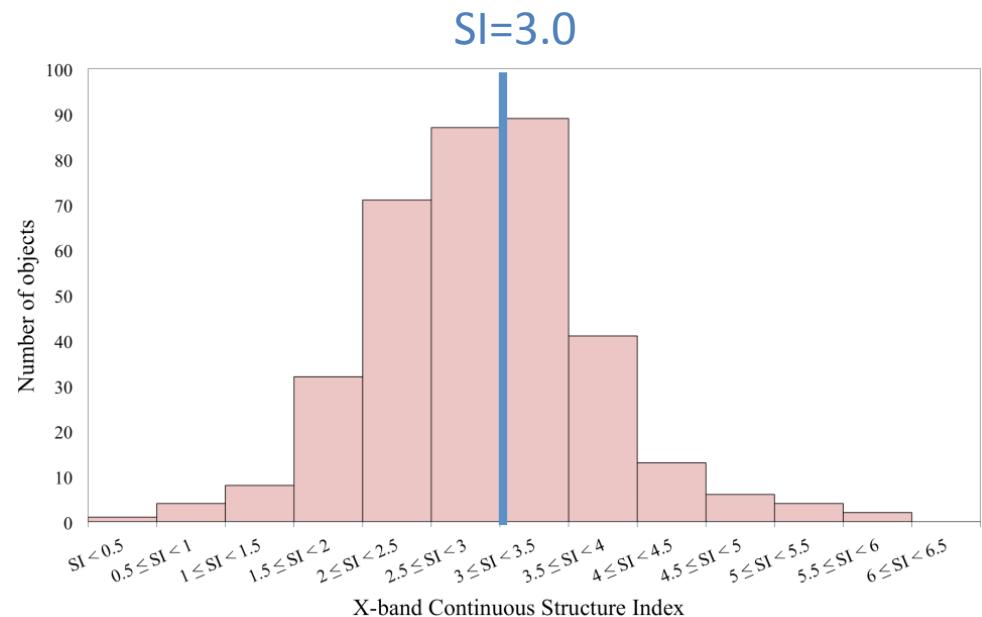
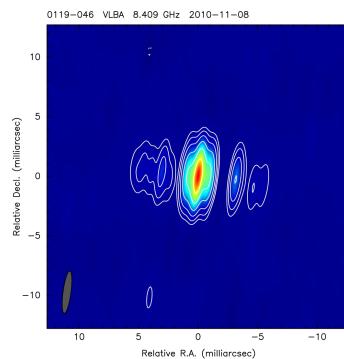
2. Radio properties:

- Structure index (SI) calculated
 - for all sources with images available (33%)
 - excluding VCS sources

(Bourda & Charlot 2012)

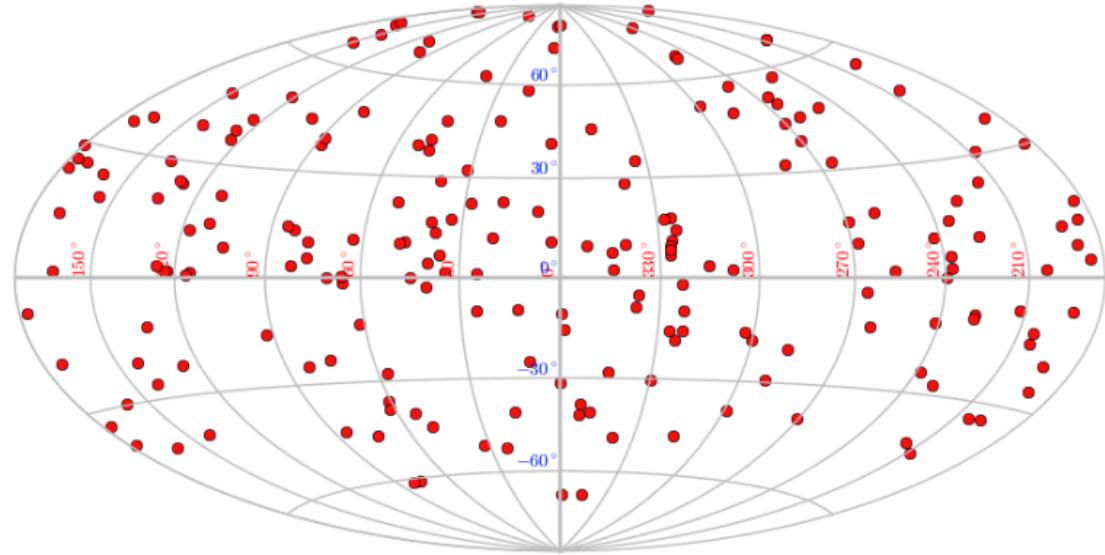
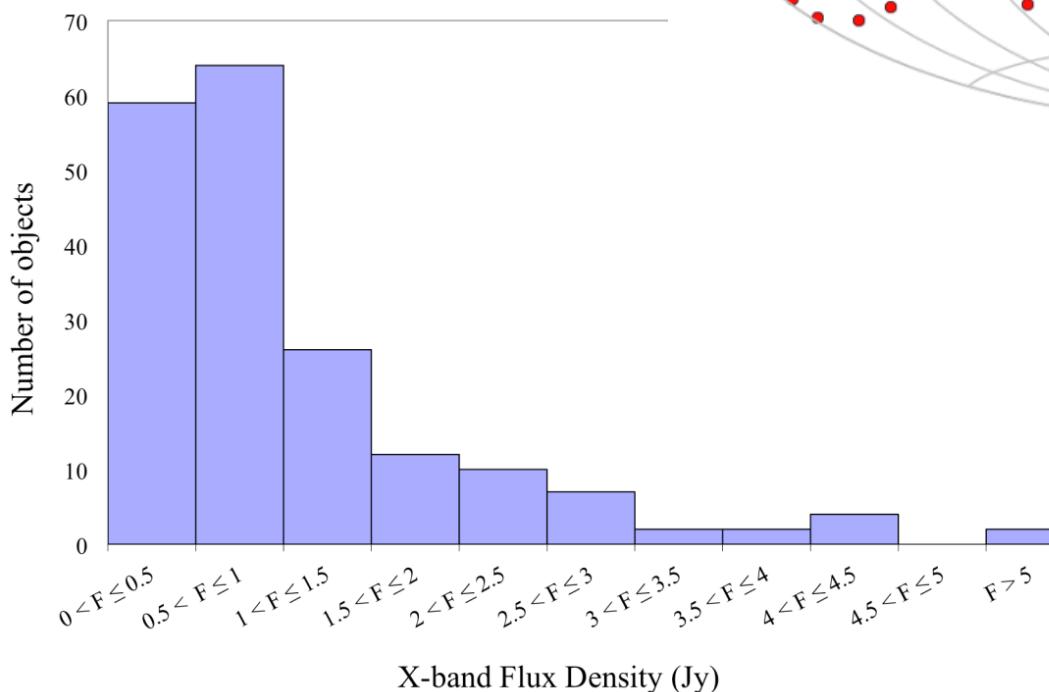
- **195 suitable sources**

132 defining, 65 non-defining



ICRF2 Transfer sources

Sky distribution of the 195 ICRF2 transfer sources



Flux density of the 195 ICRF2 transfer sources

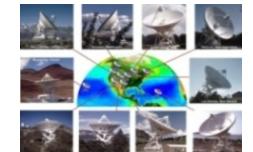
Median ~660 mJy

Transfer sources selection – 2

- VLBI project initiated to find additional transfer sources using EVN and VLBA
- Original sample:
 - 447 weak sources selected from NVSS ($\delta \geq -10^\circ$)
 - Proper optical counterpart
 - Not in ICRF2
- Three observational stages
 - Detection: 96 hours EVN @ 1Gbps
 - Sample reduced to 398 sources ([Bourda et al. 2010](#))
 - Imaging: 192 hours EVN+VLBA @ 512 Mbps
 - 250 sources imaged
 - 119 with appropriate structure index ([Bourda et al. 2011, 2012, ...](#))
 - Astrometry: 72 hours EVN+VLBA @ 512 Mbps
 - 119 suitable sources observed



Very Long
Baseline Array



Step 1: VLBI detection

- Two 48-hour EVN experiments
(S/X @ 1Gbps)
EC025A: June 2007 – 224 sources
EC025B: October 2007 – 223 sources

Weak sources in VLBI

- High sensitivity necessary
- Need large antennas & high recording rate



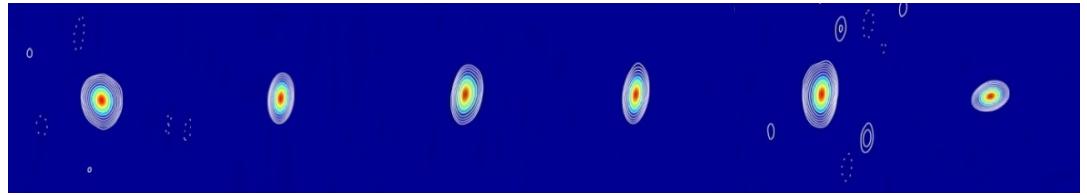
- S/X detection rates:

$$\begin{aligned} \text{EC025A} &\sim 96 \% \\ \text{EC025B} &\sim 82 \% \end{aligned}$$

Overall detection rate: **~ 89 %**
(398 sources detected)

(Bourda et al., 2010, A&A 520, A113)

Step 2: Imaging



- **Observations:** 4 successive global VLBI imaging experiments
(EVN+VLBA; S/X @ 512 Mbps)

Observing date	Duration time	# sources observed	# sources imaged (%)
March 2008	48-hr	105	105 (100%)
March 2010	48-hr	97	63 (65%)
November 2010	58-hr	118	52 (44%)
March 2011	38-hr	75	30 (40%)
TOTAL	192-hr	395	250 (63%)

(Bourda et al., 2011, A&A)

(Bourda et al., 2015, A&A, in prep.)

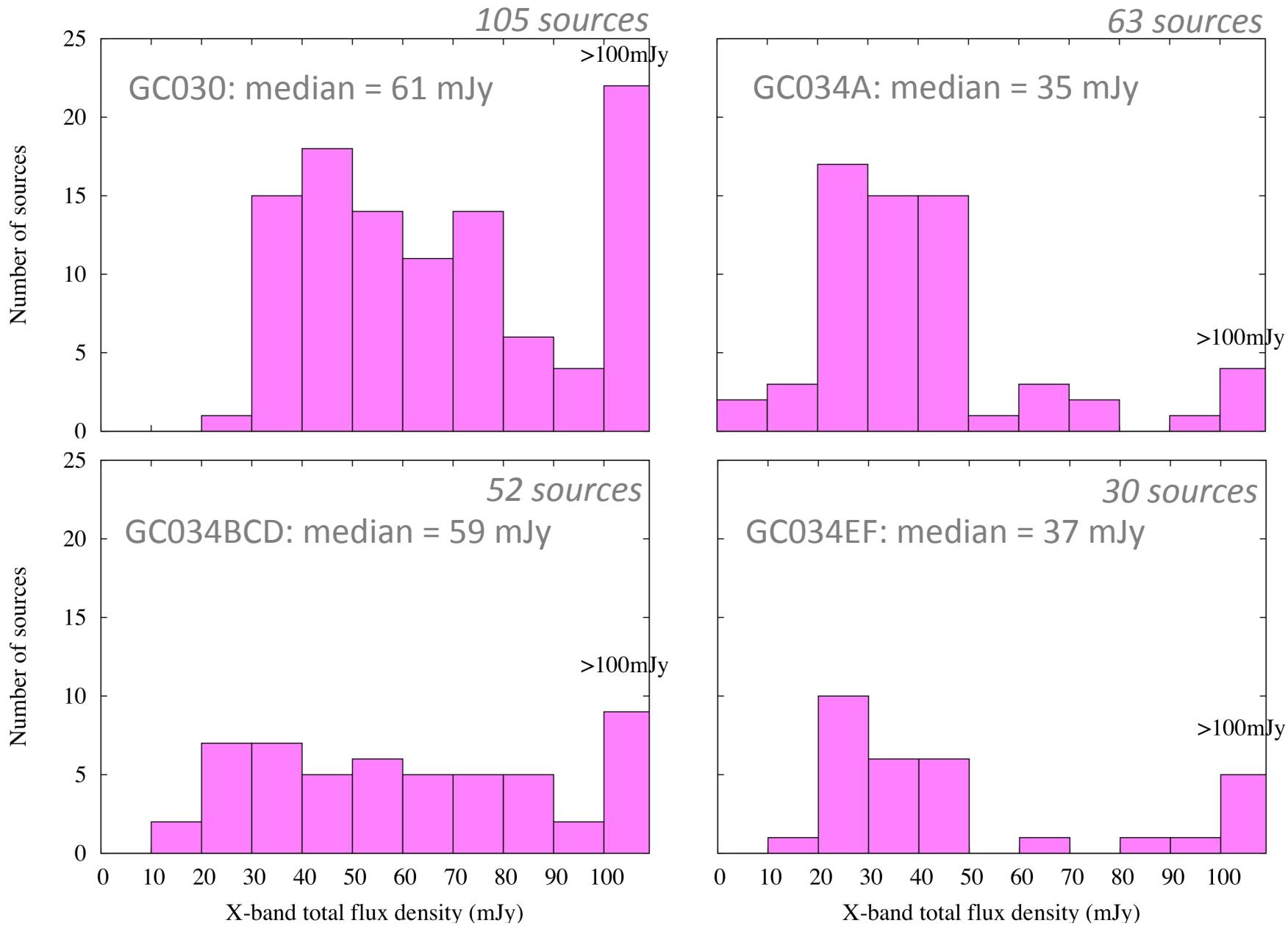
- **Results:** From the 250 sources imaged, about half were found to be point-like

→ 119 VLBI sources suitable for the alignment



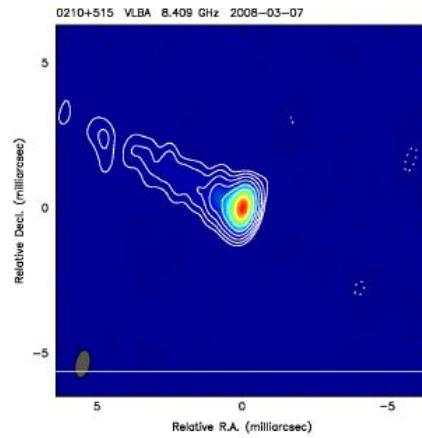
Yebes, Spain – Ø 40 m

X-band Total Flux Density

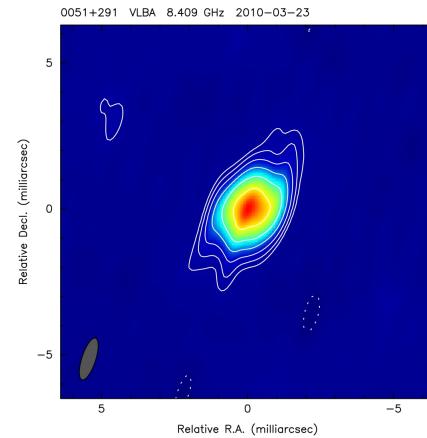


Examples of VLBI maps for « bad » sources

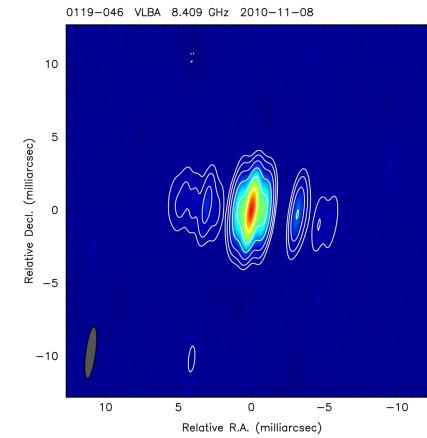
GC030



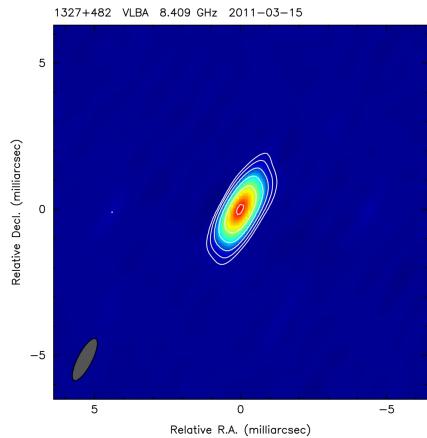
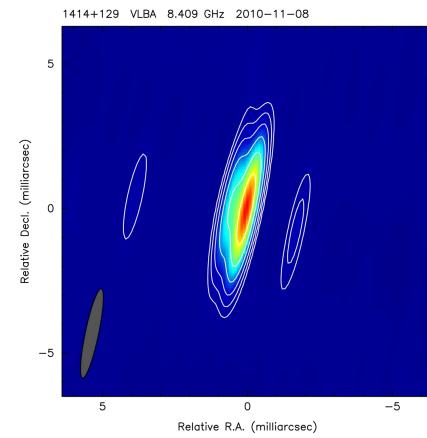
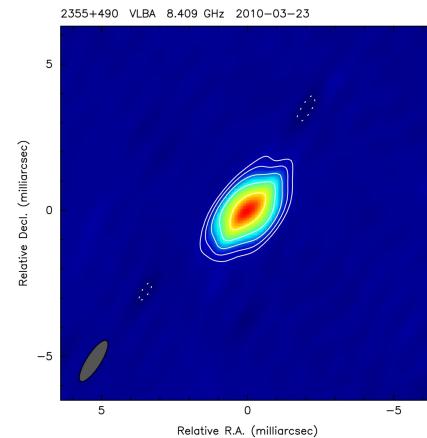
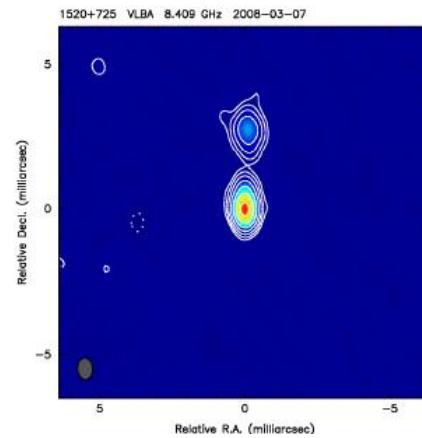
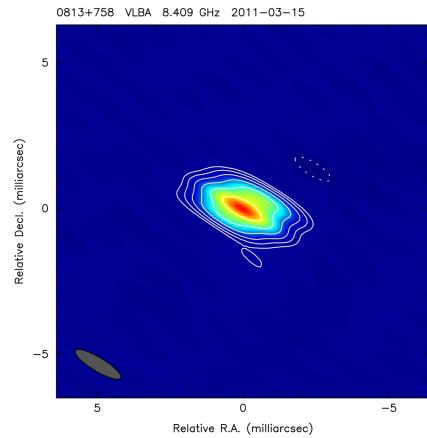
GC034A



GC034BCD



GC034EF

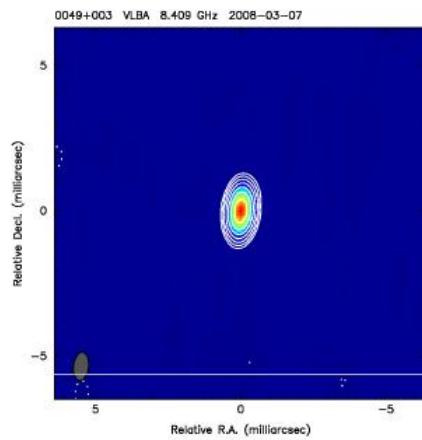


SPW 0 T~

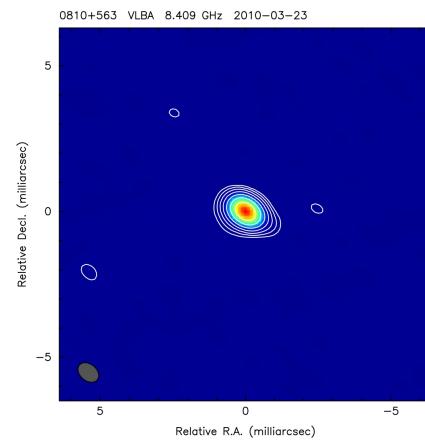
X-band – 1st contour level @ 1 – 4%

Examples of VLBI maps for « good » sources

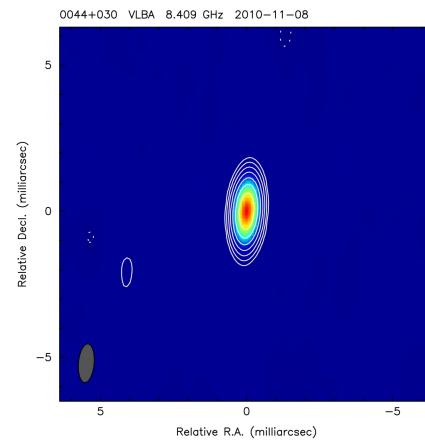
GC030



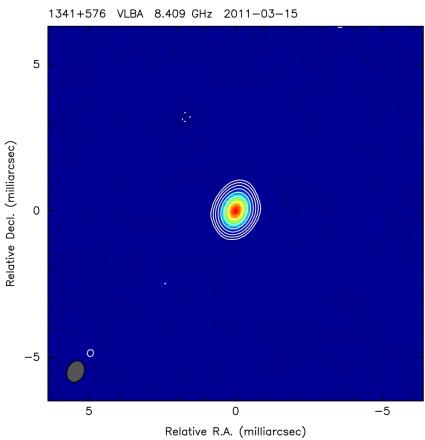
GC034A



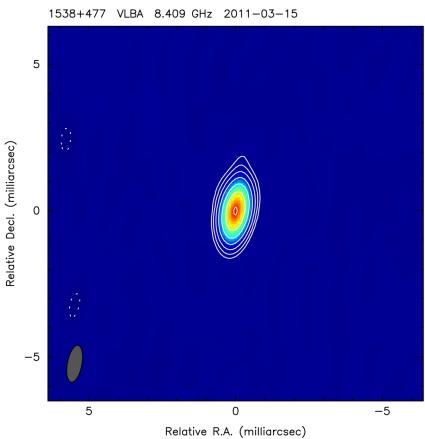
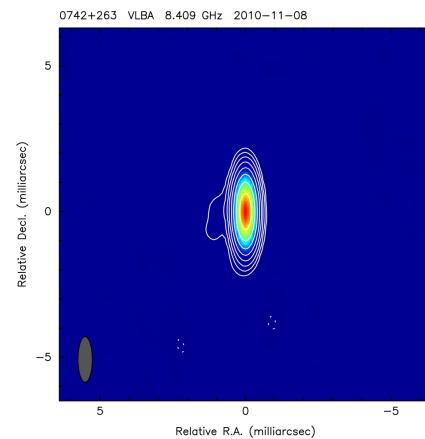
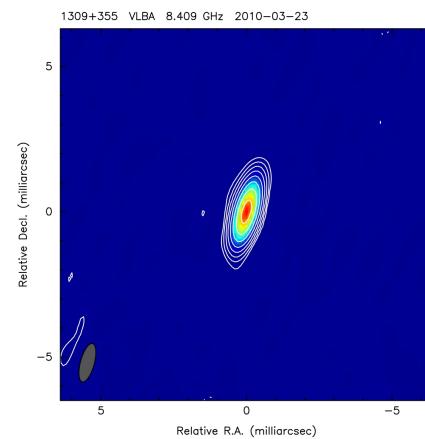
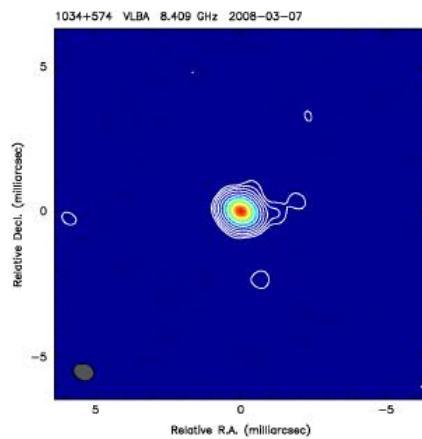
GC034BCD



GC034EF



sew 0T_~



X-band -1st contour level @ 1 – 4%

VLBI Images in BVID

The screenshot shows the homepage of the Bordeaux VLBI Image Database (BVID). The header features a logo with a radio telescope and the text "The Bordeaux VLBI Image Database". Below the header, there are logos for CNRS, INSU, and CEA. The main menu includes links for "Home BVID", "News", "BVID content", "Database access", "Citations", "Links", and "Contact". On the right side, there is a search bar with options to "Query by: Source name", "Date", or "Coordinates". A link to "For GC030:" is provided, followed by a message stating "105 sources have been found!". Below this, there is a link to "VLBI image summary (in pdf)" and buttons for "X-Band" and "S-Band". A large table lists 105 source identifiers in pairs of six columns. At the bottom right, there is a link to "Comments ? See the Contact page".

For GC030:

105 sources have been found !

→ VLBI image summary (in pdf)

X-Band S-Band

Choose a source in the list :

0003+123	0049+003	0107-025	0109+200	0130-083	0145+210
0150+015	0210+515	0446+074	0502+041	0519-074	0651+428
0652+426	0708+742	0741+294	0751+306	0757+477	0806+350
0807+083	0818+312	0821+411	0838+235	0838+456	0850+284
0854+334	0903+500	0907+336	0950+326	0950-084	0952+338
1007+716	1009+067	1009+334	1010+356	1020+292	1028+313
1032+354	1034+574	1040-056	1101+077	1126+237	1127+078
1128+517	1140+190	1141+235	1145+321	1148+592	1201+454
1201-068	1212+467	1228+077	1240+367	1242+574	1307+433
1310+314	1310+484	1312+240	1315+727	1319+006	1338+303
1340+289	1345+735	1411+746	1420+044	1429+249	1518+162
1520+725	1522+669	1535+231	1556+335	1603+699	1607+183
1607+604	1612+378	1618+530	1648+417	1653+198	1714+231
1715+425	1721+343	1722+119	1729+372	1730+604	1741+597
1742+724	1753+338	1759+756	1810+522	1811+317	1818+551
1832+208	1833+250	1838+575	2043+749	2052+239	2057+235
2111+801	2116+203	2128+333	2241+200	2247+381	2300+345
2314+160	2316+238	2322+396			

Comments ? See the [Contact page](#)

VLBI Images in BVID

The Bordeaux VLBI Image Database

0049+003 VLBA+ 8.409 GHz 2008-03-07
Laboratoire d'Astrophysique de Bordeaux, FRANCE

Relative Decl. (milliarcsec)

Relative R.A. (milliarcsec)

Example

For GC030:
105 sources have been found!
⇒ VLBI image summary (in pdf)
X-Band S-Band

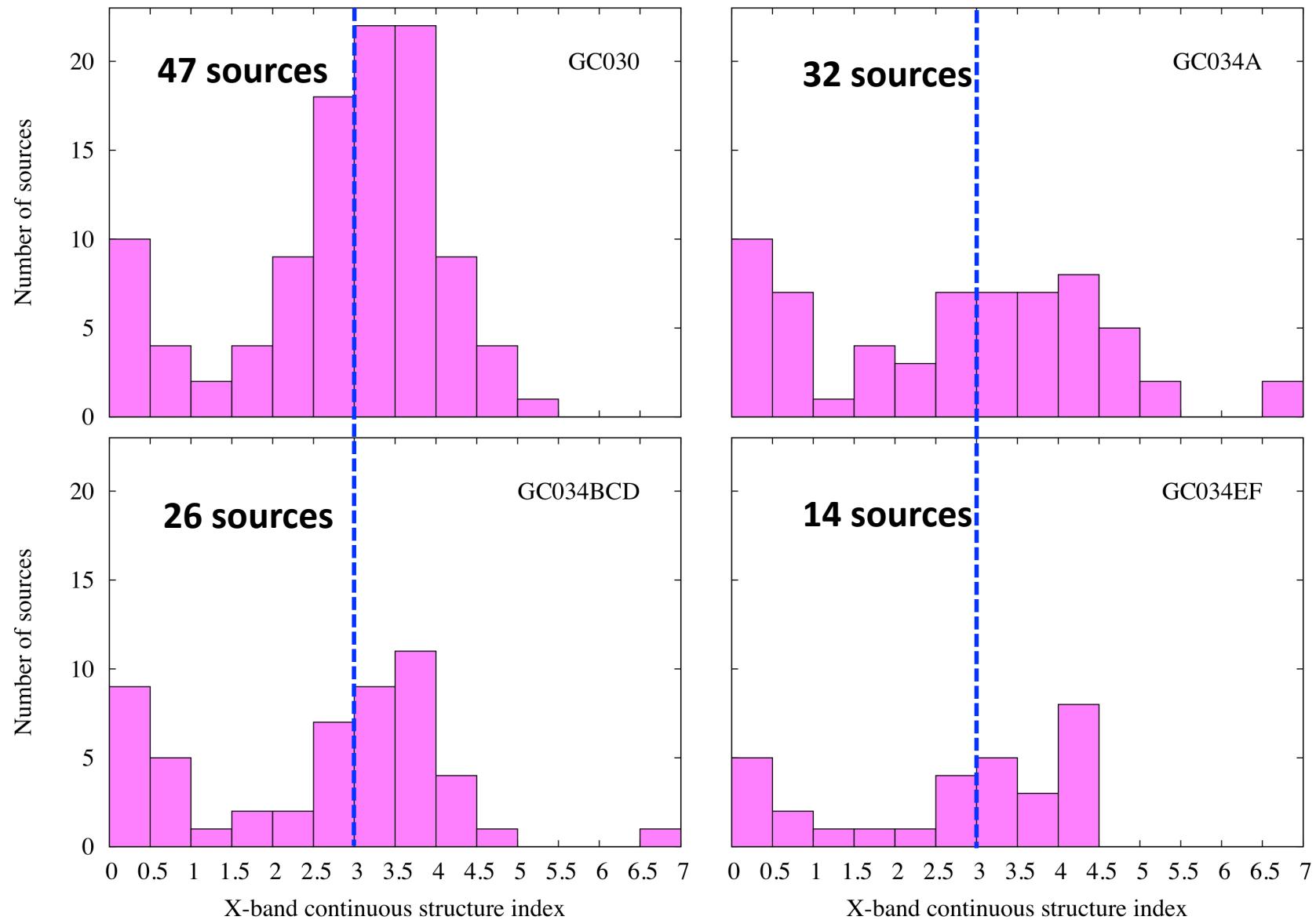
Choose a source in the list:

0003+123	0049+003
0150+015	0210+515
0652+426	0708+742
0807+083	0818+312
0854+334	0903+500
1007+716	1009+067
1032+354	1034+574
1128+517	1140+190
1201-068	1212+467
1310+314	1310+484
1340+289	1345+735
1520+725	1522+669
1607+604	1612+378
1715+425	1721+343
1742+724	1753+338
1832+208	1833+250
2111+801	2116+203
2314+160	2316+238

Comments ? See the [Contact page](#)

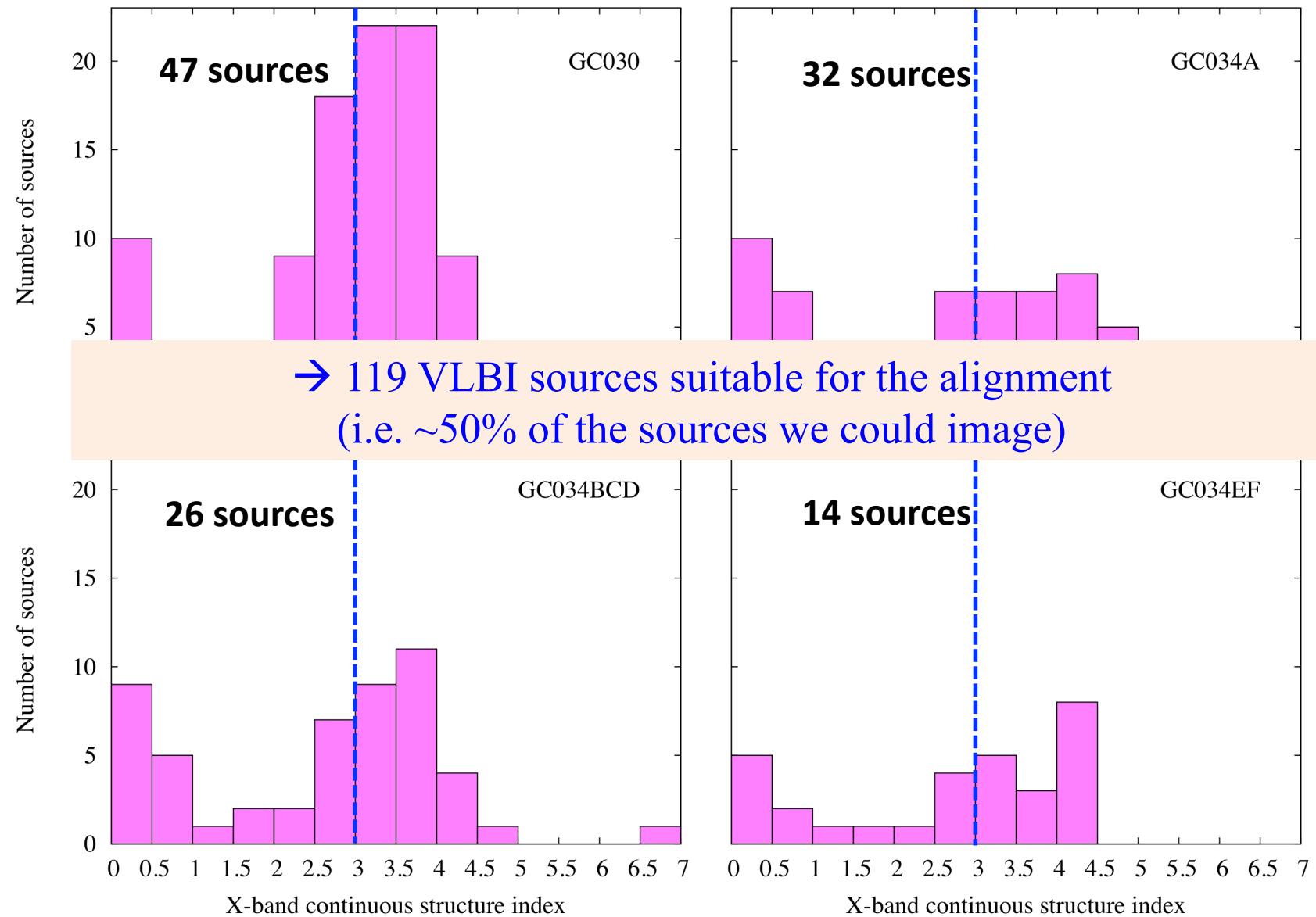
Astrometric suitability

Same criterion as for the selection of ICRF2 defining sources (continuous structure index < 3.0)



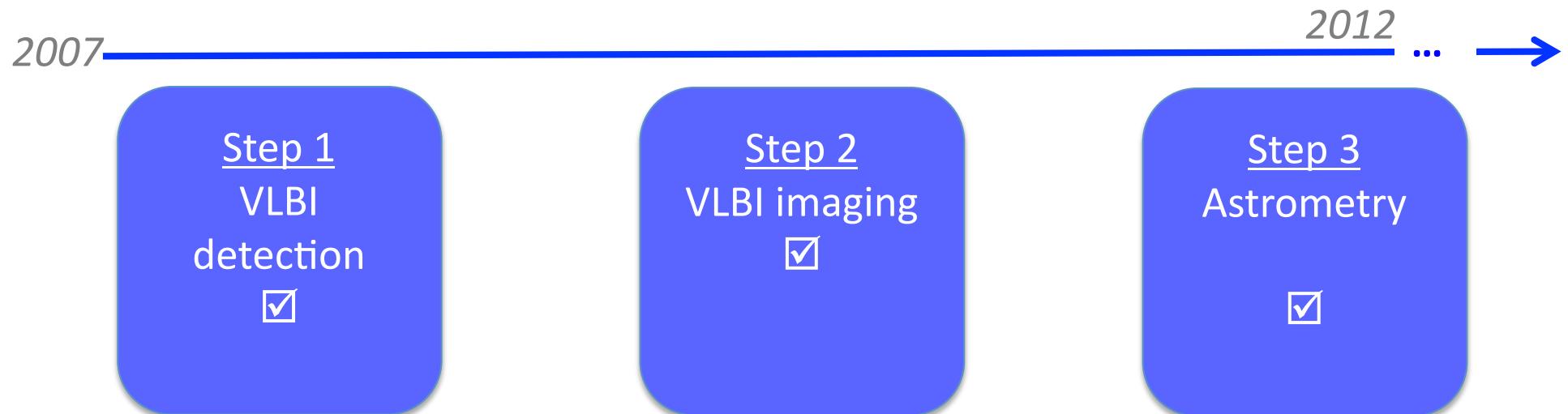
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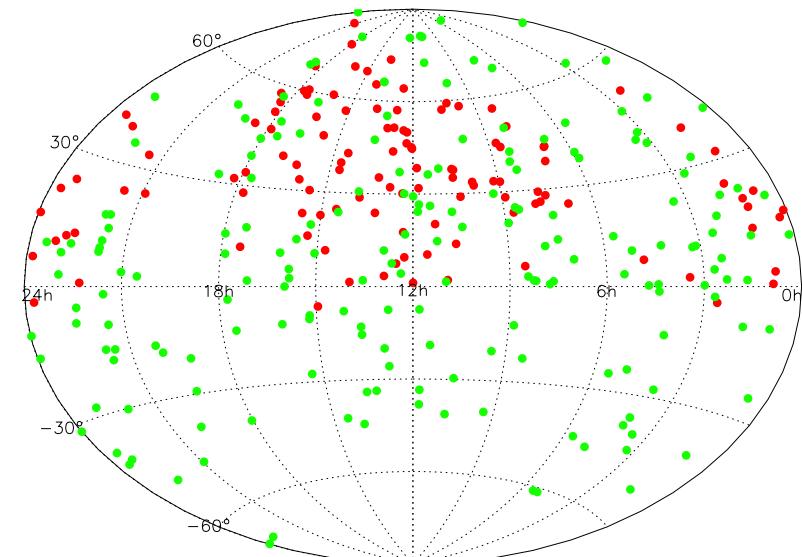
Step 3: Astrometry

- ✓ Proposal submitted 1st February 2012
- ✓ **72-hr** experiment granted and conducted in **June 2012**
- ✓ **119 point-like sources observed**
- ✓ Global VLBI array (EVN+VLBA) S/X @ 512 Mbps
- ✓ Goal: Determine VLBI astrometric positions
- ✓ On-going analyses...



Transfer sources selection – 3

- VCS → To be done (with VCS-II ?)
- LCS: LBA Calibrator Survey
 - Collab. South Africa & Australia
 - Cover southern hemisphere
 - 190 sources / proper optical counterpart
 - Imaging experiment: 1st quarter 2015
+ 2nd proposal recently submitted
 - Astrometry to carry out
- Higher frequencies
 - X/Ka: Collab. JPL *et al.* ([cf. C. Jacobs](#))
175 sources out of 660 with a proper optical counterpart
 - K-band: Beginning collaboration



Prospects – Summary

- ICRF2 transfer sources

- LQAC3 vs. OCARS
 - VCS sources to investigate in terms of SI
 - Cross checking with respect to optical properties



ICRF3 Working Group

- Current # of transfer sources:

~400 VLBI-Gaia transfer sources being identified (S/X)

→ 195 ICRF2 + 119 « weak » non-ICRF2 + ~100 potential southern (?)

- All transfer sources should be part of the core of the future ICRF3

Thanks for your attention

