Aligning VLBI and Gaia Extragalactic Celestial Reference Frames

On the basis of which sources?

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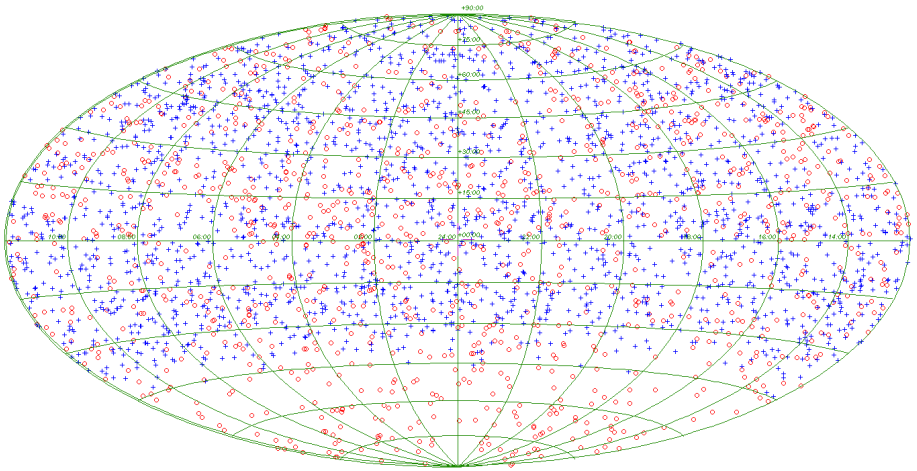
FRANCE

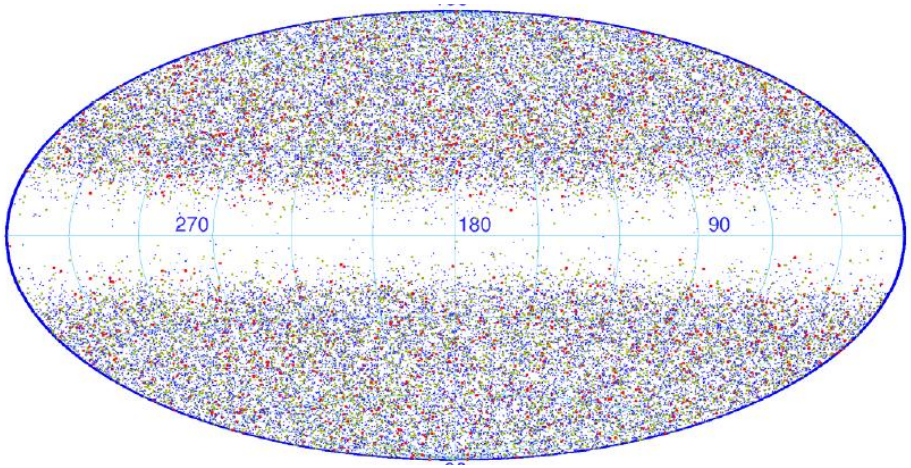
Motivation – 1

2021: Two extragalactic celestial reference frames will coexist

VLBI – Radio



Gaia – Optical



ICRF2		GCRF
3 414	*# of objects*	~10 000 – 20 000
@ best 60 µas	*Position accuracy*	~70 µas @ G=18 ~200 µas @ G=20

Lindegren et al. 2008

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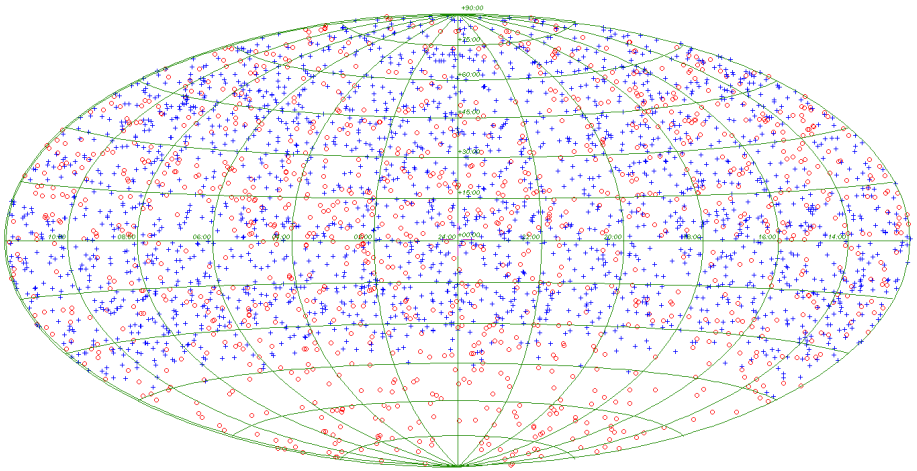

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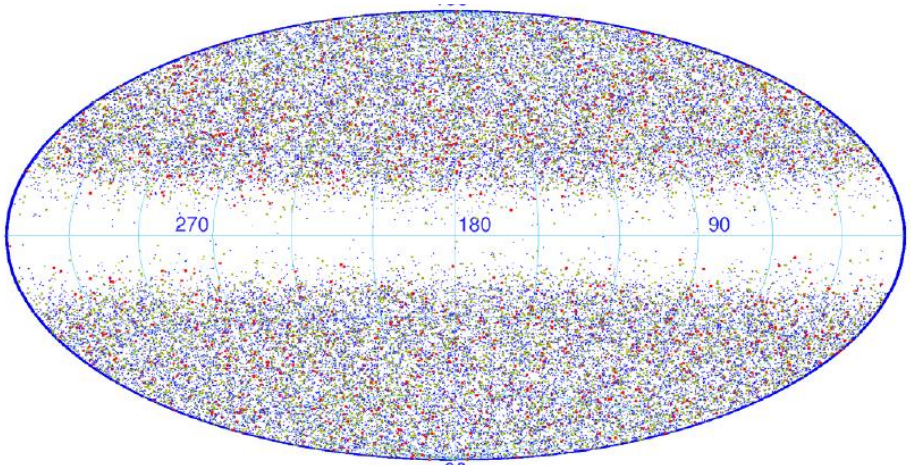

ICRF2		GCRF
3 414	*# of objects*	~10 000 – 20 000
@ best 60 µas	*Position accuracy*	~110 µas @ G=18 ~450 µas @ G=20

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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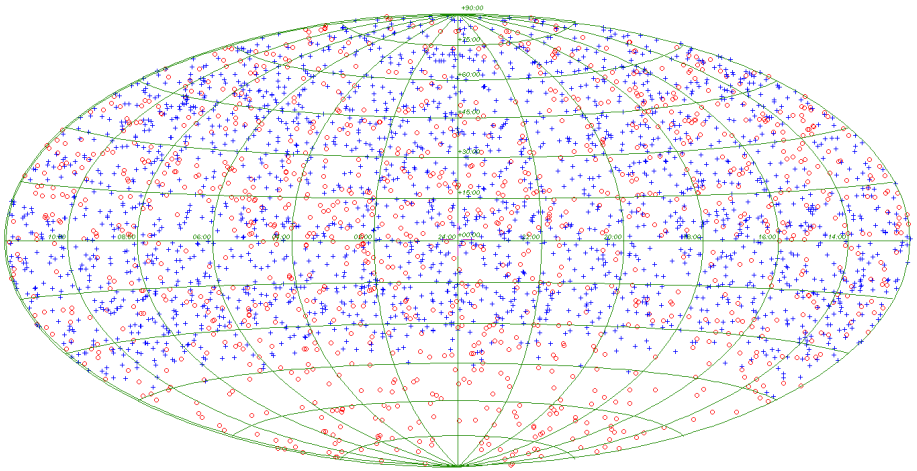
VLBI – Radio



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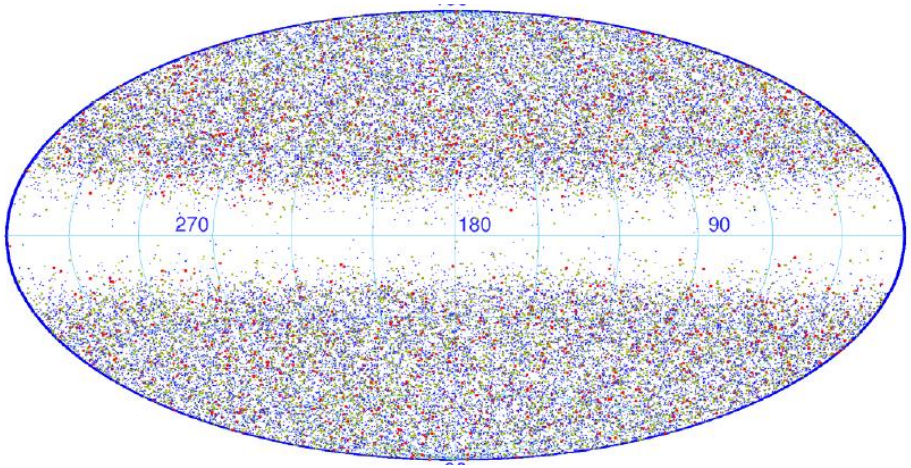

ICRF2		GCRF
3 414	*# of objects*	~10 000 – 20 000
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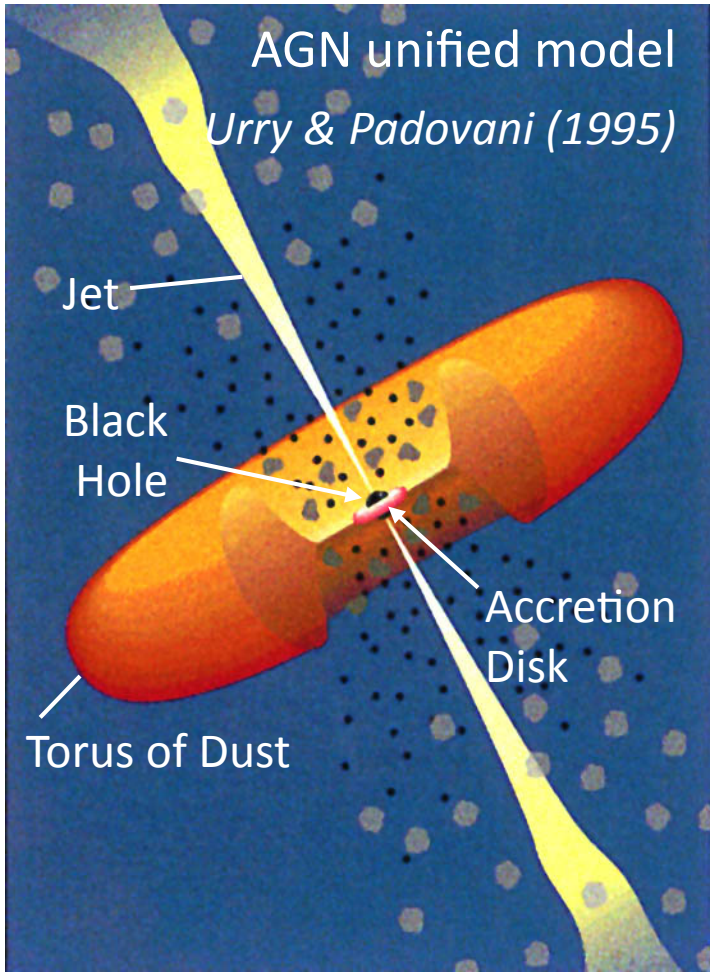
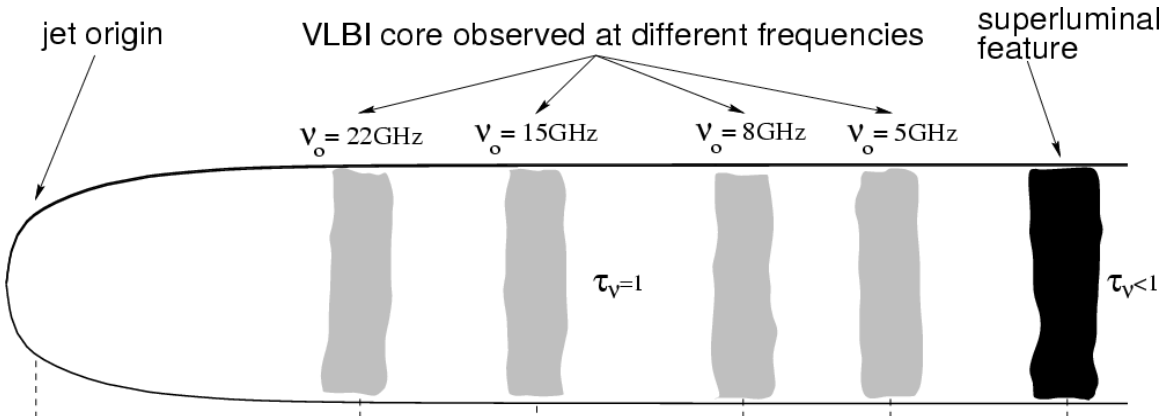
Alignment of the two frames is mandatory to ensure consistency of the measured optical and radio positions for any celestial object

Motivation – 2

Astrophysics: probe AGN geometry and physics



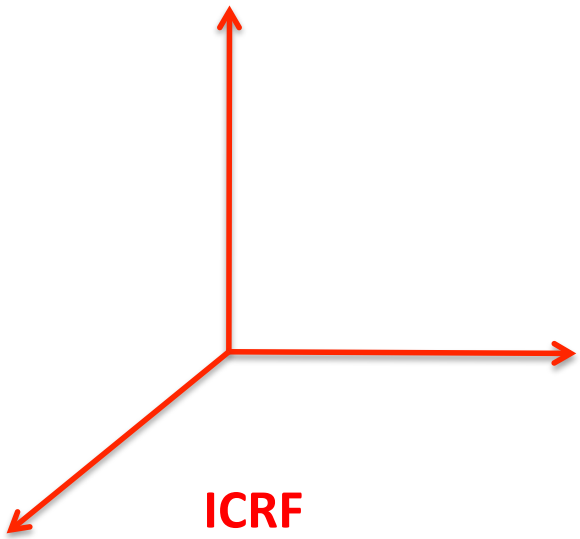


Credit: A. Lobanov

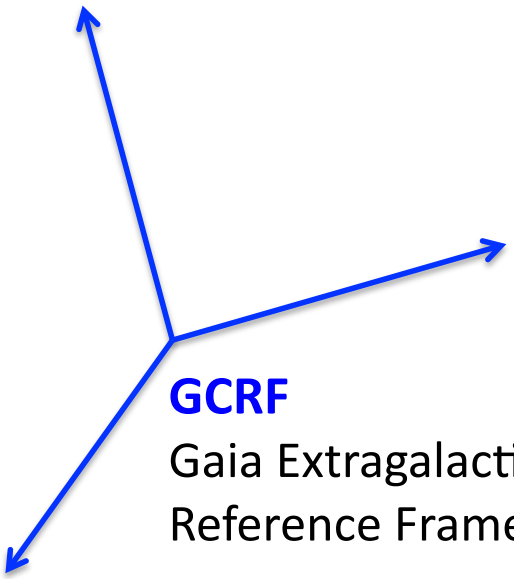
Expected shift between the optical and radio emission regions: up to 100-200 µas (*theory; e.g.* Kovalev et al. 2008)

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

Frames Alignment – Theory



ICRF
VLBI Extragalactic Celestial Reference Frame

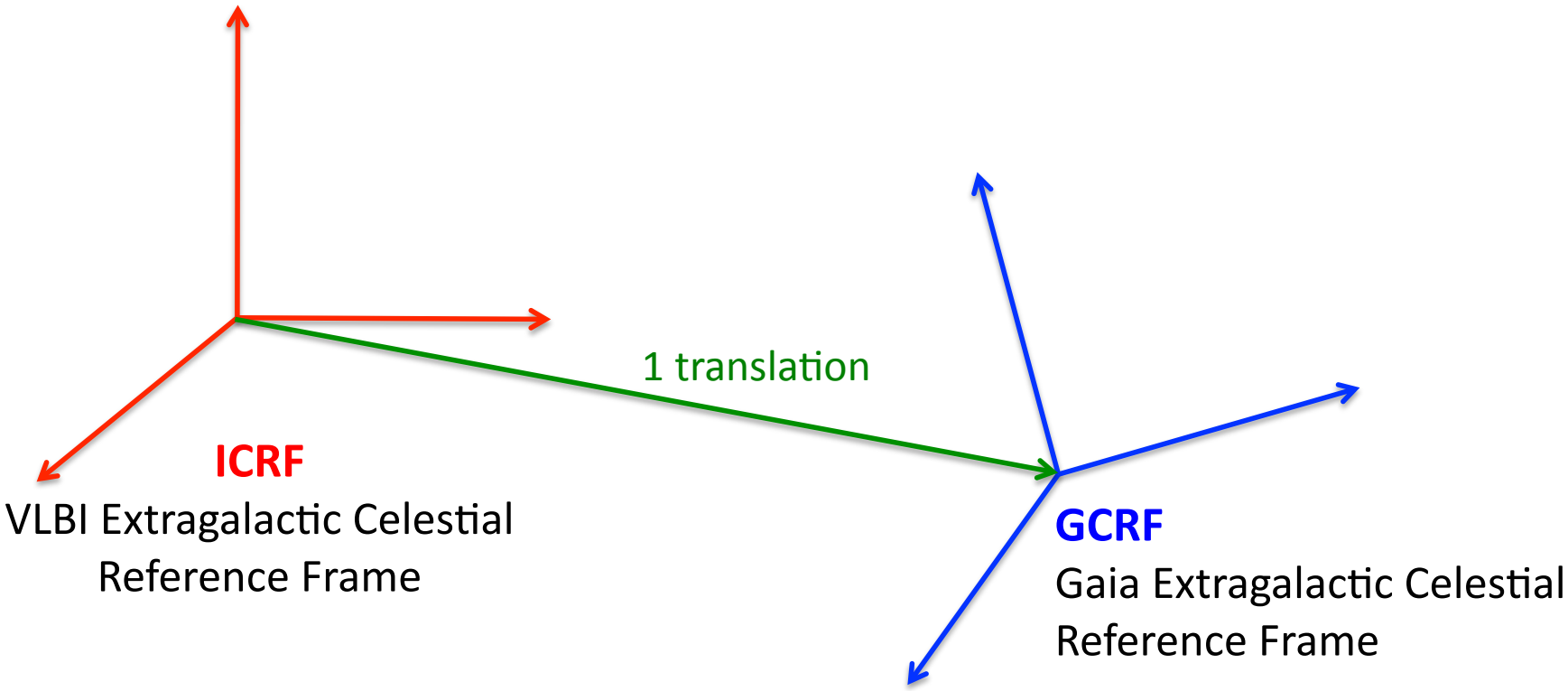


GCRF
Gaia Extragalactic Celestial Reference Frame

VLBI = Very Long Baseline Interferometry
ICRF = International Celestial Reference Frame

GCRF = Gaia Celestial Reference Frame

Frames Alignment – Theory



VLBI = Very Long Baseline Interferometry
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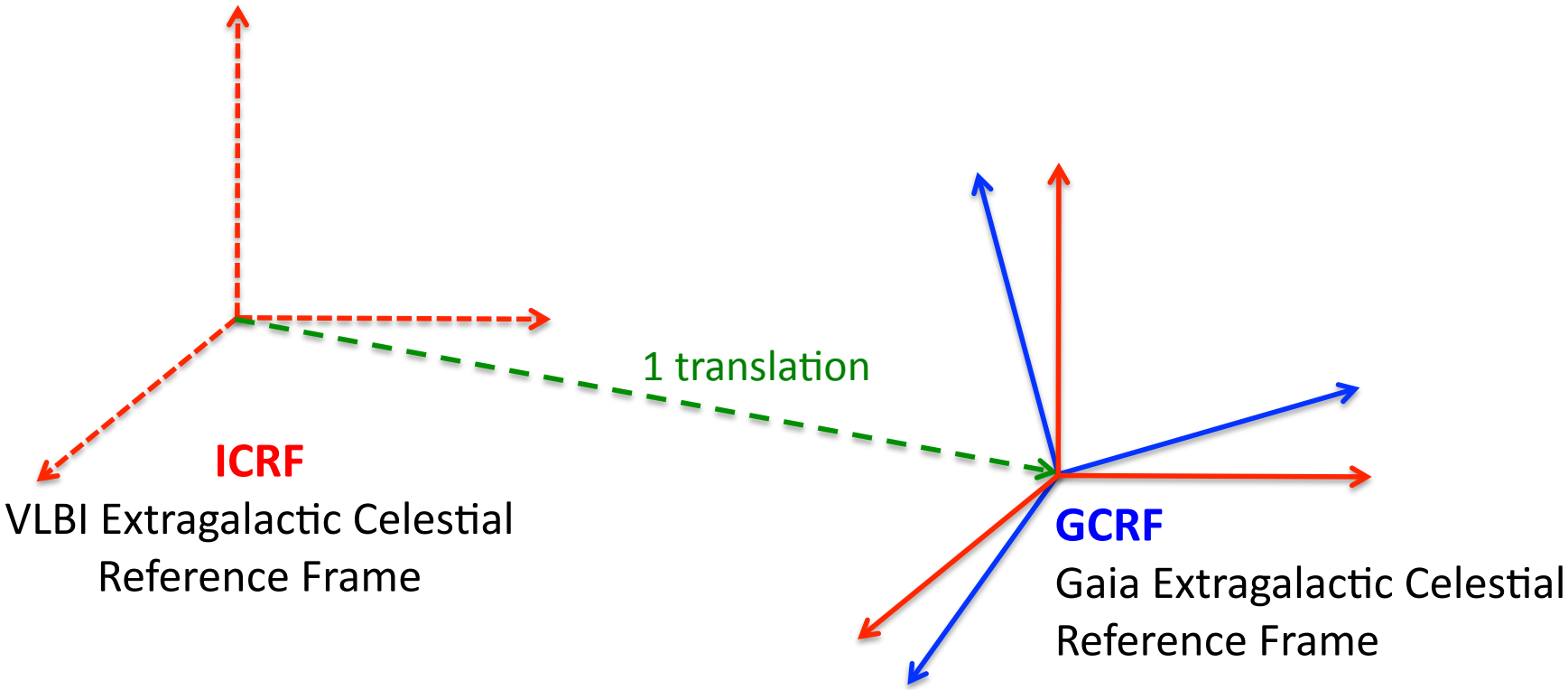

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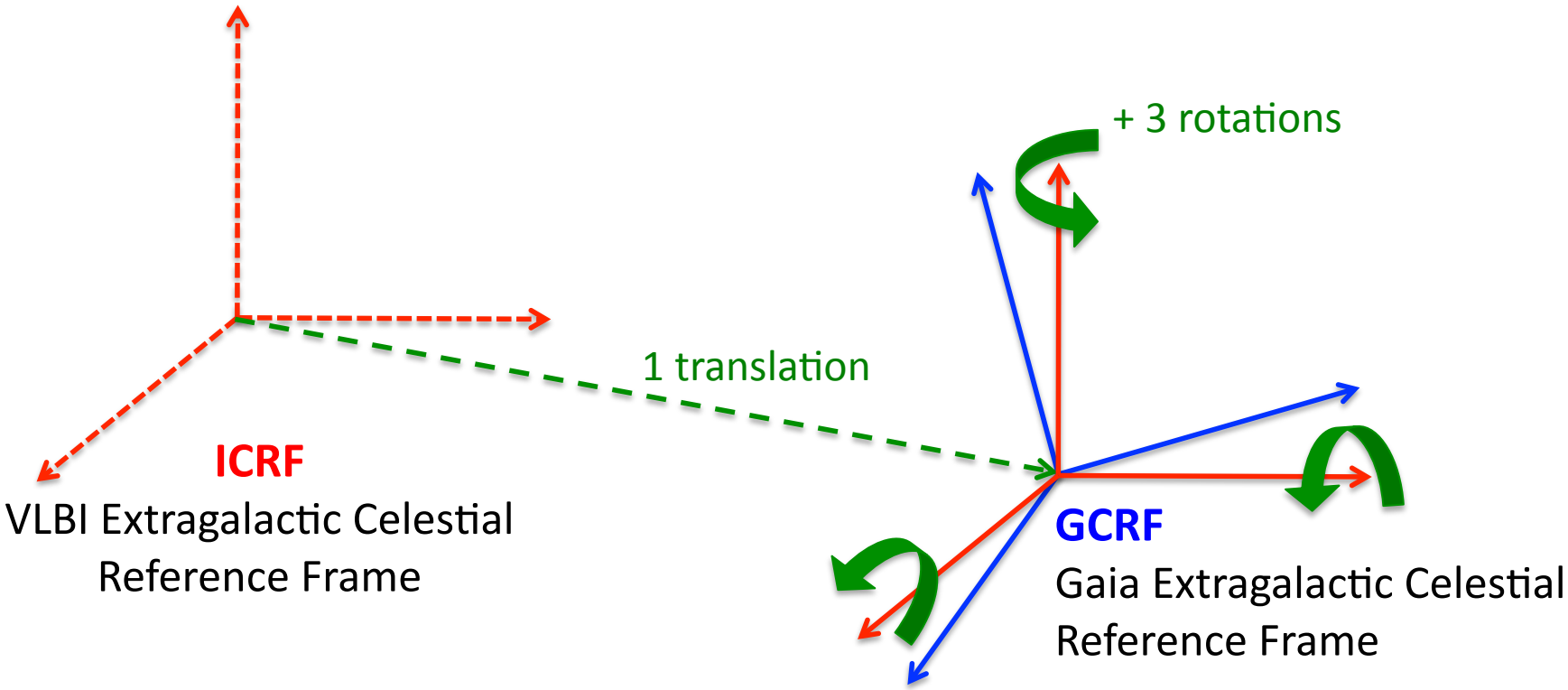

VLBI = Very Long Baseline Interferometry
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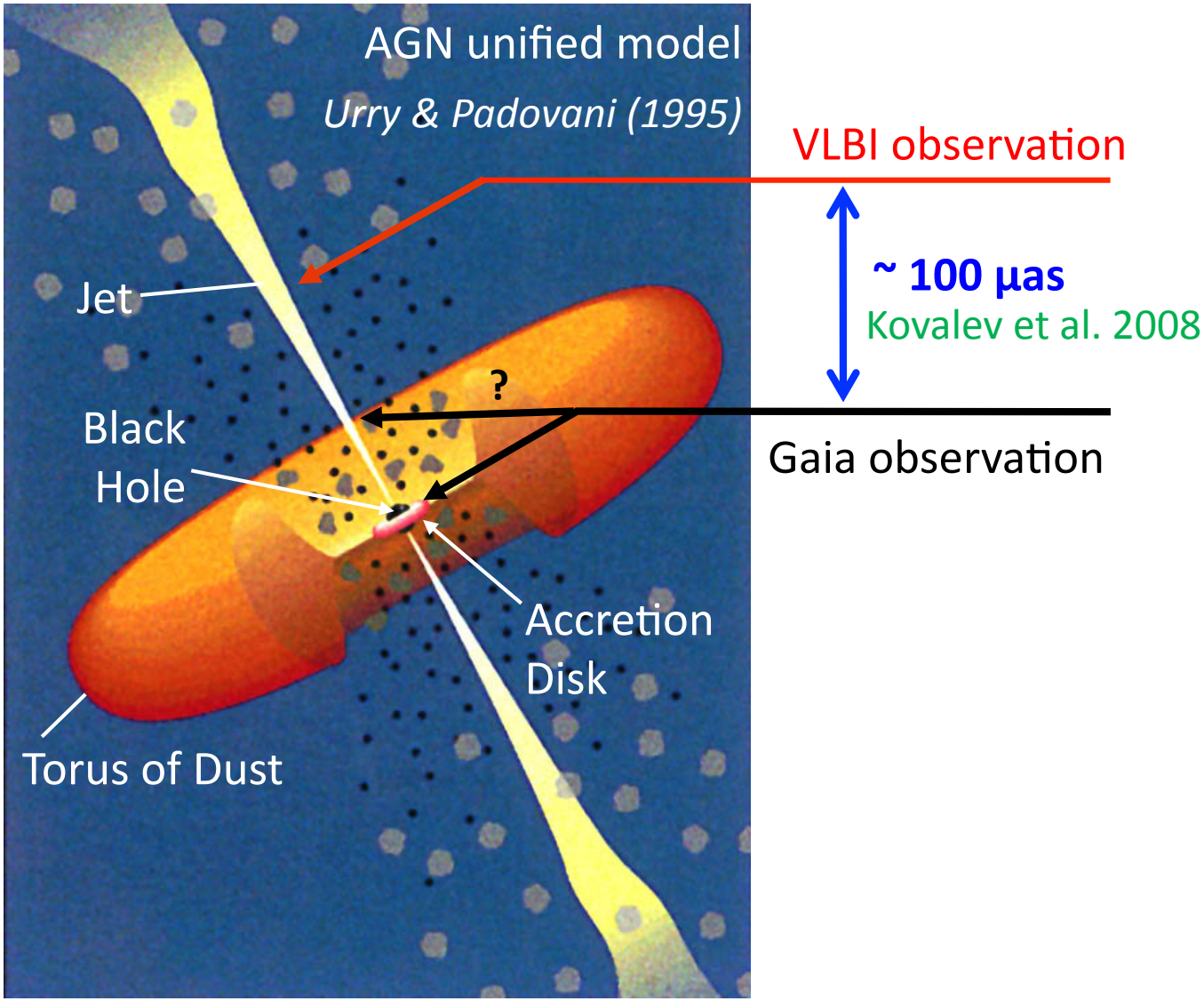
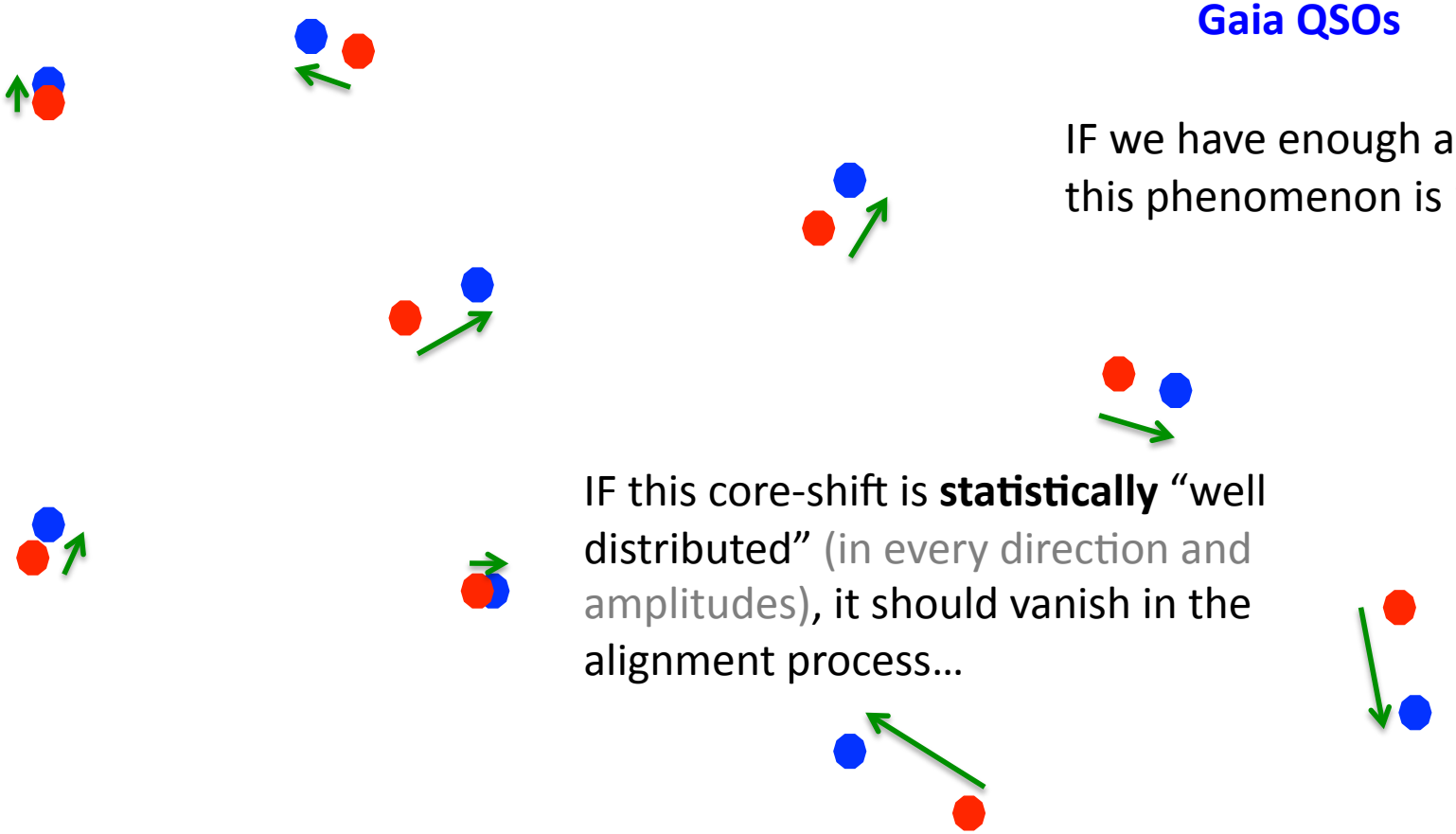
Frames Alignment – Real life

- VLBI & Gaia observations will not probe the same regions
- Interesting for astrophysical purposes: e.g. constraining the physical properties of AGNs
- <u>BUT</u>:
  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...

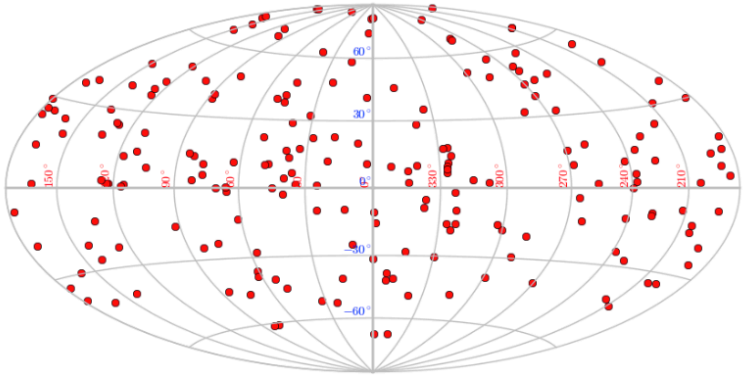
How minimizing core-shifts?

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
   - Half of which optically-bright
   - **1264 sources suitable**

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

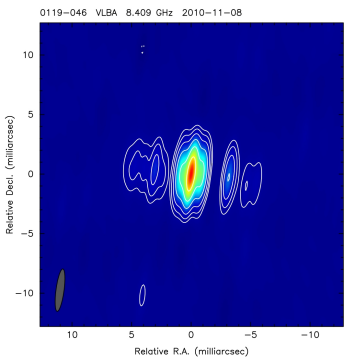
   – 0 < mag ≤ 20 from LQAC2

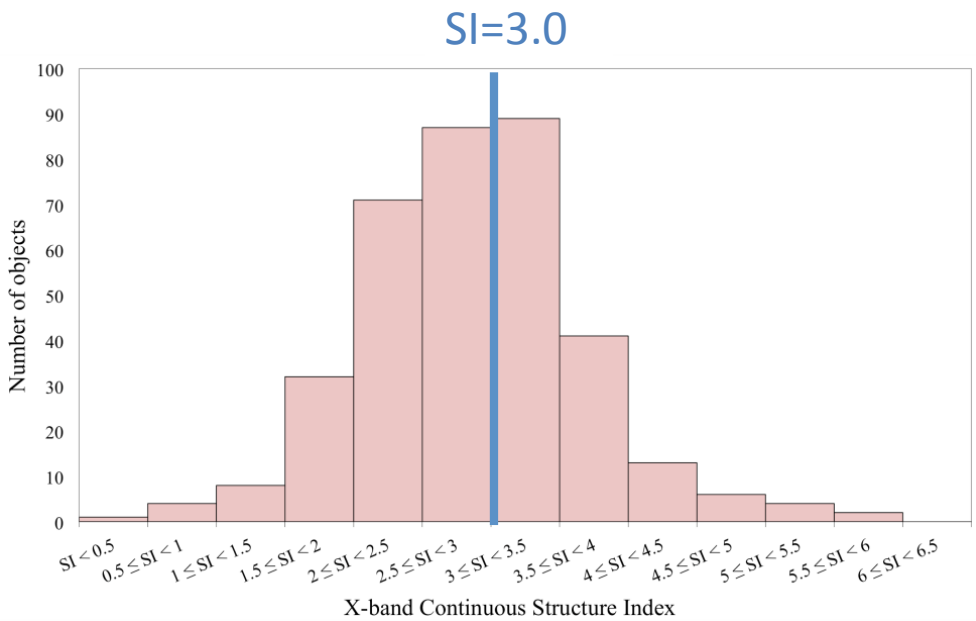
   – mag ≤ 18

2. Radio properties:
   - Structure index (SI) calculated
     - for all sources with images available (33%)
     - excluding VCS sources
   - **195 suitable sources**

     132 defining, 65 non-defining

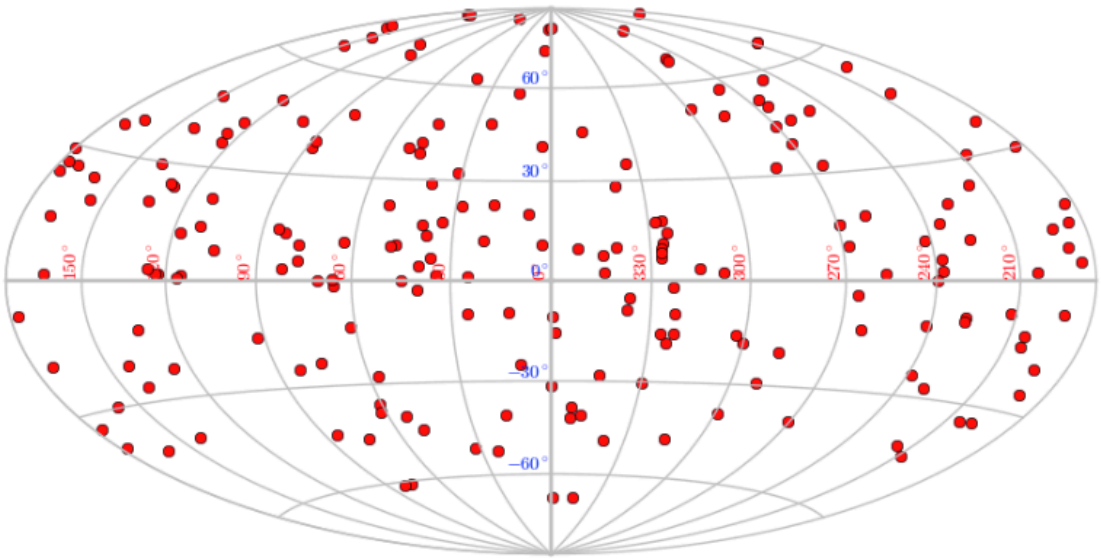
(Bourda & Charlot 2012)

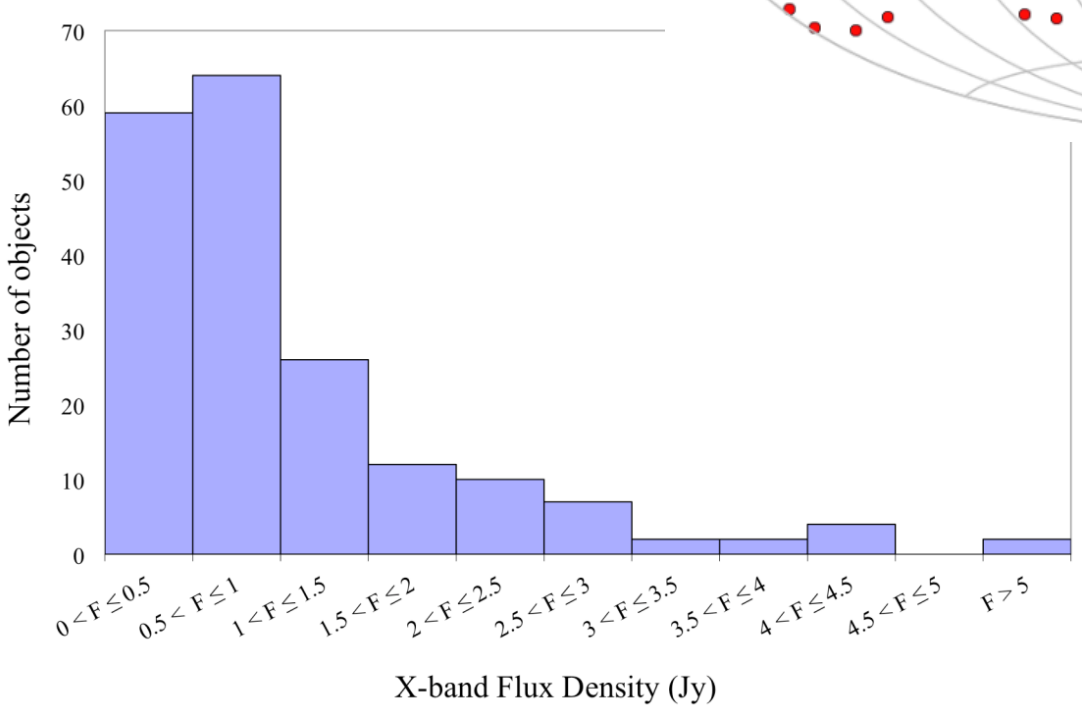




ICRF2 Transfer sources

Sky distribution of the 195 ICRF2 transfer sources





Flux density of the 195 ICRF2 transfer sources

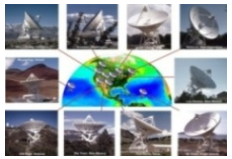
Median ~660 mJy

Transfer sources selection – 2

- VLBI project initiated to find additional transfer sources using EVN and VLBA
- Original sample:
  - 447 weak sources selected from NVSS ($\delta \geq -10°$)
  - 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

EUROPEAN vlbi NETWORK

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

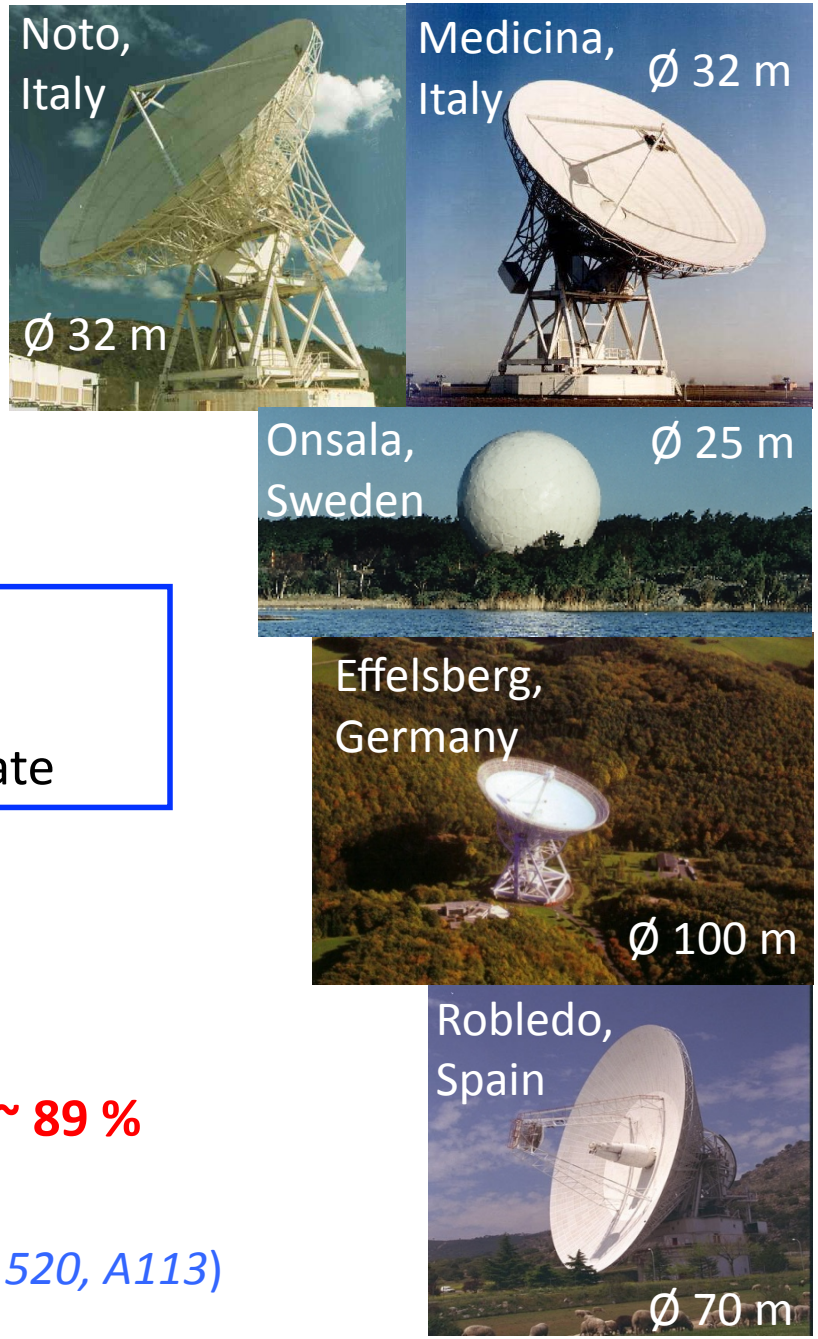
- S/X detection rates:

  EC025A ~ 96 %

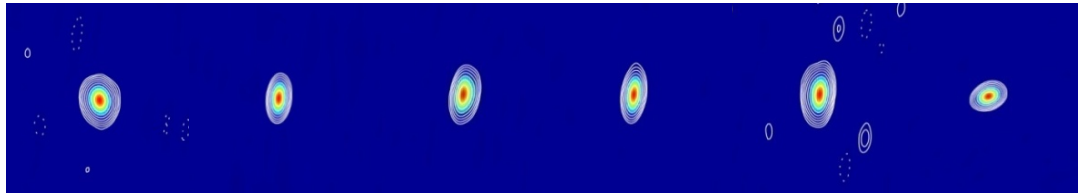
  EC025B ~ 82 %

  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%)**

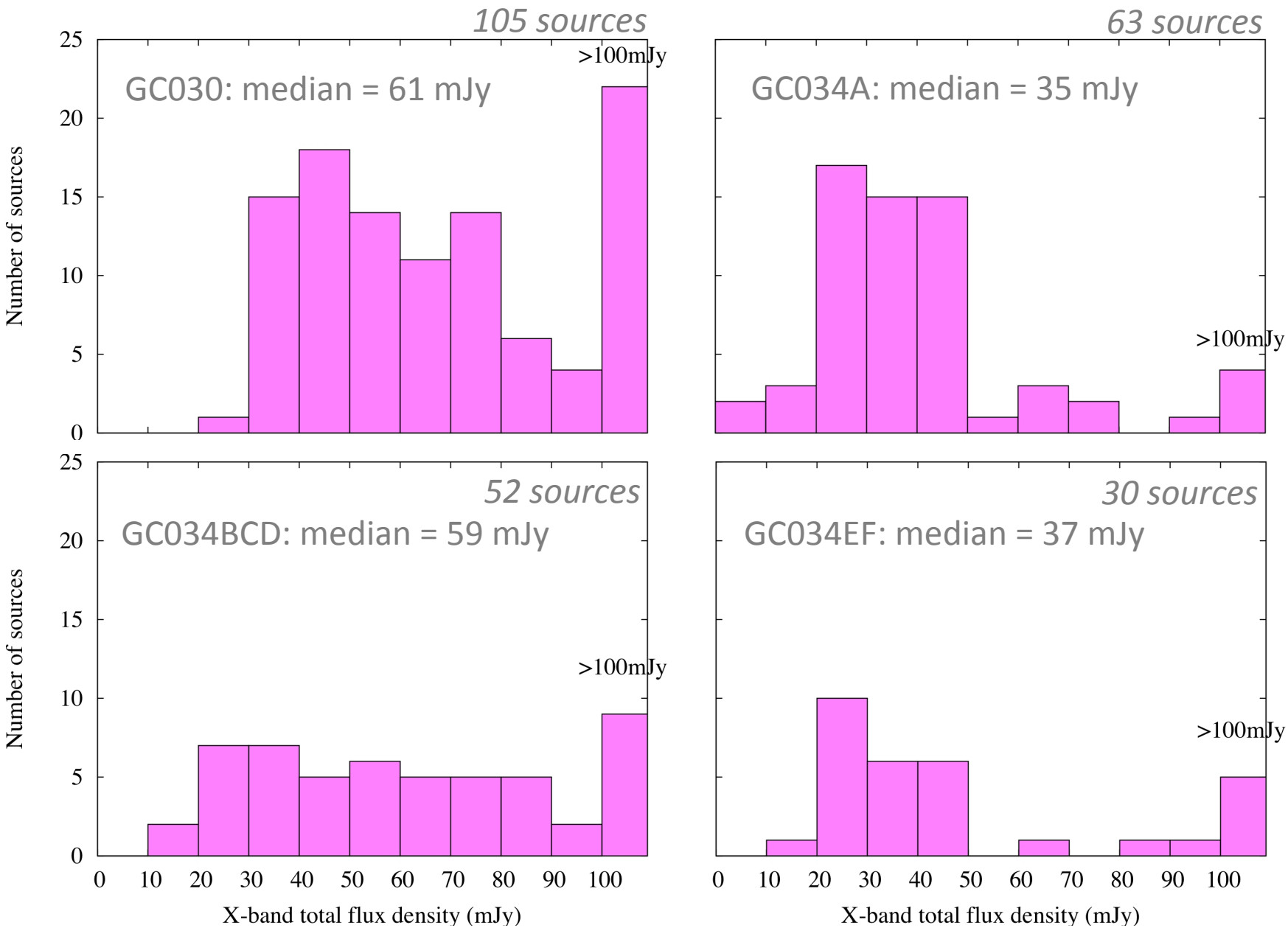
(Bourda et al., 2011, A&A)

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

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

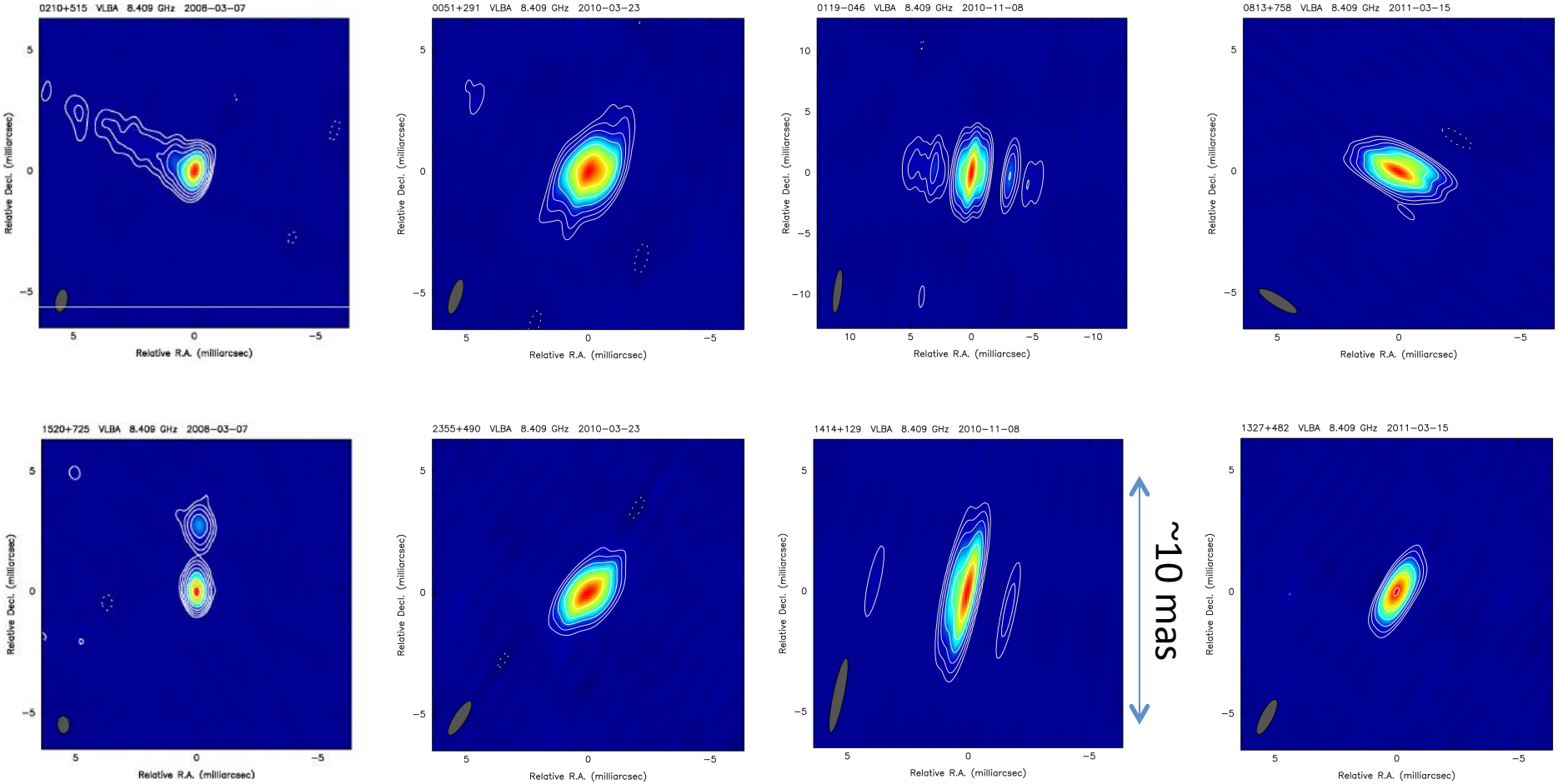
  → 119 VLBI sources suitable for the alignment

X-band Total Flux Density



Examples of VLBI maps for « bad » sources

GC030 GC034A GC034BCD GC034EF



X-band −1st contour level @ 1 − 4%

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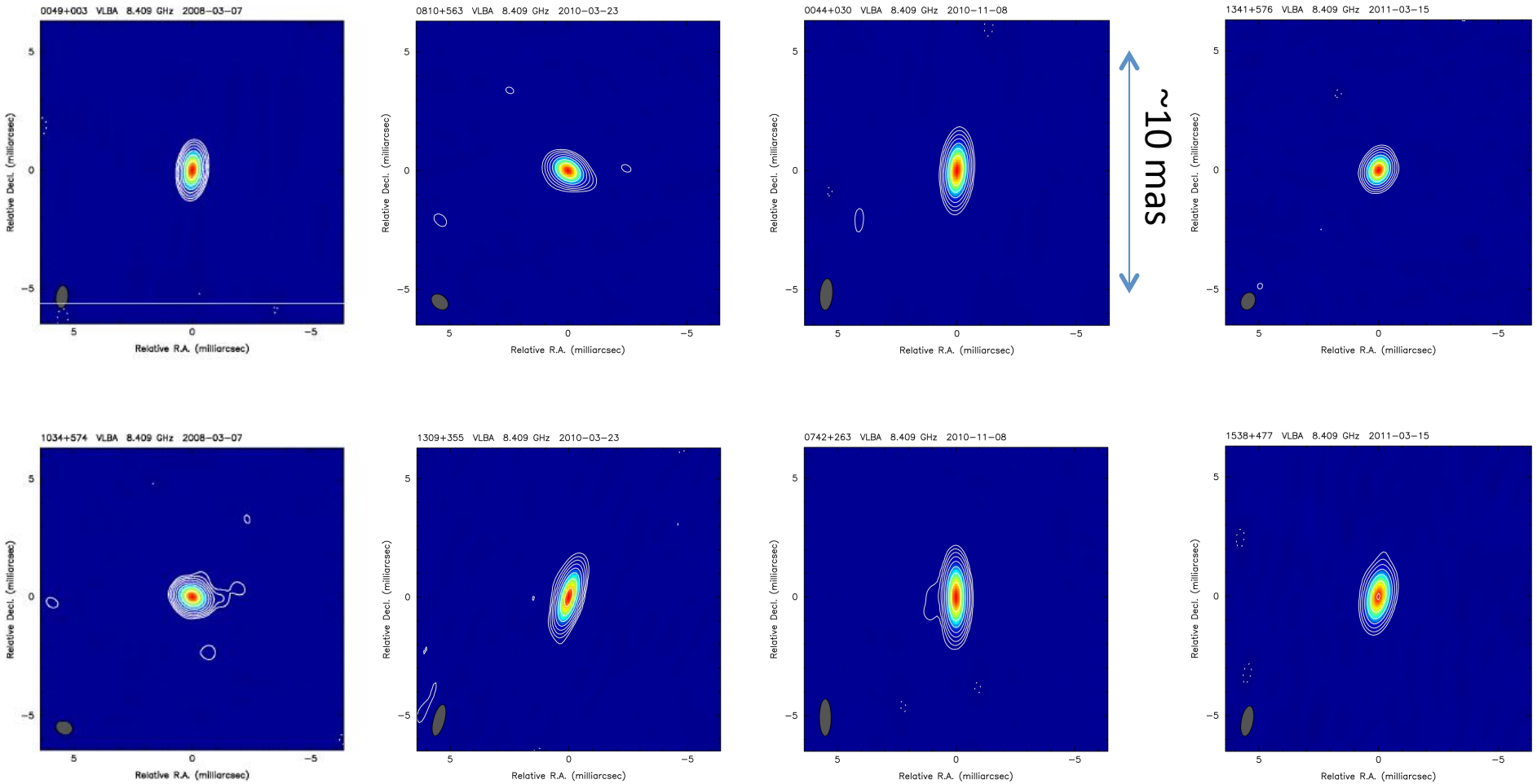
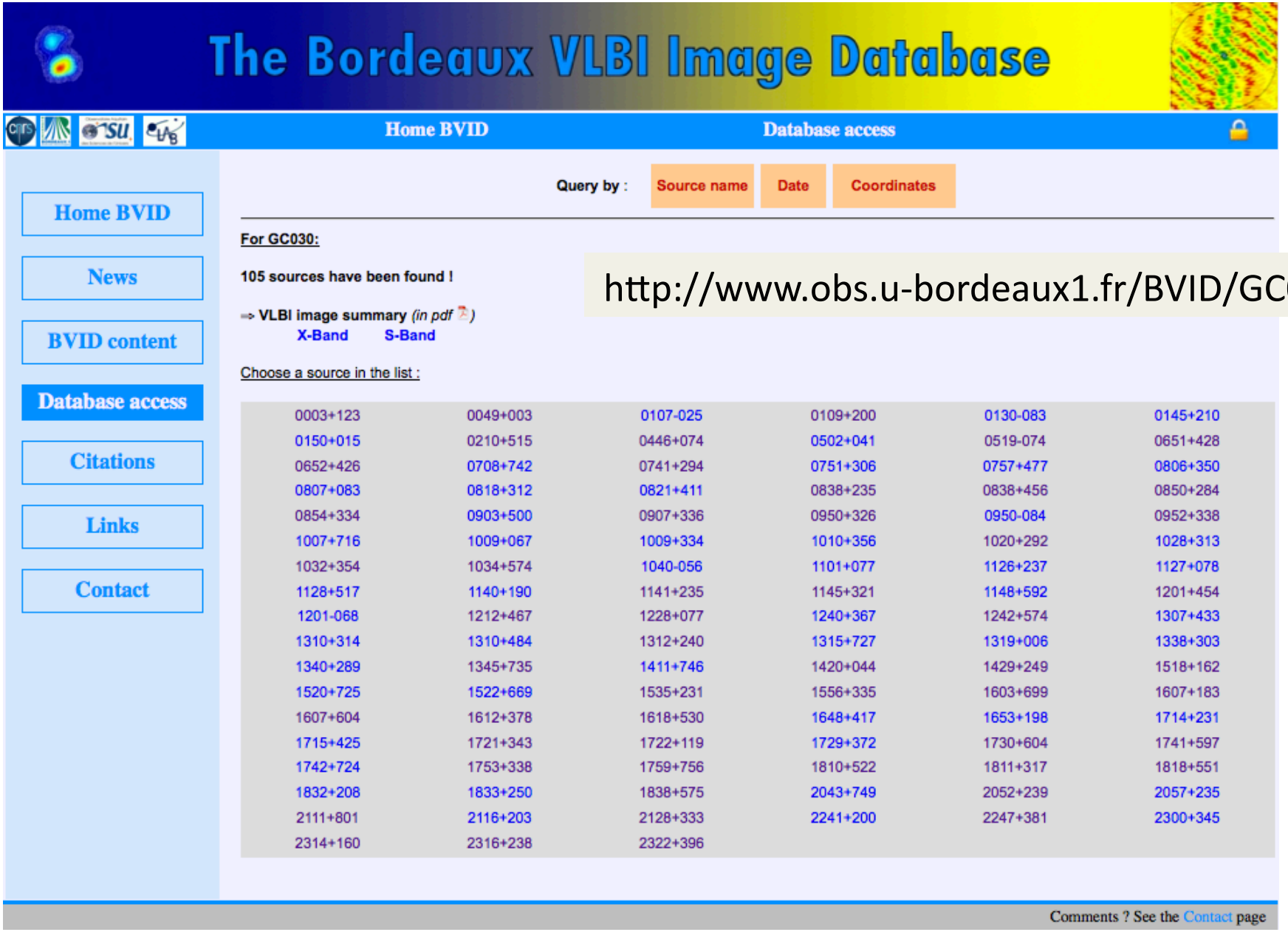


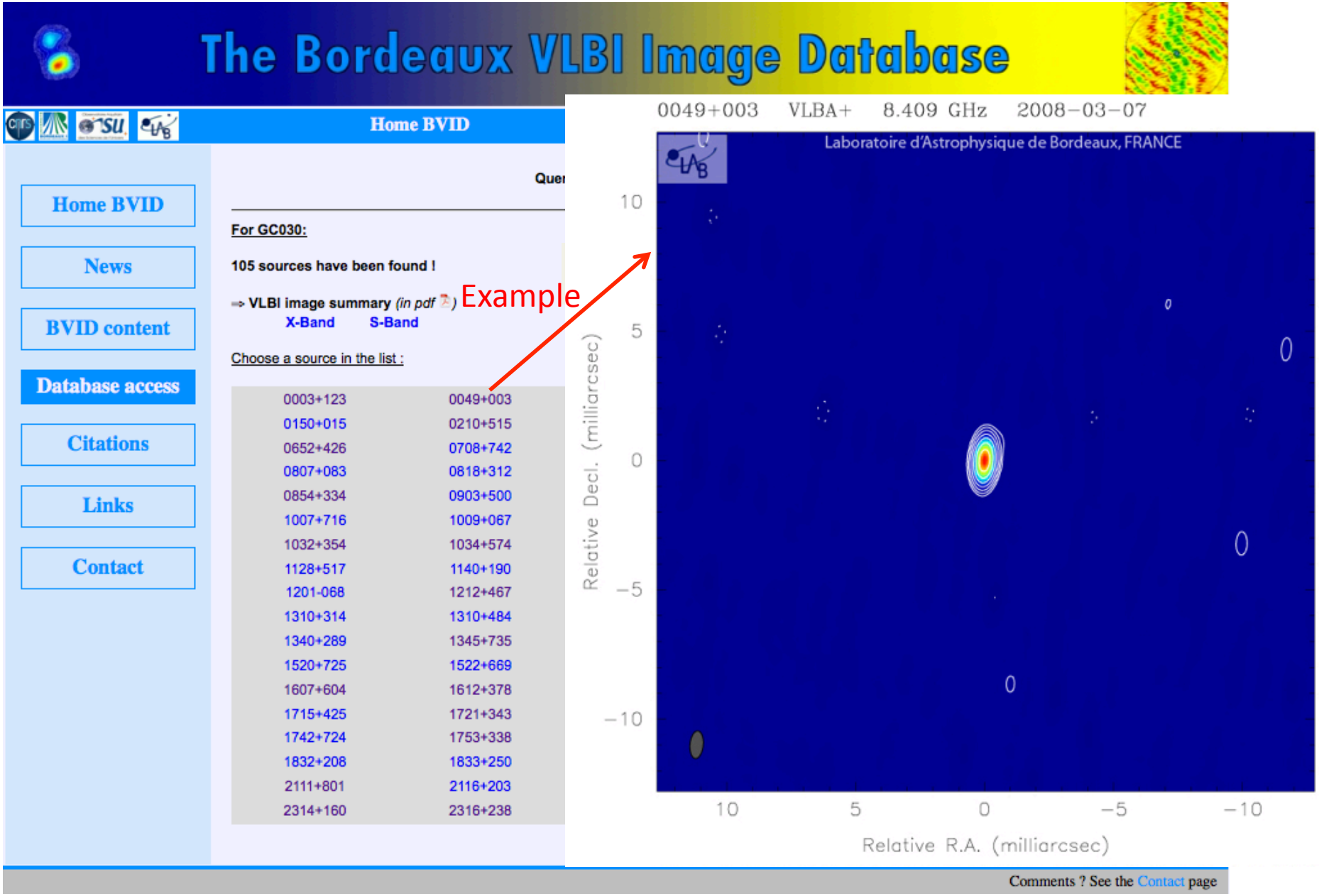
X-band –1st contour level @ 1 – 4%

VLBI Images in BVID



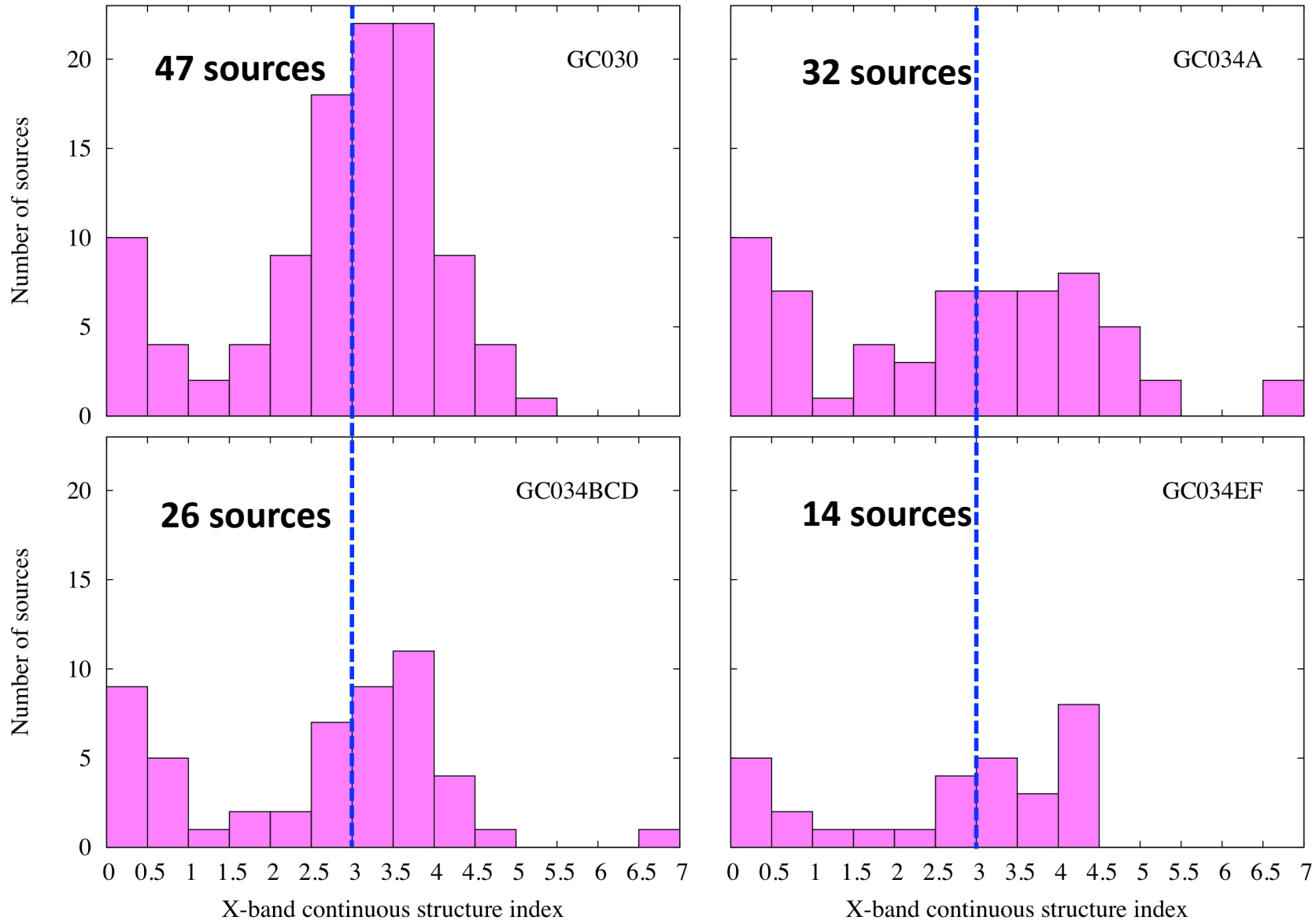
http://www.obs.u-bordeaux1.fr/BVID/GC030

VLBI Images in BVID



Astrometric suitability

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



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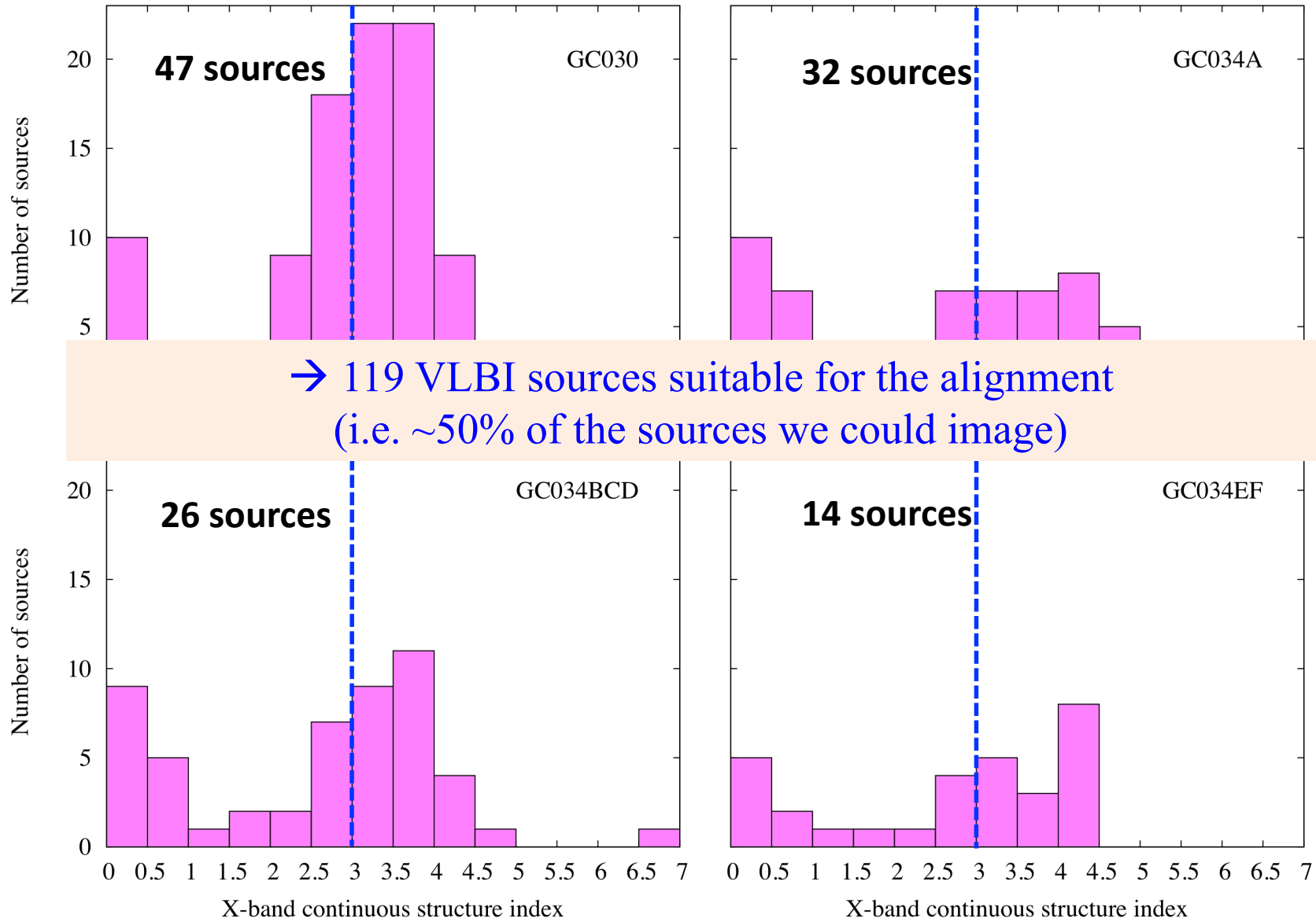
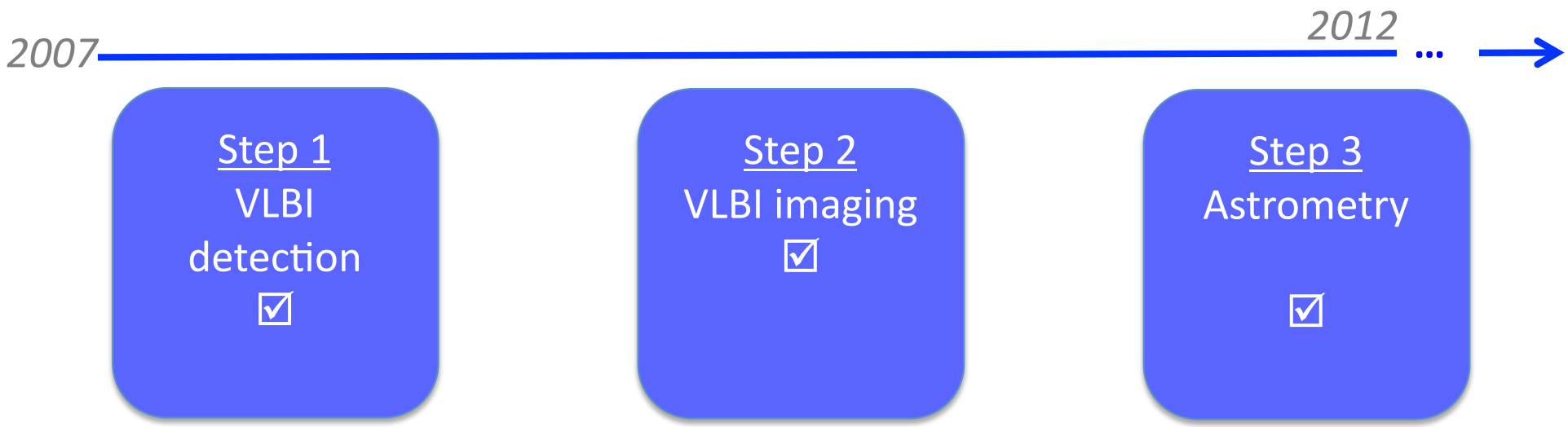


→ 119 VLBI sources suitable for the alignment
(i.e. ~50% of the sources we could image)

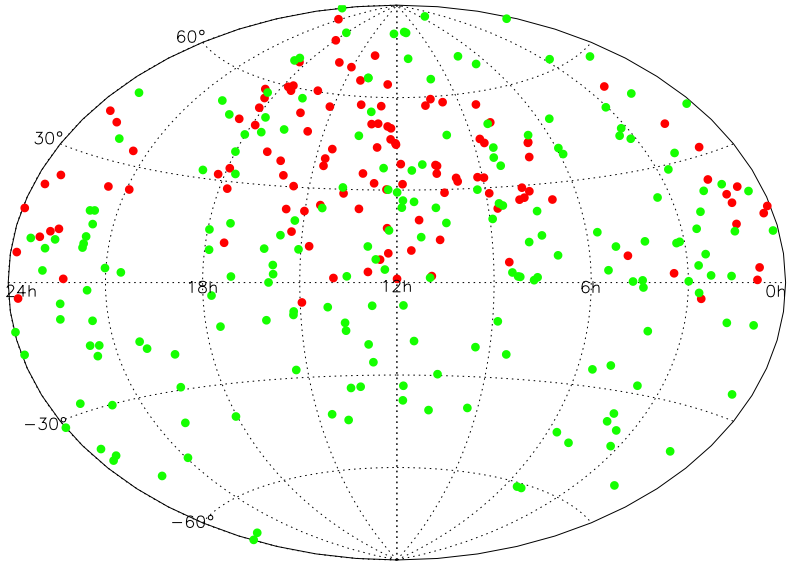
Step 3: Astrometry

- ✓ 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

- <u>ICRF2 transfer sources</u>
  - LQAC3 vs. OCARS
  - VCS sources to investigate in terms of SI
  - Cross checking with respect to optical properties

ICRF3 Working Group

- <u>Current # of transfer sources</u>:

  ~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