Global VLBI observations of weak extragalactic radio sources:

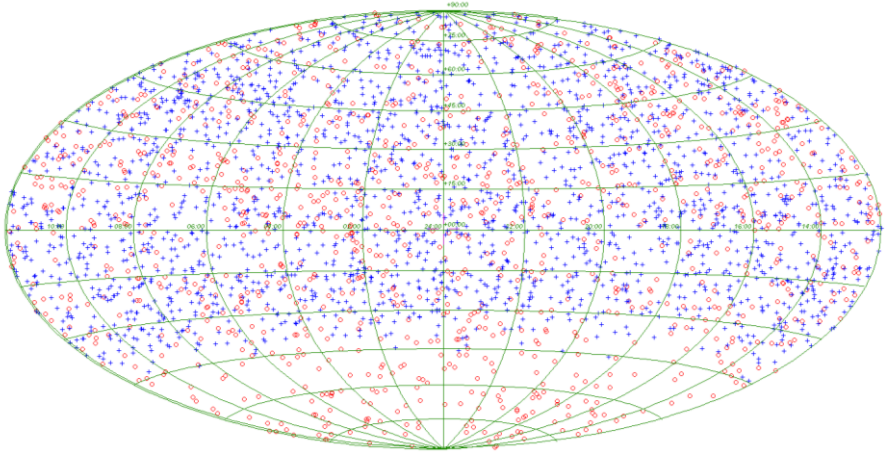
Imaging of candidates to align the VLBI and Gaia frames

G. Bourda	Laboratoire d'Astrophysique de Bordeaux (LAB), France
A. Collioud	LAB, France
P. Charlot	LAB, France
R. Porcas	MPIfR, Bonn, Germany
S. Garrington	Jodrell Bank Observatory, UK

Context

By 2015-2020: Two extragalactic celestial reference frames available

VLBI (Radio)



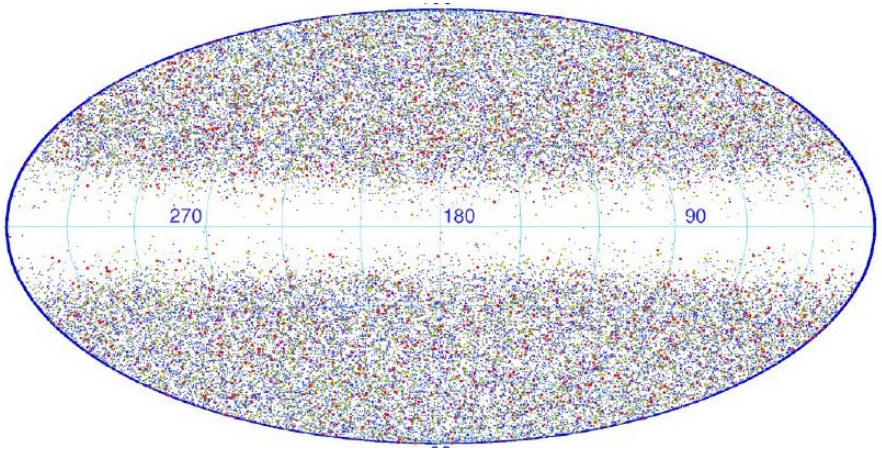
Position accuracy:

1997: ICRF1 − 717 sources − $\sigma \geq 250$ µas

2009: ICRF2 − 3414 sources − $\sigma \geq 40$ µas

2020: ICRF3 ???

Gaia (Optical magnitude ≤ 20)



Anticipated position accuracy:

2015−2020: ~10 000 − 20 000 QSOs /

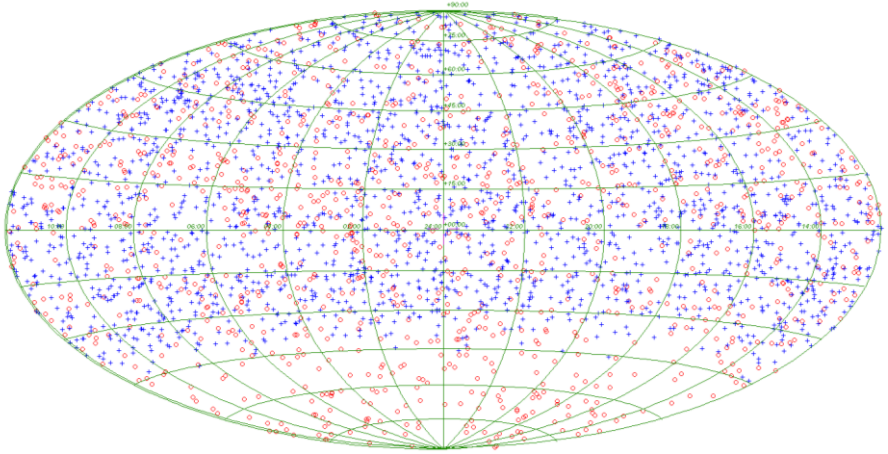
16 µas ≤ σ ≤ 70 µas @ 15 ≤ V ≤ 18

Lindegren et al., 2008

Context

By 2015-2020: Two extragalactic celestial reference frames available

VLBI (Radio)



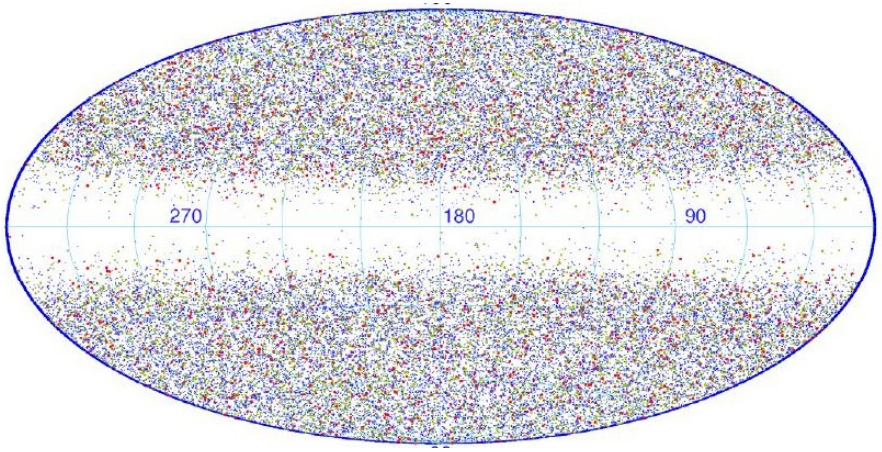
Position accuracy:

1997: ICRF1 – 717 sources – $\sigma \geq 250$ µas

2009: ICRF2 – 3414 sources – $\sigma \geq 40$ µas

2020: ICRF3 ???

Gaia (Optical magnitude ≤ 20)



Anticipated position accuracy:

2015–2020: ~10 000 – 20 000 QSOs /

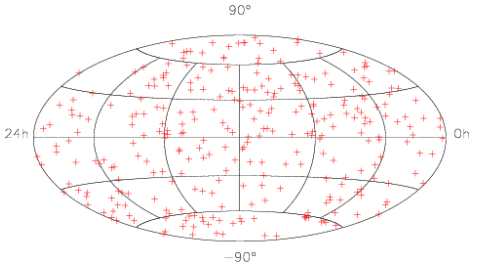
16 µas $\leq \sigma \leq$ 70 µas @ $15 \leq V \leq 18$

Lindegren et al., 2008

Linking these 2 frames is important:

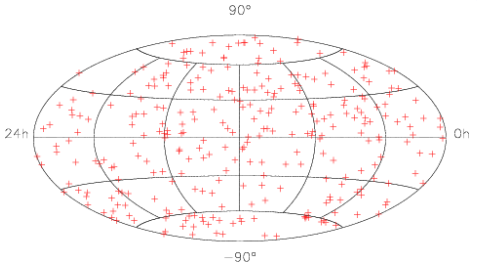
- to ensure continuity of the fundamental celestial reference frame
- to register optical & radio positions with the highest accuracy

Gaia-Radio frames alignment



- **Requirements:**
  - ✓ Several hundreds of common sources
  - ✓ With a uniform sky coverage
  - ✓ Link sources must have:
    - Accurate Gaia position → Optically-bright (V ≤ 18)
    - Accurate VLBI position → Good astrometric quality (point-like VLBI structure)

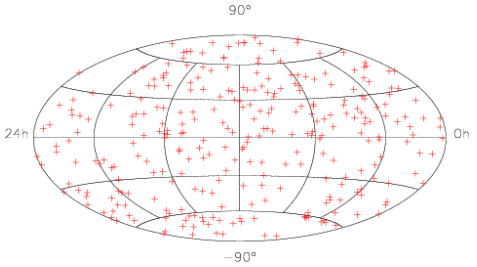
Gaia-Radio frames alignment



- **Requirements:**
  - ✓ Several hundreds of common sources
  - ✓ With a uniform sky coverage
  - ✓ Link sources must have:
    - Accurate Gaia position → Optically-bright (V ≤ 18)
    - Accurate VLBI position → Good astrometric quality (point-like VLBI structure)

- **Current status:**
  - ✓ ICRF1: 10% of ICRF1 sources suitable (*Bourda et al., 2008*)
  - ✓ ICRF2: < 50% of *defining* sources with a proper optical counterpart

Gaia-Radio frames alignment



- **Requirements:**
  - ✓ Several hundreds of common sources
  - ✓ With a uniform sky coverage
  - ✓ Link sources must have:
    - Accurate Gaia position → Optically-bright (V ≤ 18)
    - Accurate VLBI position → Good astrometric quality (point-like VLBI structure)

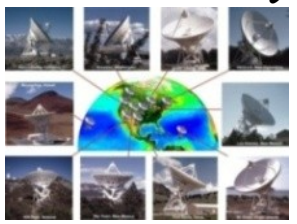
- **Current status:**
  - ✓ ICRF1: 10% of ICRF1 sources suitable (*Bourda et al., 2008*)
  - ✓ ICRF2: < 50% of *defining* sources with a proper optical counterpart

➡ Need to find new radio sources suitable for accurate Gaia–VLBI alignment

Our project

EUROPEAN vlbi NETWORK

Very Long Baseline Array

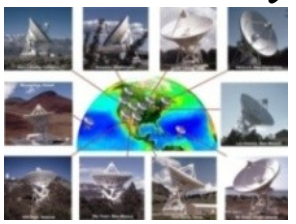


- Idea: New candidates → Weak sources
- Specific VLBI observing program designed (with EVN & VLBA)

Our project

EUROPEAN VLBI NETWORK

Very Long Baseline Array



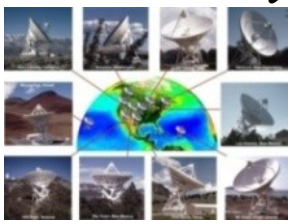
- Idea: New candidates → Weak sources
- Specific VLBI observing program designed (with EVN & VLBA)
- Observing Sample: 447 weak extragalactic radio sources
  - ✓ NVSS catalog (excluding ICRF and VCS sources)
  - ✓ Optical magnitude $V \leq 18$
  - ✓ Total flux density (NVSS) ≥ 20 mJy
  - ✓ $\delta \geq -10^{o}$

NRAO VLA Sky Survey
(Condon et al., 1998)

Our project

EUROPEAN VLBI NETWORK

Very Long Baseline Array



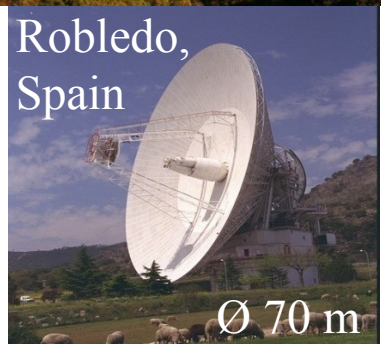
- Idea: New candidates → Weak sources
- Specific VLBI observing program designed (with EVN & VLBA)
- Observing Sample: 447 weak extragalactic radio sources
  - ✓ NVSS catalog (excluding ICRF and VCS sources)
  - ✓ Optical magnitude V ≤ 18
  - ✓ Total flux density (NVSS) ≥ 20 mJy
  - ✓ $\delta \geq -10^{o}$

NRAO VLA Sky Survey
(Condon et al., 1998)

- Observing Strategy:
  1. VLBI detection (*Bourda et al., 2010a, A&A submitted*)
  2. Imaging (*Bourda et al., 2010b, A&A submitted*)
  3. Accurate astrometry (for the most compact sources)

Step 1: VLBI detection

- Two 48-hours experiments
  (S/X dual-frequency geodetic style @ 1Gb/s)
  - EC025A: June 2007 – 224 sources
  - EC025B: October 2007 – 223 sources



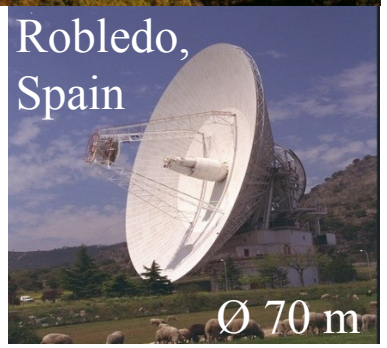
Step 1: VLBI detection

- Two 48-hours experiments
  (S/X dual-frequency geodetic style @ 1Gb/s)
  - EC025A: June 2007 – 224 sources
  - EC025B: October 2007 – 223 sources

Weak sources in VLBI

➡ High sensitivity necessary

➡ Need large antennas & high recording rate



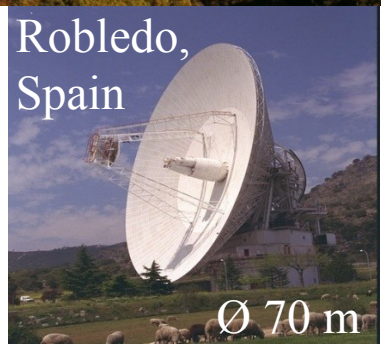
Step 1: VLBI detection

- Two 48-hours experiments
  (S/X dual-frequency geodetic style @ 1Gb/s)
  - EC025A: June 2007 – 224 sources
  - EC025B: October 2007 – 223 sources

Weak sources in VLBI

➡ High sensitivity necessary

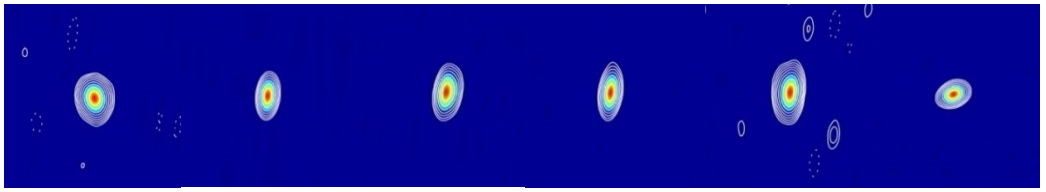
➡ Need large antennas & high recording rate



- S/X detection rates:
  - EC025A ~ 94 %
  - EC025B ~ 82 %

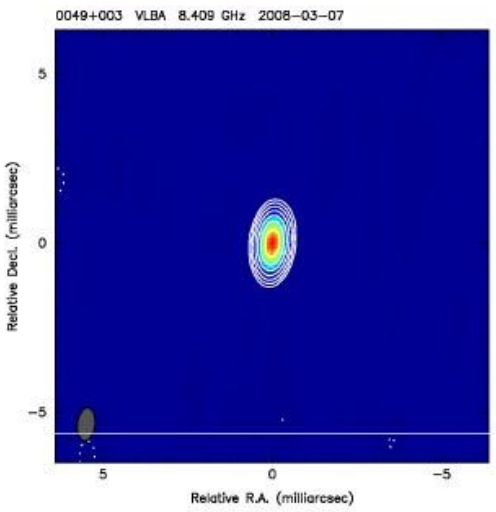
  Overall detection rate: ~ **89 %**
  (398 sources detected)

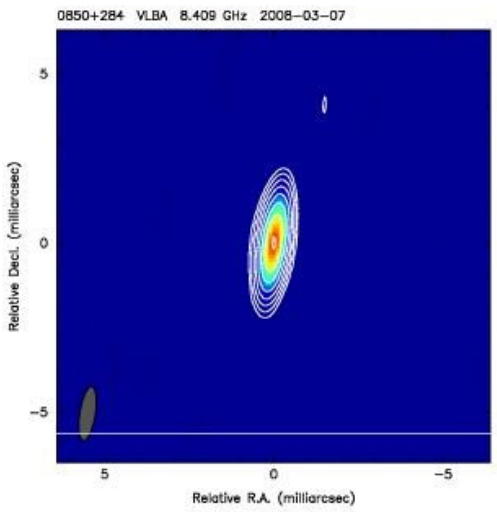
Step 2: Imaging

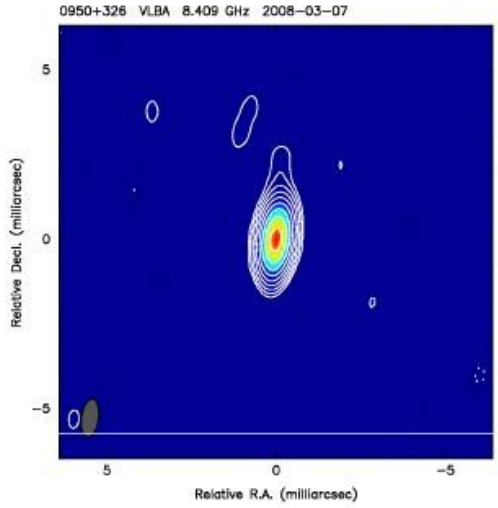


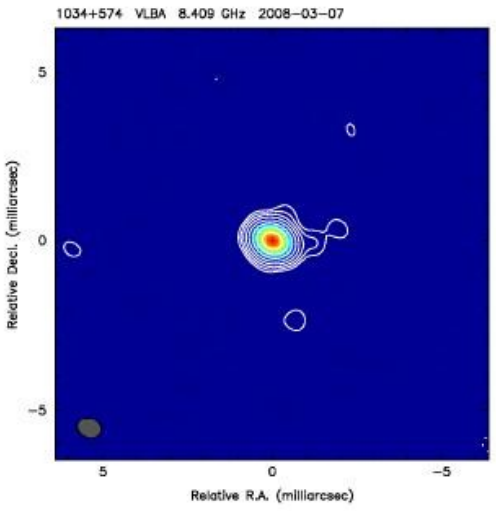
- **Pilot imaging experiment**
  - ✓ 25% of the sources detected
  - ✓ March 2008 − 48 hours
  - ✓ Global VLBI array (VLBA + EVN)
  - ✓ S/X dual-frequency geodetic style @ 512 Mb/s

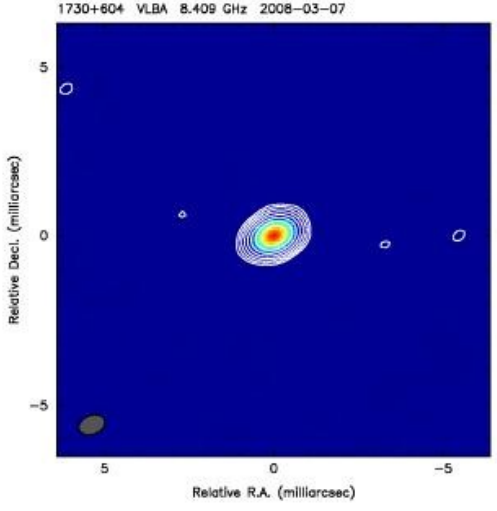
Some very good link sources

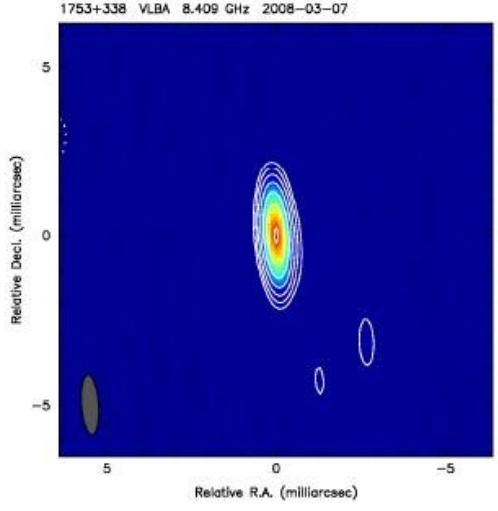




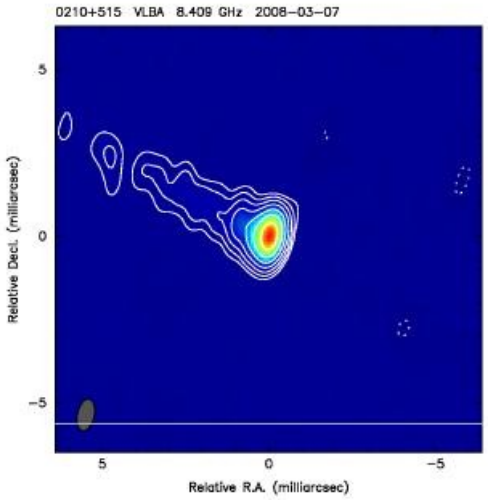


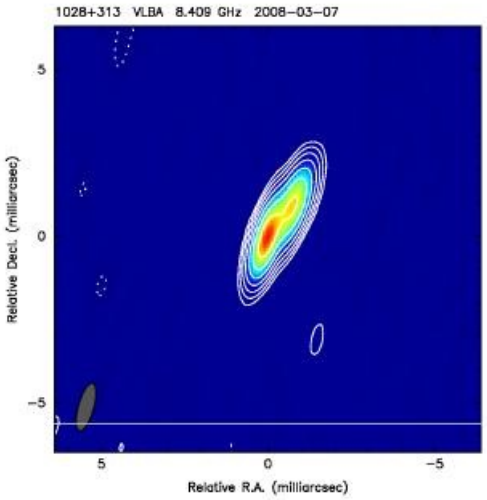


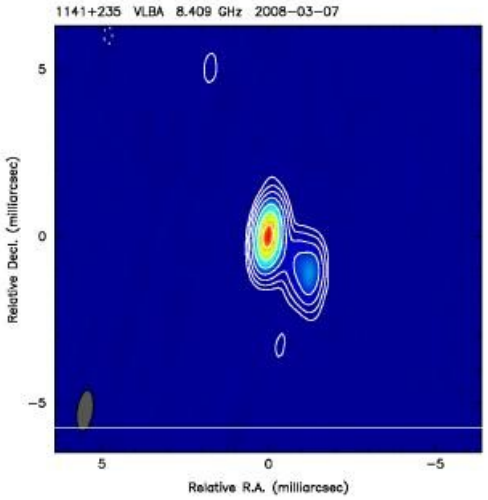


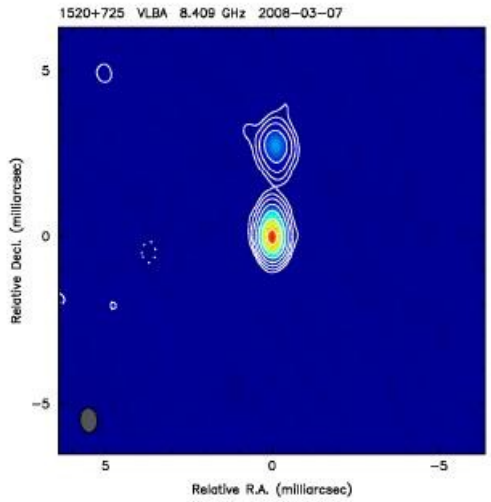


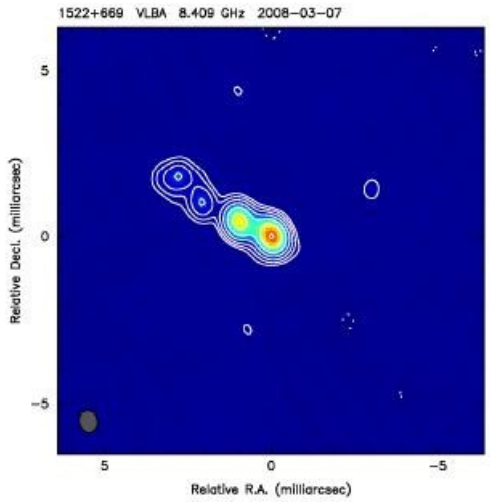
but also some not so good link sources…

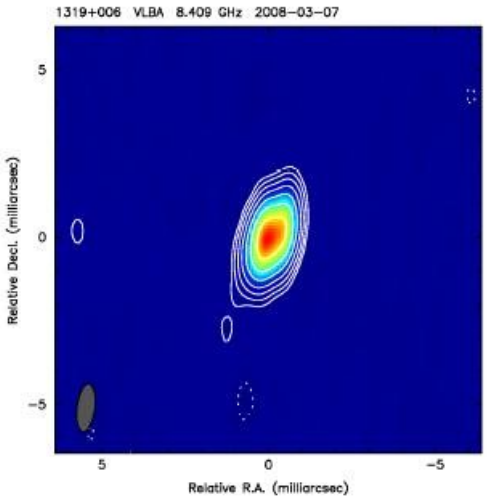


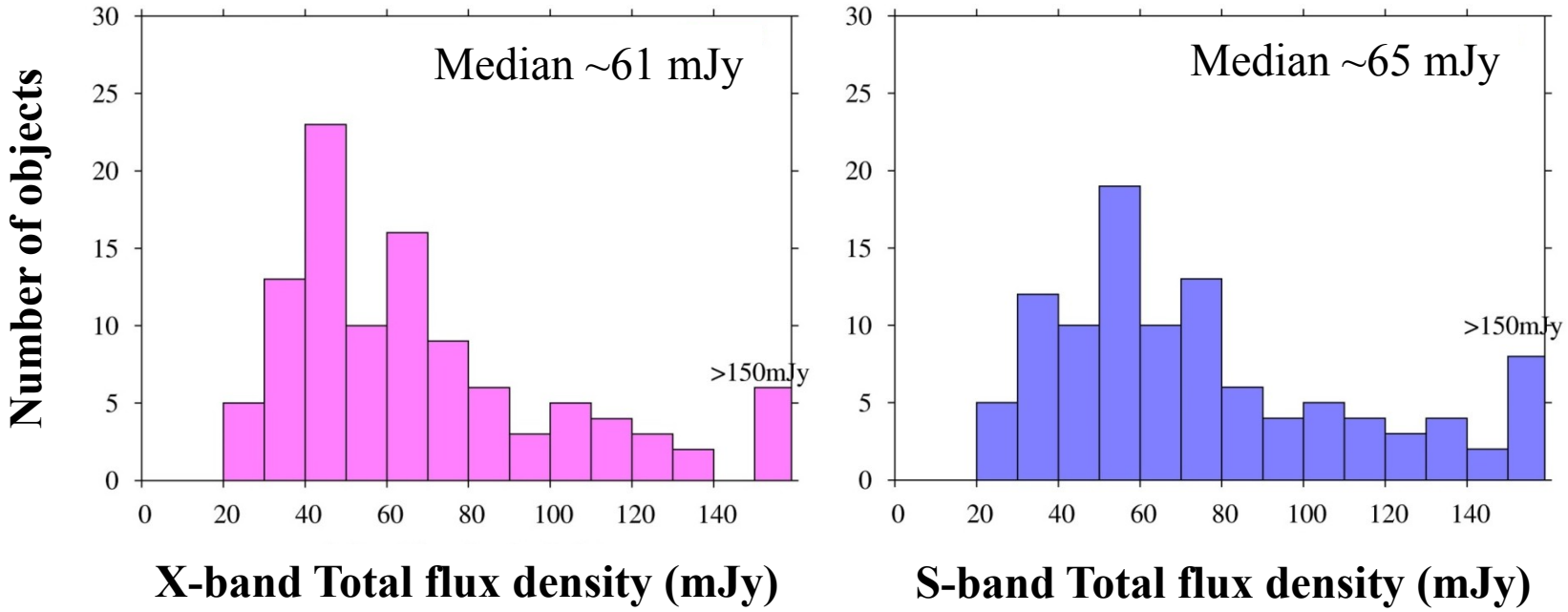


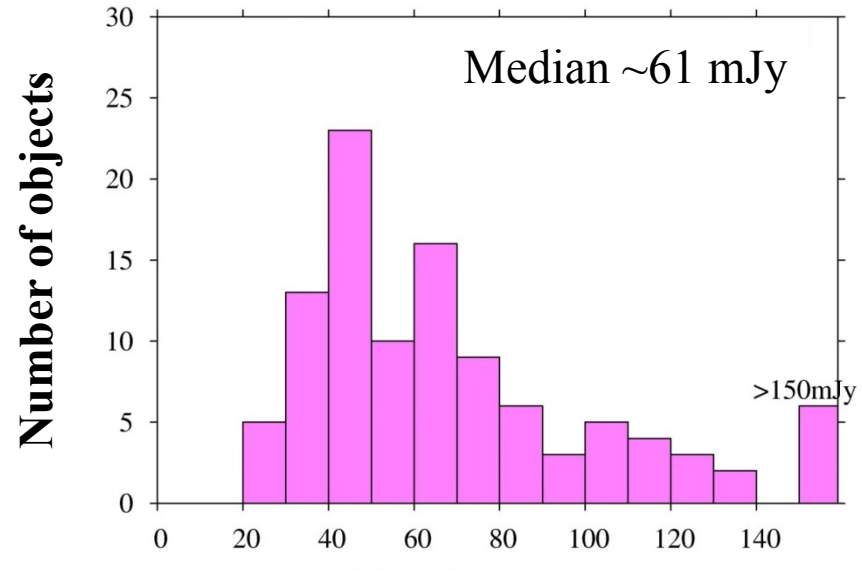


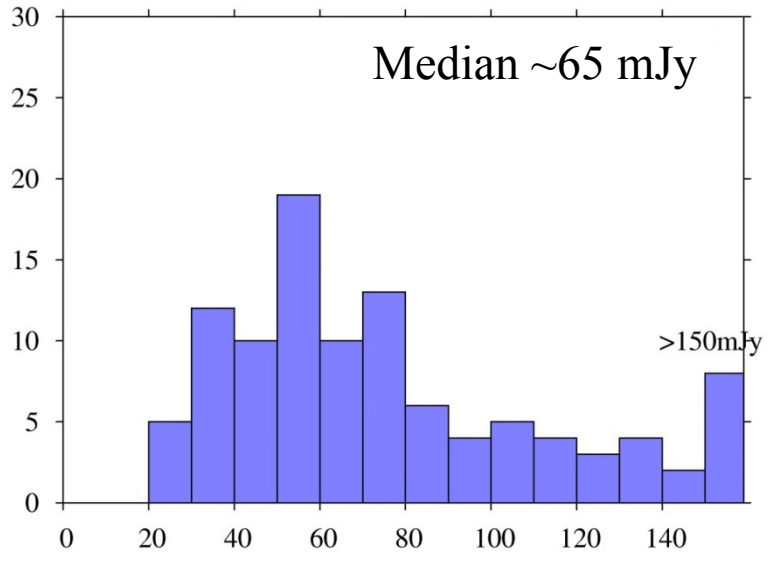


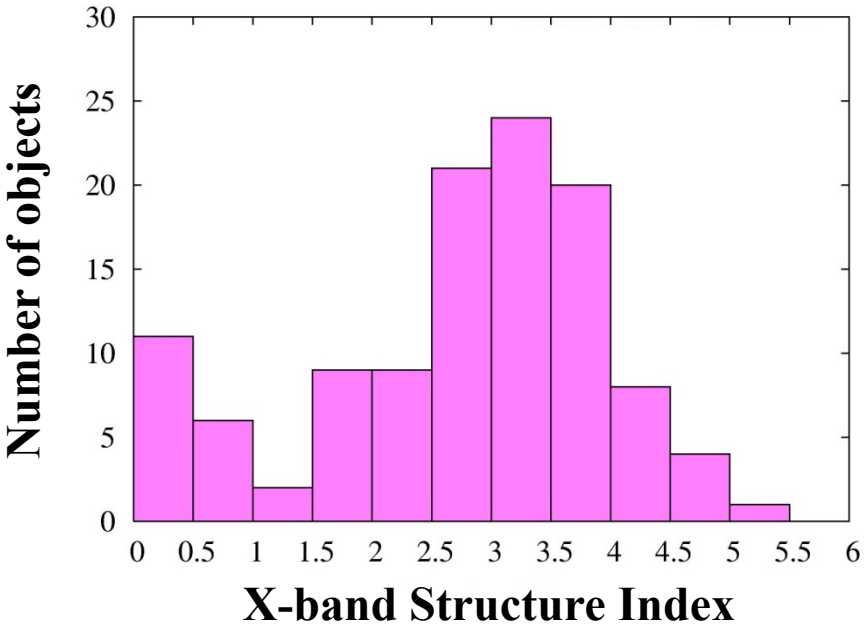


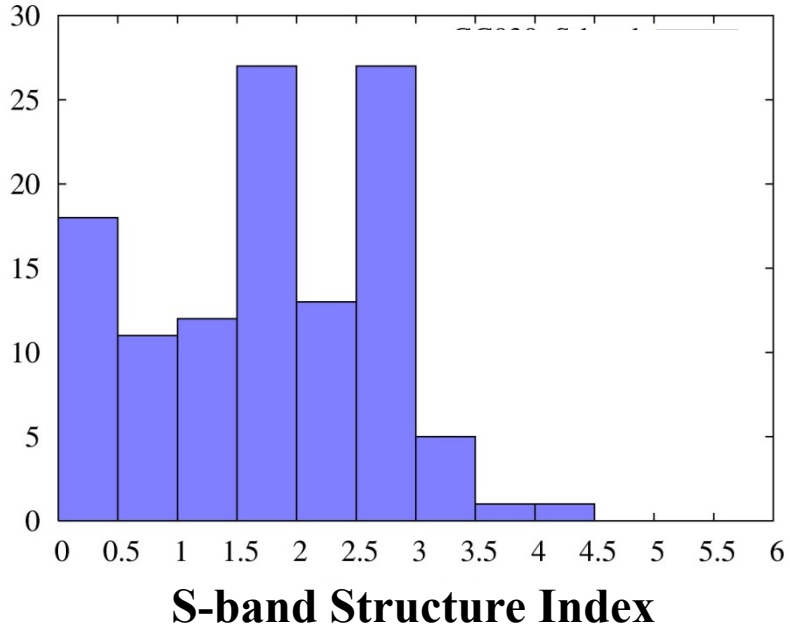


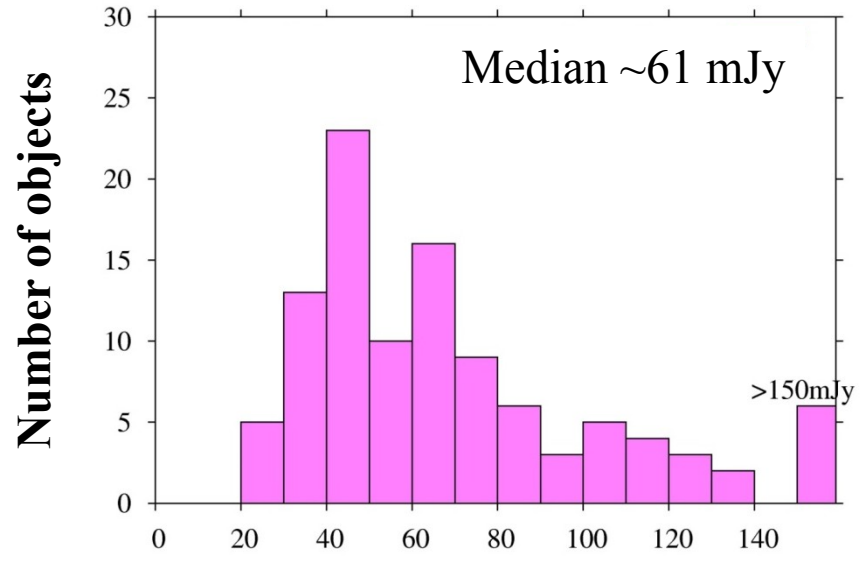

Number of objects
Median ~61 mJy
>150mJy
X-band Total flux density (mJy)
Median ~65 mJy
>150mJy
S-band Total flux density (mJy)

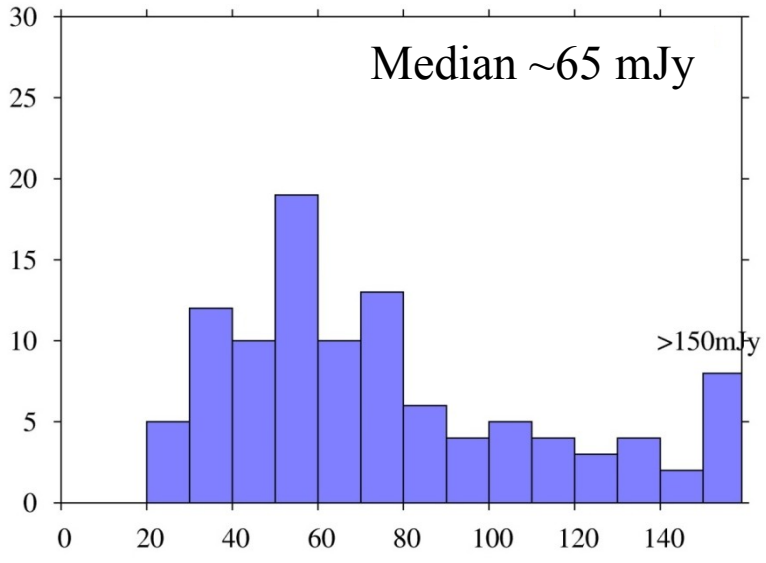

Median ~61 mJy
>150mJy
Number of objects
X-band Total flux density (mJy)

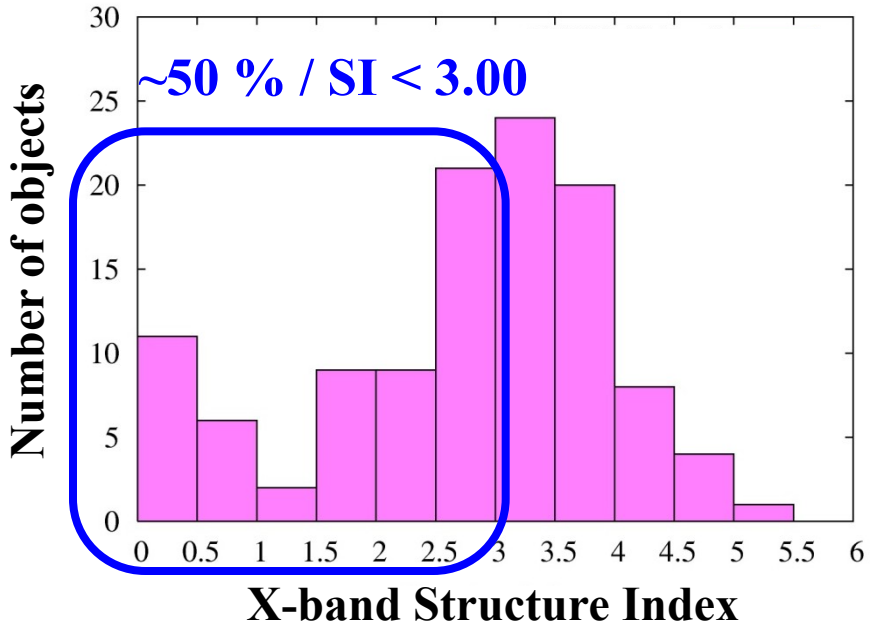

Median ~65 mJy
>150mJy
S-band Total flux density (mJy)

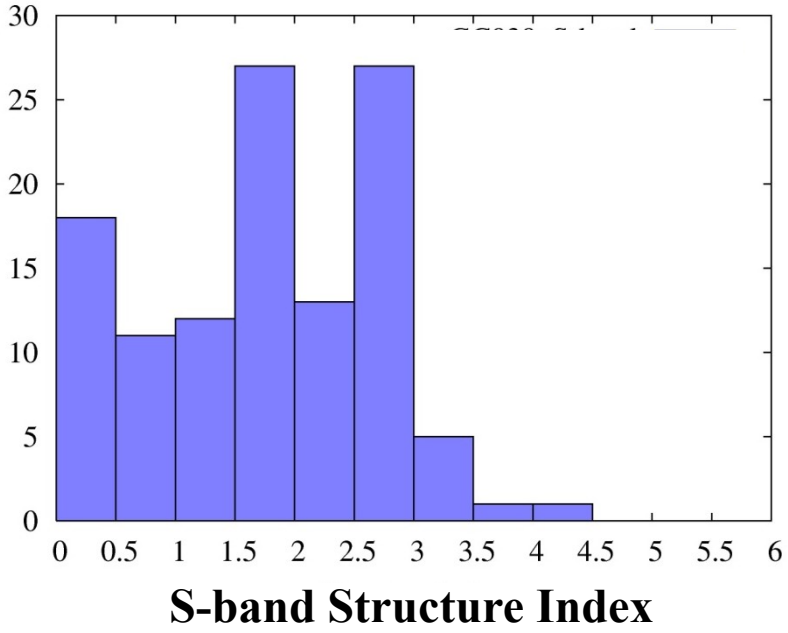

Number of objects
X-band Structure Index


S-band Structure Index

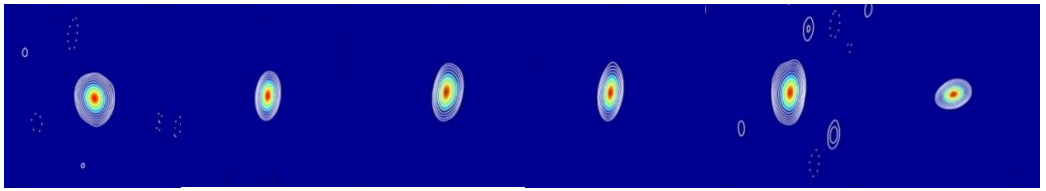

Median ~61 mJy
>150mJy
Number of objects
X-band Total flux density (mJy)


Median ~65 mJy
>150mJy
S-band Total flux density (mJy)


~50 % / SI < 3.00
Number of objects
X-band Structure Index

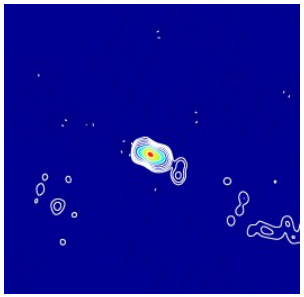

S-band Structure Index

Step 2: Imaging



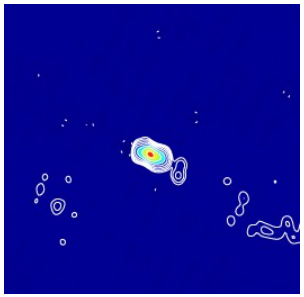
- **Pilot imaging experiment**
  - ✓ 25% of the sources detected
  - ✓ March 2008 − 48 hours
  - ✓ Global VLBI array (VLBA + EVN)
  - ✓ S/X dual-frequency geodetic style @ 512 Mb/s
- **Results**
  - ✓ All 105 sources successfully imaged at both X & S bands
  - ✓ Dynamic range 1:100
  - ✓ **~50% point-like or compact sources**

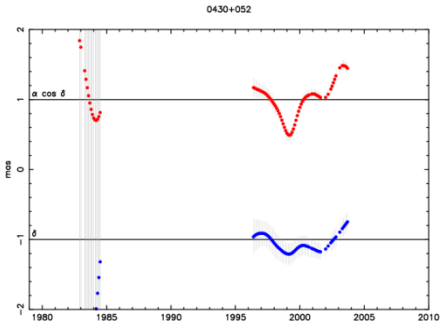
Next stages



- **VLBI imaging follow up**
  - ✓ 293 remaining sources
  - ✓ **Proposal submitted in October 2009 – 144 hours**
  - ✓ **Accepted** (2 or 3 sessions) → Begins in March 2010

Next stages





- **VLBI imaging follow up**
  - ✓ 293 remaining sources
  - ✓ **Proposal submitted in October 2009 – 144 hours**
  - ✓ **Accepted** (2 or 3 sessions) → Begins in March 2010

- **Astrometry**
  - ✓ Carry out global astrometry on the most compact sources (200 ?)
  - ✓ Positions wanted to better than <100 μas
  - ✓ Proposal in 2010

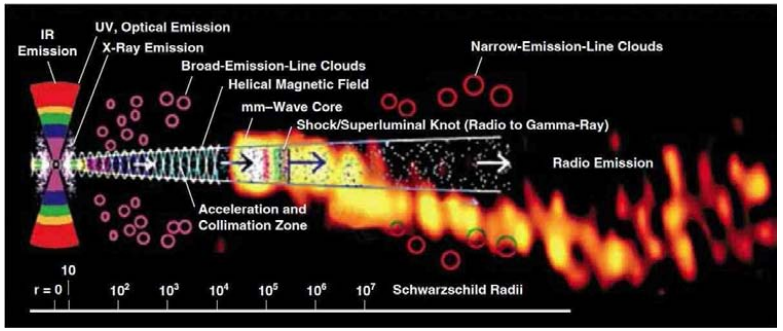
Conclusion & Prospects

June 2007	October 2007	March 2008	March 2010 + ...	2010/2011?
Step1:	Step1:	Step2:	Step2:	Step3
EC025A	EC025B	GC030	GC034A + B, C	??
224 sources	223 sources	105 sources	293 sources	~200 sources?
48-hrs	48-hrs	48-hrs	3*48-hrs = 144-hrs	2*48-hrs?
EVN	EVN	EVN+VLBA	EVN+VLBA	??
☑	☑	☑	☐	☐

Conclusion & Prospects

June 2007	October 2007	March 2008	March 2010 + ...	2010/2011?
Step1:	Step1:	Step2:	Step2:	Step3
EC025A	EC025B	GC030	GC034A + B, C	??
224 sources	223 sources	105 sources	293 sources	~200 sources?
48-hrs	48-hrs	48-hrs	3*48-hrs = 144-hrs	2*48-hrs?
EVN	EVN	EVN+VLBA	EVN+VLBA	??
☑	☑	☑	☐	☐

- In the future:
  - ✓ Cover southern hemisphere
  - ✓ Astrophysics: Issues of core shifts




Thanks for your attention ...
Thanks to IAG for travel support !!

AGN geometry/physics & ICRF−Gaia alignment

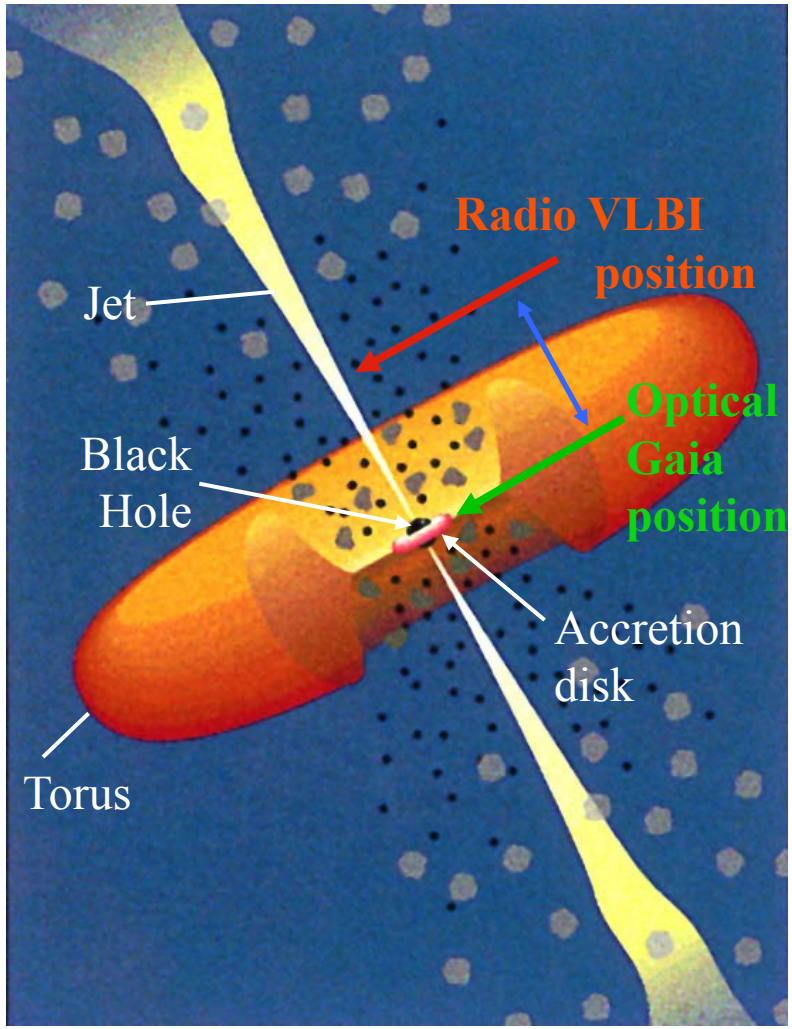
ICRF−Gaia alignment:

Determining AGN optical/radio core shifts

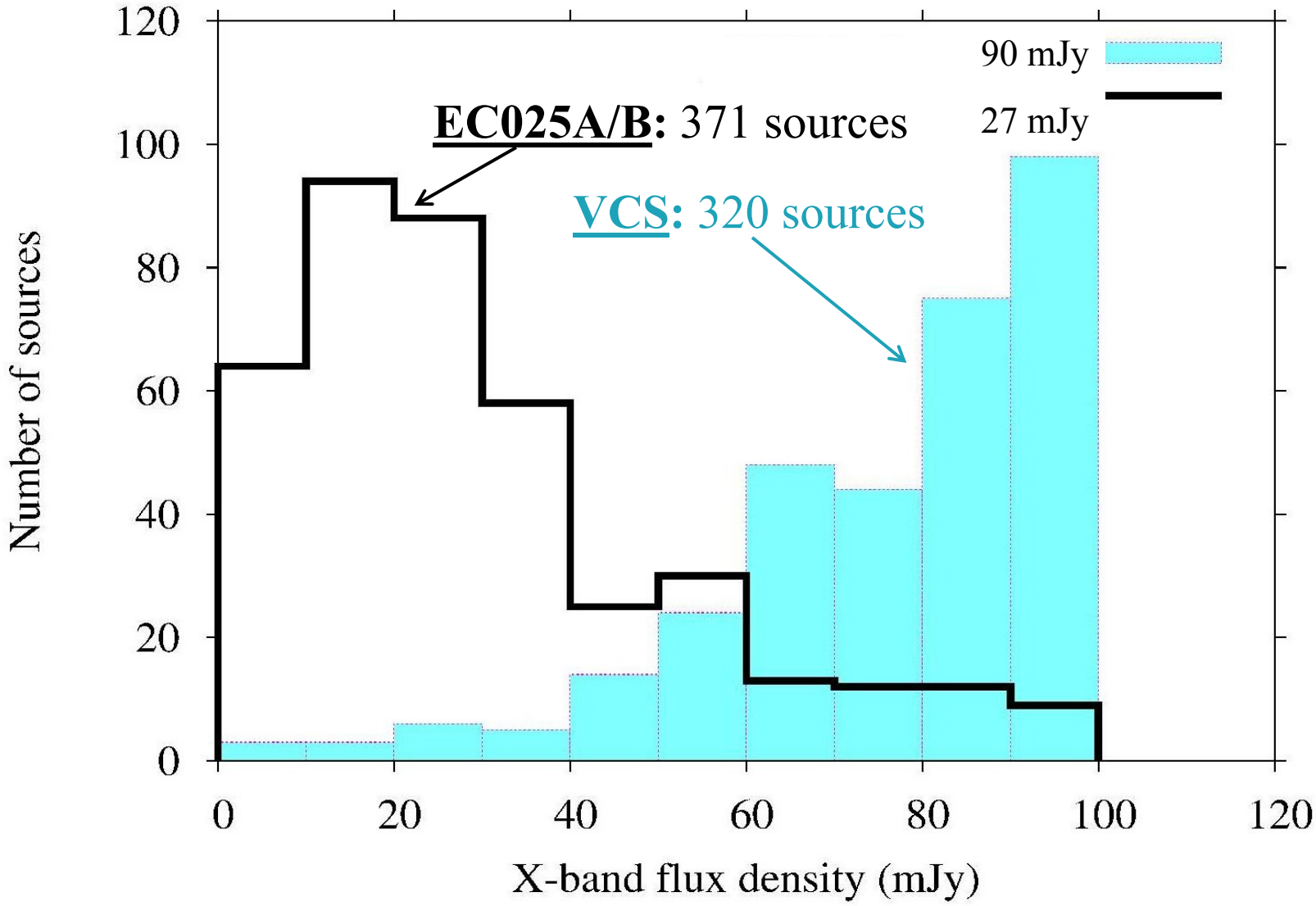
➡ Constrain AGN general geometry

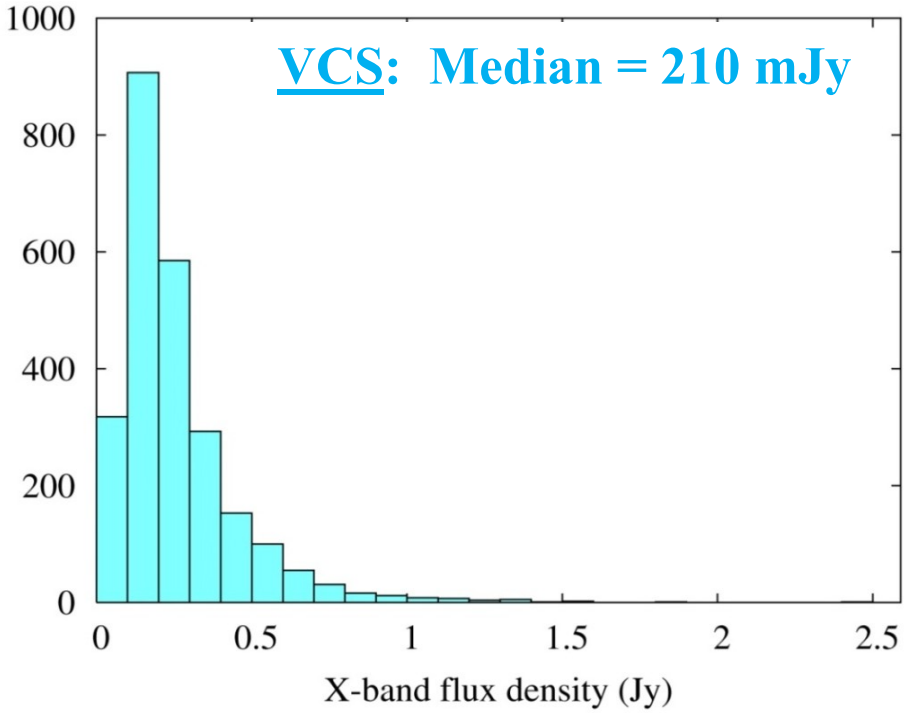
Recent estimation: ~100 μas (Kovalev et al. 2008)

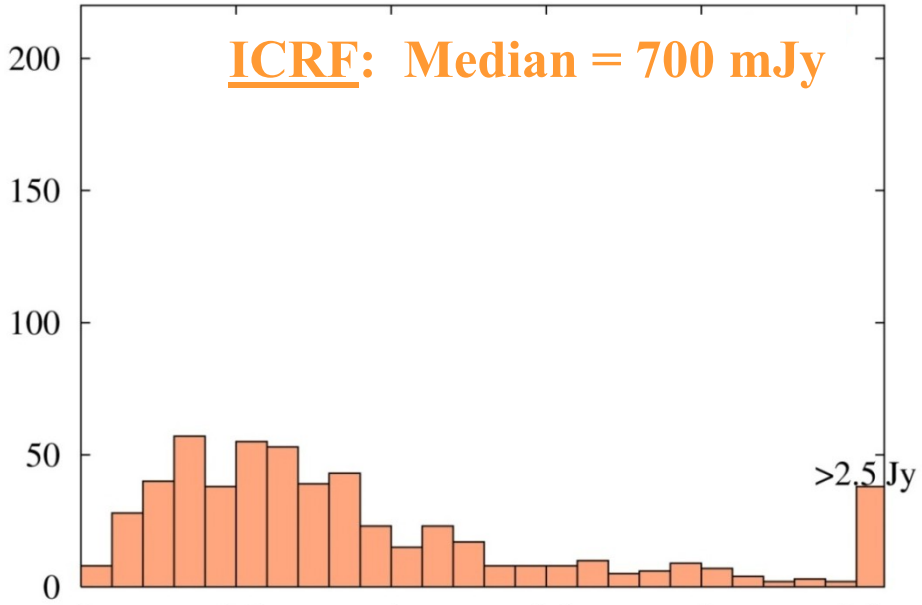
AGN unified model
Urry & Padovani, 1995

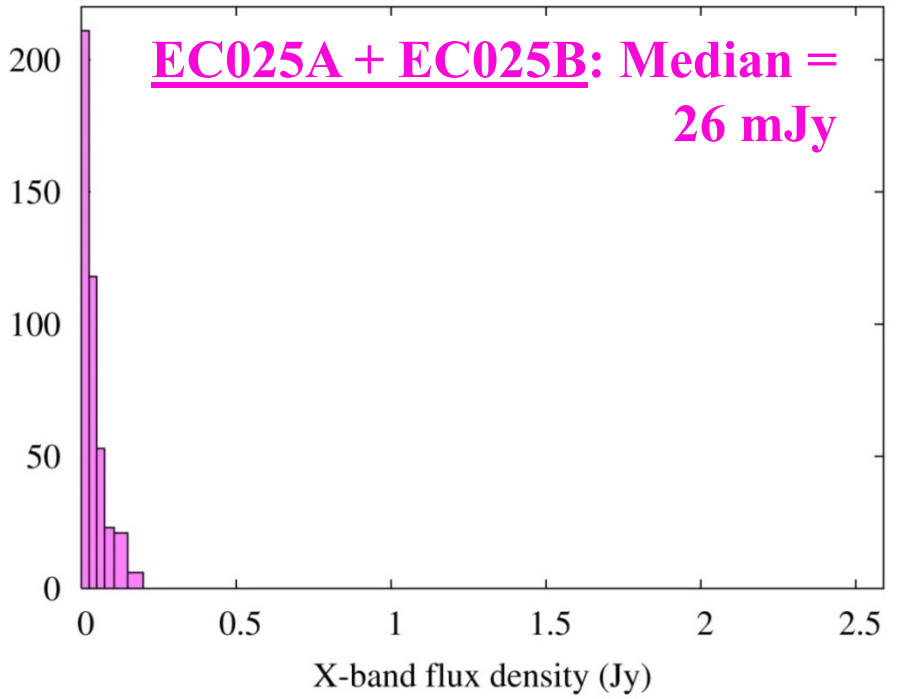


Zoom: < 100 mJy region









X-band mean correlated flux density distribution