Towards an accurate alignment of the VLBI frame and the future Gaia optical frame

Global VLBI imaging observations of a sample of candidate sources

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By 2015-2020: Two extragalactic celestial reference frames available

**VLBI** (Radio)
- 1997: ICRF1 – 717 sources – $\sigma \geq 250$ $\mu$as
- 2009: ICRF2 – 3414 sources – $\sigma \geq 60$ $\mu$as
- 2015-2020: ICRF3 ???

**Gaia** (Optical magnitude $\leq 20$)
- Anticipated position accuracy: 2015–2020
  - 20 000 QSOs $@ V \leq 18 \rightarrow 16$ $\mu$as $\leq \sigma \leq 70$ $\mu$as
  - 500 000 QSOs $@ V \leq 20 \rightarrow 16$ $\mu$as $\leq \sigma \leq 200$ $\mu$as

Lindegren et al., 2008
Context

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VLBI (Radio)

Position accuracy:
1997: ICRF1 − 717 sources − σ ≥ 250 μas
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2015-2020: ICRF3 ?

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Anticipated position accuracy: 2015–2020
20 000 QSOs @ V≤18 → 16 μas ≤ σ ≤ 70 μas
500 000 QSOs @ V≤20 → 16 μas ≤ σ ≤ 200 μas

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

- **Some requirements:**
  - Several hundreds of common sources
  - With a uniform sky coverage
  - Link sources must have:
    - Accurate Gaia position $\rightarrow$ Optically-bright ($V \leq 18$)
    - Accurate VLBI position $\rightarrow$ Good astrometric quality (no extended VLBI structure)
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  - ICRF1: 70 sources suitable (*Bourda et al.*, 2008)
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**Current status:**

- ICRF1: 70 sources suitable (*Bourda et al., 2008*)

→ Need to monitor these ICRF2 sources suitable for the alignment
→ Need to find new radio sources suitable for accurate Gaia-VLBI alignment
Our project

- **Idea**: New candidates $\rightarrow$ Weak sources ($< 100$ mJy)
- **Specific VLBI observing program designed** (with EVN & VLBA)

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  - **Observing Sample:** 447 weak extragalactic radio sources
    - NVSS catalog (excluding ICRF and VCS sources) $\rightarrow$ Not in ICRF2!
    - Optical magnitude $V \leq 18$
    - Total flux density (NVSS) $\geq 20$ mJy
    - $\delta \geq -10^\circ$

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**Observing Strategy**:
1. VLBI detection  
   *(Bourda et al., 2010, A&A 520, A113)*
2. Imaging  
   *(Bourda et al., 2011, A&A 526, A102) (Bourda et al., 2012, in prep.)*
3. Accurate astrometry (for the most compact sources)

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*Very Long Baseline Array*  
*NRAO VLA Sky Survey*  
*(Condon et al., 1998)*
Step 1: VLBI detection

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

Robledo, Spain
Ø 70 m

Effelsberg, Germany
Ø 100 m

Onsala, Sweden
Ø 25 m

Noto, Italy
Ø 32 m

Medicina, Italy
Ø 32 m

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Step 1: VLBI detection

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Weak sources in VLBI

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

- Four Global VLBI imaging experiments (EVN+VLBA) (S/X @ 512 Mbps)
  - GC034A: March 2010 – 48-hrs – 97 sources
  - GC034BCD: November 2010 – 58-hrs – 118 sources
  - GC034EF: March 2011 – 38-hrs – 75 sources

→ In total, **192 hours** to observe **395 sources** (previously detected)
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→ In total, **192 hours** to observe **395 sources** (previously detected)

  - GC030: All 105 sources successfully imaged at both X & S bands (100%)
  - GC034A: 63 VLBI maps (65%)
  - GC034BCD: 52 VLBI maps (44%)
  - GC034EF: 30 VLBI maps (40%)

→ In total, X-band VLBI maps determined for **250 sources** (63%)
X-band Total Flux Density

**GC030**: median = 61 mJy

**GC034BCD**: median = 59 mJy

**GC034A**: median = 35 mJy

**GC034EF**: median = 37 mJy
Examples of VLBI maps for « good » sources

X-band $-1^{st}$ contour level @ 1 – 4%

GC030  GC034A  GC034BCD  GC034EF

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Examples of VLBI maps for «bad» sources

**X-band** 1st contour level @ 1 – 4%

- GC030
- GC034A
- GC034BCD
- GC034EF

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## VLBI Images in BVID

### The Bordeaux VLBI Image Database

**Home BVID**

**News**

**BVID content**

**Database access**

**Citations**

**Links**

**Contact**

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5-8 March 2012, Madrid – Spain

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For GC030:

105 sources have been found!

→ VLBI image summary (in pdf)

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

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Astrometric suitability

Number of sources

X-band continuous structure index

GC030

GC034BCD

GC034A

GC034EF

5-8 March 2012, Madrid – Spain
Astrometric suitability

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

- 47 sources
  - X-band continuous structure index
  - GC030

- 26 sources
  - X-band continuous structure index
  - GC034BCD

- 32 sources
  - X-band continuous structure index
  - GC034A

- 14 sources
  - X-band continuous structure index
  - GC034EF
Astrometric suitability

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

$\rightarrow$ 119 VLBI sources suitable for the alignment (i.e. ~50% of the sources we could image)
Next stage

Step 1
VLBI detection ✔

Step 2
VLBI imaging ✔

Step 3
Astrometry ☐

• Astrometry
  ✔ Proposal submitted 1\textsuperscript{st} February 2012
  ✔ Determine VLBI astrometric positions (for the most compact sources)
    → 119 point-like sources
  ✔ 72 hours asked
  ✔ Global VLBI array (EVN+VLBA)
Future prospects

- Investigate further southern hemisphere
- Optical studies/observations for these candidates are on the way
- Quasi-simultaneous VLBI & Gaia observations will be carried out during the mission (*Gaia scanning law*) → Stability/Variability
- Astrophysics: Issues of core shifts
Thanks for your attention ...
The Gaia astrometric mission

- Gaia will observe 1 billion stars, 500,000 QSOs and 350,000 asteroids
- Astrometric accuracy

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</table>

- Launch: fall 2012
- Preliminary catalog: ~ 2015
- Final catalog: 2018-2020
ICRF2 optical counterparts

- **Cross Identification:** ICRF2 $\cap$ LQAC $\rightarrow$ 3195 sources
- **From these:** 276 defining sources (out of 295 ones within ICRF2)

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<th>0 &lt; mag ≤ 18</th>
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<td>Magnitude I</td>
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Number of radio sources from ICRF2 with an optical counterpart within LQAC [Large Quasar Astrometric Catalog; Souchay et al. 2009]
ICRF2 sources suitable for the alignment

Number of objects

0<$\nu$≤500
500<$\nu$≤1000
1000<$\nu$≤1500
1500<$\nu$≤2000
2000<$\nu$≤2500
2500<$\nu$≤3000
3000<$\nu$≤3500
3500<$\nu$≤4000
$\nu$>4000

X-band Flux Density (mJy)
The structure index (SI) indicates the expected magnitude of the effects of intrinsic source structure on VLBI delay observations, according to the median value of the structure delay corrections ($\tau_{\text{median}}$) calculated for all projected VLBI baselines that might be observed, using the algorithm devised by Charlot (1990). While Fey & Charlot (1997) separated sources into four categories, with values of the structure index ranging from 1 to 4, a continuous scale was adopted for the present work (as also done for the ICRF2; see IERS Technical Note 35). It is defined as follows:

$$SI = 1 + 2 \log(\tau_{\text{median}})$$

(1)

where $\tau_{\text{median}}$ is expressed in picoseconds (ps). Additionally, SI values are constrained to be always positive by setting SI = 0 when $\log(\tau_{\text{median}}) < -0.5$ (i.e. $\tau_{\text{median}} \lesssim 0.3$ ps). There is close correspondence at the (discrete) SI boundaries between the continuous SI values defined here and the values defined in Fey & Charlot (1997) (SI = 1.95 vs. 2 for $\tau_{\text{median}} = 3$ ps, SI = 3.00 vs. 3 for $\tau_{\text{median}} = 10$ ps, SI = 3.95 vs. 4 for $\tau_{\text{median}} = 30$ ps).
Interests for the physics of QSOs

Core shifts → Put constraints on the physics of AGNs?

Kovalev et al. 2008
Challenge: AGN radio-optical core-shift

AGN = Active Galactic Nuclei

Frequencies in VLBI:
S ~ 2 GHz
X ~ 8 GHz
K ~ 24 GHz
Ka ~ 32 GHz
Q ~ 43 GHz

VLBI observation ~ 100 µas
Kovalev et al. 2008

Gaia observation

AGN unified model
Urry & Padovani (1995)

Jet
Black Hole
Torus of Dust
Accretion Disk
Examples of related scientific questions

- Dominating optical emission mode within AGNs? Thermal emission (i.e. accretion disk) or non-thermal (relativistic jets)?
- Origin of the relativistic jets observed within AGNs?
- Is the core-shift within AGNs depending on frequencies? On time?

![Diagram of AGN emission modes](image)