Multi-step VLBI observations of weak extragalactic radio sources

Aligning the ICRF & the future Gaia frame

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Overview

Multi-step VLBI observations of weak extragalactic radio sources

1. **Context:** Why these observations?

2. **Strategy of observation**

3. **First-step experiments**
   Some results

4. **Conclusions & Prospects**
Motivation: 2015-2020  →  2 extragalactic celestial reference frames

Ma et al. 1998 / Fey et al. 2004
*International Celestial Reference Frame*

Perryman et al. 2001
1. Context

**Motivation:** 2015-2020 → 2 extragalactic celestial reference frames

- ICRF: 717 extragalactic sources
  - ICRF-2: ~1000 sources
- Radio; VLBI (S/X bands; 2/8 GHz)
- Position accuracy:
  - ICRF: $\sigma = 250 \, \mu\text{as}$
  - ICRF-2: $\sigma < 100 \, \mu\text{as}$
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- **Position accuracy:**
  - ICRF: $\sigma = 250 \ \mu\text{as}$
  - ICRF-2: $\sigma < 100 \ \mu\text{as}$
- **Position accuracy:**
  - $16 \ \mu\text{as} \leq \sigma \leq 70 \ \mu\text{as} @ 15 \leq V \leq 18$

- **Gaia:**
- 2011
- ~10 000 QSOs
- Optical domain / $V \leq 20$

September 23-26, 2008

9th EVN Symposium – Bologna, Italy
1. Context

**Motivation:** 2015-2020 → 2 extragalactic celestial reference frames

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**Important to align accurately the ICRF & the future Gaia frame:**

- Several hundreds of common sources
- Precise radio (VLBI) and optical (Gaia) positions:
  - 18~
  - No extended VLBI structures

(Charlot 1990) (Mignard 2003)
1. ICRF sources with an accurate Gaia position: $V \leq 18$

Optical magnitude distribution
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Optical magnitude distribution

~30% ICRF
1. ICRF sources with an accurate Gaia position: $V \leq 18$

2. Accurate ICRF position:
   Compact sources (i.e. SI = 1 or 2)

Fey & Charlot 1997, 2000; Charlot et al. 2006

Optical magnitude distribution
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Optical magnitude distribution

X-band Structure Index distribution
1. ICRF sources with an accurate Gaia position: $V \leq 18$

2. Accurate ICRF position:
   - Compact sources (i.e. $SI = 1$ or $2$)
   - $\sim 30\%$ ICRF

$\sim 10\%$ ICRF

70 sources is not enough: Necessity to find other VLBI radio sources suitable for aligning accurately VLBI & Gaia frames
VLBI sources currently available for astrometry & geodesy

**ICRF catalogue**

**VCS catalogue**
VLBA Calibrator Survey
Petrov et al. 2008
VLBI sources currently available for astrometry & geodesy

- **ICRF catalogue**
  - 717 extragalactic radio sources
  - X-band flux density ~700 mJy

- **VCS catalogue**
  - ~3000 extragalactic radio sources
  - X-band flux density ~200 mJy
VLBI sources currently available for astrometry & geodesy

- ICRF catalogue
  - New VLBI sources: To go to weaker sources < 100 mJy
  - 717 extragalactic radio sources
  - X-band flux density ~700 mJy

- VCS catalogue
  - ~3000 extragalactic radio sources
  - X-band flux density ~200 mJy

September 23-26, 2008 9th EVN Symposium – Bologna, Italy
2. **Strategy of observation:**

Multi-step VLBI observations of weak radio sources

- **Criteria for the sample:** ~ 450 sources

- **VLBI network:** EVN

- **Strategy of observation:** 3 steps over several years
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  - Dense radio catalogue NVSS (NRAO VLA Sky Survey): ICRF & VCS excluded
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  - NVSS total flux density $\geq 20$ mJy
  - $\delta \geq -10^\circ$

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- **VLBI network:** EVN
  - The most sensitive VLBI network:
    - Large antennas (ex. Effelsberg, Ø 100 m).
  - High rate recording (1Gbps)

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• Strategy of observation: 3 steps over several years

  1. VLBI detection
  2. Mapping of the sources detected
  3. Accurate astrometric positions for the most compact sources.

Because mostly never observed before in VLBI…
3. First-step experiments: VLBI detectability

Two 48-hours experiments (S/X dual-frequency geodetic style @ 1Gbps):

- **EC025A**: June 2007 → 224 sources observed (mostly from CLASS)
- **EC025B**: October 2007 → 223 sources observed
3. First-step experiments: VLBI detectability

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\end{align*}
\]

European network: 4/5 antennas

- Effelsberg, Germany (Ø 100 m)
- Noto, Italy (Ø 32 m)
- Medicina, Italy (Ø 32 m)
- Onsala, Sweden (Ø 25 m)
- + Robledo, Spain (Ø 70 m) for EC025B
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**European network:** 4/5 antennas

<table>
<thead>
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S/X detection rates:

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\begin{align*}
\text{EC025A} & \Rightarrow \quad \sim 94 \% \\
\text{EC025B} & \Rightarrow \quad \sim 82 \%
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**S/X detection rates:**

- **EC025A**: ~ 94 %
- **EC025B**: ~ 82 %

*Overall detection rate: ~ 89 %*
Flux density distributions: EC025A/B

X-band (mJy)

Median ~26 mJy

S-band (mJy)

Median ~46 mJy
VCS: Median = 210 mJy

ICRF: Median = 700 mJy

EC025A + EC025B: Median = 26 mJy

X-band flux density distribution
Zoom: < 100 mJy region

- **EC025A/B**: 371 sources
- **VCS**: 320 sources
S/X Spectral Index distribution

median = -0.34

398 sources detected
224 sources from CLASS

Number of objects

S/X Spectral Index $\alpha$

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S/X Spectral Index distribution

- Median: -0.34

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224 sources from CLASS

224 CLASS sources
S/X Spectral Index distribution

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Sources with compact core: \( \alpha > -0.5 \)
4. Conclusion & Prospects

- **What’s new?**

  398 new VLBI sources as candidates for the ICRF–Gaia link
  
  Link sources ~30 x weaker than ICRF sources
  
  First step very promising
  
  ~90% detection rate → Detection step unnecessary?
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• **Follow up:**

  Estimate VLBI positions for the sources detected
  
  VLBI imaging of the sources detected (second step):
  
  105 sources observed in March 2008
  
  VLBA + EVN (48h, S/X @ 512 Mbps)
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  398 new VLBI sources as candidates for the ICRF–Gaia link
  Link sources ~30 x weaker than ICRF sources

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• **Further objectives:**

  1. Optical survey of these weak radio sources for variability studies.
  2. Survey in the southern hemisphere (APT)?
  3. Study of physical properties of weak sources.
ICRF–Gaia alignment:

Determining AGN optical/radio core shifts

→ Constrain AGN general geometry

Recent estimation: \(~100 \, \mu\text{as}\) (Kovalev et al. 2008)

AGN unified model
*Urry & Padovani, 1995*
Acknowledgements

- John Gipson (SKED)
- Dave Graham / Walter Alef (Correlation)
- Alexander Andrei (optical positions delivery)
- RadioNet for financial support during the 9th EVN Symposium
Structure Index (X-band)

Fey & Charlot 1997, 2000
Charlot et al. 2006

0642+449
SI = 1
Point-like source

OJ287
SI = 2
Source not extended

0656+082
SI = 3
Extended source

0711+356
SI = 4
Source very extended

~30 mas
**Flux density distributions**

**X-band EC025A:** 222 sources; median = 32 mJy

Weakest source ~4 mJy

**S-band EC025A:** 211 sources; median = 55 mJy

Weakest source ~20 mJy
Flux density distributions

X-band EC025A: 222 sources; median = 32 mJy
Weakest source ~4 mJy

S-band EC025A: 211 sources; median = 55 mJy
Weakest source ~20 mJy

X-band EC025B: 216 sources; median = 19 mJy
Weakest source ~1 mJy

S-band EC025B: 188 sources; median = 37 mJy
Weakest source ~8 mJy
S/X Spectral Index distribution

\[
\frac{\text{Flux (S-band)}}{\text{Flux (X-band)}} = \left( \frac{2.3}{8.4} \right)^\alpha
\]

Sources with compact core: \( \alpha > -0.5 \)

EC025A: 211 sources; \( \alpha \approx -0.3 \)

EC025B: 187 sources; \( \alpha \approx -0.35 \)
S/X Spectral Index distribution

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Results summary:

EC025A + EC025B

398 sources S/X detected

median = -0.34

224 CLASS sources
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9 % 22 % 69 %