Extending the X/Ka Celestial Reference Frame to the South Polar Cap: Results from combined NASA-ESA baselines to Malargüe, Argentina

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Overview

• How do astrometric sources change with wavelength? Why Ka-band?

• X/Ka in the context of other Celestial Frames: S/X, K, Q

• Prospects for Improvements:
  SNR, Instrumentation, Troposphere

• Southern Geometry:
  • Our plan to reduce the largest error is a NASA collaboration with ESA’s X/Ka 35-m in Malargüe, Argentina
  • First fringes Malargüe to Australia, California, Spain
  • South Polar Cap first results: 95 sources detected! 2/3 non-ICRF2

• Optical frames: tying to ESA’s Gaia mission at 10 μas level
• **Sensitivity worsens** at shorter wavelength/high frequency
  Higher system temperature: atmosphere H$_2$O (22 GHz), O$_2$ (60 GHz)
  Antenna pointing more difficult
  Antenna surface shape control more difficult
  Atmospheric absorption
  Resolved sources

• **Quasar astrophysics gets better for astrometry**
  Sources more compact at shorter wavelength (higher frequency)
  More sources resolved at higher frequency--> less sources
  Less extended structure: plume is steep spectrum
  Core shift reduced at short wavelength/high frequency
Source Structure vs. Wavelength

S-band
2.3 GHz
13.6 cm

X-band
8.6 GHz
3.6 cm

K-band
24 GHz
1.2 cm

Q-band
43 GHz
0.7 cm

The sources become better

Ka-band
32 GHz
0.9 cm

Images credit: P. Charlot et al, AJ, 139, 5, 2010
CRF Context for X/Ka

**S/X ICRF2:** 3.6cm, 8 GHz  (Ma et al, IERS, 2009)

**K-band:** 1.2cm, 24 GHz  (Lanyi et al, AJ, 2010)
  (Charlot et al, AJ, 2010)

**X/Ka-band:** 9mm, 32 GHz  (Jacobs et al, ISSFD, 2012)
ICRF2  S/X: 8.4 GHz, 3.6cm: 3414 sources

40 μas floor. ~1200 obj. well observed, ~2000 survey session only

Credit: Ma et al, eds.: Fey, Gordon, Jacobs, IERS Tech. Note 35, Germany, 2009
VLBA all northern, poor below Dec. -30°. ΔDec vs. Dec tilt= 500 μas

Cal. to Madrid, Cal. to Australia. **Weakens southward. No ΔDec tilt**
X/Ka sources (blue) which are surrounded by Red squares are also in the Fermi 2FGL gamma-ray point source catalog. Over 1/3 of X/Ka sources (~175) have gamma-ray detections.
• **SNR**: low cost disk drives \(\rightarrow\) more bits!

• **Instrumentation**:  
  - Digital Back Ends: Baseband Conversion, Filters  
  - Phase calibration for X/Ka-band  
  Ruszczyk et al, IVS, 2012; Tuccari, IVS, 2012  
  García-Miró et al, IVS, 2012  
  Hamell, Tucker, Calhoun, 2003

• **Troposphere cals:**  
  - JPL Advanced WVR: 1 mm accuracy  
  Tanner et al, R.Sci, 2003;  
  Bar-Sever et al, IEEE, 2007

• **Southern Geometry**  
  Collaborate with ESA’s X/Ka station in Malargüe, Argentina
50 sessions, No Sim. Southern Data  Adding Simulated data

Credit: Bourda, Charlot, Jacobs, ELSA Conf., 2010

- 50 real X/Ka sessions augmented by simulated data
  simulate 1000 group delays, SNR = 50
  ~9000 km baseline: Australia to Argentina

- Completes Declination coverage: cap region -45 to -90 deg
  144 south polar candidate sources (*Sotuela et al, Porto, 2011*)
  200 µas (1 nrad) precision in south polar cap,
  mid south 200-1000 µas, all with just a few days observing.

Declination Sigma
Orange: < 100 µas
Red: < 200
Green: < 300
Blue: < 500
Purple: < 1000
White: > 1000

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Malargüe: The Next X/Ka VLBI Station

X/Ka: ESA Deep Space Antenna DSA 03

- **Malargüe, Argentina**
- Fall-2012 NASA/ESA collaboration
- 35-m, X/Ka-band, 9,500 km baseline
  Argentina-Australia covers south polar cap
  Full sky coverage for X/Ka!!
- Argentina-California & Australia-California orthogonal baselines for mid-latitudes
- High (1.5km), dry desert site: good for Ka-band
- HA-Dec coverage: Tidbinbilla to Malargüe:

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Malargüe, Argentina 35-meter as of 26 Sept. 2012
Photo credit: European Space Agency
http://www.esa.int/Our_ACTIVITIES/Operations/Malarguee_-_DSA_3

ESA Deep Space Antenna
X/Ka-band capable
Malargüe: The Next X/Ka VLBI Station

Malargüe, Argentina

ESA’s DSA 03 35-meter

Dec 2012

Photos credit: Leslie A. White
Malargüe: The Next X/Ka VLBI Station

Malargüe, Argentina

ESA’s DSA 03 35-meter

Dec 2012

Photos credit: Leslie A. White

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ESA’s Argentina 35-meter antenna adds 3 baselines to DSN’s 2 baselines

- Full sky coverage by accessing south polar cap
- near perpendicular mid-latitude baselines: CA to Aust./Argentina
1st Ka fringes NASA to ESA-Malargüe
60 sec integrations, 256 Mbps (16 channels, 4 MHz, I/Q, @2bit)

ESA’s Argentina 35-meter antenna adds 3 baselines to DSN’s 2 baselines
• Full sky coverage by accessing south polar cap
• near perpendicular mid-latitude baselines: CA to Aust./Argentina

Maps credit: Google maps
Goldstone, CA to Madrid & Australia + Malargüe to Australia.
95 in south cap (dec<-45); 19 ICRF2 Defining; 2/3 of cap non-ICRF2
Goldstone, CA to Madrid, Australia. **Weakens southward, no south Cap**

Credit: Jacobs et al, ISSFD, Pasadena, 2012
Goldstone, CA to Madrid & Australia + Malargüe to Australia.
Gaia/VLBI frame tie & Accuracy test

Gaia: 10^9 stars
- 500,000 quasars V< 20 mag
  20,000 quasars V< 18 mag
- radio loud 30-300+ mJy
  and optically bright: V<18 mag
  ~2000 quasars
(Mignard, IAU, Beijing, 2012)

- Quasar Precision
  70 μas @ V=18
  25 μas @ V=16

Figure credit: http://www.esa.int/esaSC/120377_index_1_m.html#subhead7

S/X frame tie Strategy:
Bring new optically bright quasars into the radio frame
(Bourda, EVN, Bordeaux, 2012)

X/Ka frame tie:
Measured X/Ka precision and simulated Gaia optical precision
yields frame tie alignment of ~ 10 μas per 3-D rotation angle
Limited by Xka precision, but improving as more data arrives.

XKa: 146 optically bright counterparts: V< 18 mag

(optical V magnitudes: Veron-Cetty & Veron, 2010)
Conclusions

• Increasing frequency -> lower sensitivity, but more compact

• Celestial Frame Overview:
  - S/X ICRF-2 ~70 μas  3414 sources
  - K-band ~100 μas  268 sources
  - X/Ka-band ~250 μas  577 sources

• Future Improvements:
  - SNR (2Gbps), Instrumentation: DBEs, PCGs, Trop.: WVRs

• ESA-NASA collaboration: add Malargüe, Argentina 35-meter
  - Improves net from 2 to 5 baselines, orthogonal mid-lat baselines
  - Full sky coverage by accessing south polar cap!
  - 95 in south polar cap (dec<-45). Cap sources 2/3 non-ICRF2
  - 19 ICRF2 Defining in south polar cap

• Frame tie: XKa VLBI/Gaia optical tie precision ~10 μas.
BACKUP SLIDES
Instrumental Stability: Allan St. Dev.

- Spain: Cebreros-DSS 55
  Ka-band, 10km baseline, 2000 sec of data

- Time Scale 60 - 1200 sec
  Slope = -0.69
  consistent with 2-D
  Kolmogorov frozen flow
trop noise (slope = -2/3)
(Treuhaft & Lanyi, R.Science, 1987)

- Time scale 1-20 sec: Slope = -0.84
  shows some sign of white noise
  limitation (slope ~ -1)

- Time scale 20-60 sec: Slope = -0.18
  3-D trop turbulence noise (-1/6)
  from small scale fluctuations?
  thermal drift of instrument?

Validated ESA-DSN baseline & interfaces  (Jacobs et al, EVN, Bordeaux, 2012)
South polar cap: two sessions (3 hr + 8 hr)
Some parts of Declination -45 to -60 not yet observed
RA-Dec correlation for 577 XKa sources

Note systematic trend in correlation vs. declination
ICRF2 type for 577 XKa sources

Note 19 ICRF2-Defining sources in South polar cap: Declination -45 to -90 deg
Optical redshift, \( z \).
Very distant \((z > 2)\) sources may be of value in cosmological studies.
Optical magnitude for 577 XKa sources

Optical Visual magnitude, V.
Gaia satellite will detect $V < 20$ and $V < 18$ is “bright” for Gaia.
The Potential for a

Ka-band Worldwide VLBI Network

Journees, Vienna, 2011.  C. S. Jacobs¹,

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