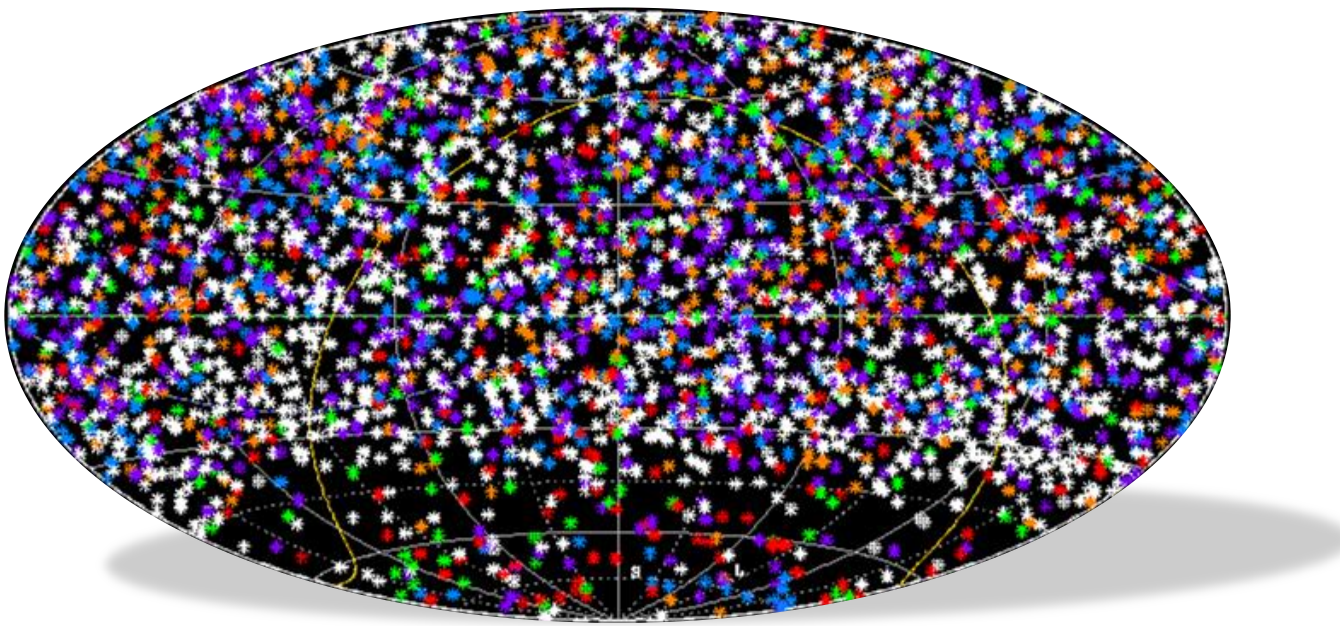
The ICRF-3:

Status, plans, and progress on the next generation International Celestial Reference Frame



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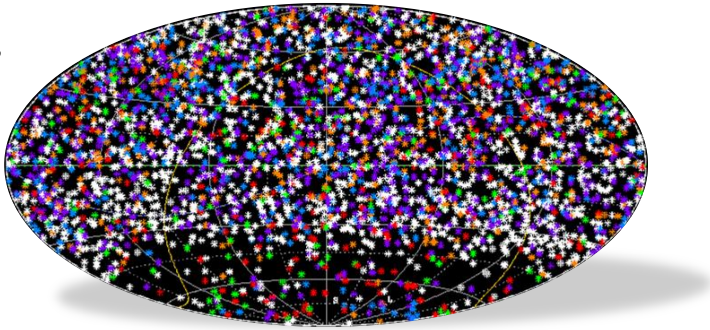
Overview

- ICRF-2: what we got and what we still have to work on
- Plans for improving the ICRF
- Connecting radio and optical frames

Overview of 2^{nd} International Celestial Reference Frame

Brief description of how the current ICRF-2 was realized:

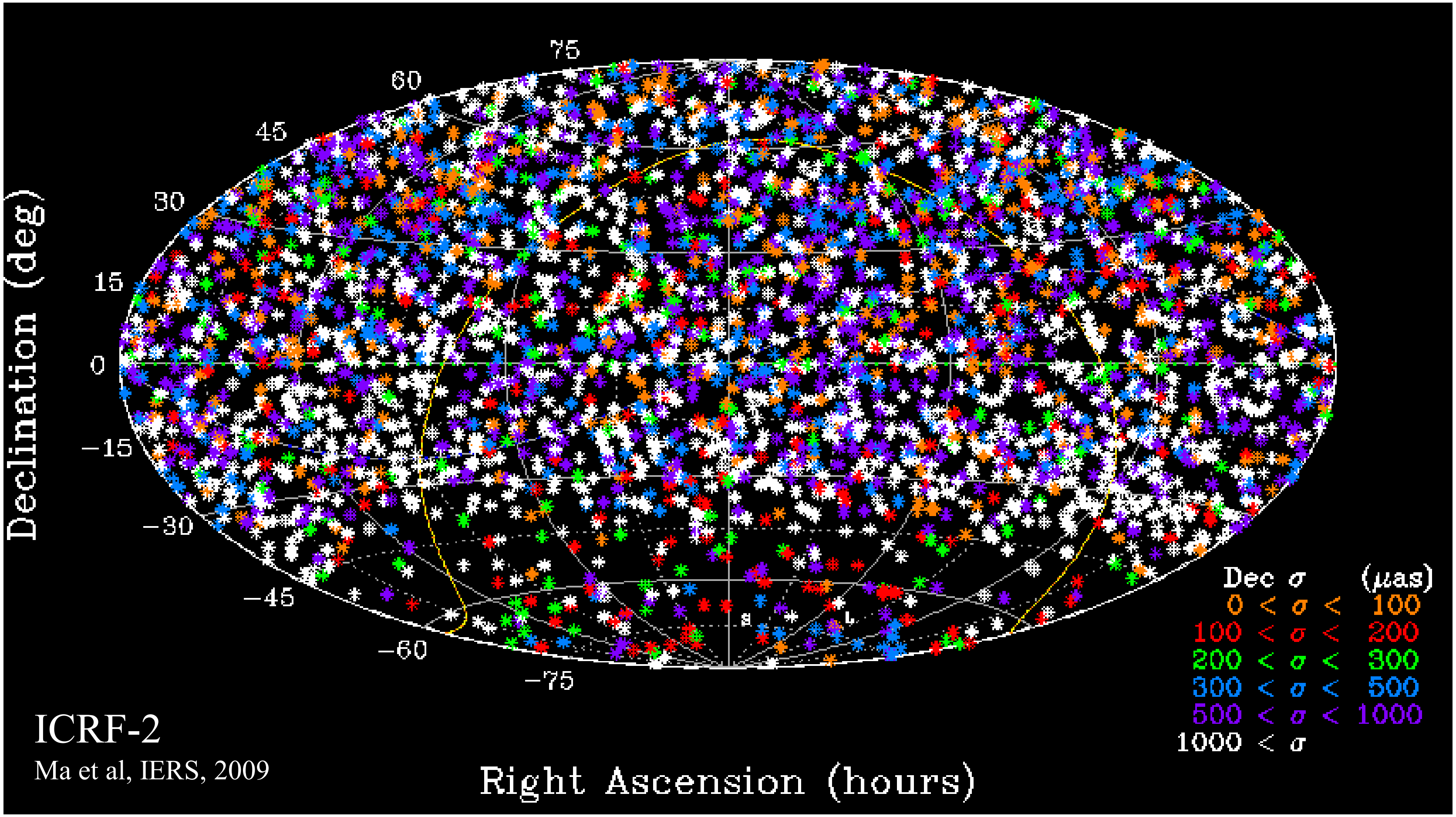


- S/X data (2.3/ 8.4 GHz or 13/ 3.6 cm) for 3414 sources
- 6.5 Million group delay observations 1979 to 2009
- No-Net-Rotation relative to ICRF-1
- Estimate TRF and EOPs internally from VLBI data
  Constrain to VTRF2008 (VLBI part of ITRF-08: *Böckmann et al, JGeod, 84, 2010*)
  as ITRF2008 was not yet released.
  4 constraints: Positions: No-Net-Translation, No-Net-Rotation
  Velocities: No-Net-Translation, No-Net-Rotation
- Produced from a single monolithic fit.
  Verified with solutions from various groups using independent software packages.

Details in ICRF-2 Technical Note: Ma et al, IERS, 2009.

http://adsabs.harvard.edu/abs/2009ITN....35....1M

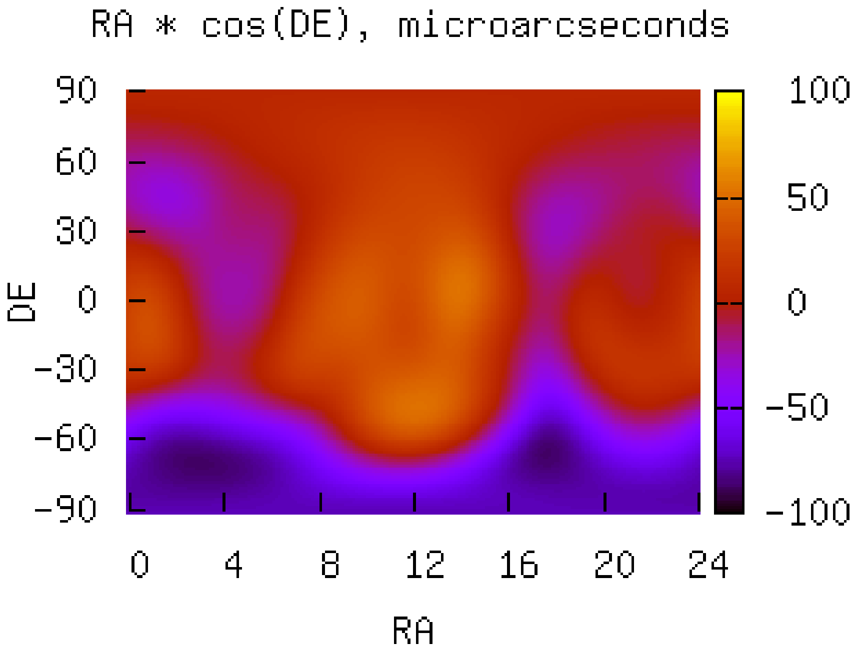
S/X-band (2/8 GHz) ICRF-2

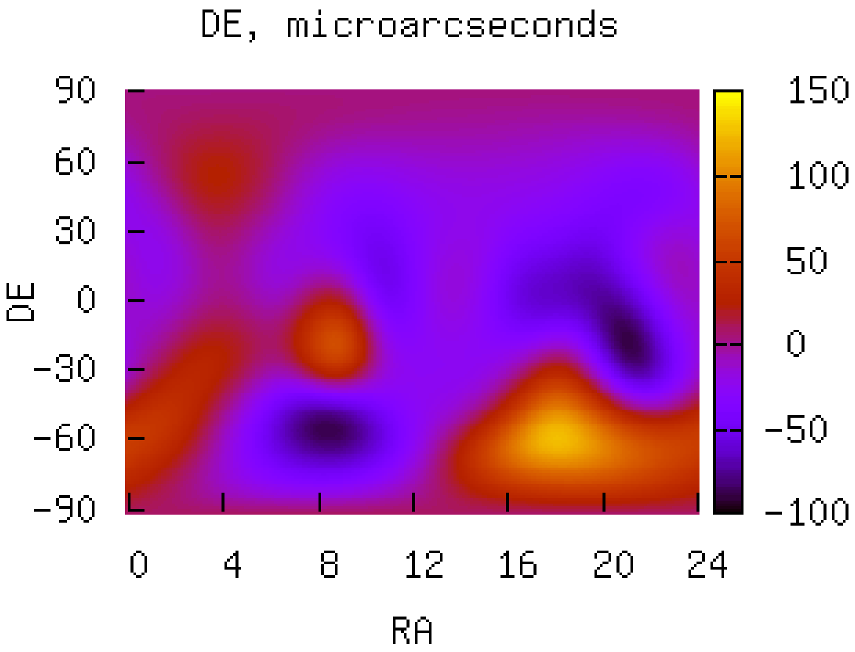


- 3414 Sources in ICRF2. Huge improvement over ICRF1's 608 sources
- ~2200 are single session VCS sources (VLBA Calibrator Survey).
- ICRF-2 is sparse south of about -40 deg.

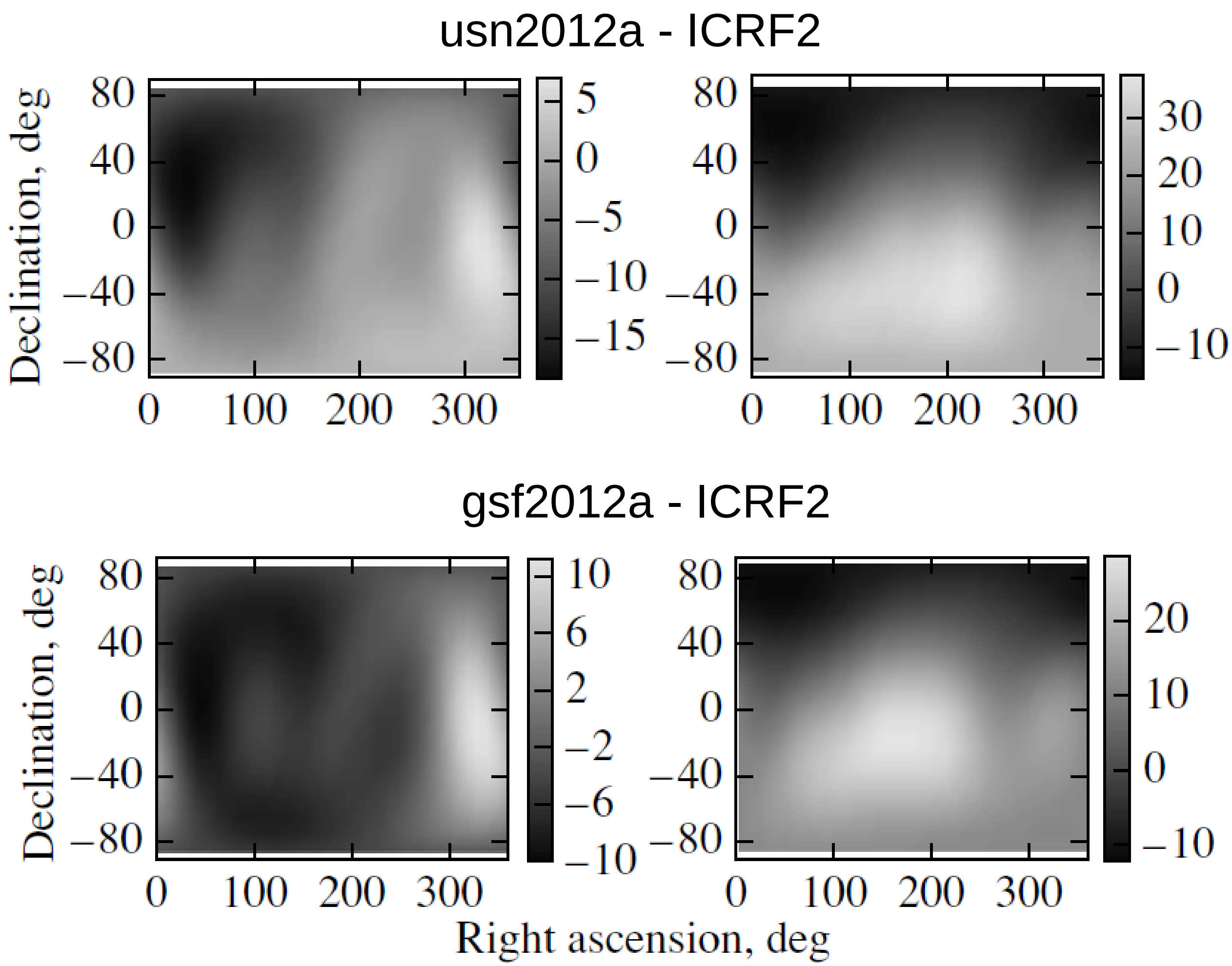
Systematic errors

ICRF2 - ICRF, smoothed differences, μas



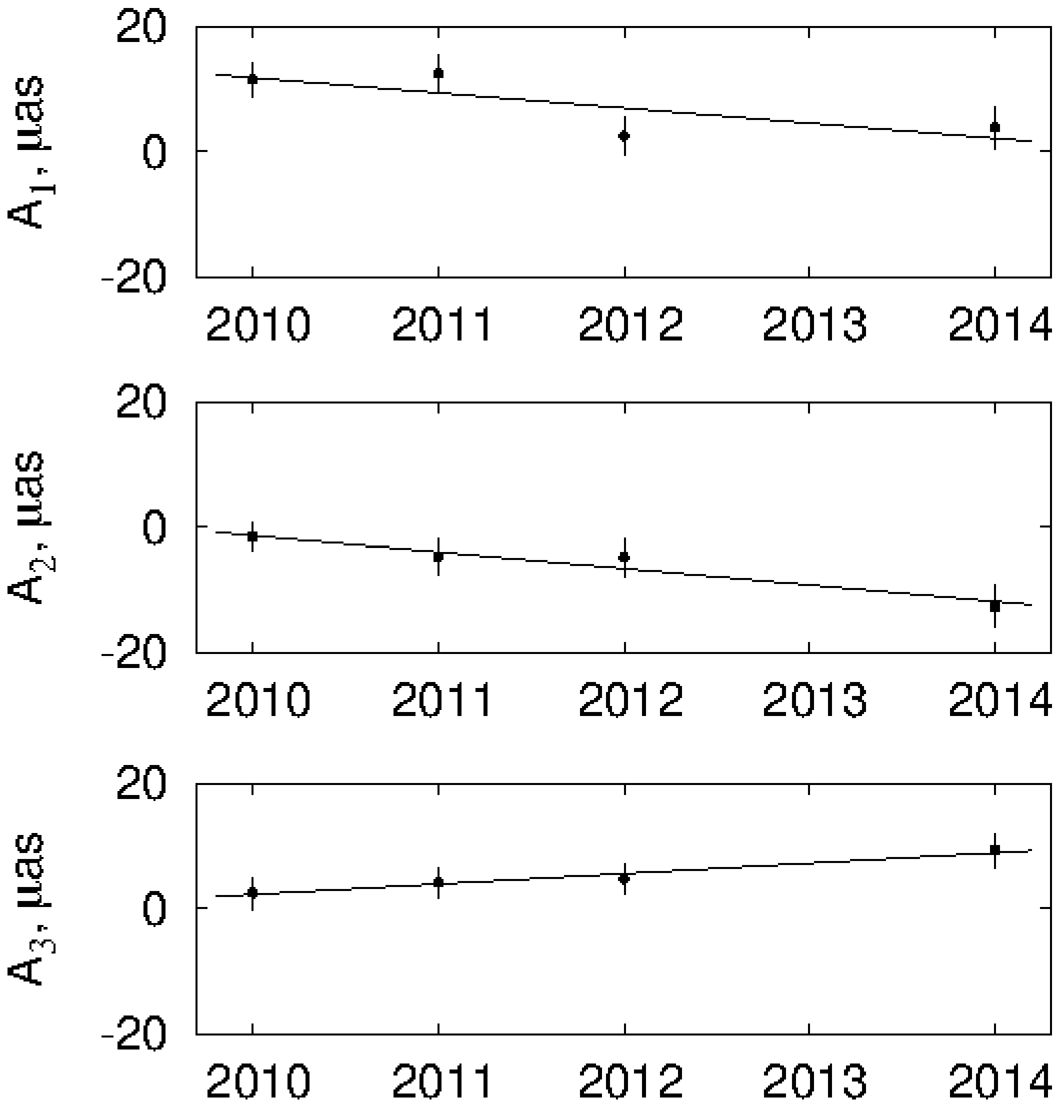


Differences between recent VLBI catalogues and ICRF2, µas



Sokolova, Malkin (2014)

Rotation of GSFC astrometric catalogues w.r.t. ICRF2

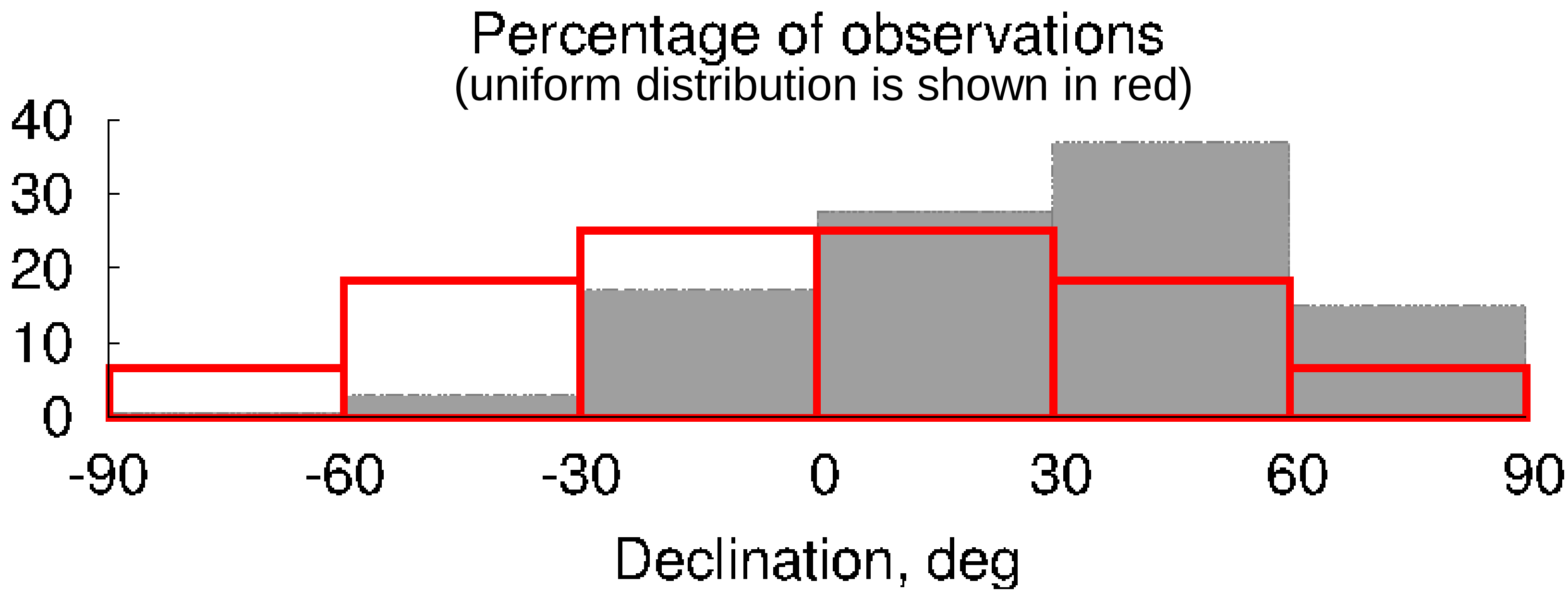


Malkin (2014)

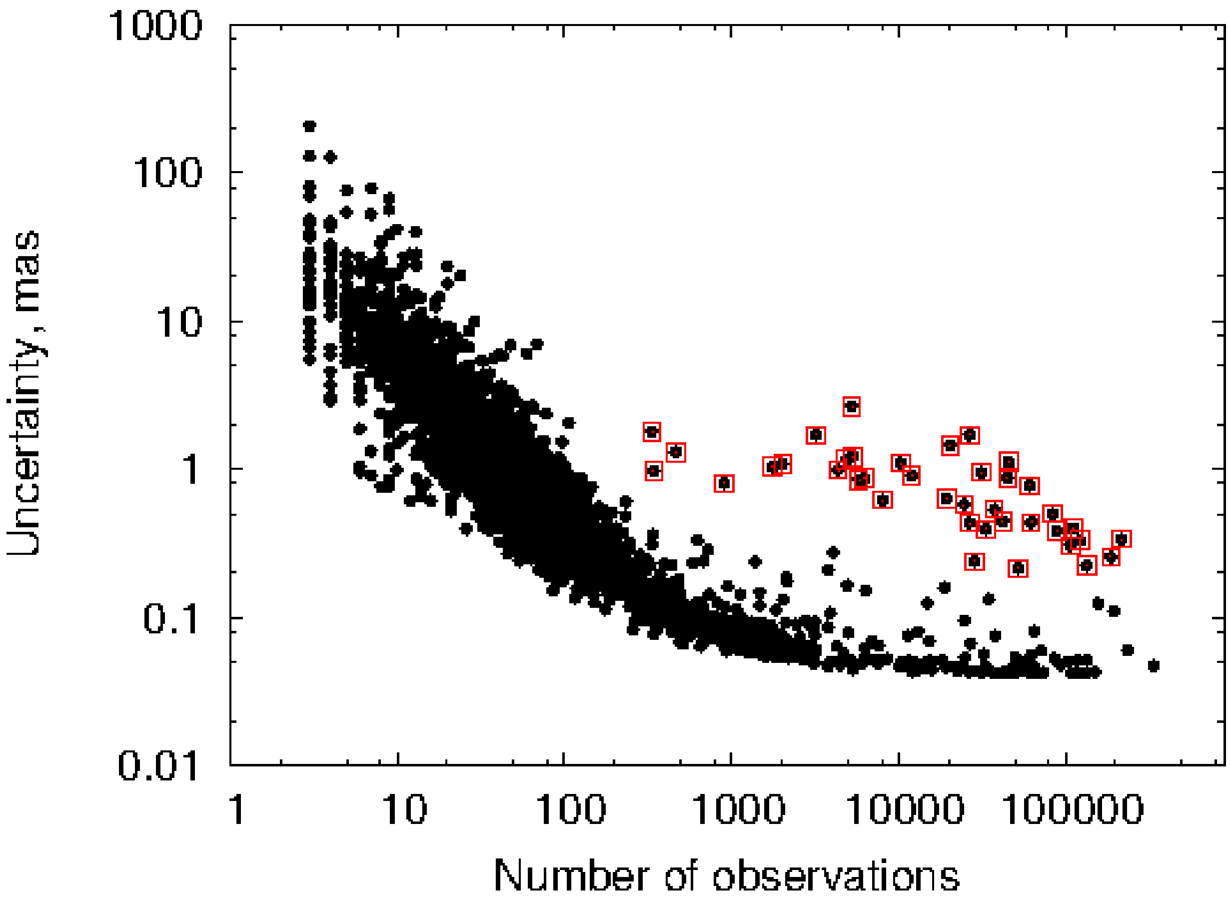
Observations by declination zones

Number of observations, thousand

Epoch	–90... –60	–60... –30	–30...0	0...+30	+30...+60	+60– ...+90
ICRF1	9 (**0.5%**)	13 (**0.7%**)	296 (**16.6%**)	617 (**34.7%**)	632 (**35.5%**)	213 (**11.9%**)
ICRF2	23 (**0.3%**)	136 (**2.0%**)	1163 (**16.8%**)	1949 (**28.2%**)	2668 (**38.6%**)	965 (**14.0%**)
Current	60 (**0.6%**)	279 (**2.9%**)	1653 (**17.1%**)	2673 (**27.6%**)	3569 (**36.9%**)	1446 (**14.9%**)



Non-uniform uncertainties



Arc sources (highlighted) do not follow the general law!

ICRF2 Summary: What we got and what we still need

Achieved

- Increasing total # of sources from 608 (717 with two extensions) to 3414.
- Increasing # of the defining sources from 212 to 295.
- More uniform distribution of the defining sources.
- Improving the source position uncertainty (from 250 µas to 40 µas for noise floor).
- Elimination of large systematic error at the level of ~0.2 mas.

To do

- Increase # of ICRF multi-session sources.
- Increase # of core (defining) sources.
- Improve the source position uncertainty and accuracy.
- Provide more uniform distribution of both all and core sources.
- Provide more uniform distribution of the source position errors
  (VCS sources, southern sources, arc sources).
- Mitigate the large-scale systematic errors (slides 5, 6) to a level of below 5-10 µas.
- Enhance CRF at higher frequencies.

S/X-band Plan for Southern Improvements

- Plans from Titov et al, IAG, 2013

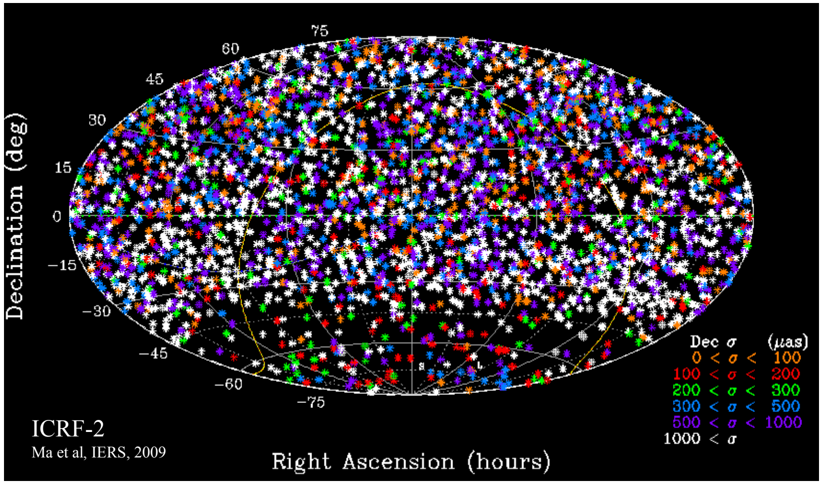
- 2013-15: Observe 100-200 **strong sources** (> 400 mJy) using the small, fast stations of the southern CRF Network at S/X-bands.

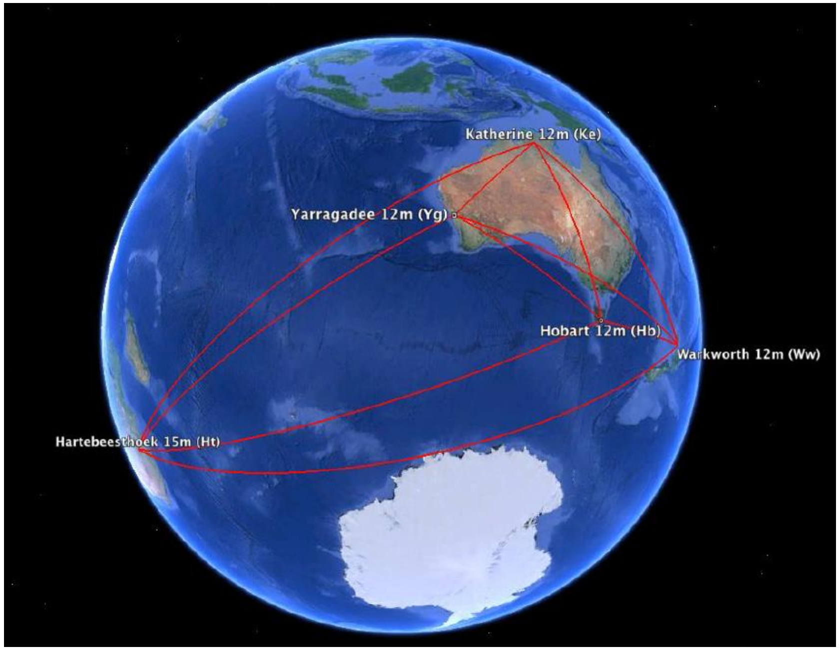
- Goal > 100 scans per source, 50 μas precision.

- 7 astrometric sessions observed since January 2014 as a part of AuScope observing program.

- **Weaker sources** observed with large telescopes: Parkes, DSS45, Hobart26, HartRAO 100-200 sources over 2 years.

- Goal 20 scans/source, 100-150 μas precision.

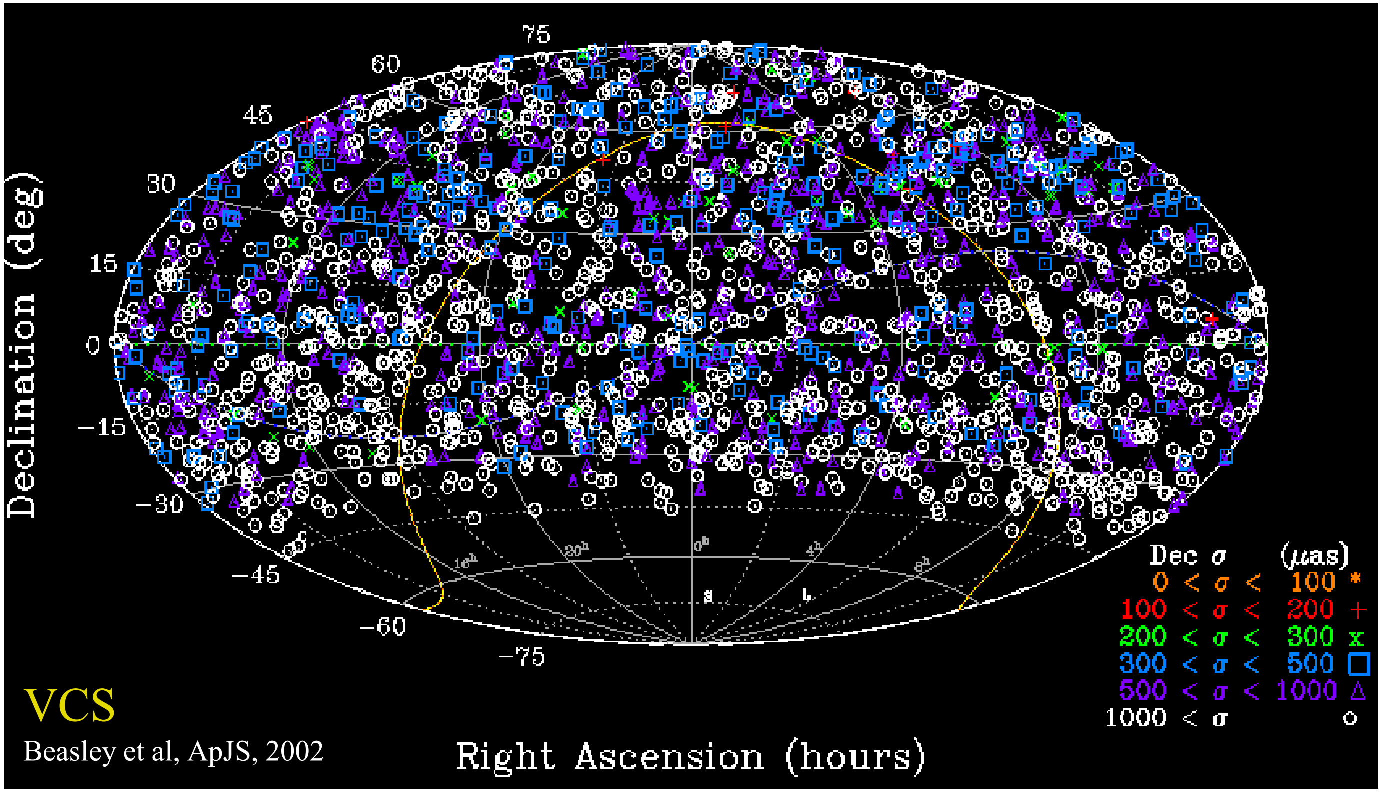




Southern Hemisphere CRF stations
Credit: Titov el al, IAG, 2013

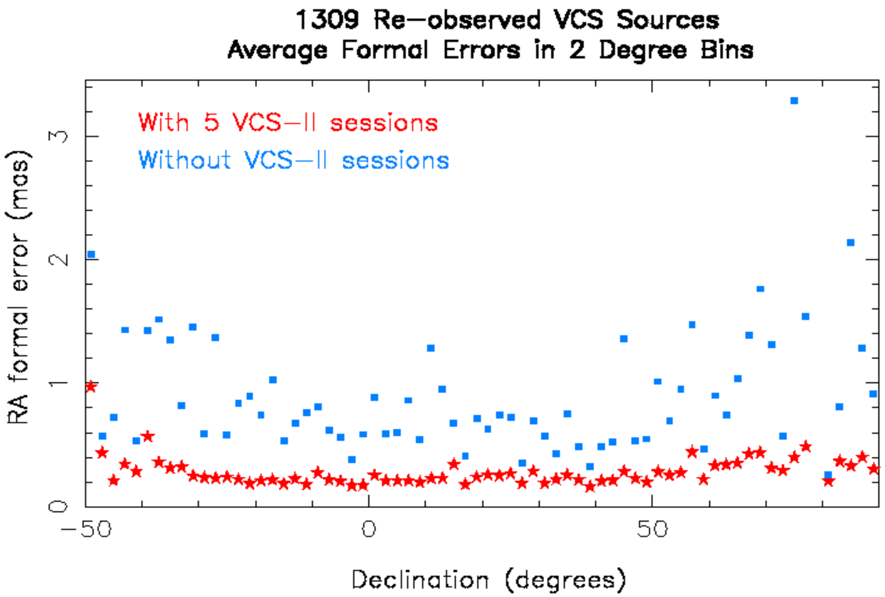
S/X Survey sources (VCS)

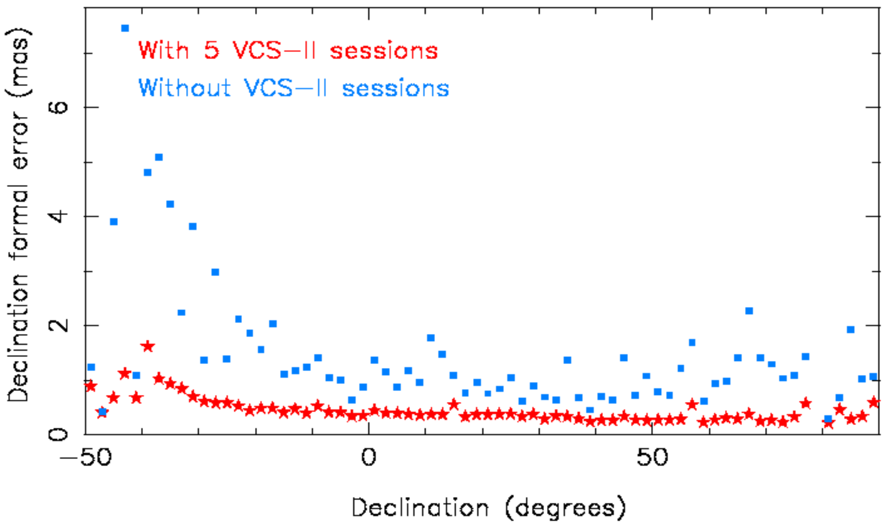
- VCS precision is typically 1,000 μas or 5 times worse than the rest of ICRF-2



- Deficiency: Uneven precision of ICRF-2 VCS's 2200 sources (2/3 of the ICRF-2)
  Plan: Re-observe VCS sources with VLBA
- VLBA approved 8 x 24-hour sessions to re-observe VCS sources. PI: David Gordon.
- 5 sessions completed and processed, 3 more scheduled, waiting in VLBA queue

VCS-II

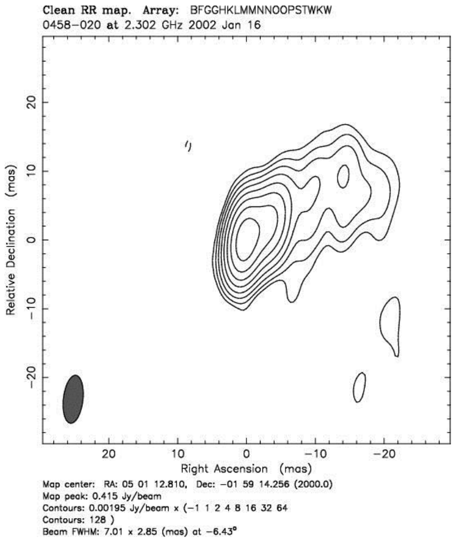


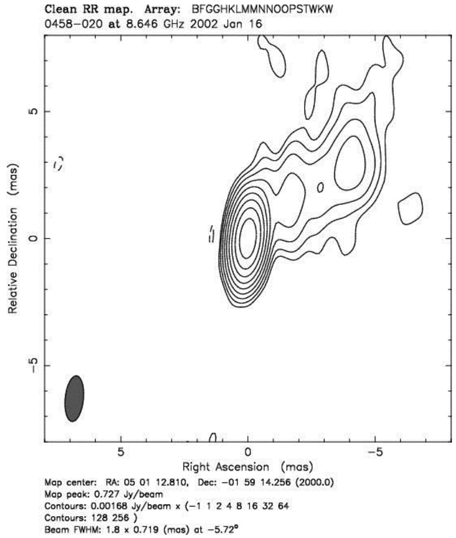


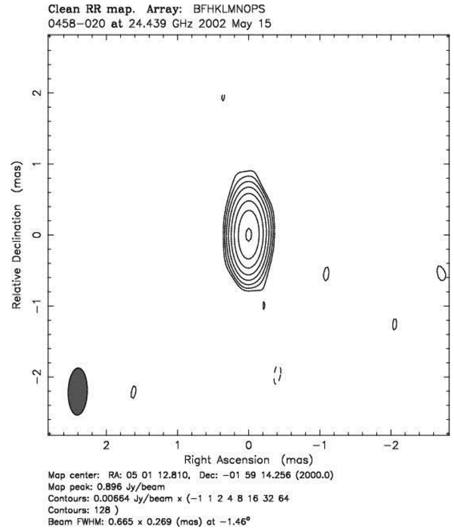
Note ~3X improvement in precision and much more uniform distribution of the position uncertainties over declination.

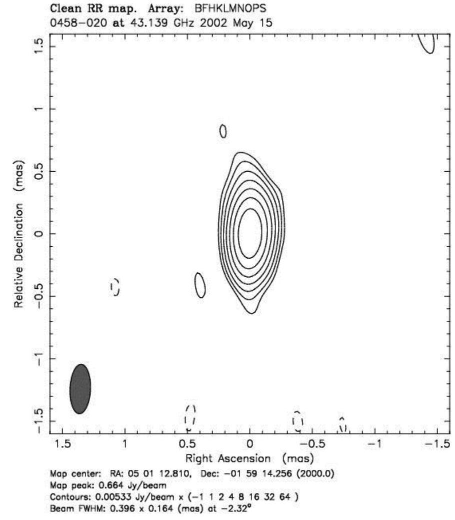
Gordon, 2014

Source Structure vs. Wavelength









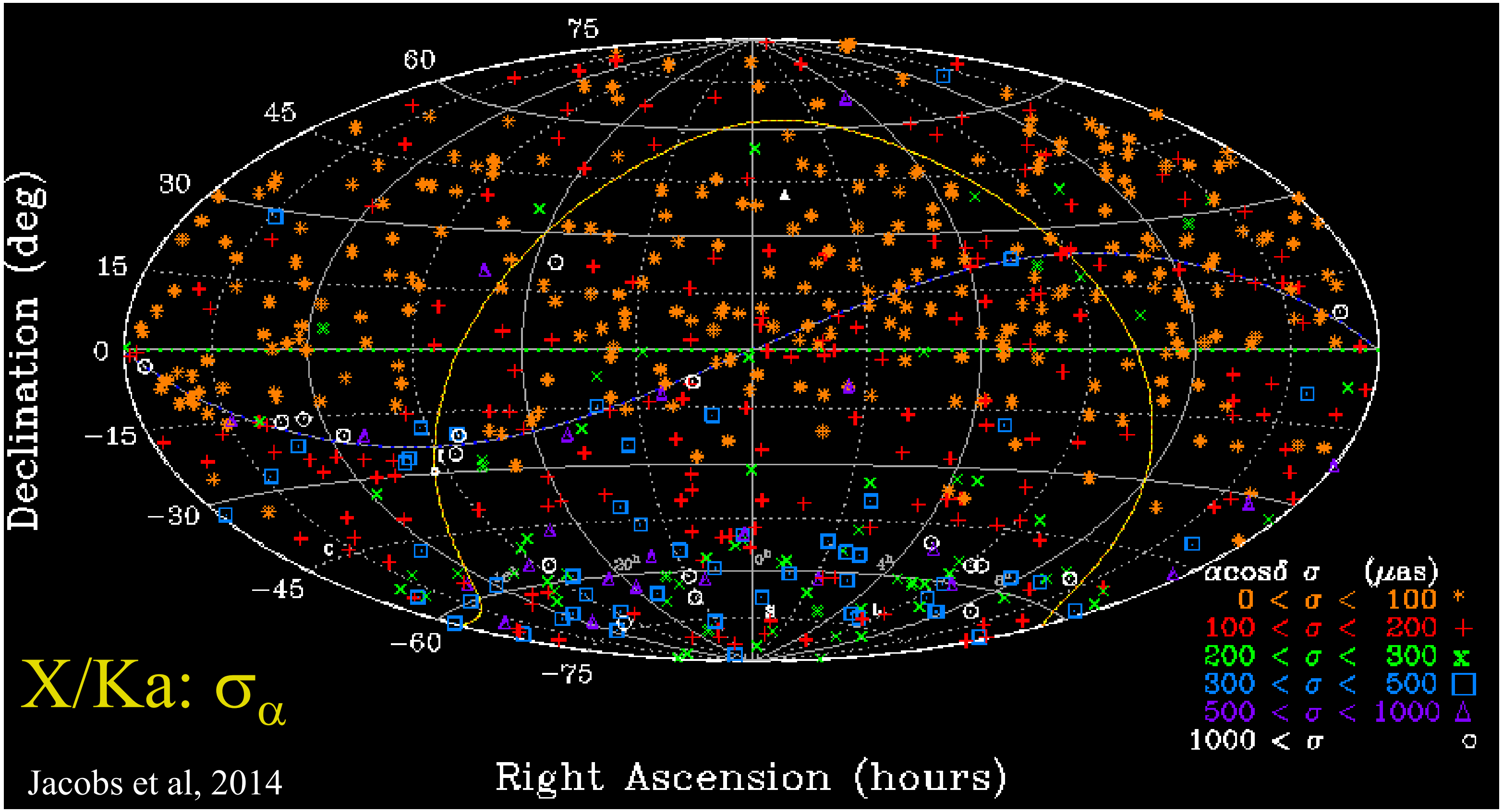
S-band	X-band	K-band	Q-band
2.3 GHz	8.6 GHz	24 GHz	43 GHz
13.6cm	3.6cm	1.2cm	0.7cm

The sources become better ----->

Ka-band
32 GHz
0.9cm

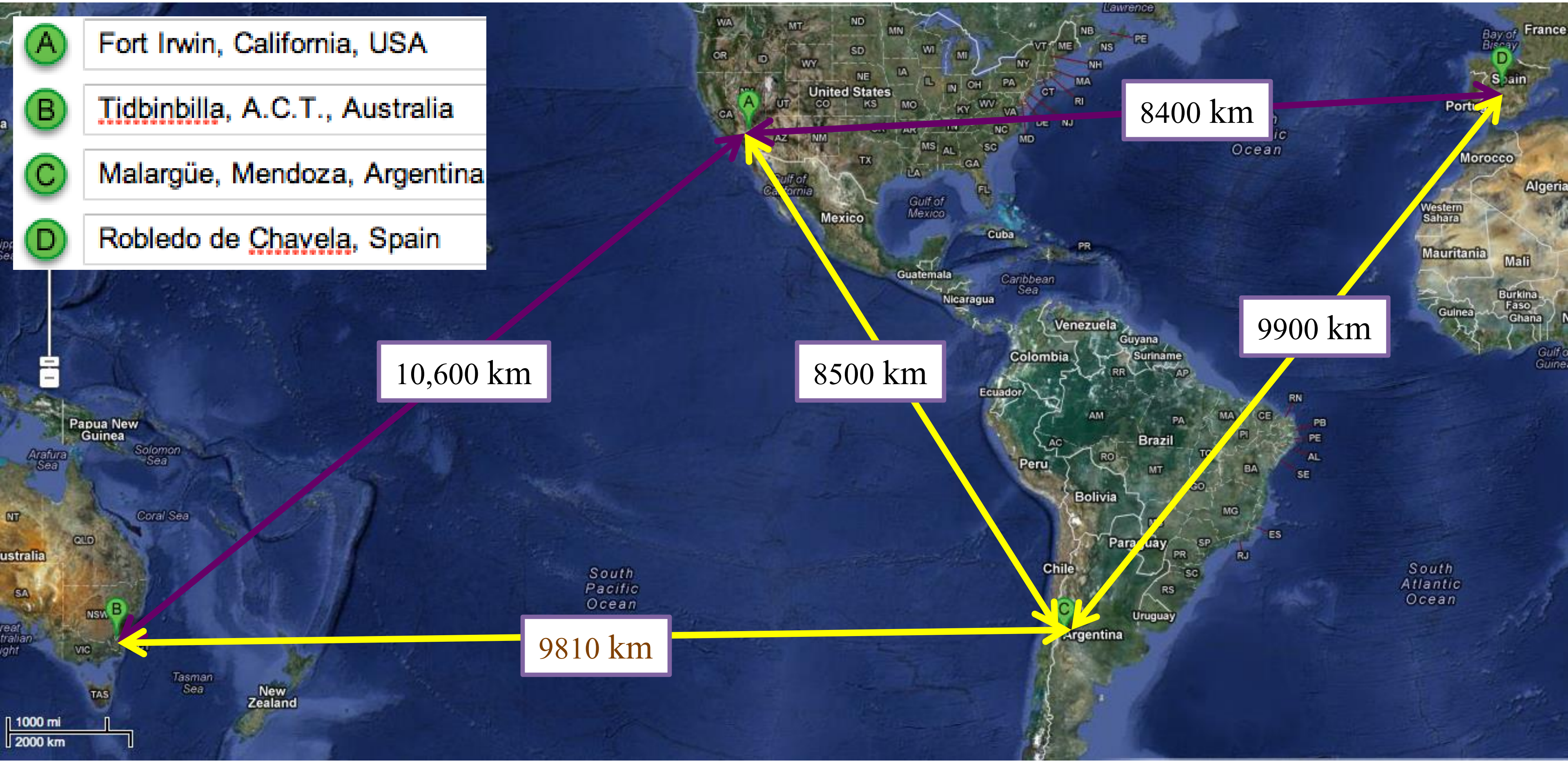
Image credit: P. Charlot et al, AJ, 139, 5, 2010

X/Ka-band (8/32 GHz) CRF



- Deficiency: Weak in the south. S. cap 134 sources (dec< -45); 27 ICRF2 Defining
- Full sky coverage (644 sources): NASA baselines CA to Madrid & Australia + recently added ESA Malargüe, Argentina to Tidbinbilla, Australia, PI: Jacobs
- 2 Gbps operational data acquisition.
- Ka-band phase cal installed at Goldstone.
- Median RA precision now 85 μas matching ICRF2 for the 525 common sources.

Plan to improve X/Ka: baselines to Argentina

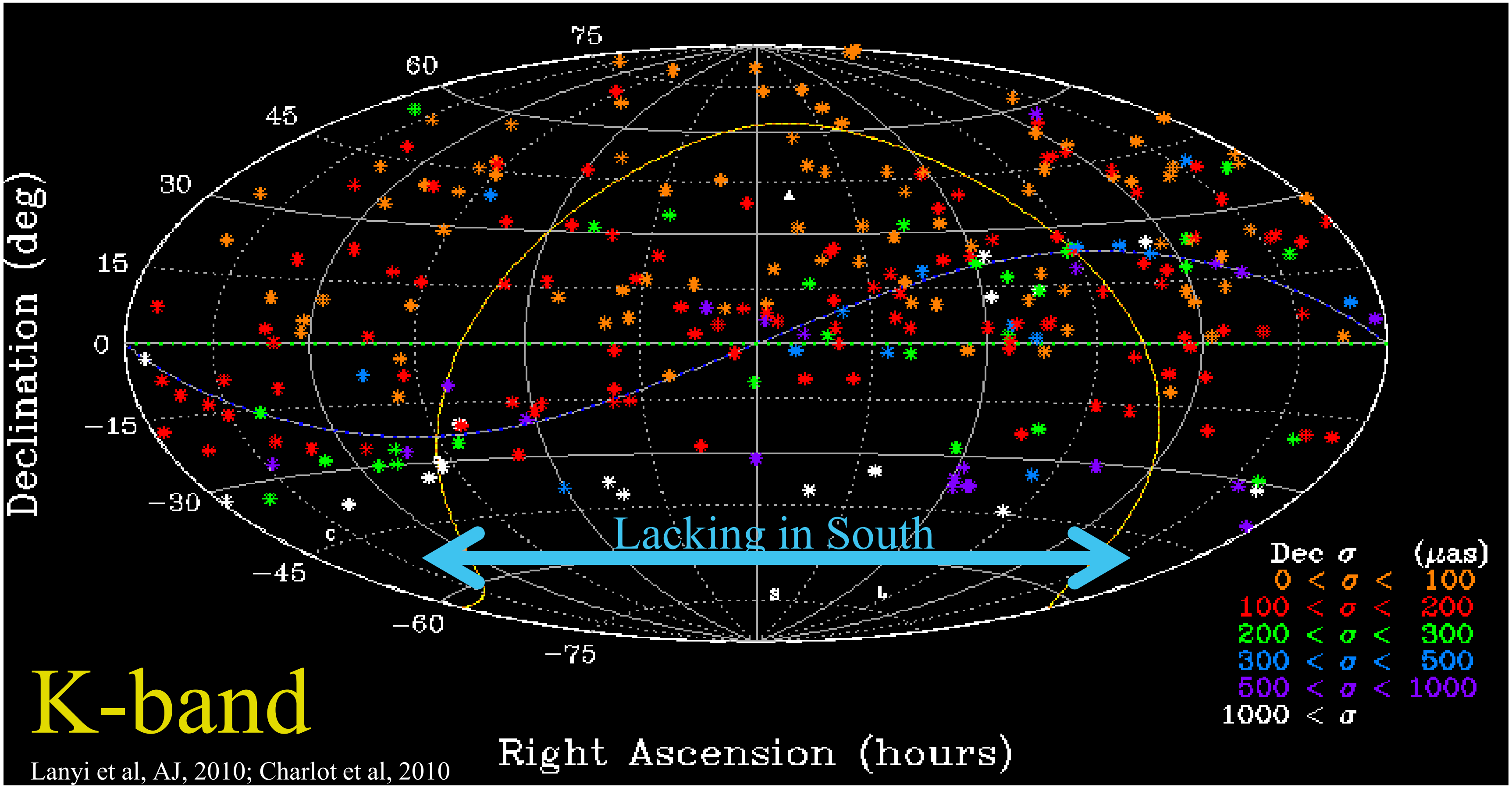


Maps credit: Google maps

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

K-band (24 GHz) CRF: 275 sources



- Deficiency: lacking in the south

Plan: New K-band full sky coverage collaboration (*Bertarini+, Journees, 2013)*

First southern K-band fringes: Hobart-HartRAO (23 Aug 2013)

First 24h southern session: 21 Dec 2013, **in correlation** *(de Witt+, IVS-2014)*

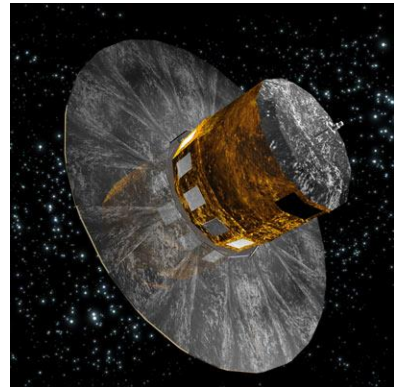
Gaia/VLBI frame tie & Accuracy test

Gaia:
- 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, 2013*)

- S/X frame tie Strategy:
  Bring 100+ new optically bright quasars into the radio frame (*Bourda, et al., 2008-2012*).

- 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 X/Ka precision, but improving as more data arrives.

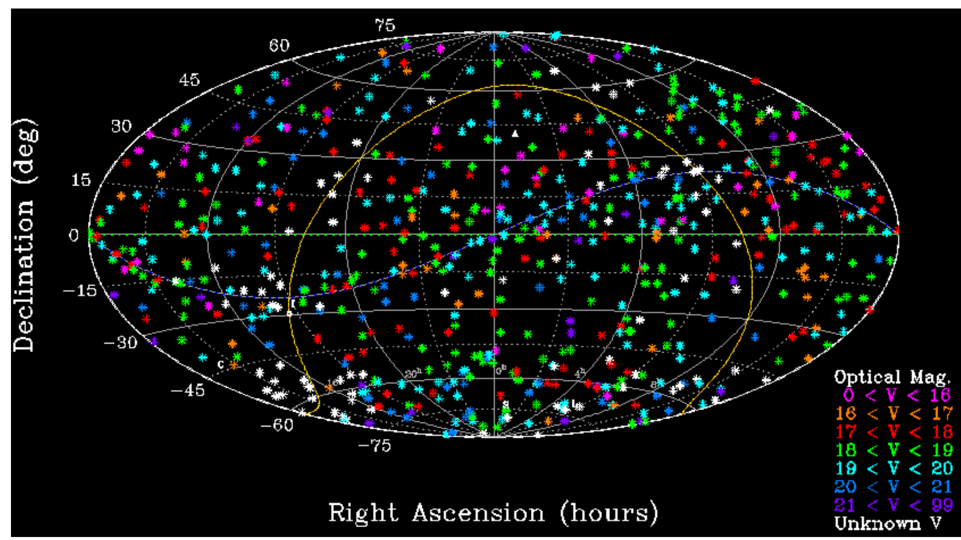
- Several groups: Titov *et al.* , Andrei *et al.*, Taris *et al.* working on optical measurements of the current and prospective ICRF sources (identification, redshifts, photometry).



- Quasar positions precision
  70 µas @ V=18
  25 µas @ V=16

may get worse due to stray light, especially for fainter objects

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



XKa: ~175 optically bright counterparts: V< 18 mag
(optical V magnitudes: Veron-Cetty & Veron, 2010)

Optical vs. Radio positions

Positions differences from:

• Astrophysics of emission centroids

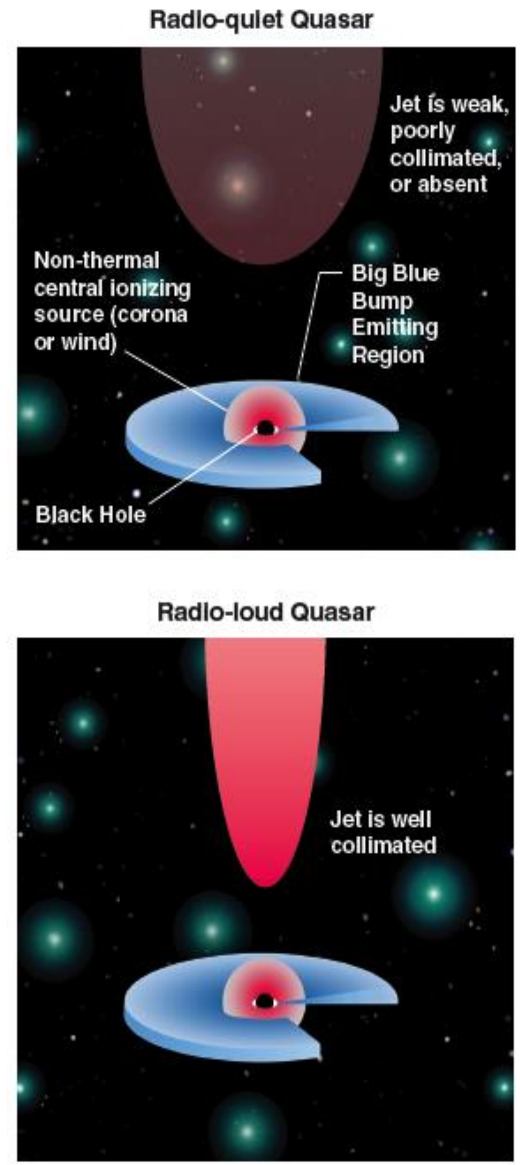
- radio: synchrotron from jet

- optical: synchrotron from jet?
  non-thermal ionization from corona?
  "big blue bump" from accretion disk?

- optical centroid biased by host galaxy?

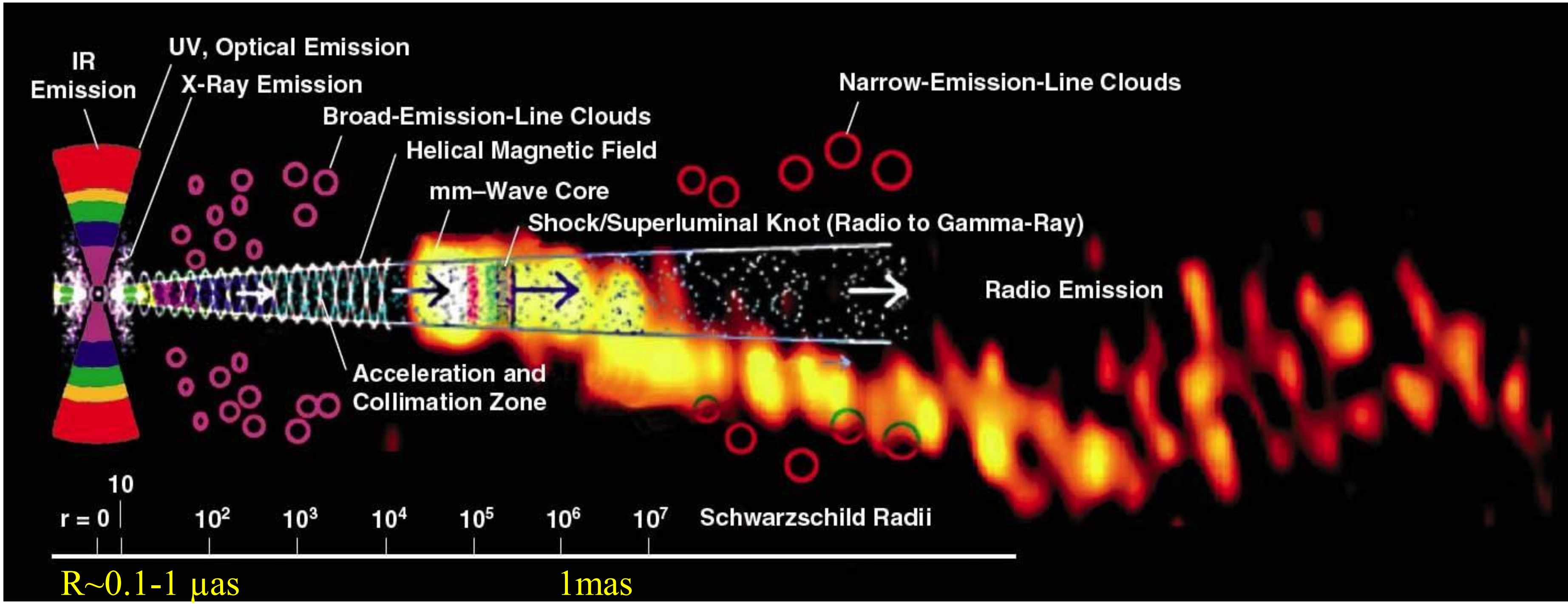
• Instrumental errors both radio & optical

• Analysis errors



Credit: Wehrle et al, μas Science, Socorro, 2009

9mm vs. 3.6cm: Core shift & structure



Credit: A. Marscher, Proc. Sci., Italy, 2006.
Overlay image: Krichbaum, et al, IRAM, 1999.
Montage: Wehrle et al, ASTRO-2010, no. 310.

Positions differences from ‘core shift’

- wavelength dependent shift in radio centroid.
- *3.6cm to 9mm core shift:*

  100 μas in phase delay centroid?

  <<100 μas in group delay centroid? (*Porcas, AA, 505, 1, 2009*)
- shorter wavelength closer to Black hole and Optical: 9mm X/Ka better

LQAC-3

Third release of the Large Quasars Astrometric Catalogue

Objectives:

- Compilation of all the recorded quasars (~374000)
- Strategy insisting on astrometric quality
- Cross-identifications between ICRF and optical catalogues
- Extended photometry & redshift
- Morphology indexes
- Calculation of absolute magnitudes M_I & M_B
- Basis for regular up-dates (=> GAIA)
- Final ASCII file with V.O. tools in parallel
- Comparisons / statistics / coherence

Souchay et al., in prep. end 2014

Summary of ICRF-3 tasks:

- Improving **VLBA Cal Survey's** 2000+ positions
  → More uniform precision for all sources
- Improving **southern observations**
  → More uniform spatial coverage
- Improving number, accuracy, and southern coverage of **high frequency frames** 24, 32, 43? GHz (K, X/Ka, Q?)
  → Improved frequency coverage

- ICRF-3 completed by **Aug 2018 in time for** comparisons & alignment with **Gaia** optical frame
- Competitive accuracy with Gaia ~ 70 μas (1-sigma RA, Dec)
- Improving set of **optical-radio frame tie** sources for Gaia

IAU Working Group on ICRF3

Charter for IAU Division A Working Group on the Third Realization of the International Celestial Reference Frame

The purpose of the IAU Division A Working Group on the Third Realization of the International Celestial Reference Frame (ICRF) is to produce a detailed implementation and execution plan for formulation of the third realization of the ICRF and to begin the process of executing that plan.

The implementation plan along with execution progress will be reported to IAU Division A at the XXIX General Assembly of the IAU in 2015.

Targeted completion of the third realization of the ICRF will be the XXX General Assembly of the IAU in 2018.

Derived from VLBI observations of extragalactic radio sources, the third realization of the ICRF will apply state-of-the-art astronomical and geophysical models and analysis strategies, and utilize the entire relevant astrometric and geodetic data set. The Working Group will examine and discuss new processes and procedures for formulating the frame along with the potential incorporation of new global VLBI arrays, and new observing frequencies offering the potential for an improvement over ICRF2. The Working Group will provide oversight and guidance for improving the relevant data sets.

IAU Working Group on ICRF3

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