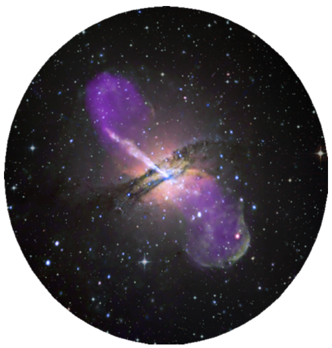
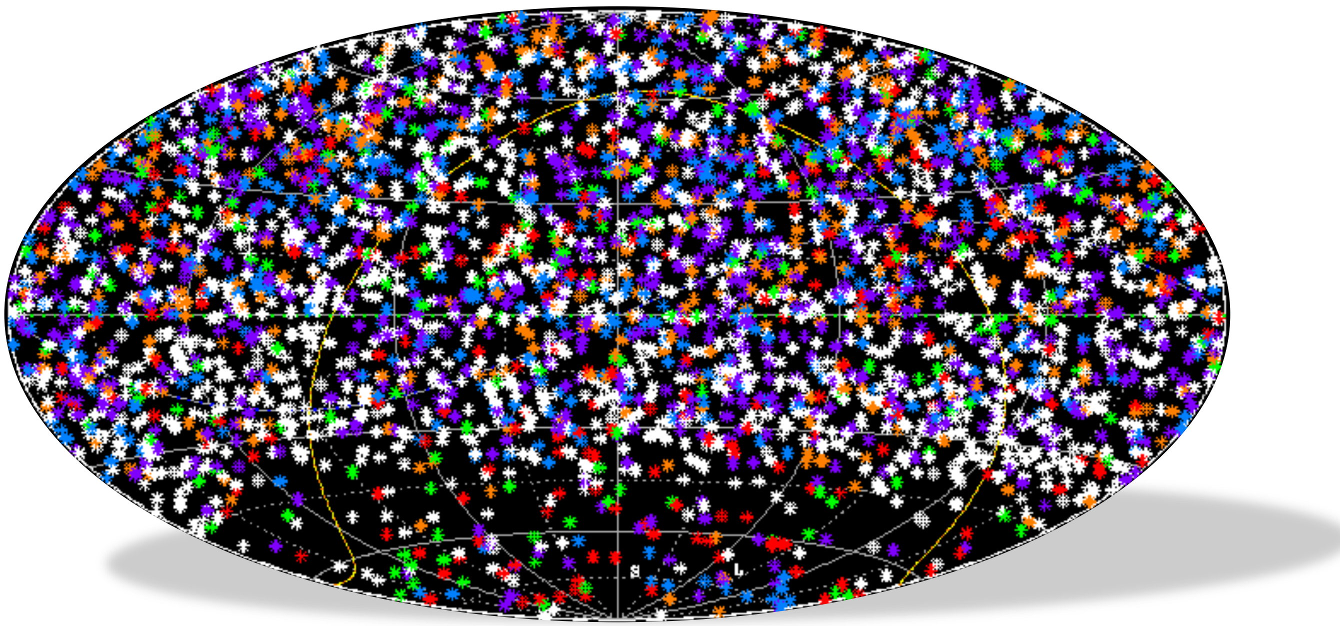
EVGA 2015, Ponta Delgada, Azores

ICRF-3: Status, Plans, and Multi-wavelength Progress towards the next generation ICRF





Christopher S. Jacobs (ICRF-3 chair),

Jet Propulsion Laboratory, California Institute of Technology

IAU ICRF-3 Working Group: Arias, Boboltz, Boehm, Bolotin, Bourda, Charlot, de Witt, Fey, Gaume, Gordon, Heinkelmann, Kurdubov, Lambert, Ma, Malkin, Nothnagel, Seitz, Skurikhina, Souchay, Titov

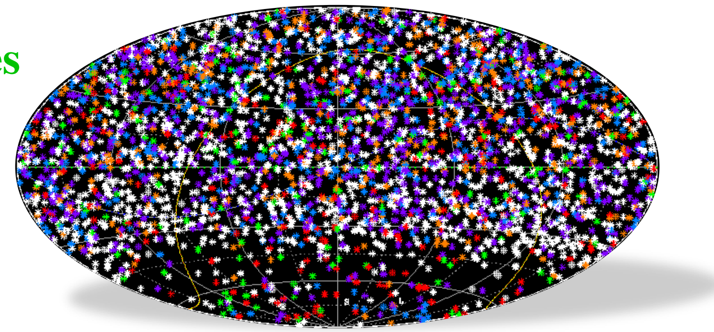
2015 May 17-21

Overview

- ICRF-2 history and benefits vs. ICRF-1
- Assessment of needed improvement in ICRF-3
- Plans for improving the ICRF
  more uniform precision: VCS-II
  more uniform spatial coverage: southern CRF
  improved frequency coverage: K, X/Ka
- Gaia: radio-optical frame tie
  Wavelength dependent systematic errors in CRFs

Overview of 2nd International Celestial Reference Frame

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

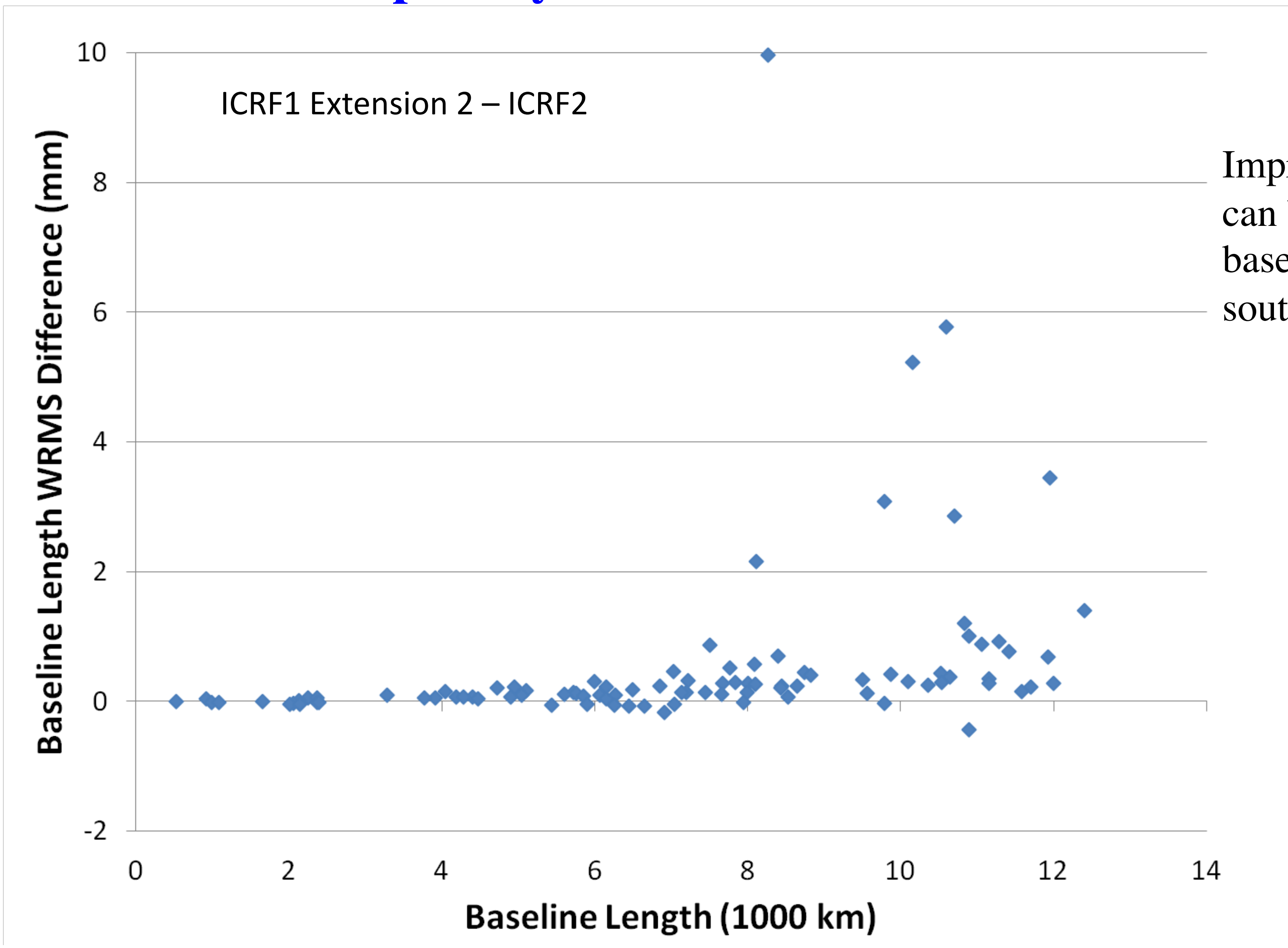


- S/X data (2.3/ 8.4 GHz or 13/ 3.6 cm) for **3414 sources**
- **6.5 Million group delay observations** 1979 to 2009
- No-Net-Rotation relative to ICRF-1
- Estimate TRF and EOPs internally from VLBI data
  Constrain to VTRF2008 (VLBI part of ITRF-08: *Böckmann et al, JGeod, 84, 2010*)
  as ITRF2008 was 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

Geodetic impact by the switch from ICRF1-ext.2 to ICRF2



Improvements can be found for baselines including southern stations!

Courtesy D. MacMillan, GSFC

Geodetic impact by the switch from ICRF1-ext.2 to ICRF2

Table: EOP differences w.r.t. IGS

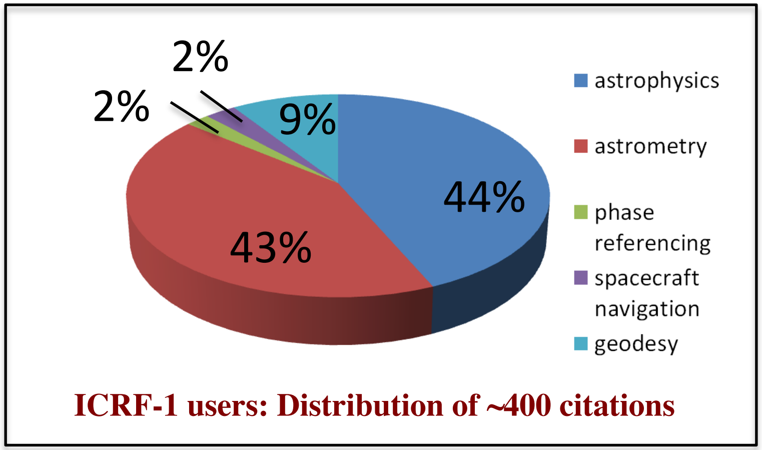
EOP	ICRF1 Ext.2 fixed		ICRF2 fixed	
	WRMS	Chi2/dof	WRMS	Chi2/dof
x-pole	123.4	3.3	113.5	2.8
y-pole	113.3	3.1	109.6	2.9
X-pole rate	318.9	2.1	305.0	1.9
Y-pole rate	315.1	2.1	302.7	1.9
LOD	19.6	3.7	18.9	3.4

Courtesy of D. MacMillan, GSFC

All EOPs improved with ICRF2!

ICRF-3 assessment of Needs

Assessment of users for ICRF-3



Credit: R. Heinkelmann

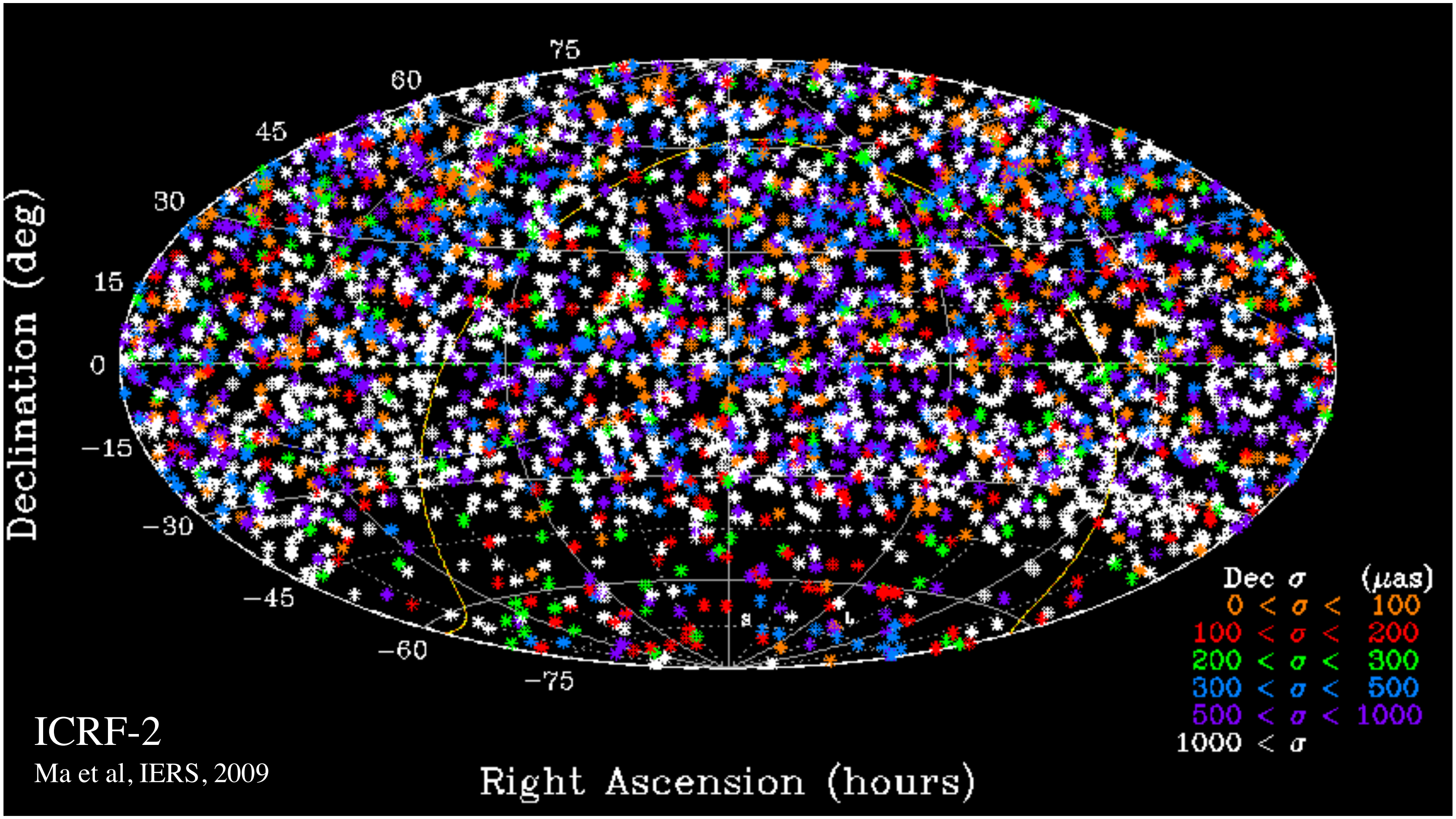
Assessment of user relevant deficiencies

1. VLBA Calibrator Survey (VCS) is most (2/3) of ICRF-2
   but positions are 5 times worse than the rest of ICRF-2

2. ICRF-2 is weak in the south especially below -40 deg Declination.

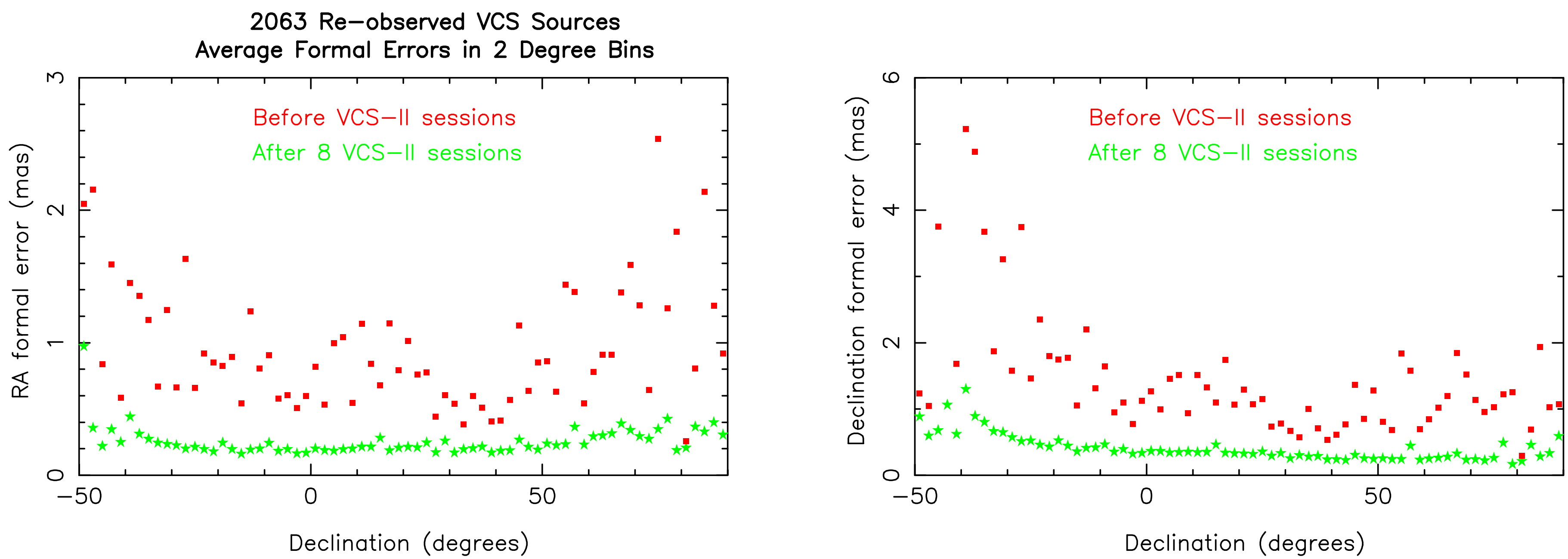
3. High frequency frames have more point-like sources
   but also fewer sources at present.
   As with S/X, high frequency CRFs are weak in the south.

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



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

VLBA Calibrator Survey improvement

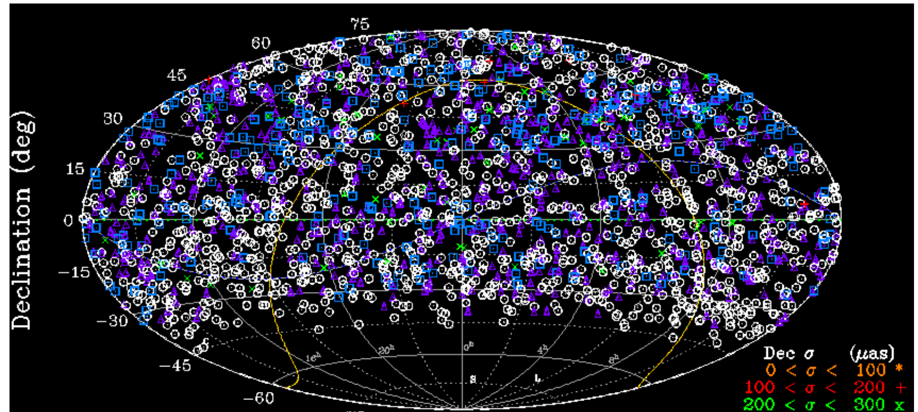


~3.7 times X improvement in precision

much more uniform distribution of the position uncertainties vs. declination.

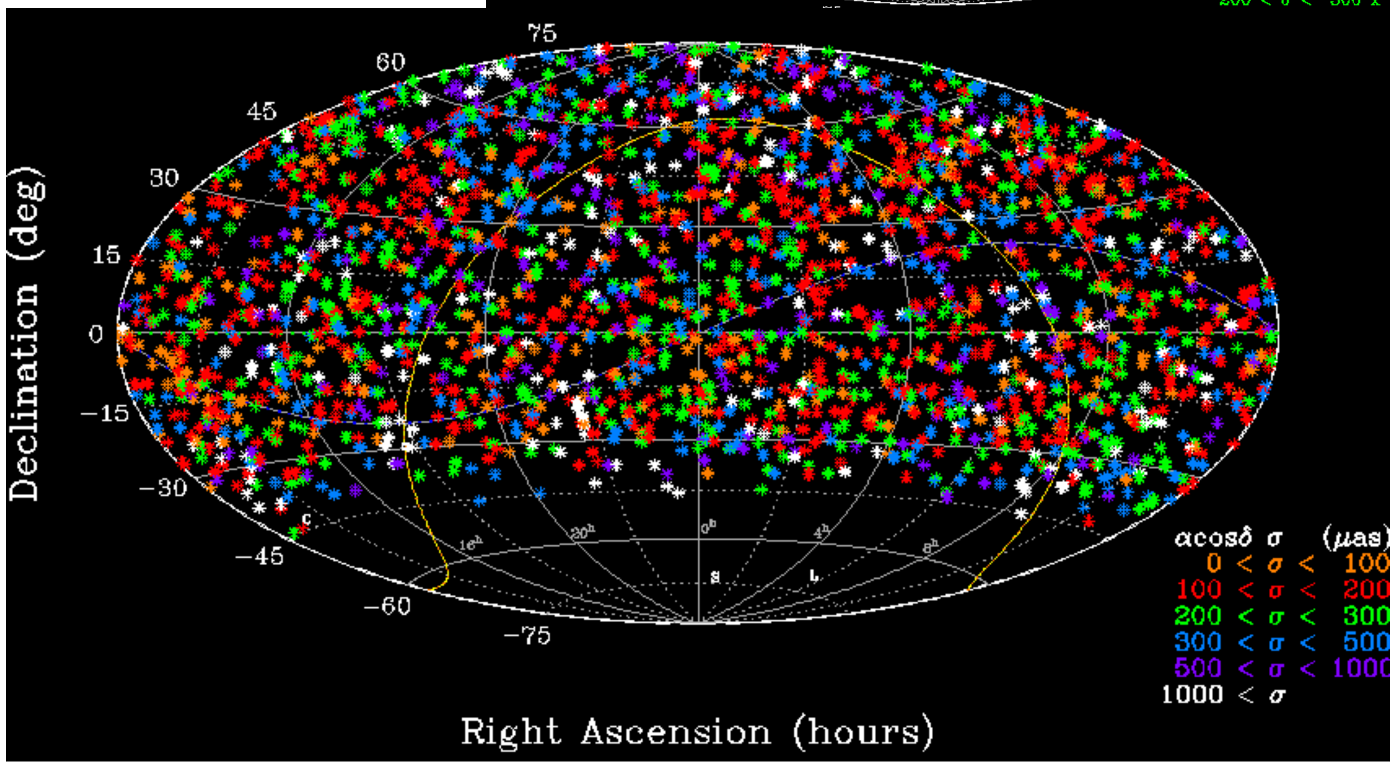
VLBA Calibrator Survey improvement

VCS-I: ~1 mas precision
for 2200 sources
credit: Beasley et al, AJ, 2002



VCS-II:
RA 0.23 mas
Dec 0.39 mas

Improvement
~3.7 times



Credit: Gordon et al, GSFC, private .commmunication, 2014

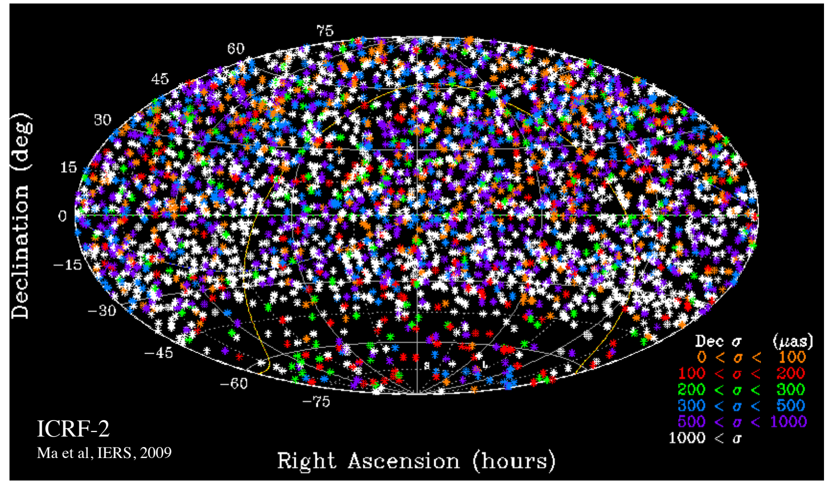
S/X-band Plan for Southern Improvements

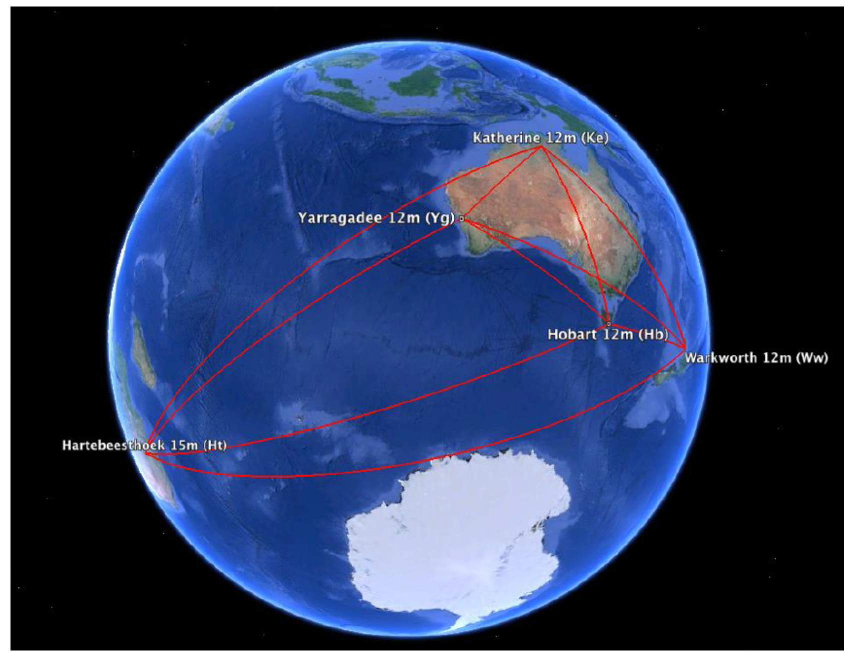
- Recent southern work: Lovell's talk
- 2013-15: Observe 100-200 **strong** (> 400 mJy) sources using the small, fast stations of the southern CRF Network at S/X-bands.

  Six (6) sessions completed.

- Goal > 100 scans per source, 50 μas precision

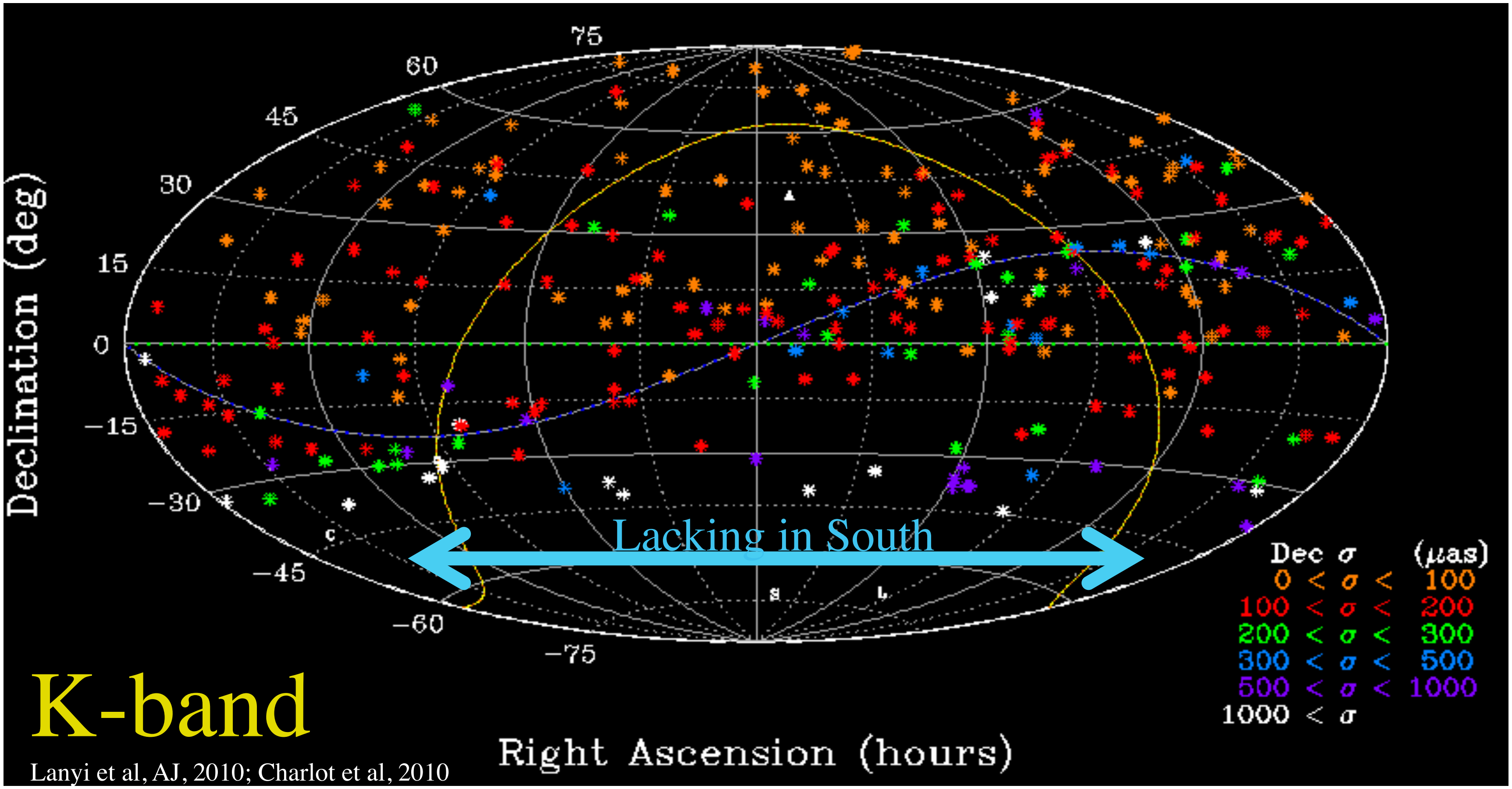
- **Weaker sources** observed with large telescopes: Parkes, DSS45, Hobart26, HartRAO
  100-200 sources over 2 years,
- Goal 20 scans/source, 100-150 μas precision





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

K-band (24 GHz) CRF: 275 sources



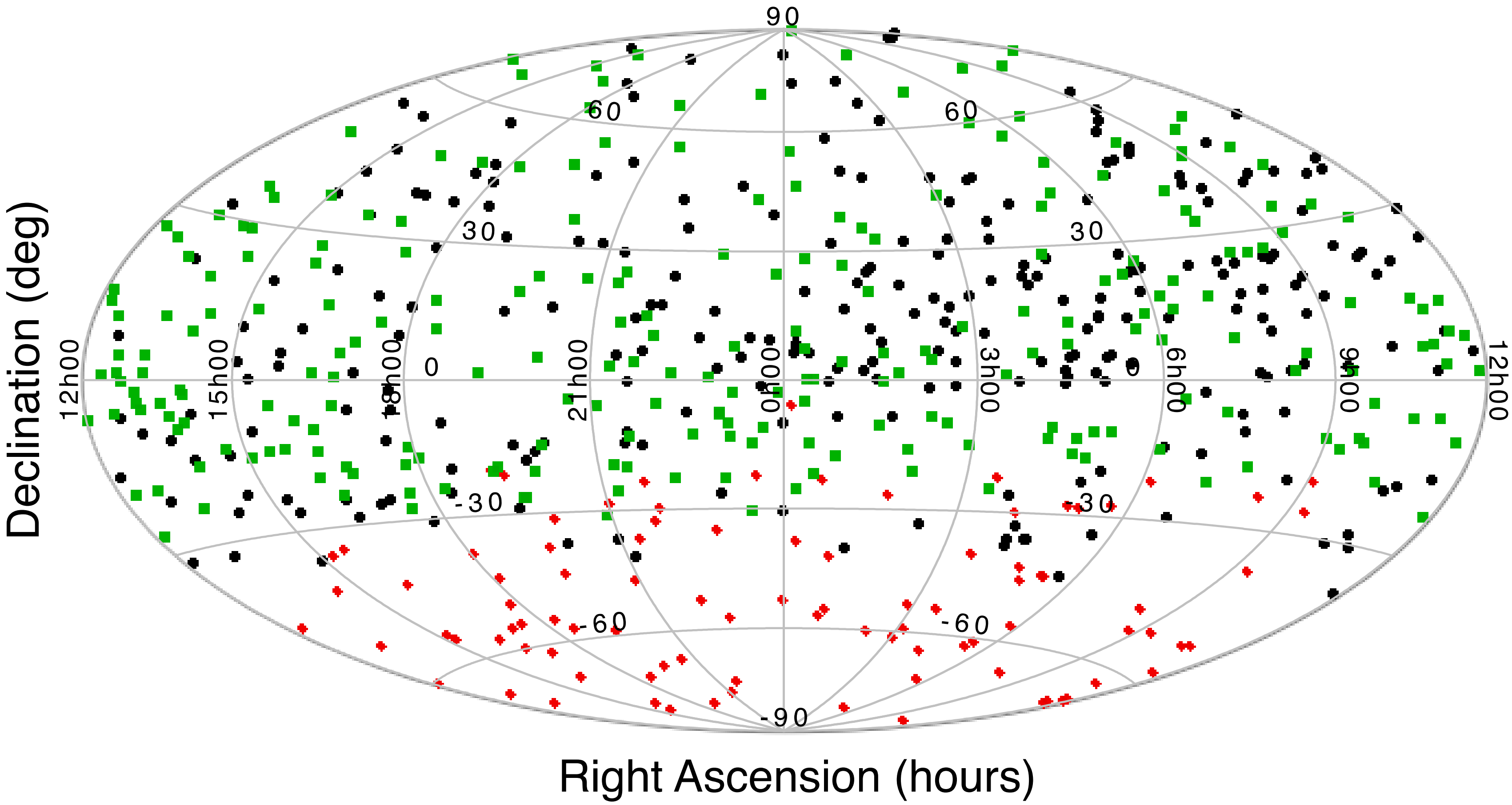
K-band full sky coverage collaboration: De Witt+ poster

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

Data completing full sky coverage being processed.

VLBA approved time to densify the north -> expect 500+ sources total

K-band (24 GHz) CRF: > 500 sources

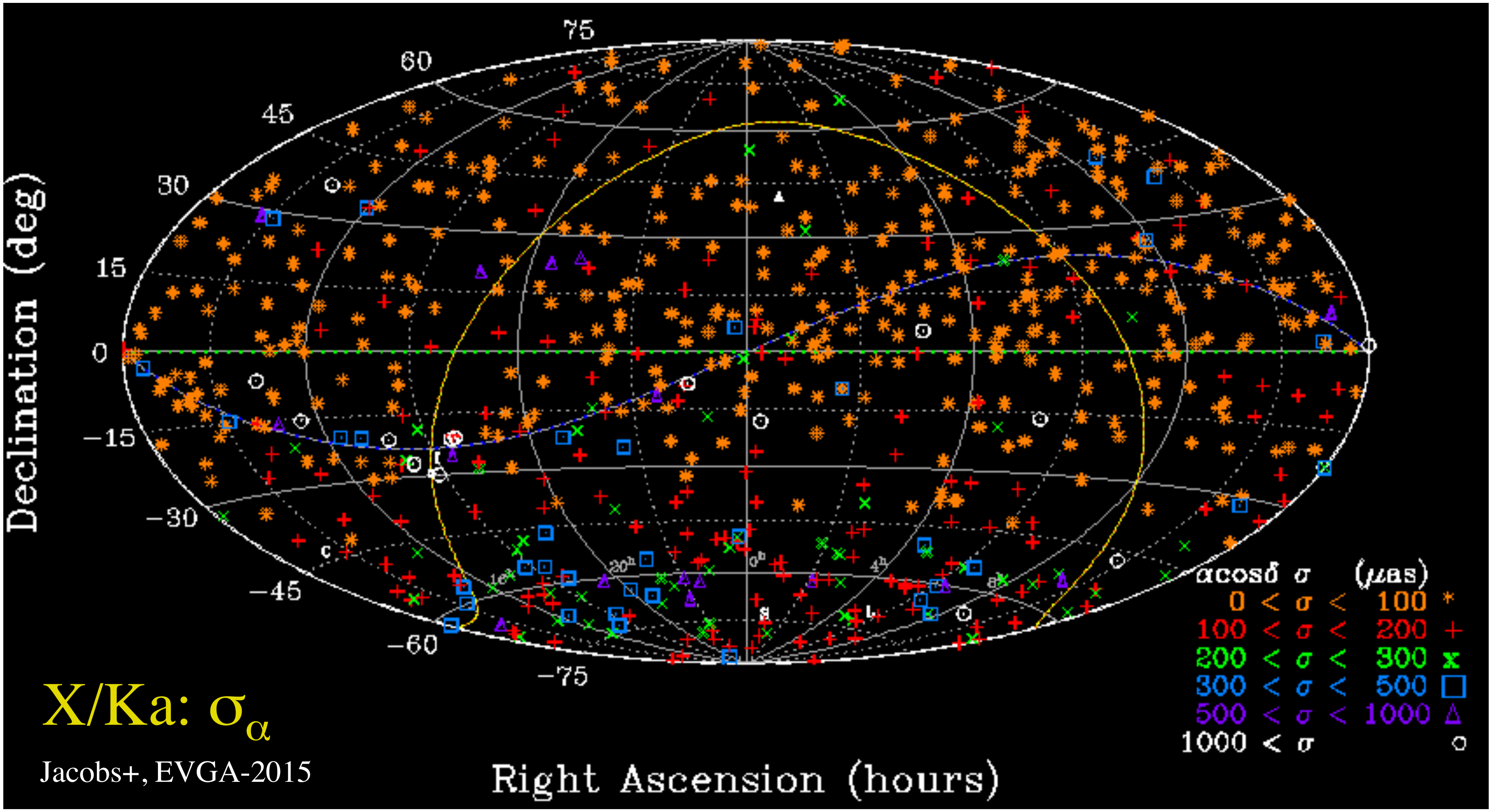


- K-band existing (Lany+, Charlot+).
- New K-band data fron Bertarini et al collaboration (see De Witt+ poster)

Data completing full sky from (Australia –South Africa) being processed.

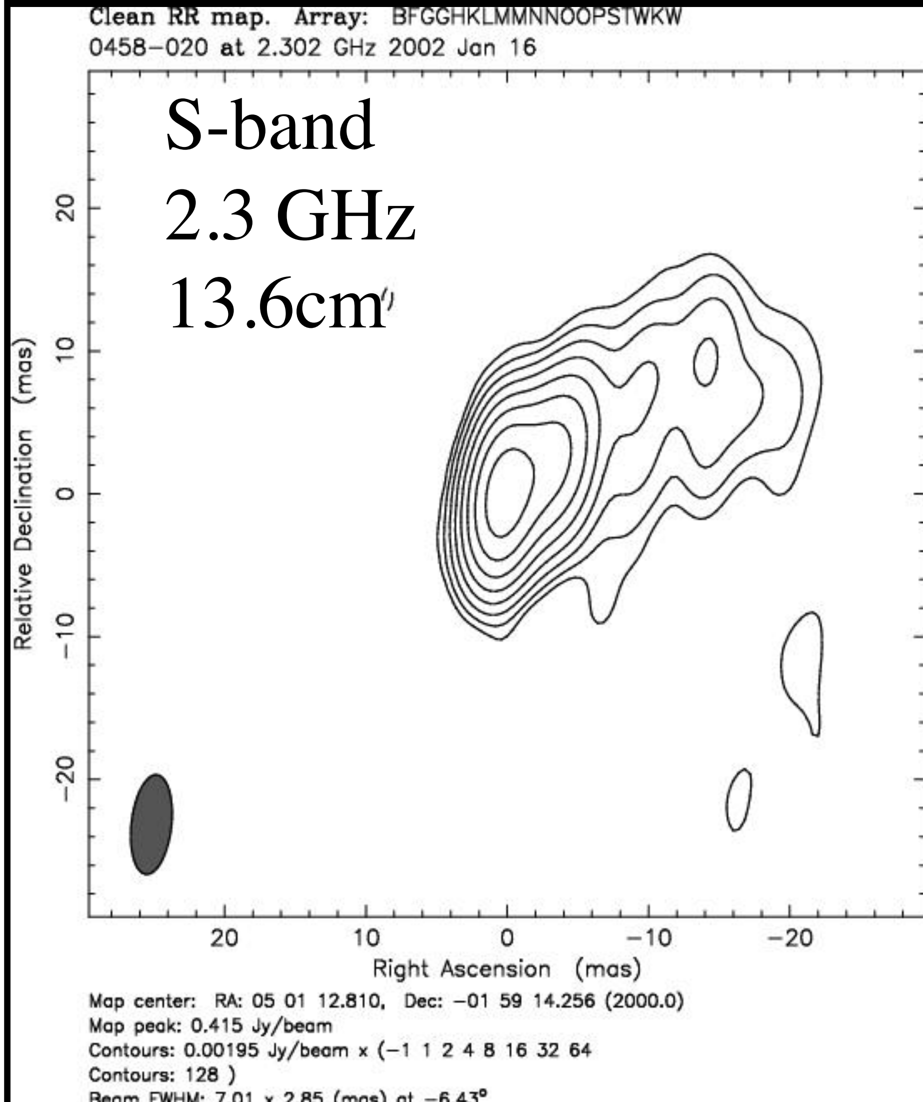
VLBA approved time to densify the north. Expecting > 500 sources total

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

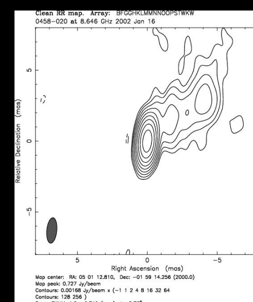


- Median precision slightly better than ICRF-2. South cap adds 100 sources to ICRF-2
- 660 sources; Full sky coverage: NASA baselines CA to Madrid & Australia
  - recently added ESA Malargüe, Argentina to Tidbinbilla, Australia

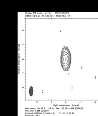
Source Structure vs. Frequency (absolute scale)



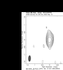
X-band
8.6 GHz
3.6cm



K-band
24 GHz
1.2cm



Q-band
43 GHz
0.7cm

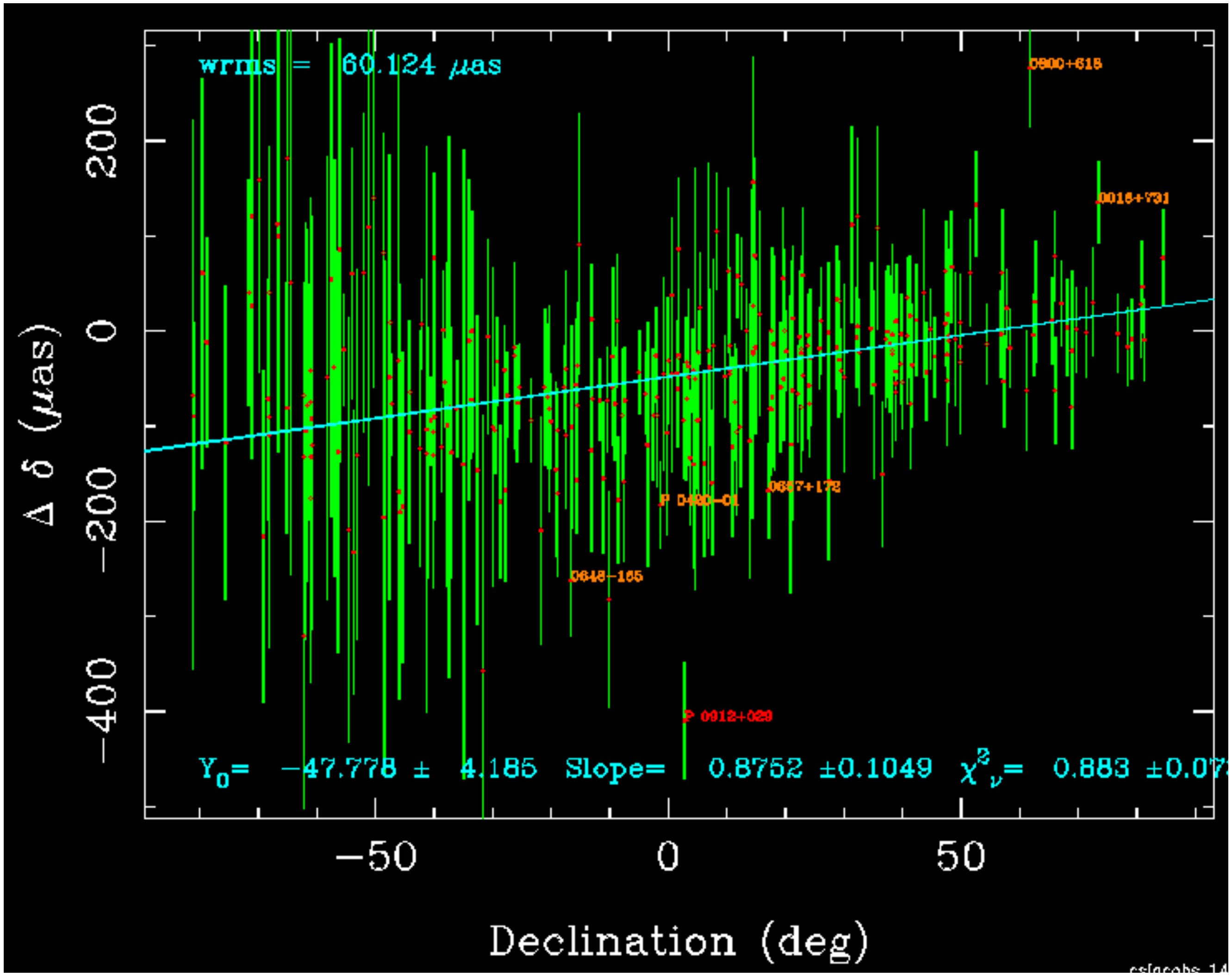


The sources become better → smaller structure indexes (Fey & Charlot 1997)

Ka-band
32 GHz
0.9cm

Images credit: P. Charlot et al, AJ, 139, 2010

S/X zonal errors: ICRF2 vs. Recent S/X



Credit:
Gordon et al, GSFC,
private .comm., 2014

GSFC-2014bp3 – ICRF2 Definings: 0.5 ppb zonal error in Declination

Multi-wavelength Defining Sources?

ICRF-3 working group is exploring making the Defining sources
to be a set of sources with common positions
based on combined observations at

S/X (8 GHz)
K (24 GHz)
X/Ka (32 GHz)

and, perhaps, optical if possible.

Initial studies show some promise in the radio for this concept
of a multi-wavelength ICRF.

Data is being taken and more studies will be done before a final decision is made.

<u>Gaia-Optical *vs.* VLBI-radio</u>:

Celestial Frame tie
and
Accuracy Verification

Gaia frame tie and accuracy verification

Gaia: 10^9 stars

- 500,000 quasars V< 20
  20,000 quasars V< 18
- radio loud 30-300+ mJy
  and optically bright: V<18
  ~2000 quasars
- Accuracy
  100 μas @ V=18
  25 μas @ V=16

Launched Fall 2013

Gaia References:

Lindegren et al, IAU 248, 2008
http://adsabs.harvard.edu/abs/2008IAUS..248..217L

Mignard, IAU, JD-7, 2012
http://referencesystems.info/uploads/3/0/3/0/3030024/fmignard_iau_jd7_s3.pdf
http://adsabs.harvard.edu/abs/2012IAUJD...7E..27M

- S/X Frame Tie Strategy:
  Bring new optically bright quasars
  into the S/X radio frame
  use sources with S/X fluxes 30-100 mJy
  (Bourda et al, EVN, Bordeaux, 2012)

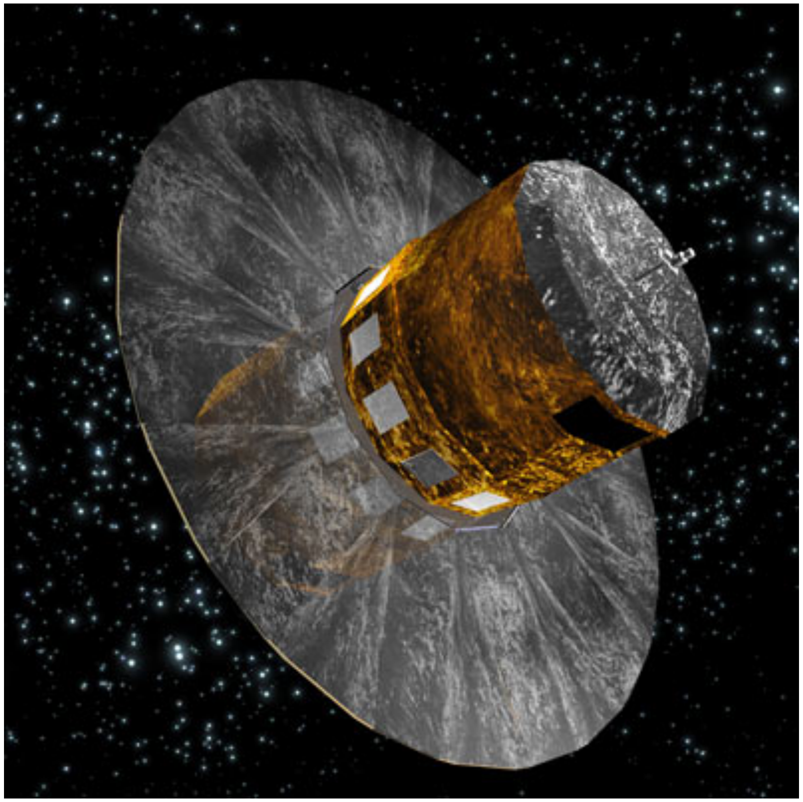
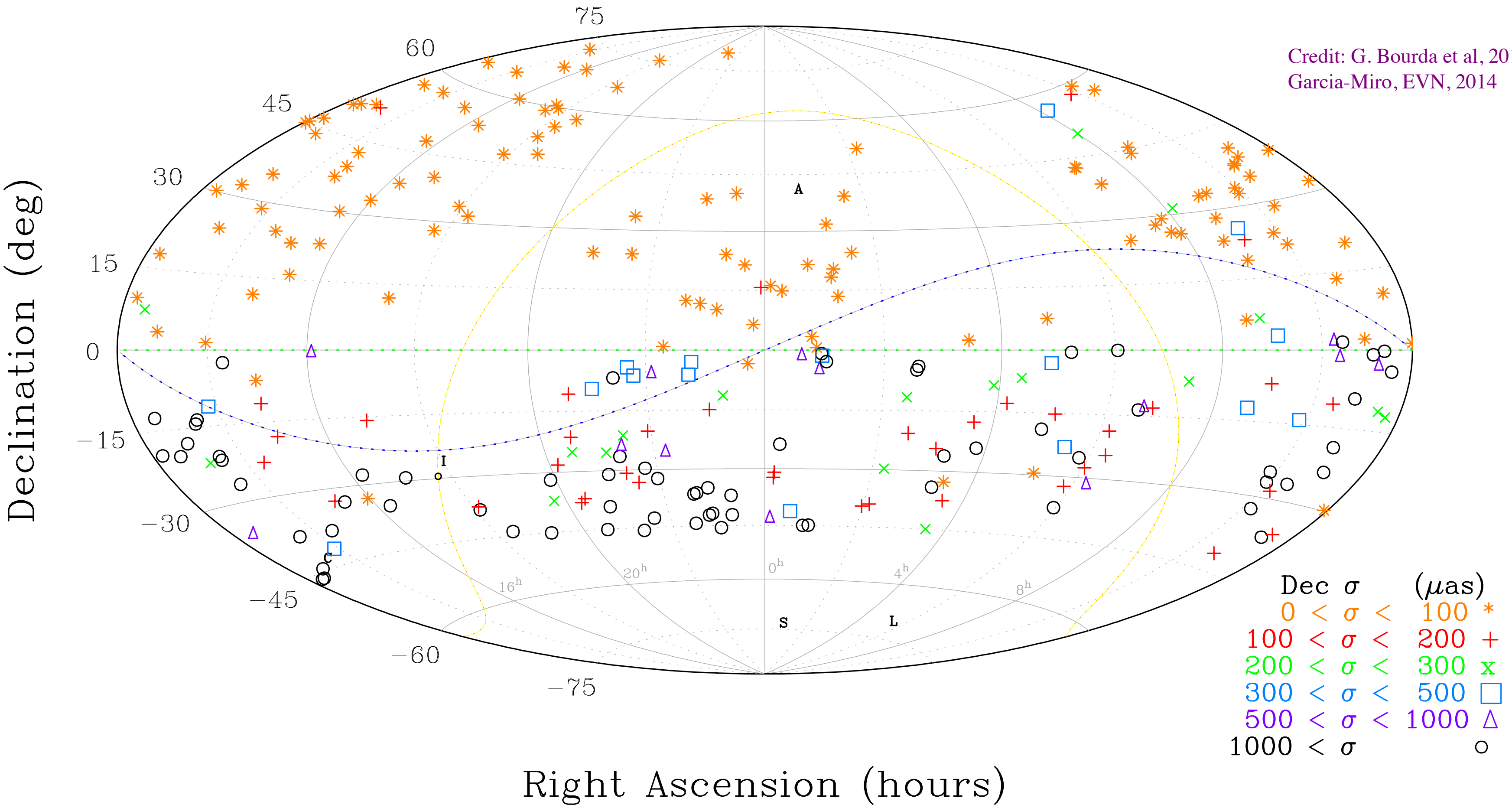


Figure credit: http://www.esa.int/esaSC/120377_index_1_m.html#subhead7

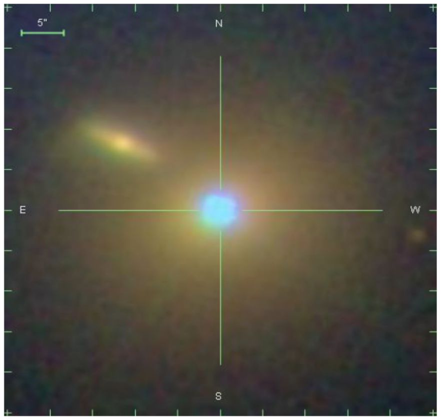
Adding optically bright sources to radio



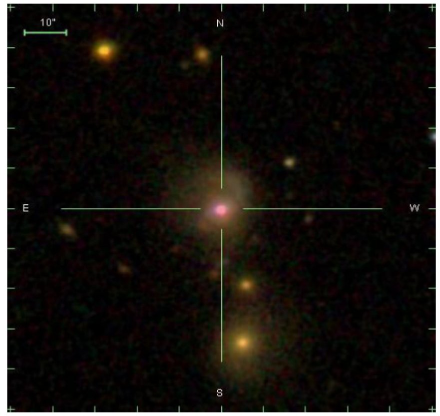
- S/X (3.6cm): Detected ~275 optically bright sources on long baselines
- Southern hemisphere additions just starting.
- XKa (9mm) will only see a fraction (10-20%) of these due to sensitivity limits

Optical vs. Radio systematics offsets

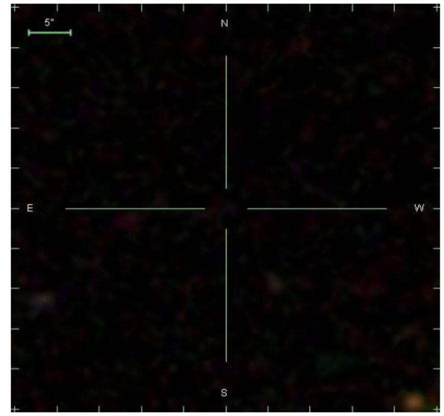
Credit: SDSS



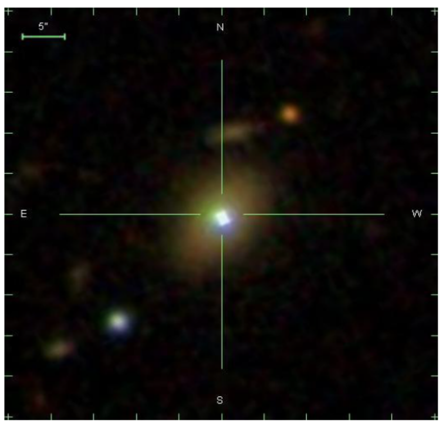
1101+384



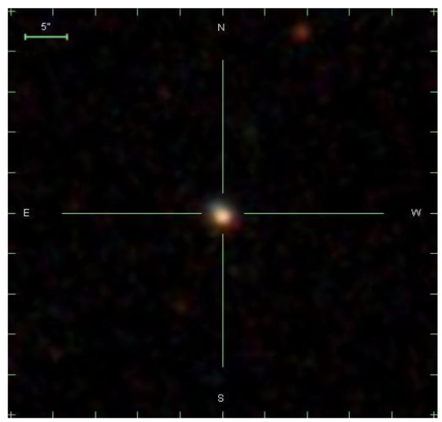
0007+106



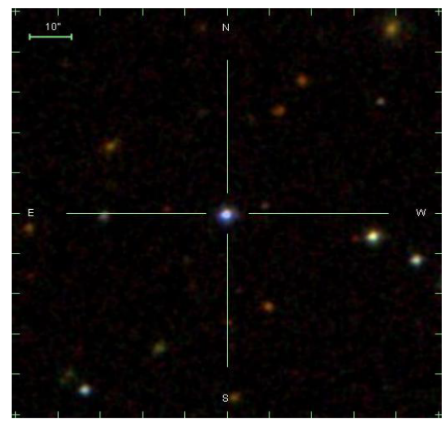
0920+390



1418+546



1514+192



1546+027

- Optical structure: The host galaxy may not be centered on the AGN or may be asymmetric. Review Zacharias & Zacharias (2014) who see evidence for many milli-arsecs of optical centroid offset. This could dominate the error budget.
- Optical systematics unknown, perhaps as large as 10 mas optical centroid offset? (Zacharias & Zacharias, AJ, 2014)

Summary of ICRF-3 goals:

- Improving **VLBA Cal Survey's** 2000+ positions
  → 3X improvement: 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
- Precision equal or better than Gaia (70 μas, 1-sigma)
- Improving set of **optical-radio frame tie** sources for Gaia