The Second International Celestial Reference Frame (ICRF2)

Chopo Ma
for the
IERS/IVS Working Group
and the
IAU Working Group

6th IVS General Meeting
February 7-13, 2010
Hobart, Australia

The Second Realization of the International Celestial Reference Frame

IERS/IVS Working Group

Charter: The purpose of the working group is to generate the second realization of the ICRF from VLBI observations of extragalactic radio sources, consistent with the current realization of the ITRF and EOP data products. The working group will apply state-of-the-art astronomical and geophysical models in the analysis of the entire relevant S/X astrometric and geodetic VLBI data set. The working group will carefully consider the selection of defining sources and the mitigation of source position variations to improve the stability of the ICRF. The goal is to present the second ICRF to relevant authoritative bodies, e.g. IERS and IVS, and submit the revised ICRF to the IAU Division I working group on the second realization of the ICRF for adoption at the 2009 IAU general assembly.

Goal: Produce ICRF2 for IERS/IVS consideration and for submission to the IAU Working Group.

Active: 2006-2010

Members:

O. Titov, Australia
R. Heinkelmann, Austria
G. Wang, China
F. Arias, France
P. Charlot, France
A.-M. Gontier, France
S. Lambert, France
J. Souchay, France
G. Engelhardt, Germany
A. Nothnagel, Germany
V. Tesmer, Germany
G. Bianco, Italy
S. Kurdubov, Russia
Z. Malkin, Russia
E. Skurikhina, Russia
J. Sokolova, Russia
V. Zharov, Russia
S. Bolotin, Ukraine
D. Boboltz, USA
A. Fey, USA
R. Gaume, USA
C. Jacobs, USA
C. Ma, USA (Chair)
L. Petrov, USA
O. Sovers, USA

The Second Realization of the International Celestial Reference Frame

IAU Working Group – Division I

Charter: The purpose of the working group is to oversee the generation of the second realization of the ICRF from VLBI observations of extragalactic radio sources. The reference frame will apply state-of-the-art astronomical and geophysical models in the analysis of the entire relevant S/X astrometric and geodetic VLBI data set. The working group will ensure the selection of defining sources and the mitigation of source position variations and the consistency with the ITRF and the IERS EOP to improve the stability of the ICRF. The goal is to present the second ICRF at the 2009 IAU general assembly.

Goal: Oversee generation, validation and utility of ICRF2; engage in formulation of the resolution of adoption by IAU.

Active: 2006-2009

Members:

Alexandre Andrei, Brazil
Felicitas Arias, France
Bob Campbell, Netherlands
Patrick Charlot, France
Alan Fey, USA
Ed Fomalont, USA
Ralph Gaume, USA
Chopo Ma, USA (Chair)
Jean Souchay, France
Yaroslav Yatskiv, Ukraine
Norbert Zacharias, USA

The Second Realization of the International Celestial Reference Frame

ICRF2 Highlights

3414 Compact Extragalactic sources
5 times more than ICRF1

Noise floor of approximately 40 micro-arcsec
5-6 times better than ICRF1

Axis stability of approximately 10 micro-arcsec
2 times better than ICRF1

IERS Technical Note 35: The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry, Presented on behalf of the IERS / IVS Working Group, A. Fey, D. Gordon and C. Jacobs (eds.). (IERS Technical Note 35) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2009. 204 p., in print

http://www.iers.org/nn_11216/IERS/EN/Publications/TechnicalNotes/tn35.html

The Second Realization of the International Celestial Reference Frame

The Data

Very Long Baseline Interferometry Observations

30 Years of accumulated data
1979 August to 2009 March

Simultaneous S/X-band (2.3/8.4 GHZ) observations

6.5 million S/X-band ionosphere-corrected group delay measurements

VLBA data comprises roughly 28% of all the data used in ICRF2

Additional details can be found in Section 2 of IERS TN 35

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The Software

Several software packages have been developed over the years for VLBI processing and/or analysis. All have been developed independently by different groups. Four such software packages were used in studying the data included in ICRF2 and in generating preliminary and final solutions.

CALC/SOLVE – Goddard Space Flight Center

SteelBreeze - Main Astronomical Observatory of the National Academy of Sciences of Ukraine

OCCAM – Geoscience Australia

QUASAR - Institute of Applied Astronomy of the Russian Academy of Sciences

Preliminary catalogs were submitted by seven different analysis centers using these four independent software analysis packages. A combination catalog was also generated. Comparisons of individual catalogs between themselves and the combined catalog were made to investigate systematic effects in individual solutions.

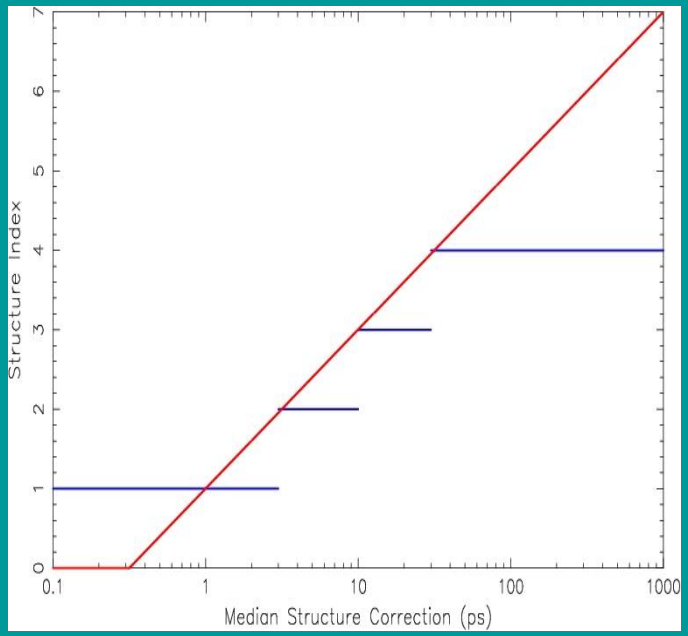
These comparisons showed that systematic effects in general are at the level of 50 micro-arcseconds – additional details can be found in Section 8 of IERS TN 35

The Second Realization of the International Celestial Reference Frame

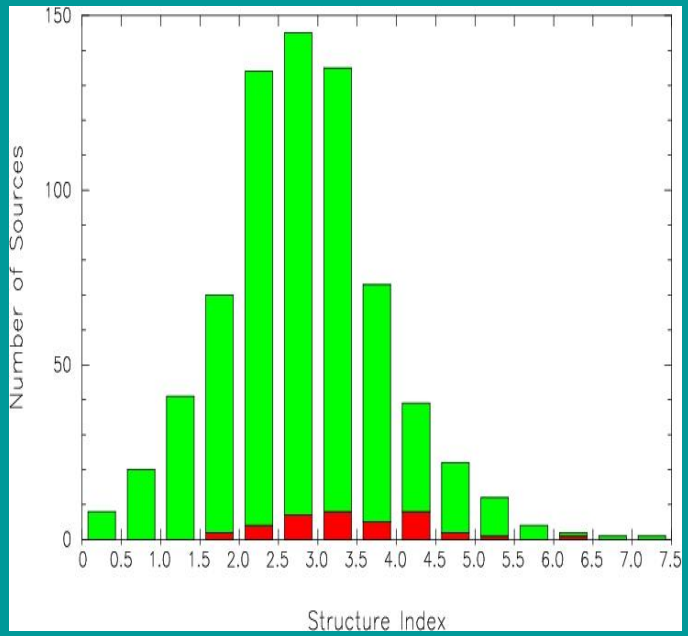
Characterization of Source Structure

There is now a large amount of imaging data which can be used to both filter out the most extended sources and identify the most compact sources for defining the ICRF2 frame. In order to assess the astrometric quality of the sources, we used the so-called ``structure index'' (SI), modified to obtain a continuous structure index scale.

Correspondence between “old” SI and continuous SI



Continuous SI for 707 sources with VLBI images



Additional details can be found in Section 5 of IERS TN 35

The Second Realization of the International Celestial Reference Frame

Special Handling Sources

Source position times series were examined

- Goal was to identify sources so unstable as to require special handling

Sources with unstable positions were treated as “arc” in global solutions

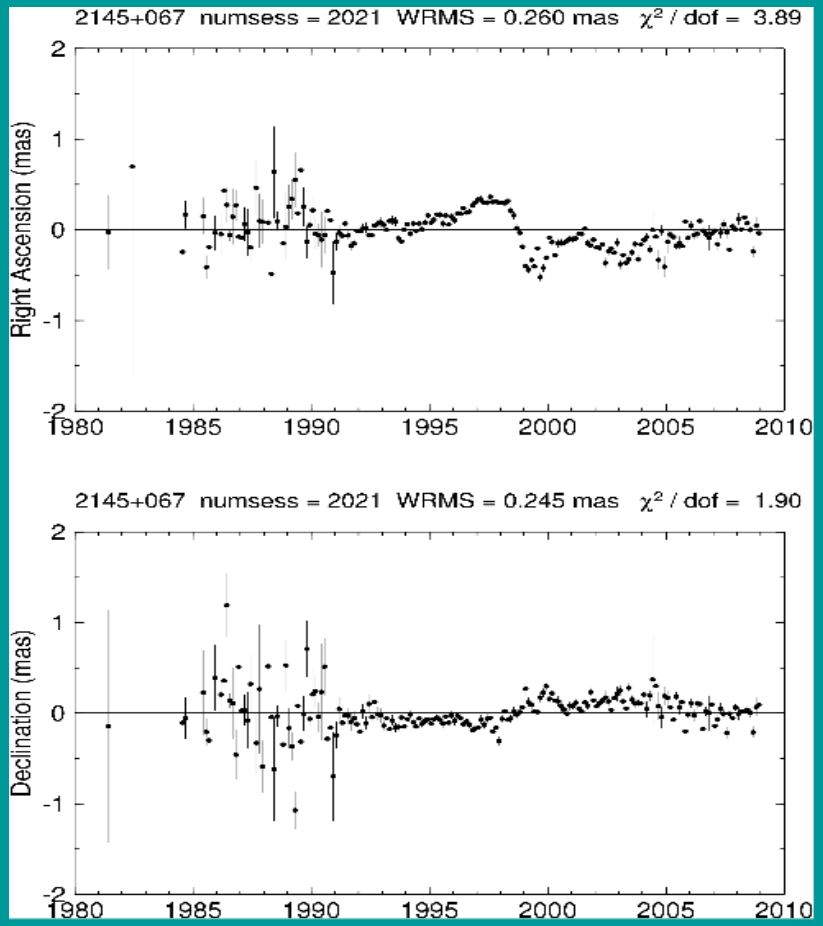
- i.e., a position was determined for each observing session

39 “Special Handling” sources identified

All other sources were treated as “global”

- i.e., one position from all observations

Position Time Series for 2145+067



Additional details can be found in Section 4 of IERS TN 35

The Second Realization of the International Celestial Reference Frame

State-of-the-art Modeling

Full CRF / EOP / TRF solution

for consistency with VTRF2000 and EOP products

Atmosphere gradients

The VMF1 troposphere mapping function model

Antenna thermal deformation model

Atmospheric pressure loading

and other standard VLBI models

Additional details can be found in Section 6 of IERS TN 35

The Second Realization of the International Celestial Reference Frame

ICRF2 Solution

Generated using CALC/SOLVE at GSFC

- single solution as opposed to combination
- preserves consistency between CRF / EOP / TRF

4540 VLBI sessions - 1979 August 3 and 2009 March 16

6.5 million observations (group delay only)

3375 “global” source positions

39 “arc” source positions (special handling sources)

Formal errors inflated

- scaled by a factor of 1.5 (same as ICRF1)
- root-sum-square with 0.040 mas (a factor of 6 smaller than ICRF1)

Additional details can be found in Sections 7 and 9 of IERS TN 35

The Second Realization of the International Celestial Reference Frame

Selection of ICRF2 Defining Sources

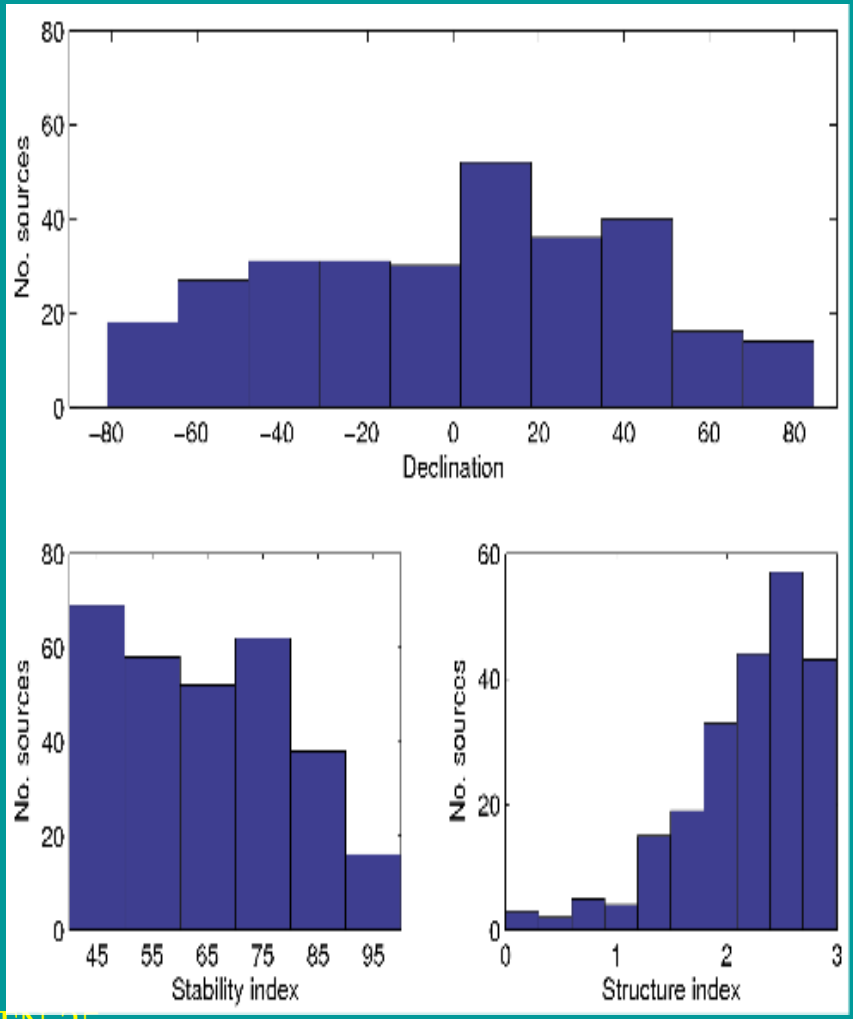
Criteria for consideration

- Position estimated “globally”
- Observed in at least 10 sessions
- Greater than 2-year observation history

Sources ranked based on

- Position stability from position time series
- Formal error from least-squares solution
- Structure Index

Selection made on basis of axis stability as a function of the number of “defining” sources (see TN35 for explanation)



Additional details can be found in Section 11 of IERS TN 35

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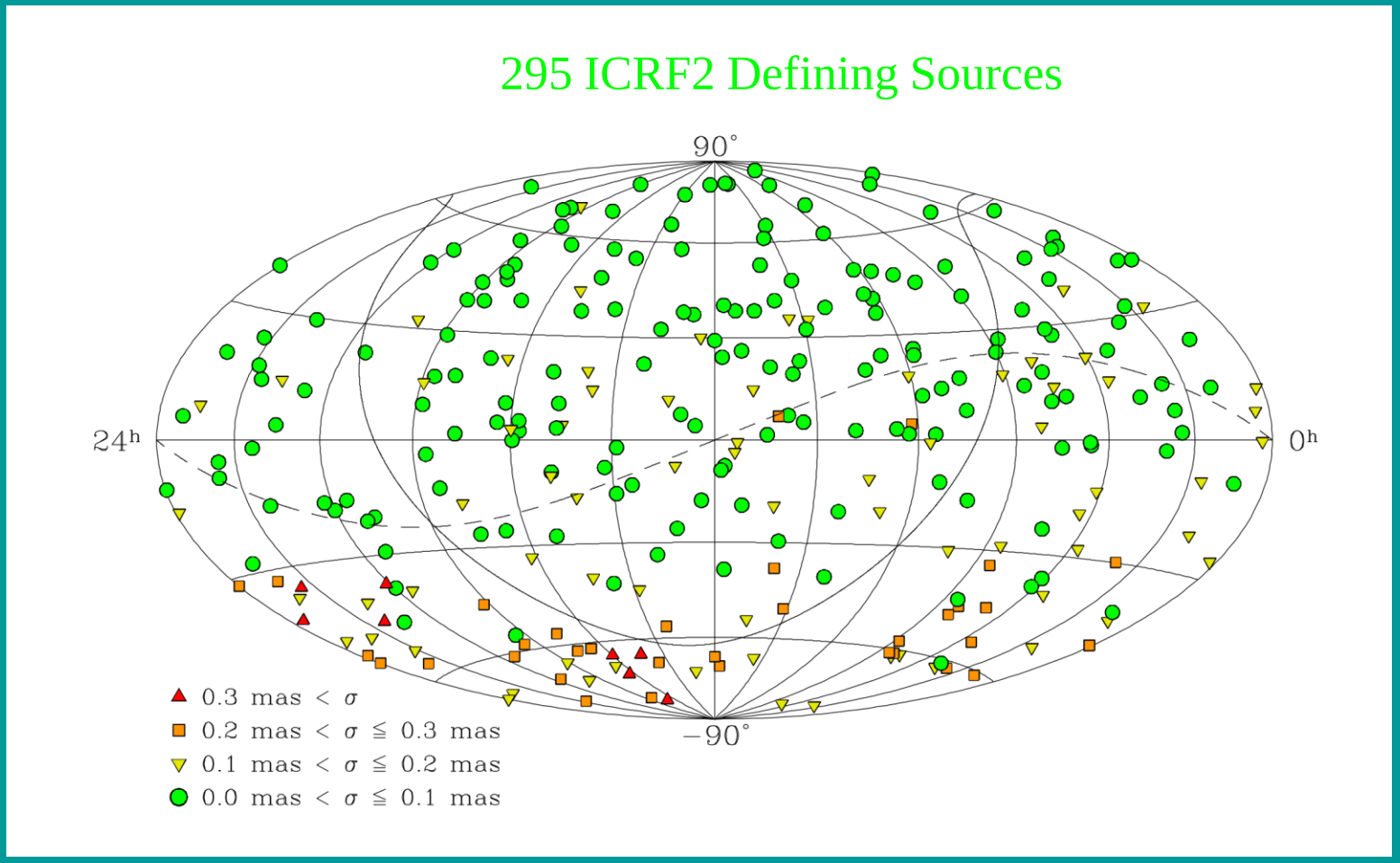

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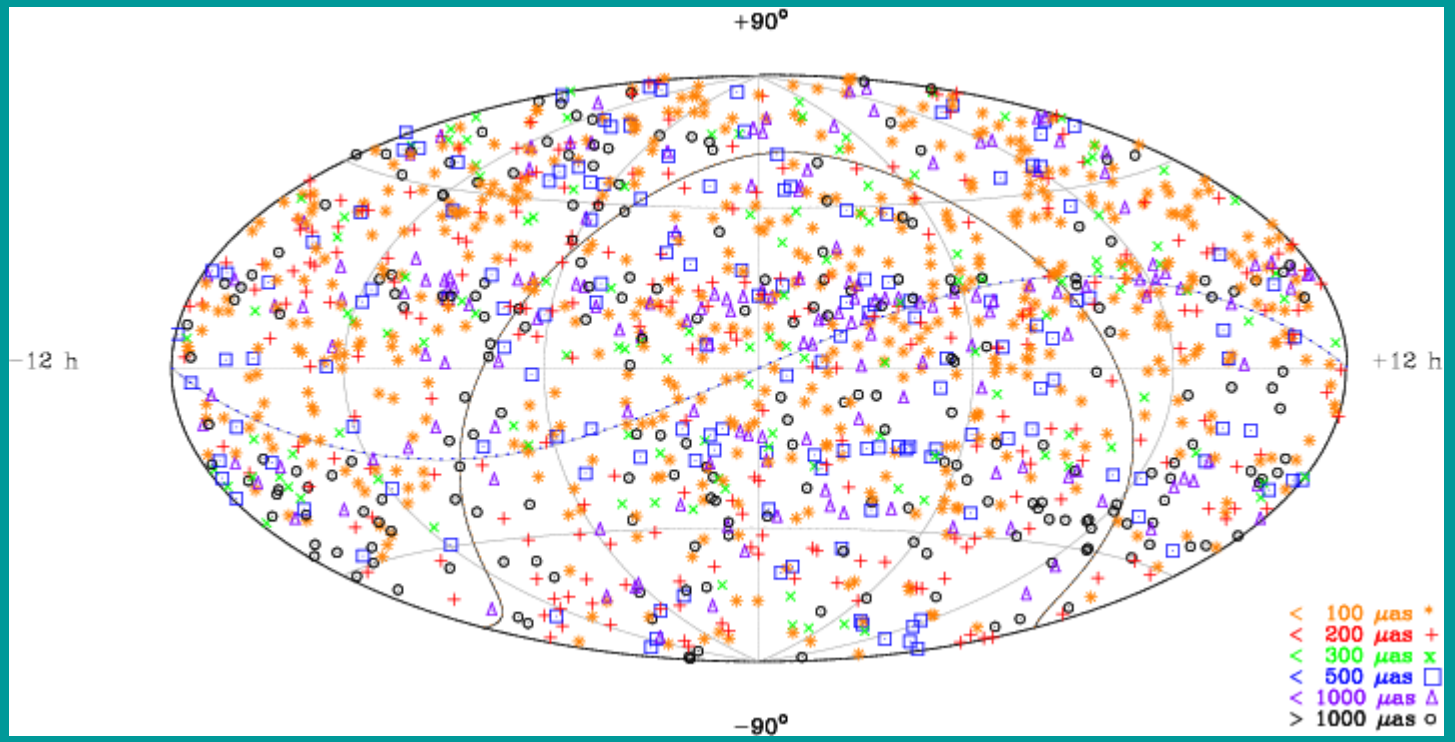
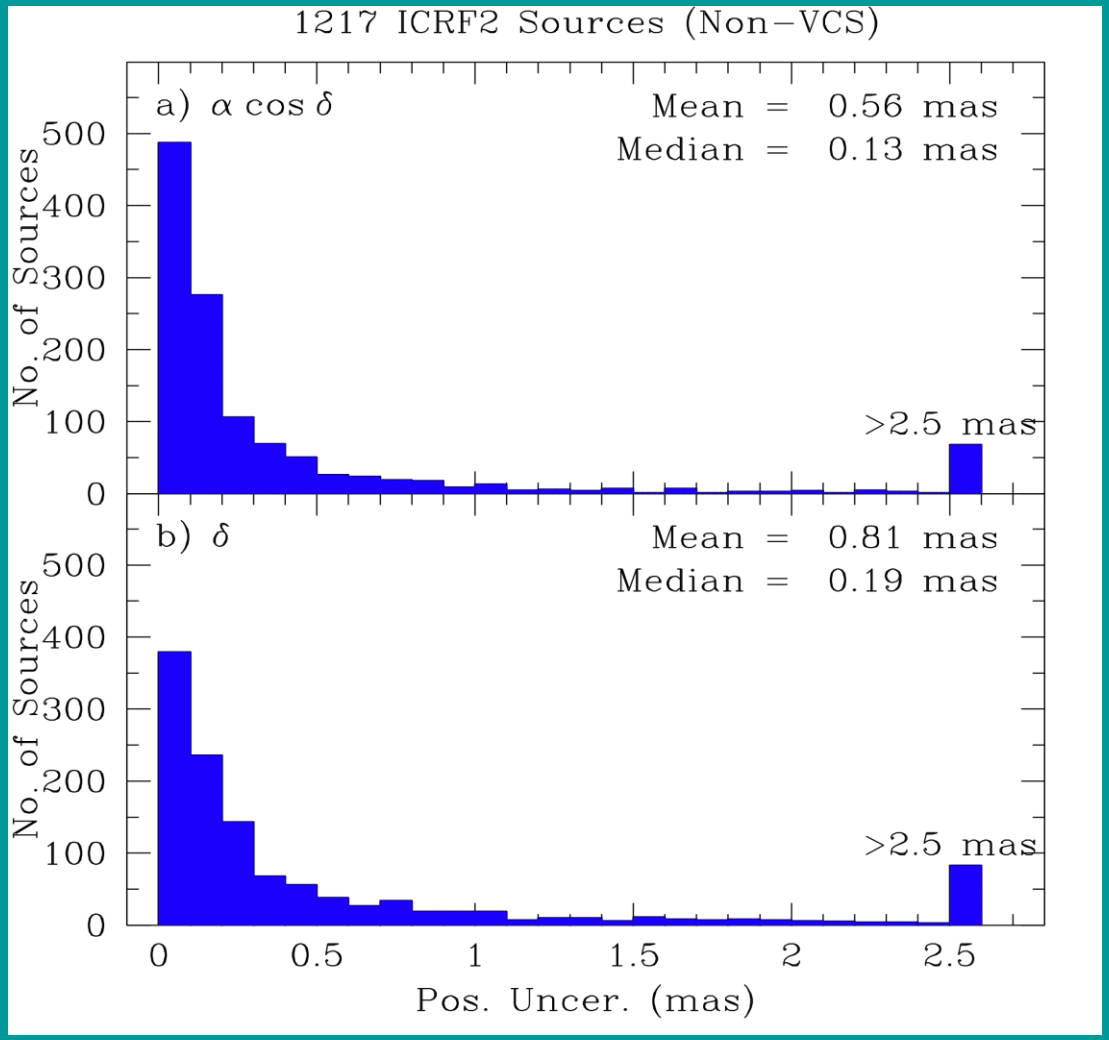
1448 ICRF2 Sources observed in multiple sessions



Plotted are formal errors as indicated by the key

The Second Realization of the International Celestial Reference Frame



Histograms showing the inflated position uncertainties for the 1217 Non-VCS ICRF2 sources.

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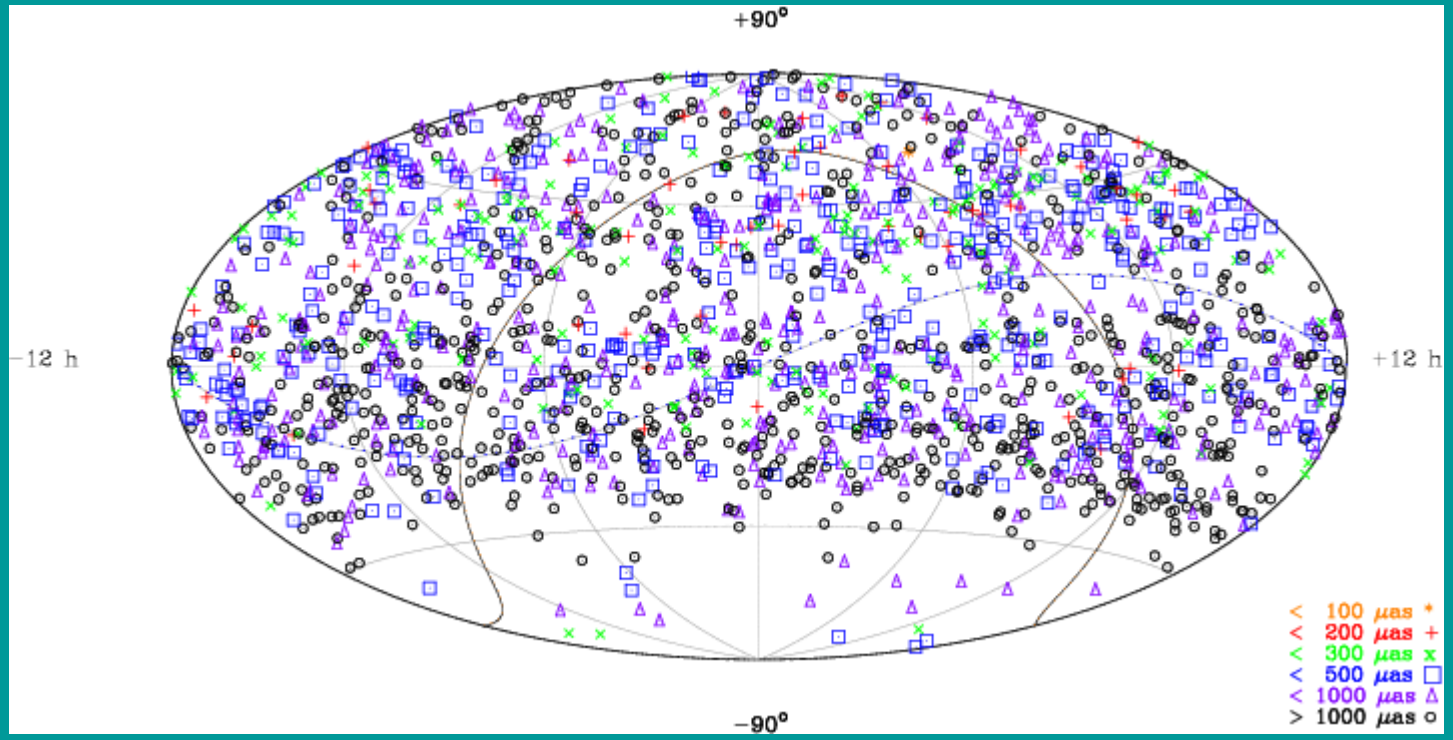
1966 ICRF2 Sources observed in single sessions



Plotted are formal errors as indicated by the key

These are mostly VLBA Calibrator Survey (VCS) sources

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Further information can be found in IERS Technical Note 35

Section 1 – Introduction
Section 2 – The Data
Section 3 – VLBI Analysis Software
Section 4 – Selection and Treatment of Special Handling Sources
Section 5 – Characterization of Source Structure
Section 6 – Data and Modeling Comparisons
Section 7 – The ICRF2 Solution
Section 8 – Combination and Comparison of Contributed Catalogs
Section 9 – Determination of Realistic Errors
Section 10 – External Validation
Section 11 – Selection of ICRF2 Defining Sources
Section 12 - Alignment of ICRF2 onto ICRS and Axis Stability
Section 13 – The ICRF2 Catalog
Section 14 – Statistics of the ICRF2 Catalog
Section 15 – Conclusions and Future Work

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The Second Realization of the International Celestial Reference Frame

- Endorsed by the IVS Directing Board
- Endorsed by the IERS Directing Board
- Endorsed by the IAU Working Group – Division I
- Adopted by the IAU General Assembly on Aug. 13, 2009

RESOLUTION B3
on
the Second Realization of the
International Celestial Reference Frame

The International Astronomical Union XXVII General Assembly,

noting

1. that Resolution B2 of the XXIII General Assembly (1997) resolved “That, as from 1 January 1998, the IAU celestial reference system shall be the International Celestial Reference System (ICRS)”,
2. that Resolution B2 of the XXIII General Assembly (1997) resolved that the “fundamental reference frame shall be the International Celestial Reference Frame (ICRF) constructed by the IAU Working Group on Reference Frames”,
3. that Resolution B2 of the XXIII General Assembly (1997) resolved “That IERS should take appropriate measures, in conjunction with the IAU Working Group on reference frames, to maintain the ICRF and its ties to the reference frames at other wavelengths”,
4. that Resolution B7 of the XXIII General Assembly (1997) recommended “that high-precision astronomical observing programs be organized in such a way that astronomical reference systems can be maintained at the highest possible accuracy for both northern and southern hemispheres”,
5. that Resolution B1.1 of the XXIV General Assembly (2000) recognized “the importance of continuing operational observations made with Very Long Baseline Interferometry (VLBI) to maintain the ICRF”,

RESOLUTION B3
on
the Second Realization of the
International Celestial Reference Frame

recognizing

1. that since the establishment of the ICRF, continued VLBI observations of ICRF sources have more than tripled the number of source observations,
2. that since the establishment of the ICRF, continued VLBI observations of extragalactic sources have significantly increased the number of sources whose positions are known with a high degree of accuracy,
3. that since the establishment of the ICRF, improved instrumentation, observation strategies, and application of state-of-the-art astrophysical and geophysical models have significantly improved both the data quality and analysis of the entire relevant astrometric and geodetic VLBI data set.,
4. that a working group on the ICRF formed by the International Earth Rotation and Reference Systems Service (IERS) and the International VLBI Service for Geodesy and Astrometry (IVS), in conjunction with the IAU Division I Working Group on the Second Realization of the International Celestial Reference Frame has finalized a prospective second realization of the ICRF in a coordinate frame aligned to that of the ICRF to within the tolerance of the errors in the latter (see note 1),
5. that the prospective second realization of the ICRF as presented by the IAU Working Group on the Second Realization of the International Celestial Reference Frame represents a significant improvement in terms of source selection, coordinate accuracy, and total number of sources, and thus represents a significant improvement in the fundamental reference frame realization of the ICRS beyond the ICRF adopted by the XXIII General Assembly (1997),

RESOLUTION B3
on
the Second Realization of the
International Celestial Reference Frame

resolves

1. that from 01 January 2010 the fundamental astrometric realization of the International Celestial Reference System (ICRS) shall be the Second Realization of the International Celestial Reference Frame (ICRF2) as constructed by the IERS/IVS working group on the ICRF in conjunction with the IAU Division I Working Group on the Second Realization of the International Celestial Reference Frame (see note 1),
2. that the organizations responsible for astrometric and geodetic VLBI observing programs (e.g. IERS, IVS) take appropriate measures to continue existing and develop improved VLBI observing and analysis programs to both maintain and improve ICRF2,
3. that the IERS, together with other relevant organizations continue efforts to improve and densify high accuracy reference frames defined at other wavelengths and continue to improve ties between these reference frames and ICRF2.

Note 1: The Second Realization of the International Celestial Reference Frame by Very Long Baseline Interferometry, Presented on behalf of the IERS / IVS Working Group, Alan Fey and David Gordon (eds.). (IERS Technical Note ; 35) Frankfurt am Main: Verlag des Bundesamts für Kartographie und Geodäsie, 2009. See <www.iers.org/MainDisp.csl?pid=46-25772> or <hpiers.obspm.fr/icrs-pc/> .