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VLBI Celestial Reference Frames and Assessment with Gaia

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Montreal, 22. Juni 2018

Outline

- History of Astrometry
- Vienna solution
- Various modifications
- Gaia-CRF2
- Vector spherical harmonics
- Transformation parameter

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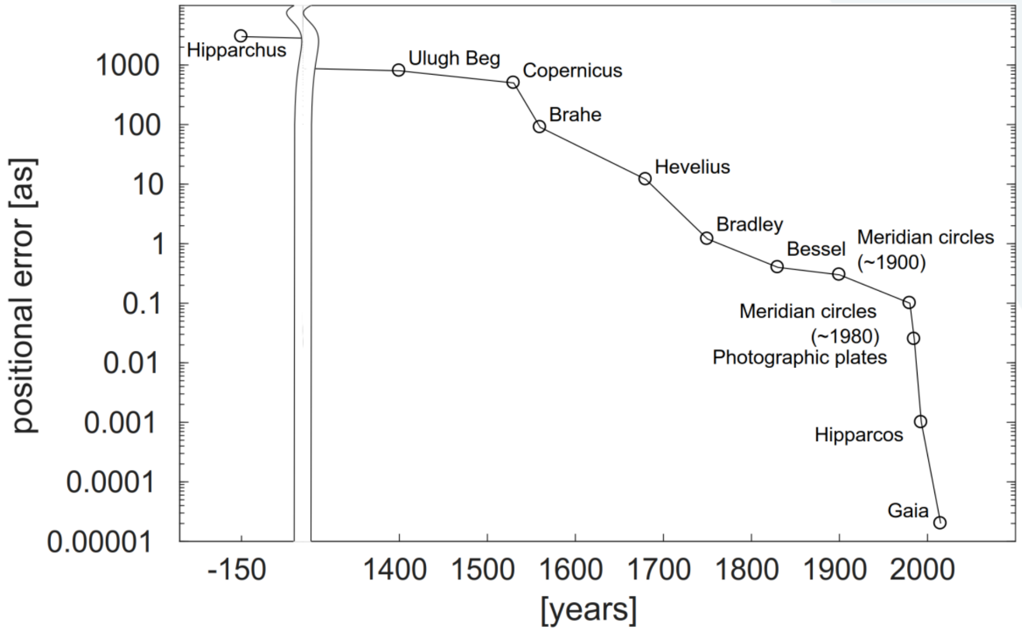
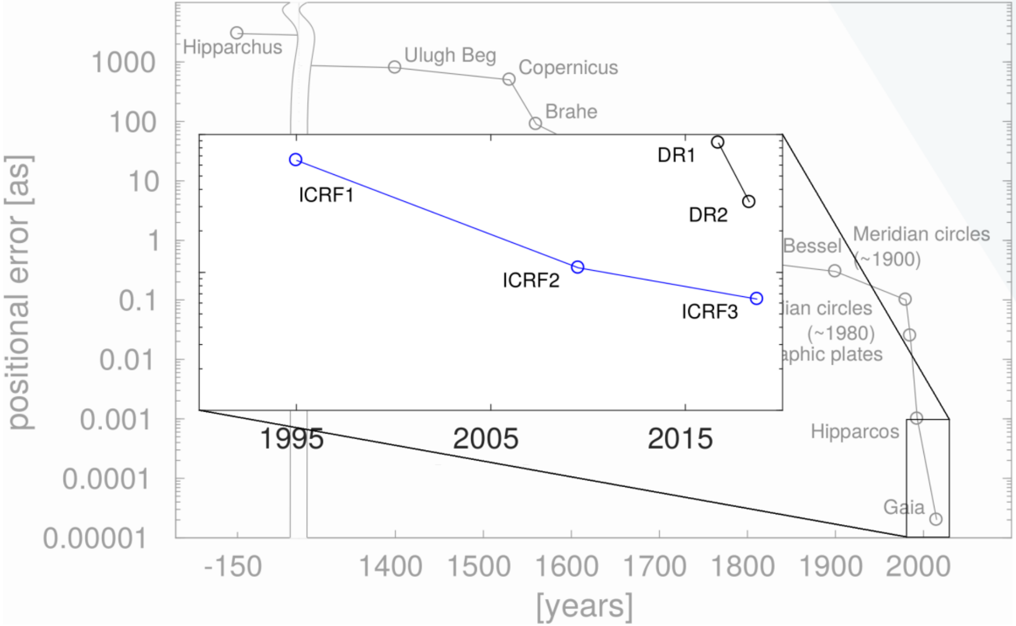
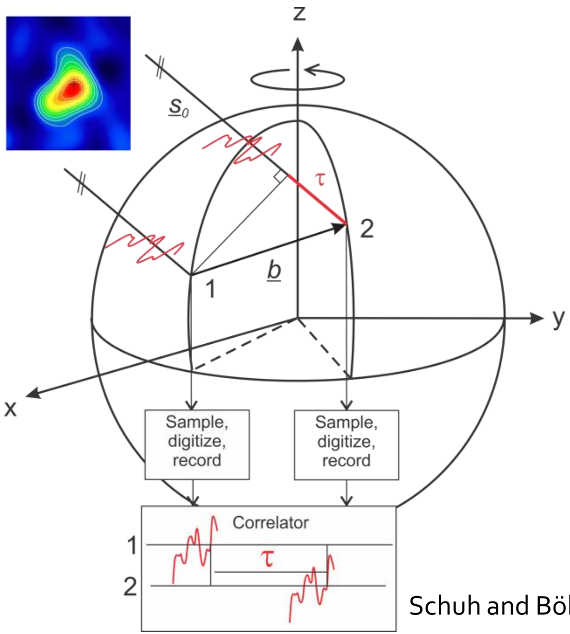
History of Astrometry



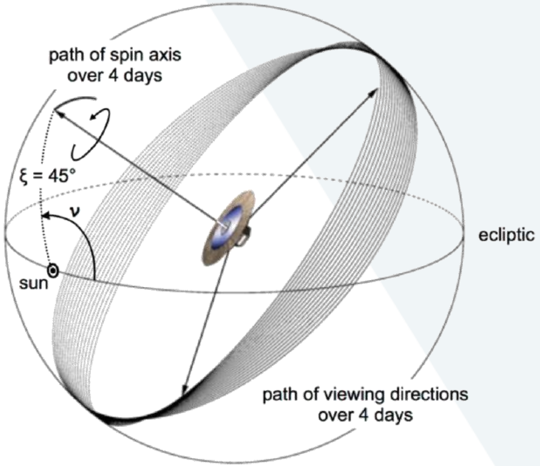
History of Astrometry



VLBI vs Gaia



Schuh and Böhm (2013)

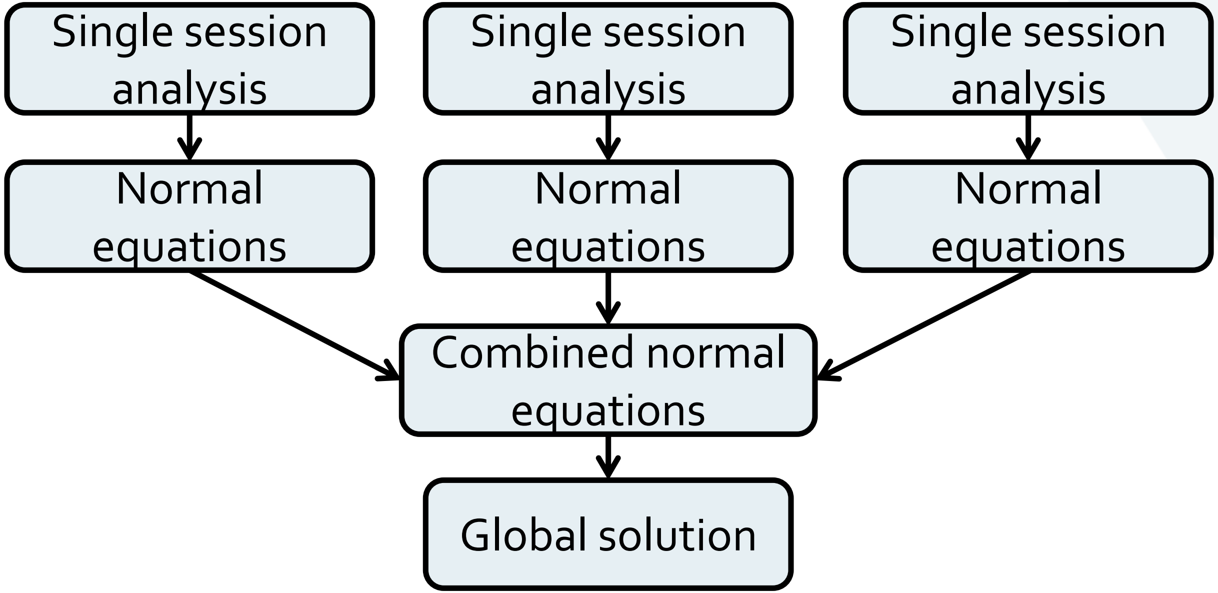


Gaia Collaboration, Prusti, T., et al. (2016)

Motivation

- Several goals were set for the ICRF3:
- Finished by 2018
- **Competitive accuracy to Gaia**; Find and correct systematic effects
- Precision spread more evenly among sources; Dedicated observing programs with the VLBA
- Improved spatial coverage; Dedicated observing programs in the Southern Hemisphere
- Included high frequency catalogs
- Increased number of sources for frame ties to Gaia; Include in IVS program

Estimation of a VLBI reference frame

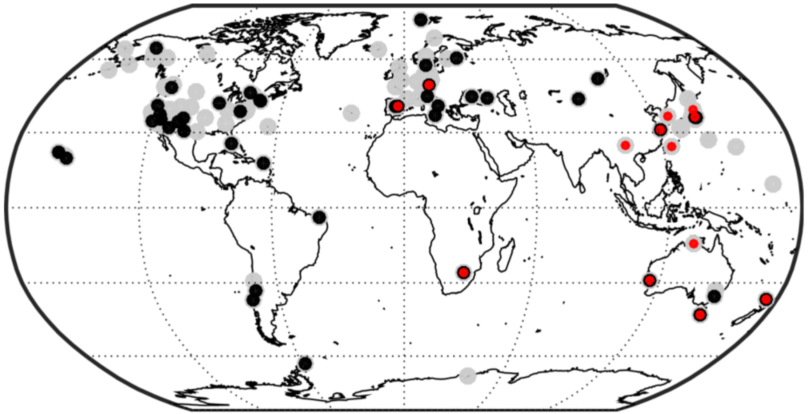


Vienna solution – Single session parameterization

- ICRF3 solution data set used. Data from 1979 – March 2018, 6199 sessions in total
- Troposphere estimation
  - ZWD as PWLO every 30 min with relative constraints
  - A priori DAO gradients
  - Gradients estimated as PWLO every 6h with relative and absolute constraints
- Clock estimation
  - One rate and one quadratic term
  - PWLO every 60 min with relative constraints

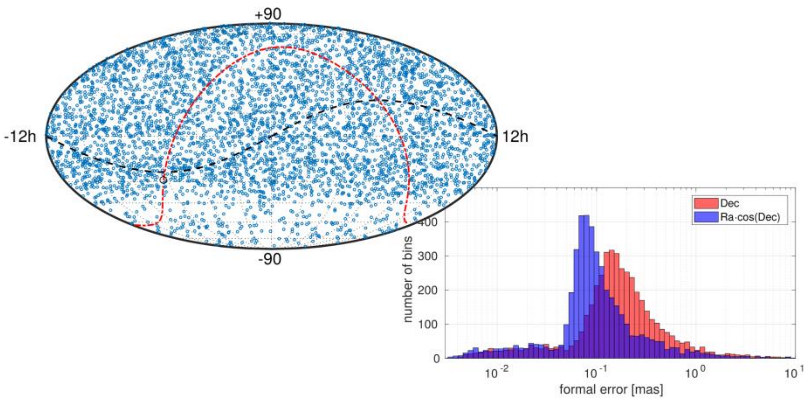
TU WIEN VieVS
Vienna VLBI and Satellite Software

Vienna solution – Global solution parameterization



- Estimated parameters
  - Positions and velocities of 96 stations (21 are in datum)
  - Positions of 4482 sources (295 are in datum)
- Reduced parameters
  - 68 stations
  - 39 sources

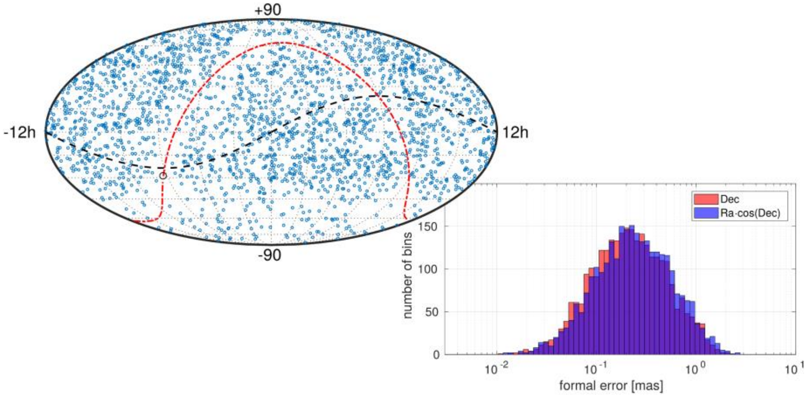
Vienna solution – Source distribution



Most of the sources in the ICRF3 are VCS sources observed by the VLBA.

The VLBA can only observe to about −40º declination → hole in the far south

Gaia DR2 – The celestial reference frame (Gaia-CRF2)

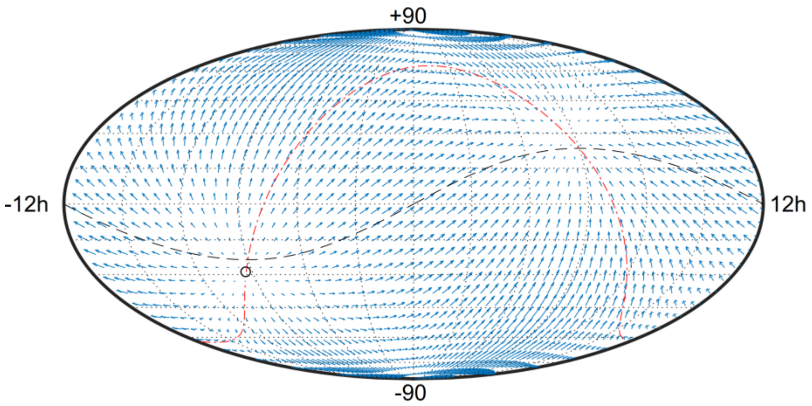


The Gaia-CRF2 contains 550 000 sources.

2800 have an **ICRF3 counterpart**.

It is aligned to the ICRF3 prototype catalog.

Modeling and analysis choices –Galactic Aberration (GA)



Apparent motions caused by galactic aberration.

5.8 µas/yr with the center of the Galaxy at 17h45min40sec in RA and −29º00’28’’ in DEC.

Modeling and analysis choices – Troposphere

- Gradients
  - A priori models; DAO or GRAD model
  - Absolute and relative constraints
  - Sampling interval
- ZWD estimation; Sampling interval and relative constraints
  - A priori ray-traced delays; Derived from 1° ECMWF data with 6h resolution (program RADIATE)
- Elevation dependent weighting

Modeling and analysis choices – Others

- Clock estimation; Sampling interval and relative constraints
- NNR constraints; Strength of constraint, sources used for the NNR
- Axis offset (AO); Estimating AO, using AO altitude correction
- Phase calibration at Hobart12
- Estimating special handling sources
- Estimating station seasonal harmonics
- Inflation of formal error

Vector Spherical Harmonics (VSH)

State of the art tool to compare astrometric catalogs. Large scale rotations and deformations are reflected by degree 1.

Rotation:

$$\Delta\mu_\alpha \cos\delta = r_1 \cos\alpha \sin\delta + r_2 \sin\alpha \sin\delta - r_3 \cos\delta$$
$$\Delta\mu_\delta = -r_1 \sin\alpha + r_2 \cos\alpha$$

Glide:

$$\Delta\mu_\alpha \cos\delta = -d_1 \sin\alpha + d_2 \cos\alpha$$
$$\Delta\mu_\delta = -d_1 \cos\alpha \sin\delta - d_2 \sin\alpha \sin\delta + d_3 \cos\delta$$

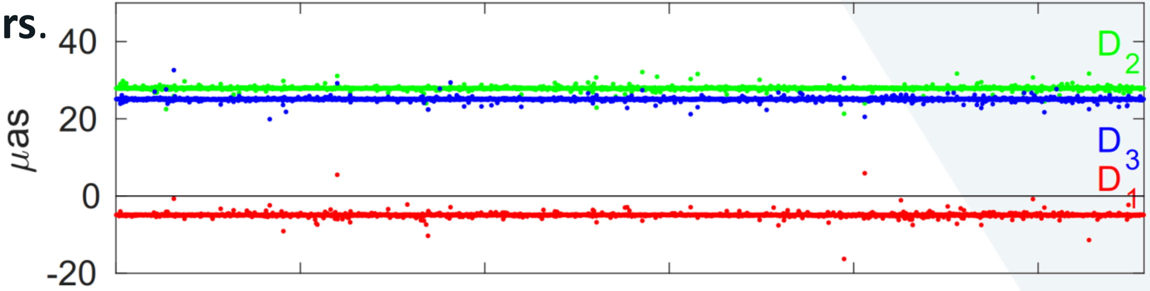
+ degree 2

Vector Spherical Harmonics (VSH) – Outlier

We found that the **standard** outlier detection suggested by Mignard (2016) **does not work well** for the data set at hand.

- Systematic differences are on the level of the formal uncertainties
- Significant deviation from Rayleigh distribution

We **calculated VSH 2800 times** each time excluding one of the sources. The **scatter can be used to detect outliers.**



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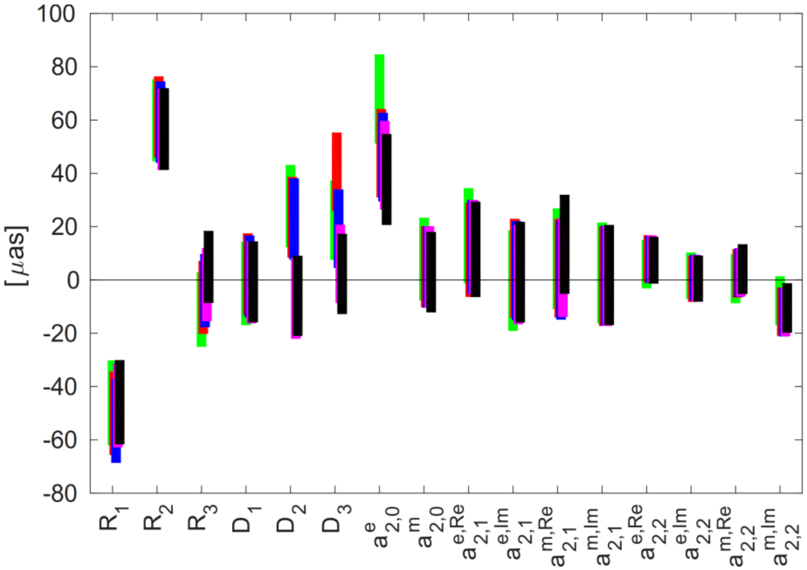
Transformation parameters – w.r.t. Gaia-CRF2



Vie18

+ Ray-traced delays

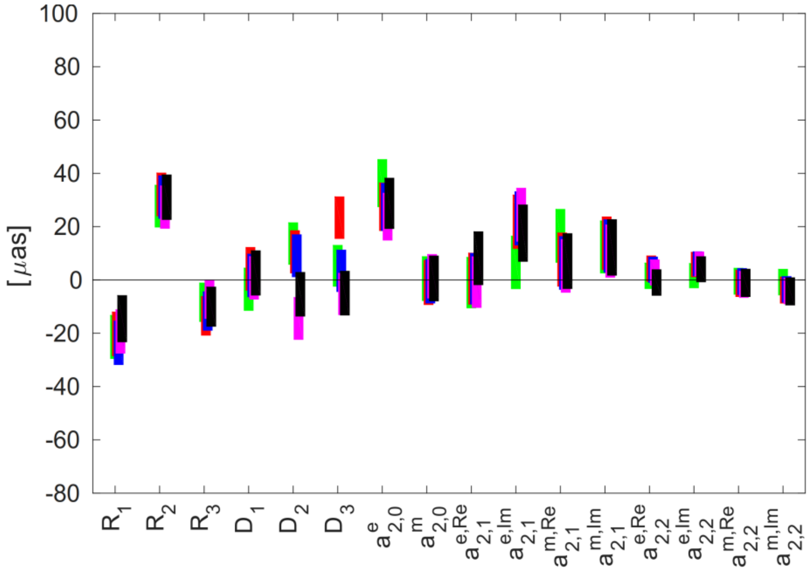
+ no abs. const. on grad.

+ galactic aberration

+ error inflation

Deformations of degree 1 can be explained by modeling and analysis choices. However, a significant $a^{e}_{2,0}$ parameter persists no matter the modeling choices.

Transformation parameters – Mignard outlier test



Vie18

+ Ray-traced delays

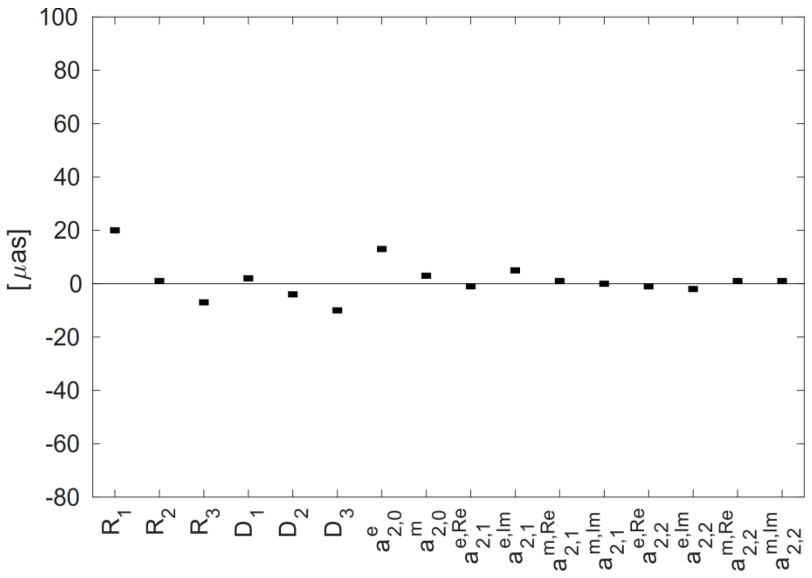
+ no abs. const. on grad.

+ galactic aberration

+ error inflation

Result very dependent on the outlier estimation technique.

Transformation parameters – Validation with ICRF3



Vie18
+galactic aberration
+ special handling est.
+ ICRF3 defining
+ ICRF3 a priori
+ error inflation

Good agreement with ICRF3.

Summary and Conclusion

- Various **ICRF3** solutions were compared with the **Gaia-CRF2** catalog
- The comparison is done with **VSH of degree 2**
- Vienna ICRF3 shows a **good agreement** with the Gaia-CRF2
- Systematic **deformations of order 1 can be explained** by modeling choices when estimating the VLBI solution
- However, the $a^e_{2,0}$ **parameter** of order 2 **can not be explained**
- The Vienna ICRF3 shows **a large variability in the D_3 parameter**, which is directly connected to the source declination. This reflects the unevenly distributed VLBI station network

Why do we need the ICRF?

- Astrophysics and astrometry; studies about Active Galactic Nuclei etc.
- Astronomy; sources used for phase referencing
- Geodesy; accurate determination of EOP
- Spacecraft tracking; determine position of spacecraft w.r.t. stable background

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Thanks for your attention

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