Astrometry and reference frames in the Gaia era

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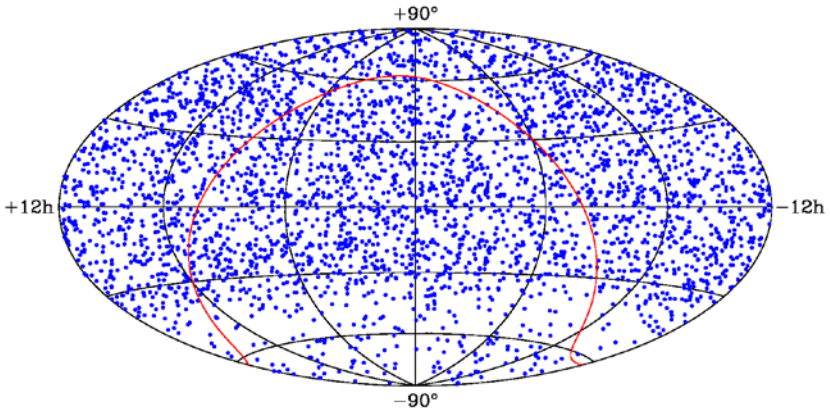
Outline

- Background: ICRF2
- ICRF3 construction
  - Observing status
  - Work plan till 2018
- The Gaia mission
  - Overall status of the mission
  - Gaia Data Release 1
- Comparing radio and optical reference frames

Background

- ICRF2 build in 2009
  - 3414 sources in total
  - 295 defining sources
  - 2200 one-epoch VCS sources
  - Noise floor: 60 μas

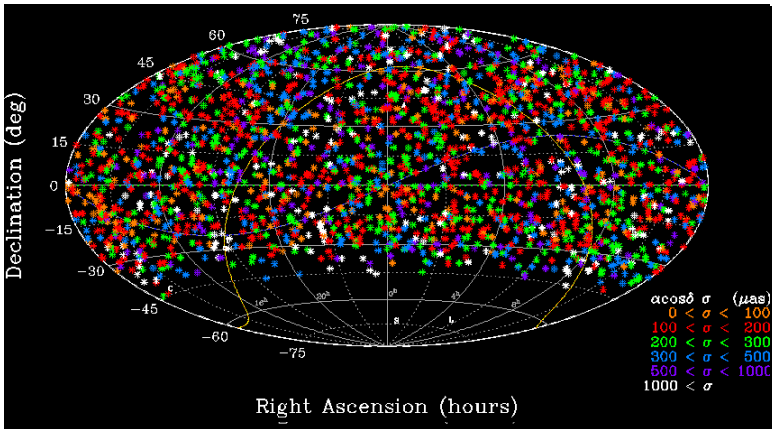


- IAU Working Group formed in 2012 to build ICRF3 for adoption by IAU at 2018 General Assembly
  (Chair 2012-2015: C. Jacobs; Chair 2015-2018: P. Charlot)
- Main goal: produce the “best” VLBI reference frame to serve as reference for aligning the Gaia frame, allowing comparison of optical and radio positions at < 100 μas

Observing status: S/X

- 1400 additional VLBI (IVS) sessions since ICRF2 was built in 2009
  - → An increase of 30% in the number of sessions
  - → Amount of data 60% larger

- Reobservation of the VCS catalog (2400 sources) *Gordon et al. (2016)*
  - → 8 VLBA sessions in 2014-2015 (24-hour each, 2 Gb/s)
  - → 7 times improvement in position precision



S/X reference frame

- VCS sources

Gordon et al. (2016)

VCS sources	Right Ascension wrms (μas)	Declination wrms (μas)	Number of sources
VCS-I	2110	3560	2197
VCS-I + VCS-II	290	500	2197

- Defining and non-VCS sources

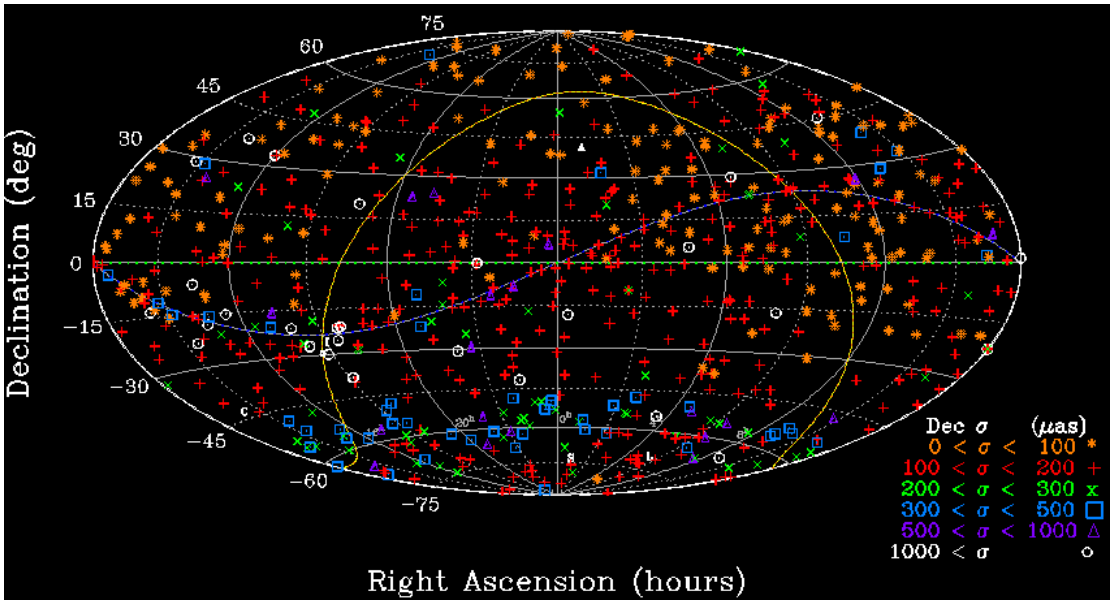
Gordon et al. (2016)

Defining & non-VCS sources	Right Ascension wrms (μas)	Declination wrms (μas)	Number of sources
ICRF2 (1980-2009)	55	81	1217
Current solution (1980-2016)	33	45	1217

Observing status: X/Ka

The current X/Ka (32 GHz) catalog

Jacobs et al.

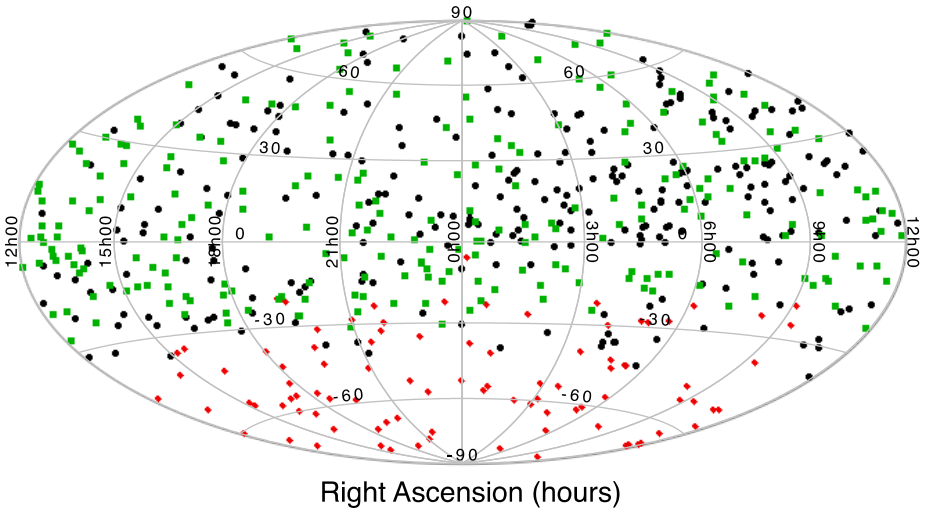


Credit: C. S. Jacobs

- → 674 sources covering the entire sky
- → DSN + (Malargue. ESA, Argentina) observations
- → Errors at the ~ 100 μas level

Observing status: K-band

The current status of the K-band (24 GHz) catalog



Credit: C. S. Jacobs

- 275 sources from Lanyi et al. (2010) / Charlot et al. (2010) σ ~ 200 μas
- 4 additional VLBA sessions that observed 246 sources - *Jacobs et al.*
- Completion of the Southern hemisphere with South Africa – Australia observations - *de Witt et al.*

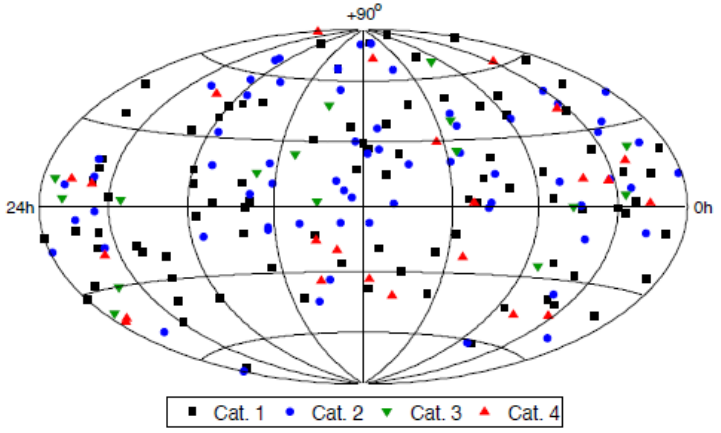
→ 541 sources at present

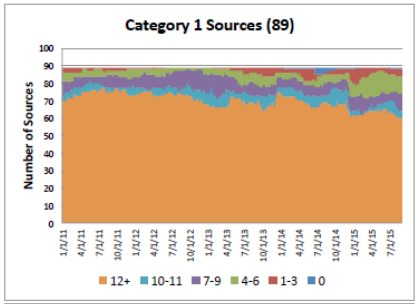
Gaia transfer sources

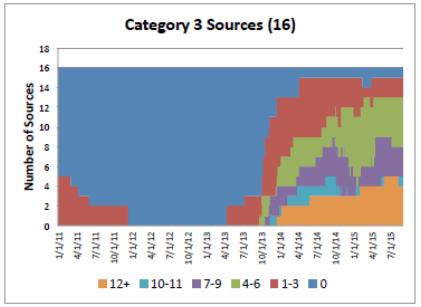
Selection criteria: optical mag < 18 + structure index < 3

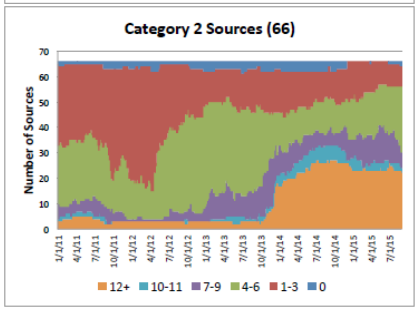
- 195 ICRF2 sources (excl. VCS)

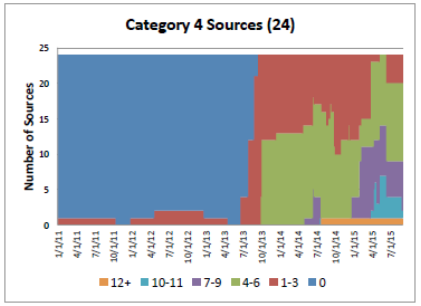
→ IVS observations strengthened











Bourda & Charlot (2012); Le Bail et al. (2016)

- An additional 163 VCS/ICRF2 sources identified
- 119 weak non-ICRF2 sources from dedicated EVN/VLBA project – *Bourda et al.*
- Another ~100 sources in the deep South (δ <-30°) – to be observed with the HARTRAO-HOBART baseline – *de Witt et al.*

→ In total 500+ sources

Upcoming plans

- 2016
  - Prototype ICRF3 catalogs made by September 1, 2016
  - Extensive comparisons between S/X catalogs
  - Extensive comparisons between catalogs at S/X, X/Ka and K bands
- 2017
  - Make pre-final ICRF3 catalogs
  - Decide whether ICRF3 should be single-frequency, multi-frequency or combined
  - Decide on defining sources
  - Produce final ICRF3
- 2018
  - Prepare IAU resolution
  - Write Technical Note and ICRF3 paper
  - Adoption of ICRF3 at IAU 2018 General Assembly

Moving on Gaia…

- Gaia launched on 19 December 2013 at 09:12:19 UTC
- Routine operations since July 2014
- Final Gaia catalog available > 2020

Gaia targets

- 1 billion stars (distance, motion, physical properties,…)
- 1 million galaxies
- 500 000 quasars
- 100 000 extragalactic supernovae
- 100 000 new Solar System bodies
- 7000 exoplanets
- 200 gravitational lenses

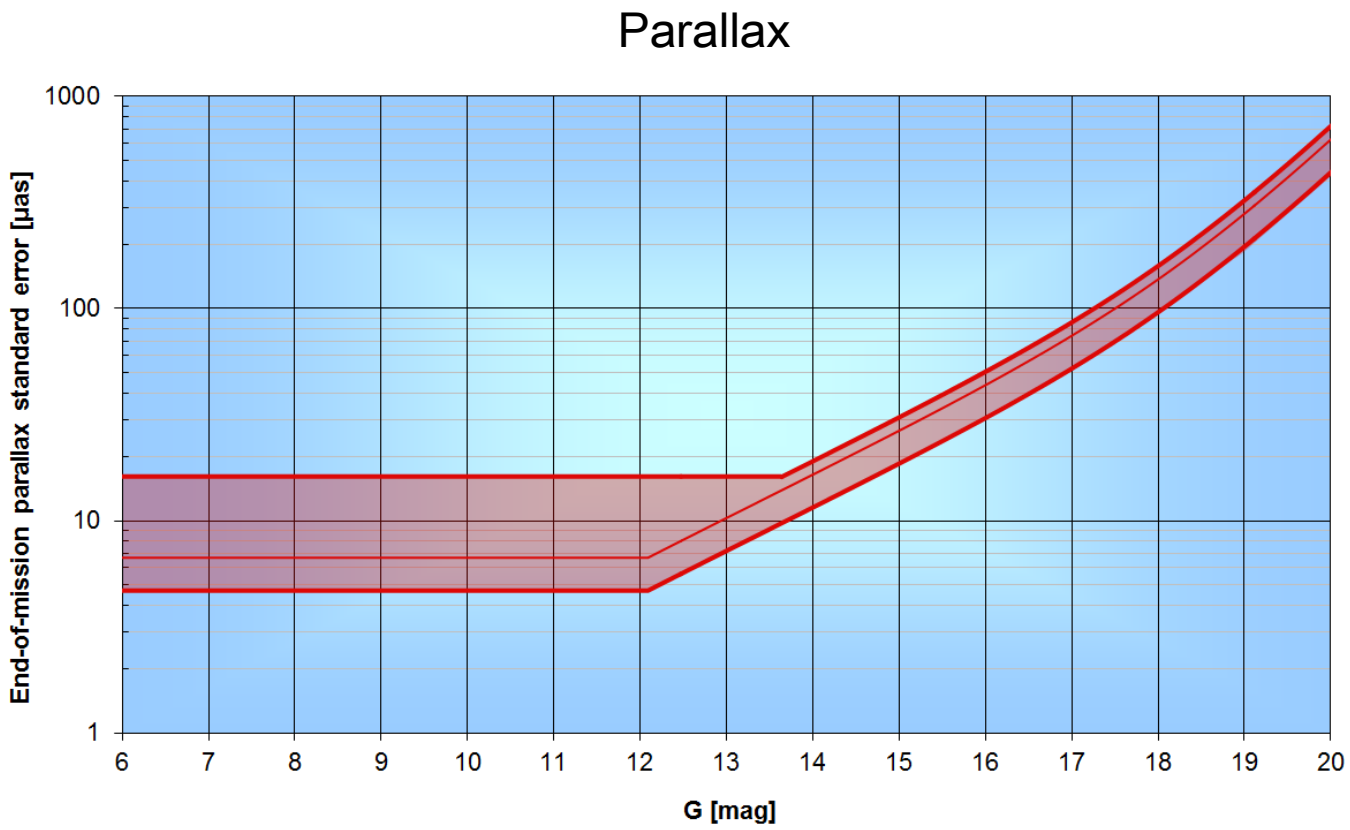
+ survey of the variable sky

+ alerts on transient objects

Gaia science goals

- Structure and dynamics of the Galaxy
- The star formation history of the Galaxy
- Stellar astrophysics
- Binaries and multiple stars
- Brown dwarfs and planetary systems
- Solar system
- Galaxies, quasars and the reference frame
- Fundamental physics: General Relativity

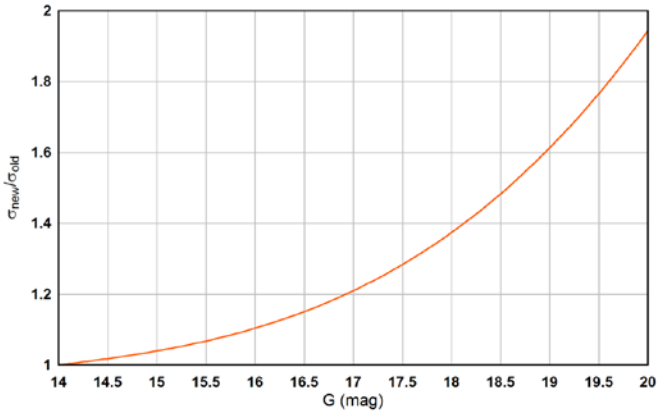
End of mission astrometric performance



Factor of 0.7 and 0.5 for positions and proper motions

Unwanted surprises (1)

- Stray light both from astronomical sources and the Sun
  - Sun stray light due to scattering of fibres at the edge of the Sun shield
  - Impact faint sources
  - Astrometry less affected than photometry and spectroscopy

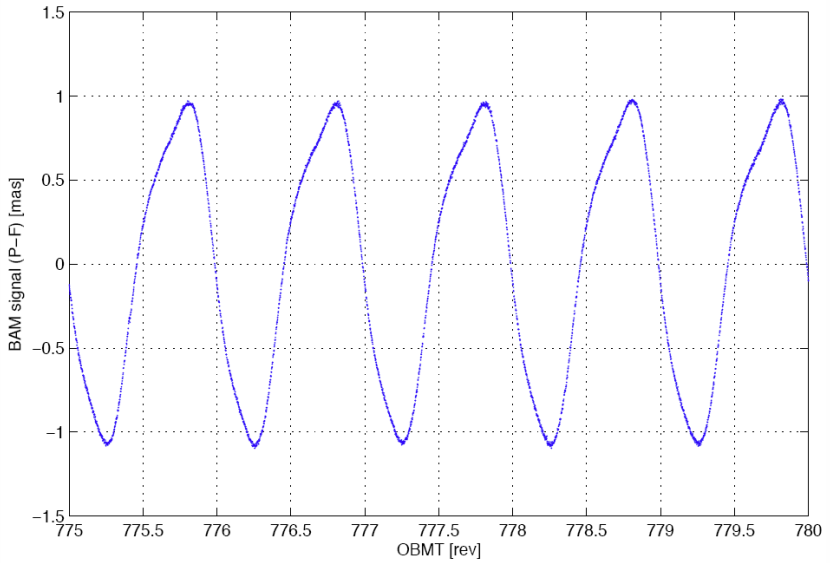


Degradation on astrometric accuracy

- Transmission loss due to continuing contamination of mirrors by water
  - Periodic heating to solve the problem
  - Water source diminishing

Unwanted surprises (2)

- Basic Angle variation larger than expected
  - Very regular oscillations with 1 mas amplitude
  - Can be calibrated to 10 μas accuracy (1%)



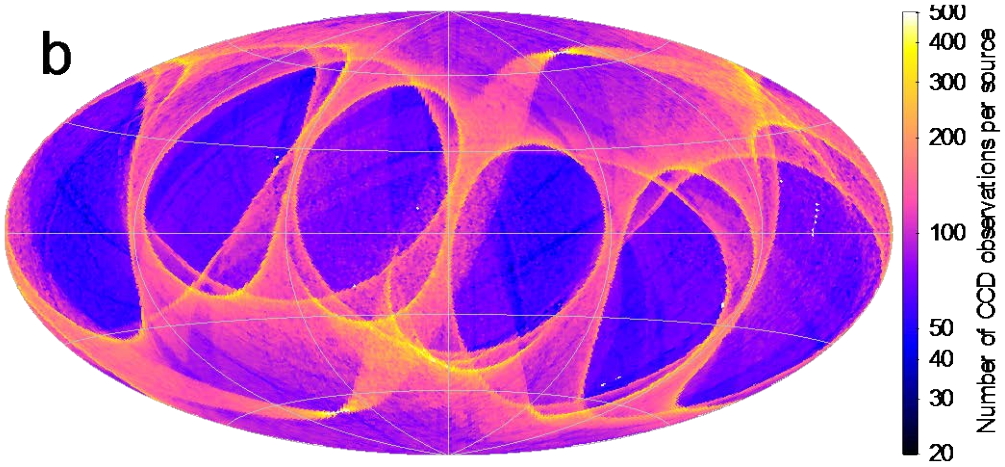
- Attitude disturbances
  - Micro-meteoroids and clanks

Gaia Data Release 1 input data

14 months of Gaia data used

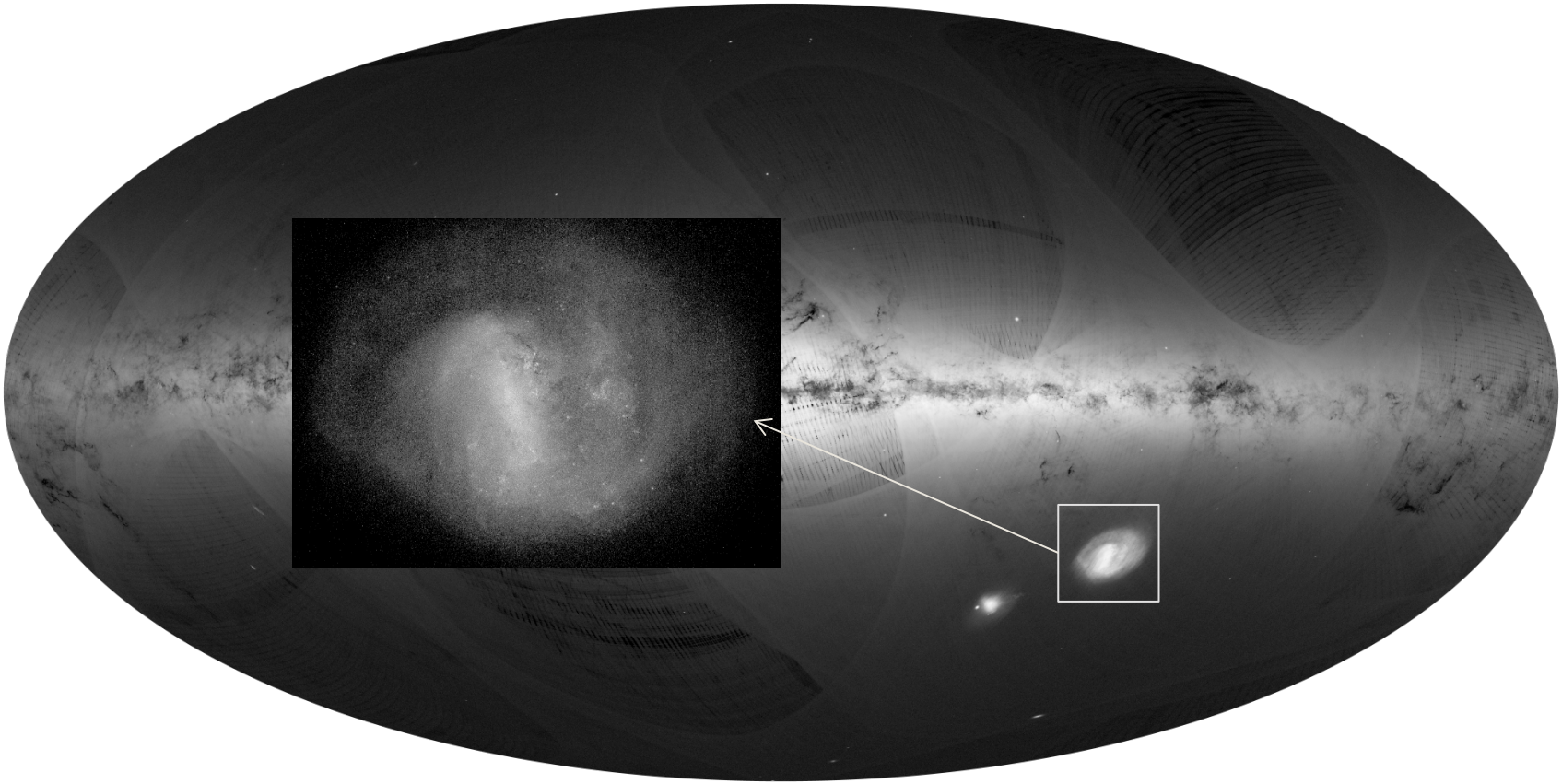
- 23 billion transits across focal plane
- All sources treated as single

Mean number of observations per source



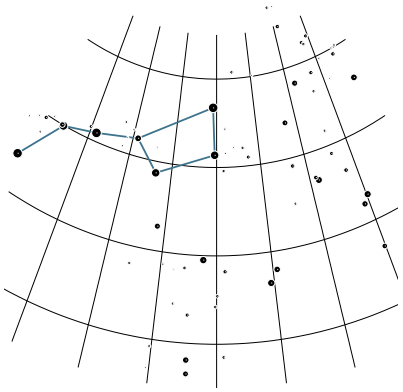
Lindegren et al. (2016)

Gaia Data Release 1 (14/09/2016)



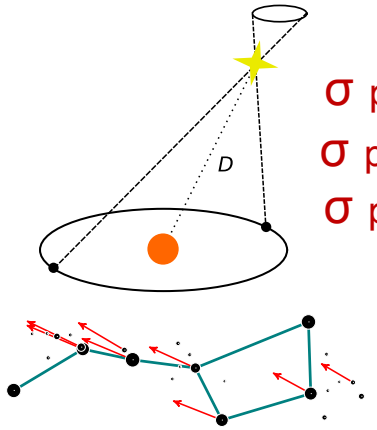
Brown et al. (2016)

What's in the Gaia DR1 delivery ?



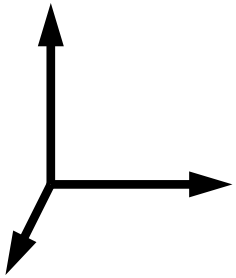
σ pos. = 10 mas

1 billion star atlas

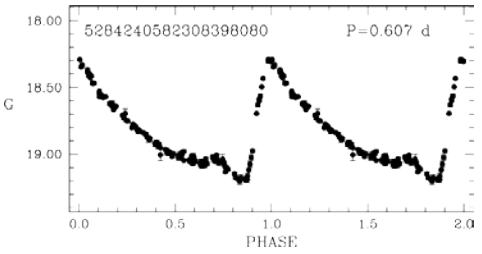


σ par. = 0.3 mas
σ pos. = 0.3 mas
σ pm = 1 mas

2 million proper motions and parallaxes (TGAS)



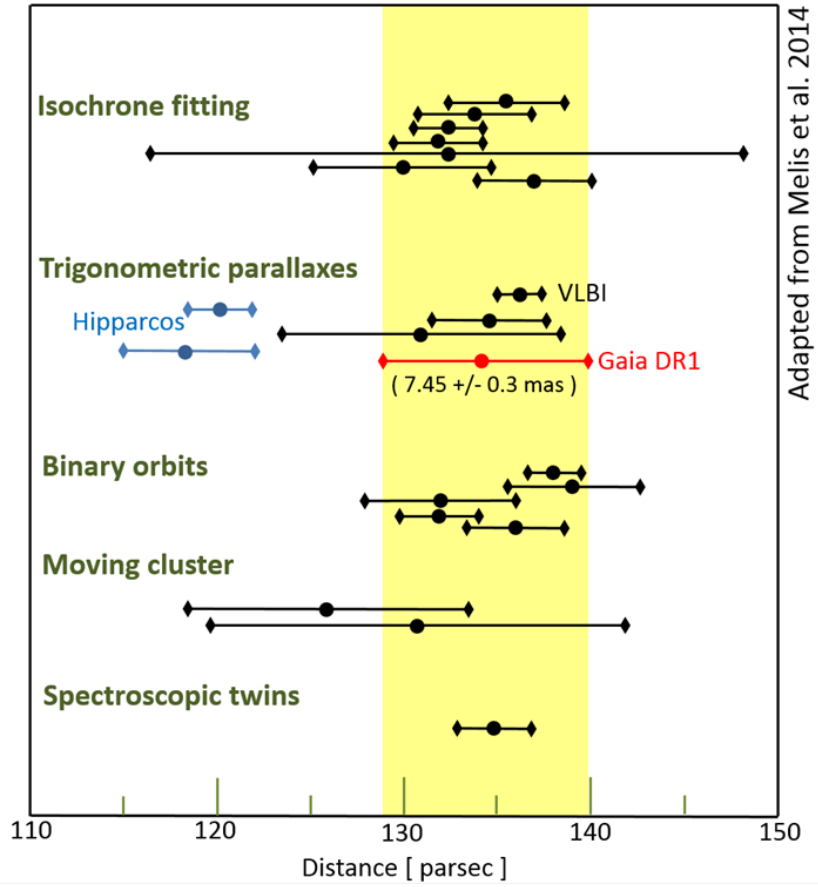
Positions and magnitudes for 2200 ICRF2 quasars



Light curves of variable stars near the South ecliptic pole

On the Pléiades cluster distance...

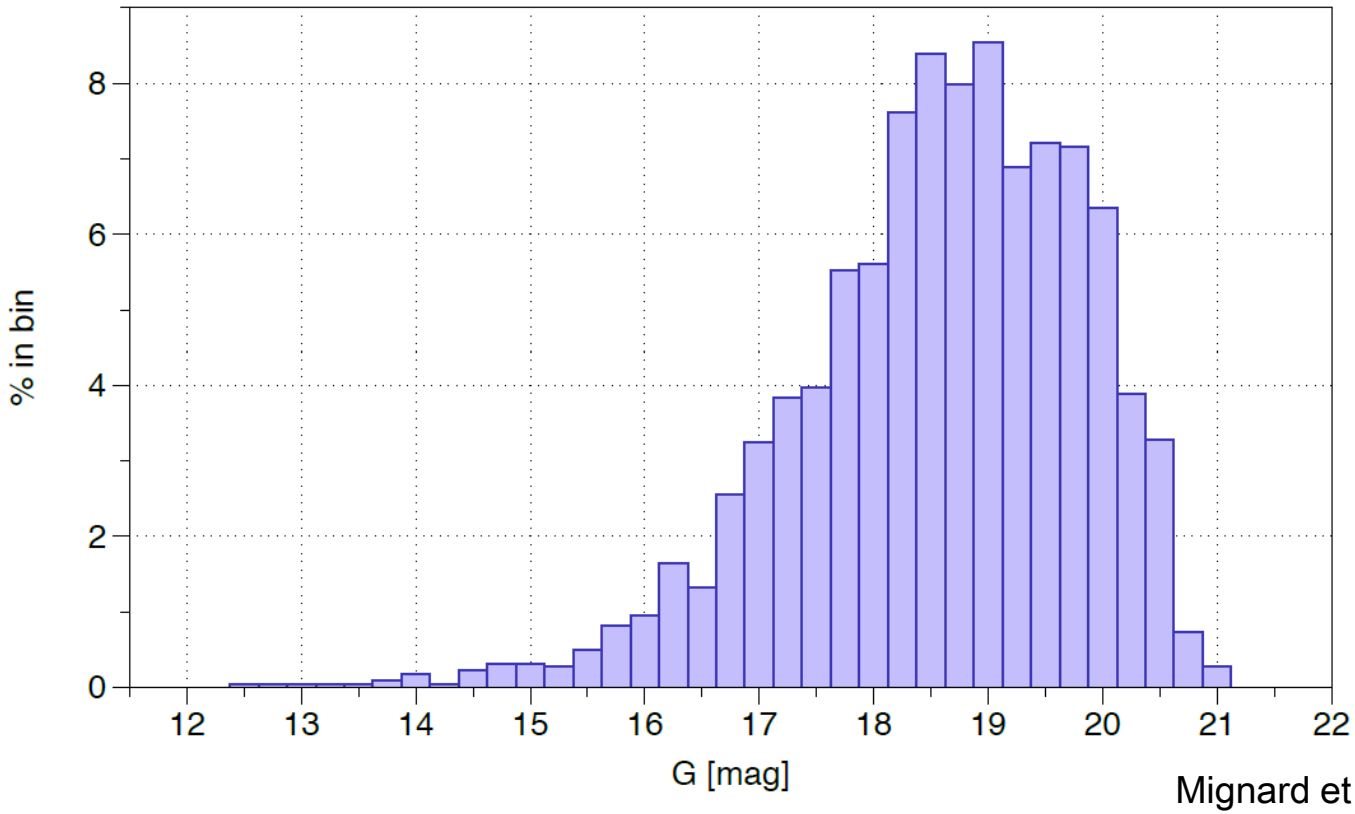
- Preliminary distance estimate: 136 ± 6 pc
- Limited in accuracy by:
  - Simplistic analysis
  - Systematic and correlated errors in the parallaxes
  - Incomplete survey of the cluster
- Good agreement with VLBI estimate
- Definite conclusion on the distance not yet possible



Brown et al. (2016)

Optical magnitudes of ICRF quasars

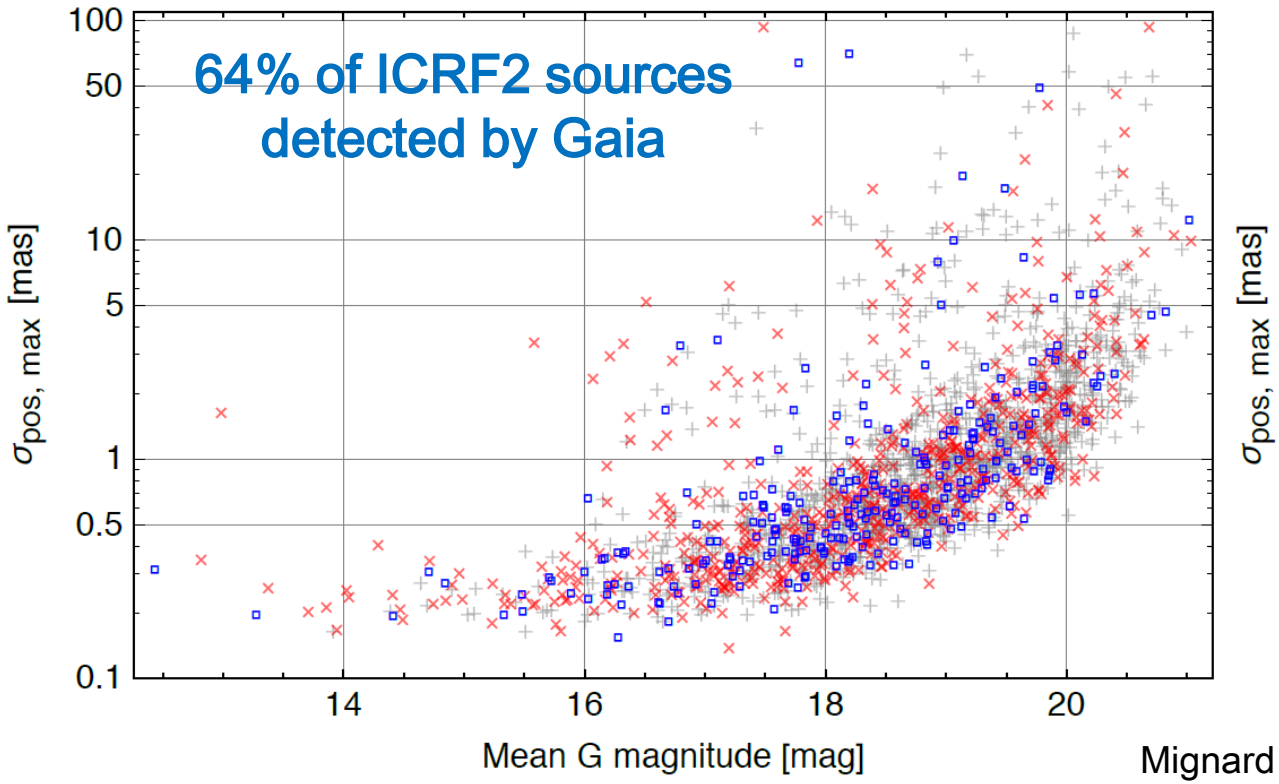
2152 ICRF2 quasars



Mignard et al. (2016)

Position uncertainty of ICRF quasars

2191 ICRF2 quasars

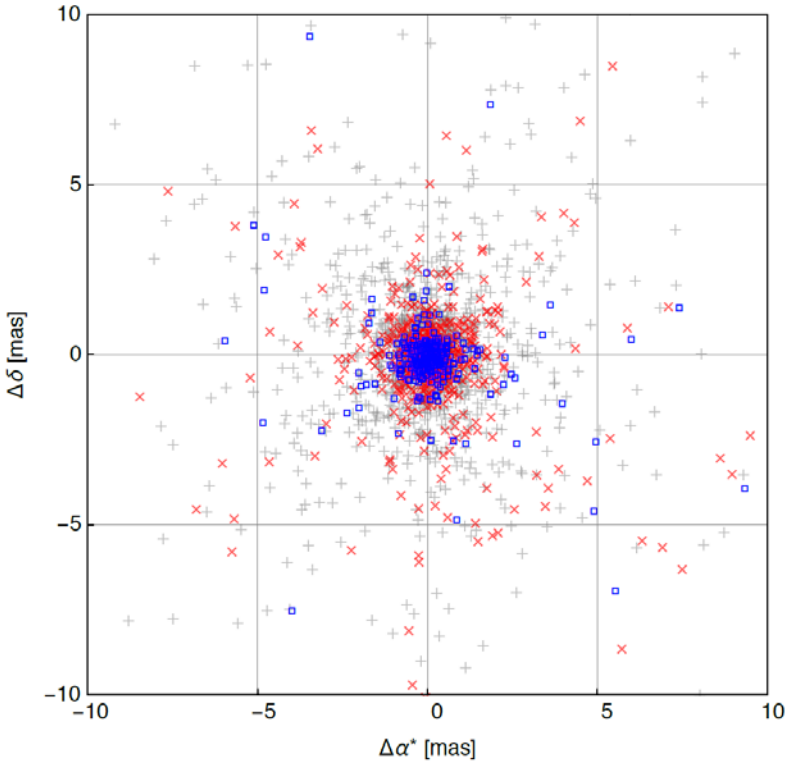


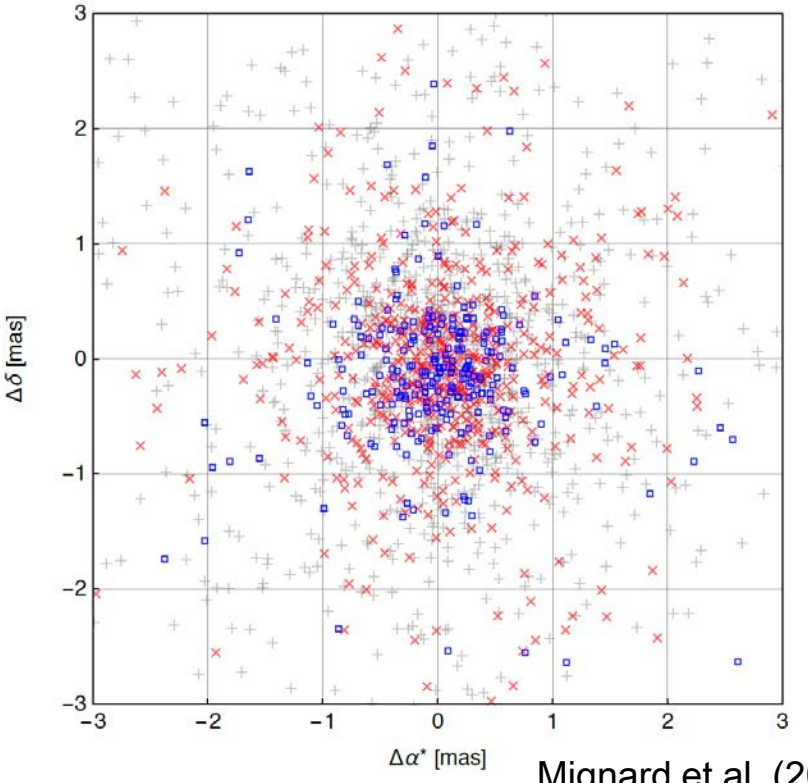
Floor of
0.25 mas

Mignard et al. (2016)

Defining sources Non-VCS sources VCS sources

Optical-radio position differences (1)

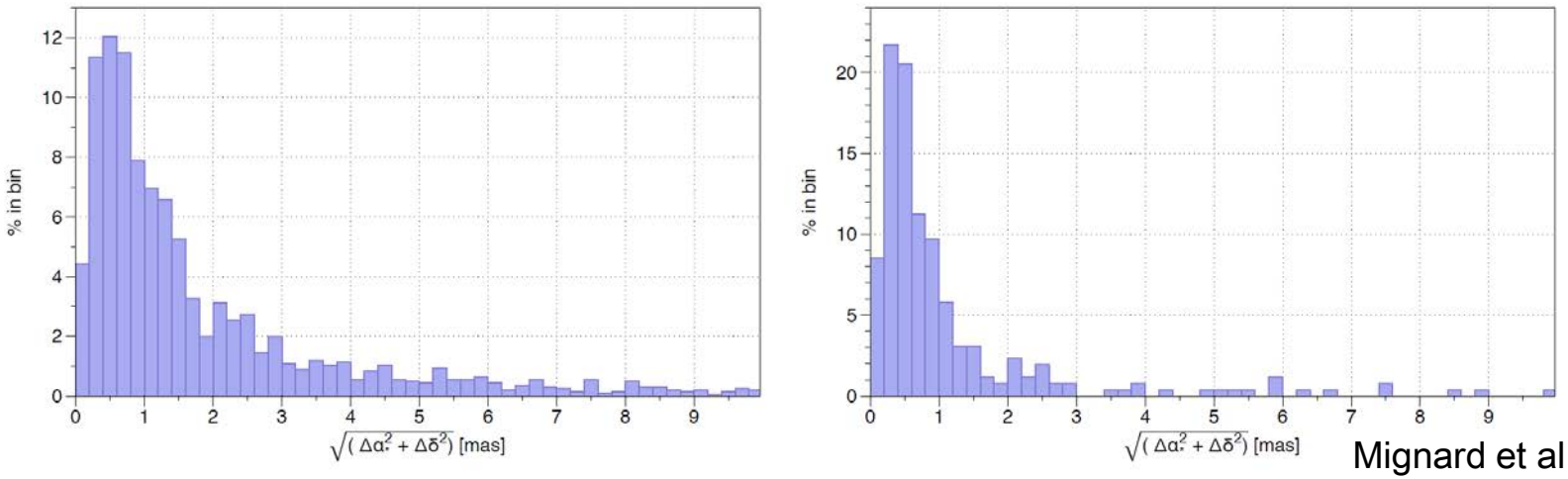




Mignard et al. (2016)

Defining sources Non-VCS sources VCS sources

Optical-radio position differences (2)



Mignard et al. (2016)

Agreement < 10 mas for 94% of all sources (98% of the defining sources)

Agreement < 1 mas for 44% of all sources (71% of the defining sources)

Differences generally consistent with the combined ICRF2 and Gaia position uncertainties

Among the sources with the most precise radio & optical positions, there is no indication of physical optical-radio offsets exceeding a few tens of mas

Conclusion

Stay tuned !

- ICRF3 coming up in < 2 years
- Gaia DR2 coming up in ~ 1 year
  - Full astrometry (positions, parallaxes, proper motions) where available
  - Radial velocities for bright stars, two-band photometry

In the mean time, have fun with the Gaia DR1 data!

A&A special issue on Gaia DR1

The *Gaia* mission⋆

Gaia Collaboration, T. Prusti[1,⋆⋆], J. H. J. de Bruijne[1], A. G. A. Brown[2], A. Vallenari[3], C. Babusiaux[4], C. A. L. Bailer-Jones[5], U. Bastian[6], M. Biermann[6], D. W. Evans[7], L. Eyer[8], F. Jansen[9], C. Jordi[10], S. A. Klioner[11], U. Lammers[12], L. Lindegren[13], X
D. Pourbaix[18,19], S. Randich[20], G. Sarri[2]

Gaia Data Release 1

Summary of the astrometric, photometric, and survey properties

Gaia Collaboration, A. G.A. Brown[1,⋆], A. Vallenari[2], T. Prusti[3], J. H.J. de Bruijne[3], F. Mignard[4], R. Drimmel[5], C. Babusiaux[6], C. A.L. Bailer-Jones[7], U. Bastian[8], M. Biermann[8], D. W. Evans[9], L. Eyer[10], F. Jansen[11], C. Jordi[12], W. O'Mullane[14], C. Panem[16], D. Pourbaix[17,18],

Gaia data release 1

Pre-processing and source list creation

C. Fabricius[1], U. Bastian[2], J. Portell[3], J. Castañeda[3], M. Davidson[4], N. C. Hambly[4], M. Clotet[3], M. Biermann[2], A. Mora[5], D. Busonero[6], A. Riva[6], A. G. A. Brown[7], R. Smart[6], U. Lammers[8], J. Torra[3], R. Drimmel[6], G. Gracia[9], W. Löffler[2], A. Spagna[6], L. Lindegren[10], S. K

Gaia Data Release 1

Astrometry – one billion positions, two million proper motions and parallaxes

L. Lindegren[22], U. Lammers[9], U. Bastian[2], J. Hernández[9], S. Klioner[14], D. Hobbs[22], A. Bombrun[9], D. Michalik[22], A. Hutton[9], P. Parsons[9], H. Steidelmüller[14], N. Bach[9], C. Barache[19], U. Becciani[26],

Gaia Data Release 1

The reference frame and the optical properties of ICRF sources

F. Mignard[1], S. Klioner[2], L. Lindegren[3], U.Bastian[4], A. Bombrun[5], J. Hernández[6], D. Hobbs[3], U. Lammers[6], D. Michalik[3], M. Ramos-Lerate[7], M. Biermann[4], A. Butkevich[2], G. Comoretto[8], E. Joliet[9,5], B. Holl[10], A. Hutton[11], P. Parsons[12], H. Steidelmüller[2], A. Andrei[13], G. Bourda[14], and P. Charlot[14]