Gaia binaries: get ready!

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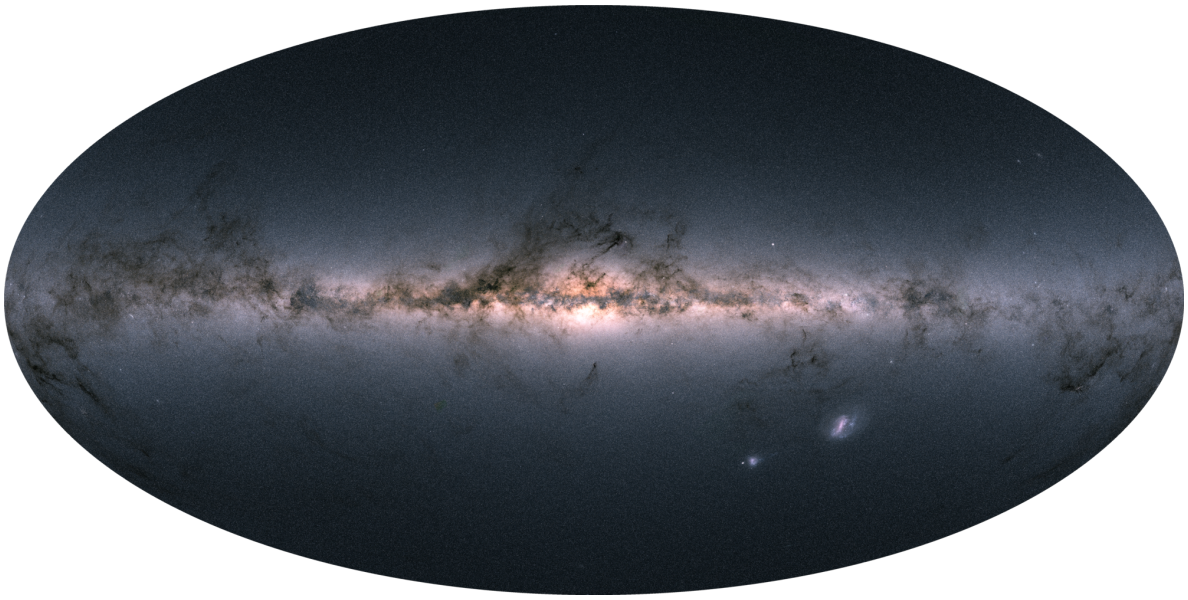
Gaia 2nd Data Release (April 2018)



- 1.7B positions and G fluxes
- 1.4B RP and BP fluxes
- 550k variable stars (w/L.C.)
- 1.3B parallaxes and proper motions
- 7.6M radial velocities
- 14k solar system objects

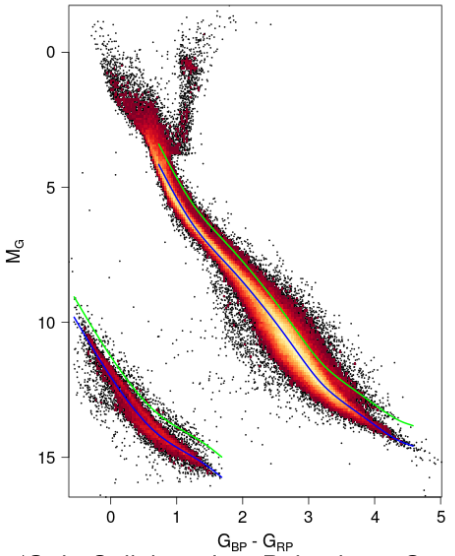
2000+ papers citing Gaia DR2 results.

Binaries cannot hide very long

Some binaries already identified in Gaia DR2: secondary locus vertically shifted by ~ 0.75 mag wrt the main stellar locus, corresponding to unresolved twins.

- Twins are quite common;
- Their parallaxes are already correct (even though the adopted model is physically wrong).

For some investigations, filtering them out is all that matters, so identifying them is enough.



(Gaia Collaboration; Babusiaux, C et al., 2018A&A...616A..10G)

All that glitters is not gold! Suchkov & McMaster (1999) identified over luminous FV stars in the Hipparcos catalogue (ESA 1997). Griffin & Suchkov (2003) confirmed the binary nature for 58% of them only.

Should binaries deserve any special care?

Looking back at Hipparcos,

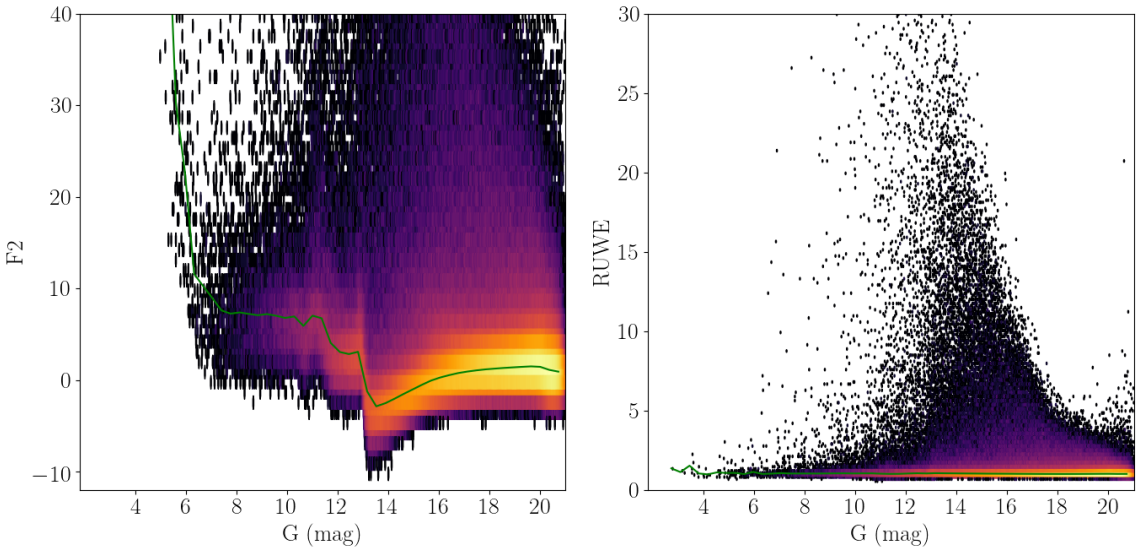
- yes, we should care
  - HIP 88848: μ revised from $(138.07, -18.58)$ mas/yr to $(106.59, -30.84)$ mas/yr with the orbital model (Fekel et al., 2005AJ....129.1001F).
  - HIP 65835: ϖ changed from 1.62 ± 2.43 mas to 8.44 ± 1.00 mas by returning to the 5p-model (originally VIM, Pourbaix et al., 2003A&A...399.1167P);
- but the benefit is sometime limited
  - HIP 14124: $P = 363.1$d, 5p-model. Imposing an orbital model would change the parallax but such a model is not very robust (Campbell vs Thiele-Innes).
  - HIP 116360: $P = 348$d, 5p-model. The parallax is right (compared to the orbital parallax) because the mass ratio is close to 1 and, therefore, the size of the photocentric orbit is close to 0.

The astrometric wobble of the unresolved twins is null so both their parallaxes and proper motions based on the single star model are the best one can derive.

If you study twins, Gaia DR2 is already your Holy Grail.

From F2 to RUWE

F2 (Wilson & Hilferty's cube root transformation of the χ^2) follows a N(0, 1) distribution, i.e. does not depend on the number of observations. With Hipparcos, that was experimentally true.



RUWE, released a few months after Gaia DR2, is supposed to correct for the weaknesses (magnitude and colour terms) of UWE or F2 in DR2.

DR3 teaser

Disclaimer

The following results are based either

- on DR3 observations processed with an early version of the astrometric pipeline,
- or on DR2 spectroscopic or photometric observations.

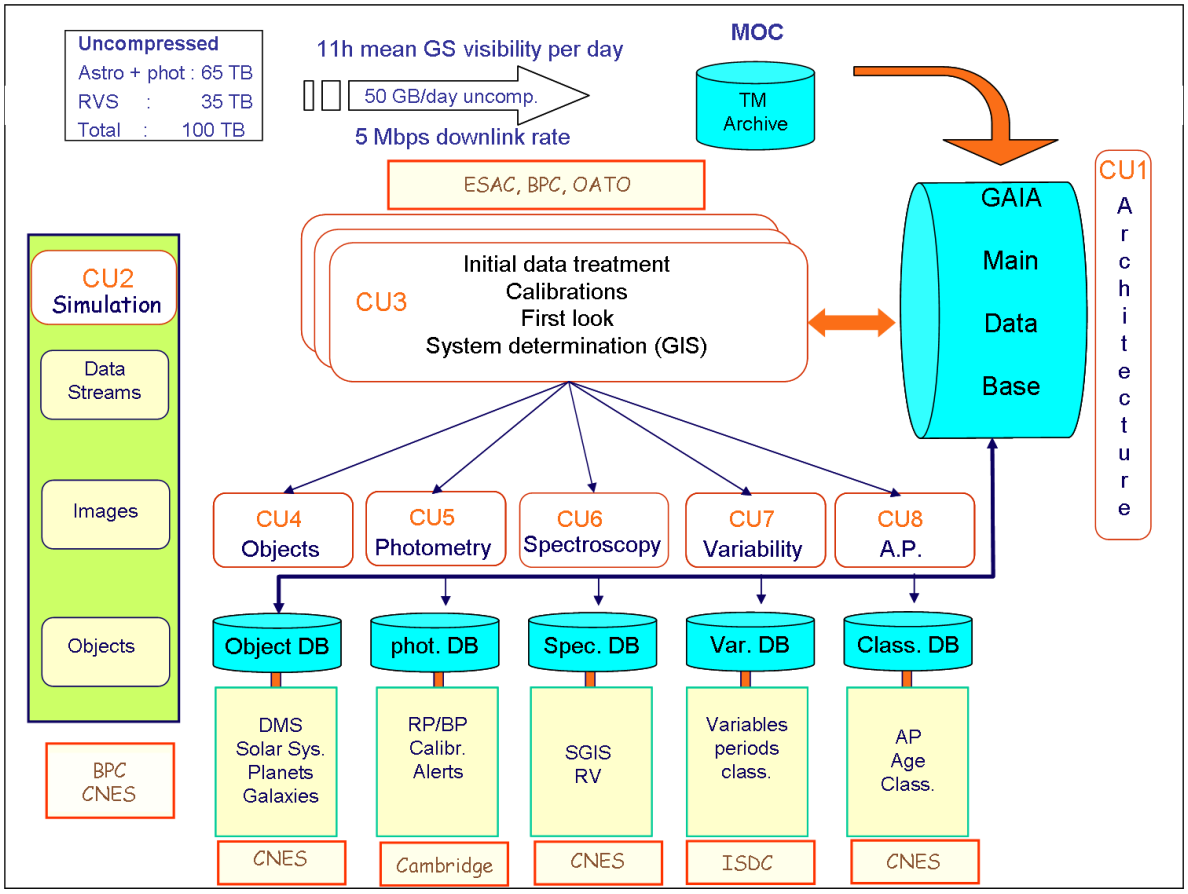
They are therefore preliminary and only aim at offering a feeling of what will be available eventually.

No input catalogue, the identification of the candidate binaries result from:

- a poor single star fit (astrometry),
- a variability of the radial velocity, or
- a special shape of the light curve.

The Gaia DR3 results will be based on $\sim$ 1000 days of the nominal mission only.

Why 1,000 days only? Gaia object processing



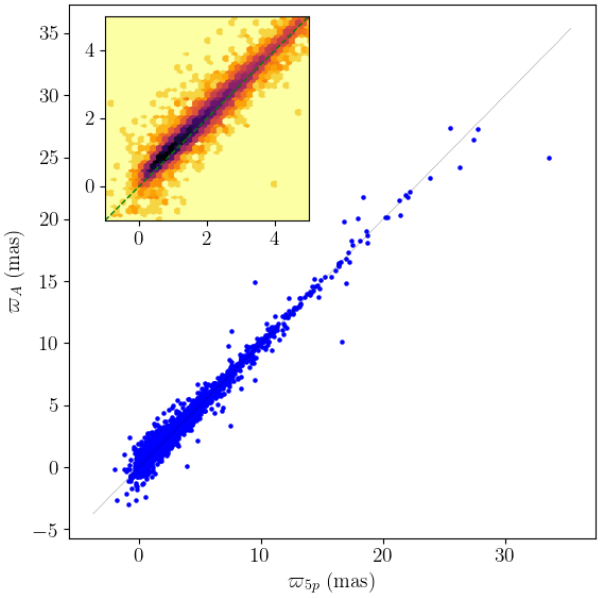
Astrometric non-single stars - Accelerations

Acceleration models account for the first and possibly second time derivatives of the proper motion.

Typically holding for long period binaries (i.e. much longer than the mission duration) for which any fitted Keplerian orbit would otherwise be just one among millions of equally good possibilities.

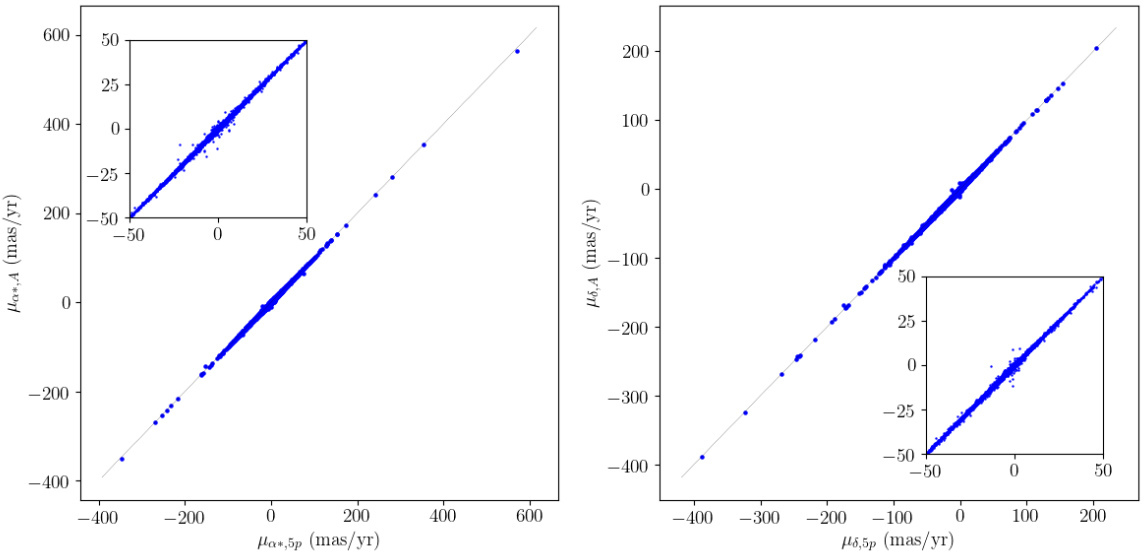
The impact on the parallax is anticipated to be small.

Here, the '5p' solutions are preliminary astrometric solutions derived assuming the objects are single. They are not the DR2 results.



Accelerations - Proper motions

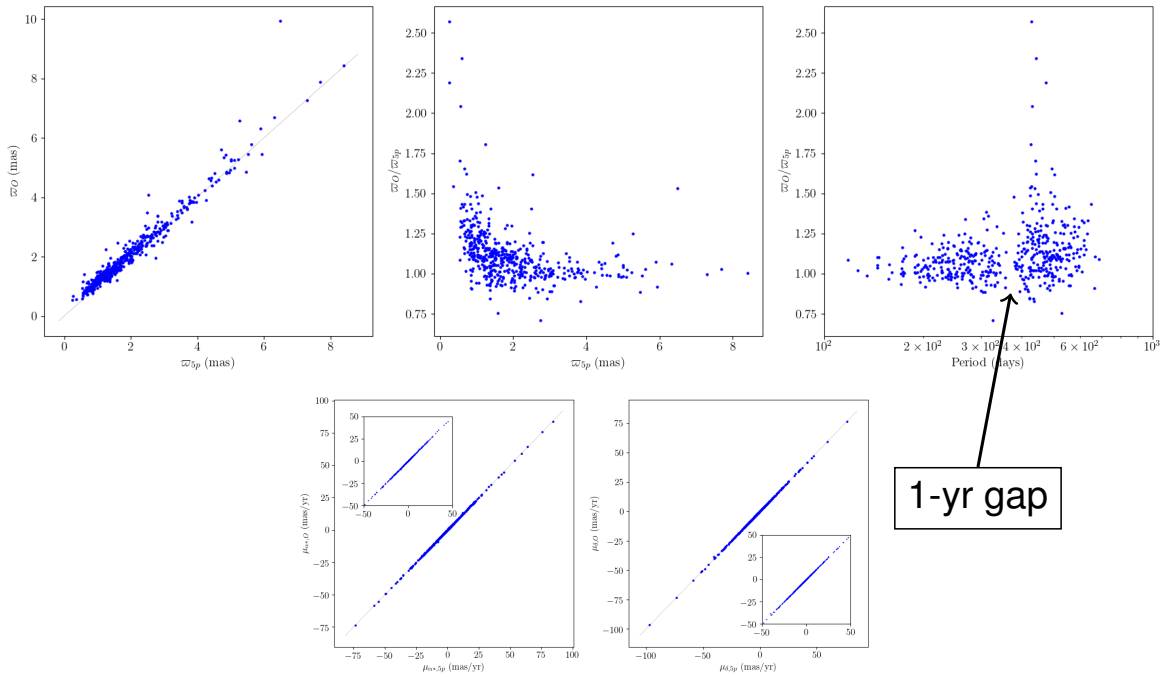
Away from 0, the impact on the proper motion is also rather limited.



Good at detecting long period binaries, i.e. improving the binary census. Gaia DR4+ might see some of them changed into orbital solutions.

Orbital solutions - parallaxes

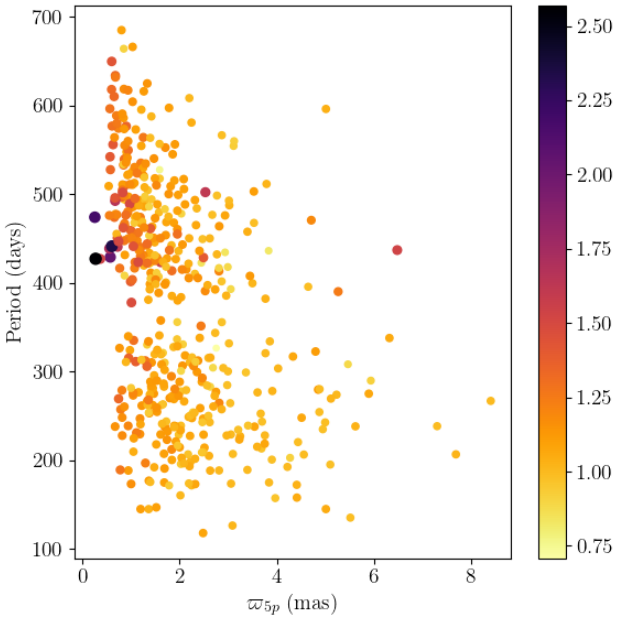
In fewer cases, acceleration terms are not enough and a Keplerian model is considered.



Will my DR2-based results be affected?

There is a risk indeed that your results/conclusions need some update because the DR2 parallaxes got tuned a little bit.

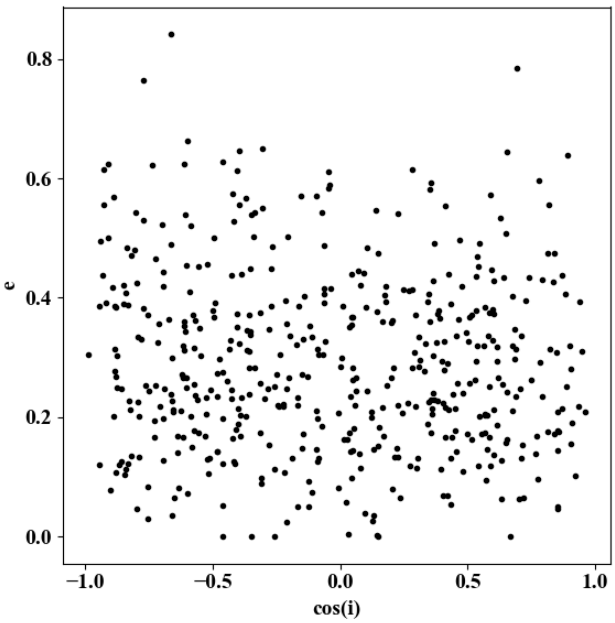
For the time being, problems seem to be limited to periods in the 400–500 day range and small parallaxes . . . but this is not a sufficient condition!



Warning: DR3 will come in two steps (1 year apart):

- eDR3: photometry and astrometry assuming single star model;
- DR3: spectroscopy, AP, double multiple stars, . . .

Size and orientation of the astrometric orbits



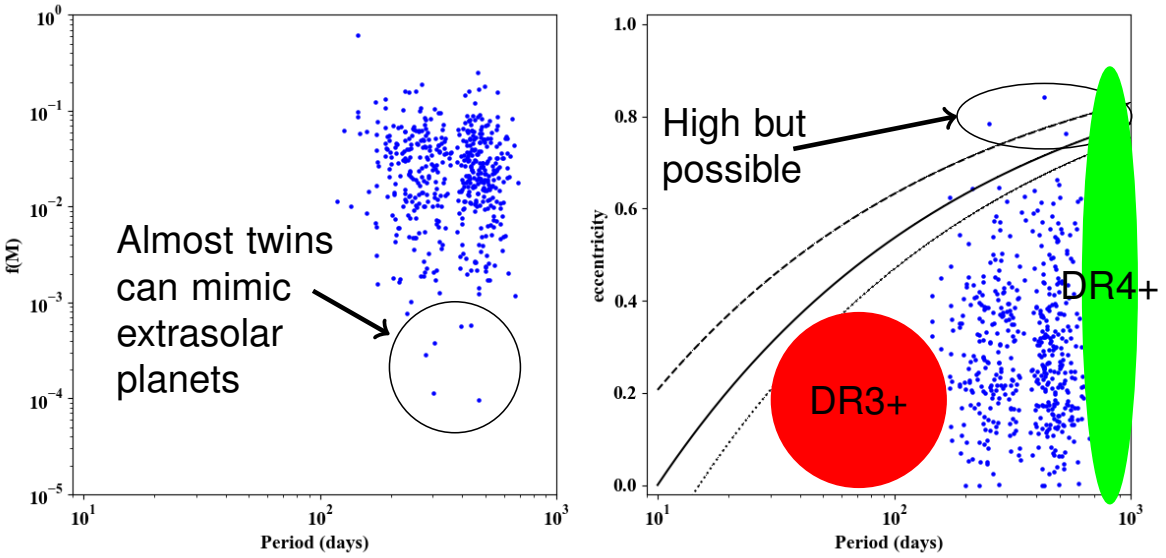
No bias on the inclinations: $\cos i \sim U([-1, 1])$

Precision on the inclination left as homework: the Thiele-Innes constants are normally distributed, so i is not.

Absolute orbit of the photocentre: a small semi-major axis can result from:

- a light weight secondary (extrasolar planet)
- two stars with similar brightness and mass.

Distribution of orbital parameters



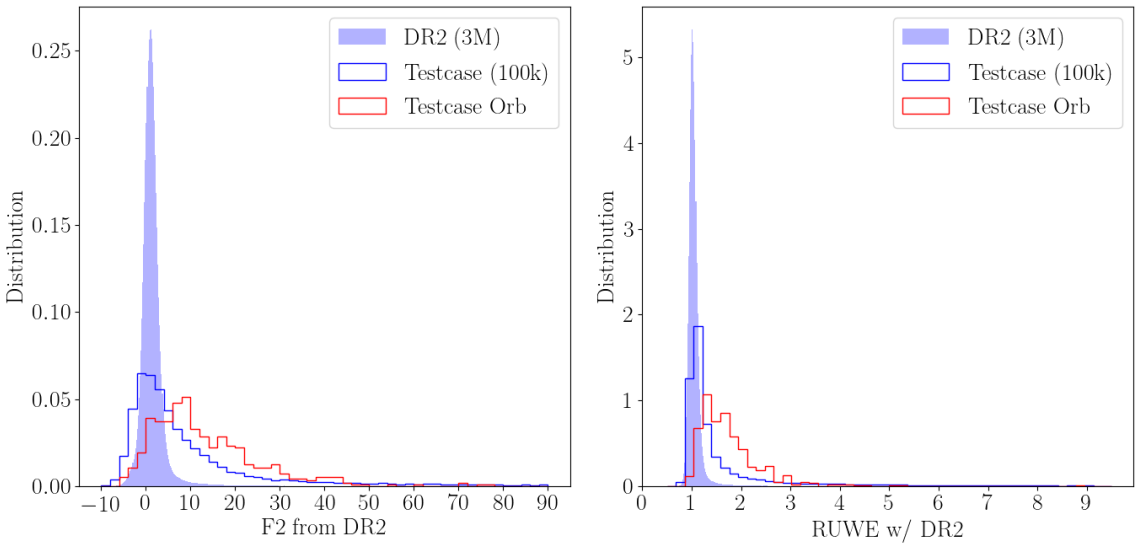
Astrometric binaries: so far

Number of objects to be processed	97359
Number of solutions of type Acceleration7	11117
Number of solutions of type Acceleration9	8563
Number of solutions of type Orbital	3113
Number of solutions of type OrbitalPoorlyConstrained	2616
Number of solutions of type Stochastic	50403
Number of solutions of type SingleStar	1221
Number of objects effectively processed	77033
Number of objects processed without solution	37
Number of objects lost with too few data	20288
Number of objects lost with math exception	1

Unfortunately, a lot of the seemingly valid orbital solutions turn out to be spurious, resulting from previously unidentified harmonics in the scanning law ($P < 100$ days).

Relation with F2 and RUWE

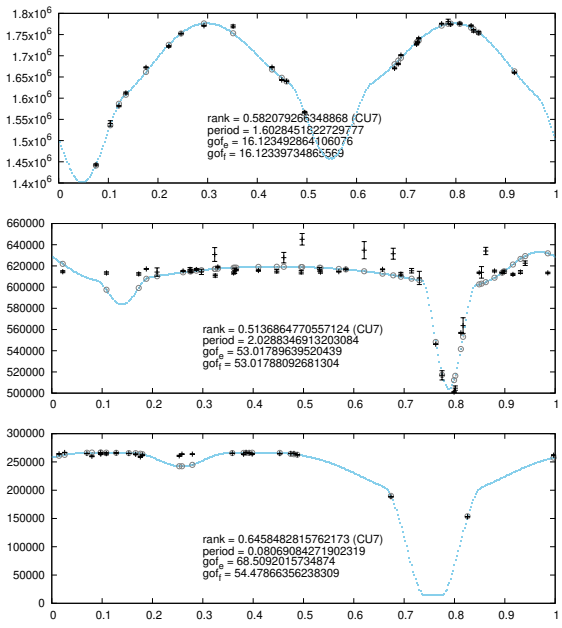
Most of the 100k objects were selected due to their large RUWE.



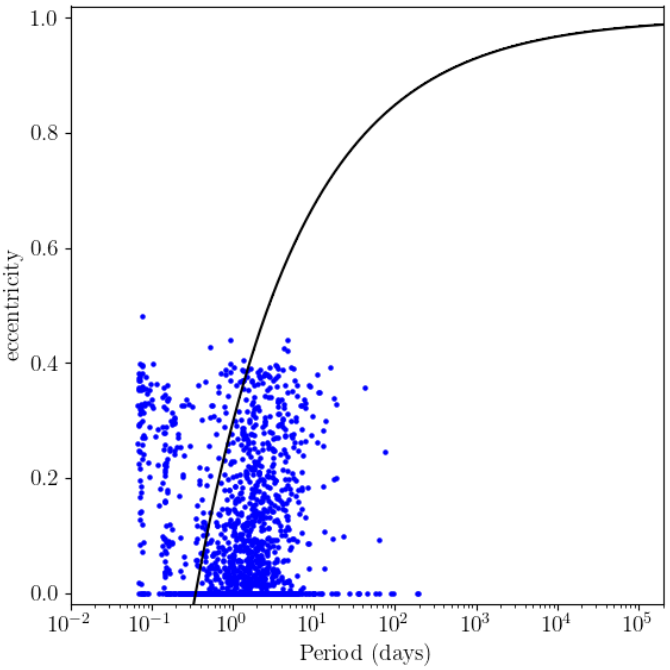
Only 470 are kept as validated orbital (i.e. with full orbital solution + astrometry of the centre of mass). As a matter of facts, in Hipparcos, there were only 235 orbital solutions, only 45 of which were totally unconstrained.

Eclipsing binaries

- ∼0.5–1M eclipsing binaries classified as such through the shape of their light curve, already identified but filtered out before DR2.
- Cycle N results based on what was classified as EB during cycle $N-1$ thanks to photometric measurements derived earlier during cycle $N-1$.
- Fine tuning the observing time is impossible so some eclipses might remain poorly constrained for a while.

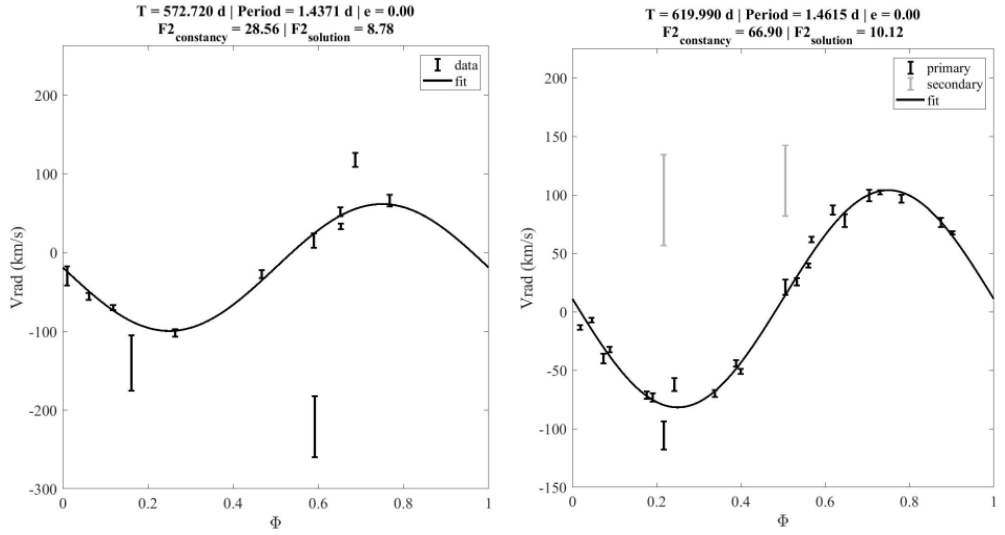


Eclipsing binaries - parameter distribution



- Sparse phase coverage, likely responsible for the spurious eccentricities at short periods (less than 4%).
- The additional observations (up to 3 photometric bands) shall make the classification more robust and the fitted model more reliable.
- Eccentric systems with periods up to 10 days already well populated despite the DR2-like data.

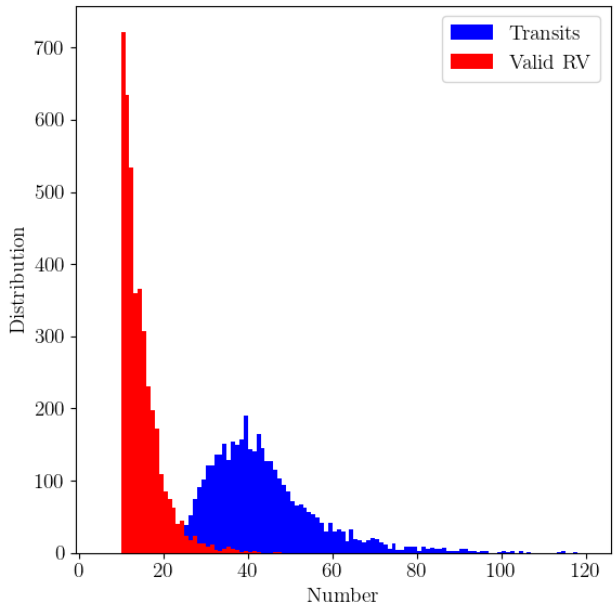
Spectroscopic binaries



The DR2 or advertised end of mission precision on the velocity of single stars is somehow misleading for binaries (uncertainties on epoch data vs uncertainty on the mean): Gaia RVS is not HARPS but it gives RV for dozens of millions of stars!

Spectroscopic binaries

Present limitations:



- Limited magnitude range (G∼5.5–15 (13 for SB2), limited to 13th in DR2)
- Reduced T_{eff} interval (3550–6900K in DR2)
- Fewer observations (about 50% wrt astrometry)

The ranges eventually adopted for single stars first and binaries afterwards will be set during the pre-DR3 validation phase.

Conclusions

- Despite the preliminary nature of the inputs, it is already clear where we head on: there will be binary results in DR3 (second half of 2021).
- Binaries can be seen as validators of some upstream processing: even the single star solutions can benefit from the modelling of binaries.
- DPAC teams are making progress everyday so DR3 will not only benefit from more observations, they will also be better calibrated, better corrected for instrumental effects, . . . : DR2- still suffer from some *growing pains*.
- There are still way too many uncertainties to make any claim about the number of binaries in DR3 (even a rough estimate would be presumptuous).

DR3 will contain the results only. Wait for DR4 for the observations. Practice with Hipparcos if you cannot wait!

SB9

- At the IAU GA in 2000, a group of scientists decided to continue the work of A. Batten;
- The 9th Catalogue of Spectroscopic Binary Orbits has grown from 1 469 systems to almost 3 900 since January 2001 (787 refereed publications added);
- These spectroscopic orbits are now regulary used as validators for Gaia;
- If you are willing to make your own orbits accessible more easily, feel free to get in touch with me (pourbaix@astro.ulb.ac.be);
- Try it (already 377 citations):

  http://sb9.astro.ulb.ac.be