Stellar multiplicity: a teaser of the hidden treasure in the Gaia Data Release 3

Gaia collaboration, Arenou et al., 2022, A&A

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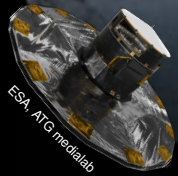


ESA, ATG medialab

ESA/Gaia/DPAC

Arenou et al., 2022 PV paper aims

- **Illustrate the richness of the Not Single Star DR3 products**
- Explore some inspiring science cases
- Identify particularly **interesting objects**
- **Guide the Gaia user through the complexity NSS data**
- Warn for biases and caveats in the data
- Provide recommendations for **data selection**

DR3 CU4 NSS products

- Gaia is a **complete observatory** for identification and study of binaries/multiple stars
  - Provides 3 main methods: **Astrometry, Radial Velocities / Spectroscopy, Photometry**
- Many different ways to identify and characterize binaries, so **many solution types**

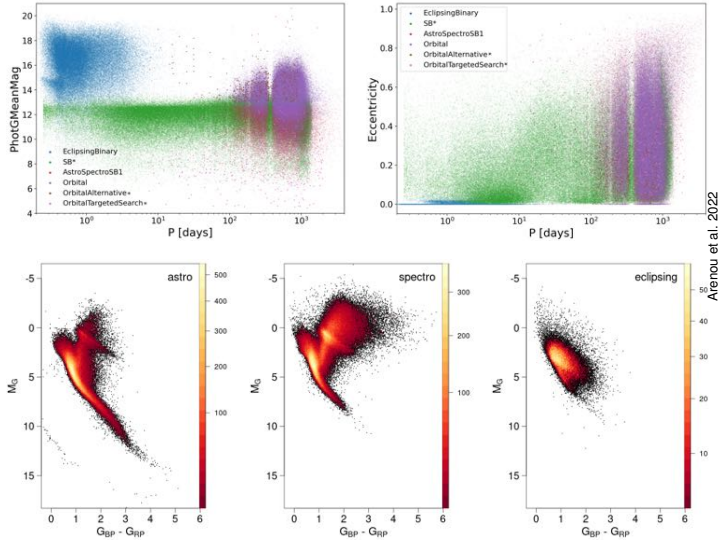
Table	Solution type	Solutions	Description
nss_acceleration_astro	Acceleration7	246 947	Second derivatives of position (acceleration)
	Acceleration9	91 268	Third derivatives of position (jerk)
nss_two_body_orbit	Orbital	134 598	Orbital astrometric solutions
	OrbitalAlternative*	629	Orbital astrometric, alternative solutions
	OrbitalTargetedSearch*	533	Orbital astrometric, supplementary external input list
	AstroSpectroSB1	33 467	Combined orbital astrometric + spectroscopic solutions
	SB1 or SB2	186 905	Orbital spectroscopic solutions
	EclipsingSpectro	155	Combined orbital spectroscopic + eclipsing solutions
	EclipsingBinary	86 918	Eclipsing binaries
nss_non_linear_spectro	FirstDegreeTrendSB1	24 083	First order derivatives of the radial velocity
	SecondDegreeTrendSB1	32 725	Second order derivatives of the radial velocity
nss_vim_fl	VIMF	870	Variable-induced movers fixed

Arenou et al. 2022

- Higher multiplicity ignored in this release
- See **processing papers**: Halbwachs et al. 2022, Holl et al. 2022, Gosset et al. 2022, Damerdji et al. 2022, Siopis et al. 2022, and **on-line documentation**

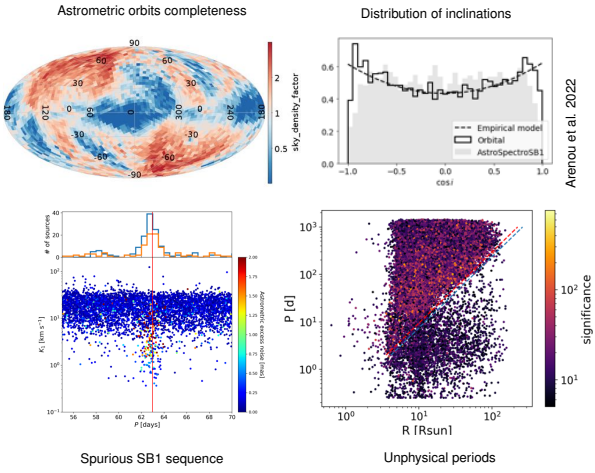
Statistics

- **Huge number of orbits**
  - **135k Astrometric** orbits
  - **185k Spectroscopic** orbits
  - **33k Astro+Spectro** orbits
  - **87k Eclipsing B.** orbits
- **45** times more spectroscopic orbits than in the **SB9 Catalogue**
- **300** times more astrometric orbits than in **Orb6 Catalogue**
- Covering the entire HR diagram, including WD sequence
- See also **2.2M Eclipsing Binaries** from Variability Analysis (`vari_eclipsing_binary`)



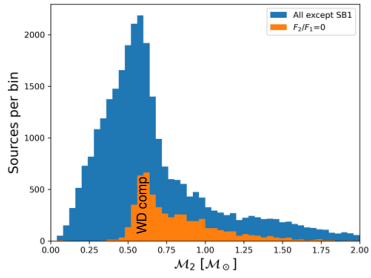
Caveats, limitations & recommendations

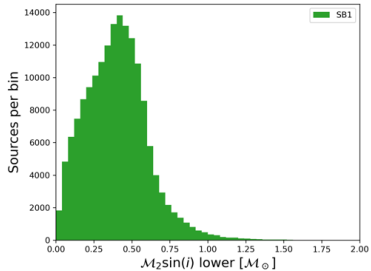
- A **big validation effort** was done during paper preparation
- Characterize completeness and biases
- **Identify bad solutions**
  - Some bad solution removed from the release, **some others still present in the release**
- Caveats and **recommendations** for filtering bad solutions are presented
  - SB1 solutions with $P \sim 62.97$ days and `ipd_frac_multi_peak` > 20 are due to close pairs
  - SB1 solutions with short P and high e are probably due to aliasing of long periods



Catalogue of masses

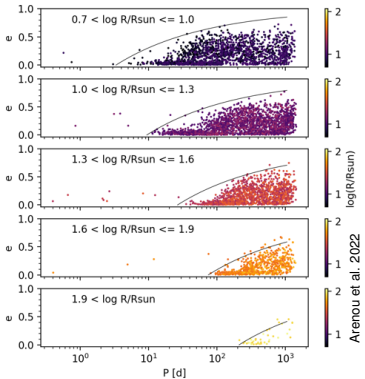
- **Masses of the components** were estimated in the paper
  - **Table** `binary_masses` in the **Gaia Archive**
  - **195 315** entries
  - $\mathcal{M}_1$, $\mathcal{M}_2$, F_2/F_1 and their confidence ranges
  - Only lower limit of $\mathcal{M}_2 \sin(i)$ provided for `SB1` solutions
- Only for systems with primaries on the **Main Sequence** and White Dwarfs sequence
- $\mathcal{M}_1$ derived with isochrone fitting of G, $G_{\rm BP} - G_{\rm RP}$ and 3D extinction map of Lallement et al. (2019)
- Take into account **NSS parallax** and **flux ratio** in mass computation
- $\mathcal{M}_1$ derived down to 0.1 $\mathcal{M}_\odot$
- Use MonteCarlo to estimate confidence ranges

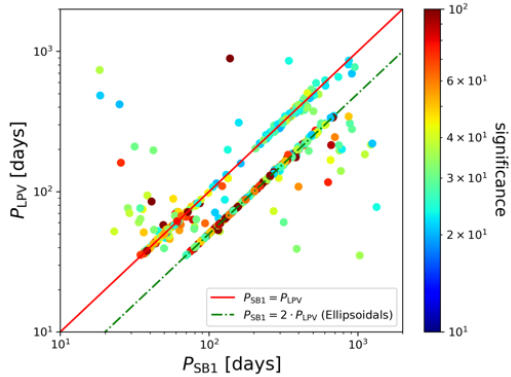




Binaries in the RGB/AGB

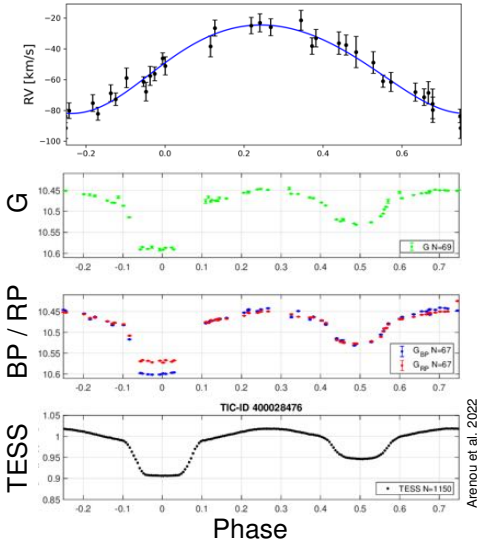
- **Circularization as function of radius** clearly detected
- **Long Period Variables and SB1**
  - Some Ellipsoidal SB1 mistaken as Long Period Variables
  - Some Long Period Variables mistaken as SB1: RV evolution due to pulsation
  - LPV-SB1 with $P_{\rm SB1} = P_{\rm LPV} \leq 100$d: starspot modulation on a spin-orbit synchronised primary?





EL CVn systems

- **EL CVn systems** are **rare eclipsing binaries** composed by a A/F main sequence star and a pre-Helium thermally bloated White Dwarf
- Deeper eclipse is due to the A/F main sequence star eclipsing the White Dwarf, RV from A/F star
- 5 EL CVn systems identified, 1 already known

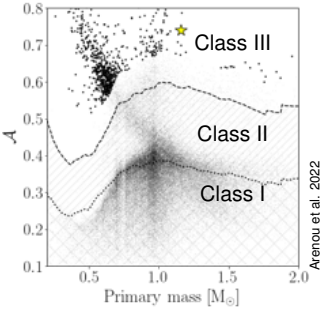


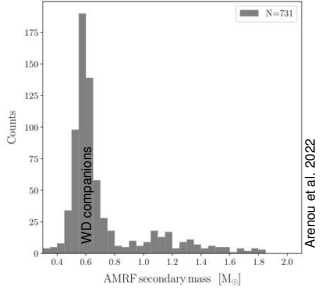
Compact objects

- **Compact objects identified with Astrometric Mass Ratio Function** (Shahaf et al. 2019)

$$\mathcal{A} \equiv \frac{a_0}{\varpi}\left(\frac{\mathcal{M}_1}{\mathcal{M}_\odot}\right)^{-1/3}\left(\frac{P}{\mathrm{yr}}\right)^{-2/3}$$

- 3 classes of objects, at increasing AMRF
  - Class I: compatible with Main Sequence companion
  - Class II: compatible with companion which is a binary of Main Sequence stars
  - Class III: compact object
- **731 Compact objects candidates**, mostly White Dwarfs

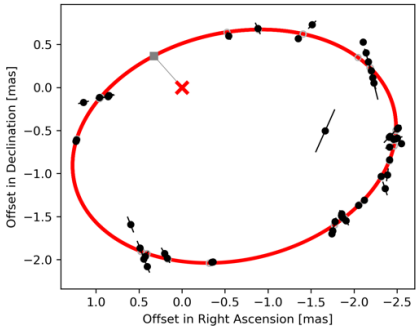




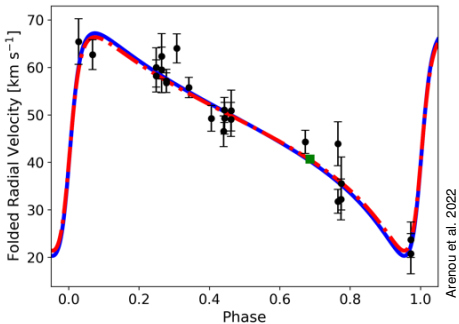
A Neutron Star

- Gaia DR3 5136025521527939072: Very solid candidate for a **dormant Neutron Star**
- **Detected both in radial velocity and astrometry**
- Radial velocity confirmed on ground with SOPHIE
- $\mathcal{M}_1 = 1.16\mathcal{M}_\odot$, $\mathcal{M}_2 = 1.59^{+0.21}_{-0.19}\mathcal{M}_\odot$, period 546 days, eccentricity 0.65

Astrometric orbit

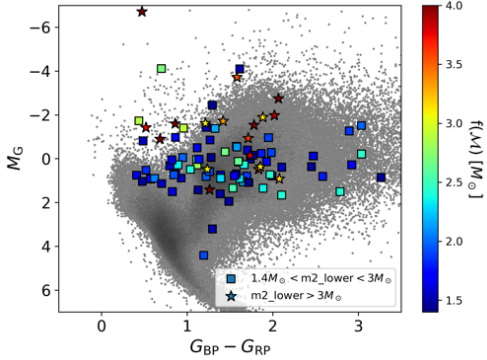


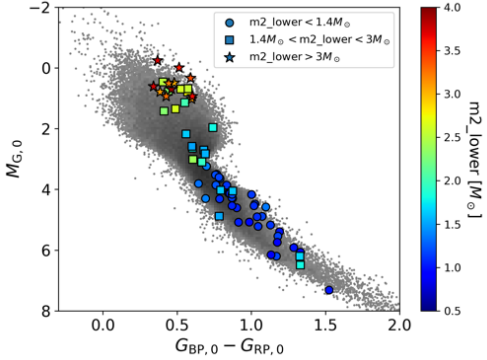
Spectroscopic orbit



Large masses from SB1

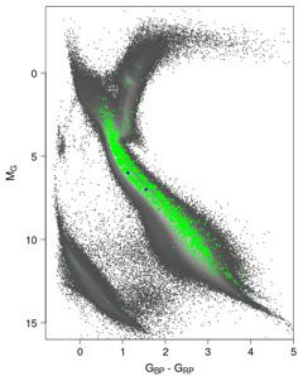
- 94 sources among **giants** with mass function $f(\mathcal{M}) > 1.4\mathcal{M}_\odot$, and 20 among them $f(\mathcal{M}) > 3\mathcal{M}_\odot$
- 11 sources in **Main Sequence** with $\mathcal{M}_2 \sin(i)_{\rm lower} > 3\mathcal{M}_\odot$ and $\mathcal{M}_2 \sin(i)_{\rm lower} > \mathcal{M}_{\rm 1upper}$
- Candidates to have a dormant **Neutron Star or Black Hole** companion

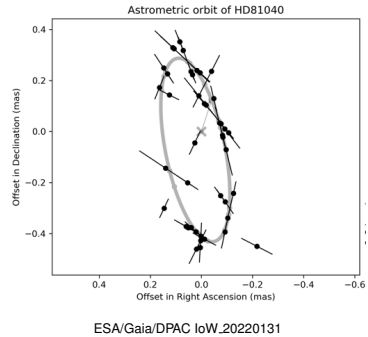




Substellar companions

- **1843 Brown Dwarfs and 72 Exoplanets candidates found from astrometric solutions**
  - 10 BD and 9 EP already known
  - 1 Exoplanet around a WD
  - Some literature EP found to be BD
- **6k SB1** have $\mathcal{M}_2 \sin(i) < 0.08 \mathcal{M}_\odot$
  - Many are probably aliases of longer periods
  - 10 candidate Exoplanets
  - One known transiting super-Jupiter correctly detected
- See also Holl et al. 2022

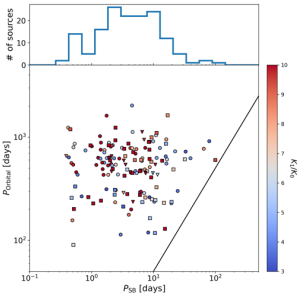


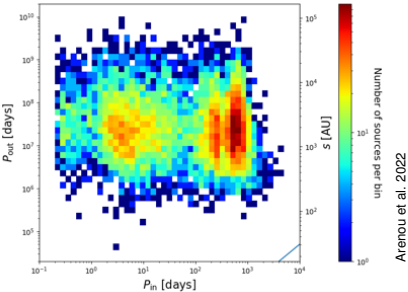


- **Gaia candidate exoplanet list** `https://www.cosmos.esa.int/web/gaia/exoplanets`
- Will be added to Exoplanet Encyclopedia `http://exoplanet.eu`

Multiples stars

- NSS solutions can be used to find **multiple stars**
- **152 triple systems** from `Orbital+SB*`
  - `Orbital` solution correspond to external orbit, `SB*` to internal one
- Found **10k triple systems and 52 quadruple system** by matching NSS binaries with **wide binaries** (El-Badry et al. 2021) components
- Over abundance of inner periods below 10 days due to **tidal interaction**?



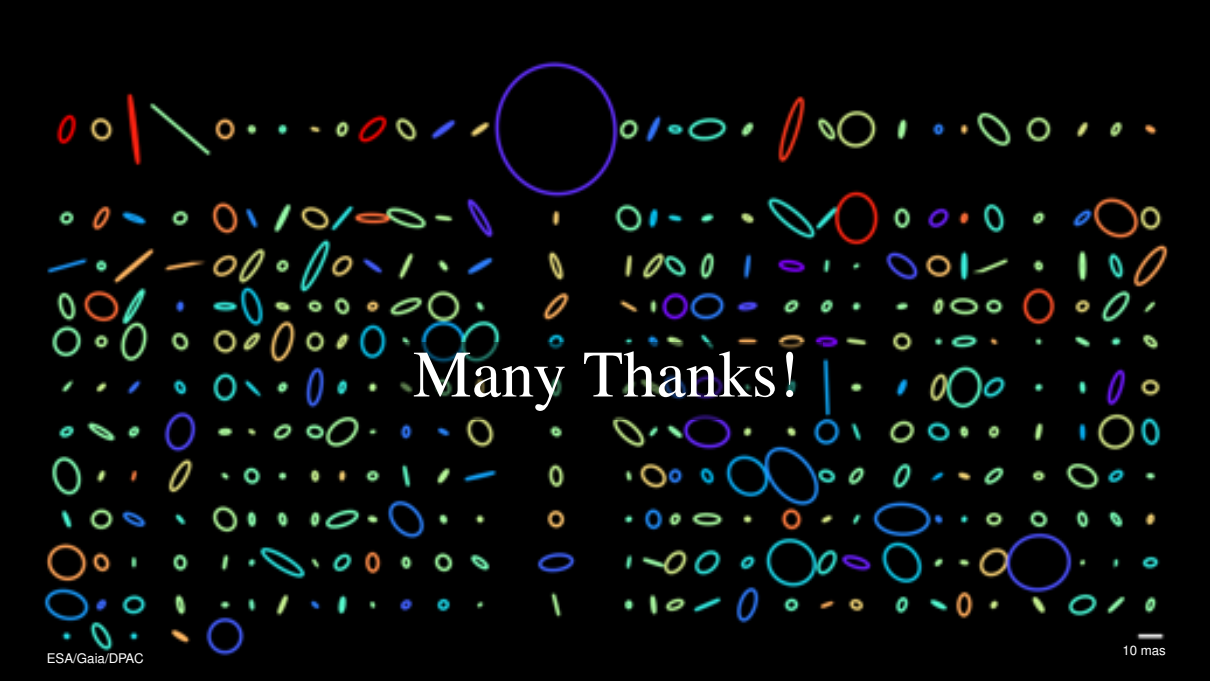


Arenou et al. 2022

Conclusions

- The Gaia DR3 provide an **extremely rich dataset to study binarity/multiplicity**
- A **major increase in the number of binaries with orbits** respect to literature
- The Arenou et al. 2022 paper is just a teaser of what can be done

- **Understanding of how data were processed is important to correctly exploiting Gaia data**
- **Let's take this opportunity to open new collaborations between DPAC people and researcher**


Many Thanks!
ESA/Gaia/DPAC
10 mas

Extra slides

Companions of Ultracool Dwarf

- Gaia can **detect binaries** also **among Brown Dwarfs**
- 13 binaries found in the Gaia Ultra Cool Dwarfs (GUCD) Catalogue, 7 previously unknown