WEIZMANN INSTITUTE OF SCIENCE

Triage of *Gaia* DR3 orbits

MW-Gaia WG 2/1 Hybrid Workshop

Naples, September 2022

Sahar Shahaf

Shahaf, Mazeh, Faigler & Holl, 2019

Shahaf, Bashi, Mazeh, Faigler, Arenou, El-Badri & Rix, 2022

TRIAGE

Classification scheme

The Astrometric Mass Ratio Function is a unitless quantity that can be derived for unresolved astrometric binaries. It provides a relation between the observables and the unknown quantities of the binary system.

Observables:

α_0, ϖ and P. We also assume that we can observationally constrain the mass, M_1.

$$\mathcal{A} \equiv \frac{\alpha_0}{\varpi}\left(\frac{M_1}{M_\odot}\right)^{-1/3}\left(\frac{P}{\text{year}}\right)^{-2/3}$$

Unknowns:

The mass ratio, $q = M_2/M_1$, and the flux ratio, $\mathcal{S} = I_2/I_1$.

$$\mathcal{A} = \frac{q}{(1+q)^{2/3}}\left(1 - \frac{\mathcal{S}(1+q)}{q(1+\mathcal{S})}\right)$$

Simultaneous constraints on the mass-ratio and intensity-ratio.

Shahaf, Mazeh, Faigler & Holl, 2019

TRIAGE

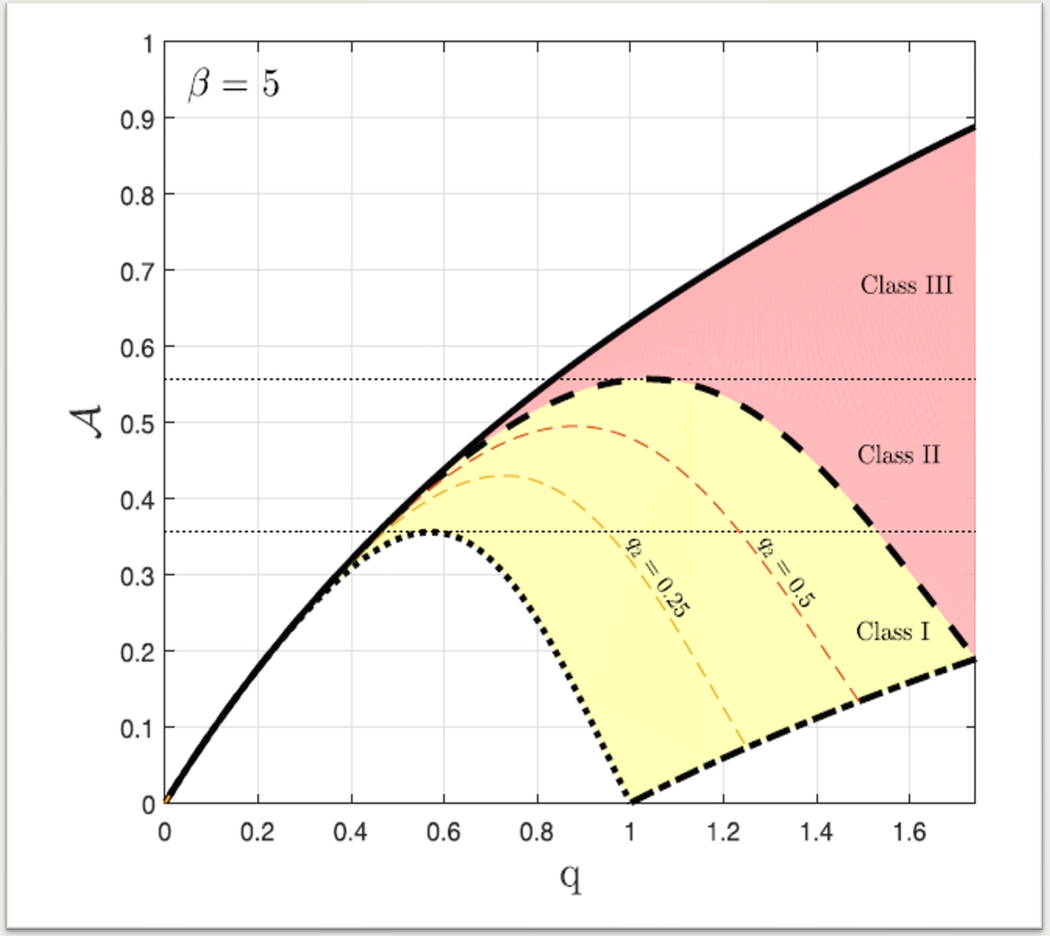
Classification scheme

$$\mathcal{A} = \frac{q}{(1+q)^{2/3}}$$

A fiducial model: $\mathcal{S} \equiv 0$

If a mass-luminosity relation can be modelled, the AMRF can be used to constrain the properties of the companion.

- **Class-I:** The secondary is probably a single MS star.
- **Class-II:** the secondary cannot be a single MS star. Probably a triple system.
- **Class-III:** the secondary cannot be a single MS star or a close binary of two MS stars. Non-luminous massive secondary.



TRIAGE

Classification scheme

$$\mathcal{A} = \frac{q}{(1+q)^{2/3}}\left(1 - \frac{\mathcal{S}(1+q)}{q(1+\mathcal{S})}\right)$$

A fiducial model: $\mathcal{S} \equiv {}^{I_2}/_{I_1} = q^{\beta}$

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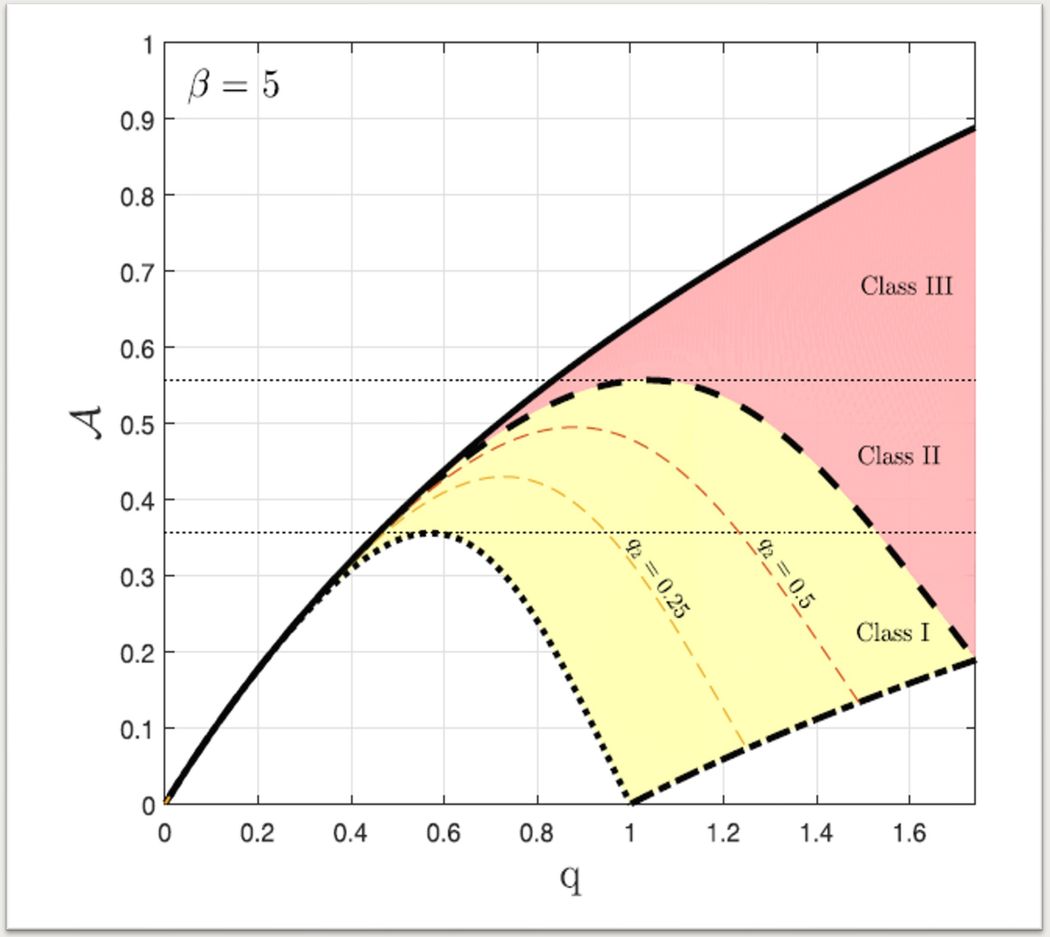
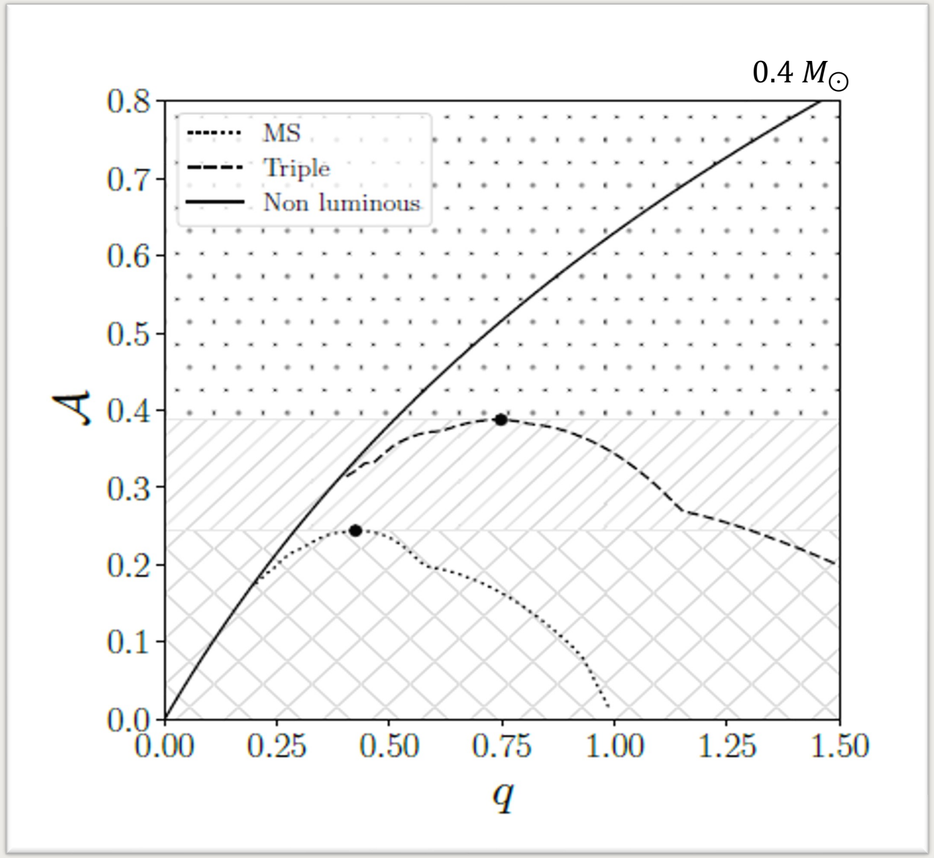
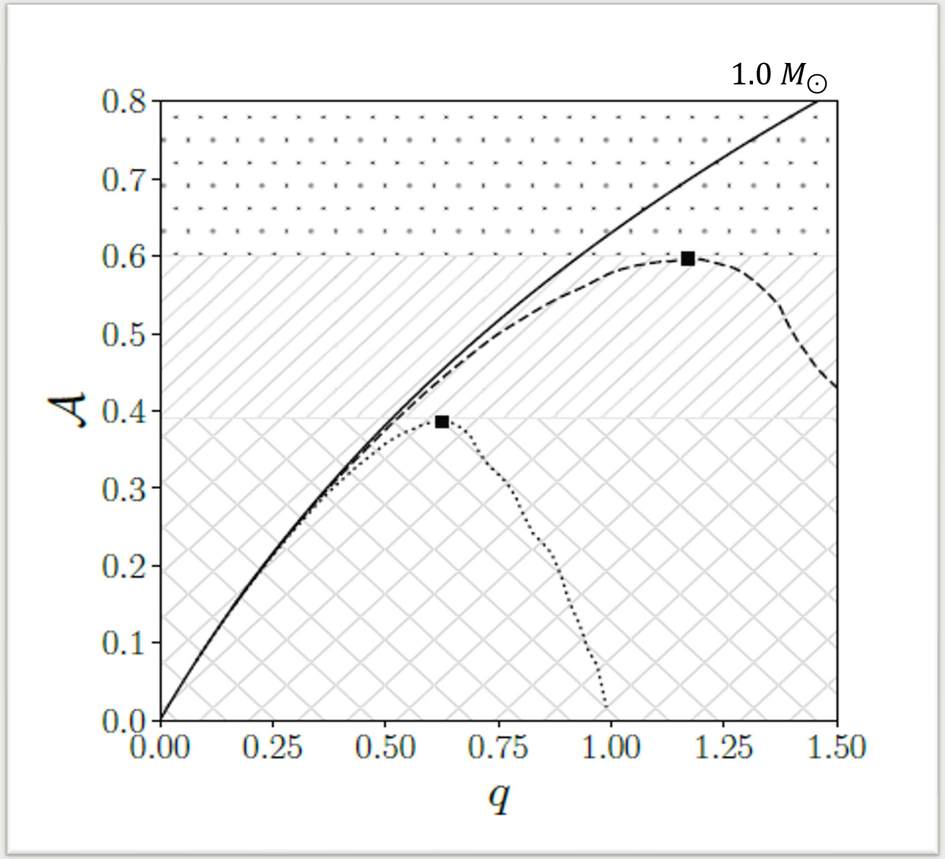


TRIAGE

Classification scheme

Realistic Main-sequence mass-luminosity relations are not a simple power law, and the result may depend on the primary mass.





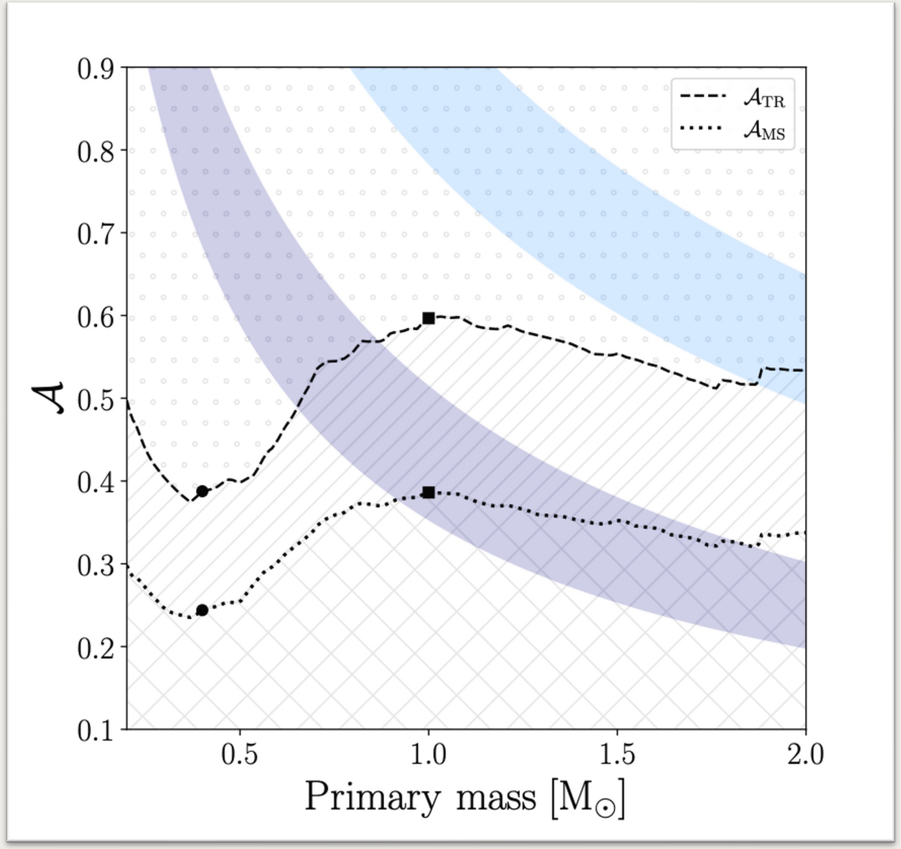
TRIAGE

Classification scheme

Realistic Main-sequence mass-luminosity relations are not a simple power law, and the result may depend on the mass of the primary star.

The classification limits, therefore, depend on the mass of the primary.

The ability to detect compact objects of different types also depends on the primary mass.



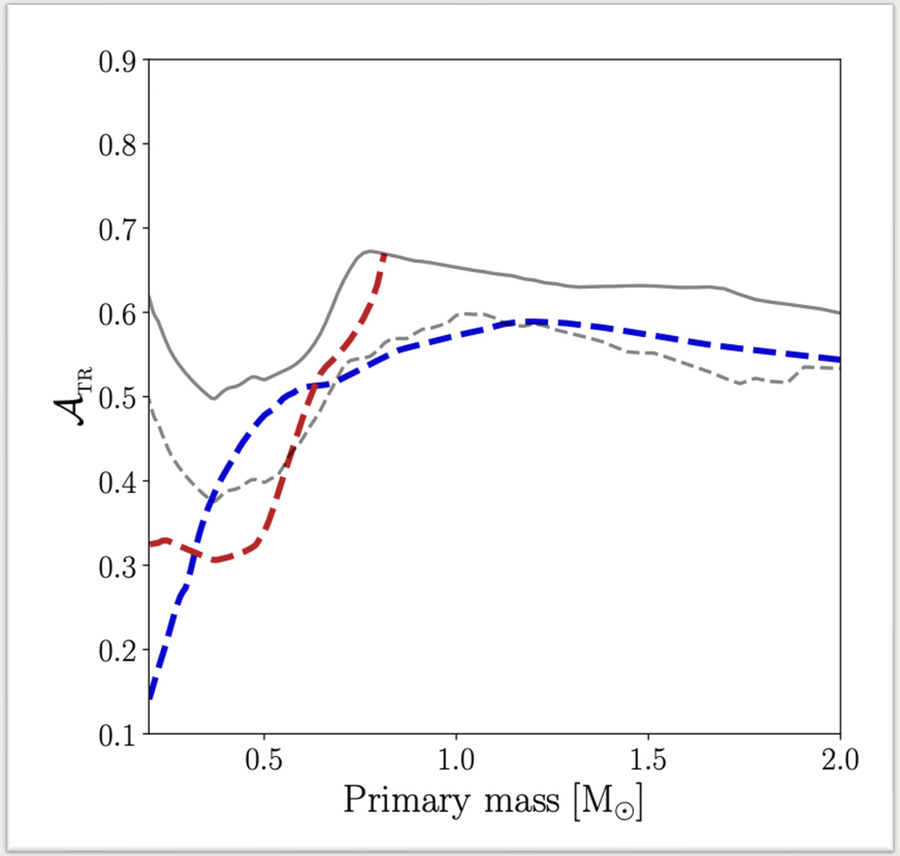
TRIAGE

Classification scheme

The components in the system probably formed together and have the same age and composition.

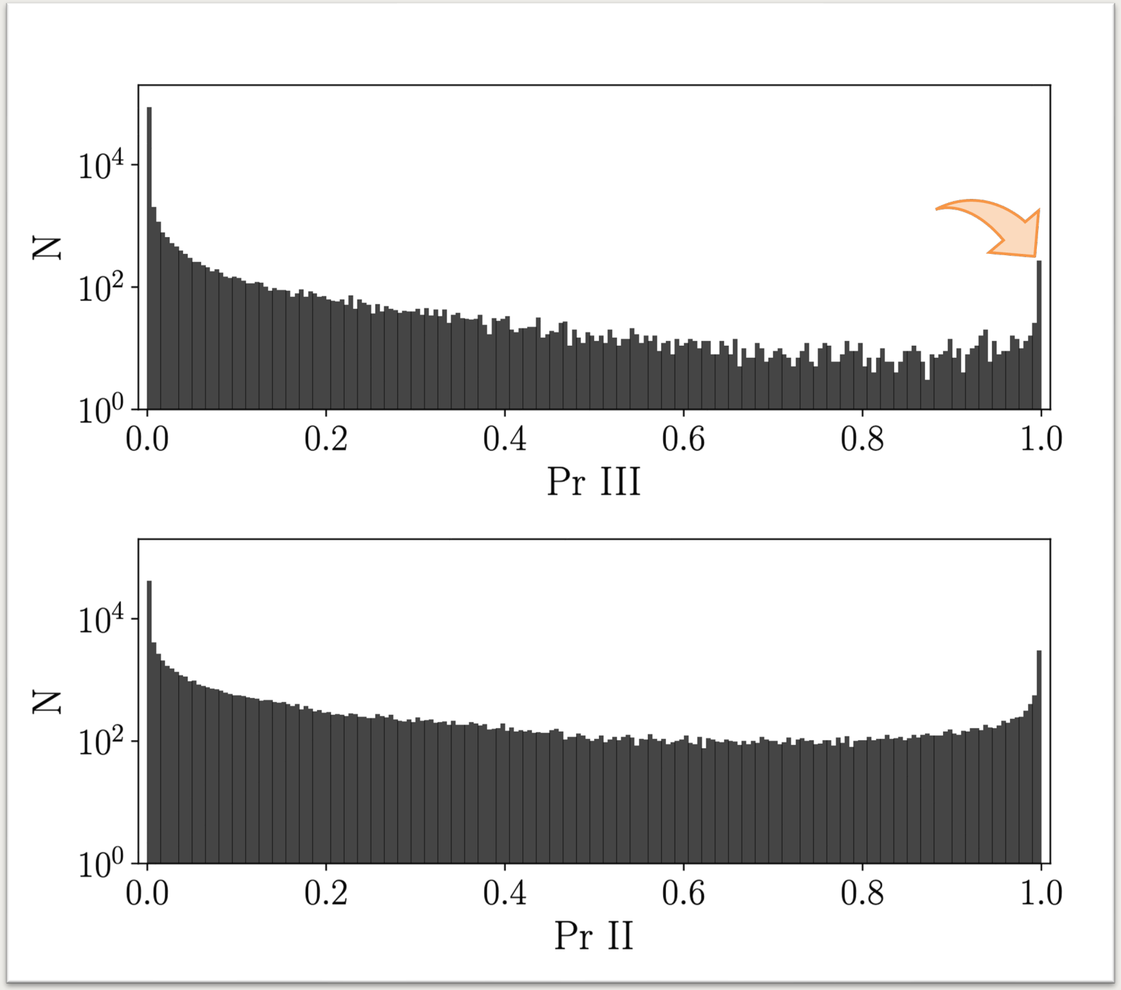
As a result, a general mass-luminosity relation is insufficiently accurate.

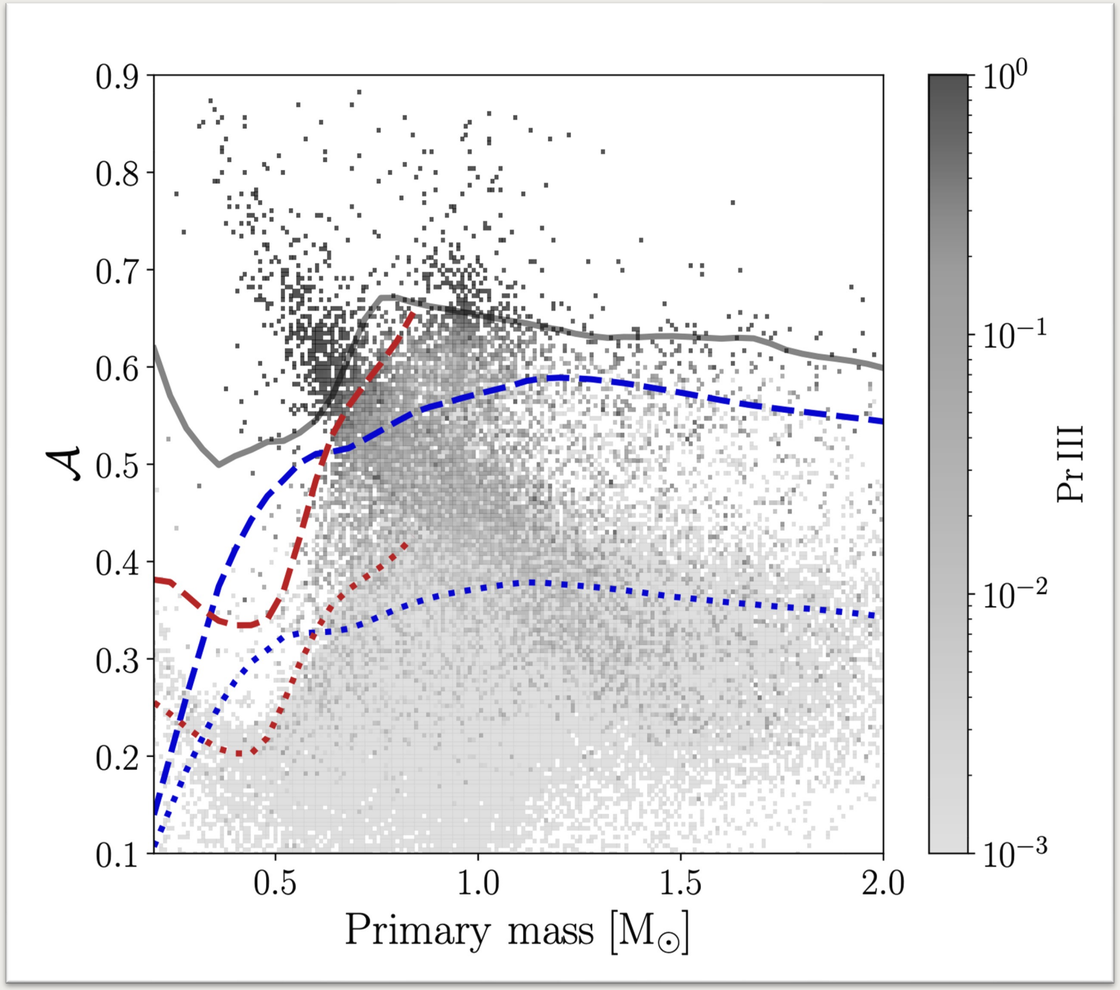
The classification limit depend on the mass, age and composition of the primary star.



Sample

Classification probability

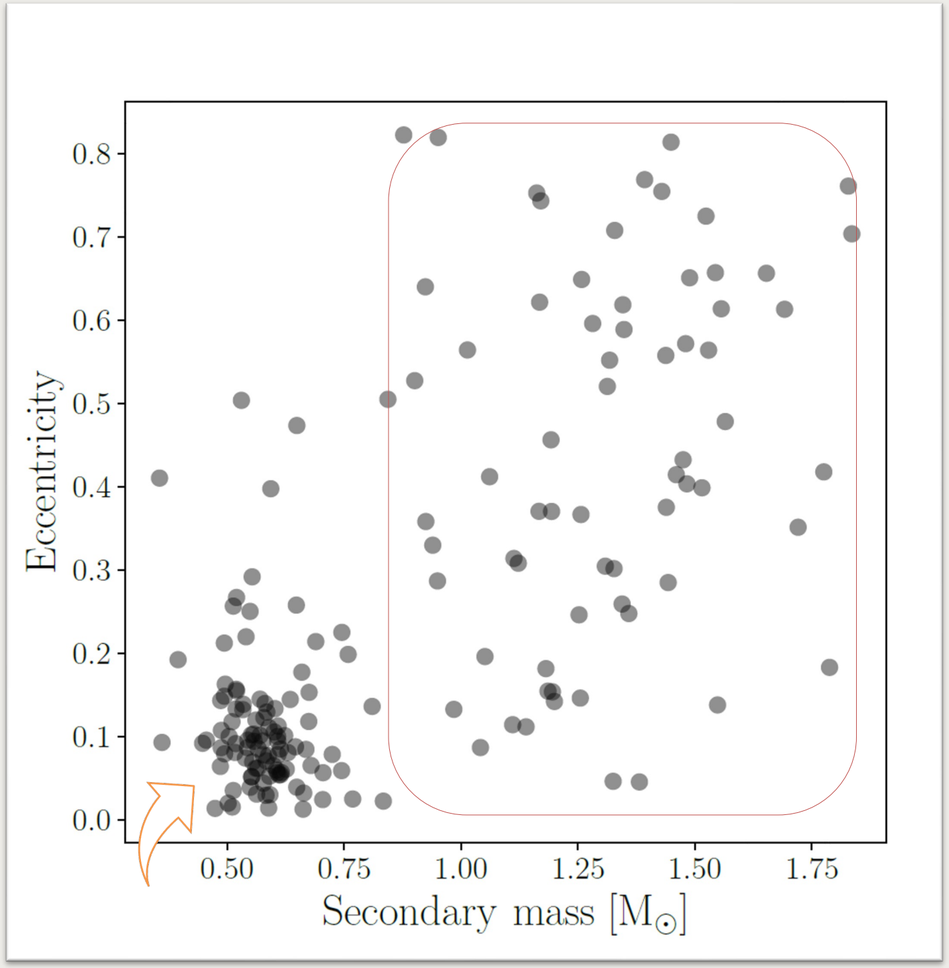


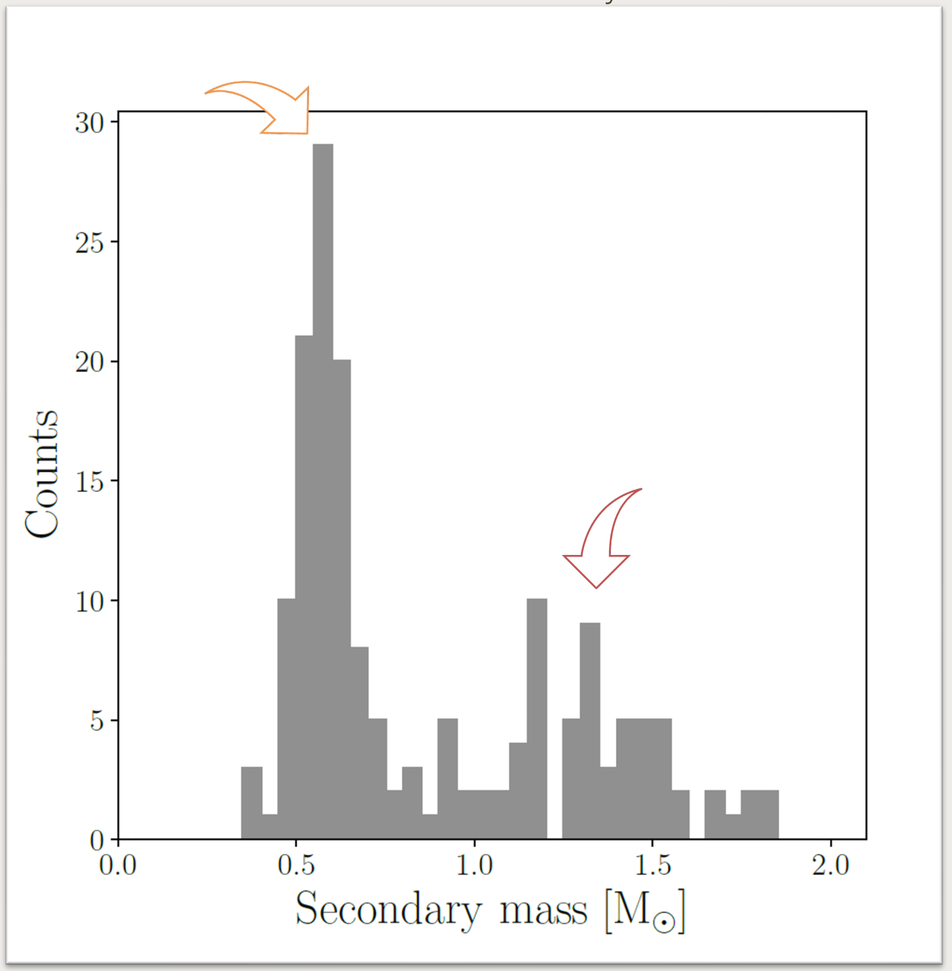


Compact objects

Sample properties

+ a few black-hole candidates...

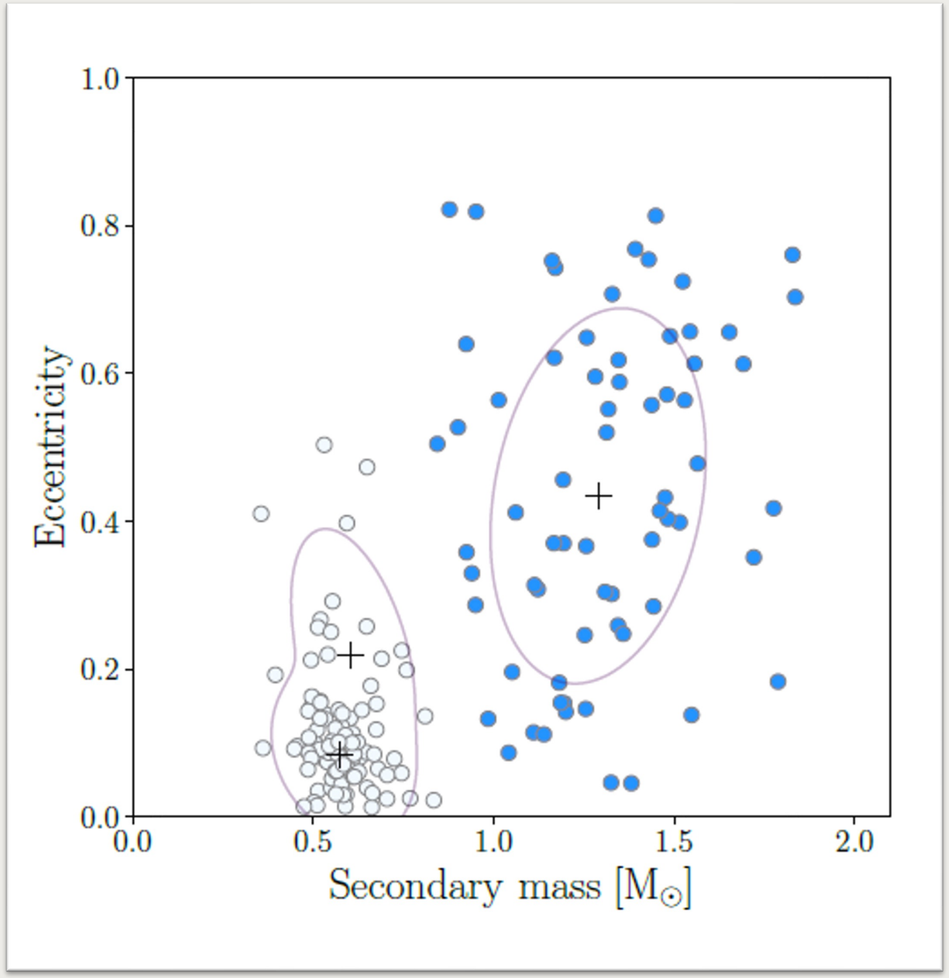


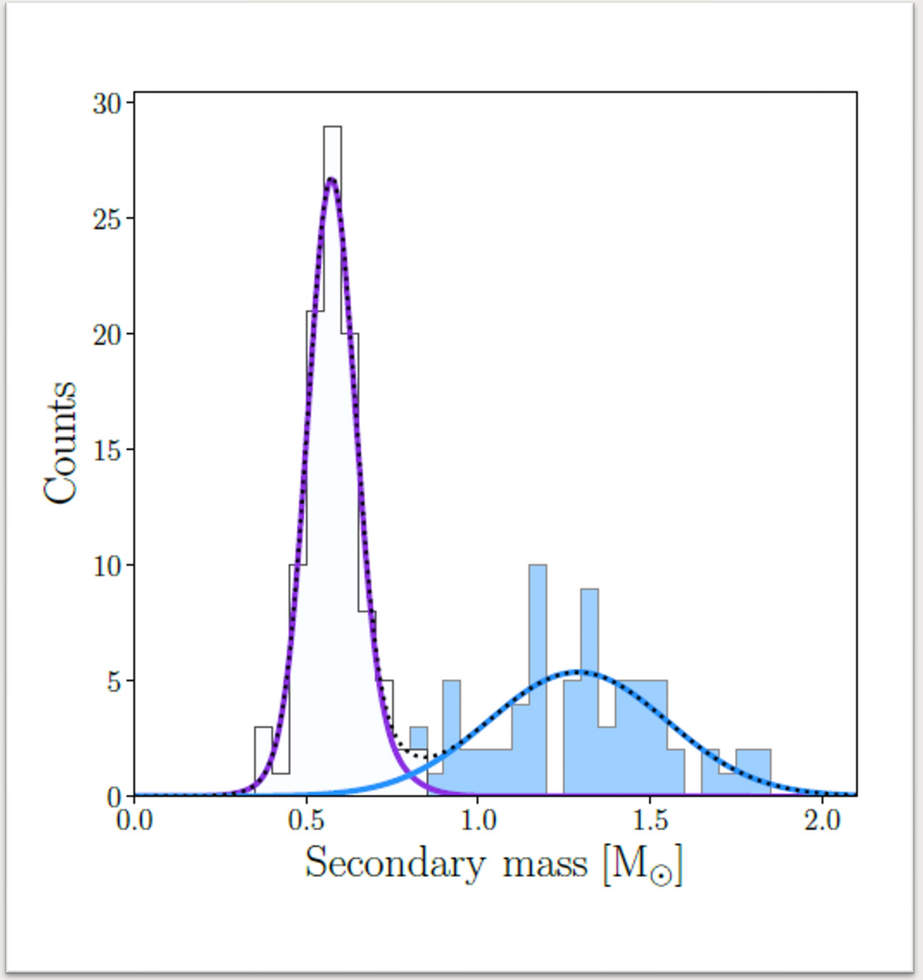


Compact objects

WD & NS

Tentative (and crude) division between WD and NS. WD have typical masses of $\sim 0.6 \pm 0.06\ M_\odot$ and eccentricities below ~ 0.1.

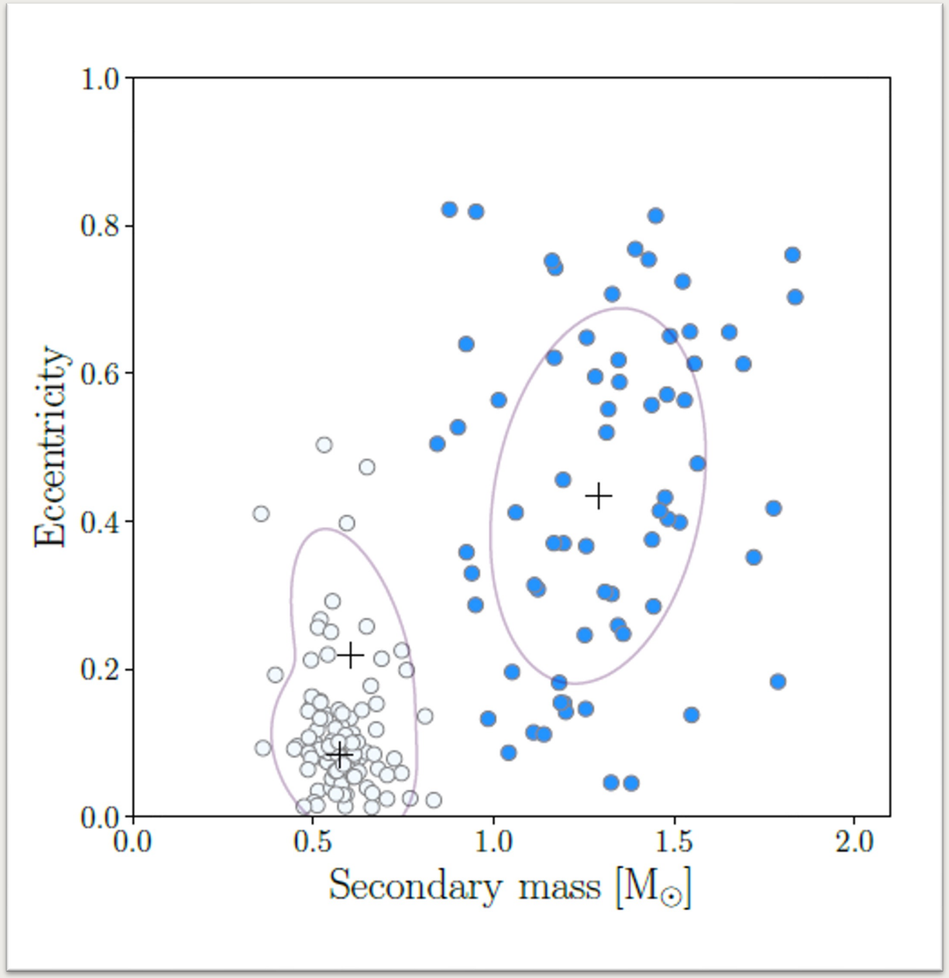


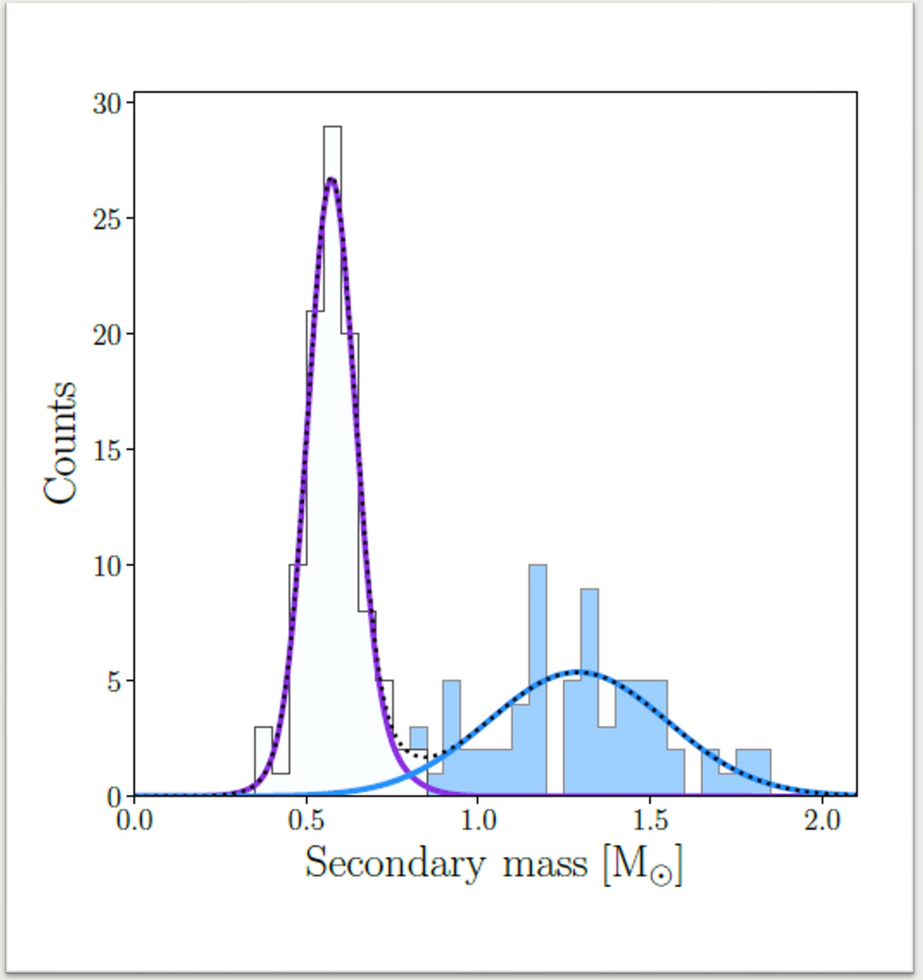


Compact objects

WD & NS

Tentative (and crude) division between WD and NS. NS have typical masses of $\sim 1.3 \pm 0.3\ M_\odot$ and cold have eccentricities a wide range of eccentricities.

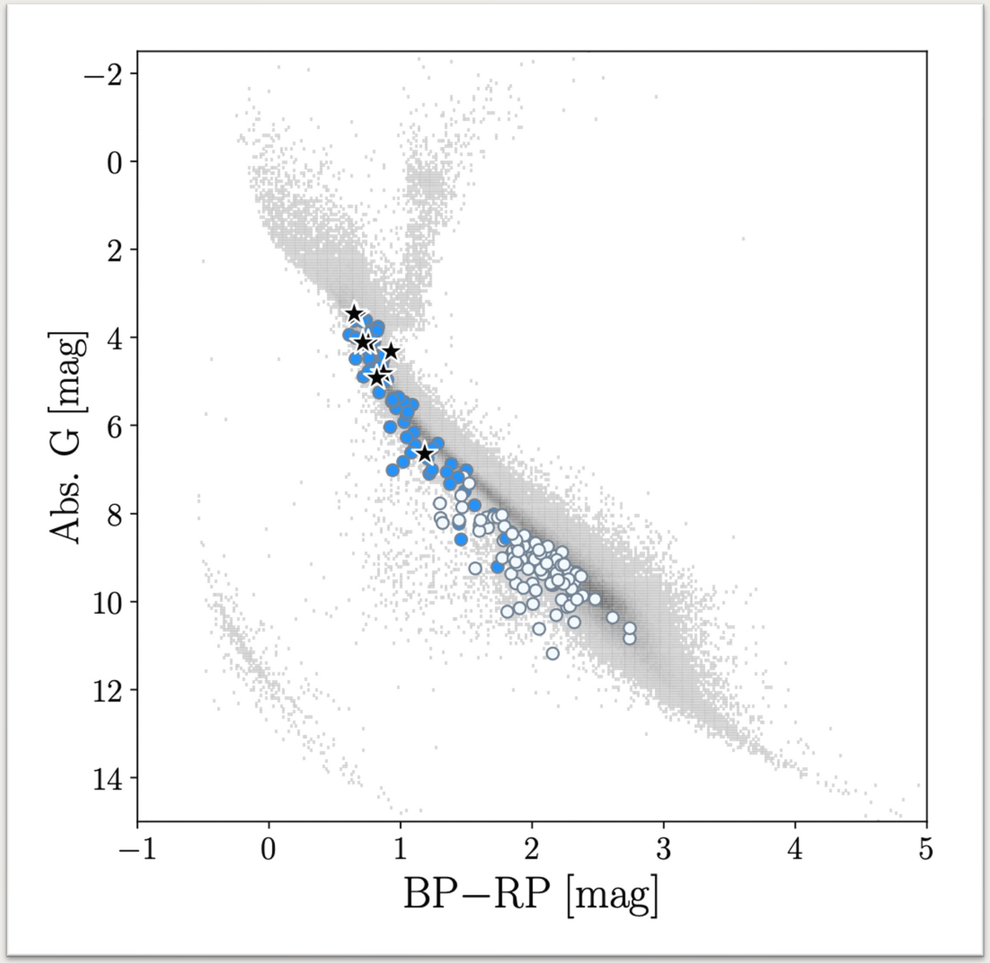


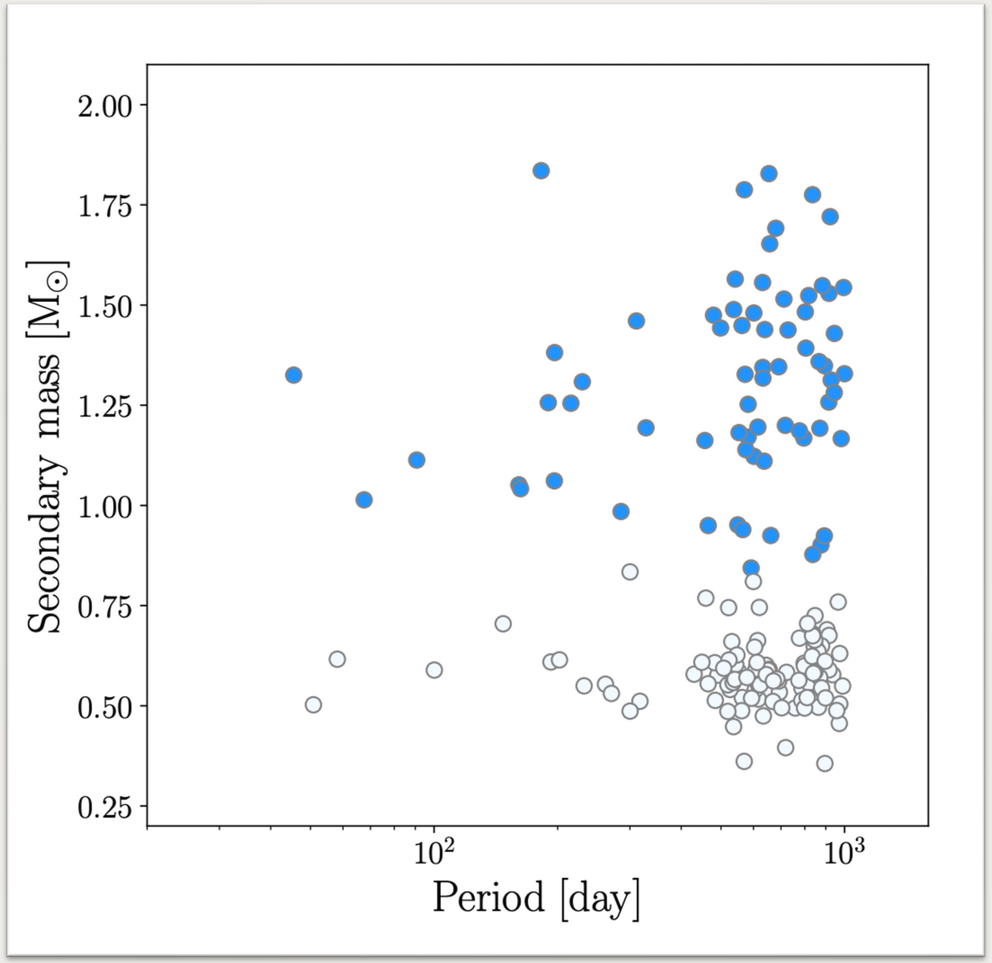


Compact objects

HR & mass-period diagrams

HR diagram is consistent with non-luminous companions but shows that in some cases our classification requires further consideration. There is a tentative upper envelope in the mass-period diagram.





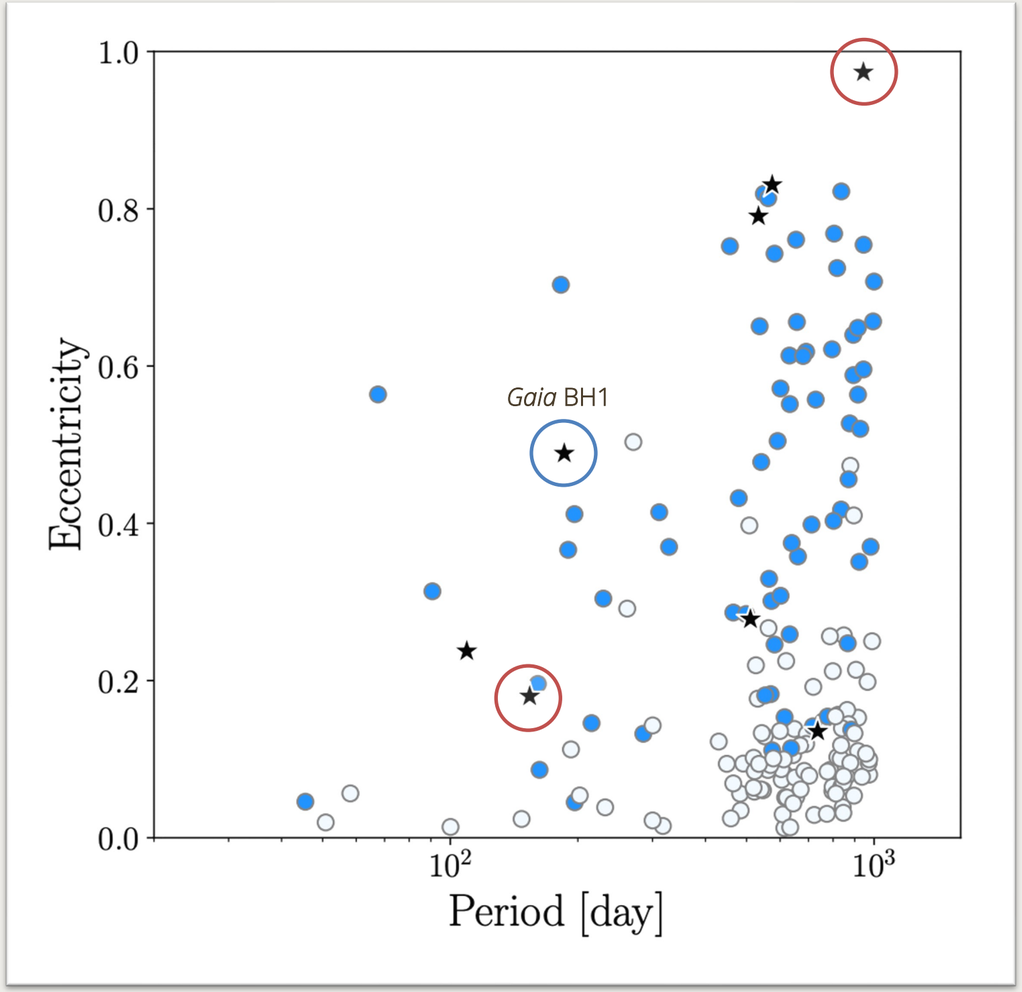
Compact objects

BH candidates

Out of the entire sample, we found 8 systems with masses larger than $\sim 2.4\ M_\odot$. We consider these as BH candidates.

Out of the eight targets, two were identified and followed up spectroscopically by El-Badry et al., 2022. One was found to be real BH+MS binary (Gaia BH1) and one was refuted by RV follow-up during the same campaign.

The other BH candidates are of $2.4 - 3.7\ M_\odot$ and require further validation. One system shows particularly high eccentricity and an orbital period consistent with the duration of Gaia DR3 temporal baseline.

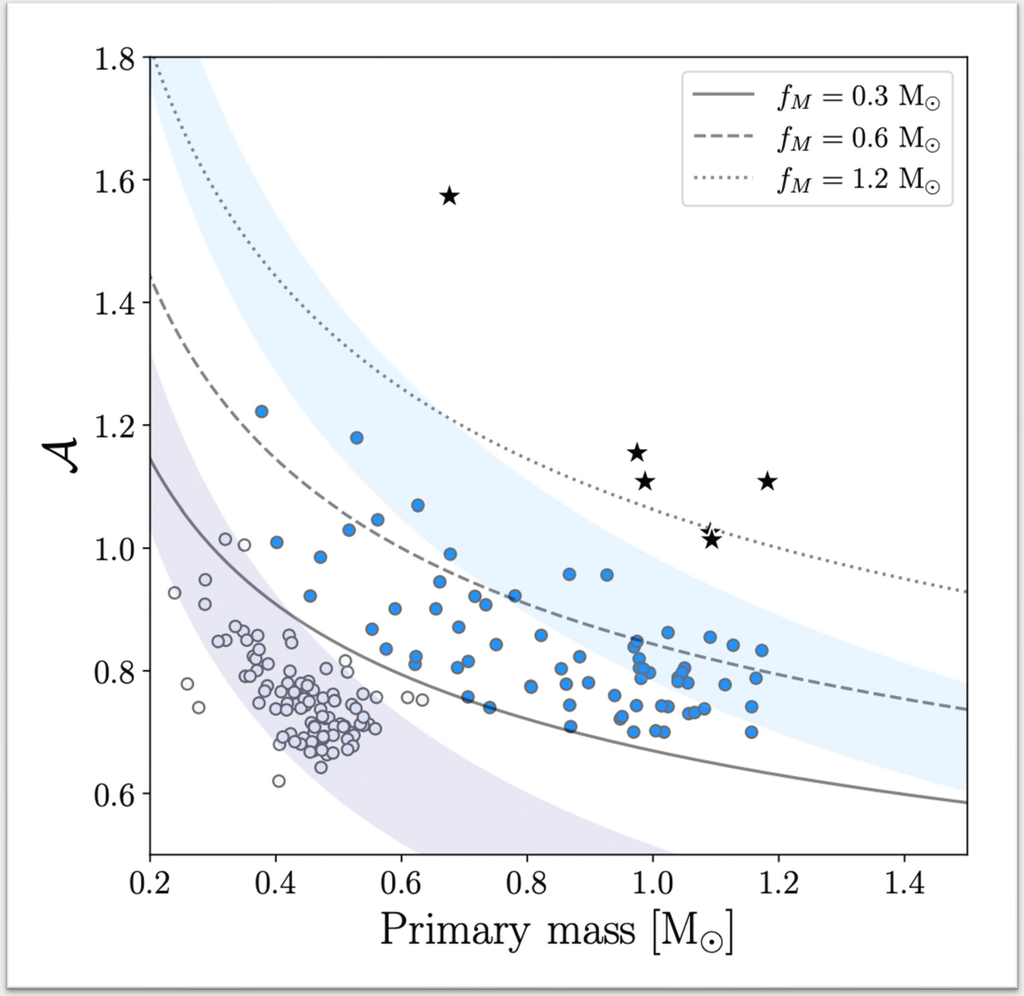


Compact objects

Selection effects

The resulting sample is biased:

- The Triage classification scheme is inherently biased, since the classification limits depend on the mass of the primary star.
- The selection scheme of Gaia DR3 binaries probably could, implicitly, bias the companion mass distribution.
- The timespan of observations analyzed in DR3 limits the detection of orbits longer than ~3 years. On the other hand, the detection of binaries in relatively short periods could be limited by properties and the spacecraft.



Summary

& future prospects

- **Using the astrometric triage scheme, we identified a sample of 177 binaries that are likely to have a compact object as a faint companion.** The sample includes 8 black-hole candidates. One candidate, Gaia BH1, was identified and confirmed by El-Badry et al. (2022).

- **The astrometric triage method enables the detection of compact objects with lower mass**. For G-type primaries or earlier – it enables the detection of NSs and WDs. However, for massive primaries it might be important for the detection of BHs.

- ***Gaia* provides empirical constraints* on the mass, eccentricity and period distribution of WDs and NSs.** These samples can be used to probe processes of WD and NS formation. The orbits and WD\NS classification require further validation.

- **There are additional MS+WD binaries in the sample that were identified as class-II binaries.** We currently extend the search, building an extended list of wd companions (in prep).

- What should we expect from *Gaia* DR4?

Thank you