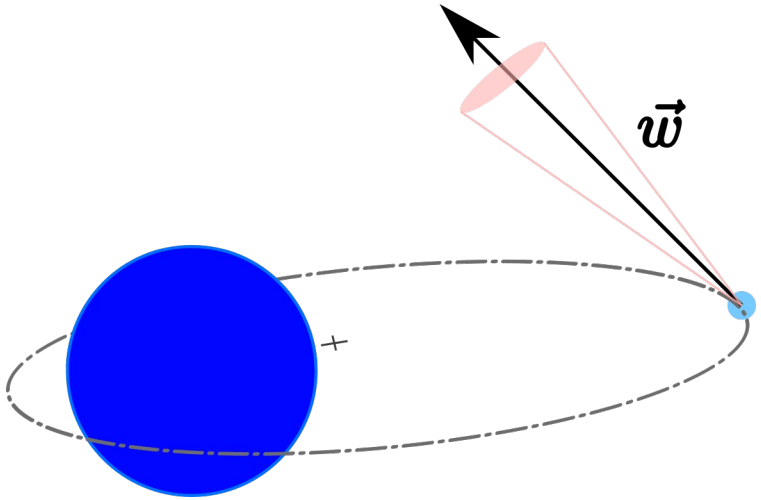
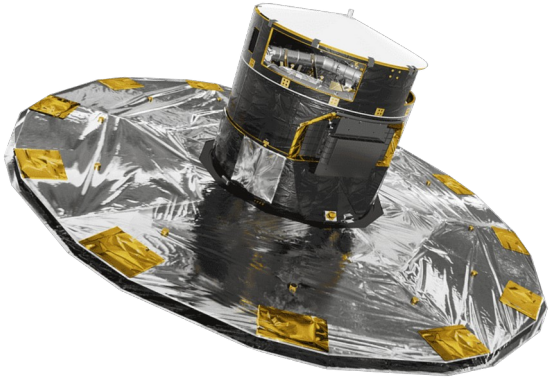
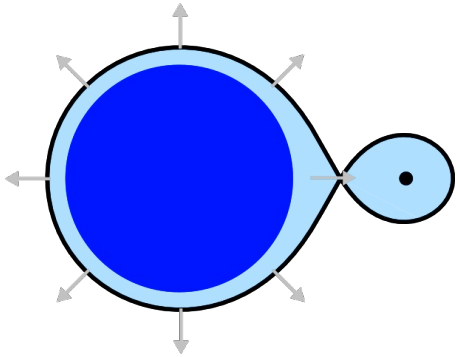
Constraints to neutron star kicks in High-Mass X-ray binaries with Gaia EDR3



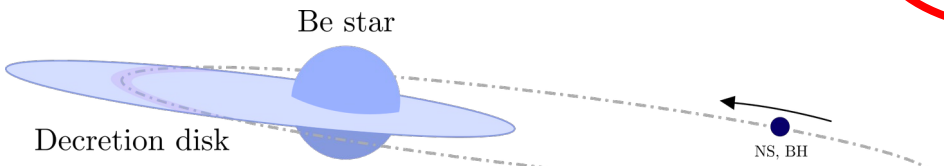


F. Fortin, F. Garcia, S. Chaty, E. Chassande-Mottin & A. Simaz-Bunzel, A&A 2022a

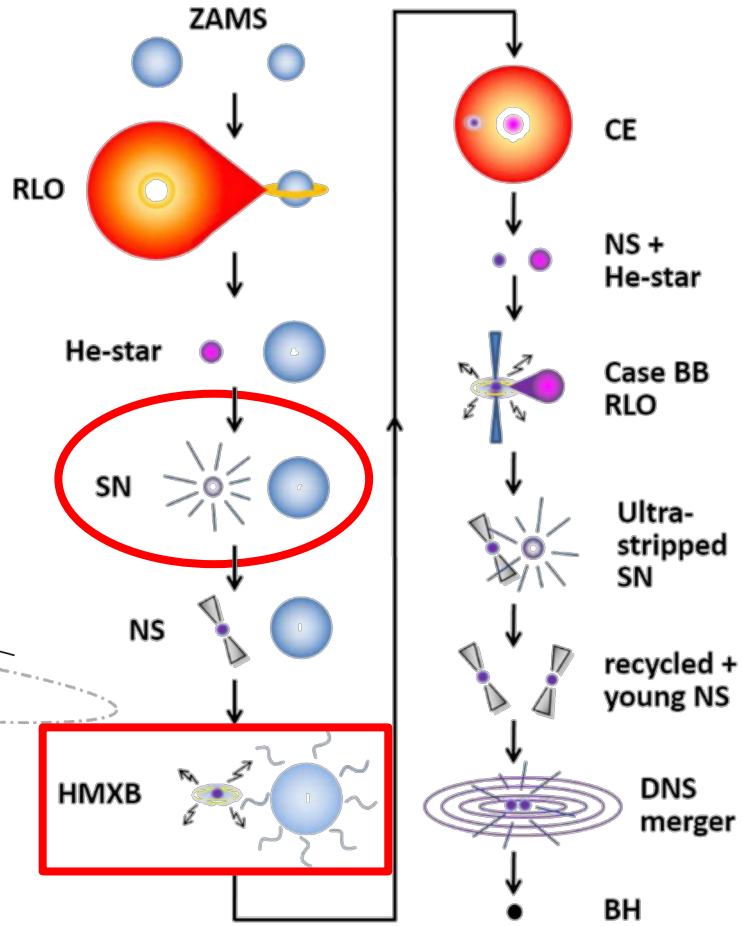
Evolution of High-Mass X-ray binaries



Wind Accretion



Decretion



Tauris+2017

Survival rate ?

Impact on orbit ?

Natal kicks – State of the art & Aims

→ Analytical solution of its impact on orbital parameters in binaries (Kalogera 1996)

→ Cir X-1 velocity & orbit explained by massive natal kick of ~500 km/s (Tauris+1999)

→ Black Hole X-ray binary with high runaway velocity (Mirabel+2002)

→ Isolated pulars: preferential direction of the kick wrt spin ? (Ng & Romani 2013)

→ Natal kick derived on an HMXB with the Australian LBA radio interferometer (Miller-Jones+2018)

→ Radio interferometry + Gaia DR2  to derive kick on 16 BH X-ray binaries (Atri+2019)

Kicks are still misunderstood, most studies tackle a single source in the case of binaries

→ Infer the NS kick magnitude in known HMXBs of our Galaxy

→ Use of astrometric data from Gaia EDR3

→ Characterize the NS kick distributions across HMXB subtypes

Pre-requisites

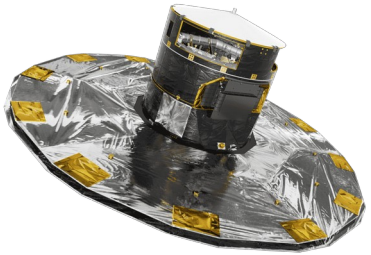
i) Build a list of HMXBs known in the Milky Way

- cross-match between old HMXB catalogue (Liu+2006) with current INTEGRAL sources (Bird+2016)
- cross-match with Simbad (Centre de Données astronomiques de Strasbourg)
- some candidate HMXBs in previous catalogues are now confirmed/discarded
- retrieve exact references for spectral type, mass, period, eccentricity, radial velocity (1D)

ii) Find the Gaia counterparts of those HMXBs & retrieve position (3D) and proper motion (2D)

→ 6D data (position + proper motion + radial velocity)

Peculiar Velocity = Velocity – Galactic orbital motion



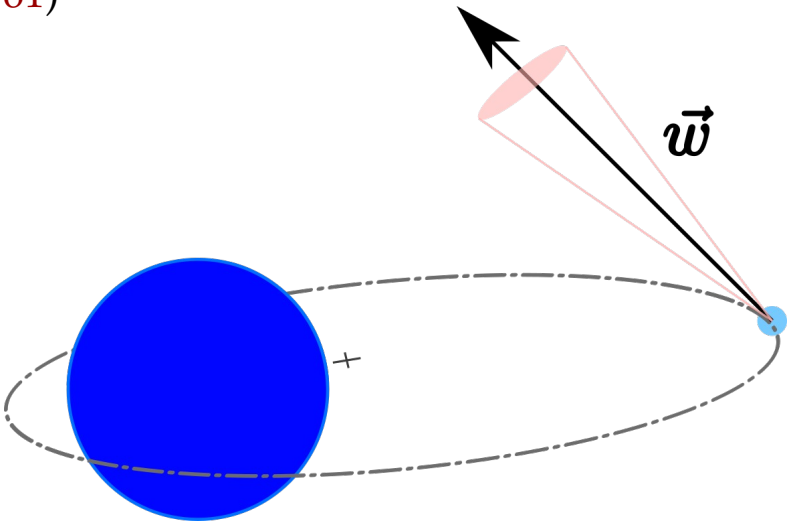
Deriving neutron star kicks

Analytical equation linking pre-SN to post-SN orbital parameters (Kalogera 1996), assuming an **isotropic probability of the kick direction**.

- Blaauw kick (spherically symmetric mass loss, Blaauw 1961)
- Asymmetric kick (random direction)

Hypotheses:

- circularized systems Dosopoulou & Kalogera 2016
- fixed NS mass @ $1.4M_{Sun}$ Kiziltan+2013
- companion is unaffected by the supernova Liu+2015

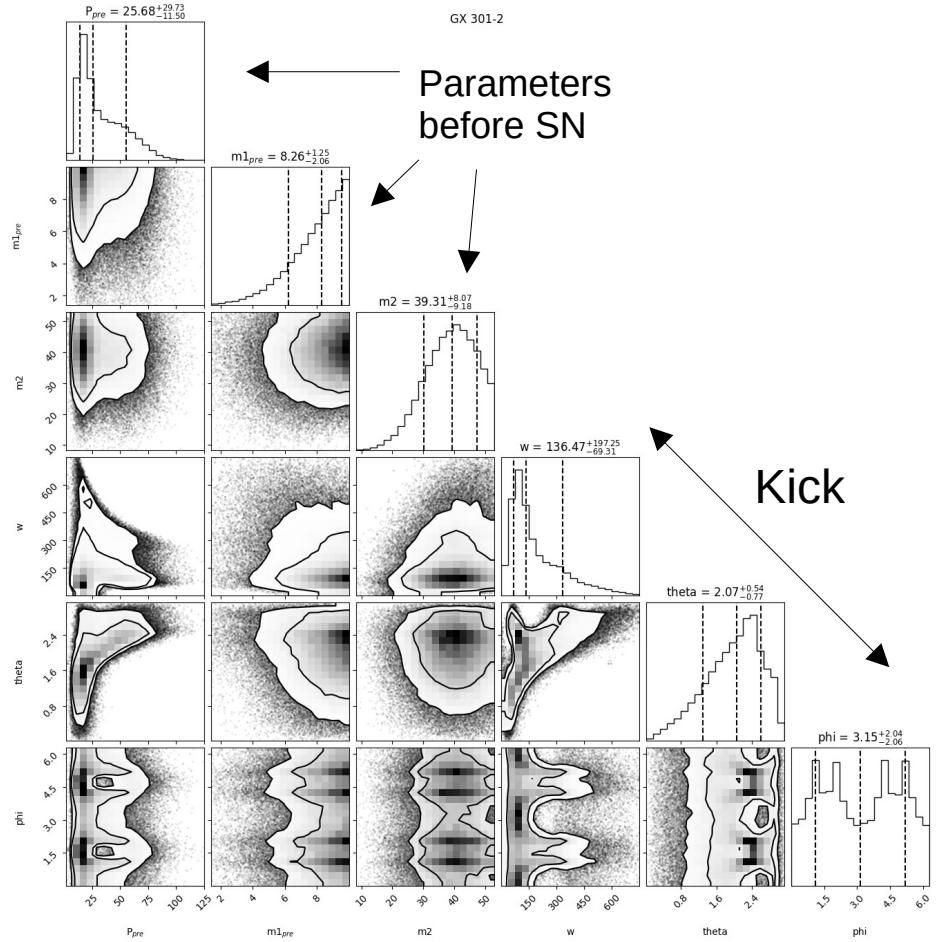


Deriving neutron star kicks

Bayesian approach:

- Priors on kick magnitude, initial P_{orb} and pre-SN mass
- Likelyhoods: Gaia observables, companion mass, P_{orb} & eccentricity

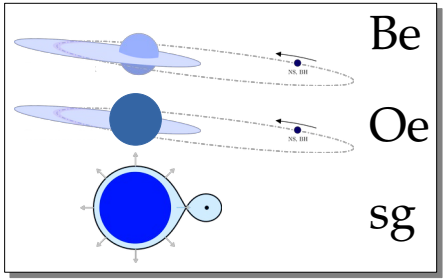
→ Explore the posterior distributions using Markov Chain Monte Carlo (MCMC)



Inferring kick distributions on HMXB subtypes

We have a posterior probability of kick velocities for each 35 HMXBs.

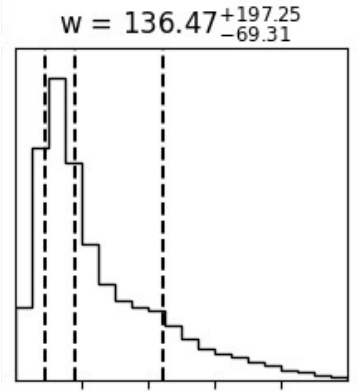
→ How can we characterize the kick distributions on each HMXB subtypes ?



To get a representative distribution, we use a bootstrap method:

- for each HMXB, draw a random kick velocity according to its posterior probability
- 1 bootstrap iteration is a collection of those random draws, effectively one possible posterior for the whole HMXB subtype population in question
- iterate 1000 times

→ Fit each posteriors with a Gamma function, retrieve median parameters.



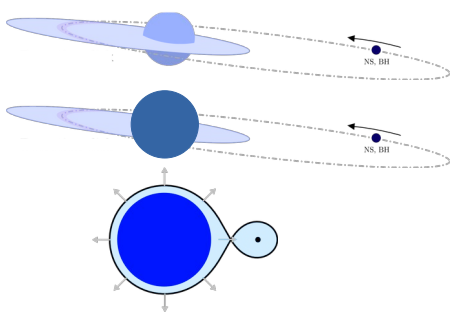
Results on kick distributions

Inferred kick magnitudes on 35 HMXB :

17 Be

8 Oe

10 Sg

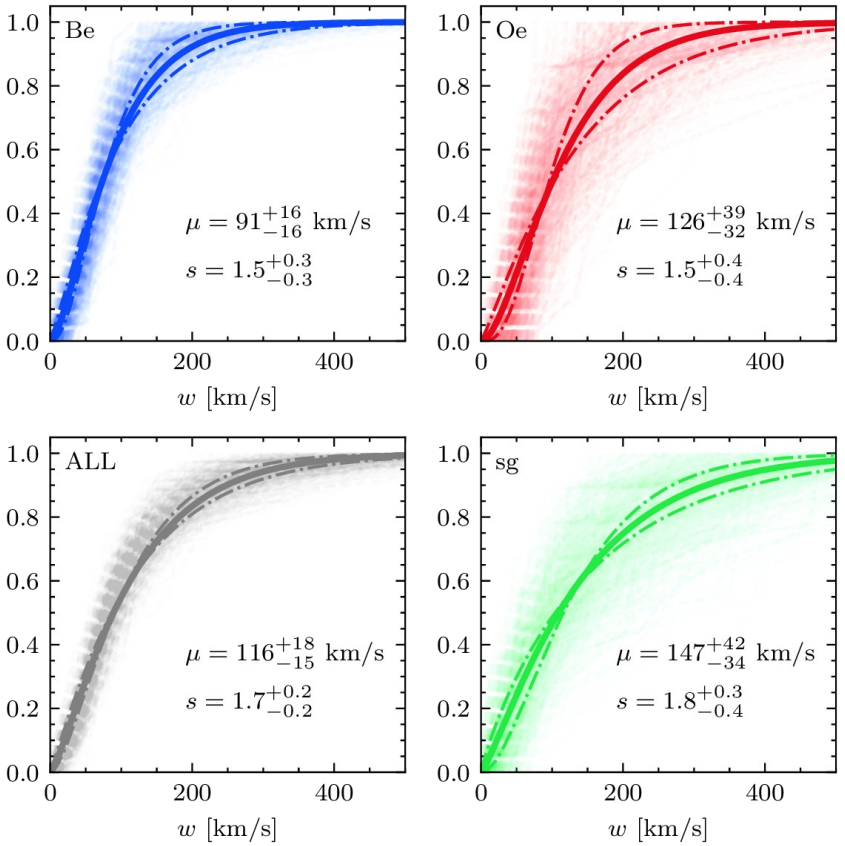


→ Kicks are reproduced with Gamma functions

→ More low-kick contribution

Disrupted systems, stripped progenitors...

Cumulative distributions of kicks



Disrupted systems, isolated NS velocities

Tauris & Takens 1998 : equations for velocity of a NS kicked-out of the binary after the SN event

Observed velocity distribution of isolated radio pulsars :

Hobbs+2005 → **265 km/s**

Igoshev 2020 → **230 km/s** (or 146 + 317 km/s)

We keep track of disrupted systems (5 to 50% of simulation outcomes depending on the binary)

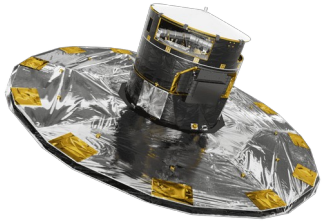
→ NS velocity from disrupted systems in our sample : **110 km/s**

→ In case of disruption, < 3% result in fast pulsars (> 500 km/s, large initial period > 1000 d required)

→ Binary evolution unlikely to be a formation channel for fast isolated NS.

Take away message

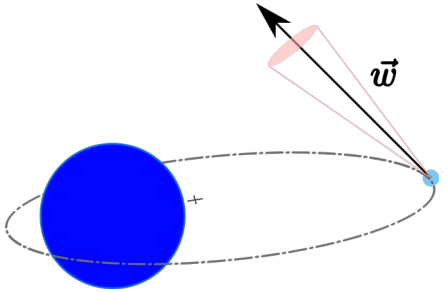
Neutron star kicks in 35 galactic HMXBs thanks to Gaia astrometry.



→ Might be of interest for :

- NS populations (isolated & in binaries)
- Supernovae explosions (CCSN vs ECSNe)
- ...
- and of course the formation channels of compact mergers

Population of GW mergers ↔ currently known X-ray binaries ?




Thank you for your attention !

Prospects: Gaia DR3 & the birthplace of HMXBs

- Upcoming release(s) of Gaia

→ Gaia DR3 improvement over EDR3: addition of astrophysical parameters & some RVs

→ No additional source, no improvement on astrometry

→ Full release TBD, extra sources with more constrained astrometry.

- Finding the birthplace of HMXBs in the Galaxy (Fortin et al. A&A 2022b)

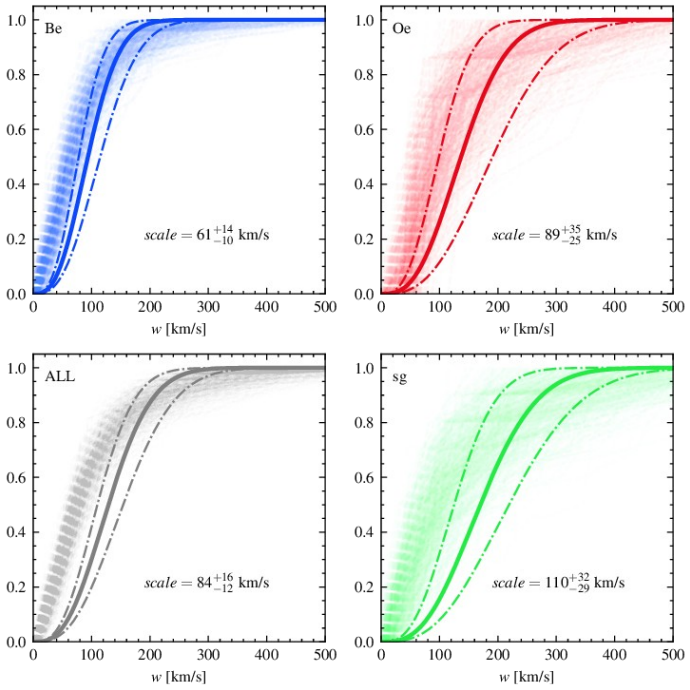
→ We have the peculiar velocity of HMXBs

→ If they are born within clusters, we could find them in Gaia → get their peculiar velocity

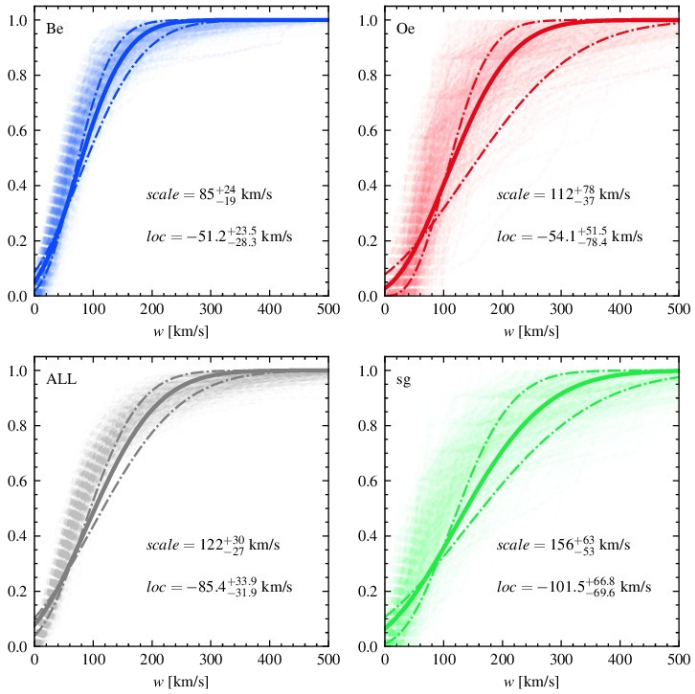
→ Integrate orbits over ~Myr to find candidate birthplaces for Galactic HMXBs.

Extra: Maxwellian vs. Gamma

Maxwellian is historically used to model kicks in isolated pulsars (Hobbs+2005, Ng & Romani 2007, Noutsos+2013)



Classical Maxwellian



Shifted Maxwellian

Unbound systems ?

→ observed vs. pop synth.

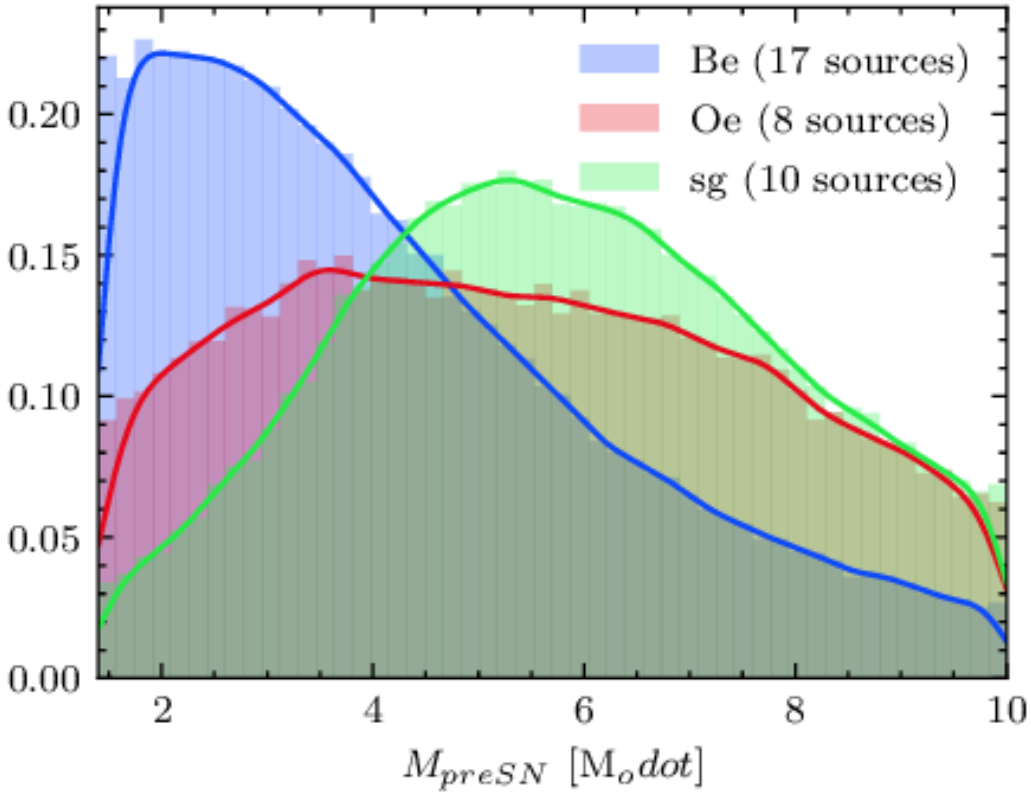
Stripped progenitors ?

→ lower pre-SN mass

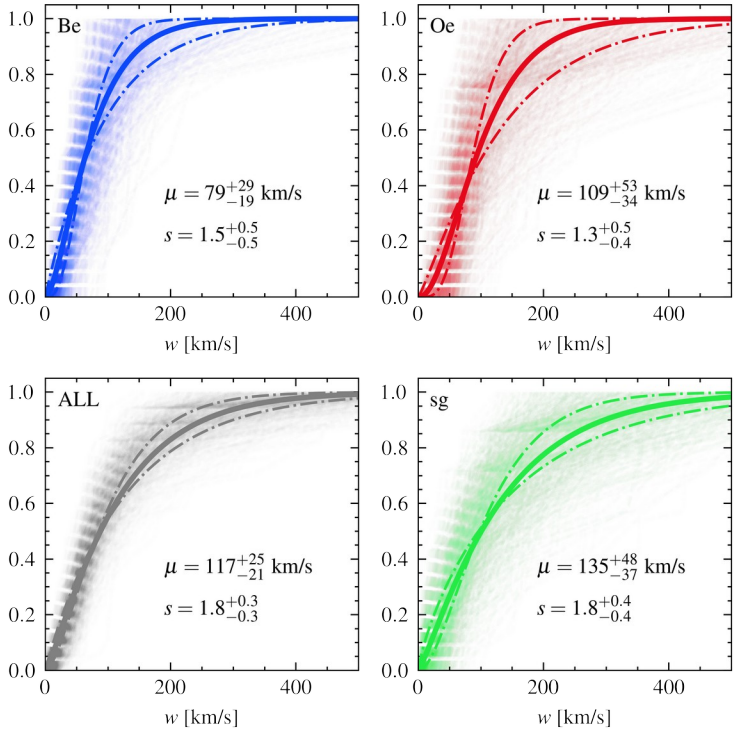
Kick isotropy ?

→ NS spin axis

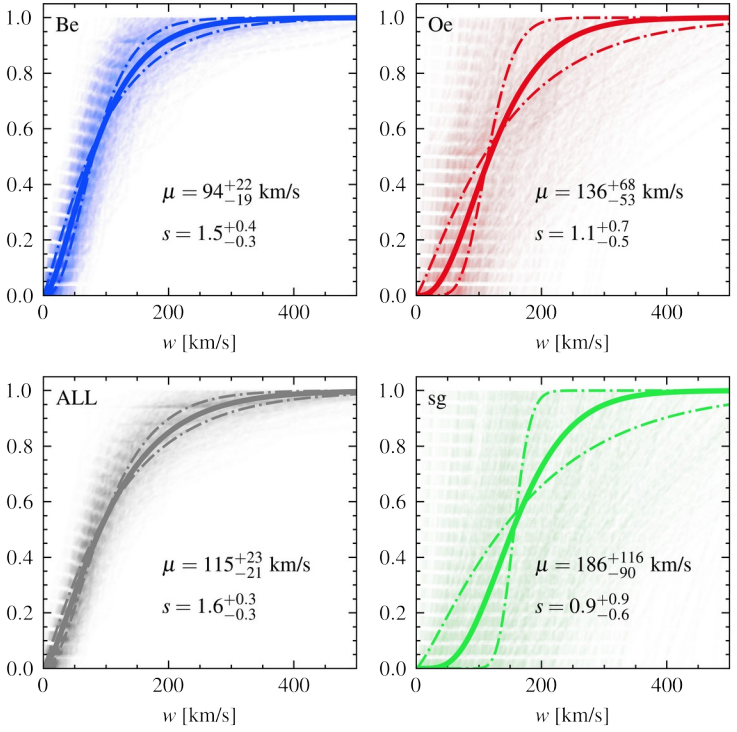
Extra: $M_{pre\text{-}SN}$ distribution



Extra: impact of missing radial velocity



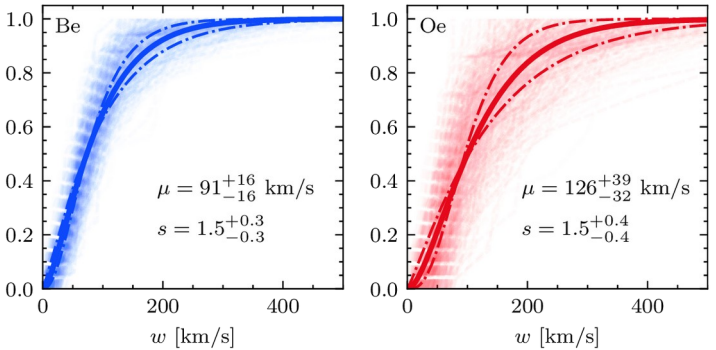
With RV only



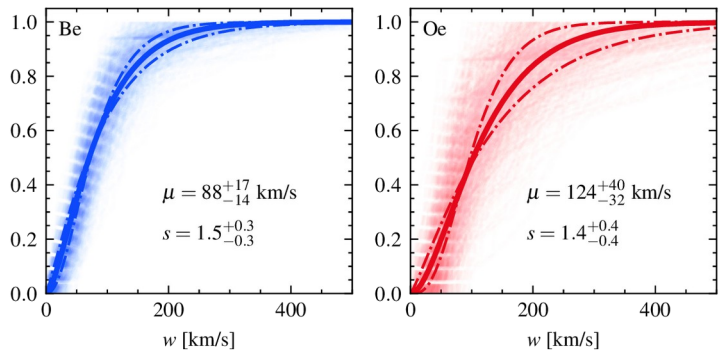
Without RV only

Extra: impact of neutron star mass

→ Assumed constant NS mass of 1.4 Msun, what about more massive NSs ?



$M_{NS} = 1.4\ M_{Sun}$



$M_{NS} = 1.8\ M_{Sun}$

No notable difference on the fitted parameters

→ NS mass variation are much smaller than $M_{pre\text{-}SN}$ uncertainty

Extra: building the list of HMXBs

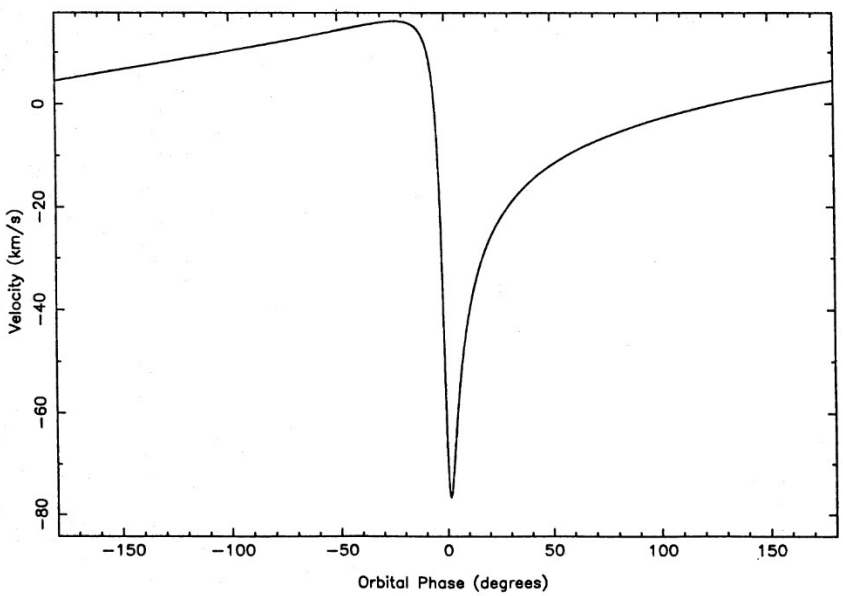
Example: PSR B1259-63

Radial velocity followup of the Oe companion star

→ Curve is presented but no value of the systemic velocity is given in the paper !

→ WebPlotDigitizer: we retrieved the data from the plot and fitted the systemic velocity

→ Do that for 130 HMXBs in the Galaxy.



Radial velocity of PSR B1259-63 (Johnston+1994)