Natal Kicks of stellar-mass Black Holes

Serena Repetto[1,2], Melvyn B. Davies[2], Steinn Sigurdsson[3]

[1]Department of Astrophysics/IMAPP, Radboud University Nijmegen

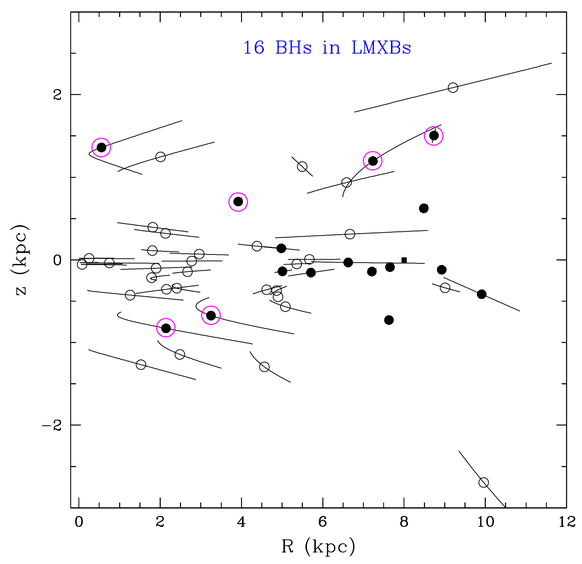
[2]Lund Observatory, Department of Astronomy and Theoretical Physics, Lund University

[3]Department of Astronomy & Astrophysics, Pennsylvania State University

Abstract

The case for neutron stars receiving a natal kick at birth has long been established. Do black holes born in core-collapse supernovae receive these natal kicks too? And if so, are these kicks of comparable size of neutron star natal kicks? By studying the orbit of a black-hole binary, or even its location within the Galaxy, one might obtain a limit on the range of allowed natal kicks. We perform population synthesis calculations of Galactic low-mass X-ray binaries harboring a BH, applying both kicks due to the supernova mass-loss and natal kicks to the newly-formed black hole. These binaries will then orbit in the Galactic potential and their positions will be a function of the natal kick at birth.

The observed population of BH low-mass X-ray binaries



Black holes can be studied via interacting low-mass X-ray binaries which contain them. In these systems, the massive primary has evolved to form a BH via a core-collapse supernova and material is currently flowing from the lower-mass secondary onto the black hole via an accretion disc. A number of observed BH-LMXBs are found in excess of 1 kpc from the Galactic disc.

- Is the mass-loss kick enough or a natal kick is required for the binary to reach the current position?

Effect of the Supernova on the Galactic dynamics

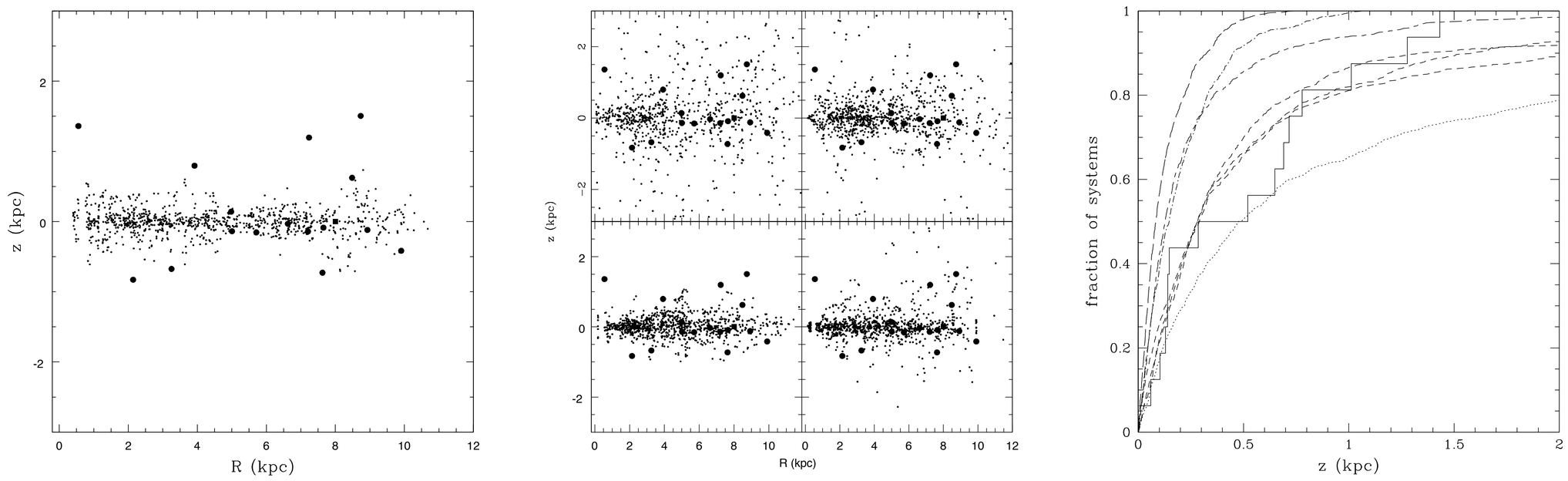
When the primary explodes as a supernova, the mass loss from the system can unbind the binary or at least give it a kick (so-called *mass-loss kick*). In addition, any *natal kick* (NK) received by the black hole will add to the mass-loss kick, affecting the binary orbit within the Galaxy.
BHs are thought to be formed via fall-back of material onto the proto-neutron star. We investigate two types of scenario for the BH natal kick:

- Full natal kick, when $\tau_{fb} \lesssim \tau_{nk}$:
  the BH receives the same NK as neutron stars
- Reduced natal kick, when $\tau_{fb} > \tau_{nk}$:
  the NK is reduced by the ratio M_{NS}/M_{BH}

A synthetic population of BH low-mass X-ray binaries

- We build a synthetic population of BH binaries taking average binary properties
- We populate the thin disc of the Galaxy taking as weighting factor the stellar surface density
- We impart the binary a velocity with respect to the Galactic rotation. This velocity is the combination of the mass-loss kick and of the natal kick (both full and reduced) to the black hole. We choose two types of NS natal kick distribution, one picked at 300 km/s, the other picked at 100 and at 700 km/s.
- We integrate the trajectories of the binaries in the Galaxy
- We compare the synthetic Galactic distribution with the observed one

Results: Galactic distribution of BH-LMXBs as a function of the Natal Kick



Left: no natal kick has been imparted to the BH. Bigger dots correspond to the observed systems, smaller ones to our simulation.
Middle, top panels: full natal kick imparted to the BH from the two different neutron-star natal kick distributions; bottom panels: corresponding reduced NKs.
Right: fraction of binaries that at some time over the trajectory are located at a distance z from the plane. Both a zero NK and a reduced NK (upper three lines) are clearly worse fits.

Conclusions

We find that natal kicks are necessary to reach the large distances above the Galactic plane achieved by some binaries. In addition, we find that the simulated Galactic distribution of BH-LMXBs is most similar to the observed one when the black-hole natal kicks are drawn from *the same velocity distribution as for neutron stars*, rather than one where the kick velocities are reduced by the ratio of black hole to neutron star mass (i.e. where the kicks have the same momentum). This result is somewhat surprising; in many pictures of stellar-mass black-hole formation, one might have expected black holes to receive kicks having the same momentum (rather than the same speed) as those given to neutron stars.

References

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s.repetto@astro.ru.nl, mbd@astro.lu.se, steinn@astro.psu.edu