The Lives and Death-Throes of Massive Stars
Proceedings IAU Symposium No. 329, 2016
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doi:10.1017/S1743921317002095

Is the Link Between the Observed Velocities of Neutron Stars and their Progenitors a Simple Mass Relationship?

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While the imparting of velocity 'kicks' to compact remnants from supernovae is widely accepted, the relationship of the 'kick' to the progenitor is not. We propose the 'kick' is predominantly a result of conservation of momentum between the ejected and compact remnant masses. We propose the 'kick' velocity is given by $v_{\rm kick} = \alpha\,(M_{\rm ejecta}/M_{\rm remnant}) + \beta$, where α and β are constants we wish to determine. To test this we use the BPASS v2 (Binary Population and Spectral Synthesis) code to create stellar populations from both single star and binary star evolutionary pathways. We then use our Remnant Ejecta and Progenitor Explosion Relationship (REAPER) code to apply 'kicks' to neutron stars from supernovae in these models using a grid of α and β values, (from 0 to 200 km s^{-1} in steps of 10 km s^{-1}), in three different 'kick' orientations, (isotropic, spin-axis aligned and orthogonal to spin-axis) and weighted by three different Salpeter initial mass functions (IMF's), with slopes of -2.0, -2.35 and -2.70. We compare our synthetic 2D and 3D velocity probability distributions to the distributions provided by Hobbs *et al.* (1995).

Neutron stars from supernovae in single stars are expected to produce a uni-modal velocity distribution while in binaries a bi-modal distribution is expected. This is because merged systems will have higher ejecta masses then non-merged systems which can experience mass stripping by the companion. We test the fit of the uni- and bi-modal forms of the Gaussian, Maxwell-Boltzmann and lognormal distributions using the maximum likelihood estimator (MLE), and a grid of each of the distribution variables. Our results show a clear preference for a bi-modal distribution suggesting binary evolution for the majority of neutron stars.

While single star models provide a poor fit to both the 2D and 3D distributions, binary models with values of $\alpha = 70\,{\rm km\,s^{-1}}$ and $\beta = 110\,{\rm km\,s^{-1}}$ reproduce the observed 2D velocities and $\alpha = 70\,{\rm km\,s^{-1}}$ and $\beta = 120\,{\rm km\,s^{-1}}$ reproduce their inferred 3D velocity distribution. We find no statistically significant preference for any of the 'kick' orientations, or for any of the three different IMF's.

We use the α and β values identified above, and create synthetic runaway star velocity and NS-NS binary system period probability distributions. These too we find to agree well with the observational data of Tetzlaff *et al.* (2014) and Andrews *et al.* (2015) respectively.

References

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