Searching for ejected supernova companions in the era of precise proper motion and radial velocity measurements

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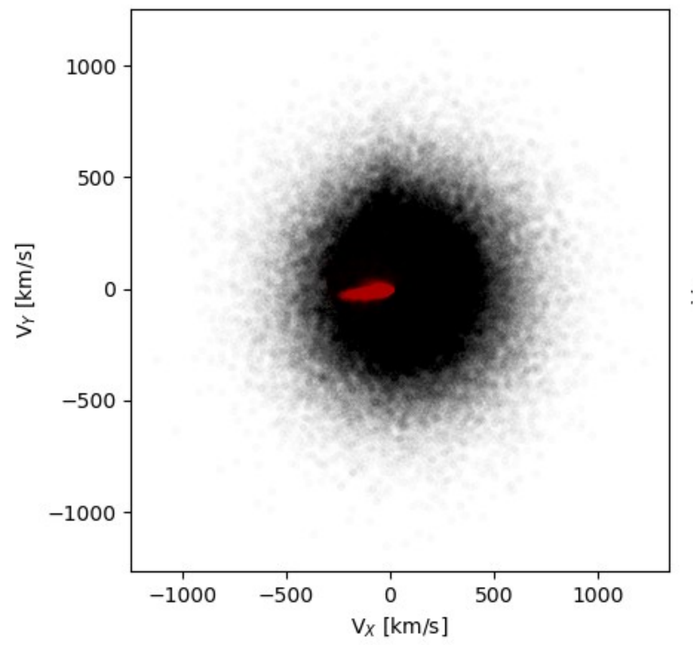
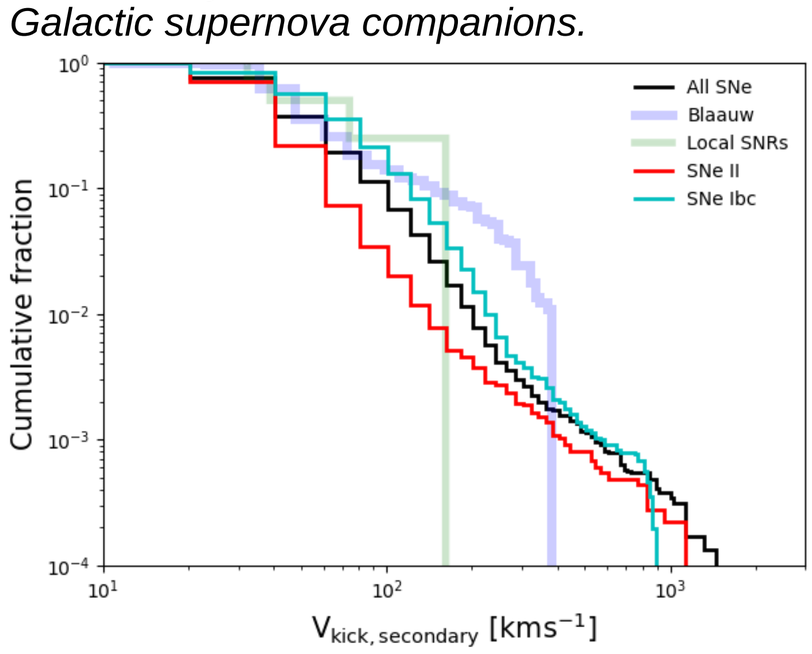
1. THE OPPORTUNITY

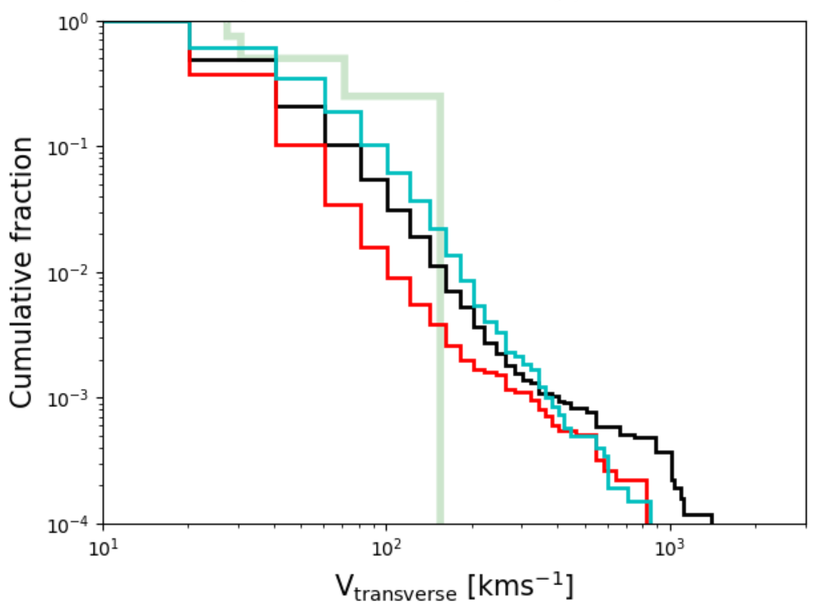
Most massive stars are in binaries [1]. When the primary star goes supernova (SN), this typically unbinds the system, ejecting the secondary [2]. These ejected stars obtain a peculiar velocity with respect to the local standard of rest, and have been termed walkaways (v_{pec}<30km/s) or runaways (v_{pec}>30km/s). By tracing back their motion, we can search for past trajectories which intersect a SN remnant (SNR) or neutron star (NS). In this work, we show that with *Gaia*, and long baselines between deep NIR images, *we can substantially incease the number of known Galactic supernova companions.*

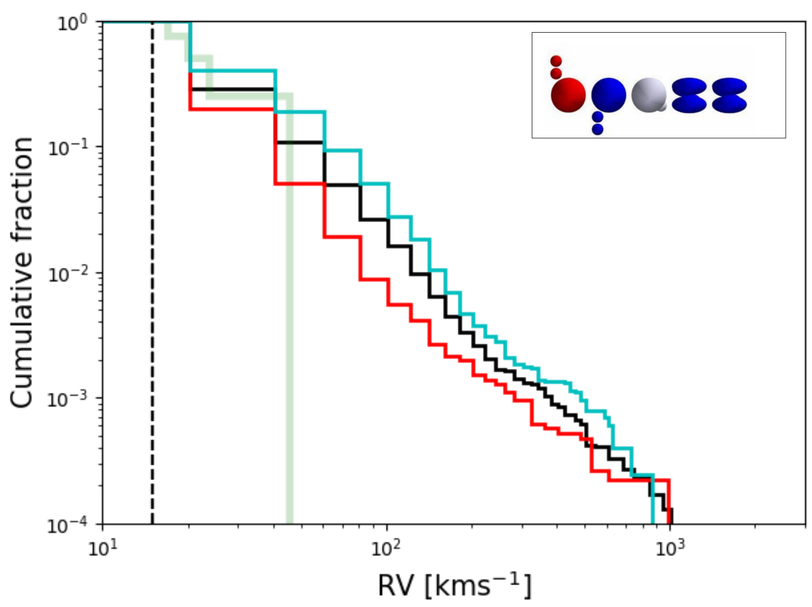
2. SUPERNOVAE IN BINARIES

We produce predicitons for ejected stars, and place these in the context of new observational opportunities. We start with the binary stellar evolution models of BPASS [3]. We identify models where the primary goes SN, splitting these by whether they produce a type II or type Ibc event. We then run the binary parameters for these models through a dynamical model for supernovae in binaires [4]. We use Hobbs NS kicks by default [5], but also trial the distribution of Verbunt [6] and Blaauw kicks [7]. Each primary is exploded *N* times, each time a random NS kick and direction (drawn isotropically) is chosen.



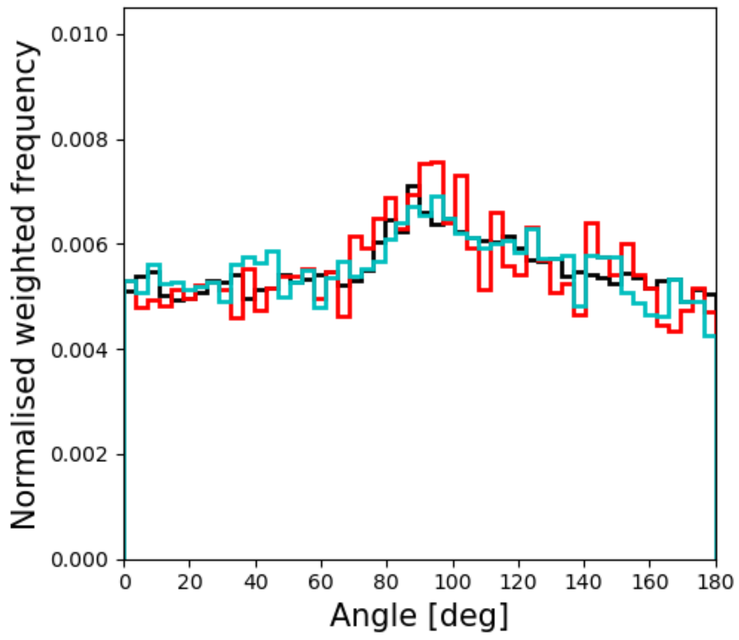






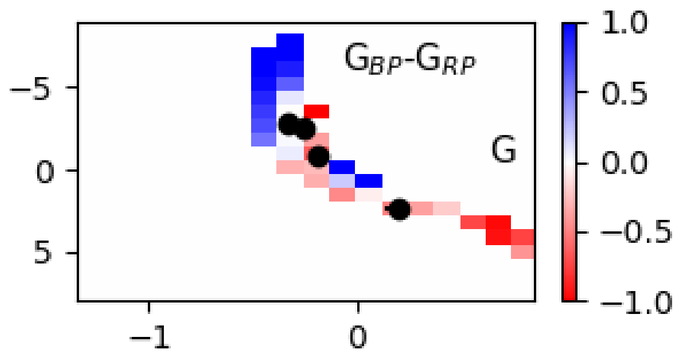
3. RESULTS: KINEMATICS

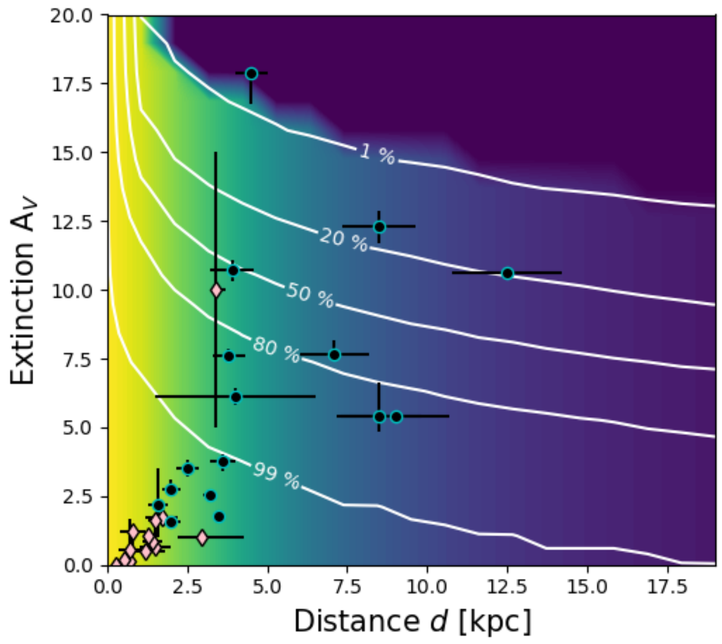
Row above, left to right: predictions for the total 3D velocity of unbound companions; projected transverse velocities (assuming random viewing angles), observable as proper motions; and projected 1D (radial) velocities. Also shown on the last panel is the minimum velocity measurable by upcoming instruments 4MOST and WEAVE (assuming R~20000). On each panel, we also show the velocities of four candidate runaways, identified in a sample of 13 SNRs by [8] and [9] with *Gaia* DR2. *Top right:* the X and Y velocity components of unbound secondaries (red) and neutron stars (black). *Right:* the distribution of angles between the NS and secondary proper motion vectors. A peak at ~90 degrees arises due to the tendancy of the secondaries to continue (approximately) on the pre-SN trajectory, versus the near-isotropic NS velocities (see *top right*).

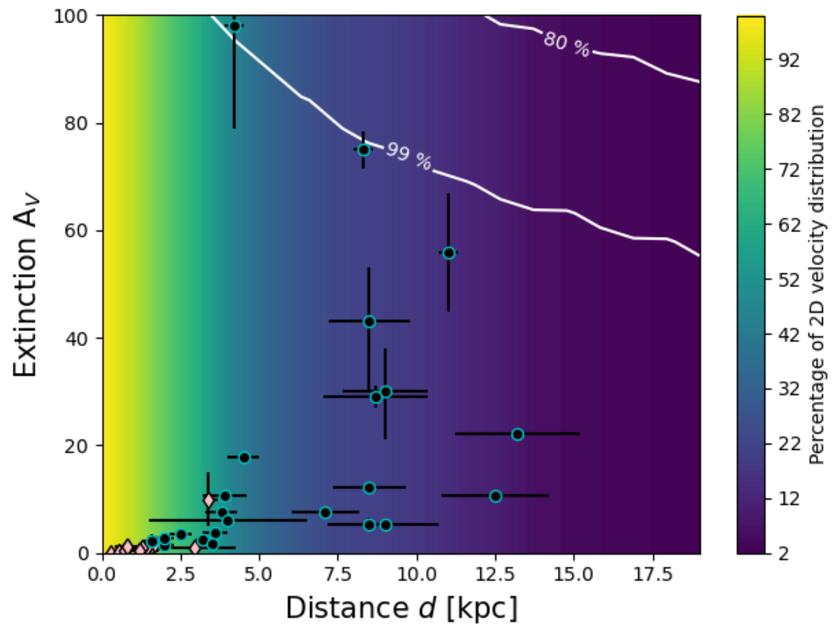


4. RESULTS: PHOTOMETRY

We also produce predictions for the photometry of the unbound companions, including *Gaia* and JWST specific predicitons. For each colour-magnitude diagram cell, we show the relative contribution of stars ejected by type II (red, all type II = -1) and type Ibc (blue, all type Ibc = 1) SNe repspectively. *Right: Gaia* predictions overlaid with photometry of the four candidates of [8] and [9].







5. APPLICATIONS

Lower left: as a function of distance and extinction, (i) the percentage of runaways detectable (white contours) and (ii) the percentage of the velocity distribution measurable (shading) – for a given limiting magnitude and minimum measurable proper motion. *Far left:* a *Gaia* example, assuming G < 20.5 and μ_{min} = 1mas/yr. *Near left:* also assuming μ_{min} = 1mas/yr, but for JWST (i.e. two epochs of imaging) with F277W < 26. Overlaid are SNRs (diamonds, [8,9]) and 23 magnetars (circles, [10,11]). From the percentage of parameter space accessible, we infer the number of runaways discoverable through proper motions in each case. For *Gaia* it is 5 (SNRs) and 3 (magnetars). For JWST, it is 5 for both. This demonstrates that proper motions rapidly become the limiting factor. We are finalising this probability calculation code, and will release it alongside the paper (in prep). *Thanks for reading, please get in touch if you have any questions or suggestions!*

REFERENCES: [1] Sana et al. 2012 – [2] Renzo et al. 2019 - [3] Eldridge et al. 2017 – [4] Tauris et al. 1998 – [5] Hobbs et al. 2005 – [6] Verbunt et al. 2017 – [7] Blaauw 1961 – [8] Boubert et al. 2017 – [9] Fraser et al. 2019 – [11] Olausen & Kaspi 2014 – [11] Chrimes et al. 2022