PROCEEDINGS OF SCIENCE

The Height Distribution of Core Collapse Supernovae in Disk Galaxies

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Core collapse (CC) supernovae are exploding massive stars and are therefore expected to occur in the disks of spiral galaxies. However, in the historical record some CC SNae can be noticed outside the disks. To investigate this further, the distribution of SNae above and below the disks of spiral galaxies is examined for the case of edge-on galaxies. The CC SNae that are observed away from their parent Population I in the galaxy planes must previously have left the disks due to dynamical encounters or SN explosions of companion stars. We develop a simple interpretative model that describes the observed height distribution of the SNae, taking into account kick velocities imparted during the explosive events. We also briefly comment on the radial distribution of SNae, utilizing face-on galaxies for this purpose.

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1. Supernovae Observed to be Runaway Objects

Binary systems in which the primary star undergoes a supernova explosion often have their orbital dynamics drastically altered, sometimes unbinding the system and sending the secondary out with a high peculiar velocity. Alternatively, a high peculiar velocity may be obtained after a dynamical encounter with other stars. The detection of supernovae (SNae) that have left their place of birth is made easier by investigating SNae in edge-on (disk) galaxies. We selected host galaxies from the Asiago SN database with an inclination of 80-90 degrees. A total of 62 Core Collapse SNae belonging to this sample of edge-on galaxies, the parent objects of which are expected to reside within the disk of the galaxy (being Population I objects), was selected in an investigation into the vertical distribution of SNae about their host galaxies. From the SN offsets (with respect to the centres of the host galaxies) the vertical height above/below the disk and the projected radial distance along the disk are calculated. From Figure 1 it is clearly seen that there are instances where a SN can be significantly displaced from the disk of its host galaxy.

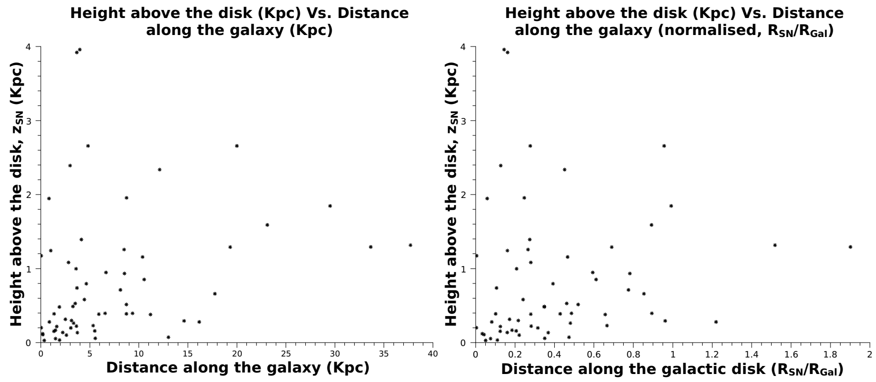
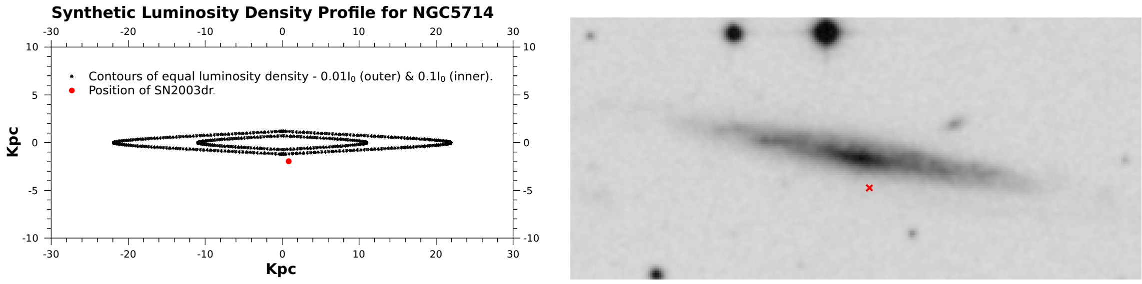


Figure 1: The height distribution of SNae about their host galaxy. In the left panel, the height of the SN (z_{SN} in kpc) as a function of its projected distance along the mid-plane of the galaxy (R_{SN} in kpc), while in the right panel, the distribution normalised to the radial extent of the galaxy (R_{Gal}).

We used photometric profiles of edge-on galaxies to develop a methodology to establish a simple test and determine if a SN can be considered away from the disk. A synthetic luminosity density profile is created for each of the host galaxies based on parameters from the Asiago SN database (Galaxy type, isophotal diameter) and on the known light profiles of disk galaxies [1]. The height profile of each disk is of the form $\text{sech}^2(z_{SN}/h_z)$, where z_{SN} is the height of the SN above the disk and h_z the vertical scaleheight of the luminosity density distribution. The scaleheight for each profile depends on the type of galaxy in which the SN resides, early type disk galaxies have h_z= 0.4 kpc which extends to a maximum of 1.2 kpc for later type galaxies [2]. The radial profile is of the form $\exp(-R_{SN}/h_R)$ where for each galaxy the value for h_R is dependent on the (B_{25} magnitude) isophotal diameter such that $h_R = 0.3\ R_{Gal}$. As a criterion, we chose that, if the luminosity density at the position of the SN is less than 1% of the central galaxy luminosity, this SN is considered a candidate for being positioned outside the disk. We have omitted 4 potential candidates that occurred in barred galaxies where the chosen photometric profiles don't adequately describe the



(a) Synthetic Luminosity Density Profile

(b) NGC5714 with SN2003dr

Figure 2: Figure 2a shows the contours (1% and 10% of the central luminosity density) of constant luminosity for our synthetic representation of galaxy NGC5714. The position of the SN2003dr is shown by the red dot and from our method the luminosity density at this point (using a scaleheight of $h_z = 0.6$kpc) is ≈0.5% of the central luminosity. Figure 2b shows the position of SN2003dr on an image from the POSS II catalogue and highlights the effectiveness of our method at selecting SNae that are located away from the general structure of its host galaxy.

host galaxy morphology. For our sample of 58 SNae approximately 17% are deemed to be located away from their disk galaxies and therefore can be considered runaway candidates.

By expanding the selection criterion this method should serve to easily separate runaway candidates from a large sample using parameters that are available from archival data. The number of runaway candidates discerned from the method described above is higher than the fraction of runaways from the population synthesis by [3] of 2% but this discrepancy could be caused by the probable loss of SNae counts in edge-on galaxies due to the opaque disk. The observational value for the number of runaways is said to be 10-30% for O-stars and 5-10% for B-stars [4]. The values relating to the O-star runaway population are high compared to our percentage of runaway candidates and may be explained by *(i)* most early type stars still reside in their optically thick parent gas cloud, which diminishes the total number that the runaways are compared with and *(ii)* not all runaways will travel out of the disk.

A scaleheight of SNae distribution is constructed by determining the amount of SNae in distinct height bins (in this case 0.1 kpc - i.e. the first bin is from 0 kpc to 0.1 kpc, the second from 0.1 kpc to 0.2 kpc etc.). An exponentially decaying function is then easily fit to the data giving a scaleheight of 0.629 kpc as shown in Figure 3. This corresponds well to the scaleheights derived from photometry of edge-on spirals by [2] whose sample produced a narrow distribution of scaleheights between 0.4 kpc and 1.2 kpc. Our scaleheight is at the lower end of this distribution and may be explained by the fact that CC SNae progenitors reside primarily in a thin disk with a much smaller vertical range than other components of the light distribution.

2. Interpretative Modelling of Progenitor Ejection

Using Monte-Carlo methods, an explorative model was developed in order to investigate the dynamics and distributions of SNae after they had been imparted with a velocity “kick” following the SN of their former binary companion. The initial distribution of the test particles was based on observed Milky Way parameters and they were then given a velocity kick consistent with the

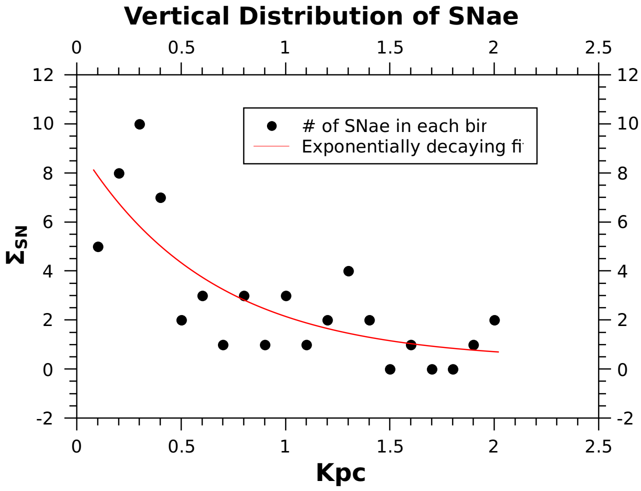


Figure 3: Each point represents the number of SNae in each distinct vertical height bin. The first point gives the number of SNae found at a height between 0 kpc and 0.1 kpc, the second point gives the number between 0.1 kpc and 0.2 kpc etc. An exponentially decaying function was then fit to the distribution giving a scaleheight for CC SNae of 0.629 kpc.

distribution of peculiar velocities of known early-type runaway stars ($v_{peculiar} \approx 90kms^{-1}$, $\sigma_v \approx 30kms^{-1}$; [5]). The test particles were initially distributed about a disk with scalelength h_R=3.79 kpc [6] and scaleheight h_z=1.2 kpc [2] and given a "kick" in a random direction. The test particles then travel in a Miyamoto-Nagai gravitational potential of the form

$$\Phi(R,z) = \sum_{i=1}^{2} \frac{GM_iM_{test}}{(R^2+A_i^2)^{1/2}}$$

where $A_i = (a_i + (z^2 + b_i^2))$.

Here, constants with subscript i relate to the matter distribution of a spherical bulge ($i = 1$) and a flattened disk ($i = 2$), the total potential being the sum of these two components [7]. M_i relates to the mass of the spherical bulge (M_1) and the flattened disk (M_2) while M_{test} is the mass of the test particle. The constants a_i and b_i determine the "flatness" of the component, i.e., in the case of the spherical bulge component a_1 = 0 kpc. The trajectory of each particle was then determined up to a maximum lifetime of 10Myr. For simplicity we have chosen our test particles to have a mass of $\approx$20$M_\odot$ upon leaving the disrupted binary system and given them a lifetime of 10Myr [8]. The preliminary results of the model suggest that a SN could be significantly displaced from a galaxy disk with about 14% of the total population in the simulation ending up beyond the maximum extent of the initial distribution of the model disk.

3. Radial Distribution

In an investigation into the radial distribution of SNae in (face-on) disk galaxies we have used, to the best of our knowledge, the largest sample ever for this purpose with a total of 457 CC SNae

([9] use a sample of 224 CC SNae). The sample includes host galaxies with an inclination between 0 and 50 degrees and for each case the projection effect on SN position due to inclination has been corrected. The radial distance of each SN (R_{SN}) from the centre of its host galaxy is normalised to the (B_{25}-Mag) radius of the galaxy (R_{Gal}) so that they can be compared. A surface density profile of the form $\Sigma_i = n_i/\pi(r_{i+1}^2 - r_i^2)$ has been created where n_i is the number of SNae in the annulus with inner radius r_i and outer radius r_{i+1}. An exponentially decaying profile is then fit to the radial distribution yielding a scalelength of 0.34 R_{Gal} (Figure 4). This value agrees well with a previous study by [9], the radial distribution of HII regions [10] and the general light profiles of disk galaxies. This result suggests that the distributions of CC SNae are good tracers for star formation in disk galaxies.

The surface density profile also shows that there is a deficit of SNae in the centres of disk galaxies which is amplified with increasing distance to the host galaxy (Figure 5a). This effect was first shown by [11]. By normalising the radial distance of each SN to the maximum extent of the disk this selection effect, due to distance, can be removed to reveal an intrinsic deficit of CC SNae at the centres of disk galaxies (Figure 5b). This agrees with the widely accepted view that there is a low density of CC SNae progenitors (OB stars) near the centres of disk galaxies (also evident in; [12] or [13]).

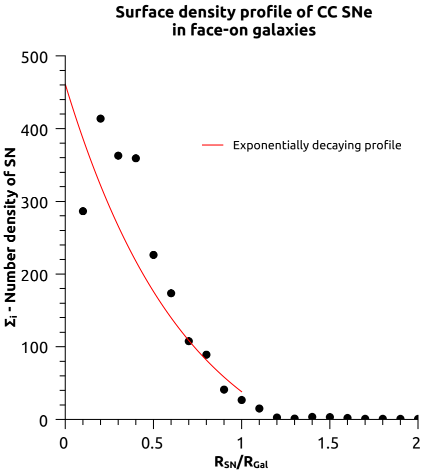
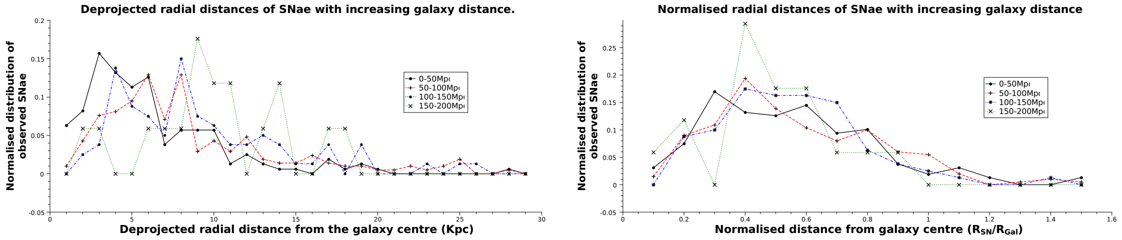


Figure 4: The surface density distribution of SNae in (face-on) disk galaxies is easily fit with an exponentially decaying profile and corresponds to a scalelength of 0.34 R_{Gal}. It is also clear that there is a deficit of SNae towards the centre of disk galaxies which cuts off sharply for $R_{SN} < 0.2 R_{Gal}$.



(a) Surface Density of SNae

(b) Normalised Surface Density

Figure 5: Figure 5a shows that, with increasing galaxy distance, SNae become ever more rare towards the centres of disk galaxies. To remove this selection effect due to distance the radial distance of each SN has been normalised to the maximum extent of the disk, R_{25} (corresponding to the B_{25}-mag isophotal diameter). This reveals, as in Figure 5b, an intrinsic deficit of CC SNae inwards of 0.4 R_{25} which is consistent with a low density of CC SNae progenitors (i.e. OB stars).

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