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CORRELATION OF SN POSITIONS WITH SPIRAL ARMS

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Abstract. We present the first results of a three part study of supernova (SN) ages using positional age indicators in spiral galaxies. We have measured the positions of 80 spectroscopically identified Type Ia and Type II SNe (SNe Ia and SNe II) relative to spiral arms in their host galaxies, making a special effort to reduce inhomogeneity in the process of arm tracing for different galaxies. We find that SNe II are more tightly concentrated to the arms than SNe Ia, but both kinds of SNe occur closer to arms than a random disk population. This indicates that most SNe Ia occur in progenitors less than 0.5 Gyr old.

1. Introduction

SNe Ia, unlike SNe II, sometimes occur in elliptical galaxies, and so are assumed to originate in an older population. However, SN Ia rates are higher in late-type and irregular galaxies than in ellipticals (van den Bergh, 1994), and some studies have indicated that those ellipticals which do produce SNe Ia are more likely to be active or unusual in some regard (*e.g.*, Oemler & Tinsley, 1979). This suggests that the bulk of SNe Ia may occur in a population that is not very old, perhaps less than 10^9 years. Other indicators point to a greater age; for example, studies of chemical evolution in our Galaxy (Shigeyama *et al.*, 1990) have found that iron enrichment from SNe Ia may not have begun until 1.5 Gyr after the Galaxy's formation.

Various theories of SN Ia formation also give conflicting predictions for their progenitor ages. Simulations of binary white dwarf coalescence show that such events should begin $\sim 10^8$ years after star formation (Ruiz-Lapuente *et al.*, 1995); however, these computations are quite sensitive to

the assumed value of the common envelope ejection parameter α, which is poorly understood. Efforts to identify existing white dwarf binaries that will eventually coalesce have had limited success; the only identified candidates will take several Gyrs to spiral together.

An observational determination of the ages of SN progenitors can be obtained from their location in spiral galaxies. Because spirals include localized star formation and stellar populations of different ages, they offer a number of positional age indicators. Several excellent studies (Van Dyk, 1992; Bartunov *et al.*, 1994) have examined the positions of different types of SNe relative to HII regions. Others have focused on the radial distribution of SNe in the disk, correlation of SNe with spiral arms, and SNe as members of the bulge or disk populations.

Maza & van den Bergh (1976) measured the positions of 84 SNe relative to spiral arms, and found that SNe II were largely confined to the arms, while SNe I were more uniformly distributed. However, their sample included only 17 spectroscopically classified SNe I, some of which must have fallen into the Type Ib and Ic subclasses not recognized at that time. More recently, Bartunov, Tsvetkov, and Filimonova (1994; BTF) compared a much larger sample of SNe II, SNe Ia, and SNe Ib/c against spiral arms and found that all three types were more closely correlated with arms than expected of a random sample. They concluded that SNe Ia in spirals arise from an intermediate-age population, rather than a very old or evolved one.

This is the first part of a three-pronged study of the ages of SNe Ia and SNe II using their position relative to spiral arms, their membership in the bulge or disk populations, and their scale height in the galactic disk. The primary purpose of this study is to identify the ages of SN Ia progenitors, using SNe II for comparison as a control sample of known age.

2. Sample Definition and Observations

The key to any statistical study is careful sample selection. Our initial sample, chosen to be as large as possible, included every well-identified SN Ia and SN II identified in galaxies of type S0 or later. All SNe described as peculiar in the IAU Circulars or with uncertain spectroscopic identification in the Asiago or van den Bergh catalogs were excluded immediately. The SNe Ia, in particular, were included only if there had been a spectroscopic type determination (Leibundgut, 1991). SNe Ib and Ic were excluded because they do not form a sufficiently large sample and because our focus is on SNe Ia. All of the host galaxies of the SNe in the initial sample were targeted for observing. Later divisions of the sample were made from examination of the images obtained specifically for this study.

Since homogeneity of the data is a central goal of our effort, all of

the northern hemisphere data were obtained with the same telescope and CCD set-up. Three runs were made on the KPNO 0.9-m at f/7.5 with the Tektronix 2048 × 2048 CCD (T2KA), in February and November of 1994 and March of 1995, providing the bulk of the data for this study. These images covered 23 arminutes on a side with a scale of 0.68 $''mm^{-1}$. Southern hemisphere observations were carried out with the CTIO 0.9-m, a sister telescope of the one at KPNO, and a TI quad-readout CCD providing 13.5 arcminute images at 0.396 $''mm^{-1}$.

All exposures were 15 minutes long, to allow for good signal-to-noise down to the sky level without saturating the nuclei of the brighter galaxies. Each galaxy was observed in both V and I; the V images are used for identification of the blue spiral arms, while the I images are for color information and smooth surface photometry with less interference from dust.

3. Reduction

One shortcoming of previous studies of SN distances from spiral arms (Maza & van den Bergh, 1976; BTF) is that they used an inhomogeneous set of images, with different types of photographic plates exposed for different times through changing filters. By using similar telescopes and instruments, constant exposure times, and identical reduction methods, we have reduced this source of inhomogeneity. An equally important source of variation comes from the different distances of the host galaxies. SNe Ia are significantly brighter than SNe II, thus they can be observed at much greater distances. As a result, samples of SN Ia host galaxies have larger mean distances than their SN II counterparts, and are typically observed with coarser spatial resolution. Since fainter arm structure becomes undetectable at large distances, the selection effect naturally causes supernovae at greater distances to appear farther from the spiral arms than nearby supernovae.

To overcome this problem, we smoothed and rebinned our images so that the entire sample of galaxies would appear as if they were at a common distance. Two difference distances were considered: 50 Mpc ($h = 0.75$), which kept more of the original resolution, but sacrificed part of the galaxy sample, and 100 Mpc, which included more of the observed galaxies. By comparing the results from these two samples, we could test for the effect the different distance distributions had on our results. The width of the gaussian used for the smoothing in each case was determined by

$$\sigma^2 = 1.415\,(\frac{D_{\rm std}}{D_{\rm gal}})^2 - \sigma^2_{\rm orig} \qquad (1)$$

where $D_{\rm std}$ is either 50 or 100 Mpc, $D_{\rm gal}$ is the galaxy's actual distance, and $\sigma_{\rm orig}$ is the width of the PSF in the original image. The constant was determined by the average seeing of 1.8″.

Determination of the SN position in each galaxy was hampered by the lack of accurate astrometry for many SNe. In general, the offsets between SNe and galaxy nuclei published in the IAU Circulars, and listed in SN catalogs (Barbon *et al.*, 1989; van den Bergh, 1994), are only accurate to 2-3″, and in some cases, especially with older SNe, are good to no better than 10″. Absolute positions for some SNe were published in the IAUCs; others are available from remeasurements (Porter, 1993) of old photographic plates. Wherever a position was quoted to sub-arcsecond precision, that position was considered to be accurate and was used instead of the nuclear offset. A few of the most recent SNe were unambiguously visible in the images we obtained; for these, we used a centroid of the SN's PSF.

The actual identification of the nearest arm to a SN position was made by eye, using a consistent set of rules. For the purposes of this study, an "arm" is defined to be a local maximum in the surface brightness of the galaxy which is extended with an axis ratio of 6 or more. In the case of very flocculent galaxies, an arm may also be defined by three or more co-linear "clumps," all of which must be larger than a typical stellar PSF. When a SN occurred near an isolated clump, a note was made of this fact, but the distance was measured to the nearest arm fitting our definition.

For galaxies with inclinations greater than 30° (de Vaucouleurs *et al.*, 1991), we corrected the measured arm distance for projection effects using

$$d^2 = \left(\frac{r\,\sin(\Delta\theta)}{\cos i}\right)^2 + (r\,\cos(\Delta\theta))^2 \qquad (2)$$

where r is the measured distance to the nearest arm, i is the inclination of the galaxy, and $\Delta\theta$ is the difference between the position angle of the galaxy's major axis and the direction from the SN to the arm.

4. Analysis

After reduction, our sample includes 80 SNe that occurred between 1917 and 1994 for which arm distances were measured at the 50 Mpc or 100 Mpc equivalent resolution. We used a negative distance to indicate a SN which occurred on the inner edge of an arm. These offsets were converted to a linear separation in kpc using galaxy distances taken in most cases from the Tully catalog. For the fainter galaxies where no distance was available, we assumed $H_o = 75\ kms^{-1}Mpc^{-1}$ and used either SN velocities (Barbon *et al.*, 1989) or galaxy velocities (de Vaucouleurs *et al.*, 1991).

A random sample of SNe, uncorrelated with arms, was generated for comparison with the results for the real SNe. For this purpose, a single template galaxy, NGC 5457, was chosen to host the random sample, because of its face-on inclination, well-defined arms, and smooth surface brightness

profile, and also because its distance is known quite accurately to be 7.5 Mpc (Kelson, 1995). The V image of NGC 5457 taken as part of this study was smoothed to simulate distances of 50 and 100 Mpc, and at each resolution the arms were traced according to the strict definition above. Using our own surface photometry measurements, we determined that an exponential disk with a scale length of 6.0 kpc made a good fit to the disk light of the galaxy. 1000 SNe were generated randomly following this exponential fall-off, and for each one the distance to the nearest arm was measured.

Figure 1 shows histograms of the arm distances for SNe Ia and SNe II at the two standard resolutions equivalent to 50 Mpc and 100 Mpc. A histogram of the distribution for the randomly generated SNe is overplotted for comparison. Note that even in the random samples, the distribution is not symmetrical around 0 kpc. This is to be expected because there is more area on the outsides of the arms (positive distances) than on the inside (negative distances).

5. Discussion

To make a quantitative comparison of the samples, we made Gaussian fits to the distribution of arm distances using the maximum likelihood method. Because of their asymmetry, the distributions do not fit a Gaussian perfectly, but the width of the best-fit Gaussian serves as a measure of how far the population has spread from the arm spine, and therefore how much time is needed for the progenitors to reach that distribution. The SNe Ia fit a Gaussian with $\sigma = 2.45$ kpc, while the SNe II were best represented with $\sigma = 1.75$ kpc. The random sample, in contrast, showed $\sigma > 5$ kpc.

Comparison of the samples using the Kolmogorov-Smirnov method confirmed the difference between SNe II and the random sample; at both resolutions, the samples show a 95% probability of being different. The contrast is less marked for the SNe Ia, which have a 69% probability of being different from the random sample at the finer 50 Mpc resolution, but only a 40% probability of disagreement at the 100 Mpc resolution.

When compared against each other, the SNe II have a 90% probability of disagreement with the SNe Ia at the 50 Mpc resolution, and a 75% chance of disagreement at the 100 Mpc resolution. Interestingly, this inconsistency drops to less than 40% at both resolutions when only the absolute distance from the arm spine is used, without consideration of the SN position inside or outside the arm. This could be due to a difference in the radial distribution of the SNe in the host galaxies, which will be studied in a continuation of this project.

Our results show that although Type II SNe are more tightly correlated with spiral arms than SNe Ia, both kinds of SNe occur closer to arms

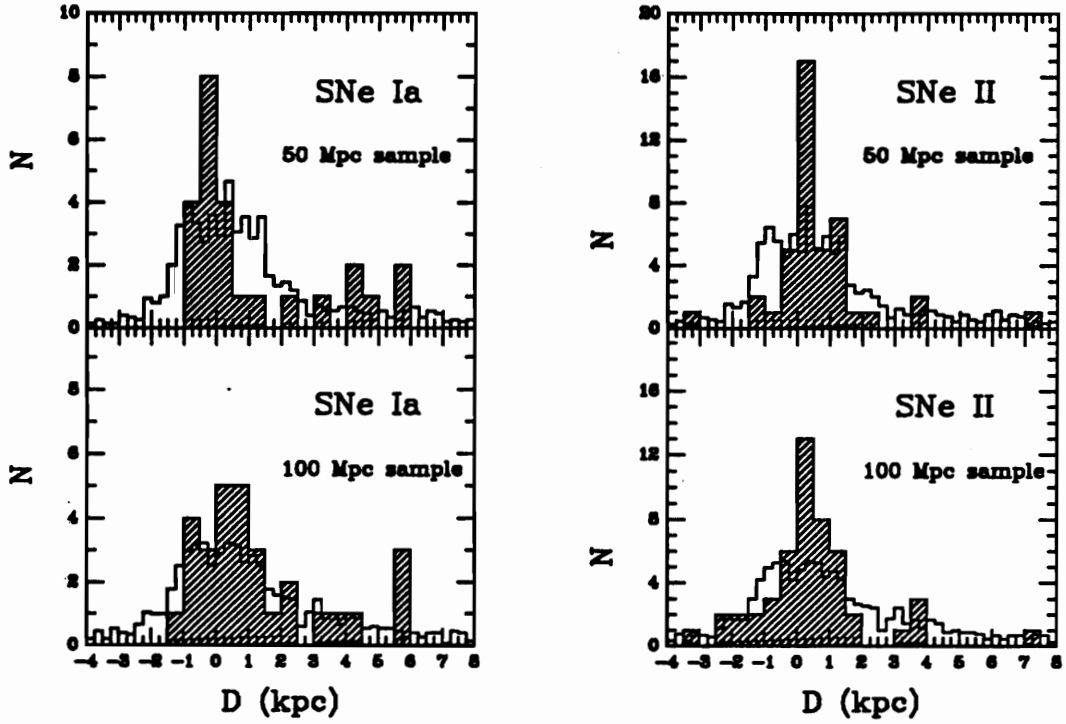

Figure 1. **Distribution of SN offsets from spiral arms for SNe Ia and SNe II at resolutions equivalent to distances of 50 and 100 Mpc. A sample of randomly-generated disk objects is overplotted for comparison.**

than would be expected of a randomized disk population. SNe II are more likely than SNe Ia to occur on the inside of an arm; when only distance from the arm spine is considered, with no distinction between offsets to the inside or outside of the arm, the two samples of SNe are statistically indistinguishable. This suggests that SNe Ia have had slightly longer than SNe II to diffuse away from the sites of most intense star formation, but they are not old enough to have formed a smooth disk. At a typical stellar birth velocity of $5kms^{-1}$, it would take $\sim 5 \times 10^8$ for a SN progenitor to diffuse out to 2.5 kpc from the arm spine.

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