ABSTRACT

We have made polarimetric observations of three Type Ia supernovae (SN Ia) and two type II supernovae (SN II). No significant polarization was detected for any of the SN Ia down to the level of 0.2%, while polarization of order 1.0% was detected for the two SN II 1994Y and 1995H. A catalog of all the SNe with polarization data is compiled that shows a distinct trend that all the 5 SN II with sufficient polarimetric data show polarizations at about 1%, while none of the 9 SN Ia in the sample show intrinsic polarization. This systematic difference in polarization of supernovae, if confirmed, raises many interesting questions concerning the mechanisms leading to supernova explosions. Our observations enhance the use of SN Ia as tools for determining the distance scale through various techniques, but suggest that one must be very cautious in utilizing Type II for distance determinations. However, we caution that the link between the asphericity of a supernova and the measured “intrinsic” polarization is complicated by reflected light from the circumstellar material and the intervening interstellar material, the so-called light echo. This effect may contribute more substantially to SN II than to SN Ia. The tight limits on polarization of SN Ia may constrain progenitor models with extensive scattering nebulae such as symbiotic stars and other systems of extensive mass loss.

Subject headings: polarimetry – stars: individual (SN1994D, SN1994Y, SN1994ae, SN1995D, SN 1995H) – stars: supernovae

1. Introduction

Polarization measurements of supernovae are very rare. So far, detailed observations with both broad band and spectral polarimetry taken at different epochs after explosion are only available for SN 1987A and SN 1993J, generally the two most well-studied supernovae. The observed polarization for SN 1987A was around 0.5% and evolved with time. Published data are available only in the first year after explosion, and unfortunately do not extend much beyond the photospheric phase (Jeffery 1991b and references therein).

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Spectropolarimetric data of SN 1987A were also obtained on days 523 and 643 after explosion, but the data are still not published (Stathakis 1995). Observations of SN 1993J yield polarizations of about 1.5% (Trammell, Hines, & Wheeler 1993; Doroshenko, Efimov, & Shakhovskoi 1995). The published data are even more limited, but cover epochs both before and after the supernova passed its second optical maximum. The observed polarization for these two supernovae is attributed to aspherical photospheres in their early phases of evolution (Höflich 1987; Jeffery 1991a; Höflich et al. 1995), or to asymmetric distributions of radioactive materials which may be the result of instabilities produced during the shock break out (Chugai, 1992).

Polarized light is the best, but not the only, signature of deviations from spherical symmetry in these two supernovae. Strong deviations from spherical symmetry are also recorded in spectroscopic observations of SN 1987A and SN 1993J. In SN 1987A, various observations show that the spectral lines of most chemical species have fine structures the strengths of which evolve with time. Most noticeable is the fine structure in Hα (Hanuschik & Dachs 1987). These fine structures are modeled in terms of high velocity 56Ni clumps ejected during the explosion (Chugai 1988). Evidence of the existence of high velocity radioactive clumps is also obvious in the spectra taken at about 5 years after the explosion of SN 1987A (Wang et al 1996). The asymmetric Hα profile of SN 1987A five years after explosion implies that 44Ti has a similar spatial distribution as 56Ni. Extensive evidence also exists for macroscopic chemical mixing in the ejecta, supported by both observations and hydrodynamical calculations. For SN 1993J, spectral evidence for deviations from spherical symmetry is perhaps most clearly observed in the late stage nebular phase spectra. The first remarkable feature is the blue shift of the [OΙ]λλ6300,6364 lines (Clocchiatti et al 1994; Wang & Hu 1994). Later evidence is given by the peculiar evolution of the Hα line (Filippenko et al, 1994). The early phase [OΙ]λλ6300,6364 lines were interpreted by Wang & Hu (1994) as due to a highly deformed photosphere. The blue shifts, however, were also observed in the late nebular stage when the ejecta became optically thin, and this is indicative of a global geometrical distortion. A nickel sphere that is off-center with respect to the the bulk of the oxygen shell provides a reasonable fit of the late time [OΙ]λλ6300,6364 profile (Chugai & Wang 1995)

A major difficulty of polarimetric studies of supernovae is to subtract the polarization produced by interstellar material. For SN 1993J, Trammell et al. (1993) accomplished this by assuming Hα to be intrinsically unpolarized, and that the interstellar polarization follows Serkowski’s law (Serkowski, 1970; Wilking, Lebofsky, Rieke, 1982). The assumption that the spectral lines are not polarized is based on the assumption that the continuum photons are polarized by Thomson scattering above an asymmetric supernova photosphere. The spectral lines are produced by resonance scattering which tends to destroy polarized photons. This picture is quantitatively justified in Höflich et al. (1995), and has proven to be useful for SN 1993J. This technique can only be applied when spectropolarimetry is available.

The observed polarization in SN 1987A and SN 1993J implies that at least some supernova explosions are aspherical. Considering the fact that supernovae are now becoming an increasingly important tool for the determination of the extra-galactic distance scale, it is important to investigate whether polarization is a common phenomenon implying that supernovae deviate significantly from spherical symmetry. Asphericity will introduce additional uncertainties in the distances determined by using SN Ia as “calibrated” candles (Reiss, Press & Kirshner 1995; Hamuy et al. 1995), and by using the expanding photosphere method for SN II (Kirshner & Kwan 1975; Eastman & Kirshner 1989).

Only two SN Ia have been previously observed with spectropolarimetry. These are SN 1983G, reported in McCall et al. (1984), and SN 1992A reported in Spyromilio (1993). McCall et al. (1984) observed polarization of about 2% for SN 1983G, but no intrinsic polarization of the supernova can be identified.
For SN 1992A, no noticeable polarization was detected down to the level of 0.3%. Theoretically, SN Ia are associated with binary stars and the ejecta should be intrinsically asymmetric at some level; however, the existing theories are not detailed enough to provide a clear picture of how the asymmetries evolve and whether they will be large enough to produce detectable degrees of polarization. On the other hand, SN Ia are bright enough close to maximum light for observational studies. A typical SN Ia in the Virgo cluster can reach 11th magnitude at maximum light. It is possible to collect enough photons so that accuracies down to 0.1% can be achieved in polarimetry.

There is no doubt that spectropolarimetry is the most powerful tool for extracting information on asymmetries in supernova explosions. Most supernovae, however, are quite faint and a systematic spectropolarimetric study seems impractical. In this paper, we report broad band polarimetry of the supernovae SN 1994D, SN 1994Y, SN 1994ae, SN 1995D and SN 1995H. The observations are described in §2, and the results are given in §3. A brief summary is given in §4.

2. Observations and Data Reductions

The observations were obtained using the Breger polarimeter mounted at the Cassegrain focus of the 2.1 meter telescope of the McDonald Observatory. The Breger polarimeter and the filter system used are described in Breger (1979). The observations were made in the B, V and R filters, and unfiltered white light (UF, hereafter). The instrumental polarizations are very small and are stable during the course of this program for all these filters. Typical instrumental polarizations are $P = 0.061 \pm 0.011\%$ at position angle $\theta = 175^\circ \pm 5^\circ$ in the R-filter, and $P = 0.051 \pm 0.003\%$ at position angle $\theta = 1^\circ.1 \pm 0^\circ.2$ in unfiltered light. Nonetheless, one or two polarized and unpolarized standard stars were observed each night for determining the instrumental polarization and the polarization angle zero point of the instrument. A difficult aspect of this project is the background subtraction. The Breger polarimeter integrates over an aperture of typical size a few arc seconds, so it does not provide a simultaneous background estimate. To achieve optimum results, we have used two different methods of background subtraction. The first was the conventional method in which the telescope was alternately pointed to the supernova and to a neighboring background free of any obvious stellar objects. The positions for taking the background exposure were chosen so as to uniformly cover the area surrounding the supernova. Typical exposure times were between 100 and 200 seconds to ensure that any change of weather conditions would not introduce large errors in sky subtraction. The second method was to change the aperture size during different exposures. Again, typical exposure times were between 100-200 seconds. The level of background was calculated by subtracting the weighted Stokes parameters U and Q in two adjacent exposures. Note that the background estimated in the latter method gave the Stokes parameter of a circular loop a few arc seconds in radius surrounding the supernova. Both methods are accurate only when the background is reasonably uniform. Observations were made using both methods whenever time permitted. The background that will be subtracted from the observations is estimated by averaging over each individual background exposure. The errors in the background estimates are obtained by calculating the standard deviation from the mean of each individual exposure. However, as will be discussed below for each individual supernova, the objects observed in this study were sufficiently bright that errors in background subtraction are usually smaller than 0.1%. The predominant uncertainties are caused by photon statistics and are given by $\delta = \delta P = \delta Q = \delta U = \sqrt{2N}$, where $N$ is the total number of photons collected. The corresponding uncertainties of the polarization position angle $\theta$ are given by $\delta\theta = 28^\circ.65 (\delta P/P)$. Low resolution spectroscopic observations of SN 1994Y
and SN 1995H were obtained using the Cassegrain spectrometer (ES2) mounted at the same telescope. A log of the observations is given in Table 1.

The interstellar polarization in our Galaxy and in the host galaxy of a supernova can often be as large as 1.0%, which makes the separation of the interstellar polarization from intrinsic polarization very difficult. The first, and perhaps the most effective, way to identify the intrinsic component of the polarization of a supernova is to monitor the time dependence by repeatedly observing the same object at well separated epochs, as has been done for the supernova SN 1987A. This method does not require spectropolarimetry and is therefore appropriate for faint objects. A second method is to study the wavelength dependence of the polarization and the position angle, and see if it contains contributions other than that of interstellar origin, as suggested by Shapiro & Sutherland (1982), McCall (1984) and McCall et al. (1984). This latter method is employed in the analyses of SN 1993J by Trammel et al. (1993), where the observed polarization of SN 1993J is nearly constant for the continuum but decreases sharply across the Hα emission line. Although the polarization of SN 1993J shows rather small time evolution before and after maximum light (Höflich et al. 1995), the abrupt change of both the polarization and position angle over the Hα P-Cygni profile argues strongly that there are at least two components, one interstellar, the other intrinsic to the supernova, responsible for the observed polarization.

In this paper, an unambiguous detection of the intrinsic polarization of a supernova is presumed if one or both of the following two criteria are satisfied:

A. Noticeable time evolution of the polarization; and
B. Apparent differences in wavelength dependence between the observed polarization properties and those of the known interstellar polarization. Here, the polarization properties can be either the degree of polarization or its position angle.

A quantitative estimate of intrinsic polarization is not easy as we do not know the exact amount of interstellar polarization, which in most cases can be comparable with, or even stronger than, the intrinsic polarization. We present here an approach which combines broad band polarimetry with spectroscopic data obtained at a comparable date to extract information on the nature of the observed polarimetry. If we assume, following Trammell, Hines, and Wheeler (1993), that the continuum and emission lines of a supernova have different polarization, we can extract useful information concerning the intrinsic polarization. Trammell, Hines, and Wheeler (1993) assumed that Hα is not intrinsically polarized, and that the observed polarization at Hα is a good measure of the interstellar component. Höflich et al. (1995) confirm that while the Hα emission line may be slightly polarized, the effect is sufficiently small to be neglected in the analysis. Because the lines and continuum are formed by very different mechanisms, a more general assumption is simply that the lines and continuum have different polarization.

It thus seems that the interstellar polarization can be subtracted from the observed multi-color broad band polarimetry if we are able to separate the continuum and absorption/emission lines in a particular filter. Denote $\epsilon(\lambda)$ as the fraction of the light integrated by a particular filter which is due to the continuum, and $Q_c(\lambda)$ and $U_c(\lambda)$ as the Stokes parameters for the continuum component. The fraction of emission lines in the filter is then $1 - \epsilon(\lambda)$ and the corresponding Stokes parameters are $Q_l(\lambda)$ and $U_l(\lambda)$. Denote also $Q_i(\lambda)$ and $U_i(\lambda)$ as the interstellar component, and $Q_o(\lambda)$ and $U_o(\lambda)$ as the observed polarization. We have then

$$Q_o(\lambda) = \epsilon(\lambda)Q_c(\lambda) + (1 - \epsilon(\lambda))Q_l(\lambda) + Q_i(\lambda)$$

(1)

and

$$U_o(\lambda) = \epsilon(\lambda)U_c(\lambda) + (1 - \epsilon(\lambda))U_l(\lambda) + U_i(\lambda),$$

(2)
where $\lambda$ is the characteristic wavelength of a filter and can represent B, V, or R in the present study. The fraction $\epsilon(\lambda)$ can be determined from spectra taken at a similar epoch to the polarimetric measurements. With certain approximations of the properties of the intrinsic polarization such as those assumed in Trammell, Hines and Wheeler (1993), the above equations can be solved for the Stokes parameters $Q_c$, $U_c$, $Q_l$ and $U_l$ if more than three colors are observed in broad band polarimetry, and the Serkowski law for interstellar polarization is assumed.

To determine the value $\epsilon$, we need to know the level of the continuum flux, or the flux of photons that have not suffered any resonance scattering. The continuum level is hard to define in a supernova spectrum because the absorption/emission lines are very broad. In this paper, this is done by simply fitting a spline to the featureless regions of the observed spectrum. However, the continuum level thus defined over-estimates the continuum flux at the absorption trough of a P-Cygni profile, for which a better representation is given by the original observed spectrum. For this reason, we need to subtract the continuum defined by the spline fit from the observed spectrum. The resulting spectrum represents the part of the spectrum that is due to various absorption/emission lines. Note that the absorption features are negative in this spectrum. The emission line spectrum is then obtained by artificially removing all the absorption features in this spectrum. The continuum spectrum is obtained by subtracting the emission line spectrum from the observed spectrum. The number $\epsilon$ for each filter can then be calculated by applying the transmission curve of the instrument in that filter to the decomposed spectrum.

The interstellar component follows the Serkowski law and can be approximated by (Serkowski, 1970; Wilking, et al, 1980; Wilking et al, 1982),

$$P_i(\lambda) = P_{\text{max}} \cdot \exp \left( -K \ln^2 \frac{\lambda_{\text{max}}}{\lambda} \right),$$

(3)

where $P_{\text{max}}$, $K$ and $\lambda_{\text{max}}$ are constants. $P_{\text{max}}$ is related to interstellar extinction $A_v$ and $P_{\text{max}} \leq 0.03 A_v$. $\lambda_{\text{max}}$ is around 5450 Å for polarization due to the Galaxy. The interstellar polarization of the host galaxy may be very different from the Galaxy. This will considerably complicate the process of extracting the intrinsic polarization of a supernova from the observations. In the case both the polarizations from the Milky Way and the host galaxy are important, the interstellar polarization in equations (1) and (2) should include both the Galactic and the extra-galactic components.

3. Results

3.1. SN 1994D

SN 1994D in NGC 4526 is a SN Ia located about 9″ west and 7″ north of the galaxy’s nucleus (Treffers et al. 1994). Polarimetric observations were obtained by D. Wills at the McDonald Observatory on March 10, 11, and 12, 1994 when the supernova was at maximum light. All the data are obtained in unfiltered light.

The extinction due to material in our Galaxy is small; Burstein & Heiles (1984) list a value of $A_B = 0.01$ mag in the direction to NGC 4526. This places an upper limit of 0.03% for polarization produced by dust in our Galaxy on the line of sight to NGC 4526. Extinction within the host galaxy can be found in Ho & Filippenko (1995) and Richmond et al (1995). Adopting the value $A_V = 0.08^{+0.04}_{-0.04}$, we found polarization due to material in the host galaxy to be less than 0.48% according to the Serkowski’s law. The observations are listed in Table 2, where $\delta$ is the error due to photon statistics. The results are corrected for instrumental polarization ($Q = 0.051\%, U = 0.002\%)$ and with background subtracted. A nearby star SAO 119497 (an
A2 star) was also observed and showed polarization of 0.15 ± 0.02% at position angle 75° ± 4°. Another neighboring star to the south of the supernova was observed and was found to be polarized at a level of 0.11 ± 0.04% at position angle 97° ± 9°. The galaxy nucleus was found to be polarized at 0.25 ± 0.05%, at position angle 137° ± 5° degree. The supernova shows a higher polarization and is at a different and varying position angle compared with the neighboring stars and the galaxy nucleus (cf. Table 2). However, the aperture used in the measurements is 7'' in diameter. Polarizations of about 0.3% could be easily produced by errors in background subtraction. The galaxy nucleus may also be intrinsically polarized. We conclude that no significant intrinsic polarization was detected from this SN.

Note, however, that the measured degree of polarization of both the neighboring star SAO 119497 and the star to the south of the SN are significantly larger than the upper limit of interstellar polarization due to dust in our Galaxy (0.03%) set by the extinction $A_B = 0.01$ mag in the direction to NGC 4526. This may indicate that the galactic extinction is 5 times larger than that given by Burstein & Heiles (1984), i.e., $\sim 0.05$ mag.

### 3.2. SN 1994ae

SN 1994ae in NGC 3370 is also a SN Ia discovered near maximum light. It was discovered at an R magnitude of 15.4 ± 0.4 on Nov. 14, 1994 by the Leuschner Observatory Supernova Search (LOSS) team. The supernova is located 30'' west and 6'' north of the galaxy’s nucleus (Van Dyk, et al, 1994). The V magnitude reached 13.13 on about Dec. 1-5, 1994 (Patat, 1994). Our polarimetric observations of SN 1994ae were obtained at two epochs: one on Jan. 2-3, and the other on Jan. 30-Feb. 1, 1995. At these times, the supernova was about one and two months past maximum light, respectively. The results are listed in Table 3. In the table, both the exposure times for the object and for the background are given, separated by a “+” sign. The observations were obtained using an aperture size of about 4'' in diameter.

As shown in Table 3, no significant polarization was detected for SN 1994ae during these observations. The polarization position angles are very uncertain because of the relatively large errors of the measurements. The sum of all the measurements weighted by the photon counting rate in unfiltered light yields $P = 0.22 \pm 0.11\%$ and $\theta = 48^\circ \pm 14^\circ$, and in the R filter yields $P = 0.10 \pm 0.28$ and $\theta = 10^\circ$. The errors due to photon statistics are quite large. Nonetheless, these numbers are suggestive of two-sigma level upper limits to the polarization of SN 1994ae of less than 0.44% in unfiltered light and 0.66% in the R filter. At one-sigma levels, the upper limits of polarizations in the R filter and white light are about 0.38% and 0.33%, respectively. The counting rate on the supernova is about 800/sec in unfiltered light and 300/sec in the R-filter. The corresponding counting rate for the sky and host galaxy background is 200/sec in the unfiltered light and 30/sec in the R filter. The polarizations of the background are $P = 0.24 \pm 0.12\%$ at position angle 170° ± 14° in the R filter, and $P = 0.20 \pm 0.10\%$ at position angle 175° ± 14° in the unfiltered light. The errors introduced by uncertainties in the background estimate are therefore about 0.01% in the R filter and 0.03% in the unfiltered light, much smaller than the errors due to photon statistics.

Note that polarization in our Galaxy and in the host galaxy of the supernova is not subtracted from the above numbers. The importance of polarization due to the host galaxy can be estimated by applying the Serkowski interstellar polarization law if the reddening to the supernova is known. The extinction toward SN 1994ae can be obtained by comparing the colors reported by Patat (1994) with those of unreddened SN Ia. If the observations by Patat (1994) were indeed obtained while the supernova was near its maximum light, the measured color $V − R = 0.01$ then implies a higher reddening than for SN 1994D. Hamuy et
al. (1991) suggest that SN 1980N suffered very little extinction, \( E(B-V) \leq 0.1 \) mag. Assuming that there is no intrinsic difference in color between SN 1994ae and SN 1980N, the extinction to SN 1994ae can be estimated to be \( E(B-V) \sim 0.07 \). The polarization due to material lying along the line of sight can therefore conceivably be as large as 0.6%. If all the measured polarization is attributed to the interstellar material, the measured small polarization indicates that the extinction toward SN 1994ae is not very much larger than \( A_v \sim 0.2 \) mag. Because of the difficulties in subtracting polarization in the host galaxy, and the lack of a clear change of Stokes parameters during the two epochs of the observation, we can only set a loose upper limit of about 0.33% for the intrinsic polarization of SN 1994ae in unfiltered light. An additional source of uncertainty is that intrinsically subluminous SN Ia are redder. If SN 1994ae is subluminous, the red color could not be attributed to interstellar polarization, so it will be even more difficult to estimate the effect of the interstellar polarization.

### 3.3. SN 1994Y

SN 1994Y in NGC 5371 was discovered by W. Wren on July 31, 1994. It is located at about 28\arcsec west and 14\arcsec north of the galaxy’s nucleus (Wren 1994). There is a field star of about 13th magnitude located 61\arcsec west and 5\arcsec south of the supernova. The supernova was discovered before maximum light (Paik et al. 1995). It was classified by Clocchiatti et al (1994) and Jiang et al (1994) as a “Seyfert 1” subclass of Type-II supernovae (Filippenko 1989), or a Type-IIIn (Schlegel 1990). At the time of our observations (Feb. 1, 1995), the SN was 245 days past discovery and had faded significantly. This supernova shows very strong and narrow H\( \alpha \) emission lines, and a slow decline of luminosity quite similar to SN 1988Z (Filippenko 1995). There is no doubt that SN 1994Y is associated with dense circumstellar material, as in the case of SN 1988Z. Late spectra show narrow absorption features on top of the broad H\( \alpha \) emission line, which is another indication of dense circumstellar material (Wang et al. 1996). The aperture for the observations was about 4\arcsec in diameter. The polarimetry of this supernova is shown in Table 4.

The R filter is dominated by the H\( \alpha \) emission line with FWHM about 100\AA. The depolarizer does not work efficiently for such narrow emission features, and introduces large instrumental polarizations. To estimate this effect, we have observed several unpolarized and polarized standards in a filter with central wavelength 6573\AA and FWHM 121\AA. To estimate the level of the instrumental polarization introduced by the filter, we have also observed in the R filter without the depolarizer. The observed polarizations in the R and the narrow band filter without the depolarizer differ by only \( Q = 0.1\% \) and \( U = 0.05\% \). This indicates that the narrow band filter alone introduces little instrumental polarization. The instrumental polarization for the entire set up was found to be quite stable with \( Q = 1.20\% \) and \( U = 0.63\% \) in the narrow band filter during the course of this program. The data shown in Table 4 were corrected for these numbers. A similar method using the same instrument but with a different detector was also employed by Wills et al. (1992) on a polarimetric study of QSO IRAS 13349+2438, and yielded results consistent with other measurements.

In the R filter, the counting rates are 590/sec and 50/sec, centering on the supernova and on the sky background, respectively. The polarization of the sky background in the R filter is 2.4\( \pm 0.8\% \), where the error was determined from calculating the standard deviation from the mean value of the many background measurements. The maximum contribution to the observed polarization from the sky and host galaxy background is then 0.2\%, with the errors in background subtraction most likely to be around 0.07\%. Uncertainties in background subtraction in the other filters are 0.10\% (UF), 0.17\% (V), and 0.19\% (B). As shown in Table 4, errors due to background subtraction are much smaller than the errors due to photon statistics, the latter are thus the major uncertainties in this measurement.
The observed values of the polarization are significantly larger than the errors due to photon statistics, suggesting the integrated supernova light is indeed polarized. The observed polarization in the neighboring star is much smaller than that of the supernova, and is at a different position angle than the supernova. This suggests that the observed polarization of SN 1994Y is unlikely to be due to polarization in our Galaxy. This is consistent with the fact that there is no noticeable extinction in the direction to the host galaxy of SN 1994Y (Burstein and Heiles, 1984). Polarization due to interstellar material in the host galaxy is quite uncertain, but may well be as large as 1.0%. The significant change in polarization position angle in the R filter (169° ± 2°) compared with that in the unfiltered white light (23° ± 3°) points to the conclusion that interstellar polarization alone can not be responsible for the observed polarimetric data. This behavior of the polarimetric parameter fulfills criterion B of §1, and is indicative of the detection of intrinsic polarization of the SN 1994Y light.

It is useful to plot the polarimetric data on the Q − U plane, as shown in Fig.1. The solid line in the figure connects the data for the R filter and the unfiltered light. The dot-dashed lines which connect the data points to the coordinate origin are drawn for clarity. It is obvious that a straight line comfortably fits all the observed data points. This is a good indication that the observed polarization can be decomposed into two components with different position angles.

Further insights into the broad band polarimetry can be obtained with the help of spectroscopic data obtained at a comparable epoch, and by making use of equations (1) – (3) derived in §2. A spectrum of SN 1994Y, taken on Feb. 8, 1995 using the 2.1 meter telescope at the McDonald Observatory, is shown in Fig. 2. This spectrum is flux calibrated but no extinction correction was applied. The dominating features are a strong Hα emission line and a basically flat continuum. The narrow Hα emission line constitutes a significant fraction of the total flux from the supernova. The R filter is sensitive in a wavelength range 7000 ± 110 Å which covers the strong Hα emission line; while the B and V filters cover basically the spectral region with strong continuum and weak emission lines. The rotation of the polarization angle in the R filter is clearly a result of an intrinsic relative difference between the Hα line and the continuum. This behavior can not be produced by interstellar polarization alone.

The values of \( \epsilon(\lambda) \) for SN 1994Y derived from this spectrum are: 0.88, 0.82 and 0.47 for the filters B, V and R, respectively. The noise level of the present data for SN 1994Y is too high for a thorough analysis in a manner outlined in §2. In the following, we will make the further assumption that the emission lines are intrinsically unpolarized, \( Q_i = U_i = 0 \). Equation 1 then simplifies to,

\[
Q_o(B) = 0.88 Q_c(B) + Q_i(B),
\]
\[
Q_o(V) = 0.82 Q_c(V) + Q_i(V),
\]
\[
Q_o(R) = 0.47 Q_c(R) + Q_i(R),
\]

and

\[
Q_o(UF) = 0.72 Q_o(UF) + Q_i(UF).
\] (4)

The equations for U are the same as the above ones for Q. These equations can be solved if we apply the Serkowski law for interstellar polarization, and assume further that the polarization of the supernova continuum is wavelength independent as expected from polarization produced by electron scattering. With these assumptions we find the continuum polarization to be about \( P_c = 1.7\% \) at position angle 176°. The interstellar component peaks at wavelength 6000Å, the maximum polarization is 1.8%, and \( P_i(B) = 1.3\%, P_i(V) = 1.4\%, \) and \( P_i(R) = 1.3\% \), at position angle 63°. It should be remembered that the noise levels in our data for SN 1994Y are high and the interstellar polarization derived here suffers large...
uncertainties of about 0.7%. Furthermore, SN 1994Y is a peculiar type II supernova, and our polarimetric data were obtained long past maximum. The polarization mechanism in SN 1994Y may be very different from that assumed for SN 1993J in the analysis of Höflich et al. (1995). In particular, there is no justification for the assumption that electron scattering is the main source of polarization for SN 1994Y. Some entirely different mechanisms, such as the light echo model outlined in §4.2, are entirely possible. However, the method outlined here should prove useful for studies with high signal to noise ratio observations. Although it is presented here for broad band polarimetry, it can also be applied to spectropolarimetric data.

3.4. SN 1995D

SN 1995D in NGC 2962 was discovered on Feb. 10.756 UT at a magnitude of 14.0. It is located 11″ east and 90″ south of the center of NGC 2962 (Sumoto, 1995). Spectroscopic observations show that the supernova is of Type Ia discovered about one week before maximum (Benetti, Mendes de Oliveira, and Manchado 1995). Our polarimetric measurements were obtained on Mar. 3, 1995 when the supernova was still at maximum light and on Mar. 30, 1995 when it was about four weeks past maximum. The results are shown in Table 5.

The large separation between the supernova and the galaxy’s nucleus makes background subtraction much easier for this supernova. The counting rate centering on the supernova is typically 20 times that on the sky background. The polarization of the sky background close to SN 1995D is 2.1 ± 0.5%. The error due to background subtraction is then 0.025%. This is, again, much smaller than the errors due to photon statistics as shown in Table 5.

An upper limit of 0.2% for the polarization of SN 1995D can be obtained from Table 5. This upper limit applies to both the maximum light and about a month later. No attempt at observations in other filters was made since the detected amount of polarization was already very low. It is impossible to apply the two criteria listed in §2 for such a low degree of polarization.

3.5. SN 1995H

SN 1995H in NGC 3526 was discovered by J. Mueller on Feb. 24, 1995, and was classified as a Type II supernova by various observers (Mueller et al. 1995). It is located 20″ west and 8″ south of the host galaxy’s center. Spectroscopic observations showed that the supernova was several weeks after explosion when discovered. The spectra were also shown to be contaminated by emissions from the host galaxy.

Our polarimetric observations of SN 1995H were obtained on March 29-30, 1995 using an aperture of diameter about 4″. The seeing was typically 1″.5 and the weather was photometric. The supernova was about 4 weeks after discovery during these observations. The observations were obtained through B, V and R filters and in unfiltered white light. The aperture was shifted back and forth from the object and the sky close to the supernova for background subtraction. The locations for the sky backgrounds were selected in a way so as to cover the neighboring area as uniformly as possible. A field star at the south west side of the SN was also observed for information on polarization produced within our Galaxy. The results are shown in Table 6.

The field star was only a few arc minutes to the south west side of the supernova and the host galaxy. The average observed polarization for the field star is \( P = 0.11 \pm 0.07\% \) and \( \theta = 52^\circ.0 \pm 17^\circ.1, \)
which suggests that the field star is not significantly polarized. The Galactic extinction to NGC 3526 is $A_b = 0.08$ mag. The maximum interstellar polarization in the Galaxy is about 0.18%, consistent with the measurement for the field star. On the other hand, the measured polarization for SN 1995H in every band is considerably larger than that of the field star. We have also taken several exposures of the host galaxy in regions close to the supernova. An upper limit for the polarization of 0.4% was obtained for polarization of the host galaxy. The polarization due to dust in the Galaxy is too small to account for the observed polarization of SN 1995H. Polarization by the host galaxy is not clear, but is perhaps not much larger than 0.4 percent as measured in the light of the host galaxy. Because the supernova is bright, error due to background subtraction is about 0.02%, much smaller than those due to photon statistics.

SN 1995H is a typical SN II which showed P-Cygni absorption profiles of H$\alpha$ and H$\beta$ during the observations. A spectrum was obtained on Apr. 4, 1995 at the 2.1 meter telescope of the McDonald observatory. In principle, the same method we used in the analyses of SN 1994Y is also applicable to SN 1995H. The corresponding values of the continuum fraction, $\epsilon$, are 0.75, 0.64 and 0.71 for the V, R filters and the unfiltered white light, respectively. Unfortunately, our spectrum does not cover the wavelength range for the B filter. We note however, that as the fraction of the continuum photons decrease, there is a gradual change of the measured polarization angles from V filter ($170^\circ \pm 9^\circ$), to white light ($159^\circ \pm 5^\circ$), and to the R filter ($24^\circ \pm 7^\circ$). Note again that the R filter covers the region for H$\alpha$ emission which is the strongest emission and absorption feature in the entire spectral region. The change in position angle is significant from V filter to R filter, and cannot be attributed purely to interstellar polarization. It implies, just as for SN 1994Y, that the supernova light is intrinsically polarized.

4. Discussion

4.1. Supernovae with polarization measurements

We have observed five supernovae with broad band polarimetry. Among them, SN 1994Y and SN 1994H are of Type II, and SN 1994D, SN 1994ae and SN 1995D are of Type Ia. The observations show that the two SN II are polarized at a level of about 1.0%, while none of the Type Ia supernovae shows significant intrinsic polarization. The Type Ia supernovae were observed at different epochs after the outburst. No firm evidence of intrinsic polarization of Type Ia supernovae at any epoch can be established.

The supernovae for which we can find polarization measurements in the literature are shown in Table 7. The table gives the SN designation (column 1) and type (column 2), the parent galaxy (column 3), the approximate date of observation past maximum light (column 4), the representative value of the observed polarization (column 5), comments on the detection of intrinsic supernova polarization (column 6), and the references (column 7). In column 6, a positive detection means that the observed polarization satisfies at least one of the criteria listed in §2, while undetermined means that no firm evidence exists for any intrinsic polarization of the supernova.

The qualities of the measurements are very different for the supernovae listed in Table 7. The data on SN 1968L were reported by Serkowski (1970), but without any comments. As pointed out by Shapiro and Sutherland (1982), the extinction due to our own Galaxy alone is $A_v = 0.33$, which suggests that polarization due to the Galaxy alone could conceivably be as large as 1%. The measurement therefore has very little diagnostic value. The data on SN 1981B was quoted by Shapiro and Sutherland (1982) from Breger’s unpublished observations. The observations were conducted only once in unfiltered light, and are apparently insufficient to establish any useful conclusion for the intrinsic polarization of the supernova.
Spectropolarimetric observations of SN 1983G and SN 1983N were obtained by McCall et al. (1984) and McCall (1985). McCall et al. (1984) detected polarization of about 2% for SN 1983G with no clear changes of polarization parameters with wavelength. McCall et al. (1984) conclude that no intrinsic polarization is detectable. Their model analysis indicates that the apparent axis ratio of the expanding atmosphere was greater than 0.5. McCall (1985) also discussed spectropolarimetric data of SN 1983N, the only Type Ib SN with polarimetric data. The observations were obtained close to maximum light and covered the wavelength range between 3700 Å and 5200 Å. Preliminary reductions indicated that the polarization spectrum dips from about 1.4% to about 0.8% at the position of the Fe II peak centered on 4600 Å. The details of the data have not been published, but this behavior of polarization satisfies criterion $B$ in §2, and therefore implies intrinsic polarization of around the same level, 1%.

Wolstencroft and Kemp (1972) claim that both linear and circular polarization are detected for the Type Ia supernova SN 1972E. The measured linear polarization is at a level of $0.35 \pm 0.2\%$, while the degree of circular polarization is $-0.028 \pm 0.04\%$. As argued by Shapiro and Sutherland (1982), however, the lack of time or wavelength dependence in the measurements makes a determination of the magnitude of the intrinsic part of the polarization very difficult.

The linear polarization of SN 1975N in NGC 7723 was measured by Shakhovskoi (1976). The observations were made in three colors at epochs corresponding to maximum light and a month past maximum light, respectively. No clear evidence of time evolution or wavelength dependence of polarization parameters was recorded. The mean level of polarization is about 1.6% and the error is typically 0.2%. Because the extinction due to our Galaxy is likely to be small, Shakhovskoi (1976) argued that the polarization was intrinsic. As shown by Della Valle and Panagia (1992), however, the extinction due to the host galaxy can be as large as \( E(B-V) = 0.36 \). This would easily produce polarizations of a few percent. The observations of Shakhovskoi (1976) are plotted in Fig. 3, together with a fit to the Serkowski interstellar polarization law. The parameters for the model fit are $P_{max} = 1.6$ and $\lambda_{max} = 4200 \text{Å}$. The observations were satisfactorily fitted with typical residuals of 0.25%. SN 1975N, like other supernovae of Type Ia, shows no convincing evidence for intrinsic polarization. Note also that the derived wavelength for maximum polarization is low compared to the average of 5400 Å in the ISM of our Galaxy (Serkowski, Mathewson & Ford 1975), however, it is comparable with the value of 4300 Å found by Martin & Shawl (1979) for M31 and Hough et al. (1987) for Centaurus A (NGC 5128). This suggests that the aligned grains which contribute to the polarization are about 20% smaller than those in our Galaxy, assuming their chemical characteristics are the same.

SN 1986G in Centaurus A (NGC 5128) is another SN Ia with good polarimetric observations. Hough et al. (1987) report UBVRJH broad band polarimetry of SN 1986G, and show that the observed polarimetry can be well fitted by Serkowski’s law for interstellar polarization. The authors used SN 1986G to derive properties of dust distribution in the host galaxy of SN 1986G. They found no detectable intrinsic polarization for SN 1986G down to the noise level of about 0.1%.

Spyromilio and Baily (1992) report spectropolarimetry of the Type Ia supernova SN 1992A in the galaxy NGC 1038. The observations were obtained 2 weeks and 7 weeks after maximum light. The extinction towards the supernova is perhaps small, as no NaD lines are present at either the red shift of our Galaxy or the parent galaxy in an echelle spectrum. The mean level of polarization is around 0.3%, and is comparable in strength to the noise level. No polarization is detected across any of the spectral features.
4.2. Are Type Ia different from Type II and Type Ib/c?

It is remarkable that in none of the SN Ia events have we positively identified any intrinsic polarization, while five Type II supernovae are found to be intrinsically polarized. Although the number of the supernovae observed is small and the quality of the observations varies, the present study seems to suggest that there is a significant difference in polarized light between Type Ia and Type II supernova. The SN Ia are less likely to be polarized, while all SN II show polarization around 1%. The only Type Ib/c supernova with polarization measurements is SN 1983N, which seems to be intrinsically polarized from preliminary analyses (McCall 1985). Fully reduced data have not been published for SN 1983N, and with a single event no statistical conclusion can be reached.

Several mechanisms can be invoked to explain polarization in a supernova atmosphere. The conventional picture involves electron scattering in an asymmetric envelope (Shapiro & Sutherland 1982; Höflich et al., 1995, and references therein). The mechanism producing the asymmetry is not clear, but may perhaps be related to stellar rotation or the existence of a companion star. The asymmetries can also be produced by an asymmetric collapse or explosion, or due to a high velocity $^{56}$Ni clump (Chugai, 1992). To reproduce the observed amount of polarization for the observed Type II supernovae with an asymmetric envelope, the supernovae ejecta would have to possess asymmetries with major axis $\sim 1.5$ times longer than the minor axis. In this picture, our measurements would suggest that the supernova envelope is more asymmetric for Type IIs than for Type Ia’s. If this is the case, SN Ia might make better distance calibrators and SN II would have to be considered with considerable caution.

Scattering by dust particles in the circumstellar and interstellar material, the so-called “light echo” of a supernova, may also produce polarized light (Wang & Wheeler 1996a). In this picture, the supernova light is scattered by the circumstellar or interstellar dust, and due to the light travel time across the circumstellar or interstellar material, some photons from earlier epochs will be integrated into the observation. The scattered light will be highly polarized, and when the scattering material is asymmetrically distributed, the integrated scattered light can also be polarized. Chevalier (1986) studied this situation for a particular case with circumstellar density distribution given by $\rho = Cr^{-2}(1 - \beta \cos 2\phi)$, where $C$ is a constant, $\beta$ is a measurement of the asymmetry and $\phi$ is the angle from the symmetry axis. The integrated polarization of the scattered light can easily be as large as several tens of a percent. As can be derived from the equations given in Chevalier (1986), the total flux of the scattered light can be a few percent of that of the supernova near maximum light. This mechanism can therefore easily produce polarizations at a level of around 1%. Dust blobs ejected by the progenitor can be even more efficient in producing polarized light.

For such a dust scattering mechanism, our observations would imply that Type II supernovae are more likely to be associated with a significant circumstellar material than Type Ia supernovae. In this case, the polarization measurements will not endanger the distance determination using the expanding photosphere method for Type II supernova (Eastman & Kirshner, 1989).

4.3. Progenitors of Supernovae

Polarimetry can set strong constraints on possible progenitors of supernovae. The low level of the observed polarization in Type Ia, in particular, may put strong constraints on various models for Type Ia. A popular model for Type Ia is that they arise in a binary system when a red-giant companion to a previously formed white dwarf finally evolves and transfers mass to the white dwarf, leading to thermonuclear explosion of the white dwarf (Iben & Tutukov 1984; Paczynski 1985; Wheeler & Harkness
1990; Wheeler 1996). The observed low level of polarization may therefore give interesting constraints on progenitor system models with cool companions such as cataclysmic variables and symbiotic systems. Some of these systems show polarizations as high as 15% (e. g. Aspin 1988; Magalhaes & Schulte-Ladbeck 1988). Scattering by circumstellar dust particles plays an important role in producing the observed polarization. It is then interesting to ask why, if they result from systems with high polarization, SN Ia are not polarized. The low level of polarization for Type Ia may also help to clarify the link between novae and supernovae. There is both observational and theoretical evidence that novae are antithetical to SN Ia. Polarimetry of novae generally show, in contrast to SN Ia, polarization at a level around 1% (Bjorkman et al. 1994). Does this rule out nova-like systems as progenitors of SN Ia? Another possibility is that SN Ia ejecta expand much faster than nova ejecta, and the asymmetries or dust particles are quickly destroyed. A closer look into these problems is necessary and is underway (Wang & Wheeler 1996b).

Another question is why SN II are polarized? While models of SN Ia generally involve binary systems, most models of SN II, on the other hand, involve only massive single stars. If the observed polarization is due to an asymmetric ejecta, it then implies that the supernova atmosphere or circumstellar environment are non-spherical. What is producing the asphericity? Can rotation alone produce asymmetries large enough to explain the asymmetry? Does this imply that all or most of the SN II are produced by binary systems as suggested for SN 1987A (Podsiadlowski 1992) and SN 1993J (Podsiadlowski et al. 1993; Shigeyama et al. 1994; Wheeler et al. 1993; Woosley et al. 1994) as well?

4.4. Perspectives of Future Supernova Polarimetry

It is obvious that more polarimetric data are needed for a clear picture of the geometric structure of supernovae. We have suggested that there may be a significant difference in polarization between supernova of Type Ia and Type II. More observations are critical to verify this proposed dichotomy and to determine if SN Ib/c are as commonly polarized as SN II. We need to understand the origin of the polarization of SN II and why, if they occur in binary systems with substantial mass transfer, SN Ia display so little polarization.

An enlarged sample of high quality polarimetric data of supernovae is not only important for studying the supernova phenomenon, but may also be useful for the study of the physical properties of the interstellar medium. If, as suggested earlier, Type Ia supernovae are not intrinsically polarized, we should then be able to use them as good indicators of interstellar polarization along the line of sight to the supernova. This will be an important method for gaining insight into interstellar polarization in galaxies other than our own.

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Fig. 1.— The observed polarization of SN 1994Y on the Q-U plane.
Fig. 2.— The observed spectrum of SN 1994Y (upper panel, solid line) and the transmission curves (lower panel) of the filters used in the polarimetric observations. The dashed line defines the continuum fraction of the observed spectrum, and the dotted line represents the fractional continuum dip.
Fig. 3.— The polarizations of SN 1975N fitted by the Serkowski law for interstellar polarization. Observations of Nov. 7, 1975 (circles), Nov. 8, 1975 (open squares), and Dec. 11, 1975 (solid squares) are plotted. The central wavelengths of the Nov. 8 and Dec. 11 data were shifted by +100Å and -100Å, respectively, for clarity. The success of the fit implies that no intrinsic polarizations can be identified down to the noise level of the data (∼ 0.2%).
Table 1. Log of Observations

| Date (UT)       | SN    | Type | Polarimeter   |
|-----------------|-------|------|---------------|
| Mar 10, 11, 12, 1994 | SN 1994D | Ia   | Polarimeter   |
| Jan 31-Feb 1, 1995 | SN 1994Y | II   | Polarimeter   |
| Feb. 8, 1995 | SN 1994Y | II   | Spectrometer  |
| Jan 2, 30, 31, Feb 1, 1995 | SN 1995ae | Ia   | Polarimeter   |
| Mar 3, 30, 1995 | SN 1995D | Ia   | Polarimeter   |
| Mar 30, 31, 1995 | SN 1995H | II   | Polarimeter   |
| Apr 4, 1995    | SN 1995H | II   | Spectrometer  |
Table 2. Broad Band Polarimetry of SN 1994D

| UT (1994) | Object | Filter | U(%)  | Q(%)  | P(%)  | θ     | δ(%)  |
|-----------|--------|--------|-------|-------|-------|-------|-------|
| Mar 10    | SN 1994D | UF     | -0.11 | -0.27 | 0.29  | 124°±4°| 0.04  |
| Mar 11    | SN 1994D | UF     | 0.11  | 0.27  | 0.29  | 34°±5°| 0.05  |
| Mar 12    | SN 1994D | UF     | 0.05  | -0.25 | 0.25  | 141°±4°| 0.04  |
Table 3. Broad Band Polarimetry of SN 1994ae

| UT (1995) | Object      | Filter | O-Time (s) | U(%) | Q(%) | P(%) | δ(%) |
|-----------|-------------|--------|------------|------|------|------|------|
| Jan 02.35 | SN 1994ae   | R      | 800+400    | -0.56| -0.25| 0.61 | 0.45 |
| Jan 02.37 | SN 1994ae   | UF     | 800+400    | -0.22| 0.20 | 0.30 | 0.16 |
| Jan 30.29 | SN 1994ae   | UF     | 400+400    | 0.33 | 0.25 | 0.41 | 0.35 |
| Jan 30.32 | SN 1994ae   | R      | 3000+1800  | 0.54 | 0.33 | 0.59 | 0.37 |
| Jan 31.25 | SN 1994ae   | UF     | 400+300    | 0.21 | 0.18 | 0.28 | 0.38 |
| Feb 01.27 | SN 1994ae   | UF     | 1600^a     | 0.08 | 0.24 | 0.25 | 0.18 |

^aBackground estimated from variable aperture size.
Table 4. Broad Band Polarimetry of SN 1994Y

| UT (1995) | Object      | Filter | O-Time (s) | Q(%) | U(%) | P(%) | θ       | δ(%) |
|-----------|-------------|--------|------------|------|------|------|---------|------|
| Jan 31.31 | Field Star  | R      | 1500+1200  | 0.15 | 0.11 | 0.19 | 18°±11° | 0.07 |
| Jan 31.41 | SN 1994Y    | R      | 3600+3000  | 2.48 | -0.96| 2.66 | 169°±2° | 0.20 |
| Feb 01.31 | SN 1994Y    | UF     | 3000+3000  | 0.89 | 0.95 | 1.30 | 23°±3°  | 0.13 |
| Feb 01.47 | SN 1994Y    | V      | 1100+800   | 0.35 | 1.25 | 1.30 | 37°±11° | 0.51 |
| Feb 01.55 | SN 1994Y    | B      | 1100+800   | 0.54 | 1.11 | 1.23 | 32°±15° | 0.63 |
Table 5. Broad Band Polarimetry of SN 1995D

| UT (1995) | Object   | Filter | O-Time (s) | Q(%) | U(%) | P(%) | δ(%) |
|-----------|----------|--------|------------|------|------|------|------|
| Mar 03.24 | SN 1995D | UF     | 600        | 0.07 | 0.05 | 0.09 | 0.15 |
| Mar 30.15 | SN 1995D | UF     | 1500+600   | -0.05| -0.05| 0.07 | 0.05 |
| Mar 30.19 | SN 1995D | R      | 1600+600   | -0.00| 0.02 | 0.02 | 0.08 |
| UT (1995) | Object    | Filter | O-Time(s) | Q(%)   | U(%)  | P(%)    | $\theta$ | $\delta$(%) |
|-----------|-----------|---------|-----------|--------|-------|---------|----------|-------------|
| Mar 30.23 | Field Star| UF      | 400+200   | -0.00  | 0.09  | 0.09    |          | 0.08        |
| Mar 31.16 | SN 1995H  | UF      | 800+400   | 0.67   | -0.60 | 0.90    | 159°±5°  | 0.15        |
| Mar 31.18 | Field Star| UF      | 200+100   | 0.05   | 0.15  | 0.16    |          | 0.11        |
| Mar 31.20 | SN 1995H  | R       | 1200+800  | 0.56   | 0.62  | 0.84    | 24°±7°   | 0.21        |
| Mar 31.25 | SN 1995H  | V       | 800+800   | 0.94   | -0.34 | 1.00    | 170°±9°  | 0.30        |
| Mar 31.28 | SN 1995H  | B       | 1000+600  | -0.49  | 1.39  | 1.47    | 55°±7°   | 0.35        |
Table 7. Supernovae with Polarimetric Measurements

| SN          | Type | Galaxy   | Date | < $P$ > (%) | Detection | Ref. |
|-------------|------|----------|------|-------------|-----------|------|
| SN 1968L    | II   | NGC 5236 | ∼ 0  | 0.2         | Undetermined | 1, 2 |
| SN 1970G    | II   | NGC 5457 | ∼ 30 | 0.5         | Yes       | 3    |
| SN 1972E    | Ia   | NGC 5253 | ∼ 30 | 0.35±0.2    | Undetermined | 4    |
| SN 1975N    | Ia   | NGC 7723 | ∼ 0.34 | 1.5       | Undetermined | 5    |
| SN 1981B    | Ia   | NGC 4536 | 56   | 0.41±0.14   | Undetermined | 6    |
| SN 1983G    | Ia   | NGC 4753 | −2   | 2.0         | Undetermined | 7, 8 |
| SN 1983N    | Ib   | NGC 5236 | 1    | Yes?        |           | 7, 8 |
| SN 1986G    | Ia   | NGC 5128 | −9, −8 | 5.2       | Undetermined | 9    |
| SN 1987A    | II   | LMC      | −84–176 | 0.5      | Yes       | 10, 11 |
| SN 1992A    | Ia   | NGC 1308 | ∼ 12 | 0.3         | Undetermined | 12   |
| SN 1993J    | IIb  | NGC 3031 | ∼ 3  | 1.5         | Yes       | 13   |
| SN 1994D    | Ia   | NGC 4526 | −10  | 0.3         | Undetermined | 14   |
| SN 1994Y    | II   | NGC 5371 | ≥ 180 | 1.5       | Yes       | 14   |
| SN 1994ae   | Ia   | NGC 3370 | ≥ 30 | 0.3         | Undetermined | 14   |
| SN 1995D    | Ia   | NGC 2962 | 14, 41 | 0.2      | Undetermined | 14   |
| SN 1995H    | II   | NGC 3526 | ≥ 33 | 1.0         | Yes       | 14   |

*Approximate date of observations past maximum light.

References. — (1) Wood & Andrews (1974); (2) Serkowski (1970); (3) Shakhovskoi & Efimov (1973); (4) Woltencroft & Kemp (1972); (5) Shakhovskoi (1976); (6) Shapiro & Sutherland (1982); (7) McCall et al. (1984); (8) McCall (1985); (9) Hough et al. (1987); (10) Cropper et al. (1988); (11) Mendez et al. (1988); (12) Spyromilio and Bailey (1993); (13) Trammell, Hines & Wheeler (1993); (14) this work.
**Fig. 1** – The observed polarization of SN 1994Y on the Q-U plane. **Fig. 2** – The observed spectrum of SN 1994Y (upper panel, solid line) and the transmission curves (lower panel) of the filters used in the polarimetric observations. The dashed line defines the continuum fraction of the observed spectrum, and the dotted line represents the fraction due to emission lines. **Fig. 3** – The polarizations of SN 1975N fitted by the Serkowski law for interstellar polarization. Observations of Nov. 7, 1975 (circles), Nov. 8, 1975 (open squares), and Dec. 11, 1975 (solid squares) are plotted. The central wavelengths of the Nov. 8 and Dec. 11 data were shifted by +100 Å and -100 Å, respectively, for clarity. The success of the fit implies that no intrinsic polarizations can be identified down to the noise level of the data (∼0.2%).