A&A 432, L53–L55 (2005)
DOI: 10.1051/0004-6361:200500018

Astronomy & Astrophysics

Optical polarimetry of SN 2004bv★

A. Pereyra and A. M. Magalhães

Departamento de Astronomia, IAG, Universidade de São Paulo, Rua do Matão 1226, São Paulo, SP 05508-900, Brazil
e-mail: antonio@astro.iag.usp.br

Received 13 December 2004 / Accepted 28 January 2005

Abstract. We report R band imaging polarimetry of SN 2004bv in NGC 6907 on June 19.299 (UT middle of observation), i.e., two weeks after maximum. We have obtained $[0.11 \pm 0.02]$% at position angle 118.°7 for the observed polarization. The average foreground polarization from field objects was estimated to be $[0.12 \pm 0.02]$% at PA 163.°4, consistent with the low reddening towards the SN. Spectroscopy reported elsewhere does not show the Na I D line in the SN spectrum suggesting that the interstellar polarization in the host galaxy is negligible. If this is the case, the data are consistent with SN 2004bv being close to spherically symmetric. The estimated R magnitude at the time of the observations was 14.5 mag. An upper limit to the SN H magnitude on June 20.259 (UT) was 13.9 mag. The role that small and medium-sized telescopes may play in studying the symmetry and time evolution of SN explosions is pointed out.

Key words. polarization – supernovae: individual: SN 2004bv

1. Introduction

SN 2004bv was discovered by Nakano et al. (2004) on May 24.70 (UT) located 3.″8 West and 20.″7 South of the center of NGC 6907. Spectroscopy near maximum brightness (Li et al. 2004) showed that it is a Type Ia supernova (SN). Li et al. (2004) point out that SN 2004bv resembles SN 1991T (Filipenko et al. 2004) and SN 1999aa (Li et al. 2004).

Polarimetry is a powerful tool to help to understand the geometry of SN explosions. A bi-modal trend is now accepted with Type Ia SNs having low or null polarization and core collapse SNs (Types II, Ib and Ic) showing significant polarization (Wang 1996). This trend implies that Type Ia SNs are close to having spherically symmetric geometry while core collapse SNs are non-spherically symmetric. Nevertheless, in the past few years exceptions to this Type Ia pattern appeared (Howell et al. 2001; Wang et al. 1997, 2003, 2004, 2005). New polarimetric data are hence needed to clarify this picture.

In this letter we present optical linear polarization measurements in the R band of SN 2004bv obtained nearly two weeks after the optical maximum. The observations and data reduction are presented in Sect. 2 and a comparison of our results with previous works, along with final comments, are in Sect. 3.

2. Observations

The observations were made using IAGPOL, the IAG imaging polarimeter (Magalhães et al. 1996), at the f/13.5 Cassegrain focus of the 0.6m IAGUSP telescope. It is sited at the Observatório do Pico dos Dias (OPD), Brazil (latitude −22°). When in linear polarization mode, the polarimeter uses a rotatable, achromatic half-wave retarder followed by a calcite Savart plate. This provides two images of each object in the field, separated by 1mm (corresponding to 25.″5 at the telescope's focal plane) and with orthogonal polarizations (see Fig. 1). One polarization modulation cycle is covered for every 90° rotation of the waveplate. The polarimeter is highly efficient and photon-noise limited for point sources. The simultaneous imaging of the two beams allows observing under non-photometric conditions and at the same time the sky polarization is practically canceled. Additional details about this polarimeter can be found in Magalhães et al. (1996), Pereyra (2000) and Pereyra & Magalhães (2002).

The data were collected on June 19.299 (UT at the middle of the observation). The measurements were made using a standard R filter with a 1024×1024 CCD, covering an area of $\sim 10' \times 10'$. A sequence of eight waveplate positions separated by 22.°5 was used. The integration time per waveplate position was 5 min and the total observing time was ($5 \times 8 =$) 40 min.

For the data reduction process, we follow the procedure indicated in Pereyra & Magalhães (2002) using the PCCDPACK package (Pereyra 2000), written for the IRAF[1] environment. Correction to convert the resulting instrumental polarization position angle to the equatorial system was found from observations of polarized standard stars taken on the same night. The instrumental polarization, obtained from observations of

★ Based on observations obtained at the *Observatório do Pico dos Dias*, LNA/MCT, Itajubá, Brazil.

[1] IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy, Inc., under cooperative agreement with the National Science Foundation.

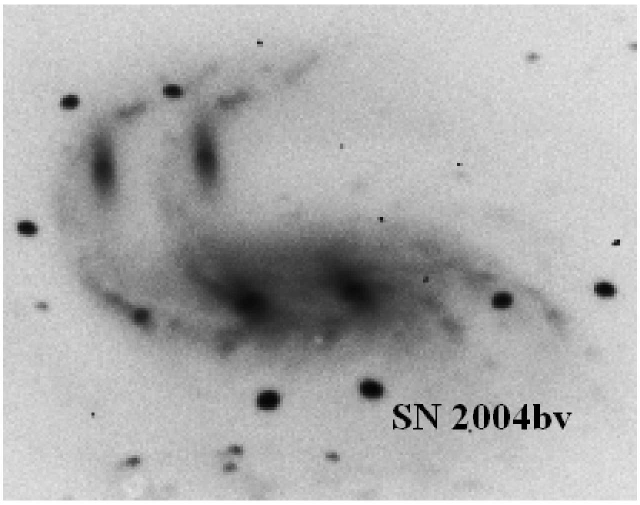

Fig. 1. Image of the SN 2004bv field obtained with the IAGPOL polarimeter in R filter on June 19.299. Each object has two images, each orthogonally polarized to the other, due to the polarimeter's calcite prism. The supernova is located 3.″8 West and 20.″7 South of the center of NGC 6907. North is to the top and East is to the left.

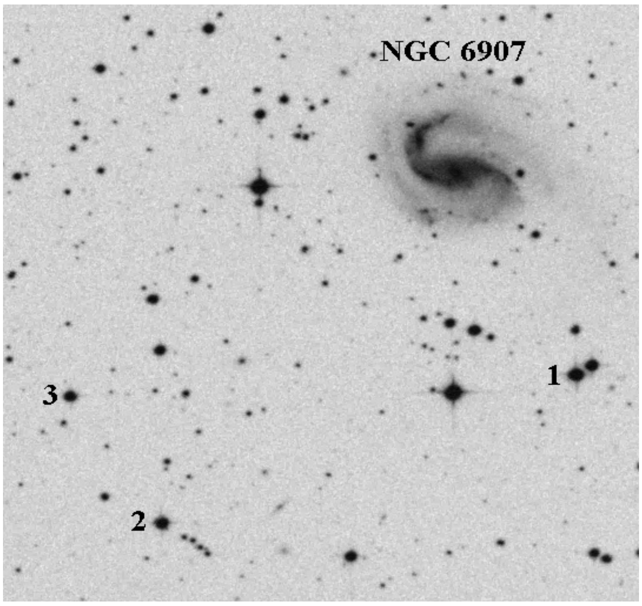

Fig. 2. Field objects around NGC 6907 used to calculate the Galactic foreground polarization towards SN 2004bv: (1) USNO A-2.0 0600-42605819; (2) USNO A-2.0 0600-42615316; (3) USNO A-2.0 0600-42617305. This DSS2 Red image covers (∼9′ × 9′). North is to the top and East is to the left.

unpolarized stars, was smaller than 0.04%, a typical value for the polarimeter/telescope combination. No correction for instrumental polarization was hence applied to the data.

The effect on the data of the sky gradient induced by the host galaxy was checked using different and increasing sky annulus (between 3.″6 and 42″). Then, the average (weighted by the errors) linear observed polarization (P) and the polarization position angle (θ, measured from north to the east) for SN 2004bv, itself measured with an aperture radius of 3″, were $P = [0.11 \pm 0.02]\%$ and $\theta = 118.^\circ7$. The polarization 95% confidence interval for this polarimetric signal-to-noise is [0.07, 0.15]% (Simmons & Stewart 1985). From field stars (see Sect. 2.1 below), the estimated SN R magnitude at the time of the observations was found to be 14.5 mag.

Images in the H (1.65 μm) band were obtained on June 20.259 (UT) with the same telescope and the observatory's near-IR CamIV camera. The total integration time for this infrared data was 5 min. Five frames dithered by 30″ were used to generate the sky frame. Individual frames were sky-substracted, flat-fielded, aligned and added before the photometry procedures. An upper limit of 13.9 mag for the SN was obtained.

2.1. Foreground polarization

The Galactic foreground polarization for SN 2004bv was estimated using field stars on the same CCD frames. The PCCDPACK package provides the polarization of each object in the CCD frames, as well as the error-weighted average Stokes parameters (Q and U) for all the objects considered. We take these parameters as the average foreground polarization towards the supernova.

The objects used (Fig. 2) were USNO A-2.0: 0600-42605819, 0600-42615316 and 0600-42617305. Their average polarization was measured to be $P = [0.12 \pm 0.02]\%$; $\theta = 163.^\circ4$. This measurement is below the expected maximum polarization (∼9$E(B-V)$, Serkowski et al. 1975) towards the supernova if a Galactic reddening is assumed ($E(B-V) = 0.064$, Schlegel et al. 1998). This small $E(B-V)$ towards the host galaxy NGC 6907 ($l = 18.^h9$, $b = -30.^\circ8$) is thus consistent with the negligible Galactic foreground polarization we found.

Li et al. (2004) do not report Na I D line in the spectrum and the low polarization for SN 2004bv would indicate also that the interstellar polarization in the host galaxy is negligible. As a check, we measured the galaxy nucleus with an aperture radius of 1.8″ and found it to be polarized at a level of $[0.26 \pm 0.07]\%$ at PA $155.^\circ2$. This value, and especially its polarization angle, is very close to the Galactic foreground polarization found above. Hence, the data are consistent with SN 2004bv being close to spherically symmetric.

An updated light curve for SN 2004bv is shown in Fig. 3. We included the R and H magnitude obtained by us at the time of our observations. The last ones are consistent with a Type Ia SN ∼ two weeks after the optical maximum (∼Jun. 04).

3. Comments

As pointed out in Sect. 1, in general most Type Ia SN with polarimetric data (∼15% of total Type Ia SNs) present low (observed or intrinsic) polarization. Examples of this pattern are SN 1972E (0.35%), SN 1981B (0.41%), SN 1992A (0.3%), SN 1994D (0.3%), SN 1994ae (0.3%), and, SN 1995D (0.2%), (Wang et al. 1996); and, SN 2002el (<0.2%), (Wang 2002). This low polarization indicates that the explosions in Type Ia SNs are preferentially spherically symmetric. The negligible optical polarization value obtained by us for SN 2004bv seems to be consistent with this overall trend.

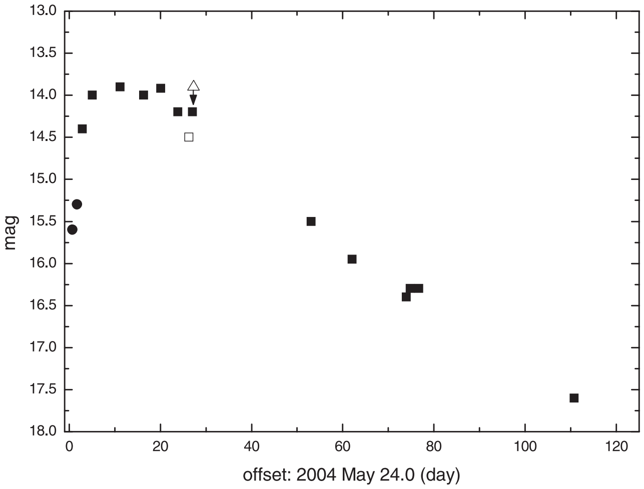

Fig. 3. Light curve for SN 2004bv from the International Supernovae Network (`http://www.supernovae.net/isn.htm`). Black dots are unfiltered data and black squares *R* filter data. Our measurements in *R* (on June 19.299) and *H* (on June 20.259, upper limit) are indicated by the open square and triangle, respectively.

However, recent polarimetric studies revealed a few Type Ia SN with intrinsic linear polarization and evidence for asymmetric explosions was claimed (Howell et al. 2001; Wang et al. 1997, 2003, 2004, 2005). In SN 1996X, Wang et al. (1997) found a low intrinsic polarization (~0.3%) and an asphericity of ~11% in the chemical distribution in the region of partial burning. In SN 1999by (Howell et al. 2001), an intrinsic polarization of ~0.8% was observed and interpreted as produced by radiation from an oblate or prolate distribution of scattering electrons with an asymmetry in the range of 17%–50%, depending on the inclination of the object relative to the line of sight. In SN 2001el (Wang et al. 2003), prior to optical maximum, the linear polarization of the continuum was ~0.2%–0.3% with a significant polarization (~0.7%) probably due to the Ca II IR triplet. The polarization was nearly undetectable a week after optical maximum. The continuum was modeled in terms of an oblate spheroid with a minor to major axis ratio of ~0.9 (asymmetry ~10%) if seen equator-on. Finally, in SN 2004dt (Wang et al. 2005), prior to optical maximum, the level of continuum polarization was as low as 0.2%–0.3% but the variation of the polarization across some of the Si II lines approached 2%, making SN 2004dt the most highly polarized SN Ia ever observed. It was interpreted as a richly-structured, partially burned silicon layer with substantial departure from spherical symmetry.

Less than 30% of Type Ia SNs with polarization measurements have intrinsic polarization estimated. Such estimates are nevertheless crucial to properly infer any asymmetries. If our observed polarization of SN 2004bv is representative of its intrinsic polarization, it would imply a deviation from spherical symmetry of less than 10% (Höflich 1991). However, calculating the polarization from new SN models (e.g., Ghezzi et al. 2004; Kasen et al. 2003, 2004) as well as new polarimetric data are needed to better ascertain the importance of asymmetries in Type Ia SN explosions. Time evolution of SN polarization is another important topic to be explored as shown by Wang et al. (2003) in SN 2001el when a polarization decrease was observed through a monitoring campaign that covered from day −4 to day 41 around maximum.

In this regard, we have shown here that valuable polarimetric data for relatively bright, nearby supernovae can be obtained from small (or medium-sized) telescopes if the time of observations can be properly scheduled and if there is an on-going polarimetric monitoring program. In particular, a medium-sized (~2.5 m) robotic telescope with polarimetric capability (e.g., Magalhães et al. 2005) would be a valuable tool for studying SN (and GRB) explosions (with $V \lesssim 21$ mag). This is of special importance for temporal evolution coverage since time intensive observations are often prohibitive with large telescopes.

Acknowledgements. The authors wish to thank the referee L. Wang for his comments and suggestions that helped to improve this letter. A. P. is thankful to FAPESP (grant 02/12880-0) and A.M.M. to CNPq for financial support. Polarimetry at IAG-USP is supported by FAPESP grant 01/12589-1. This research has made use of the SIMBAD database and VizieR catalogue access tools operated at CDS, Strasbourg, France. Also, this publication makes use of data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration (NASA) and the National Science Foundation.

References

Filippenko, A. V., Richmond, M. V., Matheson, T., et al. 1992, ApJ, 384, L15
Foley, R. J. 2004, IAU Circ., 8348
Ghezzi, C. R., de Gouveia Dal Pino, E. M., & Horvath, J. E. 2004, MNRAS, 348, 451
Höflich, P. 1991, A&A, 246, 481
Howell, D. A., Höflich, P., Wang, L., & Wheeler, J. C. 2001, ApJ, 556, 302
Kasen, D., Nugent, P., Wang, L., et al. 2003, ApJ, 593, 788
Kasen, D., Nugent, P., Thomas, R. C., & Wang, L. 2004, ApJ, 610, 876
Li, W., Filipenko, A. V., & Treffers, R. R. 2001, ApJ, 546, 734
Li, W., Foley, R. J., & Filipenko, A. V. 2004, IAU Circ., 8345
Magalhães, A. M., Rodriguez, C. V., Margoniner, V. E., Pereyra, A., & Heathcote, S. 1996, ed. W. G. Roberge, & D. C. B. Whittet, ASP Conf. Ser., 97, 118
Magalhães, A. M., Pereyra, A., Melgarejo, R., et al. 2005, in Astronomical Polarimetry – Current Status and Future Directions, ed. A. Adamson, C. Aspin, C. Davis, & T. Fujiyoshi, ASP Conf. Ser. (San Francisco: ASP), in press
Nakano, S., Kushida, R., & Kushida, Y. 2004, IAU Circ., 8344
Pereyra, A. 2000, Ph.D. Thesis, Instituto Astronômico e Geofísico, Universidade de São Paulo
Pereyra, A., & Magalhães, A. M. 2002, ApJS, 141, 469
Schlegel, D. J., Finkbeiner, D. P., & Davis, M. 1998, ApJ, 500, 525
Serkowski, K., Mathewson, D. L., & Ford, V. L. 1975, ApJ, 196, 261
Simmons, J. F. L., & Stewart, B. G. 1985, A&A, 142, 100
Wang, L., Wheeler, J. C., Li, Z., & Clocchiatti, A. 1996, ApJ, 467, 435
Wang, L., Wheeler, J. C., & Höflich, P. 1997, ApJ, 476, L27
Wang, L. 2002, IAU Circ., 7954
Wang, L., Baade, D., Höflich, P., et al. 2003, ApJ, 591, 1110
Wang, L., Baade, D., Höflich, P., et al. 2004, ApJ, 604, L53
Wang, L., Baade, D., Höflich, P., et al. 2005, ApJ, submitted [arXiv:astro-ph/0409593]