Fall 11-12-2003

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**The association of a supernova with GRB 030329[1,2] strongly supports the collapsar model[3] of $\gamma$-ray bursts (GRBs), where a relativistic jet[4] forms after**

**the progenitor star collapses. Such jets cannot be spatially resolved because of their cosmological distances. Their existence is conjectured based on breaks in GRB afterglow light curves and the theoretical desire to reduce the GRB energy requirements. Temporal evolution of polarization[5,6,7] may provide independent evidence for the jet structure of the relativistic outflow. Small-level polarization (∼1-3%)[8−17] has been reported for a few bursts, but the temporal evolution of polarization properties could not be established. Here, we report polarimetric observations of the afterglow of GRB 030329 with high signal-to-noise and high sampling frequency. We establish the polarization light curve, detect sustained polarization at the percent level, and find significant variability. The data imply that the afterglow magnetic field has small coherence length and is mostly random, probably generated by turbulence, in contrast with the high polarization detected in the prompt $\gamma$-rays from GRB 021206[18]. Our results suggest a different structure and origin of the magnetic field in the prompt vs. afterglow emission regions.**

GRB 030329 triggered the High Energy Transient Explorer, HETE-II, on March 29, 2003 (11:37:14.67 UT)[19]. The discovery of the burst optical afterglow[20,21] was quickly followed by a redshift measurement[22] for the burster of z=0.1685 (∼800 Mpc), thus making GRB 030329 the second closest long-duration[23] GRB ever studied, after GRB 980425[3]. The proximity of GRB 030329 resulted in very bright prompt and afterglow emission, leading to the best-sampled afterglow to date. Detailed optical spectroscopy revealed an underlying supernova (SN 2003dh)[1,2] with an astonishing spectral similarity to SN 1998bw (at z=0.0085, associated with GRB 980425[3]), thus strongly supporting the link of long-duration GRBs with core-collapse supernovae.

The apparent brightness of GRB 030329 also afforded a unique opportunity to study the temporal evolution of polarization in the afterglow phase. Previous single measurements found low-level (1-3 %) polarization[8−15] in optical afterglows, and the only reports on variable polarization[16,17] were based on few measurements with different instruments and modest signal-to-noise. We have overcome the previous sampling limitations with 31 polarimetric observations of the afterglow of GRB 030329 obtained with the same instrumentation (plus few more with different instruments) over a time period of 38 days for a total of an unprecedented ∼50 hours of observations with an 8 m telescope. For the first time we establish a polarization light curve for an optical gamma-ray burst afterglow.

We performed relative photometry, and derived from each pair of simultaneous measurements at orthogonal angles the Stokes parameters U and Q. In order to obtain the intrinsic polarization of the GRB afterglow, we have to correct for Galactic interstellar polarization (mostly due to dust). We performed imaging polarimetry to derive the polarization parameters of seven stars in the field of GRB 030329, and obtained an interstellar (dust) polarization correction of 0.45% at position angle 155deg. Subtraction of the mean foreground polarization was performed in the Q/U plane ($Q_{fp}$=0.0027±0.0013, $U_{fp}$=-0.0033±0.0017). Figure 1 shows an R band image of the GRB 030329 field with the polarization "vectors" superimposed.

The temporal evolution of the degree and angle of polarization together with the R band photometry is shown in Figure 2. This figure demonstrates the presence of non-zero polarization, $\Pi \sim$0.3-2.5 % throughout a 38-day period, with significant variability in degree and angle on time scales down to hours. Further, the spectropolarimetric data of the first three nights as well as the simultaneous R and K band imaging polarimetry during the second night show that the relative polarization and the position angle are wavelength independent (within the measurement errors of about 0.1 %) over the entire spectral range. These data imply that polarization due to dust in the host galaxy of GRB 030329 does not exceed ~0.3 %. Dust destruction in the vicinity of the gamma-ray burster due to the strong radiation field would result in a monotonically decreasing polarization degree at constant position angle, which is not observed during the first days. We therefore conclude that the bulk of the observed variability is intrinsic to the afterglow.

Figure 2 shows that while the polarization properties show substantial variability (for which no simple empirical relationship is apparent), the R band flux is a sequence of power laws. During each of the power law decay phases the polarization is of order few percent, different from phase to phase, and variable within the phase, but not in tandem with the "bumps and wiggles" in the light curve. We observe a decreasing polarization degree shortly after the light curve break at ~0.4 days (as determined from optical[21,24] and X-ray data[25,26]). Rapid variations of polarization occur ~1.5 days after the burst, and could be related to the end of the transition period towards a new power law phase starting at ~1.7 days. Polarization eventually rises to a level of ~2 %, which remains roughly constant for another two weeks. At late time the underlying Type Ic SN 2003dh[1,2] increasingly contributes to the total light and probably also to the observed polarization properties. Asymmetries in this type of supernova can produce polarization of order 1 %[27,28], as we observe towards the end of our campaign.

GRB 030329 belongs to a growing group of bursts for which densely monitored afterglow light curves show significant "bumps" and "wiggles" relative to a simple power law decay (most notably GRB 021004 and GRB 011211). These bumps and wiggles complicate the interpretation of the polarization properties. While the rapid decrease in polarization degree during the first night is consistent with the model predictions[5,6,7], the position angle changes are not, and thus it remains to be proven whether or not these early polarization data support the break at 0.4 days as due to a jet. A connection to theoretical models throughout the entire period covered in Fig. 2 is a daunting task. A detailed comparison of our data with characteristic features of various theoretical models is beyond the scope of this paper, and will be presented elsewhere.

In summary, our data constitute the most complete and dense sampling of the polarization behaviour of a GRB afterglow to date. For GRB 030329 we conclude that the afterglow polarization probably did not rise above ~2.5 % at any time, and that the polarization did not correlate with the flux. The low level of polarization implies that the components of the magnetic field parallel and perpendicular to the shock do not differ by more than ~10 %, and suggests an entangled magnetic field, probably amplified by turbulence behind shocks, rather than a pre-existing field. This is in contrast with the high level of polarization detected in the prompt $\gamma$-rays from GRB 021206[18] and suggests a different structure and origin of the magnetic field in the prompt vs. afterglow emission regions. Evolving polarization properties provide a unique diagnostic tool for GRB studies, and the extremely complex light curve of the optical afterglow of GRB 030329 emphasises that measurements should be carried out with high sampling frequency.

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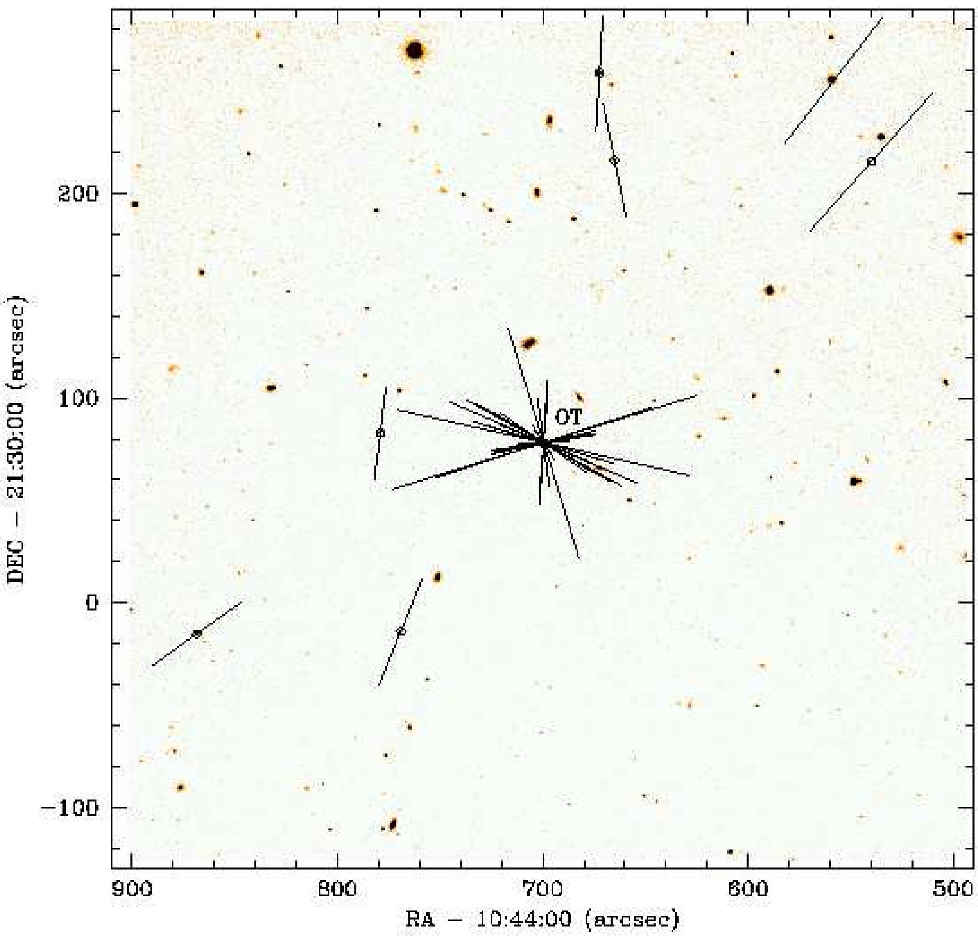
Acknowledgements

This work is primarily based on observations collected at ESO, Chile, with additional data obtained at the German-Spanish Astronomical Centre Calar Alto, operated by the Max-Planck-Institute for Astronomy, Heidelberg, jointly with the Spanish National Commission for Astronomy, the NOT on La Palma, Canary Islands, and the Observatorio Astronomico National, San Pedro, Mexico. We are grateful to the staff at the Paranal, Calar Alto and NOT observatories, in particular A. Aguirre, M. Alises, S. Hubrig, A.O. Jaunsen, C. Ledoux, S. Pedraz, T. Szeifert, L. Vanzi and P. Vreeswijk for obtaining the service mode data reported here.

**Figure 1:** R band image of the field centred on the optical afterglow of GRB 030329. The 27 FORS1 (Focal Reducer and Low Dispersion Spectrograph at VLT/Antu) measurements are shown as "vectors" where the length is a measure of the polarization degree, and the orientation indicates the position angle. While the afterglow varies in degree as well as angle, the polarization of seven field stars is constant within 0.1% in polarization degree and 1.5 degree in position angle throughout the 38 days. Linear polarization was measured from sets of exposures with different retarder plate position angles. Imaging polarimetry was obtained during the first four nights (when the afterglow was brighter than 17th mag) from sixteen different retarder plate angles, and from eight angles thereafter. Since the FORS1 polarization optics allows determination of the degree of polarization to an accuracy of ¡3x10-4 and of the polarization angle to $\sim 0.2$ deg, we consider the above variance of the field stars to represent the systematic error over the 38-day time period. Observations of polarimetric standard stars reproduced their tabulated values within 5%. The FORS1 retarder plate zero point angle of -1.2 degrees was subtracted from the polarization angle. The position angle has a systematic uncertainty of 1.5 deg, which was added in quadrature to the statistical errors.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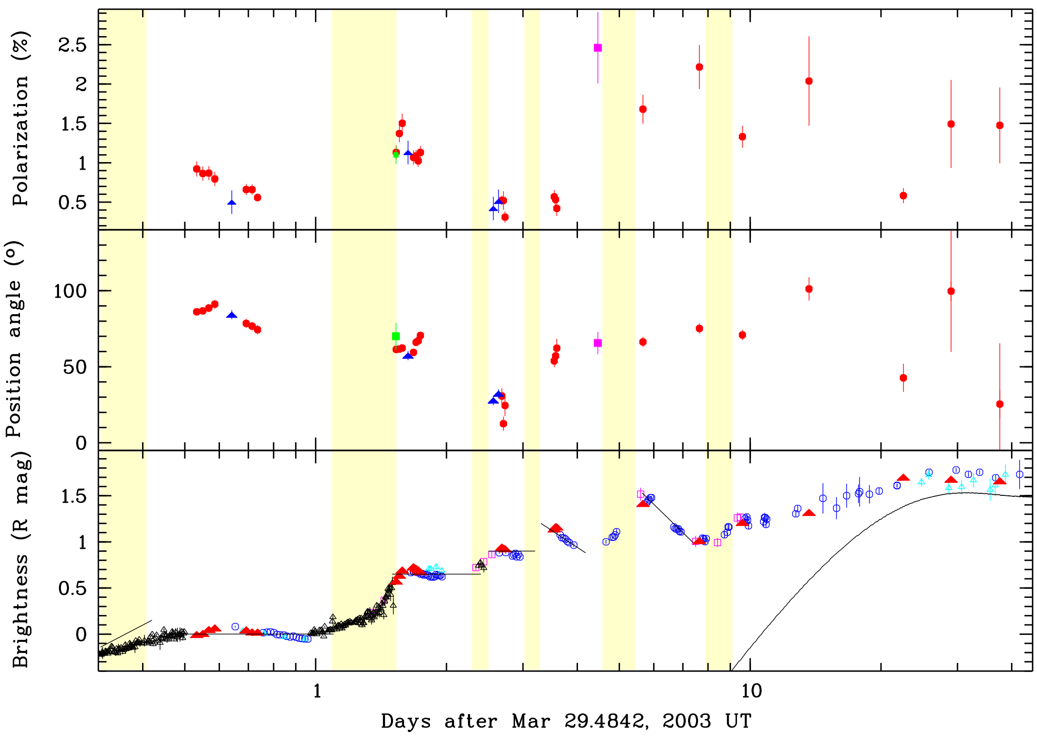


**Figure 2:** Evolution of the polarization during the first 38 days. Top and middle panels show the polarization degree in percent and the position angle in degrees. The red data points are from imaging polarimetry with FORS1/VLT. Spectropolarimetry (blue symbols, 700-800 nm range) was performed during the first three nights. The green points were obtained with CAFOS at the 2.2m telescope at Calar Alto on March 30/31. The magenta data point was obtained with AFOSC at the 2.56m NOT telescope on 2003 April 2. The bottom panel shows the residual R band light curve after subtraction of the contribution of a power law t-1.64 describing the undisturbed decay during the time interval 0.5-1.2 days after the GRB (i.e., after the early break at 0.4 days), thus leading to a horizontal curve. The symbols correspond to data obtained through: the literature (black), the 1m USNO telescope at Flagstaff (blue), the OAN Mexico (cyan), and FORS1/VLT (red). Lines indicate phases of power law decay, with the first one from early data21 (not shown). Yellow bars mark re-brightening transitions. Contributions from an underlying supernova (solid curved line) do not become significant until ∼10 days after the GRB.