www.sciencemag.org/cgi/content/full/science.1242316/DC1

Supplementary Materials for

The Bright Optical Flash and Afterglow from the Gamma-Ray Burst GRB 130427A

W. T. Vestrand,* J. A. Wren, A. Panaitescu, P. R. Wozniak, H. Davis, D. M. Palmer, G. Vianello, N. Omodei, S. Xiong, M. S. Briggs, M. Elphick, W. Paciesas, W. Rosing

*Corresponding author. E-mail: vestrand@lanl.gov

Published 21 November 2013 on *Science* Express
DOI: 10.1126/science.1242316

This PDF file includes:

Supplementary Text

Modeling

We modeled the GRB 130427A multi-wavelength afterglow emission using the standard external-shock framework (16), where a relativistic forward-shock is driven into the ambient medium by GRB ejecta and that interaction also drives a reverse shock through the ejecta. The 1-dimensional dynamics of each shock is calculated from conservation of mass, energy, and momentum, using the shock jump-conditions (25). The post-shock typical electron energy and magnetic field are calculated assuming that they acquire a certain fraction (micro-physical parameters) of the dissipated energy. Each shock produces synchrotron and inverse-Compton emissions, which are then integrated over the propagation of the shock. The self-absorption and cooling frequencies of the synchrotron spectrum are also calculated from the electron distribution and magnetic field. The best-fit to the afterglow data is then obtained by minimization of chi-square between the sum of model emission components and the observations. For the best fitting models, the effects of synchrotron self-absorption were found to not be important at the observed frequencies during the early epochs. Further, the self-Compton flux from the shocks were also found to be are smaller at all times and all frequencies than the corresponding synchrotron fluxes shown in figure 4. However, we did find that the inverse Compton process does play an important role because dominates the electron radiative cooling and determines the synchrotron efficiency above the 100 MeV cooling frequency. The cross-components of synchrotron photons produced by one shock and Compton up-scattered in the other have not been not calculated, but we expect them to be typically smaller than the joint synchrotron/self-Compton flux from the shock.

Our models that successfully fit the multi-wavelength emission require a reverse-shock that is sustained by energy injection throughout the prompt and early afterglow phases. The nature of this injection must vary in three episodes that signal a change in the dynamical and micro-physical parameters of the reverse shock. The best fit parameters for the initial time interval are flash reverse-shock (fRS)-- onset at 4 s, end at 15 s, incoming ejecta Lorentz factor 730, magnetic field parameter 0.008, electron energy parameter 0.006, index of electron power-law distribution with energy 1.9. To account for the transition from the rapid optical flash decay to the more gradual optical afterglow decay observed after 100 seconds requires a change on the reverse-shock dynamics and micro-parameters at ~15 seconds. After each change, we calculate the adiabatic and radiative cooling of the ejecta electrons of the previous injection episode. When those electrons cool to an energy below that for radiating synchrotron at 100 MeV, the 100 MeV flux from the 1/Gamma fluid moving toward the observer would display an exponential cutoff in time. However, the fluid moving at larger angles yields a brighter flux after the exponential cutoff, and shows a steep power-law flux decay. The steep power-law decay of the "large angle emission" is seen at 100 MeV after 20 s and after 3 ks in Figure 4. We find the best fit parameters for this new interval are reverse-shock energy injection starting at ~15 s and continuing to ~ 3 ksec with a Lorentz factor of 1800, magnetic field parameter of 0.0010, electron energy parameter of 0.012, and electron power-law index of 2.0.

Observations

The three RAPTOR All-Sky Monitors were the first to detect the optical emission from GRB130427A. The burst location was visible at both the Maui and Los Alamos sites at an elevation of 80° and 53° respectively. Each All-Sky Monitor consists of five unfiltered 24 mm f1.5 Canon EF lenses combining to cover about 90% of the sky above 12° elevation. Individually, each All-Sky Monitor obtains a 10 s exposure every 20 s with staggered observing schedules to provide better temporal coverage as a system. We corrected the All-Sky Monitor images using bias and dark frames obtained later that evening as well as flat fields which were created using a median of twilight frames obtained during cloudless evenings during the first half of 2013. The corrected images were then reduced to object lists using the SExtractor package (26) and astrometrically calibrated using ~8600 common field stars from the Tycho-2 (27) catalog with SDSS r' band synthetic magnitude estimates (28). Due to sky gradients caused by a nearly full moon about 75° away, these object lists were then photometrically re-calibrated using ~55 common Tycho-2 stars within 3° of the burst location.

The narrow field instruments located at the Fenton Hill Observatory in Northern New Mexico, RAPTOR-S and RAPTOR-T, began observing the burst location shortly after receiving the Swift trigger. The RAPTOR-S system consists of a single unfiltered 0.4 m telescope and the RAPTOR-T system consists of four co-aligned 0.4 m telescopes obtaining simultaneous images is four photometric bands (SDSS g', r', i', and z'). Our narrow field observations began at $T\text{-}T_o$ =132.96 s and the GRB counterpart was clearly visible in all five telescopes. The response sequence of each telescope consists of nine 5 s images followed by twenty 10 s images and 30 s images thereafter. The response images were calibrated using bias and dark frames obtained later that evening as well as flat frames created using a combination of recent twilight images and sky patrol images. The images were reduced to object lists using the SExtractor package and then calibrated using ~60 common field stars from the appropriate band in the SDSS DR9 catalog (29). The unfiltered RAPTOR-S data were calibrated to the SDSS r band values.

Our spectral energy distributions (SEDs) in the optical energy range were constructed using the g', r', i', and z' fluxes averaged over four time intervals with end points at 138, 270, 550, 3000, and 7571 seconds after the burst. We applied flux corrections based on extinction curves in Pei (30) to account for $E_{B\text{-}V}$ = 0.0202 of Galactic reddening (8) and an A_V = 0.18 dust column in the host (31). The best fit power law spectrum has a mean slope of β = -0.70±0.05 until about 3000 seconds after the burst, when it becomes slightly bluer (β = -0.59±0.05).

Table S1.

RAPTOR observations of GRB130427A. T_{mid} is the mid-exposure time in seconds since the GBM trigger (07:47:06.42 UT). The RAPTOR-T data were calibrated using field stars from the SDSS DR9 catalog (29). The RAPTOR All-Sky Monitor data were calibrated against the Tycho-2 Catalog SDSS r' estimates (28)

T_{mid} (s)	t_{exp} (s)	C_r (mag)	g' (mag)	r' (mag)	i' (mag)	z' (mag)	Telescope (name)
		RQD2—All Sky Monitors					
-9.75	10.00	> 10.1	.....	.....	.....	.....	D03
-4.33	10.00	> 9.9	.....	.....	.....	.....	D02
1.81	10.00	> 9.3	.....	.....	.....	.....	D01
5.86	10.00	8.421+.075-.070	.....	.....	.....	.....	D03
14.31	10.00	7.030+.030-.029	.....	.....	.....	.....	D02
21.48	10.00	7.501+.032-.031	.....	.....	.....	.....	D03
22.21	10.00	7.625+.061-.058	.....	.....	.....	.....	D01
33.27	10.00	8.752+.098-.090	.....	.....	.....	.....	D02
37.09	10.00	8.525+.081-.075	.....	.....	.....	.....	D03
52.71	10.00	9.215+.151-.133	.....	.....	.....	.....	D03
68.33	10.00	9.919+.291-.229	.....	.....	.....	.....	D03
83.95	10.00	10.177+.356-.268	.....	.....	.....	.....	D03
99.56	10.00	> 10.0	.....	.....	.....	.....	D03
115.63	10.00	> 10.1	.....	.....	.....	.....	D03
131.25	10.00	> 10.1	.....	.....	.....	.....	D03
		RAPTOR-S					
135.46	5.00	10.713+-0.011	.....	.....	.....	.....	
144.56	5.00	10.775+-0.011	.....	.....	.....	.....	
153.66	5.00	10.854+-0.011	.....	.....	.....	.....	
162.76	5.00	10.874+-0.011	.....	.....	.....	.....	
171.86	5.00	10.923+-0.011	.....	.....	.....	.....	
180.86	5.00	10.949+-0.011	.....	.....	.....	.....	
189.96	5.00	10.999+-0.011	.....	.....	.....	.....	
199.06	5.00	11.021+-0.012	.....	.....	.....	.....	
208.16	5.00	11.048+-0.012	.....	.....	.....	.....	
221.96	10.00	11.135+-0.011	.....	.....	.....	.....	
234.76	10.00	11.177+-0.011	.....	.....	.....	.....	
247.96	10.00	11.245+-0.011	.....	.....	.....	.....	
261.17	10.00	11.290+-0.011	.....	.....	.....	.....	
273.96	10.00	11.341+-0.011	.....	.....	.....	.....	

287.16	10.00	11.382+-0.011	.....	.....	.....	.....
299.97	10.00	11.445+-0.011	.....	.....	.....	.....
313.16	10.00	11.486+-0.011	.....	.....	.....	.....
325.97	10.00	11.558+-0.011	.....	.....	.....	.....
338.76	10.00	11.596+-0.011	.....	.....	.....	.....
351.96	10.00	11.631+-0.012	.....	.....	.....	.....
364.76	10.00	11.664+-0.012	.....	.....	.....	.....
377.56	10.00	11.721+-0.012	.....	.....	.....	.....
390.36	10.00	11.773+-0.012	.....	.....	.....	.....
403.16	10.00	11.814+-0.012	.....	.....	.....	.....
416.36	10.00	11.853+-0.012	.....	.....	.....	.....
429.16	10.00	11.877+-0.012	.....	.....	.....	.....
441.96	10.00	11.917+-0.012	.....	.....	.....	.....
454.76	10.00	11.949+-0.012	.....	.....	.....	.....
467.56	10.00	12.010+-0.012	.....	.....	.....	.....
492.56	30.00	12.049+-0.011	.....	.....	.....	.....
534.86	30.00	12.147+-0.011	.....	.....	.....	.....
577.16	30.00	12.222+-0.011	.....	.....	.....	.....
619.56	30.00	12.294+-0.011	.....	.....	.....	.....
661.96	30.00	12.380+-0.011	.....	.....	.....	.....
704.26	30.00	12.469+-0.011	.....	.....	.....	.....
746.66	30.00	12.526+-0.012	.....	.....	.....	.....
788.96	30.00	12.579+-0.012	.....	.....	.....	.....
831.76	30.00	12.663+-0.012	.....	.....	.....	.....
874.16	30.00	12.725+-0.012	.....	.....	.....	.....
916.46	30.00	12.789+-0.012	.....	.....	.....	.....
958.46	30.00	12.858+-0.012	.....	.....	.....	.....
1001.16	30.00	12.916+-0.012	.....	.....	.....	.....
1043.16	30.00	12.993+-0.012	.....	.....	.....	.....
1085.56	30.00	13.034+-0.012	.....	.....	.....	.....
1128.37	30.00	13.097+-0.012	.....	.....	.....	.....
1170.86	30.00	13.154+-0.012	.....	.....	.....	.....
1213.16	30.00	13.178+-0.013	.....	.....	.....	.....
1255.96	30.00	13.237+-0.013	.....	.....	.....	.....
1297.96	30.00	13.279+-0.013	.....	.....	.....	.....
1339.96	30.00	13.318+-0.013	.....	.....	.....	.....
1382.76	30.00	13.357+-0.013	.....	.....	.....	.....
1425.16	30.00	13.379+-0.013	.....	.....	.....	.....
1467.46	30.00	13.446+-0.013	.....	.....	.....	.....
1509.76	30.00	13.471+-0.013	.....	.....	.....	.....
1552.36	30.00	13.493+-0.013	.....	.....	.....	.....
1594.76	30.00	13.535+-0.013	.....	.....	.....	.....
1637.26	30.00	13.560+-0.013	.....	.....	.....	.....
1679.66	30.00	13.593+-0.013	.....	.....	.....	.....
1721.96	30.00	13.626+-0.014	.....	.....	.....	.....
1764.66	30.00	13.652+-0.014	.....	.....	.....	.....
1806.96	30.00	13.666+-0.014	.....	.....	.....	.....
1849.37	30.00	13.680+-0.014	.....	.....	.....	.....
1891.76	30.00	13.730+-0.014	.....	.....	.....	.....
1933.86	30.00	13.740+-0.014	.....	.....	.....	.....
1975.86	30.00	13.756+-0.014	.....	.....	.....	.....

2018.26	30.00	13.790+-0.014	.....	.....	.....	.....
2060.36	30.00	13.813+-0.014	.....	.....	.....	.....
2102.36	30.00	13.833+-0.014	.....	.....	.....	.....
2144.66	30.00	13.851+-0.014	.....	.....	.....	.....
2187.36	30.00	13.895+-0.015	.....	.....	.....	.....
2229.36	30.00	13.904+-0.015	.....	.....	.....	.....
2271.86	30.00	13.934+-0.015	.....	.....	.....	.....
2314.26	30.00	13.954+-0.015	.....	.....	.....	.....
2356.66	30.00	13.966+-0.015	.....	.....	.....	.....
2398.66	30.00	13.984+-0.015	.....	.....	.....	.....
2440.76	30.00	14.004+-0.015	.....	.....	.....	.....
2483.16	30.00	14.042+-0.015	.....	.....	.....	.....
2525.56	30.00	14.052+-0.015	.....	.....	.....	.....
2568.26	30.00	14.071+-0.015	.....	.....	.....	.....
2611.07	30.00	14.092+-0.015	.....	.....	.....	.....
2653.36	30.00	14.097+-0.015	.....	.....	.....	.....
2696.16	30.00	14.127+-0.015	.....	.....	.....	.....
2738.16	30.00	14.152+-0.016	.....	.....	.....	.....
2780.36	30.00	14.151+-0.016	.....	.....	.....	.....
2822.36	30.00	14.178+-0.016	.....	.....	.....	.....
2864.76	30.00	14.188+-0.016	.....	.....	.....	.....
2907.16	30.00	14.185+-0.016	.....	.....	.....	.....
2949.46	30.00	14.206+-0.016	.....	.....	.....	.....
2991.46	30.00	14.221+-0.016	.....	.....	.....	.....
3033.86	30.00	14.241+-0.016	.....	.....	.....	.....
3075.86	30.00	14.276+-0.016	.....	.....	.....	.....
3118.26	30.00	14.287+-0.016	.....	.....	.....	.....
3160.56	30.00	14.296+-0.017	.....	.....	.....	.....
3203.36	30.00	14.332+-0.017	.....	.....	.....	.....
3245.46	30.00	14.322+-0.017	.....	.....	.....	.....
3288.26	30.00	14.324+-0.017	.....	.....	.....	.....
3330.46	30.00	14.342+-0.017	.....	.....	.....	.....
3372.76	30.00	14.336+-0.017	.....	.....	.....	.....
3415.56	30.00	14.391+-0.017	.....	.....	.....	.....
3457.56	30.00	14.389+-0.017	.....	.....	.....	.....
3499.97	30.00	14.383+-0.017	.....	.....	.....	.....
3542.66	30.00	14.380+-0.018	.....	.....	.....	.....
3585.06	30.00	14.408+-0.018	.....	.....	.....	.....
3627.66	30.00	14.431+-0.018	.....	.....	.....	.....
3669.66	30.00	14.432+-0.018	.....	.....	.....	.....
3711.96	30.00	14.450+-0.018	.....	.....	.....	.....
3754.26	30.00	14.455+-0.018	.....	.....	.....	.....
3796.96	30.00	14.467+-0.018	.....	.....	.....	.....
3839.46	30.00	14.489+-0.018	.....	.....	.....	.....
3881.76	30.00	14.510+-0.018	.....	.....	.....	.....
3924.46	30.00	14.504+-0.018	.....	.....	.....	.....
3966.87	30.00	14.526+-0.019	.....	.....	.....	.....
4008.86	30.00	14.514+-0.018	.....	.....	.....	.....
4051.56	30.00	14.525+-0.018	.....	.....	.....	.....
4093.96	30.00	14.578+-0.019	.....	.....	.....	.....
4136.36	30.00	14.558+-0.019	.....	.....	.....	.....

4178.56	30.00	14.587+-0.019	.....	.....	.....	.....
4221.26	30.00	14.587+-0.019	.....	.....	.....	.....
4263.46	30.00	14.583+-0.019	.....	.....	.....	.....
4305.86	30.00	14.592+-0.019	.....	.....	.....	.....
4348.66	30.00	14.574+-0.019	.....	.....	.....	.....
4391.06	30.00	14.596+-0.019	.....	.....	.....	.....
4433.37	30.00	14.604+-0.019	.....	.....	.....	.....
4476.06	30.00	14.606+-0.019	.....	.....	.....	.....
4518.16	30.00	14.605+-0.020	.....	.....	.....	.....
4560.46	30.00	14.651+-0.020	.....	.....	.....	.....
4602.66	30.00	14.634+-0.020	.....	.....	.....	.....
4645.06	30.00	14.664+-0.020	.....	.....	.....	.....
4687.56	30.00	14.649+-0.020	.....	.....	.....	.....
4730.26	30.00	14.674+-0.020	.....	.....	.....	.....
4772.46	30.00	14.655+-0.020	.....	.....	.....	.....
4814.86	30.00	14.679+-0.020	.....	.....	.....	.....
4857.26	30.00	14.670+-0.021	.....	.....	.....	.....
4899.36	30.00	14.717+-0.021	.....	.....	.....	.....
4941.66	30.00	14.723+-0.020	.....	.....	.....	.....
4983.66	30.00	14.719+-0.021	.....	.....	.....	.....
5026.06	30.00	14.772+-0.022	.....	.....	.....	.....

RAPTOR-T

138.20	5.00	.....	11.098+-0.019	10.822+-0.009	10.665+-0.013	10.498+-0.025
149.62	5.00	.....	11.179+-0.019	10.894+-0.009	10.716+-0.013	10.565+-0.025
161.03	5.00	.....	11.231+-0.019	10.934+-0.010	10.800+-0.013	10.675+-0.025
172.44	5.00	.....	11.278+-0.019	10.974+-0.010	10.859+-0.013	10.716+-0.025
183.85	5.00	.....	11.263+-0.019	11.008+-0.010	10.899+-0.013	10.780+-0.025
195.66	5.00	.....	11.337+-0.020	11.080+-0.010	10.955+-0.013	10.786+-0.025
207.58	5.00	.....	11.337+-0.020	11.108+-0.010	10.971+-0.013	10.875+-0.025
218.99	5.00	.....	11.447+-0.020	11.159+-0.010	11.037+-0.013	10.902+-0.025
230.81	5.00	.....	11.451+-0.020	11.173+-0.010	11.088+-0.013	10.893+-0.026
247.24	10.00	.....	11.582+-0.019	11.289+-0.009	11.178+-0.013	10.986+-0.025
260.61	10.00	.....	11.585+-0.019	11.319+-0.009	11.178+-0.013	11.027+-0.024
273.60	10.00	.....	11.631+-0.019	11.359+-0.009	11.237+-0.013	11.127+-0.024
286.97	10.00	.....	11.687+-0.019	11.406+-0.009	11.290+-0.013	11.139+-0.024
299.96	10.00	.....	11.745+-0.019	11.467+-0.009	11.337+-0.013	11.200+-0.025
312.98	10.00	.....	11.822+-0.019	11.520+-0.009	11.414+-0.013	11.238+-0.025
325.94	10.00	.....	11.867+-0.019	11.555+-0.010	11.456+-0.013	11.300+-0.025
338.93	10.00	.....	11.909+-0.019	11.606+-0.010	11.497+-0.013	11.366+-0.025
352.30	10.00	.....	11.933+-0.019	11.672+-0.010	11.545+-0.013	11.389+-0.025
365.69	10.00	.....	12.032+-0.020	11.709+-0.010	11.604+-0.013	11.436+-0.025
379.07	10.00	.....	12.064+-0.020	11.770+-0.010	11.620+-0.013	11.469+-0.025
392.46	10.00	.....	12.088+-0.020	11.801+-0.010	11.667+-0.013	11.527+-0.025
405.83	10.00	.....	12.135+-0.020	11.842+-0.010	11.716+-0.013	11.571+-0.025
419.01	10.00	.....	12.171+-0.020	11.878+-0.010	11.735+-0.013	11.636+-0.026
431.99	10.00	.....	12.212+-0.020	11.925+-0.010	11.803+-0.013	11.606+-0.026
445.17	10.00	.....	12.261+-0.020	11.957+-0.010	11.825+-0.013	11.671+-0.026
458.55	10.00	.....	12.283+-0.020	11.974+-0.010	11.870+-0.014	11.729+-0.026
472.13	10.00	.....	12.302+-0.020	12.028+-0.010	11.883+-0.014	11.718+-0.026

485.10	10.00	.....	12.342+-0.020	12.058+-0.010	11.925+-0.014	11.757+-0.026
498.08	10.00	.....	12.399+-0.020	12.101+-0.010	11.960+-0.014	11.779+-0.026
525.15	30.00	.....	12.458+-0.019	12.153+-0.009	12.016+-0.013	11.864+-0.024
567.05	30.00	.....	12.526+-0.019	12.257+-0.009	12.119+-0.013	.....
608.32	30.00	.....	12.610+-0.019	12.324+-0.009	12.188+-0.013	.....
650.06	30.00	.....	12.696+-0.019	12.407+-0.009	12.270+-0.013	.....
691.73	30.00	.....	12.763+-0.019	12.464+-0.009	12.335+-0.013	.....
733.47	30.00	.....	12.822+-0.019	12.528+-0.009	12.396+-0.013	.....
774.78	30.00	.....	12.888+-0.020	12.589+-0.010	12.481+-0.013	.....
816.03	30.00	.....	12.949+-0.020	12.670+-0.010	12.529+-0.013	.....
857.68	30.00	.....	13.021+-0.020	12.749+-0.010	12.579+-0.013	.....
898.98	30.00	.....	13.073+-0.020	12.800+-0.010	12.659+-0.013	.....
940.65	30.00	.....	13.153+-0.020	12.877+-0.010	12.713+-0.013	.....
982.35	30.00	.....	13.241+-0.020	12.941+-0.010	12.780+-0.014	.....
1023.70	30.00	.....	13.280+-0.020	12.996+-0.010	12.873+-0.014	.....
1065.60	30.00	.....	13.365+-0.020	13.063+-0.010	12.901+-0.014	.....
1107.42	30.00	.....	13.391+-0.020	13.105+-0.010	12.978+-0.014	.....
1148.82	30.00	.....	13.453+-0.020	13.141+-0.010	13.029+-0.014	.....
1190.49	30.00	.....	13.486+-0.020	13.199+-0.010	13.052+-0.014	.....
1231.82	30.00	.....	13.539+-0.020	13.234+-0.011	13.117+-0.014	.....
1273.43	30.00	.....	13.588+-0.021	13.289+-0.011	13.162+-0.015	.....
1315.24	30.00	.....	13.632+-0.021	13.330+-0.011	13.213+-0.015	.....
1357.05	30.00	.....	13.651+-0.021	13.371+-0.011	13.253+-0.015	.....
1399.05	30.00	.....	13.683+-0.021	13.418+-0.011	13.271+-0.016	.....
1440.96	30.00	.....	13.739+-0.021	13.462+-0.011	13.324+-0.016	.....
1483.47	30.00	.....	13.766+-0.021	13.493+-0.011	13.351+-0.016	.....
1525.18	30.00	.....	13.787+-0.021	13.518+-0.011	13.377+-0.016	.....
1566.88	30.00	.....	13.830+-0.021	13.543+-0.011	13.428+-0.016	.....
1608.69	30.00	.....	13.856+-0.021	13.593+-0.011	13.438+-0.016	.....
1649.99	30.00	.....	13.886+-0.021	13.596+-0.011	13.470+-0.016	.....
1691.60	30.00	.....	13.934+-0.021	13.639+-0.012	13.514+-0.017	.....
1733.71	30.00	.....	13.961+-0.021	13.675+-0.012	13.534+-0.017	.....
1775.52	30.00	.....	13.984+-0.021	13.675+-0.012	13.530+-0.017	.....
1816.78	30.00	.....	13.989+-0.022	13.711+-0.012	13.580+-0.018	.....
1858.48	30.00	.....	14.007+-0.022	13.731+-0.012	13.603+-0.018	.....
1900.33	30.00	.....	14.039+-0.022	13.756+-0.012	13.649+-0.018	.....
1941.84	30.00	.....	14.064+-0.022	13.781+-0.013	13.655+-0.018	.....
1983.54	30.00	.....	14.088+-0.022	13.825+-0.013	13.704+-0.018	.....
2024.94	30.00	.....	14.108+-0.022	13.845+-0.013	13.716+-0.018	.....
2066.60	30.00	.....	14.145+-0.022	13.863+-0.013	13.737+-0.018	.....
2108.86	30.00	.....	14.149+-0.022	13.872+-0.013	13.774+-0.018	.....
2150.16	30.00	.....	14.180+-0.022	13.914+-0.013	13.754+-0.018	.....
2191.82	30.00	.....	14.185+-0.022	13.921+-0.013	13.776+-0.018	.....
2233.87	30.00	.....	14.213+-0.023	13.947+-0.013	13.809+-0.019	.....
2275.28	30.00	.....	14.243+-0.023	13.972+-0.013	13.867+-0.020	.....
2316.68	30.00	.....	14.262+-0.023	14.005+-0.013	13.872+-0.020	.....
2358.59	30.00	.....	14.270+-0.023	13.998+-0.013	13.885+-0.020	.....
2400.39	30.00	.....	14.317+-0.024	14.039+-0.013	13.901+-0.020	.....
2442.10	30.00	.....	14.337+-0.024	14.048+-0.013	13.894+-0.020	.....
2483.80	30.00	.....	14.327+-0.024	14.051+-0.014	13.941+-0.021	.....
2525.61	30.00	.....	14.369+-0.024	14.091+-0.014	13.934+-0.021	.....

2567.27	30.00	.....	14.388+-0.024	14.101+-0.014	13.986+-0.021	.....
2608.98	30.00	.....	14.366+-0.024	14.145+-0.014	14.026+-0.022	.....
2650.73	30.00	.....	14.422+-0.024	14.119+-0.014	14.029+-0.022	.....
2692.53	30.00	.....	14.428+-0.025	14.173+-0.015	14.048+-0.022	.....
2734.20	30.00	.....	14.457+-0.025	14.175+-0.015	14.030+-0.022	.....
2775.54	30.00	.....	14.445+-0.025	14.208+-0.015	14.072+-0.022	.....
2817.20	30.00	.....	14.494+-0.025	14.197+-0.015	14.094+-0.022	.....
2858.51	30.00	.....	14.498+-0.025	14.216+-0.015	14.095+-0.022	.....
2900.66	30.00	.....	14.524+-0.025	14.258+-0.016	14.061+-0.022	.....
2942.67	30.00	.....	14.530+-0.025	14.268+-0.016	14.111+-0.022	.....
2984.57	30.00	.....	14.564+-0.026	14.253+-0.016	14.149+-0.023	.....
3025.88	30.00	.....	14.567+-0.026	14.268+-0.016	14.136+-0.023	.....
3067.48	30.00	.....	14.552+-0.026	14.289+-0.016	14.175+-0.024	.....
3109.39	30.00	.....	14.590+-0.026	14.289+-0.016	14.188+-0.024	.....
3150.99	30.00	.....	14.586+-0.026	14.320+-0.017	14.319+-0.025	.....
3192.50	30.00	.....	14.586+-0.027	14.366+-0.017	14.194+-0.024	.....
3234.51	30.00	.....	14.606+-0.026	14.371+-0.017	14.248+-0.025	.....
3276.52	30.00	.....	14.605+-0.027	14.347+-0.017	14.242+-0.025	.....
3317.92	30.00	.....	14.660+-0.027	14.377+-0.017	14.228+-0.025	.....
3359.58	30.00	.....	14.660+-0.027	14.394+-0.017	14.312+-0.026	.....
3401.29	30.00	.....	14.673+-0.028	14.397+-0.017	14.274+-0.025	.....
3443.00	30.00	.....	14.651+-0.027	14.443+-0.017	14.431+-0.027	.....
3484.70	30.00	.....	14.701+-0.028	14.438+-0.017	14.309+-0.025	.....
3526.55	30.00	.....	14.705+-0.028	14.417+-0.017	14.311+-0.026	.....
3568.56	30.00	.....	14.748+-0.028	14.458+-0.017	14.455+-0.028	.....
3610.37	30.00	.....	14.704+-0.028	14.466+-0.017	14.361+-0.027	.....
3651.66	30.00	.....	14.740+-0.028	14.490+-0.018	.....	.....
3693.17	30.00	.....	14.826+-0.030	14.509+-0.018	.....	.....
3735.08	30.00	.....	14.773+-0.028	14.513+-0.018	.....	.....
3776.79	30.00	.....	14.753+-0.028	14.498+-0.018	.....	.....
3818.70	30.00	.....	14.751+-0.028	14.503+-0.018	.....	.....
3860.10	30.00	.....	14.759+-0.029	14.523+-0.018	.....	.....
3901.50	30.00	.....	14.789+-0.029	14.543+-0.019	.....	.....
3943.61	30.00	.....	14.759+-0.028	14.531+-0.018	.....	.....
3985.32	30.00	.....	14.819+-0.030	14.562+-0.019	.....	.....
4027.12	30.00	.....	14.823+-0.030	14.546+-0.019	.....	.....
4068.78	30.00	.....	14.843+-0.031	14.568+-0.019	.....	.....
4110.33	30.00	.....	14.880+-0.031	14.595+-0.020	.....	.....
4152.34	30.00	.....	14.843+-0.031	14.576+-0.019	.....	.....
4194.05	30.00	.....	14.842+-0.031	14.590+-0.020	.....	.....
4237.97	30.00	.....	14.885+-0.031	14.615+-0.020	.....	.....
4279.78	30.00	.....	14.873+-0.031	14.643+-0.020	.....	.....
4321.08	30.00	.....	14.868+-0.031	14.651+-0.020	.....	.....
4362.49	30.00	.....	14.913+-0.031	14.619+-0.020	.....	.....
4404.39	30.00	.....	14.950+-0.032	14.635+-0.020	.....	.....
4446.10	30.00	.....	14.893+-0.031	14.656+-0.021	.....	.....
4487.47	30.00	.....	14.950+-0.032	14.694+-0.021	.....	.....
4529.11	30.00	.....	14.913+-0.031	14.705+-0.021	.....	.....
4571.01	30.00	.....	14.950+-0.033	14.691+-0.021	.....	.....
4613.02	30.00	.....	14.971+-0.033	14.691+-0.021	.....	.....
4654.32	30.00	.....	14.990+-0.034	14.694+-0.022	.....	.....

4695.73	30.00	.....	14.996+-0.034	14.732+-0.022	.....	.....
4737.33	30.00	.....	14.978+-0.033	14.710+-0.022	.....	.....
4778.94	30.00	.....	14.954+-0.033	14.707+-0.022	.....	.....
4820.34	30.00	.....	14.965+-0.033	14.754+-0.023	.....	.....
4862.15	30.00	.....	14.978+-0.033	14.722+-0.022	.....	.....
4903.65	30.00	.....	14.968+-0.034	14.743+-0.023	.....	.....
4944.95	30.00	.....	15.035+-0.035	14.752+-0.023	.....	.....
4986.76	30.00	.....	15.027+-0.035	14.795+-0.023	.....	.....
5028.77	30.00	.....	15.013+-0.035	14.785+-0.024	.....	.....
5070.48	30.00	.....	15.026+-0.035	14.808+-0.024	.....	.....
5112.19	30.00	.....	15.019+-0.035	14.810+-0.024	.....	.....
5153.79	30.00	.....	15.064+-0.036	14.824+-0.025	.....	.....
5195.70	30.00	.....	15.072+-0.036	14.802+-0.024	.....	.....
5236.99	30.00	.....	15.071+-0.036	14.818+-0.024	.....	.....
5278.26	30.00	.....	15.063+-0.036	14.867+-0.025	.....	.....
5320.31	30.00	.....	15.051+-0.036	14.833+-0.024	.....	.....
5362.02	30.00	.....	15.090+-0.037	14.818+-0.025	.....	.....
5403.82	30.00	.....	15.040+-0.036	14.877+-0.026	.....	.....
5445.63	30.00	.....	15.123+-0.038	14.886+-0.026	.....	.....
5487.53	30.00	.....	15.110+-0.037	14.889+-0.026	.....	.....
5528.94	30.00	.....	15.165+-0.039	14.868+-0.026	.....	.....
5570.24	30.00	.....	15.099+-0.038	14.866+-0.026	.....	.....
5611.90	30.00	.....	15.074+-0.036	14.873+-0.026	.....	.....
5653.65	30.00	.....	15.159+-0.039	14.888+-0.026	.....	.....
5695.76	30.00	.....	15.186+-0.039	14.901+-0.026	.....	.....
5737.22	30.00	.....	15.189+-0.040	14.905+-0.027	.....	.....
5779.17	30.00	.....	15.185+-0.040	14.927+-0.027	.....	.....
5820.98	30.00	.....	15.192+-0.040	14.927+-0.028	.....	.....
5862.68	30.00	.....	15.163+-0.040	14.910+-0.027	.....	.....
5904.39	30.00	.....	15.194+-0.041	14.891+-0.027	.....	.....
5946.10	30.00	.....	15.194+-0.041	14.943+-0.028	.....	.....
5987.80	30.00	.....	15.183+-0.041	14.975+-0.028	.....	.....
6029.11	30.00	.....	15.177+-0.041	14.909+-0.028	.....	.....
6070.91	30.00	.....	15.169+-0.041	14.970+-0.028	.....	.....
6112.58	30.00	.....	15.125+-0.039	14.988+-0.028	.....	.....
6154.28	30.00	.....	15.231+-0.042	14.986+-0.028	.....	.....
6195.99	30.00	.....	15.204+-0.042	14.983+-0.028	.....	.....
6237.43	30.00	.....	15.212+-0.042	14.977+-0.028	.....	.....
6279.34	30.00	.....	15.238+-0.044	14.965+-0.028	.....	.....
6320.74	30.00	.....	15.256+-0.044	14.986+-0.029	.....	.....
6362.24	30.00	.....	15.257+-0.045	15.036+-0.030	.....	.....
6403.95	30.00	.....	15.208+-0.042	15.007+-0.029	.....	.....
6445.76	30.00	.....	15.258+-0.044	14.984+-0.029	.....	.....
6487.46	30.00	.....	15.215+-0.042	15.035+-0.030	.....	.....
6529.27	30.00	.....	15.367+-0.048	15.002+-0.029	.....	.....
6570.97	30.00	.....	15.256+-0.044	15.044+-0.031	.....	.....
6612.28	30.00	.....	15.329+-0.049	15.057+-0.032	.....	.....
6653.58	30.00	.....	15.242+-0.045	15.080+-0.032	.....	.....
6695.29	30.00	.....	15.245+-0.044	15.059+-0.031	.....	.....
6736.54	30.00	.....	15.322+-0.047	15.057+-0.032	.....	.....
6777.89	30.00	.....	15.295+-0.047	15.037+-0.032	.....	.....

6819.29	30.00	.....	15.340+-0.048	15.053+-0.032	.....	.....
6861.10	30.00	.....	15.276+-0.046	15.034+-0.031	.....	.....
6903.00	30.00	.....	15.294+-0.047	15.080+-0.033	.....	.....
6944.82	30.00	.....	15.294+-0.047	15.024+-0.031	.....	.....
6986.47	30.00	.....	15.224+-0.045	15.117+-0.033	.....	.....
7028.33	30.00	.....	15.355+-0.049	15.148+-0.035	.....	.....
7069.73	30.00	.....	15.372+-0.050	15.066+-0.033	.....	.....
7111.44	30.00	.....	15.348+-0.051	15.132+-0.034	.....	.....
7152.94	30.00	.....	15.340+-0.051	15.100+-0.034	.....	.....
7194.75	30.00	.....	15.283+-0.048	15.076+-0.033	.....	.....
7236.45	30.00	.....	15.378+-0.051	15.130+-0.035	.....	.....
7278.16	30.00	.....	15.354+-0.051	15.124+-0.035	.....	.....
7319.96	30.00	.....	15.425+-0.053	15.161+-0.036	.....	.....
7361.67	30.00	.....	15.396+-0.053	15.182+-0.037	.....	.....
7403.37	30.00	.....	15.333+-0.051	15.151+-0.036	.....	.....
7445.39	30.00	.....	15.458+-0.055	15.185+-0.037	.....	.....
7487.39	30.00	.....	15.428+-0.055	15.106+-0.035	.....	.....
7529.30	30.00	.....	15.337+-0.052	15.166+-0.036	.....	.....
7570.90	30.00	.....	15.475+-0.058	15.173+-0.037	.....	.....

References and Notes

1. S. E. Woosley, J. S. Bloom, The supernova gamma-ray burst connection. *Annu. Rev. Astron. Astrophys.* **44**, 507–556 (2006). doi:10.1146/annurev.astro.43.072103.150558

2. B. D. Metzger, D. Giannios, T. A. Thompson, N. Bucciantini, E. Quataert, The protomagnetar model for gamma-ray bursts. *Mon. Not. R. Astron. Soc.* **413**, 2031–2056 (2011). doi:10.1111/j.1365-2966.2011.18280.x

3. M. R. Metzger, S. G. Djorgovski, S. R. Kulkarni, C. C. Steidel, K. L. Adelberger, D. A. Frail, E. Costa, F. Frontera, Spectral constraints on the redshift of the optical counterpart to the gamma-ray burst of 8 May 1997. *Nature* **387**, 878 (1997). doi:10.1038/43132

4. A. Maselli, A. Melandri, L. Nava, C. G. Mundell, N. Kawai, S. Campana, S. Covino, J. R. Cummings, G. Cusumano, P. A. Evans, G. Ghirlanda, G. Ghisellini, C. Guidorzi, S. Kobayashi, P. Kuin, V. La Parola, V. Mangano, S. Oates, T. Sakamoto, M. Serino, F. Virgili, B.-B. Zhang, S. Barthelmy, A. Beardmore, M. G. Bernardini, D. Bersier, D. Burrows, G. Calderone, M. Capalbi, J. Chiang, P. D'Avanzo, V. D'Elia, M. De Pasquale, D. Fugazza, N. Gehrels, A. Gomboc, R. Harrison, H. Hanayama, J. Japelj, J. Kennea, D. Kopac, C. Kouveliotou, D. Kuroda, A. Levan, D. Malesani, F. Marshall, J. Nousek, P. O'Brien, J. P. Osborne, C. Pagani, K. L. Page, M. Page, M. Perri, T. Pritchard, P. Romano, Y. Saito, B. Sbarufatti, R. Salvaterra, I. Steele, N. Tanvir, G. Vianello, B. Weigand, K. Wiersema, Y. Yatsu, T. Yoshii, G. Tagliaferri, GRB 130427A: A nearby ordinary monster. *Science* 10.1126/science.1242279 (2013).

5. M. Ackermann, M. Ajello, K. Asano, W. B. Atwood, M. Axelsson, L. Baldini, J. Ballet, G. Barbiellini, M. G. Baring, D. Bastieri, K. Bechtol, R. Bellazzini, E. Bissaldi, E. Bonamente, J. Bregeon, M. Brigida, P. Bruel, R. Buehler, J. Michael Burgess, S. Buson, G. A. Caliandro, R. A. Cameron, P. A. Caraveo, C. Cecchi, V. Chaplin, E. Charles, A. Chekhtman, C. C. Cheung, J. Chiang, G. Chiaro, S. Ciprini, R. Claus, W. Cleveland, J. Cohen-Tanugi, A. Collazzi, L. R. Cominsky, V. Connaughton, J. Conrad, S. Cutini, F. D'Ammando, A. de Angelis, M. DeKlotz, F. de Palma, C. D. Dermer, R. Desiante, A. Diekmann, L. Di Venere, P. S. Drell, A. Drlica-Wagner, C. Favuzzi, S. J. Fegan, E. C. Ferrara, J. Finke, G. Fitzpatrick, W. B. Focke, A. Franckowiak, Y. Fukazawa, S. Funk, P. Fusco, F. Gargano, N. Gehrels, S. Germani, M. Gibby, N. Giglietto, M. Giles, F. Giordano, M. Giroletti, G. Godfrey, J. Granot, I. A. Grenier, J. E. Grove, D. Gruber, S. Guiriec, D. Hadasch, Y. Hanabata, A. K. Harding, M. Hayashida, E. Hays, D. Horan, R. E. Hughes, Y. Inoue, T. Jogler, G. Jóhannesson, W. N. Johnson, T. Kawano, J. Knödlseder, D. Kocevski, M. Kuss, J. Lande, S. Larsson, L. Latronico, F. Longo, F. Loparco, M. N. Lovellette, P. Lubrano, M. Mayer, M. N. Mazziotta, J. E. McEnery, P. F. Michelson, T. Mizuno, A. A. Moiseev, M. E. Monzani, E. Moretti, A. Morselli, I. V. Moskalenko, S. Murgia, R. Nemmen, E. Nuss, M. Ohno, T. Ohsugi, A. Okumura, N. Omodei, M. Orienti, D. Paneque, V. Pelassa, J. S. Perkins, M. Pesce-Rollins, V. Petrosian, F. Piron, G. Pivato, T. A. Porter, J. L. Racusin, S. Rainò, R. Rando, M. Razzano, S. Razzaque, A. Reimer, O. Reimer, S. Ritz, M. Roth, F. Ryde, A. Sartori, P. M. Saz Parkinson, J. D. Scargle, A. Schulz, C. Sgrò, E. J. Siskind, E. Sonbas, G. Spandre, P. Spinelli, H. Tajima, H. Takahashi, J. G. Thayer, J. B. Thayer, D. J. Thompson, L. Tibaldo, M. Tinivella, D. F. Torres, G. Tosti, E. Troja, T. L. Usher, J. Vandenbroucke, V. Vasileiou, G. Vianello, V. Vitale, B. L. Winer, K. S. Wood, R. Yamazaki, G. Younes, H.-

F. Yu, S. J. Zhu, P. N. Bhat, M. S. Briggs, D. Byrne, S. Foley, A. Goldstein, P. Jenke, R. M. Kippen, C. Kouveliotou, S. McBreen, C. Meegan, W. S. Paciesas, R. Preece, A. Rau, D. Tierney, A. J. van der Horst, A. von Kienlin, C. Wilson-Hodge, S. Xiong, G. Cusumano, V. La Parola, J. R. Cummings, Fermi-LAT observations of the gamma-ray burst GRB 130427A. *Science* 10.1126/science.1242353 (2013).

6. S. Golenetskii *et al*., "Konus-wind observation of GRB 130427A," GCN Circular #14486 (2013).

7. A. J. Levan *et al*., "GRB 130427A: Gemini-north redshift," GCN circular #14455 (2013).

8. D. Xu, A. de Ugarte Postigo, G. Leloudas, T. Krühler, Z. Cano, J. Hjorth, D. Malesani, J. P. U. Fynbo, C. C. Thöne, R. Sánchez-Ramírez, S. Schulze, P. Jakobsson, L. Kaper, J. Sollerman, D. J. Watson, A. Cabrera-Lavers, C. Cao, S. Covino, H. Flores, S. Geier, J. Gorosabel, S. M. Hu, B. Milvang-Jensen, M. Sparre, L. P. Xin, T. M. Zhang, W. K. Zheng, Y. C. Zou, Discovery of the broad-lined Type Ic SN 2013cq associated with the very energetic GRB 130427A. *Astrophys. J.* **776**, 98 (2013). doi:10.1088/0004-637X/776/2/98

9. J. Wren, W. T. Vestrand, P. Wozniak, H. Davis, A portable observatory for persistent monitoring of the night sky. *Proc. SPIE* **7737**, 773723 (2010). doi:10.1117/12.859039

10. W. T. Vestrand, P. R. Wozniak, J. A. Wren, E. E. Fenimore, T. Sakamoto, R. R. White, D. Casperson, H. Davis, S. Evans, M. Galassi, K. E. McGowan, J. A. Schier, J. W. Asa, S. D. Barthelmy, J. R. Cummings, N. Gehrels, D. Hullinger, H. A. Krimm, C. B. Markwardt, K. McLean, D. Palmer, A. Parsons, J. Tueller, A link between prompt optical and prompt gamma-ray emission in gamma-ray bursts. *Nature* **435**, 178–180 (2005). Medline doi:10.1038/nature03515

11. W. T. Vestrand, J. A. Wren, P. R. Wozniak, R. Aptekar, S. Golentskii, V. Pal'shin, T. Sakamoto, R. R. White, S. Evans, D. Casperson, E. Fenimore, Energy input and response from prompt and early optical afterglow emission in gamma-ray bursts. *Nature* **442**, 172–175 (2006). Medline doi:10.1038/nature04913

12. J. L. Racusin, S. V. Karpov, M. Sokolowski, J. Granot, X. F. Wu, V. Pal'shin, S. Covino, A. J. van der Horst, S. R. Oates, P. Schady, R. J. Smith, J. Cummings, R. L. Starling, L. W. Piotrowski, B. Zhang, P. A. Evans, S. T. Holland, K. Malek, M. T. Page, L. Vetere, R. Margutti, C. Guidorzi, A. P. Kamble, P. A. Curran, A. Beardmore, C. Kouveliotou, L. Mankiewicz, A. Melandri, P. T. O'Brien, K. L. Page, T. Piran, N. R. Tanvir, G. Wrochna, R. L. Aptekar, S. Barthelmy, C. Bartolini, G. M. Beskin, S. Bondar, M. Bremer, S. Campana, A. Castro-Tirado, A. Cucchiara, M. Cwiok, P. D'Avanzo, V. D'Elia, M. D. Valle, A. de Ugarte Postigo, W. Dominik, A. Falcone, F. Fiore, D. B. Fox, D. D. Frederiks, A. S. Fruchter, D. Fugazza, M. A. Garrett, N. Gehrels, S. Golenetskii, A. Gomboc, J. Gorosabel, G. Greco, A. Guarnieri, S. Immler, M. Jelinek, G. Kasprowicz, V. La Parola, A. J. Levan, V. Mangano, E. P. Mazets, E. Molinari, A. Moretti, K. Nawrocki, P. P. Oleynik, J. P. Osborne, C. Pagani, S. B. Pandey, Z. Paragi, M. Perri, A. Piccioni, E. Ramirez-Ruiz, P. W. Roming, I. A. Steele, R. G. Strom, V. Testa, G. Tosti, M. V. Ulanov, K. Wiersema, R. A. Wijers, J. M. Winters, A. F. Zarnecki, F. Zerbi, P. Mészáros, G. Chincarini, D. N. Burrows, Broadband observations of the naked-eye gamma-ray burst GRB 080319B. *Nature* **455**, 183–188 (2008). Medline doi:10.1038/nature07270

13. C. Akerlof, R. Balsano, S. Barthelmy, J. Bloch, P. Butterworth, D. Casperson, T. Cline, S. Fletcher, F. Frontera, G. Gisler, J. Heise, J. Hills, R. Kehoe, B. Lee, S. Marshall, T. McKay, R. Miller, L. Piro, W. Priedhorsky, J. Szymanski, J. Wren, Observations of contemporaneous optical radiation from a gamma-ray burst. *Nature* **398**, 400–402 (1999). doi:10.1038/18837

14. E. Rykoff, F. Aharonian, C. W. Akerlof, M. C. B. Ashley, S. D. Barthelmy, H. A. Flewelling, N. Gehrels, E. Göğüş, T. Güver, Ü. Kiziloğlu, H. A. Krimm, T. A. McKay, M. Özel, A. Phillips, R. M. Quimby, G. Rowell, W. Rujopakarn, B. E. Schaefer, D. A. Smith, W. T. Vestrand, J. C. Wheeler, J. Wren, F. Yuan, S. A. Yost, Looking into the Fireball: ROTSE-III and *Swift* observations of early gamma-ray burst afterglows. *Astrophys. J.* **702**, 489–505 (2009). doi:10.1088/0004-637X/702/1/489

15. P. Meszaros, M. Rees, Relativistic fireballs and their impact on external matter—Models for cosmological gamma-ray bursts. *Astrophys. J.* **405**, 278 (1993). doi:10.1086/172360

16. P. Meszaros, M. Rees, Optical and long wavelength afterglow from gamma-ray bursts. *Astrophys. J.* **476**, 232–237 (1997). doi:10.1086/303625

17. R. Sari, T. Piran, Predictions for the very early afterglow and the optical flash. *Astrophys. J.* **520**, 641–649 (1999). doi:10.1086/307508

18. T. Laskar, E. Berger, B. A. Zauderer, R. Margutti, A. M. Soderberg, S. Chakraborti, R. Lunnan, R. Chornock, P. Chandra, A. Ray, A reverse shock in GRB 130427A. available at http://arxiv.org/abs/1305.2453 (2013).

19. Z. L. Uhm, B. Zhang, R. Hascoët, F. Daigne, R. Mochkovitch, I. H. Park, Dynamics and afterglow light curves of gamma-ray burst blast waves with a long-lived reverse shock. *Astrophys. J.* **761**, 147 (2012). doi:10.1088/0004-637X/761/2/147

20. P. Wozniak, W. T. Vestrand, A. D. Panaitescu, J. A. Wren, H. R. Davis, R. R. White, Gamma-Ray burst at the extreme: The naked-eye burst GRB 080319B. *Astrophys. J.* **691**, 495–502 (2009). doi:10.1088/0004-637X/691/1/495

21. J. S. Bloom, D. A. Perley, W. Li, N. R. Butler, A. A. Miller, D. Kocevski, D. A. Kann, R. J. Foley, H.-W. Chen, A. V. Filippenko, D. L. Starr, B. Macomber, J. X. Prochaska, R. Chornock, D. Poznanski, S. Klose, M. F. Skrutskie, S. Lopez, P. Hall, K. Glazebrook, C. H. Blake, Observations of the naked-eye GRB 080319B: implications of nature's brightest explosion. *Astrophys. J.* **691**, 723–737 (2009). doi:10.1088/0004-637X/691/1/723

22. T. W. Giblin, J. van Paradijs, C. Kouveliotou, V. Connaughton, R. A. M. J. Wijers, M. S. Briggs, R. D. Preece, G. J. Fishman, Evidence for an early high-energy afterglow observed with BATSE from GRB 980923. *Astrophys. J.* **524**, L47–L50 (1999). doi:10.1086/312285

23. A. Panaitescu, W. T. Vestrand, Taxonomy of gamma-ray burst optical light curves: Identification of a salient class of early afterglows. *Mon. Not. R. Astron. Soc.* **387**, 497–504 (2008). doi:10.1111/j.1365-2966.2008.13231.x

24. The RAPTOR optical measurements are available in table S1 of the supplementary materials on *Science* Online.

25. R. Blandford, C. McKee, Fluid dynamics of relativistic blast waves. *Phys. Fluids* **19**, 1130 (1976). doi:10.1063/1.861619

26. E. Bertin, S. Arnouts, SExtractor: Software for source extraction. *Astron. Astrophys. Suppl. Ser.* **117**, 393–404 (1996). doi:10.1051/aas:1996164

27. E. Hog *et al.*, The Tycho-2 catalogue of the 2.5 million brightest stars. *Astron. Astrophys.* **355**, L27 (2000).

28. E. Pickles, E. Depagne, All sky spectrally matched *UBVRI-ZY* and *u′g′r′i′z′* magnitudes for stars in the Tycho2 catalog. *Publ. Astron. Soc. Pac.* **122**, 1437–1464 (2010). doi:10.1086/657947

29. C. Ahn, R. Alexandroff, C. Allende Prieto, S. F. Anderson, T. Anderton, B. H. Andrews, É. Aubourg, S. Bailey, E. Balbinot, R. Barnes, J. Bautista, T. C. Beers, A. Beifiori, A. A. Berlind, V. Bhardwaj, D. Bizyaev, C. H. Blake, M. R. Blanton, M. Blomqvist, J. J. Bochanski, A. S. Bolton, A. Borde, J. Bovy, W. N. Brandt, J. Brinkmann, P. J. Brown, J. R. Brownstein, K. Bundy, N. G. Busca, W. Carithers, A. R. Carnero, M. A. Carr, D. I. Casetti-Dinescu, Y. Chen, C. Chiappini, J. Comparat, N. Connolly, J. R. Crepp, S. Cristiani, R. A. C. Croft, A. J. Cuesta, L. N. da Costa, J. R. A. Davenport, K. S. Dawson, R. de Putter, N. De Lee, T. Delubac, S. Dhital, A. Ealet, G. L. Ebelke, E. M. Edmondson, D. J. Eisenstein, S. Escoffier, M. Esposito, M. L. Evans, X. Fan, B. Femenía Castellá, E. Fernández Alvar, L. D. Ferreira, N. Filiz Ak, H. Finley, S. W. Fleming, A. Font-Ribera, P. M. Frinchaboy, D. A. García-Hernández, A. E. G. Pérez, J. Ge, R. Génova-Santos, B. A. Gillespie, L. Girardi, J. I. González Hernández, E. K. Grebel, J. E. Gunn, H. Guo, D. Haggard, J.-C. Hamilton, D. W. Harris, S. L. Hawley, F. R. Hearty, S. Ho, D. W. Hogg, J. A. Holtzman, K. Honscheid, J. Huehnerhoff, I. I. Ivans, Ž. Ivezić, H. R. Jacobson, L. Jiang, J. Johansson, J. A. Johnson, G. Kauffmann, D. Kirkby, J. A. Kirkpatrick, M. A. Klaene, G. R. Knapp, J.-P. Kneib, J.-M. Le Goff, A. Leauthaud, K.-G. Lee, Y. S. Lee, D. C. Long, C. P. Loomis, S. Lucatello, B. Lundgren, R. H. Lupton, B. Ma, Z. Ma, N. MacDonald, C. E. Mack, S. Mahadevan, M. A. G. Maia, S. R. Majewski, M. Makler, E. Malanushenko, V. Malanushenko, A. Manchado, R. Mandelbaum, M. Manera, C. Maraston, D. Margala, S. L. Martell, C. K. McBride, I. D. McGreer, R. G. McMahon, B. Ménard, S. Meszaros, J. Miralda-Escudé, A. D. Montero-Dorta, F. Montesano, H. L. Morrison, D. Muna, J. A. Munn, H. Murayama, A. D. Myers, A. F. Neto, D. C. Nguyen, R. C. Nichol, D. L. Nidever, P. Noterdaeme, S. E. Nuza, R. L. C. Ogando, M. D. Olmstead, D. J. Oravetz, R. Owen, N. Padmanabhan, N. Palanque-Delabrouille, K. Pan, J. K. Parejko, P. Parihar, I. Pâris, P. Pattarakijwanich, J. Pepper, W. J. Percival, I. Pérez-Fournon, I. Pérez-Ràfols, P. Petitjean, J. Pforr, M. M. Pieri, M. H. Pinsonneault, G. F. Porto de Mello, F. Prada, A. M. Price-Whelan, M. J. Raddick, R. Rebolo, J. Rich, G. T. Richards, A. C. Robin, H. J. Rocha-Pinto, C. M. Rockosi, N. A. Roe, A. J. Ross, N. P. Ross, G. Rossi, J. A. Rubiño-Martin, L. Samushia, J. Sanchez Almeida, A. G. Sánchez, B. Santiago, C. Sayres, D. J. Schlegel, K. J. Schlesinger, S. J. Schmidt, D. P. Schneider, M. Schultheis, A. D. Schwope, C. G. Scóccola, U. Seljak, E. Sheldon, Y. Shen, Y. Shu, J. Simmerer, A. E. Simmons, R. A. Skibba, M. F. Skrutskie, A. Slosar, F. Sobreira, J. S. Sobeck, K. G. Stassun, O. Steele, M. Steinmetz, M. A. Strauss, A. Streblyanska, N. Suzuki, M. E. C. Swanson, T. Tal, A. R. Thakar, D. Thomas, B. A. Thompson, J. L. Tinker, R. Tojeiro, C. A. Tremonti, M. Vargas Magaña, L. Verde, M. Viel, S. K. Vikas, N. P. Vogt, D. A. Wake, J. Wang, B. A. Weaver, D. H. Weinberg, B. J. Weiner, A. A.

West, M. White, J. C. Wilson, J. P. Wisniewski, W. M. Wood-Vasey, B. Yanny, C. Yèche, D. G. York, O. Zamora, G. Zasowski, I. Zehavi, G.-B. Zhao, Z. Zheng, G. Zhu, J. C. Zinn, The ninth data release of the Sloan Digital Sky Survey: First spectroscopic data from the SDSS-III Baryon Oscillation Spectroscopic Survey. *Astrophys. J. Suppl. Ser.* **203**, 21 (2012). doi:10.1088/0067-0049/203/2/21

30. Y. C. Pei, Interstellar dust from the Milky Way to the Magellanic Clouds. *Astrophys. J.* **395**, 130 (1992). doi:10.1086/171637

31. D. J. Schlegel, D. P. Finkbeiner, M. Davis, Maps of dust infrared emission for use in estimation of reddening and cosmic microwave background radiation foregrounds. *Astrophys. J.* **500**, 525–553 (1998). doi:10.1086/305772