

= GRB 970228 =

GRB 970228 was the first gamma-ray burst ( GRB ) for which an afterglow was observed . It was detected on 28 February 1997 at 02 : 58 UTC . Since 1993 , physicists had predicted GRBs to be followed by a lower-energy afterglow ( in wavelengths such as radio waves , x-rays , and even visible light ) , but until this event , GRBs had only been observed in highly luminous bursts of high-energy gamma rays ( the most energetic form of electromagnetic radiation ) .

The burst had multiple peaks in its light curve and lasted approximately 80 seconds . Peculiarities in the light curve of GRB 970228 suggested that a supernova may have occurred as well . The position of the burst coincided with a galaxy about 8 billion light-years away ( a redshift of  $z = 0.695$  ) , providing early evidence that GRBs occur well beyond the Milky Way .

= Observations =

A gamma-ray burst ( GRB ) is a highly luminous flash of gamma rays , the most energetic form of electromagnetic radiation . GRBs were first detected in 1967 by the Vela satellites , a series of spacecraft designed to detect nuclear explosions .

GRB 970228 was detected on 28 February 1997 at 02 : 58 UTC by the Gamma-Ray Burst Monitor ( GRBM ) and one of the Wide Field Cameras ( WFCs ) on board BeppoSAX , an Italian-Dutch satellite originally designed to study X-rays . Within a few hours , the BeppoSAX team determined the burst's position with an error box - a small area around the specific position to account for the error in the position - of 3 arcminutes . The burst was also detected by the Ulysses space probe .

The burst was located at a right ascension of 05h 01m 46.7s and a declination of  $+11^{\circ}46'53''$  in optical images taken with the William Herschel Telescope on La Palma , providing the first arcsecond accuracy localization of any Gamma-ray burst . It lasted around 80 seconds and had multiple peaks in its light curve . Gamma-ray bursts have very diverse time profiles , and it is not fully understood why some bursts have multiple peaks and some have only one . One possible explanation is that multiple peaks are formed when the source of the gamma-ray burst undergoes precession .

= Afterglow =

In 1993 , Bohdan Paczyński and James E. Rhoads published an article arguing that , regardless of the type of explosion that causes GRBs , the extreme energetics of GRBs meant that matter from the host body must be ejected at relativistic speeds during the explosion . They predicted that the interaction between the ejecta and interstellar matter would create a shock front . Should this shock front occur in a magnetic field , accelerated electrons in it would emit long-lasting synchrotron radiation in the radio frequencies , a phenomenon that would later be referred to as a radio afterglow . Jonathan Katz later concluded that this lower-energy emission would not be limited to radio waves , but should range in frequency from radio waves to x-rays , including visible light .

The Narrow Field Instruments on board BeppoSAX began making observations of the GRB 970228's position within eight hours of its detection . A transient x-ray source was detected which faded with a power-law slope in the days following the burst . This x-ray afterglow was the first GRB afterglow ever detected . Power-law decays have since been recognized as a common feature in GRB afterglows , although most afterglows decay at differing rates during different phases of their lifetimes .

Optical images were taken of GRB 970228's position on 1 and 8 March using the William Herschel Telescope and the Isaac Newton Telescope . Comparison of the images revealed an object which had decreased in luminosity in both visible light and infrared light . This was the burst's optical afterglow . Deeper follow-up observations using the New Technology Telescope showed that the afterglow coincided with a distant , small galaxy : the first evidence of the extragalactic , cosmological nature of Gamma-ray bursts . After the gamma-ray bursts itself had faded

away , very deep observations taken with the Keck telescopes showed the underlying galaxy to have a redshift of  $0.695$  . The predicted radio afterglow was never detected for this burst . At the time of this burst 's discovery , GRBs were believed to emit radiation isotropically . The afterglows from this burst and several others ? such as GRB 970508 and GRB 971214 ? provided early evidence that GRBs emit radiation in collimated jets , a characteristic which lowers the total energy output of a burst by several orders of magnitude .

= = Supernova relation = =

Daniel Reichart of the University of Chicago and Titus Galama of the University of Amsterdam independently analyzed GRB 970228 's optical light curve , both concluding that the host object may have undergone a supernova explosion several weeks before the gamma @-@ ray burst occurred .

Galama analyzed the light curve of the burst and found that its luminosity decayed at different rates at different times . The luminosity decayed more slowly between March 6 and April 7 than it did before and after these dates . Galama concluded that the earlier light curve had been dominated by the burst itself , whereas the later light curve was produced by the underlying Type Ic supernova . Reichart noted that the late afterglow was redder than the early afterglow , an observation which conflicted with the then @-@ preferred relativistic fireball model for the gamma @-@ ray burst emission mechanism . He also observed that the only GRB with a similar temporal profile was GRB 980326 , for which a supernova relation had already been proposed by Joshua Bloom .

An alternative explanation for the light curves of GRB 970228 and GRB 980326 involved dust echoes . Although GRB 980326 did not provide enough information to definitively rule out this explanation , Reichart showed that the light curve of GRB 970228 could only have been caused by a supernova . Definitive evidence linking gamma @-@ ray bursts and supernovae was eventually found in the spectrum of GRB 020813 and the afterglow of GRB 030329 . However , supernova @-@ like features only become apparent in the weeks following a burst , leaving the possibility that very early luminosity variations could be explained by dust echoes .

= = Host galaxy = =

During the night between 12 and 13 March , Jorge Melnick made observations of the region with the New Technology Telescope . He discovered a faint nebular patch at the burst 's position , almost certainly a distant galaxy . Although there was a remote chance that the burst and this galaxy were unrelated , their positional coincidence provided strong evidence that GRBs occur in distant galaxies rather than within the Milky Way . This conclusion was later supported by observations of GRB 970508 , the first burst to have its redshift determined .

The position of the burst 's afterglow was measurably offset from the centroid of the host galaxy , effectively ruling out the possibility that the burst originated in an active galactic nucleus . The redshift of the galaxy was later determined to be  $z = 0.695$  , which corresponds to a distance of approximately  $8.123 \times 10^9$  ly . At this distance , the burst would have released a total of  $5.2 \times 10^{44}$  J assuming isotropic emission .