= GRB 970508 =

GRB 970508 was a gamma @-@ ray burst (GRB) detected on May 8 , 1997 , at 21 : 42 UTC . A gamma @-@ ray burst is a highly luminous flash associated with an explosion in a distant galaxy and producing gamma rays , the most energetic form of electromagnetic radiation , and often followed by a longer @-@ lived " afterglow " emitted at longer wavelengths (X @-@ ray , ultraviolet , optical , infrared , and radio) .

GRB 970508 was detected by the Gamma Ray Burst Monitor on the Italian ? Dutch X @-@ ray astronomy satellite BeppoSAX . Astronomer Mark Metzger determined that GRB 970508 occurred at least 6 billion light years from Earth ; this was the first measurement of the distance to a gamma @-@ ray burst .

Until this burst , astronomers had not reached a consensus regarding how far away GRBs occur from Earth . Some supported the idea that GRBs occur within the Milky Way , but are visibly faint because they are not highly energetic . Others concluded that GRBs occur in other galaxies at cosmological distances and are extremely energetic . Although the possibility of multiple types of GRBs meant that the two theories were not mutually exclusive , the distance measurement unequivocally placed the source of the GRB outside the Milky Way , effectively ending the debate .

GRB 970508 was also the first burst with an observed radio frequency afterglow . By analyzing the fluctuating strength of the radio signals , astronomer Dale Frail calculated that the source of the radio waves had expanded almost at the speed of light . This provided strong evidence that GRBs are relativistically expanding explosions .

= = Discovery = =

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 in space) . The initial burst is often followed by a longer @-@ lived " afterglow " emitted at longer wavelengths (X @-@ ray , ultraviolet , optical , infrared , and radio) . The first GRB afterglow to be discovered was the X @-@ ray afterglow of GRB 970228 , which was detected by BeppoSAX , an Italian ? Dutch satellite originally designed to study X @-@ rays .

On Thursday May 8 , 1997 , at 21 : 42 UTC , BeppoSAX 's Gamma Ray Burst Monitor registered a gamma @-@ ray burst that lasted approximately 15 seconds . It was also detected by Ulysses , a robotic space probe designed to study the Sun , and by the Burst and Transient Source Experiment (BATSE) on board the Compton Gamma Ray Observatory . The burst also occurred within the field of view of one of BeppoSAX 's two X @-@ ray Wide Field Cameras . Within a few hours , the BeppoSAX team localized the burst to an error box ? a small area around the specific position to account for the error in the position ? with a diameter of approximately 10 arcminutes .

= = Observations = =

After a rough position of the burst had been determined , Enrico Costa of the BeppoSAX team contacted astronomer Dale Frail at the National Radio Astronomy Observatory 's Very Large Array . Frail began making observations at a wavelength of 20 centimeters at 01 : 30 UTC , less than four hours after the discovery . While preparing for his observations Frail contacted astronomer Stanislav Djorgovski , who was working with the Hale telescope . Djorgovski immediately compared his images of the region with older images from the Digitized Sky Survey , but he found no new sources of light within the error box . Mark Metzger , a colleague of Djorgovski at the Caltech observatory , conducted a more extensive analysis of the data , but was also unable to identify any new light sources .

The following evening Djorgovski again observed the region . He compared the images from both nights but the error box contained no objects that had decreased in luminosity between May 8 and May 9 . Metzger noticed one object that had increased in luminosity , but he assumed it was a

variable star rather than the GRB afterglow . Titus Galama and Paul Groot , members of a research team in Amsterdam led by Jan van Paradijs , compared images taken by the WIYN Telescope on May 8 and the William Herschel Telescope on May 9 . They were also unable to find any light sources which had faded during that time .

After discovering the burst 's X @-@ ray afterglow , the BeppoSAX team provided a more accurate localization , and what Metzger had assumed to be a variable star was still present in this smaller error box . Both the Caltech team and the Amsterdam team were hesitant to publish any conclusions on the variable object . On May 10 Howard Bond of the Space Telescope Science Institute published his discovery , which was later confirmed to be the burst 's optical afterglow .

On the night between May 10 and May 11 , 1997 , Metzger 's colleague Charles Steidel recorded the spectrum of the variable object at the W. M. Keck Observatory . He then sent the data to Metzger , who after identifying a system of absorption lines associated with magnesium and iron determined a redshift of z = 0 @.@ 8349 ± 0 @.@ 0002 , indicating that light from the burst had been absorbed by matter roughly 6 billion light @-@ years from Earth . Although the redshift of the burst itself had not been determined , the absorbent matter was necessarily located between the burst and the Earth , implying that the burst itself was at least as far away . The absence of Lyman @-@ alpha forest features in the spectra constrained the redshift to z ? 2 @.@ 3 , while further investigation by Daniel E. Reichart of the University of Chicago suggested a redshift of z ? 1 @.@ 09 . This was the first instance in which scientists were able to measure the redshift of a GRB . Several optical spectra were also obtained at the Calar Alto Observatory at wavelength ranges of 4 @,@ 300 ? 7 @,@ 100 Å (430 ? 710 nm) and 3 @,@ 500 ? 8 @,@ 000 Å (350 ? 800 nm) , but no emission lines were identified .

On May 13 , five days after the first detection of GRB 970508 , Frail resumed his observations with the Very Large Array . He made observations of the burst 's position at a wavelength of 3 @.@ 5 cm and immediately detected a strong signal . After 24 hours , the 3 @.@ 5 cm signal became significantly stronger , and he also detected signals at the 6 and 21 cm wavelengths . This was the first confirmed observation of a radio afterglow of a GRB .

Over the next month , Frail observed that the luminosity of the radio source fluctuated significantly from day to day but increased on average . The fluctuations did not occur simultaneously along all of the observed wavelengths , which Jeremy Goodman of Princeton University explained as being the result of the radio waves being bent by interstellar plasma in the Milky Way . Such radio scintillations (rapid variations in the radio luminosity of an object) occur only when the source has an apparent diameter of less than 3 microarcseconds .

= = Characteristics = =

BeppoSAX 's Gamma @-@ Ray Burst Monitor , operating in the energy range of 40 ? 700 keV , recorded a fluence of (1 @.@ 85 ± 0 @.@ 3) × 10 ? 6 erg / cm2 (1 @.@ 85 ± 0 @.@ 3 nJ / m2) , and the Wide Field Camera (2 ? 26 keV) recorded a fluence of (0 @.@ 7 ± 0 @.@ 1) × 10 ? 6 erg / cm2 (0 @.@ 7 ± 0 @.@ 1 nJ / m2) . BATSE (20 ? 1000 keV) recorded a fluence of (3 @.@ 1 ± 0 @.@ 2) × 10 ? 6 erg / cm2 (3 @.@ 1 ± 0 @.@ 2 nJ / m2) .

About 5 hours after the burst the apparent magnitude of the object ? a logarithmic measure of its brightness with a higher number indicating a fainter object ? was 20 @.@ 3 ± 0 @.@ 3 in the U @-@ band (the ultraviolet region of the spectrum) and 21 @.@ 2 ± 0 @.@ 1 in the R @-@ band (the red region of the spectrum) . The afterglow reached its peak luminosity in both bands approximately 2 days after the burst was first detected ? 19 @.@ 6 ± 0 @.@ 3 in the U @-@ band at 02 : 13 UTC on May 11 , and 19 @.@ 8 ± 0 @.@ 2 in the R @-@ band at 20 : 55 UTC on May 10 .

James E. Rhoads , an astronomer at the Kitt Peak National Observatory , analyzed the burst and determined that it was not strongly beamed . Further analysis by Frail and his colleagues indicated that the total energy released by the burst was approximately 5 × 1050 ergs (5 × 1043 J) , and Rhoads determined that the total gamma @-@ ray energy was approximately 3 × 1050 erg (3 × 1043 J) . This implied that the gamma @-@ ray and kinetic energy of the burst 's ejecta were

comparable , effectively ruling out those GRB models which are relatively inefficient at producing gamma rays .

= = Distance scale and emission model = =

Prior to this burst , astronomers had not reached consensus regarding how far away GRBs occur from Earth . Although the isotropic distribution of bursts suggested that they do not occur within the disk of the Milky Way , some astronomers supported the idea that they occur within the Milky Way 's halo , concluding that the bursts are visibly faint because they are not highly energetic . Others concluded that GRBs occur in other galaxies at cosmological distances and that they can be detected because they are extremely energetic . The distance measurement and the calculations of the burst 's total energy release unequivocally supported the latter theory , effectively ending the debate .

Throughout the month of May the radio scintillations became less noticeable until they ceased altogether . This implies that the radio source significantly expanded in the time that had passed since the burst was detected . Using the known distance to the source and the elapsed time before the scintillation ended , Frail calculated that the radio source had expanded at almost the speed of light . While various existing models already encompassed the notion of a relativistically expanding fireball , this was the first strong evidence to support such a model .

= = Host galaxy = =