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Frontiers of Research in Gamma-Ray Bursts
ガンマ線バーストの研究最前線

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Gamma-ray bursts (GRBs) are the most energetic explosions in the Universe. Their origin and emission mechanism are at last starting to be revealed with the coordination of astronomy satellites and ground-based observations. Majority of GRBs are now believed to be associated with death of massive stars. Their prompt emission, and their afterglows have been successfully explained by a synchrotron emission from relativistic shocks.

1. Introduction

Gamma-ray bursts (GRBs) are short episodes of explosive gamma-ray emission from random positions in the sky, which typically last for tens of seconds or less. Since their serendipitous discovery in 1960's by nuclear test surveillance satellites [1], their origin had been a mystery for 30 years. Even their distance was unknown.

The discovery of their afterglows in X-ray and optical bands in 1997 [2,3], at last, convincingly showed that GRBs are the most violent explosion in the Universe that the mankind knows (except for the Big Bang) at cosmological distances with a typical redshift of >0.5. The only plausible candidates capable of releasing such large energies are the core-collapse of a star with tens of solar masses, and merger of relativistic compact stars (i.e. neutron stars or black holes), either of which results in a release of huge gravitational binding energy.

In a widely accepted scenario, accretion of stellar remnants to the newly born black hole causes collimated, repeated ejection of relativistic shells (“jets”) with a Lorentz factor of a few hundreds. The collision of the shells forms shocks. Synchrotron radiation from the shocks is relativistically beamed and observed as a gamma-ray burst. The relativistic shells propagate into the interstellar medium to form external shocks, where the accelerated particles emit afterglows in a broad band (radio to X-rays) that decay with time following a power-law with indices of 1~2 [4,5].

The fireball model successfully explained various properties of gamma-ray bursts (prompt emission) and their afterglows. However, the fundamental questions remained to be answered. What class of objects produce the explosion? When in the history of the Universe did GRBs started to occur? What influence GRB had on the their environment and the evolution of the Universe? How such huge energies can be released? How can such highly relativistic jets be formed and collimated? What can we learn from GRBs about the history of the early Universe...

We are now beginning to find handles to answer these questions. In this review I highlight a few topics in the study of gamma-ray bursts in the latest years.

2. The HETE-2 Satellite

For the study of GRBs, detection of the afterglows and the study of their prompt burst emission are both important. The High Energy Transient Explorer 2 (HETE-2) is the first satellite designed specifically for the study of GRBs. It was launched in October 2000, and is currently localizing gamma-ray bursts (GRBs) at a rate of ~20 per year, some of them in real time. The primary goals of the HETE-2 mission are the broadband observation of the burst emission of GRBs, and the prompt distribution of precise GRB coordinates to the astronomical community for immediate follow-up observations [6]. To achieve these goals, HETE-2 is equipped with three sets of gamma-ray and X-ray detectors, which share a common field of view of ~1.5 steradians, and, together, measure the light curves and energy spectra in the photon energy range of 2 keV to over 400 keV.

3. Origin of GRBs

There has been increasing circumstantial and tantalizing evidence in the last few years that GRBs are associated with core collapse supernovae (SNe). In particular, detection of a powerful type Ic supernova SN1998bw positionally and temporally coincident with GRB980425 have been often discussed as evidence for the GRB-SN association [7]. However, the low redshift of SN1998bw (z~0.008) implied that the gamma-ray luminosity of GRB980425 was ~10^4 times fainter than any other GRB observed to date. If their association is real, GRB980425 may not be a typical cosmological gamma-ray burst.

The detection and localization of GRB 030329 by HETE-2 [8] led to a dramatic confirmation of the GRB-SN connection. GRB 030329 was among the brightest 1% of GRBs ever seen. Given that GRBs typically occur at z~1—2, the probability that the source of an observed burst should be as close as GRB 030329 (z=0.167) is one in several thousand.

The fact that GRB 030329 was very bright spurred the astronomical community — both amateurs and professionals — to make an unprecedented number of observations of the optical afterglow of this event. More than 170 GCN Circulars have appeared so far, reporting optical, IR, and radio observations of the afterglow.

About ten days after the burst, the spectral signature of an energetic Type Ic supernova emerged [9] on top of the usual GRB afterglow continuum of non-thermal synchrotron emission. The underlying supernova has been designated SN 2003dh. The spectrum of SN 2003dh is strikingly similar to that of the Type Ic supernova SN 1998bw, which was putatively associated with GRB980425. The clear detection of SN 2003dh in the afterglow of GRB 030329 confirmed decisively the connection between GRBs and core collapse supernovae. We note, however, that evidence for association with supernovae has been found only with the "long soft" GRBs. We have no clue for "short hard" GRBs, which constitutes ~20% of the GRB population and for which no optical afterglows have been found.

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4. Spectral Energy Peak and Radiated Energy

HETE-2 is detecting X-ray flashes (XRFs), which are similar to regular "classical" GRBs in many ways except that XRFs have larger fluence in the X-ray band (2—30 keV) than in the gamma-ray band (30—400 keV). XRFs have received increasing attention in the past several years [10]. Using twelve *Beppo*SAX GRBs with measured redshifts, Amati et al. [11] showed that the spectral peak energy at the source frame $E_{\rm peak}^{\rm src}$ and the isotropic-equivalent radiated energy $E_{\rm iso}$ are tightly correlated, and follows a relation $E_{\rm peak}^{\rm src} \propto E_{\rm iso}^{1/2}$.

With the 10 HETE GRBs/XRFs with measured redshifts we have confirmed this relation. Furthermore, we extended this relation by three orders of magnitude in $E_{\rm iso}$ [12]. These results provide strong evidence that XRFs and ordinary GRBs form a continuum, and are a single phenomenon. The extended Amati et al relation ($E_{\rm peak}^{\rm src} \propto E_{\rm iso}^{1/2}$) suggests that the $E_{\rm peak}^{\rm src}$ and $E_{\rm iso}$ are controlled by some single parameter, which differentiate XRFs and GRBs. Understanding this key parameter should certainly lead to the understanding of the energetics and radiation mechanism of GRBs.

Observationally it is essential to obtain larger sample of XRFs and GRBs with measured redshifts. In particular, additional redshift determinations are clearly needed for XRFs with 1 keV $<E_{\rm peak}<$30 keV in order to confirm these results and to test the theories.

5. Coming Observations

In November 2004, *Swift*, a larger satellite dedicated for the GRB study [13] was successfully launched, and now in the process of performance verification. *Swift* is equipped with three main instruments: Burst Alert Telescpe (BAT) for detecting and localizing GRBs in the 15—200 keV energy band, XRT (X-ray telescope) and UVOT (UV Optical Telescope) for imaging X-ray and UV/optical afterglows. Once BAT catches a GRB and localize it, the entire spacecraft is autonomously slewed to the location of GRB to perform the observations of the afterglow with XRT and UVOT. HETE-2 is complementary to *Swift* with the soft X-ray response. The scientific discoveries that HETE-2 has made need to be confirmed and proceeded with further operation of HETE-2 in synergy with *Swift* in the coming years.

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