GAMMA-RAY BURSTS

To be short or long is not the question

The association of a short gamma-ray burst with a core-collapse supernova seems to challenge current scenarios for the origin of these extreme events. But how much can we rely on observed duration for pinpointing their progenitors?

Lorenzo Amati

Gamma-ray bursts (GRBs) are extremely bright flashes of X-ray gamma-ray photons detected about once per day from random directions and outshining for up to a few minutes any other source in the high-energy sky. Despite huge observational efforts, it took as long as thirty years from their discovery in the 1960s to unveil their cosmological origin. A further twenty years of efforts by many space and ground observatories, as well as intensive theoretical work and numerical simulations, were then needed to build up and consolidate the current scenario for their progenitors: core collapse of peculiar very massive stars for the longer ones and merging of a neutron star–neutron star (NS–NS) or neutron star–black hole (NS–BH) binary system for the shorter ones. Writing in Nature Astronomy, Tomás Ahumada, Bin-Bin Zhang, and their collaborators report significant evidence for the unexpected association of a short GRB with a stellar explosion. Do we actually need to reconsider our main paradigm for GRBs?

The mounting evidence for the existence of short (a few tens of milliseconds up to 1–2 seconds) and long (tens to hundreds of seconds) GRBs was one of the first main steps forward in our comprehension of these outstanding but elusive phenomena, based on the distribution of their durations (Fig. 1d) and on the spectral hardness–duration plane (Fig. 1a). A major step forward occurred towards the dawn of the new millennium, when the first systematic arcmin localizations of long bursts allowed the discovery of the fading multi-wavelength GRB ‘afterglow’ emission. The improved (a few arcsec) localization and the spectroscopy of the optical/near infrared afterglows by large ground telescopes and the Hubble Space Telescope led to establishing the cosmological distance scale of long GRBs (extending up to a redshift of at least ~9), the first identifications and characterizations of their host galaxies and the direct detection of a peculiar type Ib/c supernova (SN) associated with the long GRB 980425. This impressive wealth of discoveries provided strong support for the production of long GRBs by the core collapse of peculiar massive stars, a scenario already postulated in the 1970s. Such a core collapse is capable of explaining the long duration and extremely high radiated energy (up to 10^53 erg or even more) and was further strengthened in the last 20 years by the detection of a ‘bump’ over the decaying afterglow light curves with spectral features resembling those of peculiar type Ib/c core-collapse supernovas. Other evidence supporting this origin for long GRBs includes their typical location in active star-forming regions of their host galaxies (Fig. 1c), the evidence of a metal-enriched circum-burst environment, and their redshift distribution approximating the star-formation rate evolution.

Conversely, from the early 2000s, we started learning that for short GRBs the redshift distribution extends to much lower redshift than long ones, that their typical released energy is about two orders of magnitude lower and that they are often located in the outskirts of their host galaxies (Fig. 1c) without any association with star-forming regions. Together with their duration, these properties support the hypothesis that short GRBs originate from the merging of NS–NS or NS–BH binary systems, a scenario that was eventually confirmed by the association of a gravitational wave signal from a NS–NS merger (GW170817) and a short GRB (170817A).

The observations and analyses reported by Ahumada et al. and Zhang et al., however, seem to defy expectations: a SN bump was detected in the afterglow light curve of the genuinely short GRB 200826A. Although at face value this result may challenge our current understanding of the GRB phenomenon, a more global view of its properties, combined with several pieces of evidence that have emerged in the last few years, show that this event, while peculiar and of high interest, may not be so odd.

First of all, the ~1 s duration of GRB 200826A is in the range where the duration distributions of short and long GRBs still overlap (Fig. 1d), potentially making this an extreme event in the short-duration tail of the long GRB duration distribution. The location in the spectral hardness–duration plane further supports a short GRB classification, but the probability that GRB 200826A belongs to the long class is still not negligible. Moreover, the divide between the two distributions varies as a function of the energy band considered and, more generally, the characteristics of the GRB detector used to build the sample from which the distributions are drawn. To accentuate the problem, theoretical considerations and numerical simulations show that the duration of a core-collapse GRB, which depends on the time during which the ‘central engine’ (the BH accreting matter from the torus) is at work and the time taken by the produced jet to break out from the stellar envelope, can be even shorter than 0.5 s (ref. 9).

This is why duration is increasingly considered to be only one of the indicators of the origin of a GRB. Instead, these two classes of events are now frequently referred to as ‘type I’ and ‘type II’. In addition to duration, spectral hardness, location in the host galaxy and host-galaxy properties, the indicators used for discriminating the two classes of events include the ‘time lag’, the delay of the peak of the emission as a function of the energy band, and the relation between the photon energy at which the νFν spectrum in the cosmological rest-frame peaks (Epeak) and the isotropic-equivalent radiated energy (Eiso). The analysis of these indicators for GRB 200826A shows that despite its short duration, it actually belongs to the type II core-collapse class. Thus, the association of this event with a type Ib/c SN is no longer surprising, and instead provides a strong confirmation of the efficiency of our new paradigm for identifying the progenitor of a GRB. In this respect, GRB 200826A is the opposite case of another famous and challenging event, GRB 060614, which was technically a long GRB for which there was...
strong evidence of no association with a
SN15. In that case, similarly, it was thanks
time lag and location in the $E_{p,i}-E_{iso}$ plane)
that it was possible to solve the mystery
by classifying the event as a type I burst.

The extended sensitivity and energy bands
of next-generation GRB detectors (for
example, those on board the Chinese–French
mission, the Space Variable Objects Monitor,
to be launched next year), combined with
improved follow-up capabilities provided by
future ground observatories (for example, the
Extremely Large Telescope or the Thirty
Meter Telescope in the optical/near infrared,
and the Square Kilometre Array in the radio),
will allow us to eventually assess whether
currently peculiar
events like the odd balls GRB 200826A and
GRB 060614, the fraction of short GRBs
showing a soft extended emission, under-
luminous low-redshift long GRBs (for example,
GRB 980425) and the few ultra-long (thousands
of seconds) GRBs are actually tip-of-the-
icberg phenomena from large populations still
to be unveiled. This substantial progress will
allow us to definitively go beyond the GRB
classification based on duration and probably
to pinpoint
a richer variety of progenitors, including
extremely magnetized neutron stars for short
GRBs as well as different types of progenitor
stars (possibly including population
III ones) and explosive processes (for example,
pair instability) for long ones. An improved
understanding of GRB subclasses and
progenitors is also crucial for the growing
relevance of type II events for cosmology
(investigating the early Universe and possibly
cosmological parameters) and of type I events
for multi-messenger astrophysics
(as demonstrated by the amazing case of GW
170817/GRB 170817A).

Lorenzo Amati

Italian National Institute for Astrophysics
(INAF – OAS Bologna), Bologna, Italy.
E-mail: lorenzo.amati@inaf.it

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