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Late-time observations of the X-ray afterglow of GRB 060729

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We summarize the results of the late-time Chandra observations of the X-ray afterglow of the Swift-discovered GRB 060729. These Chandra observations have been the latest X-ray detections of an afterglow, even up to 21 month after the trigger. The last two Chandra observations in December 2007 and May 2008 suggest a break at about a year after the burst, implying a jet half-opening angle of about 14 degrees, if interpreted as a jet break. As an alternative this break may have a spectral origin. In that case no jet break was observed and the half-opening angle is larger than 15 degrees for a wind medium. Comparing the X-ray afterglow of GRB 060729 with other bright X-ray afterglows we discuss why the afterglow of GRB 060729 was such an exceptionally long-lasting event. The detection by Chandra in May 2008 was the latest detection of an X-ray afterglow at cosmological distance ever.

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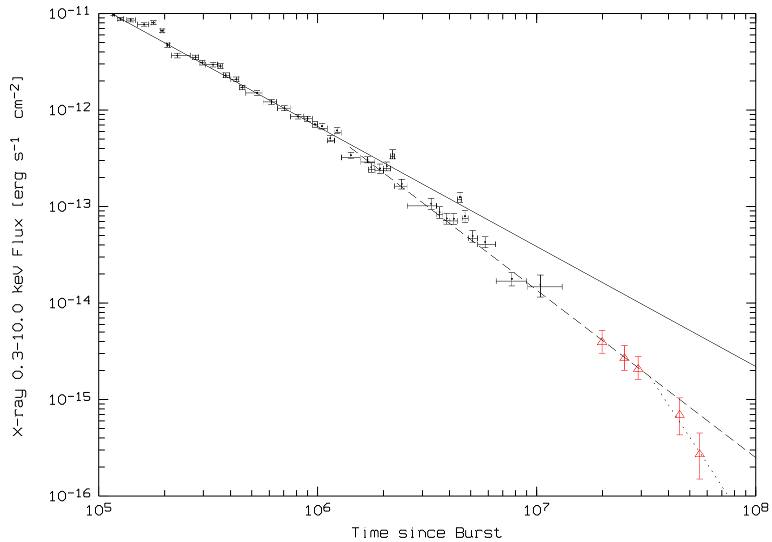

Figure 1: Swift XRT (black crosses) and Chandra ACIS-S (red triangles) light curve of the X-ray afterglow of GRB 060729. The solid line displays an initial decay slope of 1.32 ([2]), the dashed line the decay slope of 1.61 post-break at 1 Ms after the burst and the doted line the steep decay slope of 4.65 after the break at 41 Ms after the burst ([3]).

1. Introduction

One of the predictions of the GRB 'Fireball' model is that the GRB afterglow decay rate increases when the relativistic beaming angle equals or exceeds the physical jet opening angle as the jet decelerates in the surrounding medium. This can be seen as an achromatic jet break in the light curve. Since its launch, Swift has detected roughly 700 bursts (May 2012). For the majority of these bursts, jet breaks have not been detected (e.g. [8, 1]). However, one reason could be that jet breaks occur at times after Swift stopped observing the afterglow. Typically Swift follows an afterglow roughly a week or two after the detection. One exception was the X-ray afterglow of GRB 060729 which Swift was able to detect even 125 days after the trigger ([2]). However, by December 2006 the afterglow had faded below the Swift XRT detection limit. In order to extend the light curve of this exceptional X-ray afterglow, we observed it 5 times with Chandra in 2007 and 2008 (Figure 1; [3]).

2. Observations of the X-ray afterglow of GRB 060729

While Swift could detect the X-ray afterglow of GRB 060729 until the end of November 2006 it became too faint to be detected by the Swift XRT in December 2006 ([2]). All further observations of the X-ray afterglow needed to be performed by Chandra. Therefore we had 3 Chandra ACIS-S observations in March, May and June 2007 for 30 ks, 40 ks, and 60 ks respectively as part of the Penn State GTO time. These were followed by an 80 ks observation in December 2007 and an 120 ks observation in May 2008 as GO observations (see [3] for details).

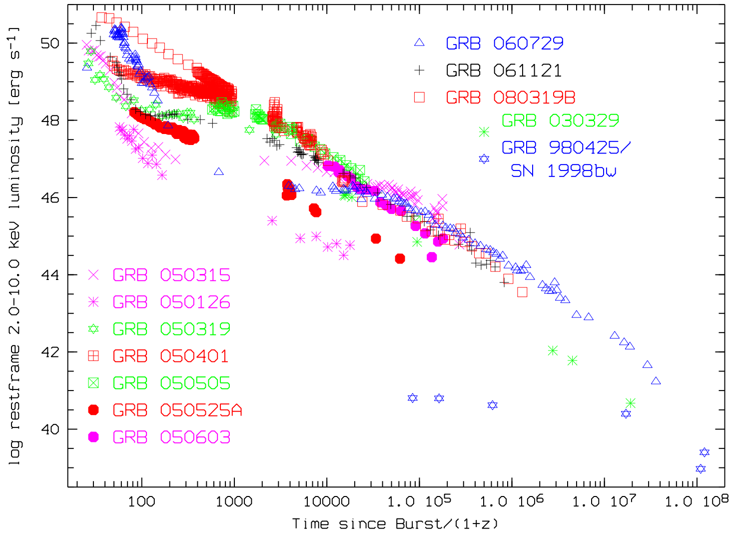

Figure 2: Combined rest-frame isotropic equivalent luminosity of several Swift and pre-Swift bursts taken from [5], including GRBs 060729, 061121, and 080319B as shown in [3].

3. Temporal Breaks in the X-ray Afterglow Light Curve

Figure 1 displays the Swift XRT and Chandra ACIS light curve of the X-ray afterglow of GRB 060729. The first day is not shown here because we focus on the late-time light curve. This light curve was fitted with multiple broken power laws. Fitting the light curve with just a single power law model with a decay slope of 1.32 as reported by [2] shows a significant deviation of the data after about 1 Ms after the burst. The hardness ratio light curve shown in [3] shows that there is also a spectral break at about 1 Ms after the trigger. The spectrum significantly hardens after this break. On the flux light curve the decay slope becomes steeper with a slope of 1.61 (shown as the dashed line in Figure 1). While the first three Chandra points (red triangles) agree perfectly with that slope, the last two point from Dec. 2007 and May 2008 seem to deviate from this line. They suggest a break at about 41 Ms after the trigger. This break is followed by a very steep decay slope of 4.6. Note, however, that this break is not well constrained.

4. Discussion

What makes the X-ray afterglow of GRB 060729 so remarkable is the fact that it was still detected even almost two years after the burst. This exceptional late-time detectability is related to three things: a) with an initial 0.3 - 10.0 keV flux of almost 10^{-7} erg s^{-1} cm^{-2} it was one of the brightest afterglows ever detected by Swift, b) its flat decay phase ([5, 9]) extended out to about 60 ks after the burst, and c) the decay slope after that break is about 1.3. Bursts like GRBs 060614, 061121, or even 080319B ([4, 6, 7], respectively) were even brighter in X-rays at about 100 s after the burst than GRB 060729, but their plateau phases are significantly shorter than that of GRB 060729. They therefore faded more rapidly than GRB 060729 at late times. Figure 2 displays the comparison of the luminosity light curves of these bursts with GRB 060729.

Analysis and modeling of the X-ray afterglow of GRB 060729 show that this burst happened in a tenuous wind which are the conclusion following the closure relations. During the early plateau phase, the energy in the external shock increased by two orders of magnitude. At $\sim$1.3 Ms after the burst, the decay slope steepened from 1.32 to 1.61 and the X-ray spectrum hardened, indicating a cooling break (the cooling frequency of synchrotron radiation crosses the X-ray band). The break at 1.3 years after the trigger tentatively indicated by the last two Chandra points coincides with a possible softening, suggesting that the break may be of spectral origin, though a hydrodynamic origin (jet break) is also possible. If due to a jet break, the implied half-opening angle 14 degrees. If due to a spectral break, such a spectral softening could be the result of a very steep power-law distribution of shock-accelerated electrons responsible for the synchrotron radiation. In this case, with no evidence for a jet break up to 642 days after the burst by Chandra, the jet half-opening angle must be 15 degrees and the jet energy 3×10^{52} erg. Such a large jet energy implies that the central engine must be a fast-rotating massive black hole, not a magnetar. Our Chandra observations presented here have shown again how important Chandra is for the late-time detections of GRB X-ray afterglows. XMM on the other hand is needed to obtain high-quality spectra of X-ray afterglows.

Acknowledgments

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