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Exploring the Nature of Gamma-ray Burst Shallow Decay

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We have studied the optical temporal evolution of 42 *Swift* GRBs. Our investigation shows that most of the optical properties can be interpreted by the external shock model and implies that the observed optical emission originated from this model. However, of the 42 GRBs, 10 show shallow decay properties in their overall optical light curve. Further investigations into the 10 GRBs found that the corresponding shallow decay properties were also found in their X-ray light curve. Apart from GRB 050730, our results also indicate that most shallow decay orginates from the external shock in both X-ray and optical. We conclude that, for some bursts, the optical and X-ray shallow decay have an extrnal origin, but some bursts have different emission mechanisms.

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1. Introduction

In the *Swift* era, some unexpected behaviors (e.g. steep decays, flares, and shallow decays) were found in many X-ray lightcurves. Those properties, thought to be connected to an active central engine, could be characterized by prompt emission from GRBs or a mixture of different emission components contributing to the observed X-ray emission [1]. In addition, the comparison of X-ray and optical light curves have clearly shown that the evolutions for the two wavelengths are generally different [2,3]. To explain possible emission mechanisms and provide reasonable interpretation, many theoretical interpretations were thus proposed [4,5]. However, there is still no conclusive picture to explain the observed X-ray and optical evolution well.

Recently, Liang et al. 2007 [6] found diverse origins for X-ray shallow decay, either of external or internal origin. Similar shallow decay properties were also found in optical lightcurves of some bursts. We studied the bursts with optical shallow decay components and investigated their X-ray and optical properties to explore possible interpretations of shallow decay in GRBs.

GRB	α_{o1} [1]	t_{o1} (day)	α_{o2}	t_{o2} (day)	α_{o3}	α_{xs} [2]	t_x (day)	α_{xn} [3]
GRB 050319	0.82	0.046	0.55	3.77	2.17	0.46	0.63	1.71
GRB 050730	0.56	0.23	1.49	–	–	0.44	0.13	2.58
GRB 050824A	0.59	–	–	–	–	0.36	0.56	0.87
GRB 060526	0.30	0.17	1.48	1.16	1.97	0.38	0.29	2.00
GRB 060729	0.06	1.15	2.10	–	–	0.23	1.16	1.65
GRB 070518	0.62	–	–	–	–	0.33	0.23	0.93
GRB 070802	0.61	–	–	–	–	0.21	0.11	1.36
GRB 071010B	−0.98	0.001	0.58	–	–	–	–	0.69
GRB 080413B	0.99	0.09	0.22	3.47	2.43	0.91	0.58	1.42
GRB 090618	0.31	0.12	1.36	–	–	0.46	0.12	1.57

Table 1: Optical and X-ray temporal properties of the 10 GRBs that exhibit optical shallow decay. The indices and break time shown in this table are approximate values from fitting.

2. Analysis and Results

We have investigated the optical properties for 42 GRBs, which have redshift and detailed optical measurements from 200 Swift GRBs. Their optical lightcurves are usually composed of several power-law segments. We found that most of the power-law segments can be simply interpreted by the standard external afterglow model [7]. However, 10 of the 42 GRBs show shallower decay indices and we could not find a reasonable interpretation from the afterglow, neither in uniform ISM nor in wind medium. In addition, we also found that some of the optical shallow decay

[1] The single power-law function is $F(\nu,t) \propto t^{-\alpha}$, where α is a single power-law index and the broken power-law function: $F(\nu,t) = F_\nu^*/[(t/t_b)^{k\alpha_1} + (t/t_b)^{k\alpha_2}]^{(1/k)}$, where t_b is the break time, α_1, α_2 are the power-law index before and after t_b, $F_{\nu,b}$ is the flux at break t_b, and k is a smoothness factor.

[2] α_{xs} is temporal decay of X-ray shallow decay.

[3] α_{xn} is temporal decay of X-ray normal decay.

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components are accompanied by X-ray shallow decays. Table 1 summarizes the optical temporal properties as well as X-ray properties of the 10 bursts. The decay indices and break time in Table 1 are determined from the best fitting result via a single power-law, a broken power-law or the combination of a signal power-law plus a broken power-law function .

Table 1 suggests that the optical temporal properties of 7 bursts, either before or after the shallow component, are consistent with the standard external shock model, while the other 3 bursts only show a shallow decay component in their overall optical lightcurves. We believe that the 3 bursts are similar to those consistent with the external shock model, but lack late time measurements to trace the properties after the shallow decay. Liang et al. 2007 [7] investigated the X-ray temporal and spectral properties after the shallow decay component for some bursts. They examined the component after the shallow decay, called "normal decay", with the standard external shock model to demonstrate the internal or external origin of the X-ray shallow decay. Next we applied the same method to the 10 GRBs and examined their X-ray temporal and spectral properties during the shallow decay (α_{xs}) and the normal decay (α_{xn}). We found that there is no spectral evolution from shallow decay to normal decay. In addition, we found that only GRB 050730 had a steep temporal decay index, and we cannot interpret it with jet break. This implies an internal origin for X-ray shallow component in GRB 050730 and that the X-ray shallow components in the other 9 bursts have an external origin.

We concluded that most of the optical and X-ray shallow decays are of external origin. In the standard external shock model, it is believed that X-ray and optical emission originate from the same emission mechanism. The X-ray and optical temporal properties would follow the predictions of the external shock model. Thus, we will examine the optical decay index (α_o) and X-ray decay index (α_x) for the 10 GRBs.

To explore the relation between α_o and α_x, we selected the X-ray normal decay (α_{xn}) as a reference and estimated the corresponding optical decay index. It is interesting to note that the combined X-ray and optical temporal evolution display three kinds of features: no break (3 bursts; GRB 050824A, GRB 070518, and GRB 071010B), achromatic break (2 bursts; GRB 060729 and GRB 090618), and chromatic break (5 bursts; GRB 050319, GRB 050730, GRB 060526, GRB 070802, and GRB 080413B) in the two energy bands. For the situations of achromatic break and no break, the bursts display a similar break time from the shallow decay to the normal decay or the bursts have a shallow component until their final measurements. On the other hand, in the case of a chromatic break, it implies a break occurred in the optical and two optical decay indices thus correspond to the X-ray normal decay.

Figure 1 demonstrates α_o - α_{xn} for 10 GRBs. It is clear to see that the standard external shock model cannot simply explain bursts with chromatic breaks. The break in the optical lightcurve shows a trend in the α_o - α_{xn} properties. Before the optical break, the locations of α_o- α_x for the 5 chromatic break bursts first fall outside the prediction of the external shock model, then approach the region consistent with it. This implies that an additional factor controls temporal evolution and the standard external shock model cannot explain the observed properties. Thus, late time temporal properties of GRB 050319, GRB 060526 and GRB 080413B could provide a clue that this additional factor becomes weak after the optical break and the temporal properties are dominated by afterglow emission. Thus, the late time temporal properties of the three bursts become consistent with the external shock model predictions.

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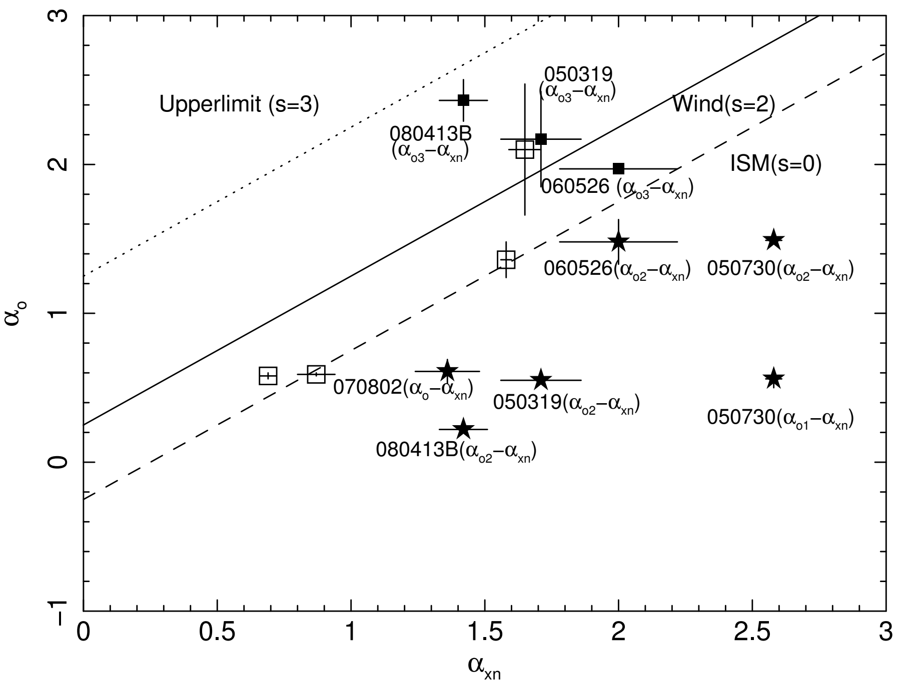

Figure 1: The $\alpha_{\rm o} - \alpha_{\rm xn}$ plot for 10 GRBs. The solid, dashed, and dotted lines show different conditions in the external shock model. It is clear to see that the 5 GRBs that have chromatic breaks first fall outside of the external shock prediction (filled star), then GRB 050319, GRB060526, and GRB 080413 approach the consistent region after the optical break (filled square). However, the GRB 050730 displays inconsistent behavior during the evolution.

On the other hand, it is important to note we concluded GRB 050730 has an internal origin in X-ray and an external shock origin in optical. This burst displays behavior inconsistent with the standard external shock model before and after the optical break. This result indicates different emission mechanisms for the X-ray and optical emission of GRB 050730. This supports the scenario of internal origin in X-ray and external origin in optical.

Our investigations suggest that the optical and shallow decay are related to the activity of the central engine, which continues to supply additional energy into the ambient medium. However, the additional energy would affect the temporal evolution of the X-ray and optical energy bands in different ways. Our results show X-ray shallow decays could have an internal or external origin and that optical shallow decays are of external origin. In the case of an internal origin for X-ray shallow decays, the X-ray temporal, spectral, and optical temporal properties do not clearly follow the standard external shock model. However, it is more complicated in the case of an external origin of X-ray and optical shallow decay. To explain why some bursts display achromatic X-ray and optical breaks or no break in the two wavelengths can be explained by the energy injection, which produces synchronous evolution in both X-ray and optical.

On the other hand, to explain the bursts with chromatic X-ray and optical breaks, an additional factor is required such as energy injection superimposed on the afterglow emission which could produce properties inconsistent with the standard shock model. Our investigation suggests that this additional factor comes from external shocks. With currently limited samples and measurements, it is still unclear what the nature of the additional factor is and how it affects the X-ray and optical properties and produces chromatic breaks in the two energy bands. A large sample of GRB afterglows is needed to investigate this puzzle.

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