Nature Astronomy, 2018, vol.2, N1, pages 69-75

Transition from fireball to Poynting-flux-dominated outflow in the three-episode GRB 160625B

Moskvitin A., Fatkhullin T., Sokolov V., Valeev A., Jeong S., Park I., Caballero-García M., Cunniffe R., Tello J., Ferrero P., Pandey S., Jelínek M., Peng F., Sánchez-Ramrez R., Castellón A.
Kazan Federal University, 420008, Kremlevskaya 18, Kazan, Russia

Abstract

© 2017 The Author(s). The ejecta composition is an open question in gamma-ray burst (GRB) physics 1 . Some GRBs possess a quasi-thermal spectral component in the time-resolved spectral analysis 2, suggesting a hot fireball origin. Others show a featureless non-thermal spectrum known as the Band function 3-5, consistent with a synchrotron radiation origin 5,6 and suggesting that the jet is Poynting-flux dominated at the central engine and probably in the emission region as well 7,8 . There are also bursts showing a sub-dominant thermal component and a dominant synchrotron component 9, suggesting a probable hybrid jet composition 10 . Here, we report an extraordinarily bright GRB 160625B, simultaneously observed in gamma-ray and optical wavelengths, whose prompt emission consists of three isolated episodes separated by long quiescent intervals, with the durations of each sub-burst being approximately 0.8 s, 35 s and 212 s, respectively. Its high brightness (with isotropic peak luminosity L p,iso ≈ 4 × 1053 erg s-1) allows us to conduct detailed time-resolved spectral analysis in each episode, from precursor to main burst and to extended emission. The spectral properties of the first two sub-bursts are distinctly different, allowing us to observe the transition from thermal to non-thermal radiation between well-separated emission episodes within a single GRB. Such a transition is a clear indication of the change of jet composition from a fireball to a Poynting-flux-dominated jet.

http://dx.doi.org/10.1038/s41550-017-0309-8

References

[1] Kumar, P. & Zhang, B. The physics of gamma-ray bursts & relativistic jets. Phys. Rep. 561, 1-109 (2015).

[2] Ryde, F. et al. Identification and properties of the photospheric emission in GRB090902B. Astrophys. J. 709, L172-L177 (2010).

[3] Band, D. et al. BATSE observations of gamma-ray burst spectra. I-spectral diversity. Astrophys. J. 413, 281-292 (1993).

[4] Preece, R. et al. The first pulse of the extremely bright GRB 130427A: a test lab for synchrotron shocks. Science 343, 51-54 (2014).

[5] Zhang, B.-B., Uhm, Z. L., Connaughton, V., Briggs, M. S. & Zhang, B. Synchrotron origin of the typical GRB Band function-case study of GRB 130606B. Astrophys. J. 816, 72 (2016).

[6] Uhm, Z. L. & Zhang, B. Fast-cooling synchrotron radiation in a decaying magnetic field and γ -ray burst emission mechanism. Nat. Phys. 10, 351-356 (2014).

[7] Zhang, B. & Pe'er, A. Evidence of an initially magnetically dominated outflow in GRB 080916C. Astrophys. J. 700, L65-L68 (2009).

[8] Hascoët, R., Daigne, F., Mochkovitch, R. & Vennin, V. Do Fermi Large Area Telescope observations imply very large Lorentz factors in gamma-ray burst outflows? Mon. Not. R. Astron. Soc. 421, 525-545 (2012).

[9] Axelsson, M. et al. GRB110721A: an extreme peak energy and signatures of the photosphere. Astrophys. J. 757, L31 (2012).

[10] Gao, H. & Zhang, B. photosphere emission from a hybrid relativistic outflow with arbitrary dimensionless entropy and magnetization in GRBs. Astrophys. J. 801, 103 (2015).

[11] Troja, E. et al. Significant and variable linear polarization during the prompt optical flash of GRB 160625B. Nature 547, 425-427 (2017).

[12] Zhang, B. et al. Discerning the physical origins of cosmological gamma-ray bursts based on multiple observational criteria: the cases of z = 6.7 GRB 080913, z = 8.2 GRB 090423, and some short/hard GRBs. Astrophys. J. 703, 1696-1724 (2009).

[13] Hu, Y.-D. et al. Internal energy dissipation of gamma-ray bursts observed with Swift: precursors, prompt gamma-rays, extended emission, and late X-ray flares. Astrophys. J. 789, 145 (2014).

[14] Preece, R. D. et al. The BATSE gamma-ray burst spectral catalog. I. High time resolution spectroscopy of bright bursts using high energy resolution data. Astrophys J. Suppl. S. 126, 19-36 (2000).

[15] Mészáros, P. & Rees, M. J. Steep slopes and preferred breaks in gamma-ray burst spectra: the role of photospheres and Comptonization. Astrophys. J. 530, 292-298 (2000).

[16] Pe'er, A. Temporal evolution of thermal emission from relativistically expanding plasma. Astrophys. J. 682, 463-473 (2008).

[17] Deng, W. & Zhang, B. Cosmological implications of fast radio burst/gamma-ray burst associations. Astrophys. J. 783, L35 (2014).

[18] Murakami, T., Inoue, H., Nishimura, J., van Paradijs, J. & Fenimore, E. E. A gamma-ray burst preceded by X-ray activity. Nature 350, 592-594 (1991).

[19] Pe'er, A., Ryde, F., Wijers, R. A. M. J., Mészáros, P. & Rees, M. J. A new method of determining the initial size and Lorentz factor of gamma-ray burst fireballs using a thermal emission component. Astrophys. J. 664, L1-L4 (2007).

[20] Castro-Tirado, A. J. et al. GRB 021004: tomography of a gamma-ray burst progenitor and its host galaxy. Astron. Astrophys. 517, A61 (2010).

[21] Racusin, J. L. et al. Broadband observations of the naked-eye γ -ray burst GRB080319B. Nature. 455, 183-188 (2008).

[22] Piran, T., Sari, R. & Zou, Y.-C. Observational limits on inverse Compton processes in gamma-ray bursts. Mon. Not. R. Astron. Soc. 393, 1107-1113 (2009).

[23] Zhang, B. & Yan, H. The Internal-Collision-Induced Magnetic Reconnection and Turbulence (ICMART) model of gamma-ray bursts. Astrophys. J. 726, 90 (2011).

[24] Ghirlanda, G., Celotti, A. & Ghisellini, G. Extremely hard GRB spectra prune down the forest of emission models. Astron. Astrophys. 406, 879-892 (2003).

[25] Wang, X.-Y. & Mészáros, P. GRB precursors in the fallback collapsar scenario. Astrophys. J. 670, 1247-1253 (2007).

[26] Proga, D. & Zhang, B. The late time evolution of gamma-ray bursts: ending hyperaccretion and producing flares. Mon. Not. R. Astron. Soc. 370, L61-L65 (2006).

[27] Metzger, B. D., Giannios, D., Thompson, T. A., Bucciantini, N. & Quatært, E. The protomagnetar model for gamma-ray bursts. Mon. Not. R. Astron. Soc. 413, 2031-2056 (2011).

[28] Komissarov, S. S. & Barkov, M. V. Magnetar-energized supernova explosions and gamma-ray burst jets. Mon. Not. R. Astron. Soc. 382, 1029-1040 (2007).

[29] Burrows, D. N. et al. Bright X-ray flares in gamma-ray burst afterglows. Science 309, 1833-1835 (2005).

[30] Ackermann, M. et al. Fermi-LAT observations of the gamma-ray burst GRB 130427A. Science 343, 42-47 (2014).

[31] Ziæepour, H., et al. Final Swift Observations of GRB 070721B GRB Coordinates Network Report 73 (2007).

[32] Gruber, D. et al. Fermi/GBM observations of the ultra-long GRB 091024. A burst with an optical flash. Astron. Astrophys. 528, A15 (2011).

[33] Zhang, B.-B. et al. Unusual central engine activity in the double burst GRB 110709B. Astrophys. J. 748, 132 (2012).

[34] Abdo, A. A. et al. Fermi observations of GRB 090902B: a distinct spectral component in the prompt and delayed emission. Astrophys. J. 706, L138-L144 (2009).

[35] Burlon, D. et al. Precursors in swift gamma ray bursts with redshift. Astrophys. J. 685, L19 (2008).

[36] Troja, E., Rosswog, S. & Gehrels, N. Precursors of short gamma-ray bursts. Astrophys. J. 723, 1711-1717 (2010).

[37] Lazzati, D. Precursor activity in bright, long BATSE gamma-ray bursts. Mon. Not. R. Astron. Soc. 357, 722-731 (2005).

[38] Zhang, B.-B. et al. A comprehensive analysis of Fermi gamma-ray burst data. I. Spectral components and the possible physical origins of LAT/GBM GRBs. Astrophys. J. 730, 141 (2011).

[39] Zhang, B.-B. et al. An analysis of Chandra deep follow-up gamma-ray bursts: implications for off-axis jets. Astrophys. J. 806, 15 (2015).

[40] Cash, W. Parameter estimation in astronomy through application of the likelihood ratio. Astrophys. J. 228, 939-947 (1979).

[41] Tang, S. M. & Zhang, S. N. Time lag between prompt optical emission and γ -rays in GRBs. Astron. Astrophys. 456, 141-143 (2006).

[42] Beskin, G. et al. Fast optical variability of a naked-eye burst-manifestation of the periodic activity of an internal engine. Astrophys. J. 719, L10-L14 (2010).

[43] Li, Z. & Waxman, E. Prompt optical emission from residual collisions in gamma-ray burst outflows. Astrophys. J. 674, L65 (2008).

[44] Fan, Y.-Z., Zhang, B. & Wei, D.-M. Naked-eye optical flash from gamma-ray burst 080319B: tracing the decaying neutrons in the outflow. Phys. Rev. D. 79, 021301 (2009).