3-2022

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Research Notes of the AAS, Volume 6, Number 3

Citation Oindabi Mukherjee and Robert J. Nemiroff 2022 *Res. Notes AAS* **6** 42

DOI 10.3847/2515-5172/ac5968

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1. Received January 2022
2. Accepted January 2022
3. Published March 2022

Gamma-ray bursts; Gravitational lensing

Abstract

A gravitational lens can imprint distinct features on the light curve of a gamma-ray burst (GRB). Most prominently, when creating multiple images, the light curves for all images should be identical, within a scale factor in amplitude. For GRB images that are bright enough to have significant counts in multiple time bins, the similarity of the light curves can be assessed with a straightforward χ^2 test. In response to a recent claim that the two pulses in GRB 200716C are lensed images of the same pulse, such a χ^2 test was computed. The test indicated that the likelihood that the two pulses are images of the same parent pulse is less than 0.218%, differing at about the 3.1σ confidence level. Therefore, under the given assumptions, GRB 200716C is not a compelling example of gravitational lensing.

1. Introduction

A recent paper by Wang et al. (2021) claimed that the light curve of GRB 200716C has been affected by a gravitational lens. Their GRB millilensing claim closely follows in time a claim by Paynter et al. (2021) in GRB 950830, and another by Kalantari et al. (2021) in GRB 090717. In response to the millilensing claim by Paynter et al. (2021), Mukherjee & Nemiroff (2021a) published a Research Note with results of a hardness test indicating that, given the softness of the second pulse in GRB 950830 in the energy range (110–320) keV, the effect of gravitational millilensing should not be considered proven. In response to the millilensing claim by Kalantari et al. (2021), Mukherjee & Nemiroff (2021b) published a Research Note in which a light-curve test, utilizing a scaled χ^2 comparison test between the two pulses, showed that they differ from each other at about the 5.0σ confidence level (99.999956%). Since gravitational lensing does not change the relative timings internal to images, all source images should have the same light curve to within a scale factor in amplitude. In this work, the two main pulses that compose the light curve of GRB 200716C are compared using both a hardness test (Mukherjee & Nemiroff 2021a) and a light curve test (Mukherjee & Nemiroff 2021b).

2. Analysis

The data used for this analysis was taken from the Gamma-Ray Burst Monitor (GBM) of the NASA's Fermi Gamma-Ray Space Telescope. The Time-Tagged Event data containing the individual detector counts were analyzed. 6 of the 12 NaI detectors clearly detected the two pulses significantly above the background: detectors n0, n1, n2, n3, n4 and n5. To test for similarities, the counts from all six of these detectors as well as all the GBM energy channels ranging from 11.8 to 983 keV, were summed. A background level was then fit with a second degree polynomial.

The starting and ending times of the first pulse were then determined. The starting time was chosen to be the time when the summed counts in 16 ms bins increased to over 6σ above the background fit—nearest the pulse peak. The pulse was then considered to continue until the summed counts dropped to below 6σ. This also gave the duration of the first pulse: 0.48 s. To be consistent with a possible gravitational lens interpretation, both pulses were taken to have this same duration. The starting time of the second pulse was found by the same logic. The resulting starting times of the two pulses were determined to be 0.112 and 2.042 s relative to the trigger time. In Figure 1 the regions inside the red dashed lines are the regions of the pulses with the above mentioned start and stop times. A second set of start and stop times for both the pulses were determined to compare a small portion of the central regions which shows that the two pulses are very different. As seen in Figure 1, the pulse width marked by the green dashed lines were compared. We call this "case 2." The starting time was chosen to be the time when the summed counts in 16 ms bins increased to over 18σ above the background fit. The pulse was then considered to continue until the summed counts dropped to below 18σ. The resulting starting times of the two pulses were determined to be 0.272 and 2.212 s relative to the trigger time.

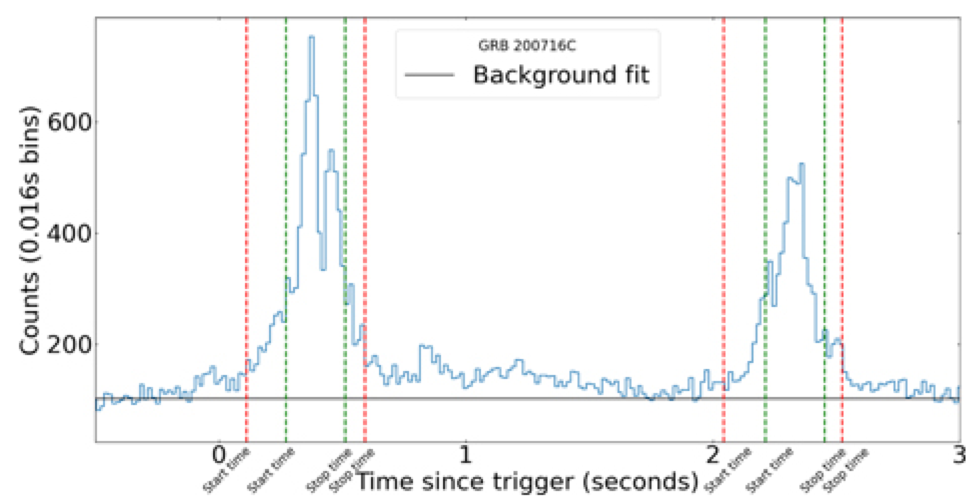

Figure 1. The light curve of GRB 200716C in 16 ms time bins.

Following Nemiroff (2000) and Hakkila & Nemiroff (2009), it was assumed that the pulses started at the same time in all energy bands. Also, following the hardness test utilized in Mukherjee & Nemiroff (2021a), we tested the hardness of each pulse and found them statistically consistent—and hence consistent with a gravitational lens interpretation.

For the light-curve test, similarity was tested with a χ^2 analysis, where a factor r was used to artificially decrease the brightness of the first pulse in order to match it with the brightness of the second pulse. Such a factor is expected from gravitational lensing which creates, in general, different amplitudes for different images. Given any r factor, the reduced formula used for the χ^2 is taken from Mukherjee & Nemiroff (2021a) which was adapted from Press et al. (1992).

The r factor that minimized χ^2 was found to be $r = 0.673$ for the case 1 and $r = 0.670$ for the case 2. Given these r factors, the χ^2 test for 16 ms binning found that the light curves of the two pulses differed from each other at about the 3.1σ level (99.782%) for case 1 and 3.97σ level (99.993%) for case 2.

Changing the start times of the pulses had little effect on the statistical significance. Changing the binning timescale did have some effect, but several binning scales also revealed a significant difference between the light curves. Changing the analyzed duration had a large effect—the difference between the pulses is mainly evident in the brightest part of the pulses. For example, when the duration of each pulse was chosen to be 1.744 s with pulse start times of −0.112 and 1.952 s and pulse stop times of 1.632 and 3.696 s, the χ^2 decreased significantly. However χ^2 still showed a significant difference between the two pulses. The pulse duration was chosen here to produce a large χ^2, which should be noted when considering its true statistical significance. The same χ^2 test applied to several of the energy channels individually also returned results indicating statistically different light curves. Hence we conclude that the postulate that the two main pulses in GRB 200716C are gravitational-lens images of the same single pulse, although intriguing, is not statistically compelling.

We thank Michigan Technological University for their general support and Jon Hakkila, Casey Aldrich and Ogetay Kayali for comments.