In search for natural wormholes

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Abstract

We have investigated 631 time profiles of gamma ray bursts from the BATSE database searching for observable signatures produced by microlensing events related to natural wormholes. The results of this first search of topologically nontrivial objects in the Universe can be used to constrain their number and mass.

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I. INTRODUCTION

Wormholes are nontrivial topological configurations of spacetime that can be represented by solutions of Einstein field equations with stress-energy tensor fields that somewhere violate the so-called average null energy condition (see Ref. [1] for a detailed discussion). Although microscopic violations of the energy conditions are well known (e.g. the Casimir effect), it is far from clear whether stable, macroscopic wormholes can naturally exist in the Universe. One of the ways in which one may obtain violations to the energy conditions is via a scalar fields coupled to gravity (see for instance [2] and references therein).

Wormhole formation at a late cosmic time requires Lorentzian topology change in space, something that appears to be more than problematic to most physicists because it implies causality violations [3,4]. However, if wormholes are created altogether with spacetime and not formed by astrophysical processes, one could expect a cosmological population of these objects without the uncomfortable predictions of topology change theorems.

In a couple of recent papers we have discussed the observable effects that could arise from an intergalactic population of natural wormholes [5,6]. Since wormhole's mouths could have a total negative mass, they should exert a repulsive gravitational force that can provide very peculiar microlensing events when acting upon the light of compact, background sources [7]. Extragalactic wormholes with absolute masses of ~ 1 $M_{\odot}$ would produce very compact Einstein rings, in such a way that just small, ultraluminous sources like the γ-ray emitting core of quasars (typical size $10^{14} - 10^{15}$ cm) might result gravitationally magnified. We have shown in Ref. [6] that the lightcurve signature of wormhole microlensing events of this sort very much resembles some kinds of gamma ray bursts (GRBs).

When a negative mass lens crosses the line of sight to a distant quasar, dragging the caustic pattern along with it, two bursting γ-ray events will appear in the observer's frame: the first one is the specular image of a fast-rise-exponential-decay (FRED) burst, whereas the second, after a period of stillness that can last several years, is a pure FRED event. In our previous study [5], we have used the available database of GRB observations gathered by the BATSE instrument, part of the Compton satellite, to set an upper limit to the amount of negative mass (under the form of compact objects of astrophysical size) in the Universe. Such limit results as low as $|\rho| \leq 2 \times 10^{-33}$ g cm^{-3} with the most optimistic assumptions.

In the present paper we give a step further and embark on the first detailed search for individual wormhole signatures in astronomical databases. GRBs produced by natural wormholes can be differentiated from those originated in fireballs because of two very definite properties: 1) they repeat, and 2) one of the repeating bursts has an anti-FRED time profile, something that cannot be the result of an explosive event [8] (the companion burst must display a FRED-like lightcurve).

We have quantitatively analysed a subsample of the GRBs included in the BATSE 3B cataloge with the aim of identify events that could be unequivocally attributed to wormhole lensing. In what follows we present the results we have obtained.

II. DATA ANALYSIS

We have analysed a sample of 631 bursts from BATSE 3B catalog whose global symmetry properties were already discussed by Link & Epstein [9], and Romero et al. [8]. This sample contains both faint and bright bursts, spanning 200-fold range in peak flux. PREB + DISC data tapes at 64 ms time resolution, with four energy channels, were used in the analysis.

Since the variety of burst profiles is huge and simple visual inspection can be misleading, we have used the skewness function $\mathcal{A}$ introduced by Link & Epstein [9] in order to separate those GRBs with anti-FRED profiles. The skewness is basically defined as the third moment of the individual burst time profile and can be directly computed from the observational data as in Ref. [9]. Negative values of $\mathcal{A}$ correspond to events with slower rising than decaying timescales, thus showing a peculiar asymmetric burst (PAB).

In a first step, we estimated $\mathcal{A}$ for all GRBs in the sample at different background cutoff levels. Just 91 out of 631 bursts present $\mathcal{A} < 0$ at any background. As discussed in Ref. [8], most of these events can be explained within the standard fireball model of GRBs [10].

Just anti-FRED–like single peaked events remain inconsistent with the explosive hypothesis. There are 26 of these GRBs in our sample (4.1 %).

Since wormhole lensing not just provides bursts with $\mathcal{A}$ <0 but also a repetition with specular signature, we have searched for time-space clustering in the sample. We have found that 15 out of 26 candidates (about 60 %) present companions within error boxes at less than 4^o (the average positional uncertainty in BATSE catalog). We have estimated the statistical significance of this level of positional coincidences through numerical simulations of random sets of 26 events against a background distribution of 605 GRBs. After 1500 simulations we established that the chance associations expected in the subsample are 13.3 ± 2.5, i.e. there is no need to claim for repetition to explain the observed coincidences at error boxes of 4^o. However, if positional coincidences separated by less than 1^o are considered, we find that 3 out of 26 events present companions. According to a new set of simulations, these results can be attributed to chance only at a 2σ level. Despite the sample is too scarce to draw any conclusion, it is worth mentioning that when a similar study is carried out with the 91 bursts with $\mathcal{A}$ <0 it is found that there are just 4 positional coincidences at less than 1^o, at 1σ confidence level. This could imply that the apparent excess is exclusively associatted to single peaked events, as expected from the microlensing model.

In order to detect whether there is some suitable wormhole candidate behind the above mentioned statistical analyses, we turned to the individual single peaked events with $\mathcal{A}$ <0 in a finer search.

III. RESULTS

In Table 1 we list by trigger number all single peaked bursts with $\mathcal{A}$ <0 in our sample. In column 2 we indicate the trigger number of any companion burst in the entire BATSE database within a circle of 4^o in radius. Columns 3 and 4 display the temporal and angular distances of pairs of events. A negative value of ΔT means that the anti-FRED event followed to its companion; such bursts can be eliminated as wormhole candidates, at least over the timescales under consideration here. The final column in the table lists the sign of $\mathcal{A}$, when defined, for companion bursts that belong to our subsample. Bursts with no entries in this column where not analyzed in the present study, circunscribed to the previously defined set of 631 GRBs.

We shall consider as candidates for wormhole microlensing just events with companions that present $\mathcal{A} > 0$ at all levels of background (notice that this is a very restrictive criterion, and eliminates the event mentioned in Ref. [6]). This left us with only 4 candidates: #254, #444, #1924, and #2201. A further step can be made now by detecting active galactic nuclei (AGNs) within the error boxes of the bursts. These AGNs would constitute the potential background sources of gamma rays.

In Table 2 we list pairs of GRBs along with the AGNs (namely compact QSOs) within the BATSE field. We also indicate the morphological type of the bursts with $\mathcal{A} > 0$. As can be appreciated from this table, three pairs of events present quasars in their fields: #254, #444, and #1924. These are the stronger candidates for wormhole microlensing events in our sample of 631 bursts. None of them, however, can be considered as a certain identification because the profiles of the second bursts in each pair are not exact FREDs despite presenting $\mathcal{A} > 0$ at all levels. These bursts have profiles with some substructure which is not present in the first event of the pair. Although such a fine substructure could be an effect of the different light propagation paths (the light can be exposed during its travel to lensing effects by ordinary matter that might result in a distortion of the original profile [11]) or even an artifact due to the different orientation of the spacecraft at the detection times, we think that the evidence is not strong enough to claim for an indisputable identification.

In the case of the pair {#2201, #2679}, both bursts are single peaked and present the correct symmetry in their profiles. By other hand, there are no cataloged AGNs in the corresponding sky field. This would not be an insurmountable problem for wormhole microlensing because even very weak and normally undetected QSOs can be enhanced by caustic crossing in such a way as to appear as a bright source during a few seconds [6]. However, in this particular case, the flux ratio of both bursts (which should be similar as it comes from the same source) is too far from unity as to make a case for the lensing argument.

The best candidate in the whole sample is the pair {#254, #2477}. They present correct symmetry properties and unity flux ratio. The event #2477 has a substructure that make of it not a perfect FRED, but this, as it was mentioned, could stem from propagation effects. Two AGNs, with redshifts of 0.15 and 1.52, are present within the positional uncertainties.[1]

The greatest difficulty at present time is the huge positional uncertainty, something that will be significantly improved in ten years time. The results of our search, although not conclusive, are sufficiently suggestive as to encourage new studies over larger samples and with the more accurate detectors of the forthcoming generation of gamma ray satellites.

IV. FINAL COMMENT

Our search for natural wormholes through microlensing was sensitive to timescales up to 3.5 years. Repetition of anti-FRED events over longer scales can not be ruled out. Tegmark et al. [12] have made a repetition study on the entire BATSE sample concluding that a repetition level of ~ 5 % with timescales of a few years is compatible with the current data. Our results show that, if repetition is associated to wormhole microlensing alone, it could reach, at most, a level $\sim 4\%$ over timescales larger than 3.5 years. At shorter scales, wormhole-induced repetitions are constrained at a level < 0.2 % (assuming {#254, #2477} as the sole possible candidate).

Since microlensing timescale increases with larger masses of the lenses, the absence of clear detections in our search might be saying that wormholes, if there exist at all, have a mass distribution peaking far beyond the few tenths of solar masses required to produce

[1] It should also be pointed out the FRED–anti-FRED pair, #688 and #2788, which is located at the same position in the sky (within 4^o) together with 156 QSOs. These two bursts might be produced by two different microlensing phenomena with timescales that span out the BATSE operation time.

typical microlensing events with timescales of a few years. If we recall that a negative mass of the size of Jupiter is necessary to keep open a wormhole throat of about 2 m in diameter [1], this result could be kindly greeted by optimistic interstellar-travel afficionados looking for larger spacetime tunnels.

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REFERENCES

[1] M. Visser, Lorentzian Wormholes, AIP Press, NY (1996).

[2] L. A. Anchordoqui, S. E. Perez Bergliaffa, and D. F. Torres, Phys. Rev. D **55**, 5226 (1997).

[3] R. P. Geroch, J. of Math. Phys. **8**, 782 (1967).

[4] S. W. Hawking, Phys. Rev. D **46**, 603 (1992).

[5] D. F. Torres, G. E. Romero, L. A. Anchordoqui, Mod. Phys. Lett. A **13**, 1575 (1998).

[6] D. F. Torres, G. E. Romero, L. A. Anchordoqui, Phys. Rev. D **58**, 123001 (1998).

[7] J. G. Cramer, R. L. Forward, M. S. Morris, M. Visser, G. Benford, and G. A. Landis, Phys. Rev D **51**, 3117 (1995).

[8] G. E. Romero, D. F. Torres, I. Andruchow, L. A. Anchordoqui, and B. Link, Month. Not. Roy. Astron. Soc., submitted.

[9] B. Link and R.I. Epstein, Astrophys. J. **466**, 764 (1996).

[10] P. Mészáros and M. Rees, Astrophys. J. **405**, 278 (1993).

[11] L. L. R. Williams and R. A. M. J. Wijers, Month. Not. Roy. Astron. Soc. **286**, L11 (1997).

[12] M. Tegmark, et al., Astrophys. J. **466**, 757 (1996).

TABLES

TABLE I. Single peaked anti-FRED–like GRBs (A-GRB) and companion bursts within the positional error boxes. Individual events are designated by BATSE trigger numbers. ΔT is the temporal distance in days between the two events, whereas Δd [^{o}] is the angular separation. The last column lists the sign of the skewness function for four different background cutoff levels. A $\mp$ stands for bursts whose values of $\mathcal{A}$ are negative but the error includes positive regions, similarly, a $\pm$ sign means a positive skewness reaching negative values for some regions of the error box. A little $\dagger$ means that $\mathcal{A}$ is not defined at the corresponding cutoff.

A-GRB	Other triggers	ΔT	Δd [^{o}]	$\mathcal{A}$
# 179				
# 254	# 1742	430	2.6	$\pm \pm - \mp$
	# 3113	1155	3.2	
	# 2477	790	3.8	$+ + + \pm$
# 353	# 2694	916	1.1	
# 444	# 2408	727	1.0	$+ + + +$
# 551	# 2431	738	2.4	$+ - - -$
# 752				
# 906				
# 1142	# 2614	700	2.7	$+ - + -$
# 1154	# 2124	397	2.9	
# 1359				
# 1461[2]	# 1663	111	0.8	$- - - -$
# 1851	# 2319	224	3.6	
# 1924	# 2830	522	0.9	$+ + \pm +$

[2]Note that NED also cite GRB 790329 within the error box (2.6^o) of trigger # 1461.

# 1968	# 2498	324	3.4	
	# 1480	-201	3.5	$\dagger$ $\dagger$ $-$ $+$
# 2161				
# 2163				
# 2201	# 2679	289	2.9	$+$ $+$ $+$ $+$
# 2220	# 1975	-153	2.2	
# 2434				
# 2788	# 686	-904	1.2	$+$ $+$ $+$ $+$
	# 1676	-530	2.6	$\mp$ $+$ $+$ $\pm$
# 2795	# 223	-254	3.5	$\mp$ $\pm$ $\dagger$ $\dagger$
	# 2081	-426	4.0	$\pm$ $\mp$ $-$ $-$
# 2823	# 2244	-336	2.6	$\mp$ $\pm$ $\dagger$ $\dagger$
# 2846	# 2603	-122	0.8	$+$ $+$ $\pm$ $-$
	# 2927	48	1.1	$+$ $+$ $\mp$ $\dagger$
	# 3132	179	2.6	
# 2918	# 2509	-220	2.8	$+$ $+$ $-$ $+$
# 2978				
# 2995	# 2945	-33	1.4	$+$ $+$ $\pm$ $\pm$
	# 2347	-373	3.0	
	# 871	-964	3.1	$+$ $\pm$ $\pm$ $\pm$
	# 2394	-347	3.9	

TABLE II. Possible candidates for microlensing by wormholes together with the corresponding background sources and the morphology of the counterpart. S stands for a single peaked temporal profile whereas S_c is a single peaked with a complex substructure.

Triggers and morphology	Object name	(l, b)	z
{#254,#2477} S_c	MG4 J190945+4833	(79.3,17.1)	0.513
	MG4 J192325+4754	(79.6,14.8)	1.52
{#444,#2408} S_c	PMN J0846+0642	(220.4,28.7)	
	[HB89] 0846+100	(217.6,30.7)	0.366
	[HB89] 0847+100	(217.6,30.7)	2.8
	RX J0842.1+0759	(218.5,28.2)	
{#1924,#2830} S_c	87GB 234437.2+512530	(112.9,-9.9)	0.044
{#2201,#2679} S			