

Wormholes, Gamma Ray Bursts and the Amount of Negative Mass in the Universe¹

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Abstract

In this essay, we assume that negative mass objects can exist in the extragalactic space and analyze the consequences of their microlensing on light from distant Active Galactic Nuclei. We find that such events have very similar features to some observed Gamma Ray Bursts and use recent satellite data to set an upper bound to the amount of negative mass in the universe.

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1 Introduction

*-I see nobody on the road, said Alice.
-I only wish I had such eyes, the King remarked in a fretful tone.
To be able to see Nobody! And at that distance too!*

Through the Looking Glass
Lewis Carroll

The possibility of constructing high speed transports has fascinated mankind along all history. And with the advent of the twentieth century concepts and technologies, specially those of General Relativity, this quest is more alive and thriving than ever before. But it is obvious to note that one way in which one can travel faster is, instead of increasing the speed, to reduce the path. Let us take a two dimensional space as an example. Is a straight line the shortest path between two points? Certainly not: just fold the space until the two points coincide and make a hole; the path is zero and this is, without doubt, the shortest distance. This could be, of course, not allowed by most game rules, but it is the very concept of wormhole physics. A subject that can be traced back up to 1916, a year after Einstein's remarkable discovery that matter curves spacetime [1].

Wormholes are analytical solutions of the Einstein field equations, and basically represent shortcuts in spacetime. By now, wormholes are theoretical entities and we can speculate but not rely on their possible existence. A key point is that to keep wormholes open, preventing them for pinching off towards a singularity, one has to thread them with exotic matter. This kind of matter violates the weak energy condition, and although quantum effects (of order \hbar) and scalar fields violate this condition, it is far from clear whether macroscopic quantities of exotic matter can exist in the universe. If exotic matter does exist, wormholes might have negative total mass [2, 3].

In this essay we shall assume that natural wormholes, or other form of negative mass matter exist, and we shall study the extragalactic microlensing scenario when light from distant Active Galactic Nuclei (AGNs) is affected by them. We shall find the unexpected conclusion that this kind of lensing very much resembles the main features of some Gamma Ray Bursts (GRBs) and shall make some highly testable predictions. Afterwards, we shall reconsider our initial hypothesis and, using recent satellite data about GRBs, we shall obtain the first upper limit on the amount of negative mass in the universe.

2 The model

2.1 Microlensing by a negative mass

Gravitational microlensing by negative masses was introduced by Cramer et al. in 1995, considering that the lensing object, typically a wormhole, could be in the galactic halo [4]. In the application we wish to develop, the lens should be isolated in extragalactic space. This makes the formulae slightly different, as for instance in the computation of distances, but the concept remains. The Einstein radius of a negative mass is given by $R_e = (4G|M|D)^{1/2}/c$, where apart from the usual meaning of the constants c and G , D represents an effective lens distance. This is a model-dependent parameter; its general expression is $D = D_{ol}D_{ls}/D_{os}$, where D_{ol} , D_{ls} and D_{os} are the observer-lens, lens-source and observer-source angular diameter distances, all them computed as in [5]. The variability timescale T of a microlensing event is defined as the time that takes the line of sight to the source to cross the Einstein radius of the lens: $T = R_e/V$, while the overall relative intensity I_{neg} is the modulation in brightness of the background source detected by the observer. This is given by [4],

$$I_{\text{neg}} = \frac{B^2 - 2}{B\sqrt{B^2 - 4}}, \quad (1)$$

where $B(t) = B_0(1 + (t/t_v)^2)^{1/2}$. Here, B_0 is a dimensionless impact parameter and t_v is the transit time across the distance of the minimum impact parameter, $t_v \propto T$. Taking $I_{\text{neg}} = 0$ for $|B| < 2$, it is possible to obtain the light enhancement profiles for a negative amount of mass M . These curves can be divided in two groups (see Fig. 3 of Ref. [4]). For $B_0 > 2$, the light profiles are similar to the positive mass cases but provide bigger light enhancement than that given by a similar amount of positive mass. For $B_0 < 2$, the curves are sharper and present divergences (caustics) of the intensity with an immediate drop to zero. This happens at two times, solutions of $B^2 - 4 = 0$; thus, for time running from $-\infty$ to $+\infty$, and during the same microlensing event, we obtain two divergences and two drops, of specular character. Unlike the $B_0 > 2$ case, these individual bursts present light profiles asymmetric under time reversal.

Although this also happens in the usual (i.e. positive mass) scheme, two points should be noticed. First, the infinities arise from the geometrical approach based on point mass objects. Any physical extent leads to finite amplifications [6]. Second, a critical requirement for such a

microlensing event to occur is that the size of the background source projected onto the lens plane must not be larger than the Einstein ring of the lensing mass [7]. Background sources whose scale size is a fraction of the Einstein radius are amplified by significant factors, while the amplification of sources whose projected sizes largely exceed the Einstein radius will be negligible.

2.2 AGNs as background sources

AGNs are compact extragalactic sources of extraordinary luminosity that can radiate as much energy per unit of time as hundreds of normal galaxies. Recent satellite observations have shown that many, perhaps most, of these objects emit most of their power in the form of X- and γ -rays [8]. The ultimate source of the energy of AGNs is widely believed to be accretion onto supermassive black holes. γ -ray emission is probably produced by inverse Compton scattering of ambient soft photons by ultrarelativistic electrons or positrons accelerated in the innermost part of the source [9]. The energy spectrum of the resulting high energy radiation is a power law with indices roughly between 1.5 and 3. The emission regions have different size scales according to the energy range of the radiation due to γ -ray absorption by pair production in the radiation field of the central source. The inner regions are very compact ($\sim 10^{15}$ cm) and can constitute excellent background sources for microlensing. The idea that GRBs could be the result of microlensing events was proposed ten years ago by McBreen & Metcalfe [10]. However, it was ruled out by the evidence provided by BATSE instrument about the basic asymmetry that most GRBs exhibit under time reversal. As we have shown above, microlensing by negative mass can produce asymmetric light curves quite naturally and the argument does not apply in such a case.

3 Output: qualitative analysis

GRBs have such a huge variety of features that they might hardly be accounted by a unique and comprehensive model. In fact, it has been previously proposed that GRBs should be explained in sets of similarity [11]. With this idea in mind, we return to the main statement of this work up to this stage: a wormhole-like lensing upon light of a background AGN very much resembles some characteristics of observed GRBs. To explore this in more detail, let us take each of the two parts of a $B_0 < 2$ event separately. Two main features of a GRB are immediately reproduced: they *burst*

and they are distributed isotropically in the sky, which without further biases is a natural extension of the model. Furthermore, coincident features are that the observed distribution of energy peaks above 50 keV, and that the spectrum at higher energies is given by a power law with exponents in the approximate range (1.5, 2.5). The durations of individual bursting events are widespread from 30ms to 100s; this can be particularly modelled for each burst, assuming different extragalactic velocities and masses for the lenses. Most bursts are, in this kind of lensing, asymmetric. But some symmetric could also take place when $B_0 > 2$ and the background source is particularly strong. The observation of counterparts at other energy bands, as well as the absence of them, is simply explained by comparing the projected size of the emitting region of the source at each wavelength with the Einstein radius. It is a matter of fact that spectra of most bursts have a cutoff at energies of GeV. At these energies, the γ -spheres of the background AGN can be large enough so as to exceed the Einstein radius and prevent the occurrence of microlensing. The same process could operate for other emission regions. The different sizes of the different emitting parts of the AGN will be reflected in different variability timescales, in such a way that this could stand for the differential durations of the counterparts in a particular GRB event.

Recently, some authors have expressed their perplexity by the fact that some GRBs, like 970828, do not present visible counterparts at all [12]. Notice that the smaller optical region in AGNs is typically $\sim 10^{16}$ cm. Thus, it is quite possible that γ -spheres of $10^{14} - 10^{15}$ cm be gravitationally magnified while the optical flux remains unaffected. Moreover, since the optical region is comparable to the outer γ -regions, the cutoff in the energy spectrum of events with optical counterparts should occur at higher energies (several tens of GeV) than in pure γ -ray events (where the cutoff should be at a few GeV).

In addition, microlensing by wormholes provide us with a highly testable prediction. Every asymmetric burst generated by this mechanism should repeat, or should have been repeated in the past. Moreover, this repetition phenomena should occur in opposite regimes: first with rising times shorter than the decays and then, vice-versa. Unfortunately, this kind of phenomena cannot be directly detected with the present satellite-borne γ -ray telescopes. The errors in position measurements are about 4° , and although individual bursts with temporal profiles in both regimes have been observed, repetition studies must be of a statistical nature [13]. These studies suggest that

repeaters can occur within a range from 2% to 7% of the whole sample of more than 1300 bursts. This is also consistent with our model, because the observed number of bursts with rising faster than the decay is larger than that in the opposite regime [14]. Timescales for repeating bursts seem to be between some months and a few years, and it is clear that we can always select the mass of the lens to fulfill this requirement.

4 A bound upon negative matter

Although we have retained this essay as a qualitative presentation, we have made simulations of temporal profiles on BATSE data files. We have found that with an assumed extragalactic velocity of 1000 km s^{-1} and a source-lens configuration of redshifts $z_l = 0.25$ and $z_s = 2.5$, bursts like BATSE #257 and #1089 can be very well fitted by substellar masses of $\sim -0.1M_\odot$ and timescales of the order of years. Now, we shall use this knowledge to reconsider our initial hypothesis and estimate how much negative mass could be in the universe.

The basic assumption here will be quite general: if compact objects of negative mass already exist in the intergalactic space, they must produce GRB-like microlensing phenomena. Thus, we can use the number of actually observed GRBs to determine an upper limit to the spatial density of negative mass in compact, wormhole-like objects. If $|\rho|$ is the density of negative mass, which for simplicity we take as constant, the optical depth to microlensing is given by [15],

$$\tau = \frac{2\pi G D_{os}^2 |\rho|}{3 c^2}. \quad (2)$$

The number of microlensing events observed in a lapse ΔT is $N = 2n\tau\Delta t/\pi T$, where n is the total number of background AGNs and T is the typical timescale for microlensing. Then, using both previous formulae in favor of $|\rho|$, we get

$$|\rho| = \frac{3 T N c^2}{4 \Delta t n G D_{os}^2}. \quad (3)$$

In (3) we have quantities of two different kinds. Most of the magnitudes involved are related to observation. We have in this group the number of background sources $n \simeq 10^9$ which comes from the number of AGNs in the Hubble Deep Field, and the observed number of BATSE triggers, $N = 1121$ during the first $\Delta t = 3$ years of operation. The angular diameter distance of the source is

also fixed because the cosmological distribution of AGNs seems to peak somewhere between $z_s = 2$ and $z_s = 3$, so we can adopt an intermediate value of $z_s = 2.5$. On the other hand, we have one model-dependent magnitude, the variability timescale of the problem, T . As $T \simeq R_e/V$, we note that both the mass and velocity of the lens, are degrees of freedom of (3). As we do want to have an upper bound on $|\rho|$ we shall choose a conservative extragalactic velocity of 1000 km s^{-1} . Concerning the mass, we choose $-0.1M_\odot$, which is suggested by the fits as a possible typical value. With these figures, we obtain,

$$|\rho| \leq 2.03 \times 10^{-33} \text{ g cm}^{-3}. \quad (4)$$

The *less than* symbol is due to the fact that we do not expect every BATSE trigger to be caused by a wormhole lensing effect. We could use the $\simeq 5\%$ of possible repeating sources [13] as the number of observed events, and then lower about two orders of magnitude in $|\rho|$. We note also that a greater lens velocity, very likely in the extragalactic medium, could also reduce the quoted number by an order of magnitude. We conclude then that the given value of $|\rho|$ must be considered as a large upper bound on the possible amount of negative mass in the universe. It is clear, consequently, that this amount is too small indeed to produce any significant cosmological consequences (remember that the mass contribution due to galaxies in the universe is $\sim 6 \times 10^{-31} \text{ g cm}^{-3}$ and the critical density is $\sim 1.9 \times 10^{-29} \text{ g cm}^{-3}$).

5 Final comment

Do wormholes really exist? Is a macroscopic amount of negative matter possible? We do not yet know the answer, but we have shown that if they do populate the intergalactic space, they should produce observational signatures arising from gravitational microlensing of the light from distant AGNs. Since these signatures are similar to some GRBs, we used the available information about them to calculate an upper limit to the density of these exotic objects. The improvement of the quality of the observations will enable us to make important conclusions about wormhole physics in the near future. Either lower limits to the number of GRB repetitions will be established or some concrete cases of repetitions will arise. In the first case, observation will point towards ruling out the existence of any significant amount of negative mass in the universe. In the second case, a study of the rising and decaying times could strongly support this existence. If finally we arrive

at the conclusion that there is no natural negative mass wormhole in the sky, basic research in the field still might render useful results beyond pure theoretical knowledge. After all, mankind did not wait to observe natural automobiles in order to build one.

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