

Gamma Ray Bursts and Cosmic Time Machines *

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Abstract

The effects of a gravitational field are non-homogeneous attraction and dragging. If the field is sufficiently strong as nearby a curvature singularity, then a combination of those effects may cause the light cones to tilt with respect to a local coordinate time axis so to generate closed time-like or null curves. If a singularity is globally naked then the space time may be causally ill-behaved allowing for closed time-like or null curves to extend to asymptotic distances and generate a Cosmic Time Machine (de Felice, 1995). It is argued whether Gamma Ray Bursts carry a signature of such a pathology.

1 Introduction

The possibility that a naked singularity forms as result of a black hole perturbation or more generally of gravitational collapse, has far reaching consequences. Naked singularities may be sources of cosmic events with an anomalously high energy and most surprisingly they can make the whole space-time causally ill-behaved. If they existed, in fact, it would be legitimate to invoke the validity of a theorem due to Clarke and de Felice (1984) (see also de Felice, 1995) which states that a generic naked singularity would

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give rise to a Cosmic Time Machine (CTM). Before illustrating this concept in Section 3 I will outline how a naked singularity could be the result of a black-hole perturbation then in Section 4 I conjecture whether Gamma Ray Bursts (GRB), the most powerful sources in the Cosmos, could be interpreted as the outcome of a Cosmic Time Machine.

2 A black hole-naked singularity transition.

Classical black-holes are generally believed to be *stable* against perturbations which would *break* the event horizon and leave naked singularities open to far observations (Wald 1974, Thorne 1974, Cohen and Gautreau 1979, Israel 1986, de Felice and Yu 1986, Semiz 1990). In a recent paper however (de Felice and Yu, 2001) it was shown that an initially maximally charged Reissner-Nordström black-hole may be turned into a Kerr-Newman naked singularity by a physically plausible accretion process. To turn a maximally charged Reissner-Nordström black-hole into a Kerr-Newmann naked singularity, one had to manufacture a rotating, neutral *disk* having the spin aligned with a radial direction and a flattening ratio:

$$\frac{h}{d} < \frac{\mu}{M} \frac{d}{2M} \left(\frac{v}{c}\right)^2 \quad (1)$$

where μ is the mas of the spinning body, h is the disk thicknes and d its equatorial radius. This is a small but physically conceivable number. Suppose that the spinning body has a mass $\mu = \mathcal{M}_\odot \approx 1.9 \times 10^{33} gr$ and the black-hole has mass $\mathcal{M} = 10\mathcal{M}_\odot$; if we allow the body to rotate to the limit of its equatorial instability, then $d(v/c)^2 \approx \mu$, where we recall $\mu = Gm/c^2 \approx 1.54 \times 10^5 cm$ and $M = 10\mu$, so from (1) we have:

$$\frac{h}{d} < 5 \times 10^{-3}. \quad (2)$$

Taking that value as an upper limit, we can estimate the angular momentum of such a flattened object. Neglecting factors of the order of unity, we have:

$$S = \frac{GJ}{c^3} \approx \mu^2 \left(\frac{c}{v}\right) \quad (3)$$

where J is the angular momentum in conventional units and we use the limiting value of d , namely $d(v/c)^2 = \mu$; hence:

$$J \sim \mu^2 \frac{c^3}{G} \left(\frac{c}{v}\right) \approx 8.5 \times 10^{48} \left(\frac{c}{v}\right) \text{ gr cm}^2 \text{ sec}^{-1}. \quad (4)$$

This is larger than the angular momentum of a typical neutron star with a period of rotation of one second, namely $J_{ns} \approx 10^{46} \text{ gm cm}^2 \text{ sec}^{-1}$ however it is not so large not to be attainable in Nature. If we require $d < M$, then from the limiting condition for d and the assumption that $M/\mu = 10$, we get $c/v \leq 3.1$. Finally we can estimate the density the disk should have to confine one solar mass in a cylinder, say, of radius d and height h : $\rho > \mu d / (\pi M^3 h) \approx 4 \times 10^{17} \text{ g cm}^{-3}$.

One can think to such an object as being the transient outcome of some astrophysical process producing a small nucleus surrounded by a highly flattened disk which can live long enough to plunge in the hole and change its parameters.

3 The CTM theorem

Let us first define as a Cosmic Time Machine a *space-time which is asymptotically flat and globally noncausal*. The above definition of CTM requires some specifications about the properties of the space-time solution:

i) The matter source which eventually evolves to a singularity, must be *physically reasonable* in order to avoid quite arbitrary geometries as possible space-times.

ii) The space-time must admit a regular flat (past and future) infinity for the definition of a CTM to make sense.

The existence of a Cosmic Time Machine as consequence of the occurrence of a naked singularity, has been established by Clarke and de Felice (1984) with a theorem; the first result of that theorem is about the nature of the singularity:

Whether or not causality is violated, if there is a naked singularity which is not shell-crossing and exists arbitrarily far into the future of a set of initial regular data, then there will be some null geodesic reaching the future null infinity from the singularity on which a strong curvature condition, in the sense of Newman (Newman, 1983) does not hold.

Specifically the first geodesics to reach infinity from a singularity are of this nature. This weakens the requirement that *all* the geodesics from a singularity should satisfy a strong curvature condition in order to rule out a shell-crossing singularity (Newman, 1983; Krolak, 1983). On the contrary it turns out that strong curvature condition is satisfied only sufficiently far to the future. Thus it appears that the most general type of singularity stemming from gravitational collapse *evolves* in strength from a weakly to a strongly singular state. Under these circumstances, the CTM-theorem establishes its second result.

Violation of strong causality occurs arbitrarily close to future null infinity. Thus a Cosmic Time Machine is naturally implied.

It should be remarked here that a distinctive feature of a singularity which generates a CTM is that of being infinitely red-shifted with respect to any of the non singular space-time points except possibly a set of measure zero. Since no physical influence reaches infinity from the singularity, then the existence of the asymptotic structure after the formation of the singularity, as required by condition *ii)* above, is justified.

4 GRB's and Cosmic Time Machines.

The energy of a Gamma Ray Burst can be as high as 10^{54} *ergs*, mostly concentrated in a pulse of the order of a second. This amount appears much more impressive if we think to it as being the energy emitted in a second-long pulse by 10^{10} galaxies each made of 10^{11} Sun-like stars concentrated in a region probably not larger than a galactic core!

There are several models which provide reasonable explanations for these high energy events; most of them however suffer of some kind of incompleteness due to the rich and complicated morphology of those sources. A common scenario requires the presence of a massive black hole as the central power house of the observed explosive events. In the papers by (de Felice and Sorge, 2003) and (de Felice et al., 2004), for example, the authors show that the combined effects of strong gravity and a strong magnetic field allows magnetically polarized particles to be confined into stable quasi-circular orbits very close to the black hole horizon. The binding energy of these orbits is high enough to assure an energy confinement of the order of the energy carried by a GRB; these configurations therefore appear to be good candidates to explain the energy output provided the stored energy is made available by some kind of local instability.

I envisage here a completely new scenario based on the hypothesis that what we believe to be massive black holes are on the contrary generic naked singularities. A universe which is also a CTM is causally ill-behaved since, as said, it would admit strong causality violation arbitrarily far away from the singularity. This pathology cannot be cured by any quantum correction to the classical Theory of Relativity before the singularity forms, because the very source of pathology is not the singularity itself but rather the space-time nearby it. Here, in fact, light cones may be so much tilted with respect to a local coordinate time direction that there exist time-like and null trajectories

which run backwards with respect to the time coordinate causing the local causal future to overlap with what would have been the causal past in a flat space-time. This effect, which is induced by gravity, occurs (whenever it does) in a small domain nearby a singularity; this region was termed *kernel* of a Cosmic Time Machine (see Clarke and de Felice, 1984)).

The most important feature of a naked singularity is that of not lasting long as such. There are various indications, as shown for example in (de Felice, 1975; 1978), that a naked singularity decays into a black hole as result of its interaction with the surrounding medium. This implies that whatever observable processes take place nearby a naked singularity, they fade away or just stop after a finite interval of the observer's proper time. As we shall see, this property is crucial to sustain the conjecture about the nature of the GRB's as I will now illustrate.

Since Cosmic Time Machines involve astronomical objects, they allow one to make predictions which could in principle be confronted *here-and-now* with observations. Let a time coordinate be chosen so to coincide with the proper-time of an observer at infinity. Consider two events in a CTM-kernel, being one to the (causal) future of the other (two subsequent flashes from the same light gun, say); then there exist light rays from these events, which propagate backwards with respect to the local coordinate time until they leave the kernel and escape to positive null infinity. It may well happen that, after leaving the CTM-kernel, these light rays reach infinity at the *same* coordinate time. But at flat infinity, the coordinate time is also the proper-time of a stationary observer, hence the latter would see the two events simultaneously on her (his) clock. If we extrapolate this example to all the events which are to the future of any given one in a CTM-kernel, we infer that in a Cosmic Time Machine the entire (causal) future development of a given domain within its kernel may be seen by a distant observer at the same

time.

Having this scenario in mind we can plausibly think to a local physical situation where an accretion disk, say, around a naked singularity, causes an energy output of about 10^{41} ergs/sec corresponding to a moderate quasar-like object shining for some 10^6 years ($\sim 10^{13}$ seconds) until the naked singularity gets hidden by an event horizon. If most of the radiation emitted in this period in the local future leave the kernel at the same coordinate time as result of the local light cone inversion, then an observer at infinity would be able to see the integrated energy of 10^{54} ergs almost at the same time.

5 Conclusions

If naked singularities exist in the Cosmos as predicted by general relativity then they may give rise to a cosmic time machine. In this case, in fact, the singularity could likely be surrounded by a space time region where the local light cones are inverted with respect to infinity. Naked singularities however will only live for a finite interval of coordinate time before decaying into a black hole hence if all that happens then we could directly observe astrophysical phenomena which are observationally constrained by the peculiarities of a time machine. This may be the case of the most energetic Gamma Ray Bursts whose impulsive emission may just be the time integration over a finite interval of the local proper-time of emission processes taking place in some CTM kernel.

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