Blueshift Without Blueshift:  
Red Hole Gamma-Ray Burst Models  
Explain the Peak Energy Distribution

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Abstract. Gamma-ray bursts are still a puzzle. In particular, the central engine, the total energy and the very narrow distribution of peak energies challenge model builders. We consider here an extreme model of gamma-ray bursts based on highly red- and blue-shifted positron annihilation radiation. The burst emerges from inside the red hole created by the complete gravitational collapse of the GRB progenitor.

GRB MODEL BUILDING CHALLENGES

Because gamma-ray bursts vary so rapidly, they must be compact. These compact gamma-ray bursts release enormous energy, and therefore they must form an intense fireball that is optically thick, pair-producing, and thermalized. But the spectrum is not thermal, and there is no sign of pair-production attenuation at the high end of the observed spectrum [1]. This seeming self-contradiction (the opacity problem) can be solved by having the fireball power a relativistic shell or jet that collides with something (perhaps itself) to produce the observed gamma rays [2]. This fireball-driven relativistic shock model is currently the leading candidate to explain GRBs [3]. It solves the opacity problem. But like almost all other published models, it fails to explain the observed spectroscopy of GRBs, particularly the narrowness of the observed peak energy distribution [4]. Furthermore, this model does not explain the high ratio of the energy of the GRB burst itself (caused by internal shocks) to the energy in the afterglow (caused by external shocks in the fireball/shock model) [5]. Nevertheless the predictions of this model for the afterglows themselves are consistent with current observations [3].

Finally, there is the problem of the overall energetics of the GRB. The two leading candidates to produce the initial fireball or fireballs—the so-called central engine—are merging neutron stars and core-collapse supernovae [6]. Both these sources have over 10^{54} ergs of total energy available. This is more than enough energy for even the most energetic GRB, but it is not at all clear how to prevent most of it
from falling into the newly created black hole that forms in the standard general relativity versions of these models.

There seems to be an inherent conflict between solving the opacity problem and solving the peak energy distribution problem. The only successful technique available to solve the opacity problem is to invoke highly relativistic bulk motion. In the relativistic frame, the gamma rays are below pair-production threshold and so do not suffer pair-production attenuation. This definitively solves the opacity problem. But unless the Lorentz gamma factor of the bulk motion can be fine-tuned to a very narrow range for all GRBs, the resulting blueshift will not only relocate the peak of the photon energy distribution; it will also substantially widen it, inconsistent with the observed narrow E-peak distribution. Thus one needs to find a way to fine-tune the Lorentz gamma factor or find some other way around this conflict. In the fireball/shock model, the gamma factor depends sensitively on the baryon loading, and hence will vary widely. Furthermore, the internal shocks model is dependent on shocks with varying Lorentz gamma factors colliding with each other. So narrowly limiting the gamma factor is not a reasonable option for this model.

A generic solution to this problem is provided if the relativistic bulk motion results not from an initial explosion, but rather from the gravitational acceleration of matter falling into a deep potential well. An arbitrarily high Lorentz gamma factor can be attained, but the accompanying blueshift will be exactly cancelled when the matter and radiation are redshifted as they emerge from the potential well. (By that time, the matter and radiation will have separated, so the opacity problem has already been solved).

A black hole can provide the necessary deep potential well. Once matter or radiation is deep in the potential well of a black hole, however, it is almost impossible for it to escape. Therefore, we will consider an alternative gravitational collapse paradigm in which it is possible to escape from deep within the potential well of a gravitationally collapsed object.

**WHY CONSIDER RED-HOLE MODELS?**

The problems with constructing a GRB model might be sufficient motivation to consider alternate theories of gravity. However, a stronger motivation comes from the theory of gravitation. Recent theoretical developments in string theory, quantum gravity and critical collapse strongly suggest the possibilities of both gravitational collapse without singularities (and without loss of information) and also gravitational collapse without event horizons [7–9]. If these possibilities are correct, we are forced to consider the phenomenological consequences (such as different models for GRBs and core-collapse supernovae) of alternate paradigms for gravitational collapse in which black holes do not form [10].
RED HOLES– A NEW PARADIGM

Many authors have considered the alternative in which a hard core collapsed object similar to a smaller harder denser neutron star forms in place of a black hole [11]. We here consider the alternative in which no such hard surface forms. Instead the spacetime stretching that forms a black hole in the standard model occurs, but it does not continue to the extent necessary to form an event horizon or a singularity. Instead, spacetime stretches enormously, but not infinitely, and forms a wide, deep potential well with a narrow throat. We call this a red hole.

This type of spacetime configuration was considered by Harrison, Thorne, Wakano and Wheeler (HTWW) in 1965, but only as a way station in the final collapse to a black hole (not yet then called by that name) [12]. In their version, part of the configuration is inside the event horizon, the collapse continues, and a singularity soon forms.

In the new alternate paradigm we call a red hole, no event horizon forms and no singularity forms. The gravitational collapse does not continue forever, but eventually stops. (Why? Perhaps due to quantum effects or string-theory dualities, but we cannot discuss this adequately here.) As the collapse proceeds, the collapsing matter becomes denser and denser until it reaches a critical point, after which, the distortion of spacetime is so great that the density decreases. This happens because the spacetime is stretching outward faster than the collapsing material can fall inward. (This decreasing density effect was already noticed by HTWW in their analysis of gravitational collapse in the context of standard general relativity [12]. In general relativity, this expansion of spacetime is mostly hidden behind the event horizon and does not prevent the formation of a singularity in a finite time. This is not the case in several observationally viable alternate theories of gravity [13,14].) This is why we are confident that the center of a red hole resembles a low-density vacuum more than it resembles a high-density neutron star. The decrease in density due to this enormous stretching may also be a factor in halting the gravitational collapse of the red hole before the stretching becomes infinite.

As a result, even though the stretching of spacetime is enormous, it never becomes fast enough to exceed the speed of light and cause an event horizon to form. And it stops before it reaches an infinite size or any other form of singularity. (Infinite density and infinite curvature also do not occur.) Nevertheless, it is very hard to escape from a red hole. First, there are trapped orbits inside the red hole for photons as well as massive particles, which allows permanent or nearly permanent trapping of mass and energy. Second, the Shapiro delay in crossing a red hole is very substantial, (in some cases, enormous). Hence particles which are only crossing the red hole or passing through are in effect temporarily trapped.

In fact most of the matter falling into a red hole will be trapped. However, radiation, and highly relativistic matter that falls directly into the center of the red hole and does not rescatter while inside the red hole, can travel straight through and emerge on the other side. This possibility is essential for our proposed new GRB models.
RED-HOLE BURST MODEL

Elsewhere, we have considered models based on relocating part or all of the standard fireball/shock model inside or near a red hole. Here, we want to consider an even more radical model. In this model, the central engine is the direct source of the gamma-ray burst. There is no intervening finely tuned jet of baryons. There is no sensitive dependence on the baryon loading factor, and no dependence on a later shock to retransform the energy into gamma rays. Instead the original pair-rich fireball (created by matter collapsing into a red hole) becomes rapidly thin as it falls into the interior of the red hole and expands. Because everything (photons, baryons, electrons and positrons) is falling into the red hole at almost the same highly relativistic speed, the photons are below pair-production threshold in the infalling frame. Therefore, the fireball is optically thin and the annihilation radiation escapes. The plasma is falling with highly relativistic Lorentz gamma factors up to 1000 or more. The pair-annihilation photons are emitted in opposing pairs. One is highly redshifted, while its twin is equally and oppositely highly blueshifted. The spectrum is highly broadened, but the central peak does not move significantly, since the net blueshift of the infalling electron-positron pair is balanced by the net (or average) redshift of the escaping photon pair. Thus this model can solve the narrow peak energy distribution with ease. The more critical question is whether the combined annihilation line and thermal spectrum of the pair-rich fireball can be stretched enough to create the Band spectrum, or whether more conventional reliance on synchrotron shock emission and/or inverse Compton scattering is necessary.

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