SUPERNOVAE AND GAMMA-RAY BURSTS POWERED BY HOT NEUTRINO-COOLED CORONAE

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ABSTRACT

Cosmological explosions such as core-collapse supernovae (SNe) and gamma-ray bursts (GRBs) are thought to be powered by the rapid conversion of roughly a solar mass’ worth of gravitational binding energy into a comparatively small amount of outgoing observable kinetic energy. A fractional absorption of the emitted neutrinos, the particles which carry away the binding energy, by the expelled matter is a widely discussed mechanism for powering such explosions. Previous work addressing neutrino emission from core-collapse like environments assumes that the outgoing neutrino spectrum closely resembles a black body whose effective temperature is determined by both the rate of energy release and the surface area of the entire body. Unfortunately, this assumption minimizes the net efficiency for both neutrino-driven explosion mechanisms. Motivated by this fact, we qualitatively outline a scenario where a hot corona deforms the neutrino spectrum away from that of a cool thermal emitter. Our primary result is that in principle, a coronal-driven explosion mechanism can enhance the net efficiency of neutrino-driven SNe and GRBs by more than an order of magnitude.

Subject headings: supernovae: general--gamma rays:bursts-- accretion, accretion disks --stars:magnetic fields -- black hole physics -- stars: neutron

1. THE BASIC IDEA AND INITIAL ESTIMATES

Core-collapse supernovae (SNe) are thought to be powered by thermal neutrinospheric emission coupling, however weakly, to an outgoing prompt shock (Bethe 1990, Herant et al. 1994, Janka 2001). After decades of theoretical and detailed numerical analysis, the robustness of the prompt mechanism is still in doubt (Lieberndorfer 2001 and references therein). It seems as though some additional physical process is required.

A popular model for powering gamma-ray bursts (GRBs) involves hyper-Eddington accretion, where the release of energy is mediated by neutrino emission, onto a stellar mass black hole (Eichler et al. 1989; Woosley 1993). In the evacuated region above the black hole, neutrinos and their anti-particles annihilate into electron-positron pairs and a relativistic fireball is formed (Woosley 1993; Goodman et al. 1987). Preliminary studies of this mechanism indicate that the efficiency of converting neutrino radiation into pairs is somewhat smaller than that needed to power a long-duration (> 2 s) burst (DiMatteo et al. 2002, Rosswog & Ramirez-Ruiz 2002).

The most common approach in circumventing the shortcomings of neutrino-powered explosions in both cases is to increase the overall neutrino luminosity. In the SNe case, the energy budget ~ a few × 10^{52}erg is capped by the mass of the star for a standard equation of state. Therefore, the proto-neutron star’s (PNSs) luminosity can only be increased by reducing the Kelvin-Helmholtz time which is set, to first approximation, by neutrino diffusion. Convection in PNSs beneath the neutrinosphere might play a prominent role in increasing the star’s luminosity at early times, but it does so by only a modest factor (Burrows 1987). In terms of GRB accretion disks, the net thermal luminosity can be increased by increasing the accretion rate. Upon doing so, the neutrino trapping radius increases and a limiting luminosity is reached, leading to low annihilation efficiencies (DiMatteo et al. 2002).

In this work, we take a different approach. Instead of finding ways to increase the total output of gravitational binding energy during the explosion epoch, we consider deformations of the neutrino spectrum away from that of a single optically thick thermal emitter. For SNe, the most important energy deposition process above the neutrinosphere is mediated by the capture of electron-type neutrinos onto free nucleons i.e.,

\[ \nu_e + n \rightarrow e + p \] (1)

\[ \bar{\nu}_e + p \rightarrow e^+ + n. \] (2)

For both of these reactions, the deposition rate can be written as

\[ Q_{\nu,N} = \sigma_0 Y_N n \frac{L_\nu}{A} \langle E_{\nu}^2 \rangle \] (3)

where \( \sigma_0 = 4.5 \times 10^{-44} \text{cm}^2 \text{MeV}^{-2} \), \( n \), \( Y_N \), \( L_\nu \), \( A \), and \( \langle E_{\nu}^2 \rangle \) is a characteristic weak interaction cross section, number density of free baryons, neutron (proton) fraction, electron (anti-electron) neutrino luminosity, surface area of the absorbing region, and spectrum-averaged square of the electron (anti-electron) neutrino energy, respectively. For GRBs powered by hyper-Eddington accretion flows the relevant deposition process is neutrino annihilation

\[ \nu_e + \bar{\nu}_e \rightarrow e^- + e^+ \] (4)

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with a corresponding deposition rate given by

\[ Q^\nu_{\nu,\nu} = \bar{\sigma}_0 \frac{L^\nu_\nu}{A} \langle E^\nu_\nu \rangle \zeta \]  

(5)

where \( \bar{\sigma}_0 = 3K G_F^2 / 4 \) is another characteristic weak interaction cross section per unit energy squared, \( G_F^2 = 5.29 \times 10^{-44} \text{cm}^2 \text{MeV}^{-2} \) is the Fermi constant, \( K \) is a phenomenological electro-weak parameter usually taken to be 0.1 – 0.2, and \( A \) is the surface area of the absorbing region. In the above expression, we assumed, for the sake of compactness, that the luminosity spectrum of both neutrino and anti-neutrinos are identical, and therefore \( \langle E^\nu_\nu \rangle \) is simply the mean neutrino energy weighted over the neutrino spectrum.\(^5\) Also, the multiplicative factor \( \zeta \) takes into account the geometry of the emitting region.

Eqs. (3) and (5) state that for a fixed amount of energy release i.e., \( L_\nu \), the efficiency of producing an explosion in either case is minimized when the spectrum resembles a pure single black body since black bodies maximize the number of emitted quanta while minimizing the mean energy per quanta for a given energy flux.\(^6\) It follows, that a significant spectral deviation from that of a single black body in eqs. (3) and (5) enhances the explosion mechanism for core-collapse SNe and GRBs. From here on, we assume a hot diffuse region that lies directly above the cool dense flow, in other words a “corona,” is responsible for producing any spectral deformations. We may simplify our discussion by separating the neutrino energy spectrum into a soft component \( L^\nu_\nu \), which emanates from the cool dense regions, and hot coronal component \( L^\nu_c \). Our simple parameterization allows us to write

\[ L^\nu_\nu \langle E^\nu_\nu \rangle = L^\nu_\nu \langle E^\nu_\nu \rangle + L^\nu_c \langle E^\nu_\nu \rangle \]  

where \( n = 1, 2 \) for the neutrino annihilation and capture, respectively. If a fraction \( f \) of the energy release is mediated by the corona, then

\[ L^\nu_\nu \langle E^\nu_\nu \rangle = L^\nu_\nu \left[ (1 - f) \langle E^\nu_\nu \rangle + f \langle E^\nu_\nu \rangle \right]. \]  

(7)

Considering the SNe mechanism (\( n = 2 \)), if \( f = 0.1 \) and if the average energy of a non-thermal or “coronal” neutrino is \( \sim 10 \) times that of the average thermal neutrino, then the deposition rate from neutrino absorption given by eq. (3) is \( \sim 10 \) times larger than the minimum thermal case. In order to obtain such a large increase in energy deposition for GRBs, the neutrino spectrum must be deformed to a much more extreme degree. Note that the above scalings applies to momentum deposition as well or in other words, the radiation force. That is, if energy deposition increases by some factor due to non-thermal coronal emission, then the neutrino radiation force increases accordingly by the same amount.

2. THE EXISTENCE OF A CORONAE IN HOT DENSE MATTER

The dynamics and energy release mechanisms which govern cool dense turbulent stratified astrophysical flows are not well understood. Regardless, we now qualitatively discuss some of the basic requirements for coronal formation in neutrino-cooled systems while keeping in mind the enormous level of uncertainty attached to our assumptions.

Two physical quantities determine whether or not coronal neutrino emission is able to drive an explosion: the fraction of gravitational power \( f \) released in the corona and the temperature \( T \) at which the neutrinos are emitted. The first quantity \( f \) is determined by the complicated physical mechanisms that determine the structure and emitted radiation spectra of these intense turbulent flows. At the same time, the coronal temperature \( T \) is calculated by specifying the amount of mass and volume in which the fraction \( f \) of the energy release is deposited.

2.1. Energetics

If all of the radiative energy release occurs in the relatively opaque dense regions, then \( f = 0 \) and conversely, if all of the energy release is mediated by a hot optically thin region, then \( f = 1 \). That is, \( f \), is the mechanical energy that is deposited in the diffuse upper atmosphere of a PNS or hyper-Eddington accretion flow. For PNSs in particular, the fraction \( f \) can be even more precisely defined as the ratio that quantifies the amount of mechanical energy that passes through the neutrinosphere of the opaque nascent star.

An obvious candidate for generating interesting values of \( f \) are the magnetic field structures generated by the putative turbulence in these flows. Below, we assess the viability of turbulent magnetic energy transport for both PNSs and hyper-Eddington accretion flows. Figure 1 illustrates the general features of a coronal-driven explosion mechanism for both SNe and GRBs.

2.1.1. Convective Proto-Neutron Stars

PNSs are thought to convective for a variety of reasons immediately after their birth (Thompson & Murray 2001, hereafter TM01; Keil, Janka, & Mueller 1996). When compared to their photon-limited main sequence progenitors, the convective zones of PNSs are \( \sim 10^4 \) times more energetic with respect to their own binding energy, implying that they are ideal sites for dynamo activity (Duncan & Thompson 1992; Thompson & Duncan 1993, hereafter TD93). At this preliminary level, we assume that the PNS in question is not rapidly rotating such that magnetic field generation occurs in the absence of a net source of helicity, similar to the field generation process found in the Sun’s inactive regions. However, unlike the solar convection zone, the turbulent diffusivity due to convection decreases outwards. Therefore, the combined actions of buoyancy and turbulent transport conspire to “pump” turbulent magnetic

\(^5\) Implicitly, we are approximating that \( \langle E^\nu_\nu \rangle^2 = \langle E^\nu_\nu \rangle \). Of course, this introduces errors at less than the order unity level for a thermal emitter at fixed luminosity. However, the shape of the spectrum must carefully be taken into account if an accurate computation of eqs. (3) and (5) is desired when considering a coronal-driven explosion mechanism. Regardless, at this preliminary level, we ignore such details for the sake of clarity.

\(^6\) Throughout this paper, when we refer to a thermal single temperature black body emitter, we necessarily imply that the neutrino chemical potential is zero. However, deviations from zero chemical potential do occur as a result of transfer effects near the neutrinosphere (e.g. Keil et al. 2003). The magnitude to these deviations to the mean neutrino energy are relatively small compared to those discussed here.
Coronal-Powered SNe and GRBs

**ENERGETIC OUTFLOW**

- **hot, diffuse, magnetized corona**
- **cool, dense, turbulent layer**
- **hotspot**
- **magnetic structure**
- **turbulent eddies**
- **$H$**

**Figure 1.** Sketch of a neutrino-driven explosion. For SNe, the outflow takes the form of a massive sub-relativistic shock, while for GRBs the outflow is a relativistic high entropy wind. Binding energy, the given system’s ultimate energy source, is stored in the cool, dense, turbulent layer – where nearly all of the mass resides. The turbulence serves as the source of magnetic energy and is generated passively in a PNS and actively in an accretion disk, perhaps by the MRI (Balbus & Hawley 1991). When magnetic structures rise to and above the surface of the cool layer, they release their energy in relatively small amounts of mass and volume. If the magnetic energy is deposited uniformly at a given radius, then the corona is endowed with a scale height $H$ as discussed in §2.2. Alternatively, the magnetic dissipation may occur inhomogenously, much like the Sun. In this case, the relevant scale for magnetic energy deposition is characteristic size of a hot spot, $R_s$ which is discussed in §2.2 as well.

Our knowledge regarding the structure and energy release mechanisms of hyper-Eddington accretion flows, which may power GRBs, does not enjoy the same relative level of certainty as their core-collapse SNe counterparts. However, the likely physical conditions of such flows suggest that the turbulent energy release is accompanied by significant magnetic energy release. The turbulent energy release is likely to be accompanied by significant magnetic energy release. The turbulent energy release is likely to be accompanied by significant magnetic energy release.

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**2.1.2. Neutrino-Powered Accretion Disks**

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7 Analysis of solar $p$-mode frequency shifts reveal that convective motions beneath the photosphere maintain significant turbulent magnetic stresses such that $\epsilon_B \sim 0.1$ down to several pressure scale heights beneath the photosphere (Goldreich et al. 1991).
parameters of both systems e.g., density, temperature, surface gravity, and surface area of the luminous neutrino emitting region are quite similar. For our work, another important similarity is that both systems are highly turbulent and magnetized.

Since a predictive theory of multi-phased relativistic accretion is currently not available, we resort to observations and analysis of photon-powered black hole sources for guidance. In the case of Cyg X-1 and other black hole X-ray binaries (BHXRBs), the radiation spectrum in the low/hard state is dominated by a hot coronal component, which is most likely generated by thermal comptonization. From this fact alone, we argue phenomenologically that the radiation spectrum emanating from hyper-Eddington accretion flows may possibly resemble that of Cyg X-1 and other BHXRBs in the low/hard state, implying a value for $f \sim 1$ during some fraction of the disk’s viscous time.

The above assertion is not completely devoid from all theoretical reasoning. For example, one model of the X-ray spectrum of BHXRBs and Seyfert 1 Galaxies invokes the transport of magnetic energy away from a cool dense disk into a hot diffuse corona such that $f \sim 1$. This notion reproduces the observed spectral features while modeling the corona as a sum of compact magnetic flares, perhaps generated by the MRI, which produce mildly relativistic pair-dominated outflows (Beloborodov 1999, see also Galeev, Rosner & Vaiana 1979 and Miller & Stone 2000). Therefore, the qualitative physical argument that further motivates the possibility that hyper-Eddington accretion flows take on large values of $f$ is that they are magnetically turbulent in a manner similar to that of sub-Eddington accretion flows. It follows, that if a corona is responsible for the majority of the radiative energy release, then $\sim$ a few $\times 10^{33}$ ergs of gravitational binding energy per $M_\odot$ accreted is emitted in a hot diffuse magnetized phase.

### 2.2. Constraints from Neutrino Absorption Opacity

The neutrino continuum scattering and absorption opacity increases with energy. This microphysical difference between neutrino-cooled and photon-cooled systems does not lead to qualitative differences so long as the flow is optically thick. However, the structure of diffuse optically thin regions heavily depends on how efficiently matter can cool and therefore, an increasing absorptivity (and emissivity) of cooled and photon-cooled systems does not lead to qualitative differences so long as the flow is optically thick. However, the structure of diffuse optically thin regions heavily depends on how efficiently matter can cool and therefore, an increasing absorptivity (and emissivity) with particle energy places different constraints on coronal structure compared to the photon-cooled case. For PNS envelopes and hyper-Eddington accretion flows, pair capture and annihilation serve as the dominant sources of opacity. The emissivity for later process may be written in terms of a local temperature

$$Q_{\nu, \nu} \simeq 5 \times 10^{33} \dot{q}_{11}^9 \text{ergs cm}^{-3} \text{s}^{-1}$$

where $T_{11} = T / 10^{11}$ K and the analogous expression for the pair capture process reads

$$Q_{\nu, \nu} \simeq 9 \times 10^{-3} \rho_{10} T_{11}^6 \text{ergs cm}^{-3} \text{s}^{-1}$$

and similarly, the corresponding absorption optical depths for a characteristic length scale $H$ (in cm) are respectively

$$\tau_{\nu, \nu} \simeq \frac{Q_{\nu, \nu} H}{4(7/8)\sigma T^2} \simeq 2.5 \times 10^{-7} T_{11}^4 H$$

and

$$\tau_{\nu, \nu} \simeq \frac{Q_{\nu, \nu} H}{4(7/8)\sigma T^2} \simeq 4.5 \times 10^{-7} \rho_{10} T_{11}^2 H$$

Note that we have assumed that all nuclei are completely dissociated into free baryons. In order to determine the structure of a neutrino-cooled corona, the (mechanical and radiative) energy deposition rate per unit mass must be specified – a task that is well outside the scope of this work. In order to proceed, we make simplifying assumptions with respect to the overall geometry of the corona and mechanical energy deposition profile. The simplest configuration requires a constant density, temperature, scale height, and mechanical energy deposition profile i.e., a corona resembling a uniform plane-parallel slab. From eqs. (3) and (5), we see that the explosion efficiency is highly dependent on the energy, and thus the temperature at which neutrinos are emitted. Our corona must be both optically thin

$$\tau_i < 1$$

and satisfy radiative equilibrium

$$f L_{\nu} = \dot{Q}_\nu$$

where $f$ represents either pair annihilation or capture and $V$ is the volume of the slab. For a PNS, $V = 4\pi R_{\text{PNS}}^2 H$ while for an accretion disk $V = 2\pi R_1^2 H$ (in cm) are respectively. Condition (14) enforces that the corona, with a surface area roughly equal to that of the cool dense emitting fluid, does not radiate at the effective black body temperature. By fiat the corona is a low density region and therefore, pair annihilation is most likely the dominant source of opacity as long as the mechanical energy is injected sufficiently far away from the cool dense regions. In this case, the above conditions yield a coronal temperature

$$T \simeq 10^{11} \frac{L_1^{1/4} L_{\nu}^{1/4}}{\tau_{1/2}^{1/2} R_{0.5}^7} \text{K},$$

which corresponds to a coronal scale height of $H \simeq 3 \times 10^4$ cm. The above temperature implies an electron neutrino energy $\sim 30$–$40$ MeV, which is $\sim$ a few times larger than for a few times larger than for the electron neutrinos emitted from a PNS.
The other coronal geometry which we explore corresponds to a region above the cool dense flow consisting of $N$ neutrino-emitting hot spots of characteristic spot size $R_s$. In this case, a hot spot can be optically thin or thick. At this preliminary level, we further assume that all of the hot spots are either optically thin or optically thick. In the optically thick case, radiative equilibrium over the entire corona requires

$$f L_{\nu} \simeq \sigma T^4 N R_s^2,$$

where $\sigma$ is the Stefan-Boltzmann constant, leading to a characteristic spot temperature of

$$T \simeq 10^{12} \frac{f^{1/4} L_{\nu}^{1/4}}{N^{1/2} R_s^{1/2}} \text{K}.$$  \hfill (18)

This particular coronal configuration of optically thick hot spots yields an optical depth per spot $\tau \sim 30$, implying a radiative diffusion times $\tau^2 R_s/c \sim \text{a few} \times 10^{-5} \text{s}$. Therefore, neutrino cooling within the hot spot is instantaneous compared to the eddy turnover time $\sim 1 \text{ms}$ i.e., the likely timescale of magnetic energy injection.

For the optically thin case, condition (14) must be enforced for each hot spot, while the volume $V$ of the emitting region is now given by $V \simeq N R_s^3$ when calculating radiative equilibrium. Here, the coronal temperature is roughly

$$T \simeq 9 \times 10^{11} \frac{f^{1/9} L_{\nu}^{1/9}}{R_s^{1/3} N^{1/3}} \text{K},$$

which marginally obeys (14) for each hot spot. The neutrino energies quoted above are $\sim 3-30$ times larger than that of the thermal electron-type neutrinos emitted from the optically thick surfaces of PNS and hyper-Eddington accretion flows. As long as mechanical energy deposition above the neutrinosphere is concentrated, either homogeneously or in-homogeneously, in a small volume at low densities, the spectral component emanating from the coronal may significantly contribute to or even entirely dominate the explosion mechanism.

### 2.2.1. A Note on $e - \nu_e$ Comptonization

The $e^+e^-$ pairs in the putative corona are highly relativistic and have thermal energies in excess of $\langle E_{\nu} \rangle_s$. It follows, that the hot coronal $e^+e^-$ pairs can cool by up-scattering the soft neutrinos as a result of the process

$$e + \nu_e \rightarrow e + \nu_e,$$  \hfill (20)

an effect that is particularly relevant for the slab geometry due to its large covering fraction. Comptonization produces a non-thermal deformation to the soft spectral component. Incidentally, this effect is believed to deform the spectrum of primordial neutrinos after an effect that is particularly relevant for the slab geometry due to its large covering fraction. Comptonization produces a non-thermal time delay parameter may be written in the following form

$$y_{e\nu} \sim \frac{\Delta E_{\nu}}{E_{\nu}} \tau_C,$$

where $\Delta E_{\nu}$ is the energy gain per scattering event, $E_{\nu} = \langle E_{\nu} \rangle_s$ is the energy of a soft neutrino prior to up-scattering, and $\tau_C$ is the Compton optical depth, which is given by $\tau_C \sim \sigma_C n_e H$. The Compton cross section $\sigma_C \sim \sigma_0 \langle E_{\nu} \rangle_s \langle E_{\nu} \rangle_c$, where $\langle E_{\nu} \rangle_c \simeq \langle E_{\nu} \rangle_s$ is the energy of a hot coronal electron. Thus, $\sigma_C$ is smaller than the annihilation and capture cross sections by a factor $\sim \langle E_{\nu} \rangle_s / \langle E_{\nu} \rangle_c$. The number density of Comptonizing leptons $n_e \propto T^3$ for high entropy radiation pressure dominated regions and is $\propto Y_e n$ for low entropy regions that are gas pressure dominated. Here, $Y_e$ is the electron fraction and $n$ is the number density of free baryons. A large energy shift $\Delta E_{\nu} \sim \langle E_{\nu} \rangle_c$ accompanies each scattering as long as the coronal temperature is significantly hotter than the cool dense region responsible for providing the soft seed neutrinos. Interestingly, the $y$-parameter may be written in the following form

$$y_{e\nu} \sim \frac{\langle E_{\nu} \rangle_c}{\langle E_{\nu} \rangle_s} \sigma_0 \langle E_{\nu} \rangle_s \langle E_{\nu} \rangle_c n_e H \sim \tau_0,$$

where $\tau_0$ is given by (12) and (13) for the radiation and gas pressure dominated cases or in other words, the pair annihilation and pair capture cases, respectively. Even for modest values of $y_{e\nu}$ such that $y_{e\nu} \sim 0.1$, Compton cooling of hot electrons plays an important role in mediating the release of a corona’s energy budget as long as the covering fraction of the up-scattering region is not too small.

### 3. Discussion

To our knowledge, all previous discussions regarding prompt neutrino emission from dense core-collapse like environments assume that the entire surface of the object in question radiates close to the black body limit. The effective temperature is determined by both the rate of gravitational energy release and the surface area of the star or disk. Therefore, total neutrino number, for a given luminosity, is maximized while the average energy per neutrino is minimized. A direct consequence of this choice is that the efficiency of a neutrino-driven explosion mechanism for both SNe and GRBs is minimized. In the previous section, we put forth a qualitative picture as to how a hot corona could alter the neutrino spectrum from that of a pure black body. In what follows, we briefly discuss how significant deviations from a pure black body can alter the respective explosion mechanisms for SNe and GRBs.
3.1. Core-Collapse Supernovae

In light of the overall uncertainty surrounding the thermal neutrino powered explosion model (Bethe & Wilson 1986) and its convective variant (Herant et al. 1994; Burrows et al. 1995), many theorists have resorted to alternate sources of energy, other than gravitational, in order to power core-collapse SNe. An obvious choice is rotational energy, which one way or the other, is believed to lead to magnetic field amplification, which subsequently gives rise to spin down torques as well as an extra source of heating (cf. Thompson et al. 2004; 2005). However, it is unlikely that rotation can effect the explosion mechanism unless the initial spin period of a young neutron star is significantly in excess of those measured in young radio pulsars. On the other hand, vigorous convection is likely to persist throughout the explosion epoch, irrespective of the initial rate of rotation (Burrows 1987; TD93). Therefore, a coronal driven explosion mechanism is relevant for all PNSs and relies only upon gravity as the ultimate source of energy.

Observations of core-collapse SNe constrain the value of $f$ for a given choice of coronal temperature. Isotropic explosion energies are measured to be anywhere from ~ a few $\times 10^{50} - 10^{52}$ ergs – only 0.001-0.1 of the PNS’s gravitational binding energy. If the corona is purely responsible for the explosion, then only modest values of $f \geq 0.001 - 0.1$ are required. The upper limit of inferred core-collapse SNe energies derives from so-called “hypernovae,” which represent only a tiny fraction of the overall core-collapse SNe population. A coronal-powered hypernova requires $f \sim 0.1$ and $T \sim$ a few $\times 10^{11}$K to persist for ~ 1s in order to power a highly energetic event with total kinetic energy ~ a few $\times 10^{52}$ ergs.

3.2. Accretion-Powered Gamma-Ray Bursts

Baryon pollution and the production of large explosion efficiencies are the two main difficulties which plague models of GRBs (Thompson 1994; Rees 1999). A coronal-powered explosion mechanism directly addresses both issues. For a given energy release, eq. (7) dictates that hot diffuse neutrino-emitting coronae greatly increases the overall explosion efficiency for adequately large values of $f$. Thus, models of gamma-ray bursts that were previously excluded on grounds of energetics may possibly be reconsidered as valid candidates e.g., mergers of compact objects and accretion-induced collapse. A coronal-powered mechanism also decouples the required intense neutrino flux from the bulk of the matter, alleviating concerns regarding neutrino induced ablation and baryon pollution. An additional feature of a coronal-powered mechanism is that for a fixed neutrino luminosity, the neutrino radiation force or momentum deposition rate is larger due to the increase in opacity, which aids in the collimation of the fireball.

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