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On the true energy budget of GRB970508 and GRB971214

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Abstract. We emphasize the already known idea that since GRB970508 released an energy of $Q_\gamma \approx 10^{51}\ \delta\Omega$ ergs in soft gamma rays alone, where $\delta\Omega$ is the solid angle of the beam, the actual energy of the e^+e^-p fireball driving the blast wave could be considerably higher than this value, $Q_{FB} > Q_\gamma$. We further argue that, for reasonably large values of $\delta\Omega$, as is probably suggested by the radio observations, the value of $Q_{FB} \sim 5.10^{51}\ t_m^3\ n_1$ erg, for GRB970508; where n_1 is the number density of the ambient medium in units of 1 proton/cm^3 and t_m is the epoch in months when the associated radio-blastwave degrades to become mildly relativistic. Thus the value of Q_{FB} for GRB970508 could be as large as 10^{53}erg or even much higher. This idea is corroborated by GRB971214 for which the value of $Q_\gamma \approx 2.10^{52}\ \delta\Omega$ is much higher than the corresponding value for GRB970508. It is likely that GRB971214 has a correspondingly higher value of Q_{FB}. We discuss that it is unlikely that this energy, $Q_{FB} \sim 10^{53}$erg was liberated by the central engine by a direct electromagnetic mode. On the other hand, as conceived by several previous authors and as is suggested by supernova theories, the e^+e^-p fireball (FB) driving the blast wave is likely to be preceded by a much stronger neutrino burst: $\nu + \bar{\nu} \to e^+ + e^-$. Although, the efficiency for e^+e^- production by this latter route is usually found to be as low as $\eta_\pm \sim 10^{-3}$, we point out that for very high values of neutrino energy release $Q_\nu > Q_{FB}$, it is possible that, the value of $\eta_\pm$ increses substantially. By considering that, the value of Q_{FB} for such GRBs is indeed $\sim 10^{53}$ erg, we envisage that the energy of the actual neutrino burst/wind could be as high as $\sim 10^{54} - 10^{55}$ erg (here we ignore likely loss of energy by gravitational energy mode).

This energy might be had from general relativistic collapse of a massive stellar core having *initial* gravitational mass, say, $M_i \sim few\ M_\odot$ to a stage having a potential well much deeper than what is present on a canonican neutron star surface. Accordingly, we predict that the new generation large neutrino telescopes may detect neutrino burst of energy $Q_\nu \sim 10^{54} - 10^{55}$ ergs, with neutrino energies touching ~ 1 GeV, in coincidence with GRBs.

Key words: gamma rays: bursts – black hole physics

1. Introduction

The discovery of an absorption line with redshift $0.835 < z < 2.3$ in the optical afterglow of the gamma ray burst (GRB) of 8 May, 1997 has now decisively shown that atleast some of these events lie at cosmological distances (Djorgovski et al. 1997, Metzger et al. 1997). The observed fluence of 3.10^{-6} ergs cm^{-2} in the (20 keV- 1 MeV) band (Kouveliotiou et al. 1997), suggests an energy release of $Q_\gamma \approx 10^{51}\ \delta\Omega$ ergs in soft gamma rays alone, where $\delta\Omega$ is the solid angle of the beam. Further, the discovery of a redshift as high as $z = 3.42$ (Kulkarni et al. 1998) for the highly luminous event $GRB971214$ implies a value of $Q_\gamma \approx 2.10^{52}\ \delta\Omega$. Taken together, they confirm the view that most of the classical GRB sources indeed lie at cosmological distances and are accompanied by an amount of energy emission (in soft gamma rays alone) which could be as large as 2-3 orders of magnitude higher than what, so far, most of the existing models have attempted to explain, i.e., $Q_\gamma \sim 10^{49-50}\ \delta\ \Omega$ erg. The objective of the present paper is to consolidate the existing view (Waxman, Kulkarni & Frail 1998, Kulkarni et al. 1998, Ramprakash et al. 1998) that the observed energy liberation in the soft gamma-band with such energy liberation is preceded by a larger energy release Q_{FB} in the form of a e^+e^-p fireball (FB). Then we would like to enhance another known point that it is extremely difficult to conceive of any central engine which can liberate the e^+e^-p fireball energy Q_{FB} by a direct electromagnetic process. Therefore, as suggested by most of the original cosmological GRB models, this FB is most likely preceded by an even much more energetic $\nu - \bar{\nu}$ burst.

We develop this paper initially around the observations of GRB970508, because though it is much less energetic than GRB971214, it is the only event for which radio afterglow studies have revealed that the associated blast wave remains relatistic several months after the main event (Frail et al. 1997, Waxman et al. 1998). This suggests that the original kinetic energy of the e^+e^-p FB could be considerably higher than Q_γ. If the radio observations could precisely fix the epoch when the blast wave becomes marginally relativistic with a bulk Lorentz factor (LF) $\Gamma_{NR} = 1 + a < 2$, ($a < 1$), it may be possible to to estimate the energy of the blast wave (at this epoch). The lab frame radius of the burst at this stage would be (Waxman 1997)

$$R_{NR} \approx 4\Gamma_{NR}^2 ct_{NR} \sim 3.2.(a+1)^2 10^{17} t_m \text{ cm} \quad (1)$$

where c is the speed of the light and t_m is the lab frame transition time in months. If it is assumed that during this period the blastwave has been sweeping the interstellar medium (ISM) of the host galaxy having a number density of n_1 in units of 1 proton cm^{-3} the terminal energy would be:

$$Q_{NR} \approx \left(\frac{\delta\Omega}{3}\right) R_{NR}^3 m n_1 a c^2 \approx$$

$$2.10^{49} n_1 a(a+1)^6 t_m^3 \delta\Omega \mathrm{ergs} \quad (2)$$

It is important here to note that the foregoing expression is actually highly sensitive to the precise value of a and t_m. And also one must add E_γ and all other radiated forms of electromagnetic energy to the foregoing value of Q_{NR} in order to infer the original value of the energy of the e^+e^-p FB, $Q_{FB} = a_\gamma Q_\gamma$, where $a_\gamma > 1$. Assuming that, for GRB970508, the blastwave was indeed found to have $a \approx 1$ at $t_m \approx few$ (Waxman et al. 1998), we would have

$$Q_{NR} \approx 1.3.10^{51} n_1 t_m^3 \; \delta\Omega \; \mathrm{ergs} \quad (3)$$

showing that, it is possible that $a_\gamma \gg 1$. As the blastwave gets dergraded to non-relativistic regime, there may be a rather sudden change in the (absolute) value of the exponet of the synchrotron spectrum (α). Obervational determination of such a fiducial point alone would not be sufficient to fix the precise value of t_m and what may be required is a detailed pattern on the evolution of α preceding this epoch. Obviously, one needs to estimate the value of n_1 too. We do not know whether radio observations have actually yielded such detailed information.

The radio observations of GRB970508, have however clearly indicated that the blastwave evolution is of adiabatic nature. Then, in principle, it is possible to fix the value of Q_{FB} in terms of a simple model which involve the magnetic field equipartition parameter, ξ_B, and electron-proton energy equipartition parameter, ξ_e. Since there is no theory to independently estimate ξ_B and ξ_e (which could be slowly evolving), we feel, it is really not possible to theoretically predict the value of Q_{FB} even if such models as such are quite satisfactory. On the other hand, we feel, it would be more desirable to fix the value of Q_{FB} by means of painstaking study of the evolution of α, and this input should, in turn be used to estimate the values of ξ_B and ξ_e subject to the uncertainty about the value of n_1. Probably, by an iterative scheme involving appropriate theoretical models one may try to obtain more reliable value for all the relevant quantities.

Further, if, as suggested by the radio observations, if $\delta\Omega \approx \pi$ (Waxman et al. 1998), we would finally have have

$$Q_{NR} \approx 4.10^{51} n_1 t_m^3 \; \mathrm{ergs} \quad (4)$$

The radio observation for GRB970508 might be consistent with a value of $t_m \sim 4-5$ or even higher, and therefore, even if the value of n_1 turns out to be considerably smaller than unity, it is possible that $Q_{FB} \sim Q_{NR} > 10^{53}$ erg.

It could be so, because, if we assume a value of $\delta\Omega \sim \pi$ for GRB971214 too, the value of Q_γ in this case would be $\approx 10^{53}$ erg. This burst being four times longer than GRB970508, it is likely that a substantial portion of Q_{FB} is already spent in producing the main burst so that the eventual value of $Q_{FB} \sim Q_\gamma \sim 10^{53}$ erg. We will see below that any reasonable extension of the direct electromagnetic modes of energy extraction is unlikely to yield this huge value of Q_{FB}.

2. Pulsar mode

If, following Usov (1992) and Duncan & Thompson (1992), we assume that some pulsars are born with period, $P \sim 1$ms, the initial Rotational Kinetic Energy (RKE) of such pulsars would be

$$RKE = \frac{1}{2} I\Omega^2 = 5.10^{52} \; I_{45}\Omega_4^2 \; \mathrm{erg} \quad (5)$$

where I_{45} is the moment of inertia of the NS in units of 10^{45} g cm^2 and Ω_4 is the cyclic frequency in units of 10^4. It follows that, the magnetic dipole luminosity could be as large as

$$L_{em} \approx 2.10^{50} B_{15}^2 \Omega_4^4 \mathrm{erg \; s^{-1}} \quad (6)$$

where B_{15} is the surface magnetic field in units of 10^{15}G. The time scale for electromagnetic mode is thus

$$t_{em} = \frac{RKE}{L_{em}} \approx 150 B_{15}^{-2} \; \Omega_4^{-2} \; \mathrm{s} \quad (7)$$

It is well known that rapidly spinning pulsars may radiate more of gravitational radiation than electromagnetic radiation (Ostriker & Gunn 1969) because of equatorial ellipticity (ϵ). For a pulsar with a solid crust, the major source of ϵ could be the dynamical anisotropies associated with the magnetic field. On the other hand, note that, a freshly born pulsar is believed to be very hot with core temperature well above 10 MeV. This means that the crust will be liquid (Meszaros & Rees 1992) and the solid crust must be formed when they become sufficiently cool by intense $\nu - \bar{\nu}$ radiation to temperature, probably, below, 1 MeV. Since the whole NS behaves like a self-gravitating liquid at this stage, a large RKE is likely to introduce an equatorial ellipticity far exceeding what is obtained by considering only the magnetic field as the source of such ellipticity.

First note that, the mean density of a canonical NS with mass $1.4 M_\odot$ and radius 10 Km is $\bar{\rho} \approx 7.10^{14}$ g cm^{-3}. Then the critical cyclic frequency at which mass sdedding occurs is $\Omega_k \approx 0.66(\pi G\bar{\rho})^{1/2} \approx 0.7.10^4$ Hz, which corresponds to a critical period of $P_k \approx 1$ ms. In our attempt to first understand the problem within the purely classical paradigm, we ignore the complexities and uncertainties associated with the actual equation of state (EOS) of hot and liquid NS (for a *cold* NS with solid crust, the cold EOS permits value of $P_{min} \sim 0.3 - 0.5$ ms). A value of $\Omega_4 \geq 1$, thus may not at all be allowed for the liquid like hot NS. If the actual value of $\Omega < 0.2(\pi G\bar{\rho})^{1/2} \approx 0.33\Omega_k \sim 2.10^3$Hz, the rotating configuration will be described by Maclaurian Spheroids with the two equatorial principal axes $a = b \neq c$, where c is (not to be confuse with speed of light) length of the principal axis along the rotation vector (Chandrasekhar 1969). Equatorial eccentricity being zero, there will not be any gravitational radiation in such a case.

However, since in the present problem, we are working in a region $\Omega \to \Omega_k$ (actually by considering $\Omega_4 \approx 1$, one, unphysically overshoots Ω_k barrier), *we are not necessarily dealing with axisymmetric configurations* because for $\Omega > 0.33\Omega_k$, the Maclaurian spheriods are *dynamically unstable* and tends to degenerate into Jacobi Ellipsoids with $a \neq b \neq c$ (Chandrasekhar 1969 and ref. therein) with equatorial ellipticity

$$\epsilon = \frac{2(a-b)}{(a+b)} \tag{8}$$

Along the Jacobi sequence, ϵ increases monotonically in keeping with the increasing angular momentum. In fact, Poincare (see Chandrasekhar 1969) showed that, the Jacobian sequence eventually bifurcates into a new sequence of *pear shaped* configuration where

$$\frac{b}{a} = 0.432232; \; \frac{c}{a} = 0.345069; \; \Omega = 0.28403\pi G\bar{\rho} \tag{9}$$

In this above limit the value of $\epsilon \to 0.8$. Consequently, even when, we exclude the regime of extreme ellipticity by hand, we find that such hot and fluid-like ultrafast pulsars may emit superstrong gravitational radiation with a luminosity (Ostriker & Gunn 1969):

$$L_{gw} = \frac{32}{5}\frac{G\epsilon^2 I^2 \Omega^6}{c^5} \approx 1.5.10^{53} I_{45}^2 \Omega_4^6 \epsilon_{.1}^2 \text{ ergs s}^{-1} \tag{10}$$

where $\epsilon = 10\epsilon_{.1}$. It is trivial to see that the corresponding *instantaneous* time scale for emission of gravitational radiation would be

$$t_{gw} = \frac{RKE}{L_{gw}} \approx 0.2 I_{45} \Omega_4^{-4} \epsilon_{.1}^{-2} \text{ s} \tag{11}$$

Since $t_{gw} \ll t_{em}$, the NS would primarily emit its RKE by gravitational radiation within a time ~ 0.1s rather than by any significant relativistic wind, and acquire a value of $P > 3P_k \approx 3$ ms for which the gravitational radiation mode will be quenched. The consequent value of L_{em} would also be insignificant for the requirement of GRB problem once P degrades to this range.

It may be relevant to point out that in a recent work extending the Usov-type mechanism (Blackman & Yi 1998), the putative hot ms pulsars have been classified into [1] Supercritical strong field rotator (SPS) for $\Omega > \Omega_{crit}$, (Ω_{crit} being the critical luminosity over which pulsar spin down is dominated by emission of gravitational radiation) and [2] Subcritical strong field rotators (SBS) with $\Omega < \Omega_{crit}$. For the SPS, the initial spindown is dominated by strong gravitational radiation with e-folding $t_{gw} < 1$s. This is somewhat analogous to our conclusion reached above. It is only with reference to the latter class, the SBS, with a relatively lower value of L_{em}, one may endeavour to correlate observation of long GRBs. But, it is seen that, the peak luminosity in such cases would be well below 10^{50} erg/s, which is grossly insufficient for GRB970508 and 971214 ($\delta\Omega \sim \pi$).

Also, recently, in several important theoretical works it has been pointed out that (Andersson, Kokkotas, & Schutz 1998, Lindblom, Owen & Morsink 1998) even when the value of $\Omega < 0.33\Omega_k$, or even if the above crude discussion on probable emission of gravitational radiation from the rotating Jacobi Ellipsoids were not precise, the NS may spin down by emitting gravitational radiation. When the NS is sufficiently hotter than $\sim 10^9$ K, and one would consider the overall configuration of the fluid to be broadly spheriodal, some degree of non-axisymmetry will set in because of velocity and density perturbations (r-mode). Lindblom et al (1998) estimate that because of r-mode instability, the NS would spin sown to a period $P_{cool} \sim 13P_k$ by the joint action of neutrino viscosity and gravitational radiation within a neutrino emission dominated cooling time, t_{cool}, to a temperature $\sim 10^9$ K. However, this paper used a somewhat old formula for NS cooling which gives a very large value of $t_{cool} \sim 1$ yr. On the other hand, the more recent work of Andersson et al. (1998), which claims to be more accurate than the previous one, points out that, if one uses more recent work on NS cooling by direct URCA process (Lattimer et al. 1994), the value of t_{cool} could be as small as ~ 20 s. It is clear that, in this case, because of rapid decrease in the value of Ω, the value of L_{em} would again be insignificant.

Even in the former case of a supposed very high value of t_{cool}, the value of L_{em} may be much less than what is implied by Eq. (6). This is because of the fact that, in the theories of formation of superstrong NS magnetic field, the field is not generated spontaneously and automatically at the moment of birth of the nascent proto-NS. Instead, it is believed to be generated either by differential rotation (Kluzniak & Ruderman 1997) or by dynamo amplification (Duncan & Thompson 1992). The latter process results in a faster generation of magnetic field and is presumably caused by vigourous convection *driven by strong neutrino flux* $F_\nu \sim 10^{39}$ erg/s/cm^2. One may have such a strong neutrino flux only if $t_{cool} \sim 10$s. If the neutrino cooling is too slow, $t_{cool} \sim 1$ yr, the value of F_ν will accordingly be too low, and *no strong magnetic field may at all be generated*. In this case, the Usov type models will be irrelevant.

Consequently, assuming a NS is born with a $\sim$ 1ms-period, it spins down to 10-20 ms range by emitting an energy $> 10^{52}$ erg in the form of gravitational wave energy and probably much more energy in the form of neutrinos. Thus, because of the r-mode instability a supposed ultrfast pulsar will hardly have an opportunity to acquire a large L_{em} independent of the actual value of t_{cool}.

Note that, in contrast, an old and recycled pulsar with spin $\sim$ 1ms will be very cold with a thick and solid crust whose value of ϵ may indeed be derermined by B and could be very low. Such cold stars with $T < 10^9$ will have superfluid interior, where the r-mode gets completely supressed (Andersson et al. 1998, Lindblom et al. 1998).

3. Accretion disk mode

A NS-NS or a NS-Black Hole (BH) collision may lead to the formation of a transient compact object-disk type configuration (Narayanan, Paczynski, & Piran 1992, Ruffert et al. 1997, Woosley 1993), and following the previous ideas by several authors, (Lovelace 1976, Blandford & Znajek 1977) that such configurations may generate relativistic beams by electromagnetic process, it has been recently proposed that NS-NS or NS-BH collisions may may generate superstrong relativistic winds (Katz 1997, Rees & Meszaros 1997). In very broad terms the power radiated by such scenarios could be understood in terms of the Lovelace (1976) model by assuming the disk to be Keplerian and thin. The magnitude of the induced disk electric field would be (standard polar coordinates are used):

$$E_r \sim \frac{1}{c} v_\phi B_z \tag{12}$$

The corresponding voltage drop between the inner radius r_i and the outer radius r_o would be (Lovelace 1976):

$$V_{io} \sim \frac{1}{c} \int_{r_i}^{r_o} dr \; v_\phi B_z \tag{13}$$

where r_i is the inner radius and r_o is the outer radius of the disk. In the absence of a any reasonable information about the profile of B_z, one may be forced to consider the most favourable order of magnitude estimate of the foregoing equation by considering $B_z = B_z(r_i) = B_i$, $v_\phi = v_\phi(r_i) = v_i$, and $r = r_i$

$$V_{io} \sim \frac{v_i}{c} B_i r_i \text{ cgs} \sim 10^{22} B_4 M_{10} \text{ V} \tag{14}$$

where $B_x = (B_i/10^x \text{G})$, $M_x = (M/10^x M_\odot)$, and we have taken r_i as the radius of the last stable circular orbit and v_i as the corresponding Keperian value:

$$r_i = 3R_g = 6GM/c^2; \qquad v_i \sim \left(\frac{GM}{r_i}\right)^{1/2} = \frac{c}{\sqrt{6}} \tag{15}$$

The current flowing along the disk axis would be $I \sim cV_{io}$ and, using Eq. (14), the maximum beam power output would be

$$L_b \sim IV_{io} \sim cV_{io}^2 \sim c\frac{B_i^2 r_i^2}{6} \sim 5.10^{49} \text{ergs s}^{-1} B_4{}^2 M_{10}^2 \tag{16}$$

For a (stellar mass) NS with weak magnetic fields, the disk may nearly touch the surface and, the above value of r_i would be appropriate for such cases too. If the above model is extended for such a stellar mass NS, we would obtain a value of L_b which is quite high for X-ray binaries:

$$L_b \sim 10^{38} \; B_8^2 \text{ erg s}^{-1} \tag{17}$$

where the value of $B_8 = B_i/10^8$ G ~ 1 corresponds to either the disk inner edge touching the NS-surface or the case of a closeby inner edge immersed in the magnetosphere of the NS. This kind of NS-disk model was actually suggested to explain the origin of supposed ultra high energy gamma rays and cosmic rays from the X-ray binary Cygnus X-3 (Chanmungam & Brecher 1985). It was argued, in the eighties, that, Cyg X-3 might contain a rapidly spinning NS, and therefore, either by direct pulsar action or by NS-disk symbiosis, as has been proposed for the present GRB case, should be a strong source of ultra high energy gamma rays and cosmic rays. By overstreching the models, it was even envisaged that a single Cyg X-3 type source could solve the problem of origin of ultra high energy cosmic rays for the entire galaxy. However, it became, clear later, that such theoretical precdictions were completely unfounded. Further, if one has to fit such models into the cosmological GRB scenario, one has to further overstretch such (unsuccessful) models by many orders of magnitude; and one would be compelled to assume an enhanced value of $B_i > 10^{14}$G to obtain a notional value of $L_b > 10^{50}$ erg s^{-1}.

3.1. Available energy

In case we are considering a BH-disk case, let us estimate first, what could be the order of magnitude of the central BH. From Eq. (15), we find the period associated with the last circular orbit to be

$$P_i = \frac{2\pi r_i}{v_i} \approx 5.10^{-4} \left(\frac{M}{M_\odot}\right) \text{s} \tag{18}$$

Thus in order to explain sub-ms time structure in some of the GRBs (Bhat et al. 1992), we should consider a value of M not exceeding a few solar masses (Woosley 1993). For a spinning canonical NS, the value of RKE is limited by the binding energy (BE), $\sim 3.10^{53}$ erg. We note here that for a NS, there is a natural electromagnetic coupling between the disk and the star, and, in principle, it is possible that the supposed beam is partially fed by RKE too. However, it does not at all mean that this is necessarily the case, and, in any case, it does not mean that the entire RKE of the NS is tapped during the finite life time of the disk. If the disk could be considered a permanent structure, a rigid conductor, and rotating synchronously in tandem with the spin of the NS, maintaining a perfect electromagnetic coupling to the NS, it is possible in principle that, given very long time, the entire RKE is harnessed. But the resultant value of L_b in such a case would be determined by the value of surface magnetic field of the NS, and not by the supposed enhanced value of $B_i > 10^{14}$G. In other words, in such cases, one reverts back to the pulsar (with intrinsic dipole moment) models. Thus, in the model of Lovelace (1976) and Chamungum & Brecher (1985), the actual source of L_b is the accretion power and not the RKE of the central compact object. In fact the values of L_b indicated by either Eq. (16) or Eq. (17), roughly suggest the conversion of an Eddington limited accretion power to electromagnetic power.

This conclusion is even more appropriate for the BH-disk case even though, technically, for a maximally rotating Kerr-Newman BH, the effective value of RKE $\sim 29\%$ Mc^2. This is so because, unlike a NS-disk case, a Kerr BH has no intrinsic charge, $Q = 0$, or magnetic moment, $\mu = 0$. Thus *there is no natural electromagnetic coupling between the BH and its disk*. There are, however, some theoretical estimates, based on *purely vacuum* electrodynamics, that a stationary axisymmetric BH, placed in an external uniform magneic field,B_0 may acquire charge by the accretion process whose asypmtotic value would be $Q = 2B_0 M$ (Wald 1974). If so, it might be possible to harness the rotational energy of the BH, which, for a maximal case could be $\approx 2.10^{54}$ erg (taking a value of $M = 3M_\odot$). Similar idea is also expressed by Blandford & Znajek (1977). Given a sufficiently long lived accretion disk (fed by external material), such ideas might be relevant for jets observed in AGNs. Nonetheless, note that, in a strictly axisymmetric and steady case, the accretion process would not deliver any net torque from the BH (Ruffini 1978) though it might be possible that in a transient case some net torque may be derived from the BH. Also note that the BH can acquire a substantial dipole moment only after substantial accretion has taken place. Thus, note that, even in the AGN context, the source of jet power is believed to be primarily the accretion power rather than the stored RKE of the BH (Begelman, Blandford, & Rees 1984).

In the transient GRB case, occurrence of substantial accretion may imply the vanishing of the disk. And unlike the case of a pulsar, the RKE of the BH (with no intrinsic diploe moment), even if it is substantial, can not deliver any power once the disk has vanished. And for the transient GRB event, a very high value of L_b can be justified by assuming the release of accretion power within a few seconds. Thus, atleast for the GRB problem, the supposed high RKE of the BH can not be meaningfully harnessed and the maximum extractable energy available by all probable processes is the the total BE of the disk of mass M_d in the gravitational potential of M. In order that the electrodynamic jet mechanism is successful, i.e. the potential drop V_{io} across is maintained, the insulating effect of the magnetic field must be effective. This condition is ensured, if for most of the region of the beam, we have $v \ll c$ (Lovelace, MacAuslan and Burns 1979), which independently demands that $E_{beam} \ll M_{disk}c^2$. For a NS-NS collision case the disk may have a mass of $\sim 0.1M_\odot$ (Ruffert et al. 1997), and thus the value of

$$E_b < E_{disk} \sim \frac{GMM_d}{2r_i} =$$

$$\frac{M_d c^2}{12} \sim 2.5.10^{52}\text{ergs}\left(\frac{M_d}{0.1M_\odot}\right) \tag{19}$$

is insufficient for explaining the energy budget of GRB970508. However, assuming a case of NS-BH collision with $M_{disk} \sim 1M_\odot$ (Meszaros & Rees 1997), it may be possible to satisfy this bare energy requirement (Q_{FB}).

4. Super strong magnetic field

Let us also ponder how far we are justified in assuming a superstrong $B \sim 10^{15}$G for a very hot new born pulsar or accretion torus. As to the origin of such magnetic fields in young pulsars, Duncan & Thompson (1992) suggest that the convective turbulence associated with strong neutrino transport with $F_\nu \sim 10^{39}$ erg/s/cm^2 causes such magnetic field by the dynamo action. This tends to suggest that the strong magnetic field is an aftermath of strong neutrino cooling and it need not be present in the nascent and hot NS. In a normal astrophysical or laboratory plasma, microscopic turbulence may convert part of the bulk kinetic energy into magnetic field. However, at the same time it should be remembered that turbulence on macroscopically significant scales may have a tendency to destroy the pre-existing strong magnetic field by producing spatially and temporally incoherent current systems and by means of ohmic heating. Thus, there may be an optimal level of turbulence conducive to production of strong magnetic field and beyond which turbulence may be counter productive.

In general, linear extrapolation of magnetic field generation ideas (in relativistically hot plasma), which are originally meant to explain much lower fields, may not be proper because note that there is a natural quantum unit of $B = B_q = m_e^2 c^3/e\hbar \approx 4.4.10^{13}$ G for B. Here e is the electronic charge and m_e is the electron mass. For $B = B_q$, the *Larmour radius of the electrons, whose current ultimately gives rise to B, becomes equal to the electron Compton wavelength*. Thus it may be possible that one can realize a value of B comparable to B_q only when there is some degree of *macroscopic quantum behaviour* of the underlying medium. Atleast, in cold neutron stars this is the case in that the source of the magnetic field can be ascribed to the existence of strong internal current systems in the form of quantized flux tubes or fluxoids carrying elementary flux $\phi_0 = \pi\hbar c/e$ (Bhattacharya & Srinivasan 1995, and ref. therein). The existence of strong internal currents may be inextricably linked to the existence of a superconducting NS -interior (protons and neutrons behave like superconducting medium in which the electron current flows). The fluxoids have the *same sense of current* and $B \sim N_F\phi_0$, where N_F is the number of fluxoids threading each cm^2. Such type II (or any other) superconductivity is a manifestation of macroscopic quantum behaviour and can be operative only below certain critical temperature, which, for NS interiors, is $T_c < 1MeV$. Therefore, it might be possible that, a new born NS, which must be very hot does not possess the observed strong field, and, the strong field is set up later at the expense of the turbulent and internal energy as the star cools below T_c and becomes quantum mechanically organized.

On the other hand, the catastrophic NS-NS collision process, which is far from the spherically symmetric near-adiabatic core-collapse scenario and results in a central compact object of $T \sim 50$ MeV (Ruffert et al 1997), might destroy the pre-existing order and the magnetic field. The same is even much more true for the resultant disk which is very hot (~ 10MeV) and macroscopically turbulent. Recall here that, there is a critical temperature above which the NS core or the disk ceases to be a superconductor. Earlier theoretical estimate was that in the density range of $T_c \sim 10^{13} - 10^{15}$g cm^{-3}, the transition temperature lies between $\sim 1 - 20$MeV. But more recent and and refined estimates find $T_c \sim 0.5$MeV even at the highest densities (Bhattacharya & Srinivasan 1995). Thus, the hot compact object or the disk resulting from tidal distortions is most unlikely to be the site of a magnetic field whose value exceeds the characteristic quantum value $4.4.10^{13}$G. Probably, the modest macroscopic quantum behaviour implied by a type II superconductor can not explain a $B > 10^{13}$G, the maximum value for radio pulsars, and it may require a greater degree of quanum coherence to have a field stronger than this. If one reqires a value of $B \gg B_q$, it may be more logical to conceive that superconductivity is due to flow of protons rather than of electrons. This will, however, demand, quantum coherence on much larger scale.

It is thus particularly difficult to conceive how the hot, turbulent, and incoherent accretion disk resulting from a NS-NS or NS-BH collision may possess a value of $B \sim 10^{14}$ G $> B_q$.

At any rate the *sustenance* of a strong NS magnetic field is certainly not due to any strong macroscopic turbulence, because, in a cold NS core or crust, there is hardly any macroscopic turbulence. It must be mentioned now that recently, in a remarkable observation, the so called Soft Gamma Ray Repeaters (SGRs) have been identified to be associated with a class of NS with strong magnetic field ∼few 10^{14} G (Kouveliotou et al. 1998). These class of NSs with superstrong magnetic fields have been termed as "magnetars". But, from our view point, the important point is that the magnetars are *extremely slow rotators* with $P \sim$ few s. Their spin down luminosity L_{em} is very low having a value of only $\sim 10^{34}$ erg/s. The stored magnetic energy of such stars is in the range of $\sim 10^{46-47}$ erg, which far exceeds the RKE $\sim 10^{44}$ erg (at the present epoch). It is interesting to note that the X-ray and particle emissions from the magnetars, which may fuel the SGR activity, are powered not by rotation but by the sporadic release of the stored magnetic energy. The magnetars discovered now may be several thousand years old with temperature, certainly, much below 1 MeV.

5. Electrodynamics immersed in accretion

A general requirement for realizing the vacuum potential drop V_{io} is that the density of the ambient plasma is not exceedingly larger than the characteristics Goldreich-Julian density (Goldreich & Julian 1969) :

$$n_{GJ} \sim 10^{-2} B_z \Omega \, \mathrm{cm}^{-3} \tag{20}$$

where Ω is the cyclic frequency of the accelerator in Hz. This is the density of space charge that arises in the magnetosphere of an unipolar inductor type device in the absence of any externally injected plasma. It is because of the unavoidable presence of this space charge that the actual available potential drop in the magnetosphere becomes considerably smaller than the vacuum value V_{io}. And one of the fundamental and pending problem of pulsar type mechanism is to self-consistently evaluate the value of the modified lower voltage $V'_{io} << V_{io}$. If it were not not so, many of the X-ray binaries containing either rapidly spinning NSs or modestly spinning white dwarfs would be strong soures of ultra-high energy cosmic rays. Even for isolated radio pulsars like Crab and Vela, the absence of emission of either ultra-high energy cosmic rays and gamma rays (the observed gamma rays lie in the TeV-range) would suggest that, even in the ideal cases, it is difficult to realize the vacuum potential drop V_{io}. Further, when external plasma is present, the problem becomes even more poorly defined, and, all estimates based on the vacuum value of V_{io} become highly suspect. In particular, if the external plasma density $n \gg N_{GJ}$, at a certain stage, the pulsar type mechanism ceases to operate. This is corroborated by noting the fact that althogh most of the bright X-ray binaries contain NSs with sufficiently high magnetic field, in general, they do not operate in the *pulsar mode*, i.e., they undergo spin up rather than spin down process. Also, intermittently, during stages of low accretion rate, usually considerably lower than the Eddington rate, some of the pulsars in the X-ray binaries, undergo brief spells of spin-down.

For the the innermost circular orbit, we have

$$\Omega_i \sim \left(GM/r_i^3\right)^{1/2} = c^3/(6^{3/2}GM) \tag{21}$$

implying a value of

$$n_{GJ} \sim \left(\frac{10^{-2} B_i c^3}{6^{3/2}GM}\right) \sim 2.10^2 B_i \left(\frac{M}{M_\odot}\right)^{-1} \tag{22}$$

On the other hand, for accretion at the Eddington rate, $\dot{M}_{ed} \sim 10^{18}$g s^{-1}, in the approximation of spherical accretion, by using Eq. (18), we find that, the density of the accretion plasma near the innermost region would be

$$n_{ed} = \frac{\dot{M}_{ed}}{4\pi r_i^2 v_i m_p} \sim 5.10^{18} \left(\frac{M}{M_\odot}\right)^{-2} \mathrm{cm}^{-3} \tag{23}$$

Further, we define a ratio to quantify the degree of contamination of the extraneous plasma:

$$\xi_{em} = \frac{n_{ed}}{n_{GJ}} \sim 3.10^{16} B_i^{-1} \left(\frac{M}{M_\odot}\right)^{-1} \tag{24}$$

For a supermassive BH of $M \sim 10^8 M_\odot$ having a value of $B_i \sim 10^4$G, or for an accreting millisecond binary pulsar with a low $B_i \sim 10^8$G, and whose accretion disk may be almost touching it, we find a value of $\xi_{em} \sim 10^4 - 10^5$. Note that, even if we consider the disk to be ideal and thin, there is alwaya a corona above and below the disk. Further, in all realistic cases, in particular, in case of minor deviation from exact axisymmertic accretion geometry, there may be a small component of quasi-spherical flow with density $n_{sp} \sim \zeta \xi_{em} n_{ed}$. This is more true for a thick accretion disks or tori. Such extremely weak quasi-spherical flows or corona need not inhibit the formation of effectively baryon free funnels along the symmetry axis, however they can certainly quench the vacuum potential drop estimated in Eq. (16).

Although, most of the accretion power of AGNs is primarily manifest in the form of ultraviolet or X-rays, we note that relativistic bipolar flows with luminositities, sometimes, comparable to $L_{accretion}$ seems to be a common features in active galactic nuclei. We also note that radiation driven or hydrodynamic jet models have difficulty in achieving a value of $\Gamma \geq 2$, (Begelman 1994) whereas most of the superluminal flows as well as gamma-ray observations require a value of $\Gamma < 10$. Here we may add that for the recently observed galactic 'micro quasars', in some cases, the inferred value of $\Gamma \sim 2.5$ while in one case, the value of $\Gamma \sim 10$ (Mirabel & Rodriguez 1997, Hjellming & Rupen 1995). And though for radiation driven jets, it is generally found difficult to obtain values of $\Gamma > 2$, recently, by using the socalled "Compton Rocket Effect" Renaud & Henri (1997) have attempted to show that radiation driven disk-jet mechanisms can overcome such limitations, and, in fact, attain a value of $\Gamma \sim 60$ in the AGN context. However, the value of the terminal Lorentz factor, in this model, is given by

$$\Gamma \sim 2\epsilon_0^{-1/3} \quad (25)$$

where ϵ_0 is the mean energy of the disk photons in units of $m_e c^2$ For the AGN problem, the value of ϵ_0 is in the ultraviolet range, but for the GRB problem, $\epsilon_0 \sim 1$, and therefore, again, we have $\Gamma \leq 2$.

Thus in the absence of alternative more successful theories about such relativistic flows (Begelman 1994), in a rather generous manner, let us assume here that it is the magnetically dominated disk-BH-jets which are working in the AGNs. By considering $L_b \sim L_{ed} \sim 10^{46} M_8$ ergs s^{-1}, we estimate, $B_{i4} \sim 1$ for $M_8 \sim 1$ so that typical $\xi_{em}^{AGN} \sim 3.10^4$ and $\zeta < 10^{-4}$.

In contrast, note that, except for the recently discovered galactic superluminal sources mentioned above, most of the known bright X-ray binaries (with accretion disks) do primarily emit the accretion power in X-rays and not by relativistic beams. The radio-jets observed in many X-ray binaries like Cyg X-3, SS433, Sco X-1, are non-ralativistic with luminosities insignificant compared to Eddington luminosities. And in the light of the recent optimistic work on radiation driven jets (Reanaud and Henri 1997), it is entirely possible that, purely electromagnetic jet mechanism is neither necessary nor functional in the X-ray binaries. Even, if one assumes that, for the stellar mass cases too, $L_b \sim L_{ed} \sim 10^{38}$ ergs $^{-1}$, one would obtain a maximum effective value of $B_i \sim 10^9$G with a corresponding value of $\xi_{em}^x \sim 10^9$. In the framework of this probable relativistic jet-mediated liberation of accretion power, we may explain the general absence of such activity in the X-ray binaries by restricting $\zeta \gg 10^{-9}$. Recall again that there will be extraneous plasma also be in the form an accretion disk corona and whose density could be proportional to the accretion rate.

The GRB disk case is similar to a stellar mass X-ray binary case with the difference that in the former case, we assume need a much higher value of $B_i \sim 10^{15}$G. But, on the other hand, note that for the GRB case, assuming that $0.1 M_\odot$ is accreted in ~ 10s, we will have an accretion rate of $\dot{M} \sim 10^{31}$g s^{-1} $\sim 10^{13}\ \dot{M}_{ed}$, so that

$$\xi_{em}^{GRB} \sim 10^{30} B_i^{-1} \left(M/M_\odot\right)^{-1} \quad (26)$$

Thus, even for an assumed high value of $B_i \sim 10^{15}$G for a GRB-disk, we will have $\xi_{em}^{GRB} \sim 10^{15}$, and with a value of $\zeta \gg 10^{-9}$, the density of the quasi-spherical flow $n_{sp} \gg n_{GJ}$, probably $n_{sp} \sim 10^{11} n_{GJ}$. Also note that, while we observe the AGN or X-ray binaries in a quasi-steady state, probably, atlest thousands of years after their formation, in the GRB disk case, what is really formed after the catastrophic collison is a torus or simply a cloud (Ruffert et al. 1997) which may be settled into a more-steady torus. And for such cases, even if the accretion were limited by the Eddington rate, the chance of a minor quasi-spherical accretion would be a genuine difficulty in achieving any idealized electromagnetic accretion machine. Thus it is very difficult to see how electromagnetic modes of energy extraction based on the idea of accelerators immersed in vacuum can work for the GRB case. In fact, the work of Ruffert et al. (1997) shows that, it is indeed likely that most of the accretion power associated with the GRB-disk is used in producing neutrinos.

6. Summary and discussion

In the past, purely electromagnetic modes of GRB origin, mostly involving (isolated) pulsar magnetospheres, have been considered from time to time in the context of galactic models or at best for the so-called galactic-halo models. Energy constraints discouraged extension of such models for the cosmological perspective because of the following simple reason. The radio pulsars are probably the best studied high energy astrophysics objects and there are strong observational reasons to believe that the pulsar magnetic fields do not exceed 10^{13}G and pulsars are not born with a period shorter that ~ 10ms (Bhattacharya & van den Heuvel 1991). While, the constraint on the initial spin period persists, recent observations have found that, there are a class of pulsars with superstrong magnetic fields of few 10^{14} G (Kouvelotou et al. 1998). However, given their age of few thousand years, they are very slow rotators with $P \sim$ few s compared to the X-ray pulsars or normal radio pulsars. The quiesent electromagnetic activity of such pulsars are completely insignificant for any kind of GRB activity, however, the intermittent release of the stored magnetic energy, plausibly fuels the SGR activity. As far has classical GRBs are concerned, these, magnetars may not be relevant.

In fact, recently, Spruit & Phinney (1998) have suggested that pulsars might be born as slow rotators because the magnetic locking between the core and the envelope of the progenitor prevents the core from spinning rapidly. This suggestion may be generally true although there must be exceptions like Crab for which the initial spin has been estimated to be ~ 19 ms (Glendenning 1996). In particular, Spruit & Phinney envisage that magnetars are born as slow rotators with $P > 2$ s.

On the other hand, the elaborate realistic numerical computations (though primarily Newtonian) to study the physics of NS-NS collisions (Ruffert et al. 1997) showed that the value of Q_{FB} could be as low as $10^{47} - 10^{48}$ erg, which falls short of the *previously assumed requisite value* $Q_{FB} \sim 10^{51}$ ergs by several orders of magnitude. In view of such discouraging results (from the GRB view point), it became, probably, important and necessary to reconsider the electromagnetic models for the cosmological GRBs too. However, in this paper, we probed some of the consequences for extending the normal electromagnetic models involving stellar mass compact objects with $L_b < 10^{38}$ erg/s to scenarios with intended $L_b \sim 10^{50-51}$ erg/s or even higher.

A hot and fluid like NS with a assumed value of $\Omega \sim 10^4$, as was *believed to be required for the GRB problem in the pre-GRB971214 era*, is likely to lose practically the entire initial RKE by gravitational radiation because of the equatorial ellipticity associated with its Jacobi Ellipsoid configuration. It is then expected to settle to a much lower value of $\Omega < 0.33\Omega_k$ within < 1s of its birth. Even then, it will be subject to r-mode instability. If the intial ν-cooling is rapid enough, $t_{cool} \sim 10$s, neutrino flux driven conduction may set up a super strong magnetic field; but, by this time, the bulk viscosity and gravitational radiation may bring down the spin to $\sim 10 - 20$ ms (we have already mentioned that such strong field magnetars might actually be born with $P > 2$ s). Thus, these models will fail to explain GRBs. And with an actual value of $Q_{FB} \sim 10^{53}$ erg, such models become even much more fragile.

We also recall here that the approximate formation time of a NS out of the proto-NS is determined by the fairly long neutrino diffusion time scale of ~ 10s (Shapiro & Teukolsky 1983) and this has been confirmed by SN1987A. Since this time scale is comparable to or, in fact larger than, most of the GRB time scales, it is unjustified to consider the sudden birth of a NS (of high magnetic field) in isolation and then seperately study its probable spin-down or cooling on a time scale of few seconds. Such supposed prompt spin down has to be studied as an integral part of the final stages of the preceding collapse process. Following the discussion of Sect. 1, as soon as, the proto-NS would be envisaged to acquire high spin, the associated gravitational damping would constrain the value of $P > 3P_k \sim 3$ms or to a much higher value. In fact, the formation stages of the torus would also certainly involve wobbling and spinning of the would be torus material. And this would again mean huge loss of angular momentum and kinetic energy from the system, though, it would practically be impossible to estimate such losses. The formation of NS always involve release of its BE $\sim 3.10^{53}$ ergs primarily in the form of neutrinos and antineutrinos. And this may indeed entail strong neutrino driven convection, and, yet it is certain that most of the neutron stars, except the few magnetars, are not born with super strong magnetic field. So our understanding of genesis of super strong NS is far from complete and we need to invoke the idea of such strong fields with caution.

Recently, Kluzniak & Ruderman (1997) have considered a scenario in which the new born pulsar has a (poloidal) magnetic field $\sim 10^{12}$, but the differential rotation winds it up to a toroidal field of $\sim 10^{17}$G. In this case, L_{em} is moderate and the the main relativistic beam arises because of the annihilation of such strong toroidal magnetic fields. However, following Duncan & Thompson (1992) and Usov (1992), even if we assume the creation of a super strong magnetic field $B \sim 10^{15}$G in new born pulsars on the plea that, unlike macroscopically turbulent accretion disks (actually torus), the core of a pulsar is non-turbulent, even though hot, it is far more difficult to conceive of a field $\sim 10^{17}$G in the absence of real macroscopic quantum coherence. And in any case, because of ultrarapid rapid gravitational energy loss, such models are unlikely to work.

In the NS-NS or NS-BH merger scenarios, for the resultant hot disk whose temperature is higher than the superconductivity transition temperature and which is macroscopically turbulent, it is extremely difficult to conceive that it possesses a magnetic field higher than $B_q = 4.4.10^{13}$G. And note that, *in the post GRB971214 era*, one needs to artificially further over stretch the value of B_i to probably 10^{16}G.

Could there be yet more novel variety of electromagnetic models of GRBs involving compact objects? Recently, Usov (1998) purported to show that the bare surface of a new born strange star would spontaneously emit pairs with luminosity $L_{\pm} \sim 10^{51}$ erg/s for about ~ 10s. However, we have already shown that this idea can not work simply because the time scale to transport thermal energy from the core of the new born strange star could be as large as $\sim 10^{13}$s, rather than ~ 10s, as assumed by Usov. The only way to transport the thermal energy on the desired short time scale of ~ 10s or shorter would be to consider the emission of $\nu - \bar{\nu}$ pairs (Mitra 1998a).

As to the disk-jet case, the resultant value of L_b would be much lower than the one estimated using vacuum electrodynamics because Ruffert et al. (1997) show that the disk would be as hot, $T_{disk} \sim 10$MeV, and therefore, even for an idealized thin disk geometry and no quasi-spherical accretion, there would be fairly dense plasma around the disk (corona) and which would tend to quench any direct electromagnetic mode. Most probably, with *accretion rates exceeding the Eddington rate by factors as large as* 10^{12}, all such electromagnetic modes of energy extraction, appropriate for radio pulsars, may not be applicable to the GRB-disk at all.

6.1. Mode of energy release

In general accretion energy will be channelized into X-rays and to neutrinos along with the relativistic beam, if any. Given this fact, it is not really possible to ascertain how much of E_{disk} would go into $E_{beam} = L_b t_w$, where t_w is the duration of the beam. Similarly, the life time of the disk (t_w) also can not be predicted, and let us just assume it to be ~ 10s. Thus, the value of L_b is to be set to the desired value by keeping B_i a free parameter and conveniently ignoring other competetive and probably much more likely process of neutrino production.

Yet, we can say that, as is the case for highly super-Eddington accretion, accretion power will primarily produce $\nu - \bar{\nu}$. In fact this is the most natural process of cooling of hot and dense astrophysical plasma. We may look at it in the following way. One of the primary task assigned by Nature to the electro-weak interaction is the drainage of energy from physical and astrophysical systems. For macroscopic bodies at relatively lower densities and temperatures, it is the electromagnetic part which undertakes the responsibility of relieving systems of excess energy and help arrive at (new) equilibrium situations. On the other hand, at high densities and temperatures, it is the weak processes which take up this responsibility, and hot astrophysical bodies cool by emission of neutrinos through pure electroweak processes (like at the late stages of evolution of massive stars) or through various URCA type processes (Chiu & Morrison 1960, Chiu & Stabler 1961).

One may try to further appreciate this problem from this simple argument: Even assuming that NS-NS or NS-BH collision process results in a disk of necessary mass, *why must it get accreted within* $\sim 10s$ when the disk of Saturn can stay put indefinitely? Well, the answer would be that there is viscous dissipation and associated loss of angular momentum of the disk material. The nature and quantitative value of disk viscosity is most uncertain and even if the source of viscosity is considered to be disk magnetic field, the *dissipation of energy in the disk necessarily means that accretion energy is primarily lost in the form of heat and neutrinos*. Thus the BH-disk GRB model of Woosley (1993) appropriately considers neutrino production as the main source of accretion energy liberation. It is a different matter that, this model, has difficulty in accounting for a value of $Q_{FB} > 10^{50}$ erg. Finally, note that, even in the AGN context, the physics of magnetically dominated disk-jets is poorly understood and "hydromagnetic propulsion as a mechanism for accelerating jets has become attractive largely through a process of elimination" (Begelman 1994) of other competetive ideas.

It hardly requires a reminder that most of the other original cosmological GRB models too logically envisaged that whether it is a NS-NS collision or a NS-BH collision, the energy is liberated in the form of $\nu - \bar{\nu}$ (and in gravitational radiation) rather than in the form of any (direct) relativistic e^+e^- beam (Goodman, Dar, & Nussinov 1987, Paczynski 1990, Haensel, Paczynski, & Amsterdamski 1991, Rees and Meszaros 1992, Meszaros & Rees 1992, Piran 1992, Mochkovitch et al. 1993). Now falling back on these works, we feel that, irrespective of the details, it is much more likely that the powerful $e^+e^-\gamma$ FB is indeed due to the annihilation of $\nu + \bar{\nu} \to e^+ + e^-$. There may be another reason why we may be compelled to invoke neutrinos in this problem.

The sub-ms time structures found in many GRBs (Bhat et al. 1992) have enhanced the general view that the dimension of the central engine of the GRBs is $< 10^7$cm. Now we repeat the already oft-repeated argument that the fact that for GRB971214, the luminosity is $L_\gamma \sim 10^{52}\ \delta\Omega$ erg/s, with a probable larger value of L_{FB}, or for GRB970508, the value of $L_{FB} \sim 10^{52}\ \delta\Omega$ erg/s would suggest a temperature of the emission zone, $T_{em} \sim 10^{10} - 10^{11}$ K. At such high temperatures, even if one has no neutrino to start with, photoneutrino processes (Chiu & Morrison 1960) ensure that neutrinos become much more numerous than $e^\pm$ pairs:

$$\gamma \to e^+ + e^- \to \nu_e + \bar{\nu_e}; \gamma + e^- \to \gamma + \nu_e + \bar{\nu_e} \quad (27)$$

The situation for such high temperature pair plasma becomes somewhat like the early universe at corresponding temperature. In most of the realistic astrophysical situations, neutrinos, being chargeless and weak particles, have much better chance of escaping than $e^\pm$ pairs (the pair plasma is already dominated by pairs at such temperatures). Thus, unless we conceive of highly fine tuned and optimistic models, the very existence of such extremely high values of L_{FB} would imply that the primary energy release mechanism from the central engine is in the form of neutrinos.

In the context of the accretion induced collapse (of white dwarfs) model, it has been estimated that, the efficiency of the pair production via the annihilation of $\nu - \bar{\nu}$ is

$$\eta_\pm \approx f \sigma_{\nu\bar{\nu}} \frac{L_\nu}{\epsilon_\nu} \frac{1}{r_i c} \quad (28)$$

Here the geometrical factor $f \sim 1$, L_ν is the luminosity of the neutrino beam, $\sigma_{\nu\bar{\nu}} \sim 10^{-44}\ (\epsilon_\nu/1\ \mathrm{MeV})^2$ is the crosssection of the process averaged over three flavours, and ϵ_ν is the mean energy of the neutrinos (Goodman et al. 1987, Piran 1992). For the supernova case where $L_\nu \sim 10^{52}$ erg/s and $\epsilon_\nu \sim 10 - 15$MeV, one obtains a very low value of $\eta_\pm \sim 10^{-3}$.

If we directly and naively use this value of $\eta_\pm$ to understand the origin of $Q_{FB} > 10^{53}$ erg, we would require a value of $Q_\nu \sim 10^{56}$ erg! But note here that, since $\sigma_{\nu\bar{\nu}} \propto {\epsilon_\nu}^2$ we find

$$\eta_\pm \propto \frac{\epsilon_\nu L_\nu}{r_i} \quad (29)$$

As L_ν increases beyond, say, 10^{52} erg/s, with a corresponding decrease in r_i (a deeper gravitational well is necessary to have

increased L_ν), the value of $\epsilon_\nu \sim (L_\nu/r_i^2)^{1/4}$ would also increase considerably. Therefore, eventually, we may have

$$\eta_\pm \propto {L_\nu}^{1.25} r_i^{-1.5} \quad (30)$$

By pursuing such probable higher values of L_ν, one might partially approach a situation, where the process $\nu + \bar{\nu} \to e^+e^-$ is in thermal equilibrium with $\eta_\pm \sim 1$. It does not mean that such a limit is exactly attained, but depending on the unknown details of the evolution of the central engine, a value of $\eta_\pm \to 0.01 - 0.1$ may be achieved. For instance, a value of $L_\nu \approx 10^{53}$ erg/s and $Q_\nu < 10^{55}$ erg might self-consistently explain the origin of $Q_{FB} > 3.10^{53}$ erg.

Here we note that some of the GRBs are stronger than even GRB971214. For instance, the fluence of GRB980329 in the (50-300)KeV band is 5.10^{-5} erg cm^{-2}, which is approximately five times larger than that of GRB971214. In fact the radio afterglow has been detected for this burst too (Taylor et al. 1998). If this burst too lie at $z > 1$, it may be possible to to postulate that the GRBs actually constitute a "standard candle" probably within a factor of 10, with respect to the value of Q_ν. Small variations in microphysics from one case to another may induce a spread in the duration, t_w (of the neutrino burst, not necessarily same as the duration of the observed GRB) with considerable spread in the value of L_ν. Then, because of the non-linear nature of the conversion efficiency (Eq. 30), there is additional spread, probably spanning two orders of magnitude, in the eventual value of Q_{FB}. If the baryon contamination is above a critical value (Shemi & Piran 1990), the resultant GRB could be very feeble and most of the FB energy would go into accelerating the baryons residing inside the FB and those lying ahead (like previuosly ejected mass shells and presupernova wind). Such events would be detectable in the electromagnetic band only if it occurs in a nearby galaxy. It may be tempting to explain the association between the weak event GRB 980425 ($Q_\gamma \sim 10^{48}$ ergs) with the mildly relativistic extraordinary supernova event SN 1998bw having a kinetic energy of $\sim 2.5.10^{52}$ erg occuring at $z = 0.0085$ (Galama et al. 1998, Soffita et al. 1998). We predict that the ejecta of SN 1998bw is not highly beamed though it could be quasi spherical and quasi symmetric contrary to several suggestions to this effect. Future observations should confirm (or reject) this simple prediction.

Such high value of $Q_\nu > 10^{54-54}$ erg, with an associated value of $L_\nu \sim 10^{53}$ erg/s would demand a value of $\epsilon_\nu \to 0.1$GeV. This difficult conclusions should not be avoided with the plea that the existing models/theories are unable to explain the origin of such prodigious neutrino luminosities. In fact the existing paradigm, that gravitational collapse can not directly yield a value of Q_ν larger than the BE of canonical NS, $Q_\nu \sim 3.10^{53}$ erg, and any attempt to harness more energy by studying collapse of relatively more massive proto-NS would give birth to a black hole with hardly any appreciable energy output *completely fails* to explain the genesis of SN 1998bw. Of course, one can try to avoid this difficulty by proposing "collapsar" models (Wooseley 1993, Wooseley, Eastman, and Schmidt 1998). Although, the intention of the present paper is not to outline any (new) GRB model, we would only like to point out that, recently, we have shown that, for continued general relativistic spherical collapse, the entire origina mass energy can be radiated (Mitra 1998b,c). But more importantly, we have shown that general relativity actually inhibits the formation of "trapped surfaces", the regions wherefrom even radiation can not move out. This opens up the possibilty that gravitational collapse of sufficiently massive stellar cores ($M_i > 3M_\odot$) does not end up as a quiet passage to a black hole. Thus, the collapse of a $M_i < 10\ M_\odot$ stellar core may account for this required Q_ν. In fact, we predict that, once the new generation giant neutrino detectors become fully operational, it may be possible to detect neutrino bursts of value $Q_\nu \sim 10^{54} - 10^{55}$ erg with neutrino energies reaching ~ 1 GeV, in coincidence with the GRB events.

We are also aware here of the fact that, luminosity apart, for explaining GRBs, one needs to conceive of situations where the baryon load of the beam is modest and the value of Γ is indeed high; but we would address all such questions in a latter work.

To conclude, we did not attempt to predict the value of Q_{FB} by presuming some canonical value of ξ_B and ξ_e. It is plausible that these two parameters actually vary substantially from case to case even for the afterglow regime. And, probably only when these parameters have an appreciable value $\xi_B > 0.01$ and $\xi_e > 0.01$, radio counterparts are found. Conversely, the absence of detectable radio afterglow for most of the GRBs may be ascribed to actual occurrence of relatively lower vales of these parameters.

Whether the blast wave produes detectable radio afterglow or not, as ensiaged previously (Mitra 1998d), there should be some remnants (GRBR), like defunct supernova remnants, of these events. These remnants may be found in nearby galaxies or in the Milky way.

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