Very high-energy neutrinos from slowly decaying, massive dark matter, as a source of explosive energy for gamma-ray bursts

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Abstract

We consider a speculative model for gamma-ray bursts (GRB), which predicts that the total kinetic energy in the ejected matter is less than the total energy in the gamma rays. There is also secondary energy in X-rays, which are emitted contemporaneously with the gamma rays. The model suggests that bremsstrahlung and Compton up-scattering by very energetic electrons, are important processes for producing the observed burst radiation. The dynamics naturally allows for the possibility of a moderate degree of beaming of matter and radiation in some gamma-ray bursts. GRB are predicted to have an intrinsically wide distribution in total energies, in particular, on the low side. They are predicted to occur out to large red-shifts, $z \sim 8$, in local regions of dense matter.

1 Introduction

The most striking empirical aspect of cosmological gamma-ray bursts (GRB) is the explosive release of a large total energy in energetic photons in a very short time interval. Of the order of $10^{52}$ ergs may emerge explosively outward from the source in less than one minute, in the form of gamma rays of $\sim 0.1$ MeV to $\sim 1$ MeV, and X-rays. The dynamical origin of such explosive emission remains a mystery, at present. This is so, despite the fact that a number of hypotheses [1, 2, 3] invoke the gravitational energy released by infalling matter in the vicinity of a black hole, or during the formation of a black hole, as the principal source of energy. Models of this type predict that a comparably large amount of energy is in the kinetic energy of matter (baryons), which is explosively ejected outwards, as the result of some unknown dynamical mechanism. This essential prediction is not unambiguously verified by the data on gamma-ray bursts, at present [4]. Indeed, there is analysis [5] of data which suggests that the kinetic energy in ejecta may be less than the energy in gamma rays. The purpose of this paper is to present some general results of the hypothesis that the primary source of the energy observed in gamma rays arises from the energy in extremely high-energy neutrinos (and antineutrinos) which accumulate over long time intervals, in the immediate vicinity of a very massive, central body which is composed of massive particles of dark matter.
These neutral, scalar quanta may be metastable. They may decay into neutrino-antineutrino pairs, but with a very long lifetime, which has been estimated to be many orders of magnitude greater than the present age of the universe, because the decay matrix element is proportional to a (relatively) tiny neutrino mass. It is now established that neutrinos have mass. The essential assumption is that the very energetic neutrinos which are present from decaying inflatons, can acquire momentum components which allow them to circulate, and accumulate in a spherical envelope, near to the massive central body, which is assumed to be near to the condition of a black hole. The relevant decaying inflatons may be circulating in the immediate vicinity of the central body. In an appendix, we give a heuristic argument that such an accumulation might be possible. For the moment, we wish to go directly to the consequences of a rapid encounter of these energetic neutrinos with a sufficiently dense toroidal configuration of infalling matter. We show that this can give rise to a gamma-ray burst, within a naturally occurring total time interval of less than 2 minutes, and with irregular fluctuations in time intervals of a natural order of magnitude of less than 1 second. These time intervals are calculated below, from the macroscopic and the microscopic dynamics. Contrary to the above-mentioned prediction, we estimate that the total kinetic energy in the ejecta is likely to be significantly less than the total energy in the gamma rays. Gravitational energy released by infalling matter is present, but it is secondary. We estimate the contribution as a source of X-rays, which are emitted contemporaneously with the gamma rays. The specific dynamics predicts an intrinsically wide distribution of observed total energy in gamma rays, in particular, for bursts at energies below \( \sim 10^{52} \) ergs. The dynamics suggests that gamma-ray bursts have been prolific at very early times in the universe, out to red-shifts of the order of 8, near to the times of activation of the first “engines” in active galactic nuclei, and of the formation of the intergalactic medium. Related to this, there is a prediction of a new kind of astrophysical entity: massive bodies which can appear to emit gamma rays (and X-rays) approximately continuously, at low luminosities. We estimate the total amount of dark matter that may be present in those discrete massive entities which are related to gamma-ray bursts; it is less than 1% of critical density. The dynamics based upon energy in circulating neutrinos, naturally allows for a moderate degree of collimated ejection of matter and radiation (beaming) in some gamma-ray bursts. Finally, we consider some general consequences of the dynamical idea of energy in circulating neutrinos, for dark-matter entities both less massive, and more massive, than those associated with gamma-ray bursts.

For quasar-like entities, the possible total energy from high-energy neutrinos is secondary to the gravitational energy released by infalling matter. In active galactic nuclei and quasars, the neutrino energy allows naturally, for the outward jetting of some energy. For binary systems suspected of harboring a compact entity like a black hole of \( \sim 10 \, m_\odot \), which are observed as X-ray transients, the luminosity in neutrinos might provide a dynamical mechanism for maintaining a region of very energetic, but diffuse and poorly radiating material, near to the compact, massive entity, in long time intervals between the X-ray outbursts.

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\(^{F1}\) The inflaton mass has been calculated in Ref. 6 to be near to \( 10^{11} \) GeV. The lifetime has been estimated to be \( \tau \sim 10^{25} \) s.

\(^{F2}\) The largest mass, probably that of \( \nu_e \), is possibly of the order of 0.06 eV. The other, lighter neutrino masses may not be less than a factor of 0.1 smaller. Flavor mixing occurs; we do not deal with this explicitly.

\(^{F3}\) The mass \( M \), and the radius \( r \), of the central body are assumed to be approximately related by \( r \geq r_S = 2GM \). For a black hole, a massless photon has a metastable orbit at \( 3r_S/2 \); particles with mass have orbits out from \( 3r_S \).
2 Sufficient total energy for GRB, and natural time scales for duration and fluctuation

Consider a massive body $M$, of about $3.3 \times 10^6 m_\odot$ ( $m_\odot$ is the solar mass, $\sim 1.1 \times 10^{31}$ GeV). Assume that the body, and its immediate vicinity, contains primarily about $3 \times 10^{52}$ dark-matter particles, inflatons of mass calculated to be about $10^{11}$ GeV. \(^{F1}\) Assume that the state of the body is close to that of a Schwarzschild black hole \([4]\), that is with a boundary at a radius $r \geq r_S = 2GM \approx 10^{12}$ cm. The particular approximate size of this dimension plays an important role in the dynamics described below. Inflatons may decay into $\nu_+ + \overline{\nu}_-$, with a lifetime estimated to be about $10^{25}$ s. \(^{F2}\) As stated in the introduction, we invoke the assumption that a significant number (idealized here as most) of these energetic neutrinos are spatially confined: they circulate and accumulate in a spherical envelope, in the immediate vicinity of the boundary. We use for this dimension $r \geq 2 \times 10^{12}$ cm, and use a spread of $2\Delta r \sim 10^{12}$ cm (see the appendix) in each of the two directions perpendicular to the (instantaneous) tangent to any great circle on the encompassing spherical envelope. The total energy in all of the decay neutrinos moving in great circles at some time $t$, (which is initially measured from $t \equiv 0$, where approximately none are present), is proportional to $(t/\tau)$, and is in this example

\[
E_{\text{total}} \approx (3.3 \times 10^{52} \text{ inflatons}) \times (10^{11} \text{ GeV}) \times \left( \frac{t_\nu}{10^{25} \text{ s}} \right) \sim 10^{52} \text{ ergs} \quad (1)
\]

for $t_\nu \sim 0.17 \times 10^{17}$ s $\sim 0.038t_U$, where $t_U$ is the present age of the universe, taken as $\sim 4.5 \times 10^{17}$ s. As explained in detail in section 4, the time interval $t_\nu$ is approximately determined by the requirement that the density of the accumulating neutrinos is still below that at which self-interaction occurs with large probability (and hence, energy dissipation through created charged particles). \(^{F3}\) \(^{F4}\) If initially measured from the universe "origin", the interval $t_\nu$ corresponds to a red-shift $z \sim 8$.

Consider that a toroidal configuration of infalling matter rapidly encounters the circulating neutrinos, at $\sim t_\nu$. A possible density \(^{F5}\) of such infalling (ordinary) matter at $r \sim 10^{12}$ cm might be $\rho \sim 3 \times 10^{20}$ cm$^{-3}$ (approximated as scaled up from an estimated $\sim 3 \times 10^{11}$ cm$^{-3}$ at $\sim 10^{15}$ cm, for a modelled, self-gravitating protostar\([3]\)). The last time interval for free-fall of the matter to the central entity would probably be of the order of a few minutes, similar to the burst duration time, estimated in the paragraph below. The infall depletes most of the matter. The dynamical time interval for interaction within the envelope of circulating high-energy neutrinos, is given by ( $c$ is the speed of light )

\[
\delta t \sim \frac{t_\nu}{c} = \frac{1}{c\sigma_\nu \rho} \approx 1 \text{ s} \quad (2)
\]

We have used an extrapolated \([4]\) $\sigma_\nu \sim 10^{-31}$ cm$^2$, appropriate to such extremely high-energy neutrinos. The fact that this cross section is naturally large, relative to that for MeV neutrinos, plays a significant role in the dynamics here. The time interval in Eq. (2) provides a natural basis for considering the empirical, highly

\(^{F1}\) In the order-of-magnitude estimate in Eq. (1), gradual loss of neutrinos due to self-interaction up to $\sim t_\nu$, is not taken into account.

\(^{F2}\) We do not explicitly consider here, effects of "climbing out" of a gravitational potential from $r \sim 3r_S$, since we are dealing with order-of-magnitude estimates, for which we also use a maximum energy in decay neutrinos.

\(^{F3}\) The matter is not extremely dense, as in some "coalescence" models\([3]\), where densities of $10^{33}$ cm$^{-3}$ are considered, because dimensions of $\sim 10^8$ cm are invoked. These models often utilize neutrino-antineutrino pairs to transport energy \([5]\) to a much larger dimension ($\sim 10^{12}$ cm), where the physical processes involving energized electrons (and positrons) occur, giving rise to the observed photons.
irregular fluctuations in intensity, within given GRB. For example, a density variation within the toroidal matter, say up by a factor of $\sim 10$, can give a time interval for a marked upward fluctuation of $\sim 0.1$ s. Little density variation results in little fluctuation over the burst duration time.

We estimate the full, burst duration time. At $\rho \sim 3 \times 10^{20} \text{ cm}^{-3}$, the approximate toroidal volume of $\sim 2\pi r(2\Delta r)^2 \sim 1.26 \times 10^{37} \text{ cm}^3$, contains $\sim 3.8 \times 10^{57}$ particles (the equivalent of $\sim 4m_{\odot}$). Within $\Delta t \sim 2\Delta r/c \sim 33$ s, the matter encounters $\sim 2\pi r(2\Delta r)^2/(4\pi r^2(2\Delta r)) = \Delta r/r$ of the neutrinos. The time for encountering all neutrinos in the spherical envelope is the approximate duration time $t_{\text{dur}} \sim (2\Delta r/c)(r/\Delta r) = 2r/c \sim 130$ s. Thus, a sensible duration time arises naturally. We have illustrated this with a definite preferred numerical example (see the appendix). If one considers a smaller massive body, say with $M$ reduced by $\sim 10^{-2}$, the duration time will be of the order of 1 s. However, the total energy will be reduced, to less than $10^{50}$ ergs, because of the smaller number of accumulated high-energy neutrinos from decay of the massive dark matter.

It is useful to briefly compare the above dynamics for $\delta t$ and $t_{\text{dur}}$ to that of common models \[\text{[15].}\] In these models, $\delta t$ arises as $R_{\text{source}}/c$, where $R_{\text{source}}$ is the radius of some unknown “internal engine”, usually set at $\sim 10^8$ cm. However, the dimension at which the observed gamma rays are emitted is necessarily much larger, $\sim r^2 R_{\text{source}} \sim 10^{12}$ cm to $\sim 10^{14}$ cm, where $\gamma \sim 10^2$ to $\sim 10^5$ is an initial, extremely large Lorentz factor for the bulk (i.e. coherent) motion of a rather limited, definite number of baryons ($\sim 10^{52}$) in a “shell” of dimension $\Delta$. The duration time is $\Delta/c$, the time that the “inner engine” is active. The dynamics by which such a large bulk $\gamma$ is brought about for the shell, is unknown. The reason for a limited number of energized baryons is unknown. The kinetic energy of the shell must be “thermalized” in energetic electrons, by internal mechanisms \[\text{[17].}\], before emission of the gamma-rays. This process is not particularly efficient \[\text{[18]},\] and leads to the prediction that there must be a large fraction of the total energy in the kinetic energy of the ejecta, and hence in “afterglow” radiation. \[\text{[16].}\] As we indicate in the next section, the present ideas lead to the opposite prediction. The necessary energy in electrons is here efficiently provided by the interaction of very energetic neutrinos with infalling matter. These energetic electrons emit photons in rapid interaction with the matter, and the electrons Compton up-scatter lower energy photons (as is discussed in detail in sections 3 and 5).

3 Smaller total energy in ejecta, and in prompt X-rays from infalling matter

The $E_{\text{total}}$ in Eq. (1) involves $\sim 10^{44}$ neutrinos ($\nu$ and $\overline{\nu}$). Collisions in a torodial configuration of infalling matter, energize electrons, and nucleons. Much of the primary available energy in the neutrinos goes into electrons; these undergo many subsequent electromagnetic interactions with the matter, over a path length of the order of $10^{12}$ cm. A mean-free path of $\sim (1/\sigma_{\text{em}}\rho) \sim 10^5$ cm, allows for $\sim 10^{12}/10^5 = 10^7$ such interactions (using an approximate cross section $\sigma_{\text{em}} \sim 10^{-25}$ cm$^2$, as discussed in section 5). Thus, there are effectively $\sim 10^{44} \times 10^7 = 10^{51}$ highly energized individual electrons. Assuming a comparable number of energized nucleons, with individual Lorentz factors of up to $\gamma_p \sim 10^3$, gives a total baryonic kinetic energy of up to about $10^{51}$ ergs, which is about $10\%$ of the energy in gamma-rays (the approximate, neutrino total energy in the example in Eq. (1)). A bulk motion of all these nucleons cannot give more (even for hypothetical bulk $\gamma$-factors of up to $10^5$).
Clearly, the present dynamics obviates the situation in which a very energetic “shell”, composed of an (apriori) limited number of baryons, must transfer energy to electrons. Here, extremely energetic electrons interact with infalling matter, transferring some amount of kinetic energy to a limited number \((\sim 10^{51})\) of baryons. The limited number arises naturally from the limited number of decay neutrinos. The prediction is clearly that the total kinetic energy of the baryonic ejecta is only a small fraction of the total energy in gamma rays.

The infalling matter which encounters the circulating neutrinos involves of the order of \(4 \times 10^{57}\) particles. The release of gravitational energy as electromagnetic radiation from these infalling particles might be roughly estimated as thermal X-rays\(^{17}\), with a luminosity given by

\[
L = 4\pi r_S^2 \sigma T^4 \sim 10^{49} \text{ ergs s}^{-1}
\]  

for \(r_S \sim 10^{12}\) cm and temperature \(T \sim 10^7\) °K, corresponding to prompt X-rays of about 1 keV. (\(\sigma\) is the Stefan-Boltzmann constant.) A similar estimate for \(L\), follows from a rate of mass infall of about \((10^{-2} m_\odot)\) s\(^{-1}\), with \(\sim 0.1\) \% efficiency for conversion of mass to electromagnetic radiation. Over \(\sim 100\) s, this total energy is about \(10^{51}\) ergs; so less than the total energy in gamma rays. Some of these photons can be subsequently Compton up-scattered by the very energetic electrons produced by the interactions of the circulating neutrinos\(^{17}\) Of the order of \(10^7\) such interactions initiated by each of \(\sim 10^{51}\) highly-energized electrons, would produce of the order of \(10^{58}\) gamma rays, with the approximate burst \(E_{\text{total}}\) of \(10^{52}\) ergs (as in Eq. (1)).

### 4 Significant spread in total energies; presence of GRB at very large red-shifts; and existence of entities with approximately continuous emission of gamma rays

The accumulation of high-energy neutrinos in the immediate vicinity of a massive, dark-matter entity must be limited by the self-interaction of the neutrinos. From a time set as \(t \equiv 0\), their density from inflaton decay grows as approximately \((t/\tau)\). Therefore, a rough estimate of a possible accumulation time interval follows from

\[
t_\nu \sim \frac{1}{e\rho_\nu(t_\nu/\tau)\rho_{\text{inf}}} \rightarrow t_\nu \sim \sqrt{\frac{\tau}{e\sigma_\nu\rho_{\text{inf}}}} \cong 0.17 \times 10^{17} \text{ s} \cong 0.038 t_U
\]

where we have used an approximate inflaton number density of \(\rho_{\text{inf}} \sim 10^{14} \text{ cm}^{-3}\), and \(\sigma_\nu \sim 10^{-32} \text{ cm}^2\), with \(\tau \sim 10^{25}\) s an approximate lifetime for decay into \(\nu_\tau\). The time interval estimated in Eq. (4) has been used in Eq. (1) to estimate \(E_{\text{tot}}\).\(^{F4}\) Accumulation of neutrinos is disrupted after \(\sim t_\nu\), and the accumulated energy is “dissipated” into other particles. For a GRB to occur, around \(t_\nu\), infalling particles in a toroidal configuration of matter must “suddenly” encounter the circulating neutrinos, very near to the central entity. An initial interval of \(\sim t_\nu\) corresponds to a red-shift of \(\sim 8\). This suggests that GRB have been prolific at very early times in the universe. The distribution of \(t\) about \((t) \sim t_\nu\) is very wide: the dispersion is \(\sim 0.5(t)\). This means that the intrinsic distribution of total energies from gamma-ray bursts is wide; in particular spreading to values well

\(^{F8}\)The number of these photons can be initially comparable to the number of gamma-rays. The burst emission of X-rays and gamma rays overlap in time. X-rays can preceed and can follow the main bursts of gamma rays. A decline of prompt X-rays relative to gamma rays is expected.
below $\sim 10^{52}$ ergs. The present dynamics clearly favors the occurrence of gamma-ray bursts at early times, in local regions of dense matter, that is in regions which may exhibit elevated star-formation activity. Such a locality is not necessarily in a galactic center. At later times, as the universe thins out, GRB become much less common, in particular in the present epoch.

After a time interval $\gtrsim t_{\nu}$, the process of neutrino accumulation, and subsequent dissipation through self-interaction, can continue to occur near to the massive, dark-matter entity. If no abrupt encounter with sufficiently dense matter occurs, the system could appear as an approximately continuous emitter of gamma-rays (and X-rays), with a luminosity building up to of the order of $\mathcal{L} \sim 10^{52}$ ergs/0.17 $\times 10^{17}$ s $\sim 6 \times 10^{35}$ ergs s$^{-1}$

$$\mathcal{L} \sim 10^{52} \text{ ergs}/0.17 \times 10^{17} \text{ s} \sim 6 \times 10^{35} \text{ ergs s}^{-1} \quad (5)$$

Such entities could exist in our local environment in the present universe, where the conditions for GRB to occur have become much less probable; observable in particular, in regions of space where gas clouds occur between the entity and the Earth, allowing very high-energy electrons from the source to interact and radiate, around the line-of-sight.

Two questions arise: what is the possible contribution of dark matter in such entities to the matter density of the universe, and what flux of extremely high-energy neutrinos might arise at the Earth (in cosmic-ray, air shower experiments), from a discrete entity which is not too distant? To roughly estimate the first from the number of gamma-ray bursts, we use a GRB rate of $\sim 300$ per year over $\sim 10^{10}$ years, so $\sim 3 \times 10^{12}$ GRB. With a mass of the dark-matter entity of $\sim 3 \times 10^{6}m_{\odot}$, the contribution to the mass density out to $\sim 10^{28}$ cm (in an equivalent “diffuse” distribution) is

$$\rho_{M} \sim \frac{10^{10} \times 10^{57} \text{ GeV}}{3 \times 10^{54} \text{ cm}^{3}} \sim 0.25 \times 10^{-8} \text{ GeV cm}^{-3} \quad (6)$$

This is only $\sim 0.05\%$ of a critical density of about $0.5 \times 10^{-5}$ GeV cm$^{-3}$. It is therefore well below limits for the contribution from such massive entities, which are claimed by recent experiments involving gravitational lensing [18, 19]. Using the luminosity in Eq. (5), and assuming that of order of one-quarter of the energy is radiated in the highest-energy neutrinos of $\sim 10^{20}$ eV, results in an estimated flux from a discrete entity at a distance of $\sim 4 \times 10^{22}$ cm, of $f_{\nu}$

$$f_{\nu} \sim \frac{2 \times 10^{38} \text{ GeV s}^{-1}}{10^{41} \text{ GeV}(4\pi \times (4 \times 10^{22} \text{ cm})^{2})} \sim 10^{-19} \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \quad (7)$$

Upcoming air-shower experiments with cosmic rays will search for a flux of neutrinos at $\sim 10^{20}$ eV, in particular through the presence of showers initiated at large zenith angles.

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$^{F9}$Gamma rays result from hadronic fragments in neutrino-antineutrino interactions, and from interactions of the neutrino-produced, very high energy electrons, with matter along the line-of-sight to the source.

$^{F10}$If the emission were to occur over only a relatively short time interval, say of the order of 100 years, a luminosity of $\sim 10^{10}$ times the solar luminosity could appear from the immediate vicinity of a compact, massive entity.

$^{F11}$If there is some beaming (as in section 6), this flux is for beaming along the line-of-sight.

$^{F12}$Approximated as a “diffuse” distribution of discrete sources out to $\sim 10^{28}$ cm, $\sim 10^{12}$ entities can give a flux of the order of $10^{-18}$ cm$^{-2}$ s$^{-1}$ sr$^{-1}$ for neutrinos which are only moderately red-shifted to lower momenta (again, assuming little reduction of observable flux due to the effect of beaming).
5 Photon emission processes

It is clear that the hypothetical dynamics discussed in this paper, allows for a prolific source of extremely high-energy electrons (and positrons). Thus, Compton up-scattering of photons must be an important source of gamma rays. There are many discussions [15] which carry a strong dependence upon synchrotron radiation, under the assumption of the existence of sufficiently strong magnetic fields, in particular at early times. There exists some data on photon polarization [21], which raises the question as to its consistency with the usual assumption concerning large magnetic fields, with spatial extension. It is well known [22] that quite large magnetic fields are necessary in order to get sufficiently short characteristic times \( t_{\text{sync}} \), for synchrotron radiation. For example, for an electron of 1 GeV, a magnetic field \( B \sim 3 \times 10^4 \) Gauss is required in order to have \( t_{\text{sync}} \sim 3 \times 10^{-4} \) s (and an energy \( \hbar \omega_{\text{sync}} \sim 2 \) keV ). For \( B \sim 3 \) Gauss, \( t_{\text{sync}} \) becomes \( \sim 3 \times 10^4 \) s.

In the present dynamical situation, it also seems likely that bremsstrahlung should be an important radiation process, providing photons which subsequently may be Compton up-scattered. For an electromagnetic cross section \( \sigma_{\text{em}} \) of the order of \( 10^{-25} \) cm\(^2\), a dynamical time of the order of \((1/\sigma_{\text{em}} \rho) \sim 3 \times 10^{-6} \) s occurs in an initial matter density \( \rho \sim 10^{20} \) cm\(^{-3}\). This is a shorter time interval than \( t_{\text{sync}} \), even assuming the presence of the above large magnetic field. Out to \( \sim 10^{15} \) cm, where the matter density is probably decreased by about nine orders of magnitude, the dynamical interaction time of \( \sim 3 \times 10^3 \) s is still shorter than the transit time of \( 10^{15} \) cm/c = \( 3 \times 10^4 \) s. Therefore, independently of the role of synchrotron radiation in some time intervals of the burst evolution, and in the emission of radiation at later times (in particular, radio waves), bremsstrahlung and Compton up-scattering should be important processes at early times.

6 Natural possibility for dynamical beaming of matter and energy

The dynamics involves the interaction of a toroidal configuration of infalling matter, with high-energy neutrinos that are traversing great circles on a spherical envelope which encompasses the immediate vicinity of a compact, massive entity. This situation provides dynamical and geometrical conditions in which a moderate degree of beaming of matter and radiation could take place in some gamma-ray bursts. If the axis of the torus is close to the line-of-sight, a maximal observed flux is possible; otherwise the observed flux is reduced. This is a “geometrical” effect which, in itself, gives rise to a broad distribution in observed total energies of gamma-ray bursts, in addition to the intrinsic broadness which we discussed in section 4. The possibility for beaming goes away as the “covering” angle of the semi-torus on the sphere increases (toward \( \pi \), i. e. no toroidal configuration). On the other hand, if the efficiency for reaching maximum luminosity is not to be reduced, the angle should not be less than of the order of \( \Delta r/r \sim 1/4 \). This suggests the possibility of a moderate degree of beaming characterized by an angle \( \theta \sim 1/4 \); thus a possible reduction to an “intrinsic” total energy by a factor of \((\theta^2/2) \sim 1/32\), from that deduced when isotropic emission is assumed. In contrast to the “standard” model [15, 16], we have not invoked the standard assumption that “relativistic beaming” of bulk matter involves effective, initial \( \gamma \)-factors of 100 to 1000. Rather, the possibility is present that such relativistic factors for approximate bulk motion may acquire only moderate, more probable values [1], say up to \( \sim 5 \), in the initial burst time interval. Then, \( \theta > \gamma^{-1} \) is not necessarily always satisfied. This is the usual condition for the possibility of marked observable effects [2], as the bulk matter slows down at later times, and \((\gamma(t))^{-1} \) changes from less than \( \theta \) to greater than
\( \theta \). If an effective \( \gamma^{-1} \) is greater than \( \theta \), then the beaming occurs within the observable angular interval around the line-of-sight (i.e. the relativistic beaming from approximate bulk motion, into \( \sim \gamma^{-1} \)), already in the initial time interval.

7 Aspects of the hypothesis of less massive, and more massive, dark-matter entities

There are observations \([12]\) that concern less massive entities, of the order of \(10m_\odot\), which are hypothetically near to the condition of a black hole. In particular, observations of binary systems involving such an entity and a low-mass companion star, referred to as low-mass, X-ray transients (LMXT). \([12]\) These systems sporadically burst into X-rays, and sometimes repeat, after relatively long time intervals of quiescence i.e. periods of approximately steady, but low luminosity. Models \([12]\) for LMXT often involve a (repeatable) instability in an “outer, cold” accretion disk, which results in an elevated rate of inflow of matter for a relatively short time, toward the compact, massive entity. An essential dynamical aspect \([12, 24]\), is the hypothetical existence, during the long periods of quiescence, of a spherical, inner configuration between the accretion disk and the central entity. This region is supposed to consist of a highly energetic, but dilute, plasma (it can contain a “hot corona” near the boundary to the outer disk). This inner configuration, which envelopes the central entity, is a poor radiator \([12, 24]\). The result is a low luminosity of radiation emitted by any rapidly infalling matter, during times other than the burst intervals. An open question \([12]\) concerns what energy source gives rise to this spherical, inner configuration. In particular, after a burst, what is the dynamical mechanism through which the physical condition of the inner region suitable for a subsequent burst, is set up? A certain possible similarity to the GRB model that we have discussed in this paper, lies in the “sudden” elevated infall of dense matter through a “dilute” spherical envelope of energetic particles, which encompasses the compact, massive entity. However, the energy for the X-ray outburst comes largely from the release of gravitational energy by the elevated amount of infalling matter, over the burst time. Our main point here, is that again assuming the presence of high-energy neutrinos in the immediate vicinity of this entity, then a minimum, nearly steady luminosity can occur during long quiescent time intervals; we estimate this. The number of inflatons of calculated \([6]\) mass \(\sim 10^{11} \text{ GeV} \), to approximately account for an entity of \(\sim 10m_\odot \) is \(\sim 10^{47} \). A comparable number probably exists in the immediate vicinity of the surface, perhaps with significant rotational motion. Inflatons may decay into neutrino-antineutrino pairs, with an estimated lifetime \([6, 7]\) of \(\sim 10^{25} \text{ s} \). The high-energy neutrinos can interact with matter at the inner edge of the outer disk, energizing electrons and producing an approximately steady luminosity of the order of

\[
\mathcal{L}_{\text{quiescent}} \sim 10^{47} \times 10^{11} \text{ GeV} / 10^{25} \text{ s} \equiv 1.6 \times 10^{30} \text{ ergs s}^{-1}
\]

This minimum luminosity may often be exceeded by that radiated (with anomalously low efficiency \([24, 12]\)) by the matter, during the short time of infall. In any case, the level of luminosity during quiescence is far below that which occurs during the X-ray outburst (\(\sim 10^{38} \text{ ergs s}^{-1} \)). \([12]\) We estimate that the minimum, steady luminosity in Eq. (8) is sufficient to “clear” an (elevated) density of ordinary matter of \(\sim 10^{19} \text{ cm}^{-3} \), from a region in the immediate vicinity of the massive entity, over a time interval of months. This time interval is comparable to observed effective burst times for LMXT (presumably related to the duration of the instability-induced, elevated mass-flow from the outer disk). \[23\]

\[23\] In an intermediate mass range between LMXT and GRB, say \(3 \times 10^3 m_\odot \), there might be a large number of compact, dark-matter entities. The dark matter in the universe might then be
It is worth noting that a well-known, active galactic nucleus (AGN) in the nearby, radio galaxy M87, may contain a very large central mass, estimated as $\sim 3 \times 10^9 m_\odot$. This system has a luminosity of only $\sim 10^{43}$ ergs s$^{-1}$, and exhibits some collimated ejection perpendicular to a disk structure, and at a sizable angle to the line-of-sight. The last time interval for infall of matter ($\sim 3 \times 10^4$ s from $\sim 10^{15}$ cm) is comparable to a radiation time ($\sim (1/c \sigma_{\text{em}} \rho) \sim 3 \times 10^4$ s for $\rho \sim 10^{10}$ cm$^{-3}$). This system is thus a very massive candidate for forming an ADAF-type of “hot, dilute” inner configuration which envelops the central mass. Within the framework of the present ideas, this region could contain a steady luminosity of very high-energy neutrinos, which can energize the infalling electrons. This naturally allows for the possibility of collimated ejection of some energy in approximately “bulk” matter; the electrons radiate from the jet. Such entities may well be nearby, as is M87.

Very energetic quasars, such as 3C273 at $z \sim 0.16$, are present at distances from the Earth which are not the greatest. Some quasars are not clearly in the center of a galaxy. Allowing for masses of the dark-matter entity of up to $\sim 10^{11} m_\odot$, results in a total energy release from the luminosity of high-energy neutrinos from decay of dark matter, of less than $10^{58}$ ergs, over about $10^6$ years. Such an energy source would be secondary to a possible total of $10^{60}$ ergs (for 3C273), presumably originating in gravitational energy which is released as radiation from infalling matter in the vicinity of the massive entity. However, the secondary energy has the natural possibility of jetting (which is marked in 3C273, where the ratio of radio wave to X-ray luminosity is about $10^{-2}$). The time for onset of quasar activity, and its presumed limited duration, is generally related to the occurrence of a sufficient rate of infalling matter; and thus to galactic collisions, and/or to epochs of elevated star formation. However, in the present model, the very massive central entity formed of massive, dark-matter particles may well have been present at an earlier time in the universe, after inflation.

8 Summary

The usual dynamics in the space near to compact massive bodies which are close to the condition of a black hole, involves the accretion of matter from nearby bodies, or generally, from a sufficiently dense surrounding medium. In this paper, we have considered the presence, and the possible accumulation in rotation, of very energetic neutrinos (and antineutrinos), which arise from the very slow decay of massive, dark-matter particles that are assumed to be present in a massive, central body, and in its immediate vicinity. In an appendix, we argue heuristically for the assumed possibility, but we are uncertain as to whether it can be realized. It is our purpose here, to raise the possibility. We have shown that a large number of interesting consequences follow. These are relevant for ongoing observations, in particular for gamma-ray bursts. Thus, further investigation of the possibility more discretely compounded, than is usually assumed to be the case. Gravitational lensing might eventually be able to reveal entities in this mass range.

It is interesting that a recent paper has speculated about an “extra” energy source for the solar corona. The origin of the energy is hypothesized to be neutral, scalar particles as light as 10 eV. These can be produced deep inside the sun itself, and some are assumed to be gravitationally retained and accumulated in orbits in the Sun’s vicinity, with no dissipation. These particles are supposed to decay into two photons (at X-ray energies), with a very long lifetime. However, it is difficult to gravitationally constrain light particles, since the escape velocity from the Sun is relatively low. Note that a flux of extremely high-energy neutrinos (as in Eq. (7)) can give rise to an external-energy “irradiation”, acting upon the whole Sun, of the order of $10^{13}$ ergs s$^{-1}$, more than that from any hypothetically localized, decaying inflaton matter.
would seem to be useful.

Appendix

Neutrinos have mass $[8, 9]$. The largest mass, probably that of $\nu_\tau$, may be about 0.06 eV. The smallest mass, presumably that of $\nu_e$, may not be less than a factor of 0.1 smaller. Large flavor mixing can occur, over sufficiently long flight paths (which lengthen with increasing neutrino energy). There may occur (meta)stable orbits $[10]$ for neutrinos with large angular momenta, out from about $3/2 \times 10^{12}$ cm around a compact, massive entity, $M \sim 3 \times 10^6 m_\odot$, which is near to a black-hole condition ($r_S \sim 10^{12}$ cm). It might be possible for these to accumulate over long periods of time, in an envelope over the sphere. A heuristic argument is as follows. Consider as measure of the “degree of stability” at some $r$, the quantity

$$\Delta r \sim \frac{1}{m_\nu r} \times (ct_U) \quad (A1)$$

Consider for stability that $\Delta r$ in either of the two directions perpendicular to an instantaneous tangent to any great circle is limited to be $< r/2$. Then, the order of magnitude of (a minimum) $r$ is determined by

$$r \sim \left\{ \frac{2ct_U}{m_\nu} \right\}^{1/2} \sim \left\{ \frac{2.7 \times 10^{28} \text{ cm}}{\left(3.3 \times 10^{-4} \text{ cm}\right)^{-1}} \right\}^{1/2} \sim 3 \times 10^{12} \text{ cm} \quad (A2)$$

for $m_\nu \sim 0.06 \text{ eV}$, $t_U \sim 4.5 \times 10^{17} \text{ s}$. As estimated in Eq. (4), $t_U$ in Eq. (A2) should be replaced by $t_\nu \sim 0.038t_U$. Then, taking a smallest $m_\nu$ as $\sim 0.006 \text{ eV}$, results in $r \sim 2 \times 10^{12} \text{ cm}$. This is close to the dimensions of (meta)stable orbits about an entity of mass $M \sim 3 \times 10^6 m_\odot$, which is near to the condition of a black hole, i.e. with a boundary at $r > 10^{12} \text{ cm}$, as used in section 2.

Clearly, for more massive entities in active galactic nuclei and quasars, with $r$ of the order of $10^{15} \text{ cm}$ to $3 \times 10^{16} \text{ cm}$, the $\Delta r$ from Eq. (A1) is $\ll 1$. The stability argument fails for the small values of $r$ relevant to the discussion of LMXT in section 7. However, in this situation accumulation of neutrinos is not required. The inner ADAF is “confined” by the outer disk; that is, the luminosity from the high-energy neutrinos tends to persistently “evaporate” matter at the inner edge of the “cold” disk, resulting in a corona of very energetic electrons.

The result in Eq. (A2) may imply a particular cosmological connection for neutrino mass. It is noteworthy that the inverse of neutrino masses of the order of $0.06 \text{ eV}$ to $0.006 \text{ eV}$, give times of the order of $10^{-14} \text{ s}$ to $10^{-13} \text{ s}$. These times are just prior to the approximate time for the breaking of electroweak symmetry in the early universe, at $10^{-12} \text{ s}$ (energy scale $\sim 1 \text{ TeV}$). Thus, neutrino mass is, in a sense, a minimal mass “uncertainty” related to this early time interval. (This suggests that neutrino mass might originate in vacuum energy $[28]$ other than the vacuum-expectation value of a Higgs field.)

References

$[15]$ The new dynamical idea discussed here is speculative. In the absence of reasons for extraordinary behavior, so are common ideas which postulate the bulk motion of $\sim 10^{-5} m_\odot$ with $\gamma$-factors of up $[15]$ to 1000, and/or the coherent rotation of a massive body $[4]$, at nearly the speed of light, in the presence of enormous magnetic fields. An essential element in the present ideas can be directly tested in upcoming experiments, which will be capable of detecting a significant flux of neutrinos in the highest-energy cosmic rays $[20, 7]$.

$[16]$ The factor $(1/m_\nu r)$ is a maximal dimensionless parameter, which arises from differentiations of the effective potential given in the caption to Fig. 19 on p. 67 of Ref. 10.
[1] B. Paczyński, in *Relativistic Astrophysics and Particle Cosmology*, Eds: C. W. Akerlof and M. A. Srednicki, 1993, Ann. N. Y. Acad. Sci., vol. 688, p 321
B. Paczyński, Astrophys. J. Lett. 484 (1998), L45
V. S. Berezinsky and O. F. Prilutsky, *Proc. 19th Int. Cosmic Ray Conf.*, La Jolla, USA, 1985; Astron. Astrophys. 175 (1987) 309

[2] S. E. Woosley, Astrophys. J. 405 (1993) 273
R. Popham, S. E. Woosley, and C. Fryer, astro-ph/9807028v2

[3] B. Paczyński, Astrophys. J. Lett. 308 (1986) L51
D. Eichler, M. Livis, T. Piran, and D. M. Schramm, Nature 340 (1989) 126
S. I. Blinnikov et al., Pis’ma Astron. Zh. 10 (1984) 422 (Sov. Astron. Lett. 10 (1984) 177)

[4] B. Paczyński, astro-ph/9909048

[5] J. E. Rhoads, astro-ph/9903400, astro-ph/9903399

[6] S. Barshay and G. Kreyerhoff, Eur. Phys. J. C5, 369 (1998)

[7] S. Barshay and G. Kreyerhoff, Nuovo Cimento 112A, 1469 (1999); 112A, 1463 (1999)

[8] The SNO Collab., Q. R. Ahmad et al., nucl-ex/0106015

[9] Super Kamiokande Collab., S. Fukuda et al., Phys. Rev. Lett. 86 (2001) 5656

[10] M. Rees, R. Ruffini, and J. A. Wheeler, *Black Holes, Gravitational Waves and Cosmology*, 1974 Gordon and Breach Science Publishers, Inc., One Park Avenue, New York, N. Y. 10016, chapter 5

[11] P. J. E. Peebles, *Principles of Physical Cosmology*, 1993 Princeton University Press, 41 William Street, Princeton, NJ 08540, p. 611

[12] *Theory of Black Hole Accretion Disks*, Edited by M. A. Abromowicz, G. Bjornsson, and J. E. Pringle, 1998, Cambridge University Press
for LMXT observations: P. Charles, p. 1
for LMXT models and advection-dominated accretion flow (ADAF): R. Narayan, R. Mahadevan, and E. Quataert, p. 148
J.-P. Lasota, p. 183
for observations on AGN: G. M. Madejski, p. 21

[13] F. Hoyle, *Astronomy and Cosmology*, 1975 W. H. Freeman and Co., U.S.A., p. 286

[14] R. Gandhi, C. Quigg, M. H. Reno, and I. Sarcevic, hep-ph/9807264

[15] T. Piran, Phys. Rep. 314 (1999) 575

[16] T. Piran, astro-ph/9807253
T. Piran, astro-ph/9907392 (in particular, observe the second paragraph on p. 22, where it is noted that the data do not support a large amount of energy in “afterglow” radiation.)

[17] S. L. Shapiro and S. A. Teukolsky, *Black Holes, White Dwarfs, and Neutron Stars*, 1983, John Wiley and Sons, Inc. U. S. A., p. 395

[18] R. J. Nemiroff et al., Phys. Rev. Lett. 86 (2001) 580
[19] P. N. Wilkinson et al., Phys. Rev. Lett. 86 (2001) 584
[20] M. Nagano and A. A. Watson, Rev. Mod. Phys. 72 (2000) 689
[21] J. Hjorth et al., Science 283 (1999) 2073
[22] M. Harwitt, Astrophysical Concepts, Second Edition 1988, Springer-Verlag New York Inc., p. 245
[23] R. Sari, T. Piran, and J. P. Halpern, astro-ph/9903339
[24] J.-P. Lasota, Scientific American, May 1999, 31
[25] M. Fukugita and E. L. Turner, astro/ph 9506129 and references therein
M. Disney, Scientific American, June 1998, 36
[26] L. Di Lella and K. Zioutas, Phys. Lett. B531 (2002) 175
[27] S. Barshay, H. Faissner, R. Rodenberg, and H. de Witt, Phys. Rev. Lett. 46 (1981) 1361
[28] S. Barshay and G. Kreyerhoff, Astropart. Phys. 10 (1999) 107