ABSTRACT

I argue that cosmic Gamma-ray Bursts (GRB) may be produced by collapses or mergers of stars made of ‘mirror’ matter. The mirror neutrinos (which are sterile for our matter) produced at these events can oscillate into ordinary neutrinos. The annihilations or decays of the latter create an electron-positron plasma and subsequent relativistic fireball with a very low baryon load needed for GRBs. The concept of mirror matter is able to explain several key problems of modern astrophysics: neutrino anomalies, the missing mass, MACHO microlensing events and GRBs. Thus this concept becomes very appealing and should be considered quite seriously and attentively.

Subject headings:  Gamma-rays: bursts — dark matter — stars: mirror — neutrino oscillations

1. Introduction

The spectacular discovery of GRB afterglows allowed to measure the redshift, and hence the distance to some of them. The energy output up to \(3.4 \times 10^{54}\) ergs \(\approx 1.9 M_\odot c^2\), for GRB990123 (Kulkarni et al. 1999) poses extremely hard questions to theorists who try to explain these superpowerful events. Even if a beaming is invoked, it can reduce the energy budget by two orders of magnitude, perhaps, but this is still too high for conventional models.

The extraordinary situation requires a revolutionary approach to the modeling of GRBs. In this Lecture I suggest a scenario which seems to be a bizarre one from the first glance, but in fact it has a reasonable theoretical basis, and observational evidence in favour of this scenario is ever growing: I believe, that observing GRBs at cosmological distances we are witnessing catastrophic deaths of stars made of the so called “mirror” matter.
2. Problems in GRB modeling

For general recent reviews on GRBs see e.g. Piran (1998a,b), Tavani (1998) and Postnov (1999).

It is well known, that assuming high values of Lorentz factor $\Gamma$ of the GRB ejecta is necessary to solve the compactness problem (Guilbert, Fabian & Rees 1983, Paczyński 1986, Goodman 1986, Krolik & Pier 1991, Rees & Mészáros 1992, Piran 1996). The typical time-scale of the variability of the gamma-ray emission $\Delta t \sim 10^{-2}$ seconds implies the size of the emitting region $R < c\Delta t$, as small as $\sim 10^3$ km. The enormous number of gamma photons in such a small volume should produce electron-positron pairs which make the emitting region optically thick. This conflicts with the observed nonthermal spectra unless one supposes that the emitting region moves towards the observer at a relativistic speed with Lorentz factor $\Gamma$, then its size would be $\Gamma^2 c\Delta t$, and the optical depth correspondingly smaller. The low optical depth and the ultrarelativistic motion requires that the fireball should be very clean (not heavily contaminated with baryons), yet the models suggested up to now are producing ‘dirty’ fireballs.

E.g., the possibility of a GRB to appear during a bare core collapse in a binary system was suggested by Dar et al. (1992). The latter model assumed a GRB to be a result of the neutrino-antineutrino pair creation and annihilation (Goodman et al. 1987) during the accretion-induced collapse of a white dwarf in a close binary system. Although the idea of neutrino annihilation is very compelling for producing GRBs, the model should be rejected on the grounds of being too contaminated by baryonic load, see e.g. Woosley (1993).

Another plausible way of forming GRBs at cosmological distances involves binary neutron star merging (originally proposed by Blinnikov et al. 1984; see more recent references and statistical arguments in favour of this model in Lipunov et al. 1995). However, as detailed hydrodynamical calculations currently demonstrate, this mechanism also fails in producing powerful clean fireballs (Janka and Ruffert 1996, Ruffert et al. 1997). On the GRB models with a moderately high baryon load see Woosley (1993), Ruffert & Janka (1998), Kluzniak & Ruderman (1998), Fuller & Shi (1998), Fryer & Woosley (1998), Popham, Woosley, & Fryer (1998). Vietri & Stella (1998) and Spruit (1999) suggest models that probably have a small contamination, but it is unlikely to derive from them the huge energy required by the most recent GRB observations.

A very interesting idea was put forward by Kluzniak (1998). He suggested that the ordinary neutrinos can oscillate into sterile ones, go out to the regions relatively free of baryons, and then convert back into ordinary neutrinos. For this model the difficulty is the same: if the oscillation length is too short than the baryon contamination is unavoidable. If it is too long then a very small number of neutrinos will annihilate.

Here I point out to the possibility of dramatically extending the latter model. The sterile neutrino are naturally produced by the mirror matter during collapses or mergers of mirror stars, made of mirror baryons. If they oscillate to ordinary neutrinos they do this in the space practically
free of ordinary baryons and can give birth to a powerful gamma-ray burst.

### 3. The concept of mirror matter

The concept of the mirror particles stems from the idea of Lee & Yang (1956) who suggested the existence of new particles with the reversed sign of the mirror asymmetry observed in our world. Lee and Yang believed that the new particles (whose masses are degenerate with the masses of ordinary particles) could participate in the ordinary interactions. Later, Kobzarev, Okun & Pomeranchuk (1966) have shown that this conjecture was not correct, and that the ordinary strong, weak and electromagnetic interactions are forbidden for the mirror particles by experimental evidence, only gravity and super-weak interaction is allowed for their coupling to the ordinary matter. But if they really mirror the properties of ordinary particles, this means that there must exist mirror photons, gluons etc., coupling the mirror fermions to each other, like in our world. Thus the possibility of existence of the mirror world was postulated first by Kobzarev, Okun & Pomeranchuk (1966), and the term “mirror” was coined in that paper. The particle mass pattern and particle interactions in the mirror world are quite analogous to that in our world, but the two worlds interact with each other essentially through gravity only.

Later the idea was developed in a number of papers, e.g. Okun (1980), Blinnikov & Khlopov (1983), and the interest to it is revived recently in attempts to explain all puzzles of neutrino observations Foot & Volkas (1995), Berezhiani & Mohapatra (1995), Berezhiani et al. (1996), Berezhiani (1996). It is shown in the cited papers that a world of mirror particles can coexist with our, visible, world, and some effects that should be observed are discussed.

It was shown by Blinnikov & Khlopov (1983) that ordinary and mirror matter are most likely well mixed on the scale of galaxies, but not in stars, because of different thermal or gasdynamic processes like SN shock waves which induce star formation. It was predicted that star counts by HST must reveal the deficit of local luminous matter if the mirror stars do really exist in numbers comparable to ordinary stars and contribute to the gravitational potential of galactic disk. Recent HST results Gould et al. (1997) show the reality of the luminous matter deficit: e.g., instead of 500 stars expected from the Salpeter mass function in the HST fields investigated for the range of absolute visual magnitudes $14.5 < M_V < 18.5$ only 25 are actually detected. It is found that the Salpeter slope does not continue down to the hydrogen-burning limit but has a maximum near $M \sim 0.6 M_\odot$, so lower mass stars do not contribute much to the total luminous mass as was thought previously. The total column density of the galactic disk, $\Sigma \approx 40 M_\odot pc^{-2}$ is a factor of two lower than published estimates of the dynamical mass of the disk Gould et al. (1997). It should be remembered that here we discuss a contribution of invisible stars to the gravity of the galactic disk which has more to do with the local Oort limit (see e.g. Oort 1958) than with the halo dark matter. Other references on the subject see also in Mohapatra & Teplitz (1999).

Okun (1980), Blinnikov & Khlopov (1983), Berezhiani (1996) have pointed out that mirror
objects can be observed by the effect of gravitational lensing. After the discovery MACHO microlensing events, I have discussed their interpretation as mirror stars at Atami meeting in 1996 (Blinnikov 1998). Recently, this interpretation is developed by Foot (1999) and Mohapatra & Teplitz (1999).

The mirror world that interacts with ordinary matter exclusively via gravity follows quite naturally from some models in superstring theory (closed strings), but those models are too poor to be useful in our problem. Especially interesting for explaining GRBs are the models that predict the existence of a light sterile neutrino that can oscillate into ordinary neutrino. The development of the idea can be traced from the following references.

Foot et al. (1991), showed that the mirror symmetry is compatible with the standard model of particle physics. Here it was assumed that the neutrinos are massless, and it was shown that there are only two possible ways in addition to gravity, that the mirror particles can interact with the ordinary ones, i.e. through photon-mirror photon mixing [this had already been discussed independently and earlier (in in a slightly different context) by Glashow (1985)] and through Higgs-mirror Higgs mixing.

In the next paper Foot et al. (1992) have shown that if neutrinos have mass then the mirror idea can be tested by experiments searching for neutrino oscillations and can explain the solar neutrino problem. The same idea can also explain the atmospheric neutrino anomaly (recently confirmed by SuperKamiokande data), which suggests that the muon neutrino is maximally mixed with another species. Parity symmetry suggests that each of the three known neutrinos is maximally mixed with its mirror partner (if neutrinos have mass). This was pointed out by Foot (1994). Finally, the idea is also compatible with the LSND experiment which suggests that the muon and electron neutrinos oscillate with small angles with each other, see Foot & Volkas (1995). Berezhiani & Mohapatra (1995) extended the latter work to a bit different model with parity symmetry spontaneously broken. In this model the mirror particles have masses on all scales differing by a common factor from the masses of their ordinary counterparts.

4. The GRB model

Now I am ready to formulate very briefly the scenario of my model.

If the properties of mirror matter are very similar to the properties of particles of the visible world, then the events like neutron star mergers, failed supernovae (with a collapse to a rotating black hole) etc. must occur in the mirror world. These events can easily produce sterile (for us) neutrino bursts with energies up to $10^{54}$ ergs, and the duration and beaming of mirror neutrinos are organized naturally like in the standard references given above. The neutrino oscillations then take place which transform them at least partly to ordinary neutrinos, but without the presence of big amounts of visible baryons. Some number of ordinary baryons is needed, like $10^{-5} M_\odot$ (Piran 1998b) for producing standard afterglows etc. This number is easily accreted by mirror stars.
during their life from the uniform ordinary interstellar matter (cf. Blinnikov and Khlopov 1983). The oscillation length required in this scenario must be less than the size of the system (10 – 100 km) multiplied by the number of scatterings of the mirror neutrinos in the body of mirror neutron star, $\sim 10^5$.

A variety of properties of GRBs can be explained as suggested by Kluźniak & Ruderman (1998) for ordinary matter.

Taking into account magnetic moment of standard neutrinos can help in producing a larger variety of GRB variability due to neutrino interaction with the turbulent magnetic field inevitably generated in the fireball. This is good for temporal features similar to the observed fractal or scale-invariant properties found in gamma-ray light curves of GRB (Shakura et al. 1994; Stern and Svensson 1996). Another extension of the model is possible if heavier neutrinos can decay into lighter ones producing photons directly (see e.g. Jaffe & Turner 1997).

5. Conclusion: arguments in favour of mirror matter models

Summarizing, here are the arguments in favour of the propose scenario.

1. The mirror matter is aesthetically appealing, because it restores the parity symmetry of the world (at least partly).
2. It allows to explain neutrino anomalies.
3. It explains the missing mass in the Galaxy disk, and in some models the Dark matter in general.
4. It explains MACHO microlensing events
5. For GRBs it provides the model with the low baryon load
6. The available baryon load on the scale of the mass of a small planet is exactly what is needed for fireball models.
7. All host galaxies for OT of GRBs are strange ones. This may be an indication for the gravitational interaction of the ordinary galaxy with the mirror one in which it can be immersed.

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