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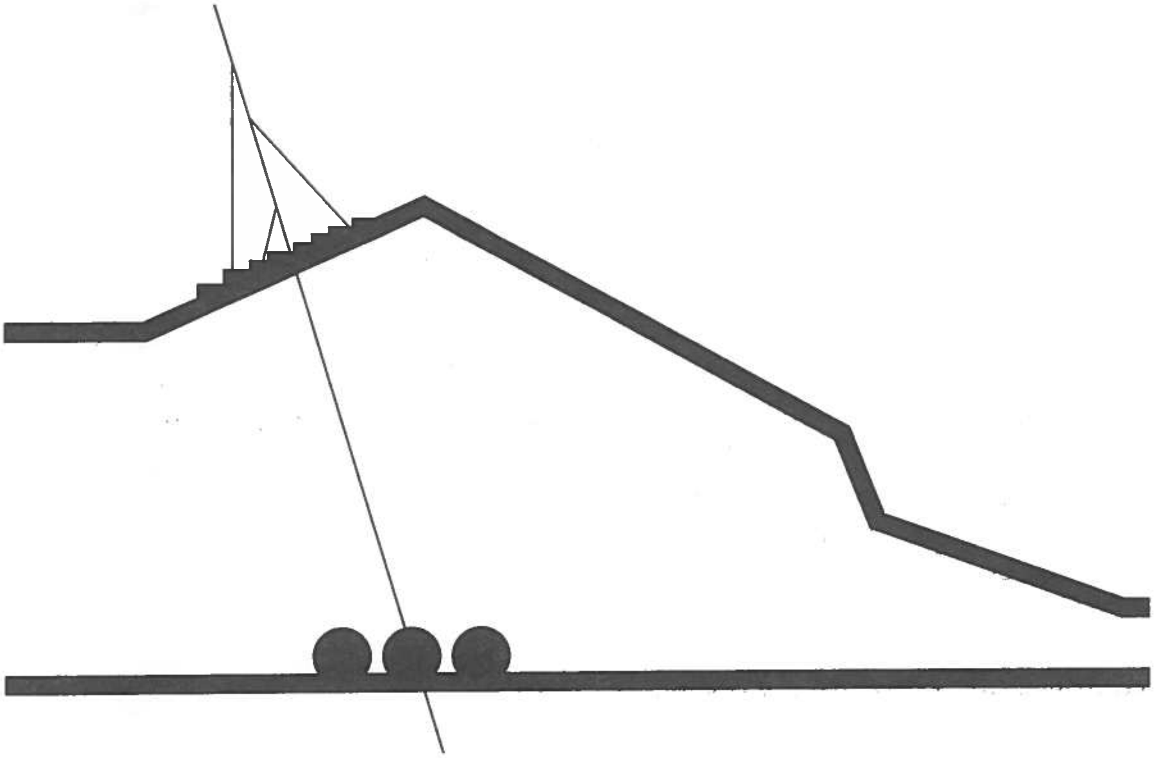

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Presupernova γ-Burst and Some Consequences of $\tilde{\nu}_e p$-Reaction

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Abstract

The production of γ-burst by absorption of neutrino emission of a collapsing star in its envelope consisting of either hydrogen or carbon; the possible detection of soundless collapse using neutrino and γ-ray telescopes, the possible explosion of the hydrogen containing objects near the collapsing stars, and other consequences of $\tilde{\nu}_e$-interaction with the protons in the star are discussed.

1 Introduction

As we know [1, 2] collapse of massive stars is accompanied by a powerful short neutrino burst. Neutrinos of all types ($\nu_{e,\mu,\tau}$ and $\tilde{\nu}_{e,\mu,\tau}$) carry off most of the gravitational binding energy of a collapsing star $10^{53} \div 10^{54}$ erg over a time of $10 \div 20$ s [3]. This energy is divided between six types of neutrino. The energy spectra of neutrinos are close to Fermi-Dirac spectra [3]–[8]. The average ν_e and $\tilde{\nu}_e$ energies are 10 and 12.6 MeV, respectively, and the average $\nu_{\mu,\tau}$ and $\tilde{\nu}_{\mu,\tau}$ energy is 25 MeV [4]–[7].

Passing through the surface layer of the collapsing star, neutrinos produce the γ-ray emission pulse (γ-burst). If the shell of the star mainly consists of hydrogen then, the $\tilde{\nu}_e p$ interactions result in γ-ray emission:

$$\bar{\nu}_e + p \to n + e^+; \tag{1}$$

$$e^+ + e^- = 2\gamma(0.511\ \text{MeV}); \tag{2}$$

$$n + p \to d + \gamma(2.23\ \text{MeV}). \tag{3}$$

Other reactions of the hydrogen cycle could be important only for hot and high density envelopes. For the first time the estimation of the γ-ray burst of a collapsing star with a hydrogen envelope was made in [9]. However stars during their evolution can lose their hydrogen envelope. If in this case the shell of the star consists of carbon then, the γ-ray burst can be caused by the neutral current excitation of the 15.11 Mev 1^+1 state in ^{12}C [10, 11]:

$$\begin{array}{l} \nu + {}^{12}C \to {}^{12}C* \\ \nu + {}^{12}C \to {}^{12}C* + \nu \end{array} \tag{4}$$

where: $\nu = \nu_{e,\mu,\tau}, \tilde{\nu}_{e,\mu,\tau}$.

$$^{12}C^* \to ^{12}C + \gamma(15.1\ \text{MeV})(96\%); \tag{5}$$

$$^{12}C^* \to ^{12}C + \gamma(4.4\ \text{MeV}) + \gamma(10.7\ \text{MeV})(4\%). \tag{6}$$

Because of the soft spectra of ν_e and $\tilde{\nu}_e$, the number of their interactions amounts to less than 5% of the total number of $^{12}C(\nu,\nu)^{12}C^*$ reactions. Practically all events of type (4) are due to the muon and tau neutrinos [12]. The intensity of the γ-burst and their duration will be discussed later on. It is also interesting to estimate the effects accompanying a neutrino transport through the star in the case of tight binary systems, and through the hydrogen contained planets, situated near collapsing stars.

2 Presupernova γ-burst or γ-burst from collapsing star

It is clear the visible γ-ray flux can be produced only in the very thin outer layer of the collapsing star envelope (shell). The total energy of the γ-burst is estimated by analogy to the calculation of the effect produced by neutrinos in the scintillation detectors taking into account the spherical geometry of the star and the photon mass energy-absorbtion coefficient, λ^{-1}. According to [4] the energy spectrum of neutrino is assumed to be:

$$\phi(E_\nu) = \frac{C\epsilon^2}{1+exp(\epsilon)} exp(-\alpha\epsilon^2), \tag{7}$$

where $\epsilon = E_\nu/kT$; kT (in MeV) is the effective temperature of the neutrinosphere of the newly formed neutrino star, having the values kT = 3.5, 4.5, and $6 \div 8$ MeV for ν_e, $\tilde{\nu}_e$ and $\nu_{\mu,\tau}$, $\tilde{\nu}_{\mu,\tau}$, respectively. The factor $exp(-\alpha\epsilon^2)$ reflects the partial nontrasmition of the layers of the star above the neutrinosphere. We have α = 0.001, 0.002, and 0 for $\nu_e, \tilde{\nu}_e$ and $\nu_{\mu,\tau}$ and $\tilde{\nu}_{\mu,\tau}$,respectively. The constant C is determined by the energy of the neutrino flux. For the estimations this energy is assumed to be 10^{53} erg. The total duration of the neutrino burst is about 20 s, but a half of the energy is carried off during $1 \div 2$ s [3, 13]. The total energy of the γ-burst produced by the neutrinos due to the νA interaction can be estimated as following:

$$E_\gamma^{tot} = C\Sigma_{\nu_i}\bar{\sigma}_{\nu_i A}\frac{N_0}{A}X_A\Sigma_{E_{\gamma_i}}\lambda(E_\gamma)n_\gamma\frac{E_{\gamma_i}}{\bar{E}_{\nu_i}}, \tag{8}$$

where

$$\bar{\sigma}_{\nu_i A} = \frac{1}{C}\int \sigma_{\nu_i A}(E_\nu)\phi(E_\nu)dE_\nu,$$

N_0 is Avogadro number, X_A is the concentration of hydrogen ($A = 1$) or carbon ($A = 12$) by weight, $\nu_i = \tilde{\nu}_e$ in the case of hydrogen and $\nu_i = \nu_\mu, \nu_\tau, \tilde{\nu}_\mu, \tilde{\nu}_\tau$ in the case of carbon. $\lambda(E_\gamma)$ is in proportional to $2/(1+X_H)$. $n_\gamma = 2$ for $E_\gamma = 0.511$ MeV and $n_\gamma = 1$ for $E_\gamma = 2.23$ MeV, and for $E_\gamma = 15.1$ MeV. $\lambda^H(E_\gamma = 0.511 \text{ MeV}) = 0.75\lambda^H(E_\gamma = 2.23 \text{ MeV})$ for hydrogen shell. For carbon shell $\lambda^C(E_\gamma = 15.1 \text{ MeV}) = 5\lambda^H(E_\gamma = 0.511 \text{ MeV})$. $\bar{\sigma}_{\tilde{\nu}_e p} = 1.1 \cdot 10^{-41}$ cm; $\bar{\sigma}_{\nu_\mu {}^{12}C} = (1.18 - 2.94) \cdot 10^{-42}$ cm^2, for kT = 6 and 8 MeV, respectively [10]. So:

$$E_{\gamma,H}^{tot} \approx 2.6 \cdot 10^{36} \text{ erg}; \tag{9}$$

$$F_{\gamma,H}^{tot} \approx 1.7 \cdot 10^{42} \text{ quanta}. \tag{10}$$

These values are very close to those obtained in [9], being a third of the energy connects with a positron annihilation.

$$E_{\gamma,C}^{tot} \approx 1.1 - 2.7 \cdot 10^{36} \text{ erg}; \tag{11}$$

$$F_{\gamma,C}^{tot} \approx 10^{41} \text{ quanta}. \tag{12}$$

We can see that $E_{\gamma,{}^{12}C}^{tot}$ is more or less equal to $E_{\gamma,H}^{tot}$ because of the three factors:

1. The cross section of $\bar{\sigma}_{\tilde{\nu}_e p}$ is close to the sum of the cross sections of the neutral current excitation of ^{12}C by muon and tau neutrinos and antineutrinos.

2. The attenuation length λ^C for $E_\gamma^C = 15$ MeV is much higher than λ^H for $E_\gamma^H = 0.511$; 2.23 MeV.

3. The ratio of $E_\gamma^C/\bar{E}_{\nu_i}$ is higher than the ratio of $\sum E_\gamma^H/\bar{E}_{\tilde{\nu}_e}$.

4. The total energy of γ-ray burst does not depend on a star radius, but the duration can be determined by the size of the shell if $R > 3 \cdot 10^{10}$ cm $(c\Delta t_\nu)$.

As the neutrino burst duration depends also on neutrino scattering above the neutrinosphere, the duration of γ-burst with energy 0.511 MeV and 15.1 MeV, roughly speaking, repeats the duration of neutrino burst. The duration of the emission of gamma's with 2.2 MeV depends on the density of hydrogen in the photosphere of the star. The time of the neutron capture by a proton is approximately equal to $\tau \approx 20/\rho_H$ μs, where ρ_H is the hydrogen density, and, for $\rho < 2 \cdot 10^{-6}$ g cm^{-3}, $\tau > 10$ s. So, the total duration of γ-burst from hydrogen envelope can be rather long, but the intensity I_γ of γ-quanta during the first second should be roughly equal to a half or a third of the total γ-ray flux [3, 13]. Hence if the collapse takes place in the center of the Galaxy (at a distance of $D = 8$ kpc) the intensity of γ-ray flux in the γ-burst near the Earth is equal to:

$$I_\gamma = \frac{I_\gamma^0}{4\pi D^2}\ ; \quad I_{\gamma,H} \approx 2.5 \cdot 10^{-4}\ \text{cm}^{-2}\ \text{s}^{-1}; \tag{13}$$

$$I_{\gamma,C} \approx 10^{-5}\ \text{cm}^{-2}\ \text{s}^{-1}. \tag{14}$$

Here one would stress that at $kT = 8 \div 10$ MeV the excitation of unbound giant resonance states in ^{12}C ($E = 18.6$ MeV) by $(\nu_{\mu,\tau}, \tilde{\nu}_{\mu,\tau})$, should be rather strong. The decay of states is accompanied by neutrons, protons and alpha- emission. The neutrons are captured by ^{12}C following the reaction $^{12}C(n,\gamma)^{13}C$. The energy of the γ is equal to 4.95 MeV and the average number of the gammas amounts to 1.3. So the total energy of the γ-ray emission in the carbon shell can be two times as large than in (11) and even more. The duration of the 4.95 MeV γ-ray burst depends on he carbon density ρ_C as $\tau_C \sim 0.018/\rho_C$ s. For $\rho_C \geq 1.8 \cdot 10^{-2}$ g cm^{-3} the time duration of the gamma-ray burst will repeat the neutrino emission time duration. In that case

$$I_{\gamma C}^* \sim 4 \cdot 10^{-5}\ \text{cm}^{-2}\ \text{s}^{-1}. \tag{15}$$

The energy spectrum of gammas becomes softer and the total intensity of gammas increases if we will take into account the secondary gammas from Compton scattering in the shell.

The fluxes (12)–(16) are not so powerful, but using gamma-ray telescope with an angular resolution better then 2° and with a detecting area larger then a few meters they could be observed.

The consequences of such observation are the following:

1. In the case of soundless collapse (without ejecting the envelope) the simultaneous detection of gamma and neutrino bursts can allow not only to detect the fact of the collapse but also to locate the collapsing star in the sky.

2. Gamma-burst indicates the time of the neutrino emission from the star.

3. If there is the Supernova phenomenon, the detection of the Presupernova gamma-burst and then the Supernova itself gives a chance to measure the time between the neutrino emission and the outburst of the envelope.

4. If the number of detecting neutrinos and gammas in the burst will be large enough it can be possible to put the limit to the neutrino mass or measure it, like in the proposal [14]:

$$\delta t = t_\nu - t_\gamma \simeq \frac{D}{2c}\left(\frac{m_\nu c^2}{E_\nu}\right)^2 . \tag{16}$$

   The underground neutrino installations with a lower energy threshold are more sensitive for this purpose. To put the limit less than 1 eV, δt should be measured with an accuracy better than $4 \cdot 10^{-3} \div 10^{-2}$ s for $E_\nu > 5$ or 10 MeV, consequently.

5. In the case of neutrino oscillations $\tilde{\nu}_\mu \to \tilde{\nu}_e$, $\tilde{\nu}_\tau \to \tilde{\nu}_e$, the gamma-ray burst from the hydrogen envelope can be up to 10 times as large than in (11) due to a more hard energy spectrum of neutrino.

   For the carbon envelope, the number of neutral current reactions should be the same, but the additional flux of gammas should appear from charge current reactions with ^{12}C due to the annihilation of positrons [15]:

$$\begin{aligned}
\nu_e + {}^{12}C &\to {}^{12}N + e^-; && (17)\\
{}^{12}N &\to {}^{12}C + e^+ + \nu_e; && (18)\\
e^+ + e^- &\to 2\gamma(0.511\ \mathrm{MeV}); && (19)\\
\tilde{\nu}_e + {}^{12}C &\to {}^{12}B + e^+; && (20)\\
e^+ + e^- &\to 2\gamma(0.511\ \mathrm{MeV}); && (21)\\
{}^{12}B &\to {}^{12}C + e^- + \tilde{\nu}_e. && (22)
\end{aligned}$$

So it is very important to make the persistent correlation analysis of the data obtained both with underground installations and satellite detectors. Such analysis was performed using LSD, LVD and BATSE data for the most powerful gamma-ray bursts [16, 17]. But for the purpose, as discussed here, it is important to make similar analysis for low intensity gamma-bursts. It was made using Artemovsk 100 tons scintillation underground detector (ASD) and all BATSE data [18]. For a period of two years (1992–1993) the number of coincidences (ASD + BATSE) in the intervals from 1 to 900 s corresponded very well to the chance coincidences. This analysis is continuing.

3 $\tilde{\nu}$ interactions in the star-companion in the binary systems and in the planets consisting of hydrogen

The $\tilde{\nu}$ flux from collapsing stars, going through the star situated on the Main Consequence, sets on fire the thermonuclear reactions due to the reaction (1) and (3). The chain is as follows:

$$
\begin{aligned}
D + p &\rightarrow He^3 + \gamma(5.49 MeV); & (23)\\
D + He^3 &\rightarrow He^4 + p(18.352 MeV); & (24)\\
He^3 + He^3 &= He^4 + 2p(12.856 MeV); & (25)\\
He^3 + He^4 &= Be^7 + \gamma(1.59 MeV); & (26)\\
Be^7 + p &= B^8 + \gamma(0.135 MeV). & (27)
\end{aligned}
$$

The total energy yield caused by the formation of one helium nucleus is equal to 26.73 MeV. It is of interest to that the chain (1–2–3) in spite of the threshold of $\tilde{\nu}p$-reaction results in energy deposit of 1.44 MeV due to the γ-emission of 0.511 and 2.23 MeV. As a result of each two $\tilde{\nu}p$ interactions the star receives the energy amounting to $2E_{\tilde{\nu}}$ + 26.73 MeV. The velocity of a helium production via the (1–3) and (23–25) reactions is many orders of magnitude larger than the velocity of that in the standard hydrogen cycle starting with a very slowly going reaction:

$$p + p \rightarrow D + e^+ + \nu. \tag{28}$$

The total energy deposit induced by neutrinos in the star depends on the distance D_1 between the collapsing star and its companion. This can be estimation as:

$$E_d^{tot} = kE_{\tilde{\nu}} < \sigma_{\tilde{\nu}p} > X_H N_0 \frac{M_H}{4\pi D_1^2}, \tag{29}$$

where: $k = 1 + 26.73/2\tilde{E}_\nu \approx 2$.

M_H is the mass of the hydrogen in the companion. The number of neutrons generated in 1 g via the reaction (1) which initiates of thermonuclear reactions for $D_1 = 10^{11}$ cm is equal to $2 \cdot 10^{18} X_H$.

Hence the neutrino radiation makes the star companion older. For $D_1 = 10^{11}$ cm the energy deposit in 1 g of the star during $\delta t = 10$ s amounts to $5 \cdot 10^{10}$ erg that is $2.5 \cdot 10^7$ times larger than that in the case of the Sun. So during 10 s the star grows old by 8 years. Passing through the envelope of the star-companion neutrinos produce the γ-burst with an energy in $(R_1/D_1)^2$ times less than γ-burst from collapsing star. R_1 is the star radius. The possibility to observe this γ-burst depends on that ratio and also on the distance of D (Earth — Star). Neutrinos under certain conditions can destroy planets consisting of hydrogen. To do this it needs the execution of the following inequality:

$$\frac{GM}{R_1} \leq \frac{E_\nu^{tot} < \sigma_{\tilde{\nu},p} >}{4\pi D_1^2} N_0 X_H; \quad \frac{MD_1^2}{R_1} \leq 2 \cdot 10^{41} \text{ g cm}. \tag{30}$$

So, around the collapsing star the hydrogen contained objects do not exist if their mass satisfies the conditions of (30). This is important for soundless collapses. The existence of this inequalities can be checked experimentally.

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