ON SOME PROBLEMS OF GAMMA-ASTRONOMY

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I. Gamma-emission from young supernova remnants. Suppose that inside a young (with an age $t_s \lesssim 10^{[illegible]}$ s) remnant of mass $M \sim 1 M_\odot$ which is expanding at a velocity $u \sim 10^{9}$ /s there exists a CR (proton) source with a power L_{cr} and a damping time $\tau \gg 10^7$ s. Such a source of accelerated particles may be a pulsar or turbulence inside the remnant itself. Generation of various emissions in young remnants was discussed in /I-5/. Undergoing nuclear interactions in a remnant, protons generate secondary particles (electrons, positrons, γ-photons and neutrinos) through π-meson decays.

Let protons with a spectrum

$$\dot{N}_p(E) = (\gamma-1)(\gamma-2)\frac{L_{cr}}{E_c}\left(\frac{E}{E_c}+1\right)^{-\gamma} \qquad (1)$$

be injected into a remnant (or accelerate inside it). Here E is the kinetic energy of a proton; we assume below $E_0=0.4$ GeV. The secondary γ-emission that occurs in this case freely leaves the remnant if its thickness is smaller than the radiation length x_{rad} (63 g/cm^2 for a hydrogen medium, 93 g/cm^2 for a helium medium). This condition is fulfilled if the remnant age

$$t_s > t_\gamma = \left(\frac{3M}{4\pi u^2 x_{rad}}\right)^{1/2} = 2{,}8\cdot 10^6\left(\frac{M}{M_\odot}\right)^{1/2}\left(\frac{10^9}{u}\right)\left(\frac{60}{x_{rad}}\right)^{1/2} s \qquad (2)$$

The emission occurring in $\pi^0 \to 2\gamma$ decays is effectively generated while the matter thickness passed by the relativistic proton before it leaves the remnant is suffucuently large: $x \gtrsim x_N$, where $x_N \approx m_p \sigma_{pp} \approx 70$ g/cm^2, $\sigma_{pp} \approx 3\ 10^{-26}$ cm^2 is the inelastic pp interaction cross-section. If protons stay in the remnant for a time $T \gtrsim t_s$, the thickness passed by them is more than the nuclear thickness, in the case

$$t_s < t_N \approx \left(\frac{3Mc}{8\pi u^3 x_N}\right)^{1/2} \approx 10^7\left(\frac{M}{M_\odot}\right)^{1/2}\left(\frac{10^9}{u}\right)^{3/2}\left(\frac{70}{x_N}\right)^{1/2} s \qquad (3)$$

(for more details see /I/). The total number of secondary γ-photons emitted by the remnant for the time t_N for the proton spectrum (I) turns out to be equal to

$$N_\gamma(E_\gamma > 100\,\text{MeV}) = \frac{2\varphi_{\pi^c}}{1-\alpha^{\gamma-1}}\left(\frac{\gamma-2}{\gamma-1}\;\frac{L_{cr}\cdot t_N}{E_c}\right) \qquad (4)$$

Here $\alpha \approx 0.5$ is the fraction of energy kept by the nucleon after collision; the quantity in brackets is the total number of protons injected into the remnant; the values of φ_{π^c} are tabulated below for different γ (inclusive π^c -meson generation cross-sections are used):

γ	2.I	2.2	2.3	2.4	2.5	2.6
φ_{π^c}	0.24	0.22	0.20	0.I9	0.I7	0.I6

For the luminosity of the remnant and for a photon flux from it we obtain from (4) ($2.I \le \gamma \le 2.6$; R is the distance to the source):

$$\dot{N}_\gamma(E_\gamma \geq 100\,\text{MeV}) \approx (1{,}3 - 2{,}8)\cdot 10^{40}\,\left(L_{cr}/10^{38}\,\text{erg/s}\right)\,\text{s}^{-1},$$

$$F_\gamma(E_\gamma \geq 100\,\text{MeV}) = \frac{\dot{N}_\gamma}{4\pi R^2} \approx (1{,}1 - 2{,}4)\cdot 10^{-6}\left(L_{cr}/10^{38}\,\text{erg/s}\right)\left(\frac{10\,\text{kpc}}{R}\right)^2 \text{cm}^{-2}\text{s}^{-1} \qquad (5)$$

Thus, for $L_{cr} \gtrsim IO^{38}$ erg/s a young supernova remnant in the Galaxy ($R \sim IO$ Kpc) is a detectable γ -source in the interval from $t_\gamma \sim I$ to $t_N \sim 5$ months after a flare. An account taken of the electron component increases the flux (5).

Note that if such remnants are main sources of galactic CR, the required value of L_{cr}, depending on the value of adiabatic CR energy losses varies from $L_{cr} \sim IO^{43}$ erg/sec in the model /I/ to $L_{cr} \sim 5\; IO^{4I}$ erg/sec in the model /4/ (it is also noted in /4/ that young remnants can also be the main sources of antiprotons observed in CR). For $L_{cr} \sim IO^{43}$ erg/s the discussed γ -emission could be registered by detectors of the type of those planned for the GRO station in the case of flares in other galaxies.

2. Annihilation line. Positrons which occur in a remnant under π^+ meson decays are decelerated (outside the acceleration region), annihilate and give the line $E_\gamma = 0.5II$ MeV.

For the remnant age t_s exceeding the recombination time $t_r = 3.4\; IO^6$ s the longest positron deceleration stage is the process of ionization losses from the critical energy E_c (determined in the cascade theory) to the nonrelativistic energy. In this case $-\frac{dE}{dt} = b \approx 2$ MeV/g.cm^{-2}. The thicknes within which there occurs deceleration is $x_b = E_c/b$. The respective age of the remnant for which the positron decelerates down to the nonrelativistic energy is given by (for a hydrogen remnant E_c = 350 MeV, for a helium remnant E_c = 250 MeV):

$$t_b = \left(\frac{3Mcb}{8\pi u^3 E_c}\right)^{1/2} = 6{,}4\cdot 10^6\left(\frac{M}{M_\odot}\right)^{1/2}\left(\frac{10^9}{u}\right)^{3/2}\left(\frac{350}{E_c}\right)^{1/2} s \qquad (6)$$

A nonrelativistic positron annihilates more rapidly. A positron decelerated by the moment

$$t_{ann}=\left(\frac{3M\sigma_0 cN_A}{8\pi u^3}\right)^{1/2}=3,3\cdot 10^7\left(\frac{M}{M_\odot}\right)^{1/2}\left(\frac{10^9}{u}\right)^{3/2}\left(\frac{350}{E_c}\right)^{1/2} \quad (7)$$

annihilates within the remnant. Here $\sigma_c=\pi r_e^2=2.5\ 10^{-25}cm^2$, $N_A=6\ 10^{23}$. Hence, the effective emission annihilation lasts from $t\sim 1$ to $t_b\sim 3$ months. The total number of annihilation photons emitted for this period is described by a formula analogous to (4) ($\varphi_{\pi^+}\approx 1.2\ \varphi_{\pi^c}$):

$$N_\gamma(E_\gamma=0{,}511\ MeV)=2\varphi_{\pi^+}(1-\alpha^{\gamma-1})^{-1}\cdot\frac{\gamma-2}{\gamma-1}\cdot\frac{L_{cr}}{E_c}\cdot(t_b-t_\gamma) \quad (8)$$

The estimate for the flux $F_\gamma(E_\gamma=0.5\ MeV)$ coincides approximately with (5).

The possibility to observe an annihilation line depends on the emission level in a continuum which is created by secondary positrons and electrons in the remnant. (It can be easily estimated that if all primary and secondary CR do not leave the remnant, the generation power e^-e^+ of the component is about $L_{cr}/6$ and the annihilation line takes up $2\ 10^{-4}$ Lcr. A further calculation of the background near $E=0.511MeV$ depends on the values of the magnetic field and of the thermal radiation density in the remnant). If, however, the whole remnant is involved in the effective CR acceleration, the energy losses of positrons may prove inessential and the estimate (8) will be largely overestimated.

3. Emission of neutrinos. Decay of charged pions in a remnant causes generation of high-energy neutrinos. In this case

$$\dot N_{\nu_\mu+\bar\nu_\mu}(E)dE=(\varphi_{\nu_\mu}+\varphi_{\bar\nu_\mu})\cdot\frac{\gamma(\gamma-1)}{1-\alpha^\gamma}\cdot\frac{L_{cr}}{E_c}\cdot\left(\frac{E}{E_c}\right)^{-\gamma}\cdot\frac{dE}{E_c} \quad (9)$$

γ	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	3.0
$10^3(\varphi_{\nu_\mu}+\varphi_{\bar\nu_\mu})$	94.6	69.8	51.9	38.1	29.7	22.8	17.7	13.8	10.9

Neutrino emission starts at the moment $t_\pi(\Gamma)$ beginning from which pions with the Lorentz-factor Γ decay at the length of their free path (σ_π is the cross-section of πN scattering, is the lifetime of a resting pion):

$$t_\pi(\Gamma)=\left(\frac{3M\sigma_\pi c\tau_\pi}{4\pi m_\pi u^3}\right)^{1/3}\Gamma^{1/3}=1.9\cdot 10^2\left(\frac{M}{M_\odot}\right)^{1/3}\left(\frac{10^9}{u}\right)\Gamma^{1/3}s \quad (10)$$

The bright phase ends at $t_s\sim t_N$.

To detect neutrinos, it is convenient to use muon production in the reactions $\nu_\mu+N\rightarrow\mu+X$ underground around the underground muon detector. At $E_\mu\gtrsim 30$-50 GeV the muon keeps the direction of the parent neutrino, which indicates the direction to the source. Transparency of the Earth for neutrino with $E_\nu=10$-10^3GeV makes it possible to eliminate the background of atmospheric muons.

The number of muons which are produced by interaction between neutrinos and ground nuclei and which passed through a detector of area S for the time t_N is equal to (the inclusive cross-sections $\nu_\mu + N \rightarrow \mu + X$ are used in the calculations, the values $K_\gamma(E)$ are tabulated):

$$n_\mu(>E_\mu) = K_\gamma (10\,\mathrm{kpc}/R)^2 \cdot (L_{cr}/10^{42}\,\mathrm{erg/s}) \cdot (S/100\,\mathrm{m}^2) \cdot (t_N/10^7\,\mathrm{s}) \qquad (II)$$

E_μ GeV γ	2.I	2.2	2.3	2.4	2.5	2.6
30	40	2I	8.8	3.5	I.4	0.54
IOO	36	I9	7.7	2.9	I.I	0.4I
IOOO	22	IO	3.7	I.3	0.4I	0.I4

Thus, the existing underground muon detectors (S=I25 m^2) can register high-energy neutrinos from a young SN remnant in our Galaxy for $L_{cr} \gtrsim$ IO^{42} erg/s.

4. *The CR origin and γ-emission from Magellanic Clouds*. The gamma-astronomical data make it possible to establish the CR intensity gradient in the Galaxy. But the available results are contradictory /7,8/. If, according to /7/, in the gamma-range of 300 MeV $< E <$ 5 GeV the radiative capacity is really constant up to the distances R $\sim$ 20 Kpc from the galactic centre, the CR halo must be very large. Then a rather effective reflection of CR would occur at the halo boundaries (CR are now assumed to go freely out of the halo /9/). The results of /7/ conform to the metagalactic model of the origin of the CR proton-nuclear component. We believe, as before, /IO/ that metagalactic models are improbable (this does not refer to CR with a very high energy E $\gtrsim$ IO^{17}-IO^{19} eV). Metagalactic models can be verified by measuring gamma-luminosity from Magellanic Clouds /II,4/. The most reliable and weakly depending on different assumptions is in this case the measurement of $\Delta = F_{SMC}/F_{LMC}$, the ratio of gamma-luminosities of the Small and Large Magellanic Clouds, say, for $E_\gamma >$ IOO MeV. In metagalactic models Δ = =0.56-0.68 depending on the value of the mass of the Clouds used /4/. Respective measurements can be carried out only with the help of the next generation of gamma-telescopes.

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