Antimatter Bounds by Anti-Asteroids annihilations on Planets and Sun

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The existence of antimatter stars in the Galaxy as possible signature for inflationary models with non-homogeneous baryo-synthesis may leave the trace by antimatter cosmic rays as well as by their secondaries (anti-planets and anti-meteorites) diffused bodies in our galactic halo. The anti-meteorite flux may leave its explosive gamma signature by colliding on lunar soil as well as on terrestrial, jovian and solar atmospheres. However the propagation in galaxy and the consequent evaporation in galactic matter gas suppress the lightest ($m < 10^{-2} g$) anti-meteorites. Nevertheless heaviest anti-meteorites ($m > 10^{-1} g$ up to $10^{6} g$) are unable to be deflected or annihilate by the thin galactic gas surface annihilation; they might hit the Sun (or rarely Jupiter) leading to an explosive gamma event and a spectacular track with a bouncing and even a propelling annihilation on atmosphere and photosphere. Their anti-nuclei annihilation in pions and their final hard gammas showering may be observable as a "solar flare" at a rate nearly comparable to the observed ones. From their absence we may infer first bounds on antimatter-matter ratio near or below $10^{-9}$ limit applying already recorded data in gamma BATSE catalog.

1. INTRODUCTION

Severe constrains on the possibility of baryon symmetrical Universe (see review in [1-3]), as well as the evident baryon asymmetry of our cosmic neighborhood, related in the modern cosmology to the process of baryosynthesis in the very early Universe ([4], see e.g.[5] for review), do not exclude the existence of relatively small amount of sufficiently large regions of antimatter in the modern Universe, reflecting the nontrivial physical processes, underlying inflation and baryosynthesis. The original idea [6,3,5] to consider antimatter in the baryon asymmetrical Universe as the tracer for the strong nonhomogeneity of baryosynthesis finds support in recently developed inflationary models with nonhomogeneous spontaneous baryosynthesis [7]. Such models reproduce in quantitative way both the possibility of diffused antiworld (regions of very low density antiproton-positron plasma) [8] and the hypothesis on the existence of antimatter stars in our Galaxy [9]. The both possibilities satisfy the severe constrains on matter-antimatter annihilation [1-3]. In particular, the antimatter globular cluster as the possible form of antimatter in our Galaxy is consistent with that constrains, since the substantial growth of annihilation zone and depletion zone at matter-antimatter boundary at redshift $z = 3$ was found in [1] for the case of large domains in baryon symmetrical Universe. According to [1] this result is not applicable to the case of small (about $10^{-6}$) relative volume, occupied by antimatter in baryon-asymmetrical Universe, when the size of antimatter domains, surviving to the present time, is determined as in [8]. At the enhanced density of antibaryons in
domain it provides formation of globular cluster of antimatter stars [9]. Moreover, it was shown recently [10] that annihilation of antimatter, lost by antimatter stars in the form of stellar wind, can reproduce the observed gamma galaxy background in the range tens-hundreds MeV. Still any source of neutral pions can lead to the same effect and the manifest signature for existence of antimatter stars is the existence of antinuclear component of cosmic rays, accessible to the future cosmic ray experimental searches, first of all in AMS-II experiment. The other profound signature of antimatter are the pieces of antimatter, coming in the form of antimatter meteorites. We study the latter possibility in the present paper and find it interesting tool to probe the origin of matter, related with the creation of antimatter. With all the uncertainties and reservations, taken into account, the search for antimatter meteorites can still provide the useful probe for the existence of macroscopic antimatter.

2. GAMMA FLASHES by ANTIMETEORITE ANNIHILATIONS ON EARTH and MOON

The present flux of meteorites with the mass $M$ observed on the Earth is nearly $10^4 \left( \frac{M}{1 \text{g}} \right)^{-1}$ event a year. This power extend for a large range of mass values. It is very possible that most of this matter has a local "solar" origin. However simple argument on nearby stellar encounters and matter exchange imply that up to 1% of the meteorites may be of galactic (extra-solar) origin. Therefore up to nearly

$$\frac{dN}{dt} = 10^6 \left( \frac{M}{1 \text{g}} \right)^{-1}$$

(1)

of meteorites, hitting the Earth any year, can be of galactic (extra-solar) nature. If the corresponding antinmeteorites rate follows the same power law, at any given suppressed ratio, $r$,

$$r = \left( \frac{N_a}{N_m} \right)$$

where $N_a(m)$ the total amount of antibaryons (baryons) in the Galaxy, (let say a part over a million or a billion or below) its signal will be anyway power-full enough to be (in most cases) observable. Indeed the amount of energy released during the annihilation follows common special relativity; for any light (milligram unit) antime-teteorites mass $M$ the energy ejected is :

$$E = 10^{18} \left( \frac{M}{1\text{mg}} \right) \text{erg}$$

(2)

its corresponding "galactic" event rate, following eq.(1) is

$$\frac{dN}{dt} = 10^9 r \left( \frac{M}{1\text{mg}} \right)^{-1} \text{year}^{-1}$$

(3)

The event of the anti-meteorite annihilation on the Earth atmosphere will give life to unexpected upward gamma shower that will mimic mini nuclear atomic test or extreme upward Gamma Shower. Even for a large suppression ratio $r = 10^{-9}$ this event rate derived from expression above (one a year) should not escape the accurate BATSE ten-year monitoring. Actually the atmosphere area below BATSE detection is nearly 1% of all Earth leading to a total probability rate of 0.1 in ten years. However the corresponding secondaries gamma flux by consequent nuclei annihilation showering into charged and neutral pion and their decays and degradation in atmosphere should lead to a huge gamma fluence $F$ observable in a near orbit satellite as Beppo-Sax or GRO Batse:

$$F \simeq 10 \text{ erg/cm}^2(M/1\text{mg})$$

$$\text{Flux} = 100 \text{ erg} \cdot \text{sec}^{-1} \text{cm}^{-2}$$

This latter flux is derived assuming a characteristic galactic velocity $v= 300 \text{ km/sec}$ for the incoming anti-meteorite and a terrestrial atmosphere of nearly 30 km height. Such a signal is nearly 10 order of magnitude above the sensitive Batse detection threshold. Smaller scale upward gamma flash are indeed known and they are called "Terrestrial Gamma Flashes". They are corresponding to just $10^8$ or $10^9$ erg of isotropic fluence energy (or even much less energy if originated by beamed upward $\tau$ airshowers at $10^{15} \text{eV}$ up to nearly horizontal ones at $10^{19} \text{eV}$) released at
millisecond up to ten of second timescales. Therefore such milligram anti-meteorite bang will be already loudly recorded on data, if they were taking place. Of course so high large event fluence would not escape also other less sensitive astrophysical or military detectors. Therefore it seem that milligram antimatter meteorite rain should be totally excluded at very low level \( r \leq 10^{-9} \). Even more dramatic and sharp gamma signature should come by their fast Moon annihilation (because of the absence of atmosphere), but at a less (Moon surface over Earth one) rate. Lunar anti-meteorite annihilation in characteristic nano-second signature, would make very strong signals at lunar orbiting gamma detectors. They provide a complementary tool to exclude very light (micro-gram) antimeteorite rains at the same severe bound \( r \leq 10^{-9} \).

3. LIGHT ANTIMETEORITE EVAPORATION CROSSING THE GALAXY

However these results may be alleviated keeping in mind that antimeteorites can be annihilated or "evaporated" during their propagation in galactic gas. Indeed the column density of atoms (protons) crossed assuming \( n_{\text{disk}} = 1 \cdot \text{cm}^{-3} \) and a galactic disk height of \( h = 100 \text{ pc} \) and a total number of crossing 100 is: \( N = 3 \cdot 10^{22} \text{ cm}^{-2} \). Each crossed matter atom annihilates on the surface of the rigid body of anti-meteorite. Putting the total mass of the crossed matter gas equal to the mass of spherical homogeneous antimeteorite of radius \( r \) and internal density \( \rho \),

\[
\pi r^2 N m_H = \frac{4}{3} \rho r^3
\]

one obtains that the antimeteorite can not escape complete annihilation, if its radius is smaller, than

\[
r_{an} = \frac{3}{4} \frac{N m_H}{\rho}
\]

and the corresponding meteorite mass, given by

\[
M_{an} = \frac{9}{16} \pi \cdot \frac{(N m_H)^3}{\rho^2}
\]

is (assuming water density) about \( 2.2 \cdot 10^{-4} \text{ g} \). The actual value of minimal mass of the antimeteorite, surviving annihilation, may be a few orders of magnitude larger. If we take into account the strong (cubic) dependence of \( M_{an} \) on \( N \), we find important the increase of \( N \) due to effects of annihilation with the gas above the disc. The mass of antimeteorite, which is completely destroyed by annihilation, can be even larger, if we take into account its atomic composition. To destroy the antimeteorite, which consists of anti-atoms with atomic number \( A \), it is not necessary to annihilate all the anti-nucleons in all its antimolecules, since even the result of one proton anti-nucleus annihilation not only destroys the anti-nucleus, but also causes the successive destructive effects by its fragments. We discuss the effects of energy and momentum transfer due to such processes in the next section, and only estimate here the increase in the minimal mass of anti-meteorite, surviving after annihilation. Putting the total number of matter gas atoms, annihilating on the surface of anti-meteorite, equal to the total number of anti-atoms with atomic number \( A \) in antimeteorite, we obtain instead of \( M_{an} \), the magnitude

\[
M_{surv} = \frac{9}{16} \pi \cdot \frac{(AN m_H)^3}{\rho^2}
\]

which is the factor of \( A^3 \) larger, than \( M_{an} \). This imply that milligam (and even much heavier, up to 0.3 g for anti-ice meteorite) antimeteorites might be suppressed and maybe almost absent in solar system: previous bound by annihilation on the Earth may be considered for heavier (10-100 milligram or above) anti-meteorites leading to a ratio \( r = 10^{-8} \) of antimatter allowable. Bounds by microgram anti-meteorite annihilation on Moon soil while being very hard and sharp, will be no more effective than the terrestrial bounds. Moreover, there are other processes that may dilute above antimeteorite presence in our solar system.

4. THE ANTIMETEORITE ANNIHILATION and DECELERATION IN GAS

Antimeteorite with a mass heavier than milligram may survive annihilation: however while crossing a gas cloud, their lateral annihilation may heat a meteorite side, leading to a rocket ejection able to decelerate and at large matter gas
density gradient even divert and bounce the trajectory. However, for realistic density gradients the latter case can not be realized and the momentum transfer due to annihilation causes the antimeteorite deceleration in matter gas, which can be described as follows. Antimeteorite of radius \( r \), moving with a velocity \( v \) in the central field of gas, distributed around the central mass \( M \) isotropically as

\[
\rho = \rho_0 \left( \frac{R_0}{R} \right)^2
\]

experiences the friction force due to annihilation

\[
F_f = -\rho(R)\pi r^2 \eta v c
\]

where \( \eta \) is the effectiveness of momentum transfer near unity; assuming an initial anti-meteorite velocity \( v_a \) and density \( \rho_a \) and a normal galactic-disk mass density \( \rho \) one finds the characteristic relaxation time \( \tau \) (for a millimeter anti-meteorite radius):

\[
\tau = \frac{4 \rho_a \cdot r}{3 \rho \cdot \eta c} = 1.3 \eta^{-1} \cdot 10^2 \cdot \text{year} \cdot \frac{r}{\text{mm}} \cdot \frac{\rho_a}{\text{g cm}^{-3}} \cdot \frac{10^{-24} \text{g cm}^{-3}}{\rho} \quad (5)
\]

Therefore in a short (in galactic scales) times any fast anti-meteorite will be slow down to a velocity comparable with common galactic gas. Therefore lightest anti-meteorite will follow a co-moving pattern with matter in galactic disk. Heavier ones (\( m >> 0.1 \) g) will not evaporate and might reach the Earth. In presence of any radial gravitational force, near stars or star clusters, the gravitational force

\[
F_g = \frac{4}{3} \frac{GM \pi r^2 \rho_a c^3}{R_0^2}
\]

and the friction action leads to a slow-down free fall up to a steady value. The equality of the two forces indeed leads to the constant velocity

\[
v = \frac{2 \rho_a \cdot r \cdot R_a c}{3 \eta \rho_0 \cdot R_0}
\]

where

\[
R_a = \frac{2GM}{c^2}
\]

is the Schwarchild radius of any central body.

The annihilation friction is effective, resulting in the anti-meteorite deceleration and successive slow drift and final annihilation towards the star center.

In nearly horizontal motions the fast anti-meteorite may bounce on the star-planet atmosphere and they may escape from the central field. In the case of general motion and matter gas distribution this effect may be estimated by assuming that a fraction of antimatter is annihilated leading to a momentum exchange (See [12]) and a velocity loss \( \Delta v \sim v \sim 10^{-3}c \):

\[
\Delta v = \eta \cdot E/M c
\]

where \( \eta \) is the fraction of annihilation energy going into effective anti-asteroid momentum exchange. Being necessary to escape from the galactic plane or from solar atmosphere a \( \Delta v > 10^{-3}c \) one finds

\[
\frac{(\Delta E)/(Mc^2)}{(\Delta M)/M} \leq 10^{-3}/\eta
\]

This value cannot exceed unity otherwise the anti-meteorite will be totally annihilated; therefore the \( \eta \) efficiency cannot be below \( 10^{-3} \) but its value is bounded by the ratio of the interaction length of charged pions on the meteorite volume; the 300 MeV pion crosses nearly 85 cm in water before interacting; the total amount of matter crossed during meteorite life-time traveling (comparable to galactic age) in the galactic disk is nearly \( 10^{-2} \) g or \( 10^{-2} \) cm. of water. However in the case of atomic antinuclei composition annihilating with hydrogen of galactic gas the main consequence will be a breakdown of antinuclei. Its fragments will deposit in a very efficient way (nearly 50%) the energy of annihilation into linear momentum as well as increasing the temperature of the solid antimatter body. Our first estimation show that the effective cooling is keeping the temperature below the solid (rock) melting point, while the antimeteorite moves in the Galaxy and Solar System. The equilibrium temperature is established, provided that the heating rate \( 2\pi r^2 \kappa \rho c^2 v \) (where \( \kappa \) is the fraction of the total energy, released in the annihilation (\( E_{an} = 2m_H c^2 \)), that heats the spher-
ically symmetric antimeteorite of radius \( r \), moving with velocity \( v \) in the matter gas of density \( \rho = m_H n \) is equal to the rate of radiative cooling \( 4\pi r^2 \sigma T^4 c \) (where \( \sigma \) is the Stephan-Boltzmann constant). In the considered approximation both heating and cooling are proportional to the surface area, so that the equilibrium temperature is given by \( T_e = 168K(n_{keV})^{1/4} \) for matter gas number density \( n = 1cm^{-3} \) and anti-meteorite velocity \( v = 300 \text{ km/s} \). Annihilation of matter gas with antinuclei on the antimeteorite surface leads to its erosion, but its effect, which may deserve special analysis for particular antimeteorite composition, does not lead to significant change of the above estimation for sufficiently large antimete-
orites. Nevertheless the "ice" anti-comets might be melt efficiently still in the galaxy and very efficiently near Solar and Terrestrial atmosphere. The reason is that the estimated value of \( T_e \) can easily be factor of 2 larger, but the antimeteorite, moving with the velocity \( v/c \approx 10^{-3} \), with the account for all the uncertainties can be hardly heated up to 1000 K due to the annihilation in the low density matter gas (with the number density \( n \approx 1cm^{-3} \)). The equilibrium condition, rewritten for energy density of radiation \( (\epsilon_{\gamma} = 2.7Tn_{\gamma}) \) and of annihilation products \( (\epsilon_{an} = 2nm_Hc^2) \) in the form \( \epsilon_{\gamma}c \approx \kappa\epsilon_{an}v \), is reached at \( T_e \leq 300K \) due to the low values of in-flow velocity \( v/c \approx 10^{-3} \) and matter gas density \( n/n_{\gamma} \approx 10^{-9} \), what compensates the large value of annihilation energy release \( 2m_p c^2 / T_e \leq 2 \cdot 10^{10} \).

5. ANNIHILATION OF ANTI-
ASTEROIDS on SUN

The "galactic anti-asteroid" rate on Sun from (1) is

\[
\frac{dT}{dt} = 10^{10} r \left( \frac{g}{M} \right) \text{year}^{-1}
\]

(7)

The consequent event rate for suppressed anti-
asteroids one over a billion is 10 events a year. The fluence \( F \) on Earth is \( 3 \cdot 10^{-7} \text{erg/cm}^2 \) and comparable to GRB fluence, with a time dilution of nearly 10 seconds. Therefore it may be well be missed or misunderstood as a low energy so-
lar flare. The rarest events at 100 g range may mimic observed solar flares. Let us remind that present bounds in solar flare activity may be even detectable at a nano-flare intensity. If the above coincidence is not just the hint of the antimat-
ter meteorites in-fall it provides the present most stringent bound on antimatter. It may be useful to mention that the two anti-meteorite searches undertaken in USSR in late 1960-s early 1970-
s, even without confirmation, exhibited the positive effect (see review in [14]). So not only stringent limits, but even positive discoveries should be in principle considered in future of such searches.

6. CONCLUSIONS

Anti-meteorites annihilations may provide the challenge to search for antimatter in our Galaxy at the same level of sensitivity which is planned to be reached in AMS-II experiment (a part over a billion). With all the uncertainty in possible relationship between the total mass of antimatter stars and the expected amount of pieces of anti-
matter to be ejected by antimatter stellar systems and all the possible reservations our first estimate on Earth and Solar events are showing rather high sensitivity \( (10^{-8} - 10^{-9}) \) in antimatter search can or even might be already reached.

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