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ON A COHERENT RADIOEMISSION MECHANISM IN QUASARS AND IN THE REMAINS OF SUPERNOVAE

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ABSTRACT

It is shown in this paper that in principle, coherent mechanisms can be responsible for the emission, of which the interpretation is otherwise difficult within the framwork of incoherent magnetic bremmstrahlung mechanism, without in any way attempting to deny, or to minimize its role in sources of cosmic radiation. To make the realization of coherent mechanisms possible, the authors invoke the earlier proposed quasistationary model of quasars, the "magnetoid"

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This report is based upon the work [1], the authors using also some of their other results [2-5]. Numerous details and calculations are found in these works. It is thus quite clear that we are not in a position to pause here with some detail at the above results, and we shall refer below only to the fundamental situations and results.

We shall speak of quasars and remains of supernovae. The joint consideration of these diversified objects is to some extent casual within the framework of the current report. As a matter of fact, the variability of radioemission from quasars and the considerable compactness of the local source of longwave radioemission in the Crab Nebula were discovered almost simultaneously in 1965.

The common trait of these quite independent discoveries lies in the impossibility to attempt the linking of the received radioemission with the standard magnetic bremmstrahlung mechanism for quasars and in the case of "compact" source in the Crab.*

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* A certain incoherent magnetic bremmstrahlung in vacuum is implied, of which the intensity is proportional to the number of emitting relativistic electrons (see, for example, [6]).

Indeed, in case of quasars and for the local source in the Crab, the registered radioemission originates from a comparatively small volume (the upper limit of dimensions of the emitting region in quasars is estimated from the characteristic time of flux vatiation, and for the source in the Crab -- from observation of its interplanetary scintillations). Meanwhile, the relativistic electrons contained in a source of limited dimensions may not, strictly speaking, emit more actively than a blackbody with temperature $T \sim E/\kappa$, where E is the characteristic energy of electrons and κ is the Boltzmann constant, no matter what their concentration. A more precise limitation may be indicated, giving ourselves the spectrum of electrons, and taking into account their re-absorption (self-absorption) in the source (see [1]). Here only one conclusion is material, namely that taking into account self-absorption, the source of relativistic electrons has for a given magnetic field a limited magnetic bremmstrahlung luminance, no matter how great the total energy of electrons in it.*

If for a source with either selection of its model (dimensions, distance luminance) an incoherent bremmstrahlung emission mechanism cannot take place on account of the cause indicated, it is customary to speak of "difficulties." As is well known in literature, a way out of these difficulties is tentatively sought for in the assumption of relatively small (not cosmological) distance to quasars ("local theory").

Without pausing at criticism of this hypothesis on quasars as small objects, appearing to us as little probable, we should like to underscore the following. In the above-indicated context we are not led to speak of any "difficulties" of the theory of magnetic bremmstrahlung. In reality, the success in applying the magnetic bremmstrahlung emission mechanism in astrophysics is to a significant extent connected with the fact that this mechanism acts effectively already in vacuum, or in a sufficiently rarefied medium. The latter implies that the following inequality is observed for the frequency of the observed emission

$$\nu \gg \nu_c \tag{1}$$

where ν_c is a certain characteristic frequency, for example, the Langmuir frequency

$$\nu_L = \frac{\omega_L}{2\pi} = \frac{1}{2\pi}\left(\frac{4\pi e^2 N}{m}\right)^{1/2} \sim 10^4\, N^{1/2} \text{cps.} \tag{2}$$

Here N is the concentration of electrons in the emitting region. Generally speaking, the frequency ν_c depends not only on ν_L , but also on gyrofrequency

$$\nu = \frac{\omega}{2\pi} = \frac{eH}{2\pi mc} \sim 3 \cdot 10^6\, H \text{ cps} \tag{3}$$

where H is the intensity of the magnetic field in the source (the field in (3) being measured in oersteds). The relationship of ν_c with ν_L and ν_π depends only on the orientation of the wave vector $\vec{k}$ of the emission relative

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* In fact, however, the total energy of electrons is obviously always limited (for more details refer to Appendix of [1]).

to the field H; the expression $\nu \sim (\nu_L + \nu_\pi)^{1/2}$ is rather characteristic. When accounting the influence of the index of refraction of the plasma on bremmstrahlung, $\nu_c \sim \nu_L / \nu_\pi$ (see [6]). Besides, ν_L and ν_π the frequency ν_c may be dependent on the medium's motion velocity $\underline{v}$ relative to the observer, or, to be more precise, on the quantity $\underline{kv}$.

So long as inequality (1) is observed, the role of the medium may be neglected and the magnetic bremmstrahlung takes place in the same way as in vacuum. In most of cases (for the Galaxy and for supernova shells) inequality (1) is entirely valid for the greater part of the radioband. For example when $N \sim 1\ cm^{-3}$ the frequency ν_L 10^4 cps and even for $N \sim 10^2\ cm^{-3}$ this frequency is

$$\nu_L \sim 10^5 cps\ (\lambda_L = c)\nu_L \sim 3 \cdot 10^4 cm \sim 300\ m;$$

and for $H < 10^{-3}$ oe, the gyrofrequency is

$$\nu_H < 3 \cdot 10^3\ cps\ (\lambda_H = c/\nu_H > 10^7 cm = 100\ km).$$

When inequality (1) is disrupted, there is no longer any foundation, and at times it is simply erroneous to limit ourselves to the consideration of the incoherent magnetic bremmstrahlung emission mechanism. This was already well known from the example of the Sun [7 - 9]. The same refers as fully to "compact" sources in supernova shells and at times to quasars. Therefore, if the magnetic bremmstrahlung model of the source is contradictory, this points in the first place to the limitation of the area of applicability of the incoherent bremmstrahlung emission mechanism laid at its basis, and not to the necessity of passing to radically different representations (artificial nature of sources, ejection of quasars from the nucleus of the Galaxy and generally the "local" origin of quasars).

Let us underscore once more that above we referred not to an arbitrary hypothesis, but to the contrary, by its very substance the "compact" source -- in the Crab Nebula and the quasars may contain in some of its regions a sufficiently dense plasma, whereas the field intensity in these or other regions may be great, with the result that the frequencies ν_L and ν_π are such that inequality (1) is disrupted.

Therefore, for a dense plasma it is natural, and sometimes necessary to turn to coherent emission mechanisms.* There are many such mechanisms, so that great possibilities arise here [1, 7 - 10]. We shall limit ourselves here to recalling three cases.

I. Magnetic Field Absent or Immaterial

Beams of particles, or, more effectively, shock waves excite plasma waves of frequency ω and wave vector k, which are limited by the relation

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* For a coherent mechanism we recognize here a mechanism for which the power of emission is proportional to the number of emitting particles, for example, the concentration N_e or the total number of relativistic electrons in the source, $\int N_e dV$.

$$\omega^2 = \omega_L^2 + \frac{3\kappa T}{m} k^2. \tag{4}$$

So long as

$$\frac{3\kappa T}{m} k^2 << \omega_L^2,$$

these waves attenuate only feebly and this is why it may be considered that to the frequency ω responds a concentration of electrons N corresponding to the frequency ω_L (see [2]). Longitudinal waves are transforming into transverse waves (radiowaves) by various means. Most simple and possibly sufficiently effective is the transformation at the expense of scattering in density fluctuations taking place with the cross section

$$\sigma \sim \sigma_T = \frac{\pi}{3}\left(\frac{e^2}{mc^2}\right) = 6.65 \cdot 10^{-25} cm^2$$

(calculated for one plasma electron). Another transformation mechanism that may still be more effective under specific conditions is the scattering in plasma waves, shock wave fronts, etc.

Estimates show [1] that this coherent mechanism variant may fully explain the emission of a "compact" source in the Crab Nebula. However, for quasars there arises a substantial difficulty linked with radiation absorption on account of collision in the nonrelativistic plasma over the path from the emitting region (where the frequency of the observed emission $\nu \sim \nu$) to the outlet of quasar's shell.

2. The Magnetic Field is Substantial and Moreover $\nu \sim \nu_H$

However, at the same time, though $\nu_L << \nu_H$ the presence of plasma is essential for the very possibility of coherent mechanism.

As is well known, normal electromagnetic waves in a magnetoactive plasma are generally neither longitudinal nor transverse (for details, see, for example [11]). High frequency normal waves of interest to us are excited by beams and low frequency waves (in particular, magnetohydrodynamic shock waves) and as a result of action by various transformation mechanisms, egress from the system in the form of observed radiowaves. In this variant, for $\nu_H >> \nu_L$ generation takes place at a level $\nu \sim \nu_H$ to which may respond a substantially lower plasma density than in the case 1. This is why, prior to their egress from the system, the absorption of waves is not as great either.

Therefore, on the one hand because of lesser radiowave absorption, and, on the other hand on account of greater energy density of high-frequency waves (the other conditions being equal), this mechanism (which could be designated as a coherent magnetoplasmic mechanism) is considerably more effective in the case of quasars. As is shown by the estimates of the work [1], it might, in principle, explain the origin of the variable part of quasar radiomeasurement in frequencies, where the incoherent bremmstrahlung mechanism is "inoperational".

3. Let us pause at still one more mechanism that is to some extent parent of both the coherent mechanism and that of incoherent bremmstrahlung. Namely, as was recently shown (for other forms of energy spectrum of electrons), in the presence of plasma the reabsorption coefficient of magnetic bremmstrahlung radiation may be negative [10]. As a result of radiation propagation in the region containing relativistic electrons, the intensity increases according to the law

$$I = I_0 \exp\left(\int_0^L |\mu| dl \right),$$

where L is the path covered. It is then important that for an isotropic distribution of electrons by directions we always have in vacuum $\mu > 0$, i. e. reabsorption takes place (see [8, 10]). As to the possibilities of enhancement ($\mu < 0$), it appears only when the influence of the medium is taken into account, that is, it may occur only in denser regions. The coherent character of this emission, just as reabsorption, is obvious from the fact that $\mu = \mu(N_e)$, where N_e is the concentration of relativistic electrons. This is why the luminance of the object depends, roughly speaking, on $N_e \exp(|\mu(N_e)|L)$, i. e., it is not simply proportional to N_e. Incidently, and independently from such a somewhat formal sign (the nonlinear dependence on N_e), it is clear that any absorption and enhancement of radiation constitute a coherent process. (Obviously, when either absorption or enhancement are linked with the action of the medium surrounding the radiating particles, the radiation may be incoherent relative to these particles. But in our case we deal with absorption or enhancement by the radiating particles themselves).

According to [10], such an enhancement mechanism may be of no interest to the Sun, for the compact source in the Crab Nebula and for quasars. It should be noted, however, that in the case of quasars this mechanism sets forth exceptionally hard requirements to plasma temperature, which must be extremely high for the bremmstrahlung absorption of coherent radiation to be small. Thus according to [10], for quasars STH-102 a plasma concentration of about $N \sim 10^8$ cm^{-3} is required when the temperature $T > 10^8$°K. But in case of quasars EC-273-B, the interpretation of its variable radioemission in the microwave band with the aid of the coherent magnetic bremmstrahlung mechanism leads for a source of dimensions $L \sim 3\ 10^{16}$ cm to

$$N \sim 5 \cdot 10^{11} \div 2 \cdot 10^{12} cm^{-3}$$

and [10]

$$T > 5 \cdot 10^9 \div 2 \cdot 10^{10}\,°K.$$

It is easy to show that in these conditions the luminance of quasars would have been mostly conditioned by the standard bremmstrahlung emission mechanism of heated plasma (practically to relativistic velocities!), whereupon this emission would have been by several orders more powerful than that received.

Summarizing, it may be concluded that in principle, coherent mechanisms may be responsible for the emission, of which the interpretation within the framework of incoherent magnetic bremmstrahlung mechanism is met with difficulties of virtually insurmountable nature. It is obvious that we do not intend to negate in any way or to minimize the role of the standard incoherent magnetic bremmstrahlung mechanism in the sources of cosmic radiation, including quasars. There is, however, a basis to turn to coherent mechanisms in the cases, when observations reveal generation of radiation in regions of sufficiently small dimensions that contain a comparatively dense plasma. In such conditions, when inequality (1) is disrupted, the electromagnetic oscillations in a system of frequency ν and the motion of particles in the plasma are closely linked among themselves, so that the radiation of that system no longer has an incoherent character.

However, the realization of coherent emission mechanisms depends not only on the presence of convenient values of electron concentration, determining the frequency ν_L , and on the intensity of the magnetic field, determining the frequency ν_H. It is obviously also necessary to assure in the radiating region a sufficiently high oscillation level (plasma waves, standard electromagnetic waves). Speaking more concretely, it is necessary that the energy density of these waves constitute a notable fraction of inner energy density $\frac{3}{2}$ NkT or of magnetic energy density $H^2 / 8\pi$. Thus, the most important, if not the fundamental question, arising during the analysis of the possibility of generation of coherent radiation is that of the presence of a sufficiently powerful source of the corresponding waves.

In connection with this we should like to emphasize that the last requirement is automatically satisfied in the earlier presented quasistationary model of quasars — the "magnetoid" [4, 5] (see also the works preceding it [2, 3 and 15]). The magnetoid constitutes a plasma configuration with high radial pressure, in which the stability, and partially also the equilibrium itself are assured at the expense of dynamic motions. The magnetic field plays a fundamental role, hindering the rapid dissipation of the latter. The magnetoid formation may be the consequence of contraction of a rotating cloud of "magnetized" plasma, in which the developed macroscopic motions were not only attenuated, but have passed at the end into a quasistationary magnetoturbulent motion. In the largest scale these motions are to a significant extent coordinated.

Let us outline some of the singularities of the magnetoid.

a) In the process of secular contraction the total energy liberation constitutes near 1% of Mc^2. Although this "efficiency factor" is only little greater than the yield of standard nuclear reactions, and owing to the possibility within the framework of this "magnetic" model of sustaining in equilibrium very large masses (to $10^9 M_\odot$), the total energy liberated (up to 10^{61} ergs) is entirely sufficient to explain the phenomena observed in quasistellar objects.

b) The "magnetic" model explains in an unconstrainable fashion the presence in quasar nuclei of magnetic fields of the order of $10^2 : 0^3$ oersteds, which may be arrived at from analysis of magnetic bremmstrahlung of objects or are required in the case of coherent mechanism of the variable radioemission component [1, 4, 12].

c) The presence of cyclical regime of motions against the background of magnetoturbulent oscillations determines the variability of the field H in the emitting region. This, and possibly also the modulation of the accelerating mechanism, leads to the variability of source's emission (for example, the radiation intensity for electrons with spectrum $N_e(E) = KE^{-\gamma}$ is proportional to $H^{(\gamma+1)/2}$ and varies correspondingly as a function of the form of the function H(t)).

d) The presence of magnetic turbulence may fully ensure the acceleration of particles as a result of well known mechanisms as well as, in the first place, of direct conversion of magnetic energy into energy of fast electrons [13].

e) As a matter of fact, magnetic turbulence is a combination of various partly chaotic motions and magnetohydrodynamic waves. As already mentioned, in the magnetoid model under discussion the problem of generation of oscillations is resolved from the very beginning, at least qualitatively.

We are not in a position to pause here in detail at the magnetoid model (see [4, 5, 14]),nor can we do it for emission mechanisms. Therefore we shall only indicate in conclusion some corollaries of the developed representations.

1. The magnetic bremmstrahlung is always either non polarized or linearly polarized in real conditions (see [6]). To the contrary, the incoherent plasma radiation, taking into account the influence of the magnetic field, may include a component polarized either elliptically or circularly. This is why it is necessary to ascertain the possibility of the presence of elliptically polarized component of sources' radioemission, which there is basis here to consider if only partially nonmagnetic bremmstrahlung.

2. The character of variations of radioemission flux must depend on the wavelength. For a coherent mechanism, within the limits of a specific frequency interval it is natural to anticipate similarity of flux's spectral density variations with phase shift, depending upon the frequency. Assume, for example, that on account of a certain perturbation at level r_1 the emission intensity in frequency ν_1 has changed, the level r_1 responding to that frequency and being counted, say, from the center of the quasar. Then the very same perturbation (for example a shock wave propagating from within) attains a level $r_2 > r_1$ with a lag, so that the intensity variation in the frequency corresponding to the level r_2 will differ by a known phase difference.

The presence of separate "ejections" in a narrow frequency interval may also be expected (analogous to those observed in sporadic solar radioemission conditioned, for example, by ejection of fast particles during local "flare" processes in the magnetoid.

3. The flux variations due to the coherent mechanism may result, beginning from a certain frequency, smaller than the corresponding variations conditioned by the magnetic bremmstrahlung mechanism. The search for this sort of "transitional" frequency (apparently lying in the microwave band in the case of 3C 273-B) is very important for the refining of parameters of quasi-stellar objects; this search could be undertaken by way of measurements of polarization, distinct in the named regions and differently depending on frequency.

Above we specially noted a few specific moments. However, in order to verify the model discussed, all other data on quasars (eventually more important and more numerous), obtained by radio and optical methods, may be useful. Of extreme necessity would be also measurements in the X-ray and gamma-ray bands [12].

At present we still are not induced to speak in terms of the complete theory of quasars. At the same time, we should like to underscore that within the framework of the material known to us the "magnetic model" is not met with contradictions, and it appears to us as being quite realistic.

At any rate, we are at present in no position to suggest an alternative, somewhat realistic method of quasar, describing from a single viewpoint a large conjunction of observed facts.

*** THE END ***

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