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APPEARANCE OF A COHERENT EMISSION IN NONEQUILIBRIUM. COSMIC MEDIUM AND THE SETI

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INTRODUCTION

It is known that the SETI problem is being discussed together with the possibility of using cosmic masers for transmission of radio signals. Therefore, the analysis of all possible cosmic maser emission regimes as well as the use of their features in the SETI became actual. In this work the most characteristic emission statistical regimes of cosmic masers and their use in the SETI have been analyzed. It is shown that cosmic masers can radiate in three different statistical regimes:

1) the noise-like (Gauss) regime;

2) quasiregular (coherent) regime;

3) stochastic (dynamical chaos) regime. It is mentioned that the most productive for the use in the SETI is the coherent emission regime, or an emission regime transitive from the noise-like to the quasiregular one.

COSMIC MASER EMISSION REGIMES

While constructing the theory of cosmic masers the concept of their noise-like emission properties is usually treated as basic. On the one hand this concept is based on the first observational estimation of statistical characteristics (Pashenko et al., 1973; Evans et al., 1972; Moran, 1981), and on the other hand on the theoretical results which give a good description of the existing observational data. However, the recent series of data for powerful H_2O-masers does not conform to the opinion that the cosmic emission of masers is only of the noise-like character (Lada et al., 1981; Mattila et al., 1985; Rowland & Cohen, 1986; Matveenko et al., 1988).

Therefore it is interesting to consider all possible emission regimes of the nonequilibrium molecular medium and the expected statistical properties of the emission.

It is well known that in the non-equilibrium media different wave processes appear. The non-equilibrium two-level molecular medium of cosmic masers is an active medium described by equations which allow solutions with various statistical characters. In such medium there can exist a hierarchy of types of critical behaviour (wave instabilities). In various realizations of wave instabilities different statistical, spectral and other emission characteristics can be expected. Consecutive development of the theory of wave instabilities in cosmic masers is important for explanation of the observed facts (and also for prediction of new ones). For this purpose we should abandon the equation of distribution for the maser emission intensities, which is usually used in traditional theory. The full set of equations must include non-stationary equations for the maser field amplitude (E), polarization density (P) and population inversion of levels of active molecules (D). For the complete description of various radiation regimes of cosmic masers and their statistical properties it is necessary to solve a set of equations of emission distribution and a material set of equations of active medium in which the emission generates and is amplified then:

$$\left(\nabla - \frac{1}{c^2}\frac{\partial^2}{\partial t^2}\right)E = -\frac{4\pi}{c^2}\frac{\partial^2 P}{\partial t^2} - \frac{4\pi}{c}\frac{\partial J}{\partial t} ,$$

$$\frac{\partial^2 P}{\partial t^2} + \frac{2}{T_2}\frac{\partial P}{\partial t} + \left(\omega_0^2 + \frac{1}{T_2^2}\right)P = -\frac{2\omega_0}{3h} d^2 ED , \tag{1}$$

$$\frac{\partial D}{\partial t} + \frac{1}{T_1}(D - D_0) = \frac{2}{h\omega_0} E \frac{\partial P}{\partial t} .$$

Here J is the electron stream density of plasma in maser sources, D_0 - the unsaturated density population inversion of active molecules, d - the magnitude of the dipole matrix element connecting the two relevant states of the molecules between which transitions occur, ω_0 - the resonant frequency, T_1 and T_2 - the time of longitudinal and transfer noncoherent relaxation of active molecules.

The presented set of equations is considerably non-linear and allows different stationary and non-stationary solutions. The first type of electromagnetic wave instability is the state of the linear maser amplifier. It appears from the first trivial stationary solution of Eqs. (1):

$$\langle E\rangle = 0, \quad \langle P\rangle = 0, \quad \langle D\rangle = D_0 \tag{2}$$

It is a kind of convection instability. This maser emission regime corresponds to the regime of cosmic masers (Litvak, 1973; Strelnitsky, 1974) which has been well investigated earlier and can be described by the distribution equation for the active molecular population difference (velocity equation). The statistical properties of the emission have a noise (Gauss) character. However Eqs. (1) give another stationary solution:

$$\langle E\rangle = E_s, \quad \langle P\rangle = P_s, \quad \langle D\rangle = D_s. \tag{3}$$

In this case one should expect absolutely new cooperative effects - self organization effects. Nonequilibrium molecular medium emission will have quasiregular time-spatial properties (Ishankuliev, 1990; 1991). In this case the field of molecules may sum up coherently if the active molecule concentration is maintained at the medium of emission into free space. A combined solution of Eqs. (1) in the vicinity of the second stationary solution (3) yields the equation which describes evolution of the cosmic maser emission amplitude:

$$\frac{\partial D}{\partial t} = \left[\lambda + \nu\left(k_0^2 + \nabla^2\right)^2\right]E - \beta E^3 + f(r,t). \tag{4}$$

Here the terms which are proportional to λ and β describe the linear and nonlinear dissipation effects, and ones which are proportional to ∇^2 and ∇^4 characterize "diffusion" of various orders, $f(r,t)$ determines the presence of various fluctuational contributions. The joint effect of these terms and the boundary conditions determines the characteristic scale of the time-spatial structures appearing in the non-equilibrium cosmic-medium.

The analysis of the Fokker-Planck equation corresponding to Eq. (4) allows us to state the possible existence of regular time-spatial wave structures, since the stationary states, most probable for the function of the electromagnetic field distribution, correspond to the linear minimum of quasifree energy.

$$F = c \cdot \int\left\{\left[\lambda + \nu(k_o^2 + \nabla^2)^2\right]E^2 - \beta E^4\right\} dV, \tag{5}$$

which is provided when $\langle E\rangle = E_s$, $k = k_0 n$. Thereby in the non-equilibrium three-dimensional two-level system the most probable appears to be the distribution of transversal electromagnetic waves with E_s amplitude in the direction $\vec{n}$ which is determined by the boundary conditions (geometrical elongation of amplification region, the presence of the background base). However more complicated structures are possible.

Further analysis of arising wave instabilities as a result of the non-equilibrium is rather difficult in the sense of a strict analytical approach. However it is possible to show that Eqs. (1) allows the existence of stochastic wave instabilities (time-spatial chaos). Namely an analysis of stability of the stationarity solution of Eqs. (1) by Lyapunov allows us to determine the region of values of the pump parameter when these stationarity solutions are permanently stable, as well as the regions with wave instability (dynamical chaos). Here the statistical properties will have a stochastic character and the spectrum will show a tendency for rapid broadening.

From the above mentioned it follows that cosmic masers are an astrophysical phenomenon which can have three different forms. The first is the most extended form. These are cosmic masers which radiate a noise-like (with Gauss statistics) electromagnetic field with a spectrum width that narrows slowly $(\ln I_0)^{-1/2}$ with the increase of intensity. The second form of cosmic maser emission can be realized when it reaches a high level of pump and saturation for second stationarity solution. In this case the maser emission may have time-spatial coherent properties and the spectrum width may rapidly narrow with increasing emission intensity ($\sim I_0^{-1/2}$). The third (strange attractor) regime of the cosmic maser emission can be reached with a further increase of the pump, when the dynamical chaos regime realizes in the region. The statistical properties here have a stohastic character tending to strong broadening with the increase of the intensity and time-spatial variations with pump condition variation.

SETI AND THE EMISSION OF COSMIC MASERS

Let us consider now what the ETI may have in common with the radio emission of cosmic masers. Apparently, if information is transmitted from an artificial source it is most likely to occur in the form of a coherent signal the same as on the Earth. Therefore, a problem arises of avoiding confusion of the ETI coherent signal with a signal from the nonequilibrium cosmic medium.

On the other hand the existence of cosmic masers allows us to use them as a signal amplifier for the SETI (Schedule and List..., Santa Crus, 1991). In this case it would be preferable to do it with the cosmic masers at the boundary of the coherent regime, or in the regime of coherent emission. The use of the boundary for transition to the coherent regime allows us to use non-stationarity and rapid anisotropy of the maser emission (Ishankuliev, 1990; 1991), hereat for changing the emission regime a small alteration of the pump level is needed, but sometimes the appearance of an artificial signal is quite sufficient. In this case there occur both the change of the emission and the alteration of its angular distribution with the increase of luminosity of a maser source to several orders. All this allows us to control an artificial signal either in time or space.

CONCLUSION

It follows from the above mentioned that the interrelation connection of the SETI and characteristics of cosmic maser emission should be considered relative to the complicated theory of origin and evolution of maser emission in the non-equilibrium three-dimensional two-level medium. Therewith such active medium has sinergetic properties (self-organization, dynamical chaos behaviour, etc.). So the problem of detecting interesting phenomena connected with cosmic masers, and particularly in the context of the SETI program, lies ahead.

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