COHERENT AMPLIFICATION OF RADIO EMISSION IN A COSMIC MEDIUM

D. A. Varshalovich
A. F. Ioffe Physico-technical Institute, USSR Academy of Sciences
Submitted 17 June 1966
ZhETF Pis'ma 4, No. 5, 180-182, 1 September 1966

A level population inversion of the hyperfine structure of the ground state $1S_{1/2}$ takes place for hydrogen atoms placed in a guided beam of unpolarized ultraviolet radiation with a continuous spectrum in the region $\lambda \sim 1216 - 912$ Å. Because of the anisotropy of the angular distribution of the incident radiation, the spin of the atom in the state $F = 1$ $(1S_{1/2})$ becomes oriented and aligned along the beam direction, so that the population of the magnetic sublevels $R(FM)$ will be different

$$\frac{R(F = 1,\ M = 0)}{R(F = 0,\ M = 0)} = 0.987, \qquad \frac{R(F = 1,\ M = \pm 1)}{R(F = 0,\ M = 0)} = 1.013. \tag{1}$$

This corresponds to spin temperatures

$$T_{S_0} = +5.2°\text{K}, \qquad T_{S\pm 1} = -5.2°\text{K}.$$

The foregoing values were obtained under the assumption that the level populations are completely determined by the interaction between the atoms and the radiation, and that collisions play no role. Such a situation is characteristic of many regions of interstellar medium, especially near radiation sources. A specific feature of the cosmic medium is that there is no thermodynamic equilibrium, that its density is negligibly small, and that the radiation flux from the nearest stars is sufficiently large.

The occurrence of the population inversion of the H I atom levels should cause the cosmic radiation at $\lambda = 21$ cm, corresponding to the transition $T = 1 \to F = 0$ $(1S_{1/2})$, to experience coherent amplification on passing through such a medium, i.e., the cosmic medium can act like a quantum amplifier or generator (maser). The radio-emission gain will depend on the frequency ν and the angle ϑ between the direction of the orienting radiation and the direction of propagation of the radio wave

$$\tau(\nu,\ \vartheta) = 0.1\ n l \cos^2\vartheta \exp[-6.6 \times 10^{-8}(\nu - \nu_0)^2], \tag{2}$$

where l is the path length of the radio wave in the inversion medium in parsecs, n is the number of H I atoms per cm^2 (the kinetic temperature is assumed to be $T_k = 150°$K). At $\nu = \nu_0$, $\vartheta = 0°$, and $n = 10^2$ cm^{-3} the radiation intensity increases by a factor $\exp(10 l)$. The populations (1) used in the calculation of τ correspond to a constant spectrum of the orienting radiation. If the radiation spectrum increases $(dI/d\nu > 0)$, on the other hand, then the degree of population inversion will be even higher.

Such a situation should take place not only for H I atoms, but also for other atoms and molecules of the cosmic medium, particularly OH molecules. In fact, the anomalous intensities of the cosmic radio emission components at $\lambda = 18.5$ cm, corresponding to transitions between the lapse of the Λ-doublet of OH [1], can be attributed in many cases to coherent amplification due to optical pumping. We note that the populations of the sublevels of the ground state of OH are very sensitive to the form of the spectrum of the optical radiation, and this is in part due to the fact that several spectral lines practically coincide with the resonant frequencies of OH. (For example, the $\lambda = 3063$ Å line of NII coincides with the resonant transition ${}^2\Sigma^+_{v=0,k=3,J=5/2} \to {}^2\Pi_{3/2\ v=0,k=1,J=3/2}$.)

Coherent amplification of cosmic radio emission must be expected primarily in regions directly adjacent to the ionization zone of hot stars.

The difference between such a natural cosmic maser and the laboratory device lies primarily in the fact that in astrophysical systems there are no reflectors or resonators, and no standing waves are set up. Essentially these are coherent traveling-wave amplifiers. The amplification of the radiation is not the result of multiple passage of the ray through the same bounded volume of gas, but the result of the giant dimensions of the amplifying system. In the laboratory device, the presence of resonators and reflectors leads to appreciable loss of radiation energy. Under astrophysical conditions there is no such loss. Therefore even a small degree of population inversion turns out to be sufficient for effective amplification.

Thus, in the stationary amplification mode, part of the energy of the optical band will be continuously transformed into radio-emission energy. A particularly large amplification effect can be observed in nova and supernova flares. In this case the excitation energy accumulated by the atoms and molecules can be released in the form of a brief but very intense burst of radio emission. This phenomenon could be observed by comparing curves characterizing the time variation of the intensity of the optical and radio emissions during the initial stage of the flare.

The foregoing gives grounds for assuming that coherent amplification of radiation is a widespread phenomenon in the Universe.

I am grateful to Doctor of Physico-mathematical Sciences A. Z. Dolginov for a useful discussion and valuable advice. I am also grateful to the participants of the Main Astronomical Observatory Seminar, and especially Doctor of Physico-mathermatical Sciences I. S. Shklovskii for a discussion of the present results and for the idea of using the results to explain the anomaly in the cosmic radio emission of OH.

[1] R. X. McGee, B. J. Robinson, F. F. Gardner, and J. G. Bolton, Nature <u>208</u>, 1193 (1965).

GIANT SUPERLUMINESCENCE PULSES

V. S. Zuev, V. S. Letokhov, and Yu. V. Senatskii
P. N. Lebedev Physics Institute, USSR Academy of Sciences
Submitted 17 June 1966
ZhETF Pis'ma 4, No. 5, 182-185, 1 September 1966

1. The giant pulses of coherent light emitted by Q-switched lasers are widely known [1-3]. For research in nonlinear optics, or for investigations of the mechanism of damage to transparent materials by a strong light field, it is of interest also to employ sources of