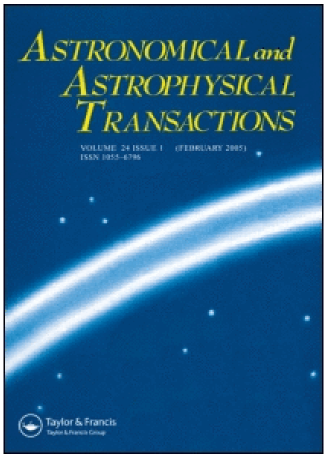

Astronomical & Astrophysical Transactions
The Journal of the Eurasian Astronomical Society
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713453505

Cosmic synchrotron maser

V. V. Zheleznyakov [a]; S. A. Koryagin [a]; G. Thejappa [b]
[a] Institute of Applied Physics, Nizhni Novgorod, Russia
[b] University of Maryland, MD, USA

Online Publication Date: 01 August 2001
To cite this Article: Zheleznyakov, V. V., Koryagin, S. A. and Thejappa, G. (2001) 'Cosmic synchrotron maser', Astronomical & Astrophysical Transactions, 20:2, 333 - 335
To link to this article: DOI: 10.1080/10556790108229723
URL: http://dx.doi.org/10.1080/10556790108229723

Astronomical and Astrophysical Transactions, 2001,
Vol. 20, pp. 333–335
Reprints available directly from the publisher
Photocopying permitted by license only

COSMIC SYNCHROTRON MASER

V. V. ZHELEZNYAKOV,[1] S. A. KORYAGIN,[1] and G. THEJAPPA[2]

[1] *Institute of Applied Physics, RAS, Nizhni Novgorod 603600, Russia*
[2] *University of Maryland, College Park, MD 20742, USA*

(Received November 21 2000)

We analyze synchrotron emission of relativistic electrons with an energy distribution giving rise to negative reabsorption (a synchrotron maser). The outgoing radiation from a homogeneous plasma layer was calculated for a fixed relativistic electron distribution over momenta and in a self-consistent, steady-state case.

KEY WORDS Masers, radiation mechanisms: non-thermal

The synchrotron reabsorption coefficient

$$\mu(\omega,\alpha) = \frac{4\pi^3 c}{\omega^2} \int_0^\infty \mathrm{d}p\, f(p,\theta)\, \frac{\partial}{\partial p}(p^2 P_\omega)\Bigg|_{\theta=\alpha}, \tag{1}$$

obtained by the method of Einstein coefficients (Wild *et al.*, 1963), depends on the specific power $P_\omega(\omega, p, \theta)$ of radiation of an electron with the momentum p and the pitch-angle θ. Here $f(p,\theta)$ is the electron distribution over momenta $\mathbf{p}$. The reabsorption coefficient (1) is negative only if the quantity $p^2 P_\omega(\omega, p, \theta)$ decreases with increasing electron momentum. In vacuum, $p^2 P_\omega$ is an increasing function of the electron momentum p. Therefore, the reabsorption coefficient μ in vacuum is always positive for any isotropic distribution $f(p)$. In a cold plasma, synchrotron emission at a given frequency ω becomes significantly depressed (Tsytovich, 1951; Razin, 1960; Ginzburg and Syrovatskii, 1966) if $p \gtrsim mc\omega^2\omega_B \sin\theta/\omega_{\mathrm{L}}^3$. Here ω_{L} is the Langmuir frequency of a cold plasma, ω_B is the nonrelativistic electron gyrofrequency. The exponential cutoff of the synchrotron emission power yields a negative reabsorption coefficient (maser effect) if energetic electrons provide the main contribution to the integral (1) (Zheleznyakov, 1966; McCray, 1966).

For the qualitative analysis, let us consider a distribution of relativistic electrons $f(p)$ which equals $A\,(p/p_0)^{-\gamma_1}$ if $p < p_0$ and $A\,(p/p_0)^{-\gamma_2}$ if $p > p_0$ (here A is a constant). If $\gamma_1 < 0$ and $\gamma_2 > 0$, this distribution peaks at the momentum $p = p_0$ and provides population inversion at $p < p_0$. We calculate the outgoing radiation from a homogeneous plasma layer for $\gamma_1 = -1$ and $\gamma_2 = 5$. We find that two characteristic maxima appear in the spectra. The first, low-frequency maximum at

$\omega \sim \omega_{\rm sm}(p_0) = \omega_{\rm L}^{3/2}\,(\omega_B \sin\alpha)^{-1/2}\,(p_0/mc)^{1/2}$ occurs due to the enhanced action of the synchrotron maser. The second, high-frequency one arises as a result of the positive reabsorption that leads to a depression on the low-frequency side of the maximum.

The inverse influence of the intense radiation on the electron distribution tends to destroy the population inversion. Eventually, this process forms a plateau-like distribution function for which $\gamma_1 \to 0$. In this case, the frequency spectrum also exhibits two maxima. The low-frequency maximum is determined by a sharp decrease of the reabsorption at $\omega \sim \omega_{\rm sm}(p_0)$. Our calculations show that the low-frequency maximum disappears for $\gamma_1 \geq 0.04$ if $\gamma_2 \gg 1$.

In more detailed calculations, we analyze the self-consistent solution of the system of equations comprising the quasi-linear kinetic equation

$$c\cos\theta\,\frac{\partial f}{\partial z} = p^{-2}\frac{\partial}{\partial p}\left[p^2\int\limits_0^\infty \mathrm{d}\omega\,\frac{P_\omega}{c}\left(f + \frac{4\pi^3 c I_\omega|_{\alpha=\theta}}{\omega^2}\,\frac{\partial f}{\partial p}\right)\right] - p^{-2}\frac{\partial}{\partial p}\left(p^2 a_{\rm acc} f\right)$$

for relativistic electrons and the radiation transfer equation in a homogeneous layer of a cold plasma. An external (nonsynchrotron) mechanism is assumed to accelerate the electrons and thus compensate their synchrotron energy losses. We assume the external acceleration to be a power-law: $a_{\rm acc}(p) = a_{\rm sp}(p_0)(p/p_0)^{\delta}$, where the parameter $\delta < 2$. In this case, the acceleration $a_{\rm acc}(p)$ of the electrons with $p < p_0$ exceeds their deceleration $a_{\rm sp}(p) \propto p^2$ due to spontaneous emission.

We calculate frequency spectra of the synchrotron-maser radiation in a thick plasma layer in which the outgoing radiation is independent of that incoming. One can distinguish two characteristic types of synchrotron-maser spectra, which are realized at different δ (Zheleznyakov and Koryagin, 2000).

If $\delta < -13/6$, the spectra take the form $I_\omega(\omega, z, \theta) = Z(z, \theta)V(\omega)$ at the low frequencies $\omega \lesssim \omega_{\rm sm}(p_0)$ where the maser mechanism operates. The frequency profile $V(\omega) = V_0\omega^{\alpha}$ is a power-law function with index $\alpha = 2\delta + 5 < 2/3$. At frequencies $\omega \sim \omega_{\rm sm}(p_0)$ the intensity I_ω reaches a maximum and decreases steeply on the high-frequency side. At higher frequencies $\omega_{\rm sm}(p_0) \ll \omega \lesssim \omega_B(p_0/mc)^2$ the reabsorption is positive and the spectra are determined by the equilibrium of spontaneous emission and reabsorption. Here the frequency profile $I_\omega \propto \omega^2$. If $\delta > -13/6$, the power-law spectrum cannot exist at $\omega \lesssim \omega_{\rm sm}(p_0)$. The amplification has a maximum at some frequency $\omega_0 \lesssim \omega_{\rm sm}(p_0)$. Eventually, the radiation energy concentrates near this frequency ω_0.

We conclude that a distinguishing feature of synchrotron-maser radiation is its double-peak spectrum. Moreover, the maser radiation at low frequencies should have strong circular polarization and be time-dependent.

References

Ginzburg, V. L. and Syrovatskii, S. I. (1966) *Usp. Fiz. Nauk* **87**, 65.
McCray, R. (1966) *Science* **154**, 1320.
Razin, V. A. (1960) *Izv. Vyssh. Uchebn. Zaved., Radiofiz.* **3**, 584.

Tsytovich, V. N. (1951) *Bull. Moscow State Univ.* **11**, 27.
Wild, J. P., Smerd, S. F., and Weiss, A. A. (1963) *Ann. Rev. Astron. Astrophys.* **1**, 291.
Zheleznyakov, V. V. (1966) *Zh. Éksp. Theor. Fiz.* **51**, 570.
Zheleznyakov, V. V. and Koryagin, S. A. (2000) *Izv. Vyssh. Uchebn. Zaved., Radiofiz.* **43**, No. 7.