Solar flare radio spikes

Yu.E. Charikov[1] **and A.G. Stupishin**[2]

[1] Ioffe Physical-Technical Institute, St. Petersburg, Russia
[2] St. Petersburg State University, St. Petersburg, Russia

According to the modern theory, solar flares originate in interacting or unstable magnetic loops in the lower corona and/or higher chromosphere. Accelerated electrons moving along magnetic fields generate both electromagnetic waves and plasma waves as soon as a beam distribution dominates the thermal tail. Another distribution is characterized by a beam feature along the ambient magnetic field and a ring distribution in the transverse direction. Such a distribution may result from the initial oblique injection of an energetic electron beam into a uniformly magnetized plasma (hollow-beam distribution, see e.g. Wu, 1985).

Decimetric and microwave radio spikes have the time scales of $20 - 200$ ms, an extremely high maximum flux is up to $10^4 - 10^5$ s.f.u., a high degree of circular polarization which can be interpreted as Electron Cyclotron Maser emission (Benz, 1986). However, there are several reasons why we consider the gyrosynchrotron maser as the mechanism of radio spikes in solar flares (Mosunov, Charikov, 1995; Stupishin, Charikov, 1998). One of the reason is the observation of spike emission up to eight harmonic of gyrofrequency (Güdel, 1991).

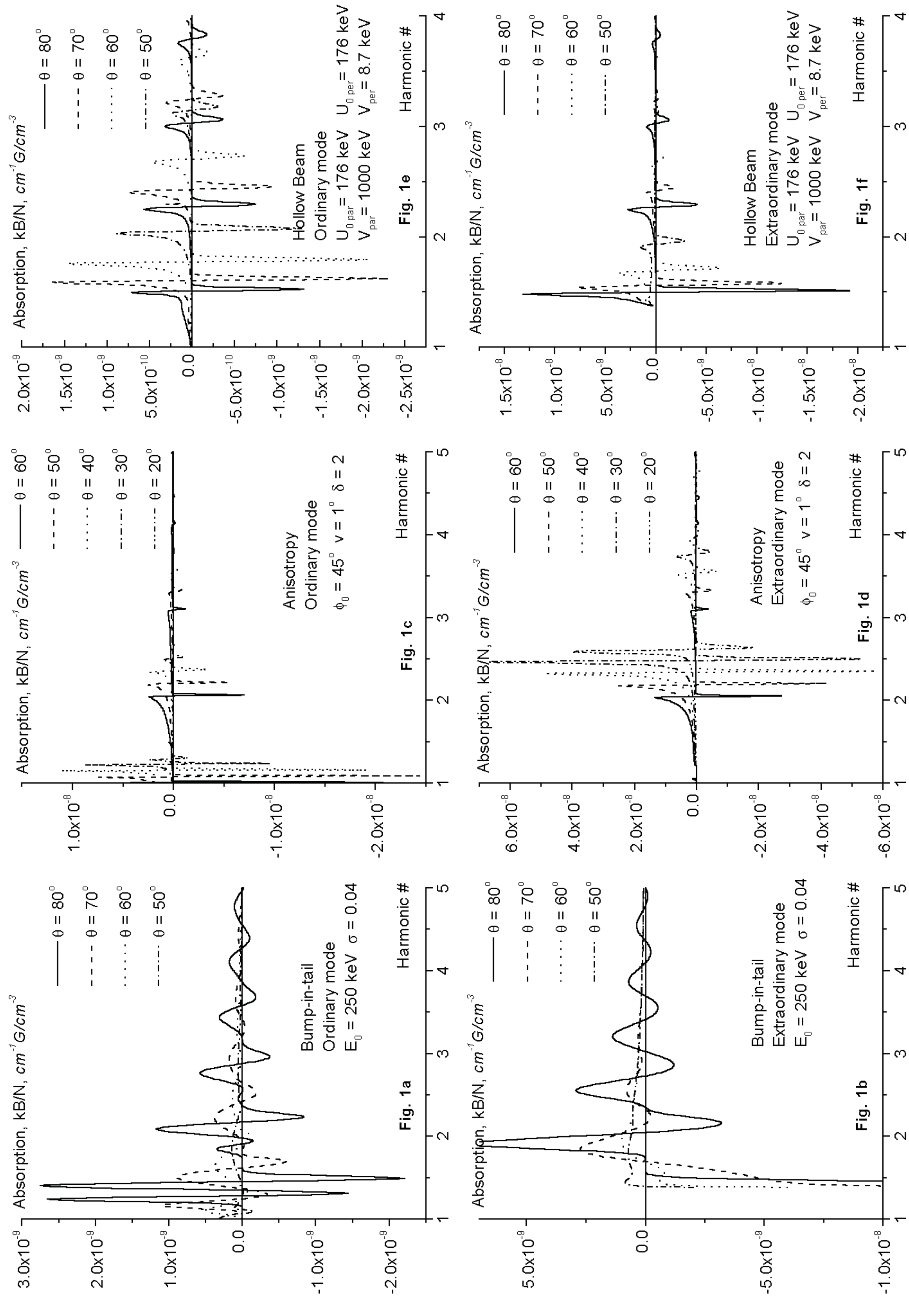
Here we considered three types of electron distributions:

1. Bump-in-tail distribution $\propto \exp(-((\gamma - \gamma_0)/\sigma)^2)$, where γ is Lorenz factor, γ_0 and σ are distribution parameters.
2. Anisotropy power-law distribution $\propto \exp(-((\varphi - \varphi_0)/\nu)^2) \times (\gamma - 1)^\delta$, where φ is pitch angle, φ_0, ν are distribution parameters and δ is power-law index.
3. Hollow-beam distribution $\propto \exp(-(\frac{U_\| - U_{0\|}}{V_\|})^2 - (\frac{U_\perp - U_{0\perp}}{V_\perp})^2)$, where $U_\| = U\cos\phi$, $U_\perp = U\sin\phi$, U is the energy, ϕ is pitch angle, $U_{0\|}, V_\|, U_{0\perp}, V_\perp$ are distribution parameters.

Gyrosynchrotron emission was calculated according to Ramaty (1969) with the corrections made by Trulsen and Fejer (1970). Some results are discussed below.

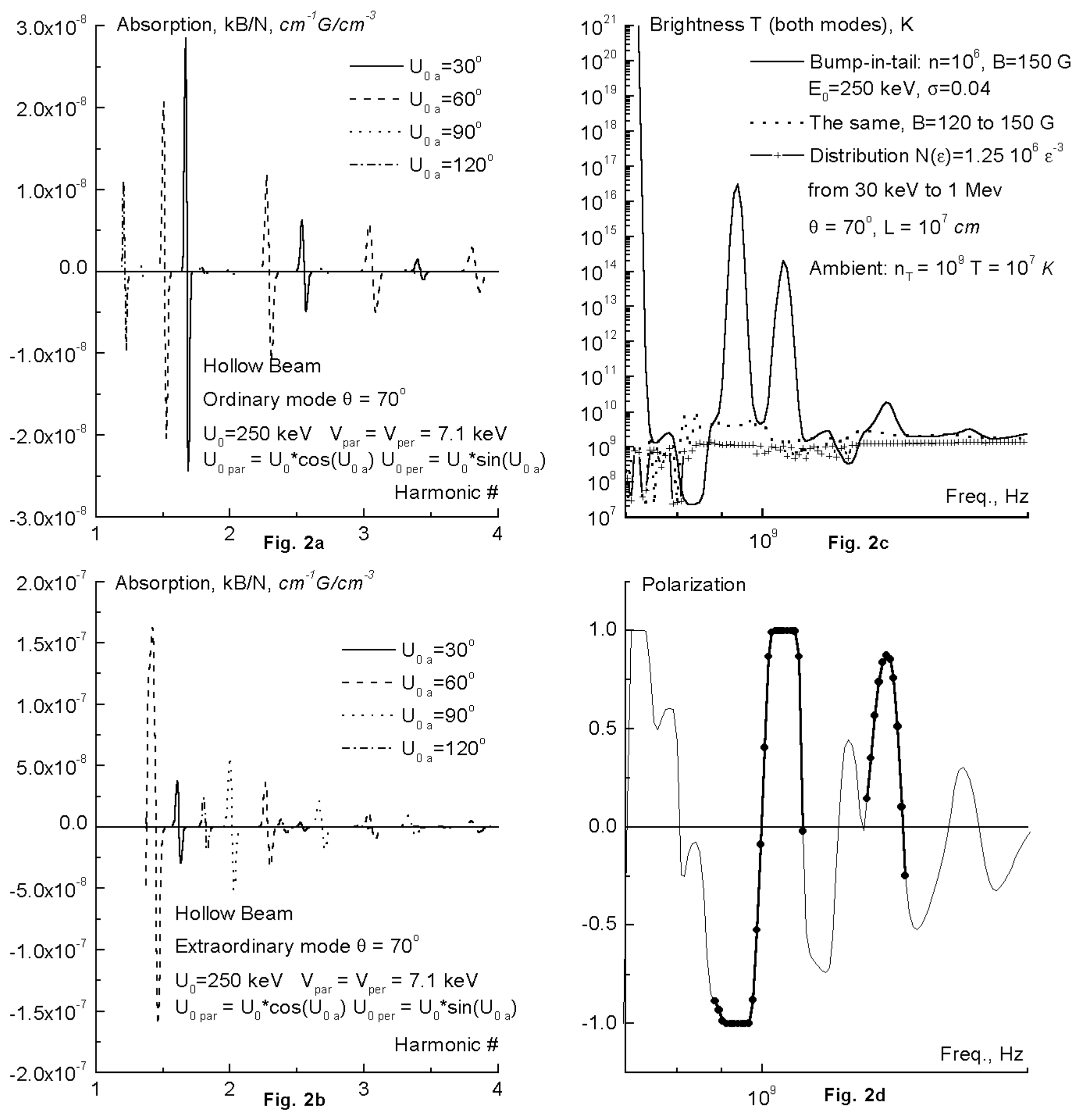
Behaviour of absorption coefficient vs. harmonic of gyrofrequency for various parameters is shown on Fig. 1 (here θ is view angle) for ordinary and extraordinary mode. Maser emission can be generated if absorption is negative. We can make some general remarks analyzing Fig. 1.

1. In all cases we can see a harmonic structure of absorption coefficient. Width of harmonic (we consider a negative areas) is about $0.3 f_B$ (f_B is the electron gyrofrequency) for bump-in-tail distribution, and less $(0.05 - 0.2 f_B)$ for anisotropy and


Absorption, kB/N, cm^-1 G/cm^-3
Harmonic #
Bump-in-tail
Ordinary mode
E0 = 250 keV σ = 0.04
θ = 80°
θ = 70°
θ = 60°
θ = 50°
Fig. 1a
Bump-in-tail
Extraordinary mode
E0 = 250 keV σ = 0.04
Fig. 1b
Anisotropy
Ordinary mode
φ0 = 45° ν = 1° δ = 2
θ = 40°
θ = 30°
θ = 20°
Fig. 1c
Anisotropy
Extraordinary mode
φ0 = 45° ν = 1° δ = 2
Fig. 1d
Hollow Beam
Ordinary mode
U0 par = 176 keV U0 per = 176 keV
V par = 1000 keV V per = 8.7 keV
Fig. 1e
Hollow Beam
Extraordinary mode
U0 par = 176 keV U0 per = 176 keV
V par = 1000 keV V per = 8.7 keV
Fig. 1f

hollow-beam. In the other hand, absolute negative value of absorption is larger for two last distributions. So we can conclude that spike radio emission can be observed most probably, from bump-in-tail distribution, while spike fluxes can be larger from the electrons with anisotropy and hollow-beam distributions. Note that in the case of bump-in-tail distribution the absolute negative value decreases slowly to the higher harmonics at large angles of view, so it can explain multiple harmonics in spike observations (Güdel, 1991).

2. Absolute value, position and frequency interval between harmonics are strongly depends on view angle. For bump-in-tail, the interval is about $0.7 f_B$; position of harmonics is varying with view angle for ordinary mode, and practically do not varying for extraordinary one. Absolute value of absorption coefficient is significantly negative for view angles $> 70°$. For other distributions the the interval between harmonics is larger $(0.7 - 1.2 f_B)$. Maximal absolute negative value appears when view angle is close to the dominating pitch angle of distribution. An example of dependency on dominating pitch angle for hollow-beam distribution is shown in Fig. 2a, b.



Now we consider a spike brightness temperature. It is necessary to know a source parameters (electron density n_T, electron temperature T, magnetic field B, and source depth L). The value of source depth of about 100 km was estimated by Stupishin and Charikov (1998). From Fig. 2c we can see that brightness temperature also has a harmonic structure, and can achieve a great values at lower harmonics. On the same Figure the brightness temperature for power-law isotropic distribution is shown for the sake of comparison. The gain due to negative absorption can be up to 10^7 times.

It is necessary to say that this effect is sensitive to the variation of magnetic field along view direction. On the same Figure the brightness temperature from the source with random magnetic field variation (from 120 to 150 G) is shown. We can see that there is no gain effect in this case.

An example of polarization vs. frequency is shown on Fig. 2d for the same source and distribution. The value of polarization can varying from -100% to $+100\%$ with frequency change of about $0.1 f_B$.

The time profile of a spike is a likely to be determined by saturation of the instability as a result of a nonlinear interaction of the beam with plasma turbulence (Charikov and Kudrjavtsev, 1991). The typical time results $20 - 40$ ms which contradicts to the quasi-linear time scale of about 100 μs (Charikov and Fleishman, 1992) and the plasma turbulence level should be equal to 10^{-3}.

As we can conclude, effect of negative absorption is very sensitive to the source parameters and to particle distribution. Hence that may be the reason why radio spikes in solar flares are observed quite rarely.

References

Benz A.O. 1986, Solar Phys., 104, 99

Charikov Yu.E., Fleishman G.D. 1992, Solar Phys., 139, 387

Charikov Yu.E., Kudrjavtsev I.V. 1991, Flares 22 Workshop, Observatoire de Paris, DASOP, 57

Güdel M. 1991, Doctoral Theses, Swiss Federal Institute of Technology, Zurich

Ramaty, R. 1969, Ap. J., 158, 753

Stupishin A.G., Charikov Yu.E. 1998, In: Success and Problems of Solar Radioastronomy, conference theses, St.Petersburg, 6-9 October 1998

Trulsen, J., Fejer, J.A. 1970, J. Plasma Phys., 4, 825

Mosunov A.N., Charikov Yu.E. 1995, Astron. Zh., 72, 911

Wu C.S. 1985, Space Sci. Rev., 41, 215