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ON THE POSSIBILITY OF THE THRESHOLD DRIFT INVERSION IN QPESIC INSTABILITIES IN WEAKLY IONIZED PLASMAS WITH ELECTRIC CURRENT FLOWING ALONG THE MAGNETIC LINES OF FORCE

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Abstract: The process of spontaneous excitation of quasi-perpendicular ion-cyclotron (QPESIC) waves of growing amplitude by an electron drift parallel to the lines of force of the magnetization field is studied theoretically in uniform weakly ionized plasmas with one ion species. It is shown that, by an appropriate treatment of the ionic off-resonance terms in the dispersion equation, one arrives at the prediction of a drift-inversion effect, i.e. the possibility that, under certain circumstances, modes pertaining to higher-order ion-cyclotron (IC) harmonics may require smaller threshold drifts than those corresponding to the lower-order ones. In the theory presented herewith, the drift inversion takes place with $T_e/T_i \approx 5$, and becomes all the more prominent as T_e/T_i is further increased. The effect is also dependent on the ion charge number z_i, being more noticeable (setting in with lower values of T_e/T_i) with doubly-charged ions than with the singly-charged ones. Most of these features seem to agree with certain experimental data.

1. Introduction

Spontaneous excitation of quasi-perpendicular electrostatic ion-cyclotron (QPESIC) instabilities (in the form of waves of growing amplitude) pertaining to various ion-cyclotron (IC) harmonics (i.e. having modal frequencies close to $R\omega_{Bi}$, $R = 1, 2, 3, ...$) by an electron drift parallel to magnetic lines of force and exceeding some threshold value was theoretically predicted long ago [1,2] and has since been experimentally observed under a variety of conditions [3-6]. One of the basic theoretical features disclosed at the earlier stage of the investigations was the prediction that the threshold drifts should increase with the number of the harmonic. In other words, if the electron drift is gradually augmented,

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one should observe the instability pertaining to $R = 1$ first, the instability $R = 2$ should come in next, etc. However, in non-isothermal plasmas with $T_e/T_i > 1$ (e.g. in gas discharges, or in the Q-machine plasmas with additional r.f. heating) one sometimes observes [3,5,6] simultaneous excitation of instabilities pertaining to various harmonics with (practically) the same drift, or even the onset of the higher-order instability sooner than the lower-order one, a situation which we designate here as the drift inversion.

The majority of theories of the IC instabilities is based on the so-called "one-harmonic approximation", in which only the resonant term (i.e. the one corresponding to $\omega \approx R\omega_{Bi}$) is retained in the infinite sum representing the ionic contribution to the dispersion equation. This approximation is unquestionably correct in plasmas with $T_e/T_i \ll 1$ [1], but the thus evaluated threshold drifts exhibit no inversion tendencies: they monotonically increase with R (if other relevant plasma parameters are kept fixed), irrespective of the plasma characteristics. With larger values of T_e/T_i, the off-resonance terms become significant as well [7,8], particularly as T_e/T_i attains the values larger than unity [9]. The approximations used in accounting for the off-resonance terms so far (the so-called Approximation I and Approximation II [9]) were actually applicable to lower-order harmonics($R \leq 3$) and moderate non-isothermalities ($T_e/T_i \leq 10$) only; consequently, the prediction of the Approximation II that a drift inversion of the modes $R = 1$ and $R = 2$ should be expected at $T_e/T_i = 4.5$ might arouse some scepticism, since this critical value of T_e/T_i seems to be rather close to the upper limit allowed by the Approximation itself. In this paper, therefore, an analytical method (Approximation III) suitable for higher non-isothermalities ($T_e/T_i \leq 20$) and higher-order IC harmonics ($R \leq 6$) is developed and applied to one-ion uniform weakly ionized plasmas. It is shown that, in the longwave domain where the electron collisions are particularly significant, a drift inversion involving not only the harmonics $R = 1$ and $R = 2$, but also the higher-order ones, indeed takes place for the non-isothermalities above $T_e/T_i \approx 5$.

2. Basic Relations

In the present work, the attention is focused on QPESIC waves and instabilities in the longwave domain ($\nu_e \gg k_\parallel v_{Te}$; $\omega\nu_e \ll k_\parallel^2 v_{Te}^2$, since the quasi-perpendicular instabilities in magnetized plasmas are known to be the easiest to excite here. The electronic contribution to the dispersion equation in this domain has the form [9]:

$$\delta\varepsilon_e^{(b)} = \frac{\omega_{pe}^2}{k^2 v_{Te}^2}\left(1 + i\frac{\nu_e}{k_\parallel v_{Te}}\frac{\omega - k_\parallel u}{k_\parallel v_{Te}}\right). \tag{1}$$

The ionic contribution is an infinite sum over all the IC harmonics and, for the quasi-perpendicular propagaton of the waves (ω, $|\omega - R\omega_{Bi}| \gg k_\parallel v_{Ti}$, ν_i), it reads

$$\delta\varepsilon_i = \frac{\omega_{pi}^2}{k^2 v_{Ti}^2}\left[1 - \sum_{m=-\infty}^{+\infty}\frac{\omega A_m(\mu_i)}{\omega - m\omega_{Bi}}\left(1 + i\frac{\nu_i}{\omega - m\omega_{Bi}}\right)\right]. \tag{2}$$

In the above expressions, $\omega_{p\alpha}$, $v_{T\alpha}$ and ν_α ($\alpha = e, i$) are, respectively, plasma frequency, thermal velocity and collision frequency of the constituent α, ω_{Bi} is the ion gyrofrequency, $k_\perp$ and $k_\parallel$ are the projections of the wave vector with respect to the magnetic lines of force,

$\mu = k_\perp^2 v_{Ti}^2/\omega_{Bi}^2$ is the finite Larmor radius parameter, and $A_m(\mu) = I_m(\mu)\exp(-\mu)$ with $I_m(\mu)$ denoting the modified Bessel functions of the first kind. The dispersion equation for electrostatic waves reads

$$\delta\varepsilon_e + \delta\varepsilon_i = 0; \tag{3}$$

consequently, it may be easily written out with the aid of (1) and (2).

Expression (2) can be simplified prior to insertion into (3). In the "one-harmonic approximation", only the resonant term (i.e. the addend corresponding to $m = R$, if one aims at studying the Rth harmonic) is retained in both real and imaginary parts of (2); the resulting spectrum and marginal instability condition, however, lead to no drift inversion, irrespective of the plasma parameters. The best way to account for the off-resonance terms [all the addends with $m \neq R$ in (2)] proposed so far [8,9] is to insert $\omega = R\omega_{Bi}$ in all of them (Approximation II). The results obtained by this procedure were related to the following functions

$$S^{(R)}(\mu) = R\sum_{m\neq R}\frac{A_m(\mu)}{R-m}, \qquad D^{(R)}(\mu) = R\sum_{m\neq R}\frac{A_m(\mu)}{(R-m)^2}, \tag{4}$$

which will be useful in the present work as well, but the whole idea of the Approximation II proved satisfactory for moderate non-isothermalities ($T_e/T_i \leq 10$) and lower-order harmonics ($R \leq 3$) only. Basicaly, this is brought about by the fact that, within a certain range of values of the variable μ, the evaluated difference $\omega - R\omega_{Bi}$ is comparatively large and tends to increase as T_e/T_i is augmented, so that the modal frequencies pertaining to the Rth harmonic eventually come up too close to $(R+1)\omega_{Bi}$. This indicates that the term $m = R+1$ cannot be regarded as a small corection, at least in the real part of (2), if T_e/T_i is sufficiently large.

In the present work, therefore, the analysis of the QPESIC instabilities is carried out by retaining the terms $m = R$ and $m = R+1$ in the real part of (2), and the term $m = R$ in its (much smaller) imaginary part, and by letting $\omega = R\omega_{Bi}$ in the remaining off-resonance terms. For the sake of brevity, this evaluation procedure will be referred to as Approximation III. The ionic contribution (2) then assumes the form:

$$\delta\varepsilon_i = \frac{\omega_{pi}^2}{k^2 v_{Ti}^2}\left\{1 - \frac{A_R(\mu)}{W_R(\mu)} - \frac{RA_{R+1}(\mu)}{(R+1)W_R(\mu)-1} - \left[S^{(R)}(\mu) + RA_{R+1}(\mu)\right] + \right.$$
$$\left. + i\frac{\nu_i}{\omega}\left[\frac{A_R(\mu)}{W_R(\mu)} + \frac{RD^{(R)}(\mu)}{1-W_R(\mu)}\right]\right\}, \tag{5}$$

where, much as in the previous studies, one introduces the quantity

$$W_R(\mu) = \frac{\omega - R\omega_{Bi}}{\omega}, \tag{6}$$

which conveniently specifies the spectrum, the connecting expression being

$$\omega = \frac{R\omega_{Bi}}{1 - W_R(\mu)}. \tag{7}$$

The corresponding dispersion equation is obtained by inserting (1) and (5) into (3), but the ensuing relation will be omitted here.

3. The Sspectra

From $\mathrm{Re}(\delta\varepsilon_e + \delta\varepsilon_i)$=0, one obtains the folloving quadratic equation for $W_R(\mu)$:

$$(R+1)N_R(\mu)W_R^2(\mu) - M_R(\mu)W_R(\mu) + A_R(\mu) = 0, \tag{8}$$

with

$$M_R(\mu) = T - S^{(R)}(\mu) + (R+1)A_R(\mu), \tag{8a}$$

$$N_R(\mu) = T - S^{(R)}(\mu) - RA_{R+1}(\mu). \tag{8b}$$

Here $T = 1 + (z_i\tau)^{-1}$, with z_i being the ion charge number, and $\tau = T_e/T_i$. The solutions of (8) are easy to find. Only one of these satisfies the requirement $W_R(0) = 0$ [the other solution amounts to $(R+1)^{-1}$ for $\mu = 0$], and it is the one to be chosen for the problem investigated. After some simplifications, this solution assumes the form:

$$W_R(\mu) = \frac{2A_R(\mu)}{M_R(\mu) + \sqrt{M_R^2(\mu) - 4(R+1)A_R(\mu)N_R(\mu)}}. \tag{9}$$

For the sake of comparison, it may be mentioned that the results analogous to (9) in the "one harmonic approximation" and Approximation II [9] read:

$$W_R^{(a)}(\mu) = \frac{A_R(\mu)}{T}, \qquad W_R^{(b)}(\mu) = \frac{A_R(\mu)}{T - S^{(R)}(\mu)}. \tag{10a,b}$$

The function (9) will not be presented graphically here, as its graph does not differ qualitatively from those of (10a) or (10b) shown earlier [9]: it starts from zero for $\mu = 0$, passes through a maximum and then decreases again, tending asymptotically to zero as $\mu \to \infty$.

The scope of applicability of the Approximation III [i.e. the significance of the term $m = R+1$, retained in the real part of (2) in writing out the expression (5)] is illustrated by the figures in Table 1. at the end of the text. They give the coordinates $(\tilde{\mu}_R, \widetilde{W}_R)$ of maxima of the functions (9) for the first six IC harmonics and for $z_i\tau$ ranging from 0.1 to 20. Whenever available, the corresponding data, as evaluated with the functions (10b), are also shown (figures in brackets) for the sake of comparison of the present data with those of Approximation II. [This latter Approximation is limited by the requirement $\widetilde{W}_R < (R+1)^{-1}$, and the dashes, appearing in certain places in the lines of figures pertaining to it, indicate that the data are not available, since this requirement has become violated].

An inspection of the figures pertaining to the Approximation III in the Table given discloses that the positions of the maxima of the functions (9) are gradually displaced to the left and upwards if $z_i\tau$ increases while R is kept fixed, and to the right and downwards if the number of the IC harmonic is increased with constant non-isothermality parameter. This is quite similar to the analogous features found within the frames of the Approximation II [9], although there may appear some noticeable quantitative differences. The Approximation III yields the positions of the maxima systematically displaced to the left and downwards, as compared with those obtained in Approximation II for the same values of R and $z_i\tau$. These differences, and their trends in particular, clearly demonstrate the scopes of the Approximation III. In this context, two basic features emerge from the figures given:

(a) The differences in the positions of the maxima, as evaluated on the ground of the Approximations II and III, begin to show up with $z_i\tau \geq 0.5$, quite in agreement with the early conclusion [1] that the "one-harmonic approximation" is wholly satisfactory if $z_i\tau \ll 1$. These differences (especially regarding the ordinates) become quite noticeable (larger than 15%) with $z_i\tau \geq 2$ for $R = 4, 5$ and 6, with $z_i\tau \geq 4$ for $R = 2$ and 3 (for $R = 3$, $\widetilde{W}_3$ may be calculated within the Approximation II in this non-isothermality domain, but this is merely formal and of little use, as the resulting values for $\widetilde{W}_3$ exceed 1/4), and with $z_i\tau \approx 20$ for $R = 1$.

(b) With the Approximation III, the requirement $\widetilde{W}_R < (R+1)^{-1}$ is satisfied, for all the IC harmonics investigated ($R \leq 6$), and for all the non-isothermalities considered ($z_i\tau \leq 20$); for $z_i\tau = 20$ the values or $\widetilde{W}_R$ are already quite close to $(R+1)^{-1}$, the closer the higher the order of the harmonic. It ought to be mentioned, however, that the requirement $\widetilde{W}_R < (R+1)^{-1}$ is no longer necessary for the Approximation III, as the term $m = R+1$ was explicitely taken into account.

4. Marginal Instability and Threshold Drifts

The condition of marginal instability (zero amplitude increment) is $\mathrm{Im}(\delta\varepsilon_e + \delta\varepsilon_i)=0$. This determines the critical electron drift for which the weakly damped waves pertaining to the given IC mode turn into waves of growing amplitude in the given direction of wave propagation (given values of $k_\parallel$ and $k_\perp$). After some modifications, this condition can be given the following form:

$$\left(\frac{u}{v_{Ti}}\right)_R = \frac{\xi_R}{W_R(\mu)} + \frac{\omega_{pi}^2}{\omega_{pe}^2}\left(\frac{v_{Te}}{v_{Ti}}\right)^4 \frac{\nu_i}{\nu_e}\frac{W_R(\mu)}{\xi_R}\left[\frac{A_R(\mu)}{W_R^2(\mu)} + \frac{RD^{(R)}(\mu)}{1-W_R(\mu)}\right]. \tag{11}$$

Here, $\xi_R = (\omega - R\omega_{Bi})/k_\parallel v_{Ti}$ and, consequently, the direction of the wave propagation mentioned is actually determined by the values of ξ_R and μ. The threshold drift is the minimum value of the above critical drifts [1], and it corresponds to some direction of wave propagation (specified by the values ξ_R^* and μ_R^*) not known beforehand. Both the threshold drift and the direction of propagation of the instability caused by it are to be determined from the conditions

$$\frac{\partial}{\partial\xi_R}\left(\frac{u}{v_{Ti}}\right)_R = 0, \qquad \frac{\partial}{\partial\mu}\left(\frac{u}{v_{Ti}}\right)_R = 0. \tag{12}$$

The solution of the system of equations (12) [their explicit form is easily established on the ground of (11)] yields ξ_R^* and μ_R^*; if these are inserted back into (11) one obtains $(u_{thr}/v_{Ti})_R$, i.e. the threshold drifts for the Rth harmonic. Moreover, if μ_R^* is inserted into (9) and then combined with (7), the modal frequency at which the instability sets in first (this is not exactly $R\omega_{Bi}$) can be determined as well. The same applies to the direction of propagation of this incipient instability; the angle it forms with the magnetic lines of force is given by $\tan\theta_R^* = \frac{k_\perp^*}{k_\parallel^*} = \frac{1}{R}\xi_R^*\sqrt{\mu_R^*}\frac{1-W_R(\mu_R^*)}{W_R(\mu_R^*)}$.

The details of solving (12), combined with (11), additionaly depend on the model adopted for the collision processes, as this determines the ratio ν_i/ν_e appearing in (11). In the present work the weakly ionized plasmas are considered, so that only the collisions of ions and electrons with the neutrals are to be taken into account, and these are assumed to comply to the strict billiard-ball model, so that one has $\nu_i/\nu_e = v_{Ti}/v_{Te}$. Under this assumption (11) becomes

$$\left(\frac{u}{v_{Ti}}\right)_R = \frac{\xi_R}{W_R(\mu)} + z_i \left(\frac{m_i}{m_e}\right)^{1/2} \left(\frac{T_e}{T_i}\right)^{3/2} \frac{W_R(\mu)}{\xi_R} Q_R(\mu), \tag{13}$$

where $Q_R(\mu)$ is an abbreviation for the expression in square brackets in (11). The procedure of dealing with (13) was elaborated previously [9], so that here one may immediately write down the result:

$$\left(\frac{u_{thr}}{v_{Ti}}\right)_R = 2\sqrt{z_i}\,\tau^{3/4} \left(\frac{m_i}{m_e}\right)^{1/4} \sqrt{(Q_R)_{min}}\,. \tag{14}$$

The minima of $Q_R(\mu)$, with $W_R(\mu)$ taken in the form (9) {instead of (10b) as in ref. [9]}, were determined numerically for various combinations of R and $z_i\tau$ in the present work. It will be convenient to re-write (14) in the form:

$$\left(\frac{u_{thr}}{v_{Ti}}\right)_R = \left(\frac{m_i}{z_i m_e}\right)^{1/4} U_R^{thr}. \tag{15}$$

Here

$$U_R^{thr} = 2(z_i\tau)^{3/4}\sqrt{(Q_R)_{min}}\,. \tag{16}$$

is a dimensionless quantity dependent on R and $z_i\tau$ only; it is related to the previously introduced quantity U_R^* [9] by $U_R^* = z_i^{-1/4} U_R^{thr}$. Its numerical values, as obtained in the present work, are shown in Table 2. at the end of the text, in a manner analogous to that of Table 1. (i.e. enabling the comparison with the data obtained within the frames of Approximation II). The general behaviour of the threshold drifts evaluated in the present work (Approximation III) is similar to the one established previously (Approximation II): for any fixed value of R, the threshold drifts first decrease as $z_i\tau$ is augmented, and then increase again after passing through a minimum. The position of the drift minimum depends on R, and the data obtained in the present work suggest that one approximately has $(z_i\tau)_{min} \approx 0.5R$. A comparison of these data with those of Approximation II, whenever the latter are available, shows that the effect of the term $m = R + 1$ retained in the real part of (5) is a slight increase (not exceeding some 7%) of the threshold drifts. Also, a trend towards smaller values of μ_R^* can be noticed, the disrepancies being most prominent for non-isothermalities around the threshold drift minimum.

An inspection of the figures in Table 2 reveals several instances of drift inversion. The effect first involves the harmonics $R = 1$ and $R = 2$, as well as $R = 1$ and $R = 3$ (but not $R = 2$ and $R = 3$), at $z_i\tau \approx 5$ ($U_1^{thr} > U_3^{thr} > U_2^{thr}$). For $z_i\tau \approx 10$, a complete drift inversion for the harmonics studied can be seen ($U_1^{thr} > U_2^{thr} > U_3^{thr} > U_4^{thr} > U_5^{thr} > U_6^{thr}$). However, this does not remain a permanent feature for all the higher non-isothermalities; indeed, for $z_i\tau \approx 20$, the order of the drifts becomes $U_1^{thr} > U_2^{thr} > U_3^{thr} > U_6^{thr} > U_4^{thr} > U_5^{thr}$. It may be of some interest to point out that the drift inversions invariably occur at non-isotermalities above those corresponding to the minima of the drifts involved.

Table 1.

Positions of maxima of the functon $W_R(\mu)$, as evaluated from Approximation III [eq. (9), upper lines of figures] and Approximation II [eq. (10b), lower lines].

Part A: lower-order harmonics ($R = 1$, 2 and 3)

$z_i\tau$	$\tilde{\mu}_1$	$\widetilde{W}_1$	$\tilde{\mu}_2$	$\widetilde{W}_2$	$\tilde{\mu}_3$	$\widetilde{W}_3$
0.1	1.46	0.0207	4.30	0.0113	8.60	0.00771
	(1.46)	(0.0207)	(4.30)	(0.0113)	(8.60)	(0.00771)
0.2	1.40	0.0393	4.00	0.0218	8.30	0.0149
	(1.40)	(0.0393)	(4.00)	(0.0219)	(8.30)	(0.0150)
0.4	1.30	0.0713	3.60	0.0407	7.30	0.0282
	(1.31)	(0.0715)	(3.65)	(0.0410)	(7.35)	(0.0284)
0.5	1.25	0.0852	3.50	0.0494	6.90	0.0346
	(1.26)	(0.0856)	(3.55)	(0.0498)	(7.00)	(0.0347)
1.0	1.07	0.140	2.90	0.0861	5.50	0.0618
	(1.10)	(0.142)	(2.95)	(0.0885)	(5.60)	(0.0639)
2.0	0.85	0.209	2.10	0.141	3.90	0.106
	(0.91)	(0.216)	(2.30)	(0.151)	(4.20)	(0.118)
4.0	0.62	0.280	1.30	0.213	2.30	0.172
	(0.72)	(0.298)	(1.60)	(0.258)	–	–
5.0	0.57	0.302	1.10	0.239	1.90	0.194
	(0.65)	(0.324)	(1.30)	(0.317)	–	–
10.0	0.37	0.361	0.50	0.304	1.00	0.236
	(0.49)	(0.401)	–	–	–	–
20.0	0.23	0.407	0.30	0.326	0.50	0.247
	(0.36)	(0.467)	–	–	–	–

Part B: higher-order harmonics ($R = 4$, 5 and 6)

$z_i\tau$	$\tilde{\mu}_4$	$\widetilde{W}_4$	$\tilde{\mu}_5$	$\widetilde{W}_5$	$\tilde{\mu}_6$	$\widetilde{W}_6$
0.1	15.20	0.00582	23.40	0.00467	33.40	0.00390
	(15.20)	(0.00583)	(23.40)	(0.00468)	(33.40)	(0.00391)
0.2	14.10	0.0131	21.60	0.00908	30.70	0.00758
	(14.10)	(0.0133)	(21.60)	(0.00911)	(30.70)	(0.00760)
0.4	12.40	0.0215	18.90	0.0173	26.80	0.0145
	(12.40)	(0.0217)	(18.90)	(0.0175)	(26.80)	(0.0146)
0.5	11.70	0.0263	17.80	0.0212	25.00	0.0177
	(11.80)	(0.0266)	(17.85)	(0.0215)	(25.10)	(0.0179)
1.0	9.20	0.0480	13.70	0.0392	19.20	0.0330
	(9.40)	(0.0499)	(14.00)	(0.0409)	(19.50)	(0.0344)
2.0	6.40	0.0854	9.40	0.0711	13.10	0.0606
	(6.70)	(0.0981)	(9.90)	(0.0837)	(13.70)	(0.0727)
4.0	3.70	0.142	5.40	0.119	7.50	0.102
	–	–	–	–	–	–
5.0	3.00	0.159	4.40	0.133	6.20	0.114
	–	–	–	–	–	–
10.0	1.60	0.190	2.40	0.158	3.30	0.135
	–	–	–	–	–	–
20.0	0.80	0.198	2.40	0.158	3.30	0.135
	–	–	–	–	–	–

Table 2.

Data on the threshold drifts obtained from Approximation III and Approximation II [in both cases on eq. (16)]

Part A: lower-order harmonics ($R = 1$, 2 and 3)

$z_i\tau$	μ_1^*	U_1^{thr}	μ_2^*	U_2^{thr}	μ_3^*	U_3^{thr}
0.1	1.40 (1.40)	8.041 (8.038)	4.00 (4.00)	10.773 (10.769)	8.30 (8.30)	13.027 (13.021)
0.2	1.27 (1.29)	7.128 (7.121)	3.60 (3.60)	9.402 (9.388)	7.20 (7.30)	11.293 (11.273)
0.4	1.04 (1.11)	6.601 (6.581)	3.00 (3.00)	8.446 (8.407)	5.90 (6.00)	10.000 (9.945)
0.5	1.02 (1.04)	6.522 (6.498)	2.80 (2.80)	8.230 (8.177)	5.40 (5.50)	9.673 (9.596)
1.0	0.75 (0.74)	6.653 (6.593)	2.00 (2.10)	7.874 (7.752)	3.90 (4.10)	8.924 (8.744)
2.0	0.49 (0.55)	7.56 (7.417)	1.30 (1.50)	8.141 (7.937)	2.60 (2.80)	8.707 (8.386)
4.0	0.28 (0.33)	9.569 (9.468)	0.70 (0.80)	9.601 (9.428)	1.50 –	9.711 –
5.0	0.22 (0.26)	10.607 (10.524)	0.60 (0.65)	10.471 (10.368)	1.20 –	10.484 –
10.0	0.08 (0.08)	15.486 (15.470)	0.30 –	15.030 –	0.60 –	14.591 –
20.0	0.03 (0.03)	23.765 (23.763)	0.13 –	22.525 –	0.30 –	22.450 –

Part B: higher-order harmonics ($R = 4$, 5 and 6)

$z_i\tau$	μ_4^*	U_4^{thr}	μ_5^*	U_5^{thr}	μ_6^*	U_6^{thr}
0.1	14.10 (14.10)	14.967 (14.959)	21.50 (21.60)	16.694 (16.685)	30.60 (30.60)	18.278 (18.268)
0.2	12.30 (12.30)	12.931 (12.908)	18.60 (18.70)	14.397 (14.370)	26.30 (26.40)	15.752 (15.722)
0.4	9.80 (10.00)	11.364 (11.295)	14.90 (15.00)	12.594 (12.513)	20.80 (21.10)	13.744 (13.652)
0.5	9.00 (9.20)	10.947 (10.851)	13.60 (13.80)	12.101 (11.987)	18.90 (19.30)	13.182 (13.055)
1.0	6.40 (6.70)	9.883 (9.649)	9.50 (10.00)	10.773 (10.488)	13.40 (14.00)	11.618 (11.292)
2.0	4.20 (4.60)	9.270 (8.835)	6.30 (6.90)	9.828 (9.281)	8.80 (9.70)	10.378 (9.693)
4.0	2.50 –	9.890 –	3.70 –	10.099 –	5.20 –	10.362 –
5.0	2.00 –	10.563 –	3.10 –	10.678 –	4.40 –	10.814 –
10.0	1.10 –	14.440 –	1.70 –	14.377 –	2.50 –	14.274 –
20.0	0.70 –	21.659 –	1.00 –	21.604 –	1.50 –	22.200 –

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PROBLEM DRIFTNE INVERZIJE KVAZI-POPREČNIH ELEKTROSTATIČKIH JONO-CIKLOTRONSKIH NESTABILNOSTI U SLABO JONIZOVANIM PLAZMAMA SA ELEKTRIČNOM STRUJOM DUŽ LINIJA MAGNETNOG POLJA

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Sadržaj: Teorijski se proučava proces spontanog pobuđivanja kvazi-poprečnih elektrostatičkih jono-ciklotronskih talasa narastajuće amplitude, uslovljenog prisustvom elektronskog drifta paralelnog magnetnim linijama sile u homogenoj, slabo jonizovanoj plazmi sa jednom vrstom jona. Pokazano je da se, adekvatnim tretiranjem vanrezonantnih članova u disperzionoj jednačini, dolazi do predviđanja efekta inverzije minimalnih driftova, tj. do mogućnosti da, pod izvesnim uslovima, jono-ciklotronski harmonik višeg reda može zahtevati manji minimalan drift nego harmonik nižeg reda. U teoriji koja je u ovom radu razvijena, inverzija minimalnih driftova nastupa kad je $T_e/T_i \approx 5$ i postaje sve izrazitija sa daljim porastom ovog odnosa temperatura. Efekt zavisi i od naelektrisanja jona, i primetniji je (nastupa pri manjoj vrednosti T_e/T_i) kod plazme sa dvostruko naelektrisanim jonima nego kod one sa jednostruko naelektrisanim. Većina ovih osobenosti je, po svemu sudeći, u saglasnosti sa nekim eksperimentalnim podacima.