Ann. Geophys. Discuss.,
https://doi.org/10.5194/angeo-2019-83-AC2, 2019


Annales Geophysicae Discussions
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# *Interactive comment on* "Excitation of chorus with small wave normal angles due to BPA mechanism into density ducts" *by* Peter A. Bespalov and Olga N. Savina

**Peter A. Bespalov and Olga N. Savina**

pbespalov@mail.ru

Received and published: 1 August 2019

Respond to all referee #2 comments

(1) Comment from Referee #2

General comments The authors study the chorus excitation in the density ducts in the frame of the beam pulse amplifier mechanism for the enhanced and depleted ducts. It is noted that the considered model allows one to explain small angles of the wave normal in the as- sumption of a single planar whistler-mode wave in a cold homogeneous plasma. The subject of the paper is significant for geoscience. The paper can



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Discussion paper

be published after minor revision. Specific comments 1) Page 2, line 9. It is written: 'In the duct, a standing wave structure occurs at the transverse coordinate.' It is not clear what the authors mean. 2) The main terms and concepts used in the paper could be explained more explicitly in the Introduction. 3) Page 3, lines 2-4. It is written that 'the WKB approximation is fulfilled'. It is better to remind the conditions for the WKB approximation validity in more detail. 4) Figure 1 is not very illustrative. Two branches are hard to see, they should be marked.There is a lot of empty place in this figure. Modification is needed. 5) Page 3, line 13. It is written: 'Let us note that there is a range of values kz, omega in which kx has not one, but two values.' It is desirable to determine this region (or regions), if this point is essential. 6) Page 3, line 18. '(laird, 1992)' should be replaced by ('Laird, 1992'). 7) Page 4, line 5. It is written: 'While performing calculations, we will con- sider that the magnetic field is uniform and the electronic cyclotron frequency omega_B = 6 Au 10**4 s**-1. The plasma density outside the duct corresponds to the condition (omega p,out/omega_B)**2 = 25. Inside the enhanced duct we have (omega p, int/omega_B)**2 = 29, while inside the depleted duct, (omega p,int/omega_B)**2 = 21.' It is desirable to explain, why these values are cho- sen. 8) Figure 2. Labels 'a' and 'b' are not shown in figure. In the figure caption nothing is told about the red curves, the corresponding explanation is given only in the text. First and seventh ducted modes, probably,correspond to p=1 and p=7, respectively, which is desirable to note in the figure caption. 9) At the end of page 4 the normal angle is estimated. Why normal angle is only considered to be small? What will be in the opposite case? Some explanation is desirable. If it is determined by observations, for example, it should be mentioned. 10) There are no explanations of all designations in Eqs. (6) - (9). For example, what is Vz in Eq. (8)? There is reference to paper Bespalov and Savina (2018), however, for self-consistency it is desirable to describe all mentioned parameters. 11) Page 7, line 21. Instead of '(7)' it should be 'Eq. (7)'. 12) The new contribution related to the previous works should be emphasized more clearly.

(2) Author's response

We would like to thank the Reviewer #2 for the time he/she spent reading, positive response, and commenting our manuscript. We have prepared a point-by-point answer to his/her comments below. The responses are marked in bold and the modified parts are marked in blue in the new marked version of the manuscript (the responses to the Reviewer #1 are marked in bold and the modified parts are marked in yellow in the marked version of the manuscript).

Reviewer's Comments: 1) Page 2, line 9. It is written: 'In the duct, a standing wave structure occurs at the transverse coordinate.' It is not clear what the authors mean.

Response: We modified the text in accordance with reviewer's comment. The text "In the duct, a standing wave structure occurs at the transverse coordinate." is replaced by "In the duct, a standing wave structure occurs across the magnetic field."

2) The main terms and concepts used in the paper could be explained more explicitly in the Introduction.

Response: We modified the introduction in accordance with reviewer's suggestion.

3) Page 3, lines 2-4. It is written that 'the WKB approximation is fulfilled'. It is better to remind the conditions for the WKB approximation validity in more detail.

Response: We modified the text in accordance with reviewer's suggestion. The list of references was extended and the text "For typical magnetospheric conditions (Haque et al., 2011) in the region of chorus excitation, the WKB approximation is fulfilled since the length of the whistler wave $\lambda \simeq 15\;km$ is less than the scale of the background plasma density distribution and the transverse size of the duct $d = 100 - 300\;km$." is replaced by "For typical magnetospheric conditions (Haque et al., 2011) in the region of chorus excitation the length of the whistler wave $\lambda \simeq 15\;km$ is less than the scale of the background plasma density distribution and the transverse size of the duct $d = 100 - 300\;km$. Therefore the inequality $\lambda/d \ll \pi$ is fulfilled and the well known WKB approximation (Budden, 1985) is valid."

4) Figure 1 is not very illustrative. Two branches are hard to see, they should be marked. There is a lot of empty place in this figure. Modification is needed.

Response: Figure 1 and its caption are modified.

5) Page 3, line 13. It is written: 'Let us note that there is a range of values kz, omega in which kx has not one, but two values.' It is desirable to determine this region (or regions), if this point is essential.

Response: The text is modified.

6) Page 3, line 18. '(laird, 1992)' should be replaced by ('Laird, 1992').

Response: The text is corrected.

7) Page 4, line 5. It is written: 'While performing calculations, we will consider that the magnetic field is uniform and the electronic cyclotron frequency omega_B = 6 Au 10**4 s**-1. The plasma density outside the duct corresponds to the condition (omega p,out/omega_B)**2 = 25. Inside the enhanced duct we have (omega p, int/omega_B)**2 = 29, while inside the depleted duct, (omega p,int/omega_B)**2 = 21.' It is desirable to explain, why these values are cho- sen.

Response: We mentioned that these values are close to the known experimental data.

8) Figure 2. Labels 'a' and 'b' are not shown in figure. In the figure caption nothing is told about the red curves, the corresponding explanation is given only in the text. First and seventh ducted modes, probably,correspond to p=1 and p=7, respectively, which is desirable to note in the figure caption.

Response: Labels 'a' and 'b' are shown near figure 2. The figure caption is corrected.

9) At the end of page 4 the normal angle is estimated. Why normal angle is only considered to be small? What will be in the opposite case? Some explanation is desirable. If it is determined by observations, for example, it should be mentioned.

Response: Some explanation is added. Finally normal angle is estimated theoretically.

10) There are no explanations of all designations in Eqs. (6) - (9). For example, what is Vz in Eq. (8)? There is reference to paper Bespalov and Savina (2018), however, for self-consistency it is desirable to describe all mentioned parameters.

Response: The text is corrected.

11) Page 7, line 21. Instead of '(7)' it should be 'Eq. (7)'.

Response: The text is corrected.

12) The new contribution related to the previous works should be emphasized more clearly.

Response: We added paragraph to the Conclusions.

(3) Author's changes in manuscript Page 2 line 9 The text "In the duct, a standing wave structure occurs at the transverse coordinate." is replaced by "In the duct, a standing wave structure occurs across the magnetic field."

Page 2 line 17 The text "It has been shown that under suitable conditions a very effective amplification of short noise pulses can occur even in a stable plasma. Pulse amplification leads to the excitation of bursts of electromagnetic radiation having the same properties as would occur due to an instability resulting from a very high anisotropy in the distribution function of energetic electrons." is added.

Page 3 line 2 The text "For typical magnetospheric conditions (Haque et al., 2011) in the region of chorus excitation, the WKB approximation is fulfilled since the length of the whistler wave $\lambda \simeq 15\;km$ is less than the scale of the background plasma density distribution and the transverse size of the duct $d = 100 - 300\;km$." is replaced by "For typical magnetospheric conditions (Haque et al., 2011) in the region of chorus excitation the length of the whistler wave $\lambda \simeq 15\;km$ is less than the scale of the background plasma density distribution and the transverse size of

the duct $d = 100 - 300\;km$. Therefore the inequality $\lambda/d \ll \pi$ is fulfilled and the well known WKB approximation (Budden, 1985) is valid."

Page 3 line 13 The text "but two values" is replaced by "but two values (see Fig. 1)"

Page 4 Figure 1 was modified.

Page 4 line 1 The text "Dependence of the transverse component of the wave vector on the frequency and the longitudinal component of the wave vector for ${({\omega _p}/{\omega _B})^2} = 25$." is replaced by "Dependence of the transverse component of the wave vector on the frequency and the longitudinal component of the wave vector for ${({\omega _p}/{\omega _B})^2} = 25$ is shown by contours with constant $k_x$ in the surface $k_x=k_x(\omega, k_z)$. Two branches $K_{x-}$ and $K_{x+}$ (see Eq. (2)) are separated by a blue line."

Page 4 line 5 The text "according to the known experimental data (see, e.g. (Hague et al., 2011; Taubenschuss et al., 2014; Agapitov et al., 2017))" is added.

Page 5 line 1 The text "Relationship between the frequency and the longitudinal component of the wave vector for the first and seventh ducted modes at ${({\omega _{p,out}}/{\omega _B})^2} = 25$:" is replaced by "Relationship between the frequency and the longitudinal component of the wave vector for the first ($p=1$) and seventh ($p=7$) ducted modes at ${({\omega _{p,out}}/{\omega _B})^2} = 25$ are shown in red:"

Page 5 line 8 The text "If" is replaced by "As it will be shown in the next section $\theta < \pi /4$ for actual modes"

Page 6 line 18 The text "where ${n_b}$ is the density of the beam coordinated with the pulse" is replaced by "where $\delta(\varsigma)$ is a delta function, ${n_b}$ is the density of the beam coordinated with the pulse, $V_z$ is the beam velocity"

Page 7 line 14 The text "The beam pulse amplifier (BPA) mechanism of chorus excitation was first studied for homogeneous plasma (Bespalov and Savina, 2018). This

mechanism explains many properties of the oblique electromagnetic chorus. The proposed model with waveguide propagation explains the possibility of excitation of chorus with small angles of the wave normal when the BPA mechanism is implemented." is added.

Page 7 line 21 The text "(7)" is replaced by "Eq. (7)"

Page 8 line 10 The text "Budden, K.G.: The propagation of radio waves: The theory of radio waves of low power in the ionosphere and magnetosphere, Cambridge University Press, Cambridge, 669 p., doi: 10.1017/CBO9780511564321, 1985." is added.

Please also note the supplement to this comment:
https://www.ann-geophys-discuss.net/angeo-2019-83/angeo-2019-83-AC2-supplement.zip

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Interactive comment on Ann. Geophys. Discuss., https://doi.org/10.5194/angeo-2019-83, 2019.



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