Enhanced Ion Acoustic Line Spectra in the High Latitude Ionosphere Due to Modified Ion-Ion Two-Stream Instatilities

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Abstract

A number of observations showing naturally enhanced ion acoustic echoes observed in the topside auroral ionosphere by means of by the EISCAT and Millstone Hill radars have been reported in the literature. The enhancements are typically 1–2 orders of magnitude in power compared to normal ion line values, and it is mostly contained in one of the two ion acoustic lines. The instability processes proposed in many literatures to explain these phenomena, one of the theories is the ion-ion two-stream instability, which is driven by large relative drifts between two or more ion species. As long as the drift velocity is of the order of the species thermal velocity, the ion acoustic fluctuation level can be enhanced well above the thermal level, leading to an enhancement in one or both ion lines. The high relative drifts require a sufficient acceleration of H^+, which might be possible at high altitudes. In this paper, the low energy H^+ ion precipitation and the O^+ ion outflow events are considered. The H^+ ion distribution function described by the bi-Maxwellian contains the field-aligned heat flow, and then the enhanced ion acoustic echoes can be interpreted using the ion-ion two-stream instabilities. The asymmetry is weaken due to the field-aligned heat flow is considered.

1. Introduction

Naturally enhanced ion acoustic lines are intermittently seen in spectra from incoherent scatter radars (ISR) at high latitudes. So-called naturally enhanced ion acoustic lines stand out as a significant problem in the understanding of incoherent scatter radar data. The characteristic incoherent scatter spectrum of NEIAL events is easily distinguished from the thermal spectra by the enhancement of one, or both, ion acoustic shoulders. The enhancements are typically 1–2 orders of magnitude in power compared to normal ion line values. The first reported observation of NEIALs stem from the Haystack observatory [1] Later on, similar observations were made in Tromsø, which is located within the auroral zone, using the EISCAT radars (224MHz and 931 MHz) by Collis et al [2]. and Rietveld et al. [3] Further north, Buchert et al. observed NEIALs for the first time in the dayside cusp/cleft region using the EISCAT Svalbard Radar (500 MHz)[4].

NEIALs have been observationally associated with a wide range of geophysical phenomena which can be summaries, for example severe geomagnetic disturbances [3], soft precipitation[2,5], high electron temperature[1,6], electric heating in the F-region [3], density enhancement in E-region[3,5], intense ion out-flow [6,7], red aurora[2,8], enhanced plasma lines [9] and active aurora[10-11]. Since the first observations, In order to explain the physical mechanisms behind the NEIAL phenomena, many theoretical investigations have been presented [10]. Although the understanding of the NEIAL phenomenon is not clear, a common theme among the explanations is instability processes. The instability processes proposed in the literature to explain the NEIAL phenomenon are divided two broad classes. i) ion-acoustic mode destabilization by counter streaming species, which can be subdivided into ion-electron two-stream instability, namely, current driven instability [1-3] and ion-ion two-stream instability[6]. and ii) parametric decay of Langmuir waves, that is the destabilization of an ion acoustic wave through quasi-linear wave coupling with frequency Langmuir (plasma) waves, which can lead to enhanced ion acoustic fluctuations[7,12].

In this publication, the ion-ion two-steam instability are modified. Ion-ion two-stream instability, namely, ion-ion dirt instability or counter streaming ion populations, is driven by large relative drifts between two or more ion species, for example O^+ and a beam of H^+. What is important for the ion-ion two-stream instability is that there exist two ion populations with different drift velocities. Particularly the good correlation of ion outflow events with low energy particle precipitation and naturally enhanced ion acoustic lines support the ion-ion two-stream instability[3,6]. The high relative drifts require a sufficient acceleration of H^+, which might be possible at high altitudes. In this paper, we propose in this paper a modified ion-ion two-stream instability to interpret on the origin of enhanced ion acoustic fluctuations observed in the upper ionosphere. For example, the low energy H^+ ion precipitation and the O^+ ion outflow events are considered. The H^+ ion distribution function described by polynomial base on the bi-Maxwellian distribution contains the field-aligned heat flow, then the incoherent scatter spectral is calculated.

A theoretical formulation of the H^+ ion approximation distribution function and the spectral density function for a multicomponent are presented in section 2. Section 3 presents the calculations of the incoherent scatter spectra. The conclusions are summarized in section 4.

2 Theoretical formulation

2.1 The distribution function of H^+ ion

The low energy H^+ ion precipitation assumed be described by follows

$$f_i = f^{(b)} \cdot \left(1 + \Phi_i\right) \tag{1}$$

$f^{(b)} = n_i \left(2\pi\right)^{-3/2} \beta_\perp \left(\beta_\|\right)^{1/2} \exp\left(-\beta_\perp c_{i\perp}^2/2 - \beta_\| c_{i\|}^2/2\right)$ is the two-Maxwellian distribution. Φ_i can be written

$$\Phi_i = -\frac{\beta_\|^2}{2n_i m_i}\left(1 - \frac{\beta_\| c_{i\|}^2}{3}\right)\boldsymbol{q}_i^\| . \boldsymbol{c}_{i\|} \tag{2}$$

where $\beta_\| = m_i / k_B T_{i\|}$, $\beta_\perp = m_i / k_B T_{i\perp}$. $T_{i\|} = T_n + \left(m_i / k_B\right) u_\|^2$ and $T_{i\perp} = T_n$ are the temperature parallel and temperature perpendicular to the magnetic field respectively, k_B is Boltzmann constant. c_i is the random velocity defined as $\boldsymbol{c}_i = \boldsymbol{v}_i - \langle \boldsymbol{v} \rangle$, $\boldsymbol{q}_i^\| = n_i m_i \left\langle c_{i\|}^2 \boldsymbol{c}_i \right\rangle$ is the heat flow vector parallel to the magnetic field. According to equation (1), the heat flow vector parallel to the magnetic field can be described as

$$\boldsymbol{q}_i^\| = 2 n_i m_i u_\|^3 \boldsymbol{e}_3 \tag{3}$$

The ion drift velocity parallel to the magnetic field is written by $u_\| \boldsymbol{e}_3$, According to defined of the random velocity, $\boldsymbol{c}_{i\|} = \left(v_3 - u_\|\right)\boldsymbol{e}_3$ and $\boldsymbol{c}_{i\perp} = v_1 \boldsymbol{e}_1 + v_2 \boldsymbol{e}_2$, where, $\boldsymbol{v}_1,\boldsymbol{v}_2,\boldsymbol{v}_3$ is component of the velocity $\boldsymbol{v}_i$ respectively. $\boldsymbol{e}_3$ is parallel to the magnetic field. Finally the integral over plane perpendicular to the magnetic field is performed, then the ion distribution function parallel to the magnetic field is obtained

$$f_{i0} = n_i \sqrt{\frac{2}{\pi}} \frac{\sqrt{\beta_\|}}{\beta_\perp} \cdot \exp\left(-\frac{\beta_\| c_{i\|}^2}{2}\right)\left[1 - \frac{\beta_\|^2}{2 n_i m_i}\left(1 - \frac{\beta_\| c_{i\|}^2}{3}\right)\boldsymbol{q}_i^\| . \boldsymbol{c}_{i\|}\right] \tag{4}$$

2.2 The spectral density function

In linear theory the spectral density function for a multi-component, collisionless, uniform, non-magnetized and non-relativistic plasma (Sheffield, 1975) may be written, in a somewhat modified form to include different plasma components, as

$$S\left(k,\omega\right) = \frac{2\pi}{k}\left\{\left|1 - \frac{\sum_j \chi_{e,j}}{\varepsilon}\right|^2 \sum_j A_j f_{e0,j}\left(\omega/k\right) + \left|\frac{\sum_j \chi_{e,j}}{\varepsilon}\right|^2 \sum_l A_l f_{i0,l}\left(\omega/k\right)\right\} \tag{5}$$

where, $\varepsilon = 1 + \sum_j \chi_{e,j} + \sum_l \chi_{i,l}$, $\chi_q = \lim_{\gamma - 0} \frac{4\pi e^2 n_{q0}}{m_q k^2} \int_{-\infty}^{\infty} d\boldsymbol{v} \frac{\boldsymbol{k} \cdot \partial f_{q0} / \partial \boldsymbol{v}}{\omega - \boldsymbol{k} \cdot \boldsymbol{v} - i\gamma}$, f_{q0} is one dimension ion velocity distribution function, $A_j = n_{e,j} \Big/ \sum_j n_{e,j}$, $A_l = Z_l^2 n_{i,l} \Big/ \sum_l Z_l n_{i,l}$.

3 Results and discussion

In the follow calculations, the electron is assumed can be described by Maxwellian, and the H+ ion beam is described by equation (4). Since ion species abundances, T_e/T_i ration and ion drifts are basic parameters of the modified ion-ion two stream instability mode. The influence of those parameters on the incoherent scatter spectra are discussed as follow.

Figure 1shows a number of calculated ion acoustic line spectra for different drift velocity of the ion (5% H^+, 95% O^+) and T_e/T_i=3,where V_d is drift velocity and V_{th} is the ion thermal velocity. From the calculation, when the ratio of the drift velocity of two ion species to each thermal velocity is 0.5, 1.0, 1.5 and 2.0 respectively, the peak value ratio between two shoulders of the ion acoustic spectra is 1.6, 1.5, 1.4 and 1.2 respectively. That is to say, the asymmetry of ion acoustic line spectra weakens as the relative drift velocity between H^+ and O^+. In Figure 2 we show that the effects of the different rations of the electron to the ion temperature on the ion acoustic line spectra for V_d=1.0V_{th}, The asymmetry of ion acoustic line spectra enhances as the electron to the ion temperature increases.

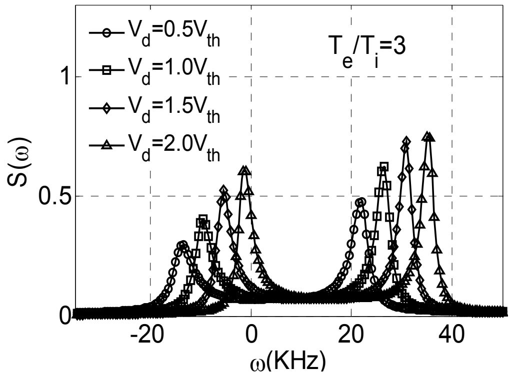

Fig. 1. A set of ion acoustic line spectra produced when both H^+ and O^+ drift with indicated fractions of their respective thermal velocity

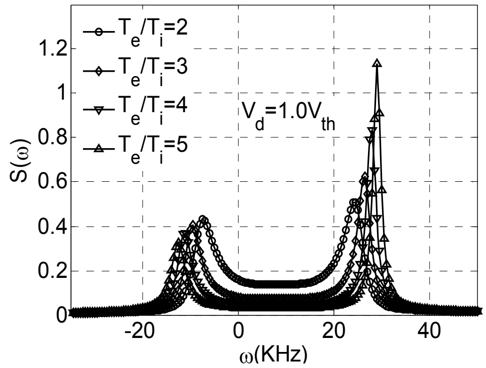

Fig. 2. The effects of the different rations of the electron to the ion temperature on the ion acoustic line spectra

In Figure 3 the effects of ion species abundances (different of H^+ and O^+ species percentage composition) on the ion acoustic spectra are discussed for T_e/T_i=4 and the drift velocity of H^+ and O^+ is 1.0V_{th}. The amplitude of the ion acoustic spectral decrease as H^+ species percentage composition increases. But when the H^+ species percentage composition is 5%, 10% and 15% respectively, the asymmetry of ion acoustic line spectra enhance, the ratio of the two ion acoustic spectra shoulders is 2.3, 2.6 and 2.8 respectively.

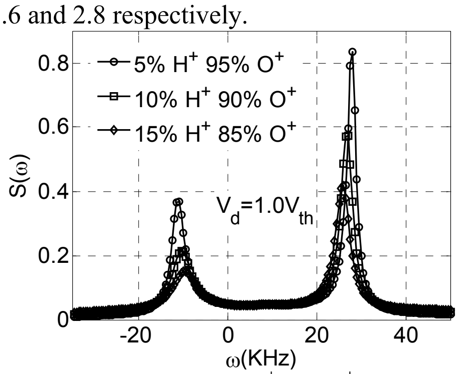

Fig. 3 The effects of the different contents of the H^+ and O^+ ion on the ion acoustic line spectra

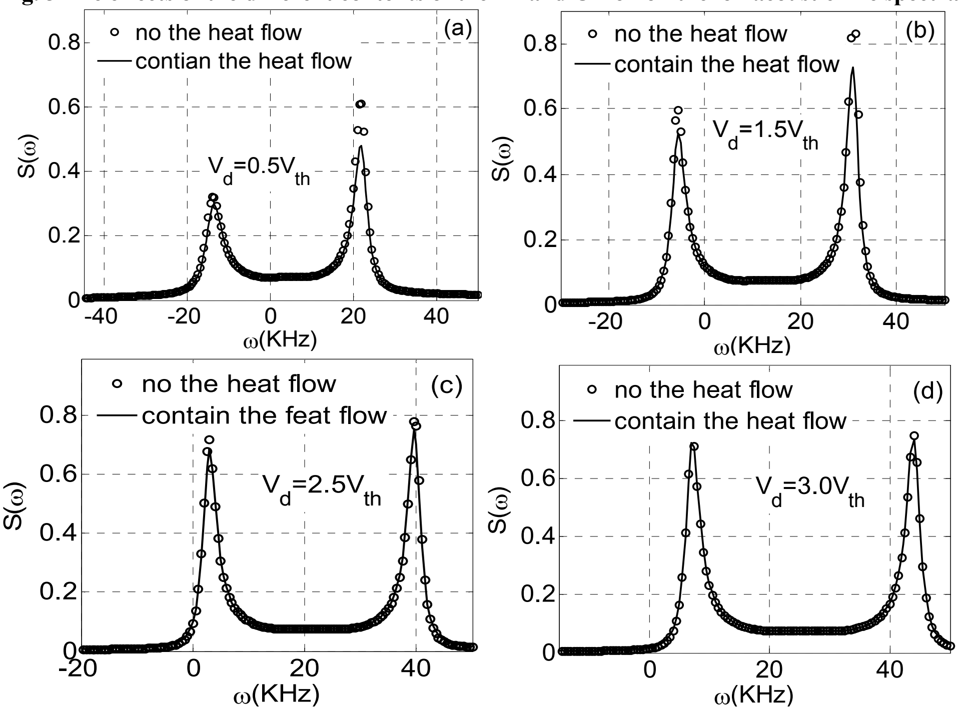

Fig. 4. The effect of the field-aligned heat flow on the ion acoustic line spectra

In this paper, the ion distribution function of the low energy H^+ ion precipitation is described by the bi-Maxwellian contains the field-aligned heat flow. The influence of the field-aligned flow on the ion acoustic spectra is shown in Figure 4. Because the field heat flow is contained in the modified ion-ion two-stream instability, the new modified ion-ion two-stream instability is more close to real than ion-ion two-stream instability. From the figure 4, the asymmetry of ion acoustic line spectra weakens due to introduce the field field-aligned heat flow, the reasons is that there is a minus in the ion velocity distribution function. The effect of field-aligned heat flow on the ion acoustic spectral is become less even no, as the relative drift velocity between ions. When V_d=3.0V_{th}, the asymmetry of ion acoustic line spectra is disappeared, but the magnitude of the ion acoustic spectral shoulders increases. This is of benefit to explain the two shoulders enhanced of ion acoustic spectral.

There is now a substantial body of literature documenting observations of enhanced ion-acoustic spectra, but there remains controversy over generation mechanisms. In this paper, the good correlation of ion outflow events with low energy particle precipitation and naturally enhanced ion acoustic lines are considered. The new modified ion-ion two-stream (for example the low energy H^+ ion precipitation and the O^+ ion outflow events) instability mode is given to explained this phenomena . The low energy H^+ ion velocity distribution function is describe by polynomial base on the bi-Maxwellian distribution contains the field-aligned heat flow. Since this news model contains the ion temperature anisotropy, ion species abundances, ion drift velocity and field-aligned heat flow. It is new attempt to interpret the enhanced ion Acoustic line spectra.

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7. References

1. Foster, J. C., del Pozo, C., Groves, K., and St. Maurice, J.-P.: Radar observations of the onset of current driven instabilities in the topside ionosphere, Geophys. Res. Lett., 15, 160–163, 1988.
2. P. N. Collis, I. Häggström, K. Kaila, and M. T. Rietveld, "EISCAT radar observations of enhanced incoherent scatter spectra; their relation to red aurora and field-aligned currents," Geophys. Res. Lett., 18, 1991, pp.1031–1034.
3. M. T. Rietveld, P. N. Collis, and J.-P. St.-Maurice, "Naturally Enhanced Ion Acoustic Waves in the Auroral Ionosphere Observed With the EISCAT 933-MHz Radar," J. Geophys. Res., 96, 1991, pp.19 291–19 305.
4. S. C. Buchert, A. P. van Eyken, T. Ogawa, and S. Watanabe, "Naturally enhanced ion-acoustic lines seen with the EISCAT Svalbard Radar, "Adv. Space Res., 23, 1999, pp.1699–1704.
5. F. R. E. Forme, D. Fontaine, and J. E. Wahlund, "Two different types of enhanced ion acoustic fluctuations observed in the upper ionosphere," J. Geophys. Res., 100, 1995, pp.14 625–14 636.
6. J.-E.Wahlund, F. R. E. Forme, H. J. Opgenoorth, M. A. L. Persson, E. V. Mishin, and A. S. Volokitin, "Scattering of electromagnetic waves from a plasma: enhanced ion acoustic fluctuations due to ion-ion two-stream instabilities," Geophys. Res. Lett., 19, 1992, pp.1919–1922.
7. F. R. E. Forme, D. Fontaine, "Enhancend ion acoustic fluctuations and ion outflows," Amm. Geophys., 17, 1999, pp.1172-1181.
8. K. J. F. Sedgemore-Schulthess, M. Lockwood, T. S. Trondsen, B. S. Lanchester, M. H. Rees, D. A. Lorentzen, and J. Moen, "Coherent EISCAT Svalbard Radar spectra from the dayside cusp/cleft and their implication for transient field-aligned currents," J. Geophys. Res., 104, 1999, pp. 24 613–24 624.
9. A. Strømme, V. Belyey, T. Grydeland, C. La Hoz, U. P. Løvhaug, and B. Isham, "Evidence of naturally occurring wave-wave interactions in the polar ionosphere and its relation to naturally enhanced ion acoustic lines," Geophys. Res. Lett., 32, L05103, 2005, doi:10.1029/2004GL020239.
10. F. Sedgemore-Schulthess, and J.-P. St.-Maurice, "Naturally enhanced ion-acoustic spectra and their interpretation," Surv. Geophys., 22, 2001, pp.55–92.
11. E. M.Blixt, T. Grydeland, N. Ivchenko, T. Hagfors, C. La Hoz, B. S. Lanchester, U. P. Løvhaug, and T. S. Trondsen, "Dynamic rayed aurora and enhanced ion-acoustic radar echoes," Ann. Geophys., 23, 2005, pp.3–11,
12. F. R. E. Forme, "A new interpretation on the origin of enhanced ion acoustic fluctuations in the upper ionosphere," Geophys, Res. Lett., 20, 1993, pp.2347-2350.