Appendix

Reply to the comments of one of the examiners

Section 2A

1. It is stated that eqn. (12) is polynomial of order 8 in \( \omega \). Therefore, it should have 8 roots. But, in the thesis only one imaginary root is shown in Fig.2A.2 and Fig.2A.3. A thorough discussion on all possible roots is required.

Further, from Fig.2A.1, one could observe, that the instability occurs for a small window of the wavelength \( k_z \), (curve a) for \( V_{dh} = 400 \text{km/s} \), the window of instability increases to higher value of \( V_{dh} \), and for the highest value of \( V_{dh} = 800 \text{ km/s} \), the instability occurs over a large window of \( k_z \). Not only that, for each curve there is a peak in the instability for each \( V_{dh} \) and then decrease with \( k_z \). It means, for lower \( V_{dh} \), instability occurs only in a small window. Has any such thing has been observed in the satellite data? Similar analysis required for the remaining two Figs. It is very important point.

**Answer:** A polynomial equation of order 8 should have 8 solutions. In this section, we are concerned with electrostatic waves which are unstable. Out of eight solutions, for the parameters used, only two solutions (complex conjugate roots) have a significant imaginary part. We thus chose the root with a positive imaginary part since it represents a growing wave.

Cometary plasma wave measurements have detected waves extending from the lower hybrid resonance frequency to the electron plasma frequency both at comets Halley and Giacobini-Zinner. In situ measurements at Halley have also revealed the existence of lower hybrid turbulence inside of the cometary bow shock.
The ion-acoustic wave is one of the more easily observed waves in the plasma environments of comets. For example, ion-acoustic waves in the frequency range of 1.0–1.5 kHz were observed by ICE (International Cometary Explorer) spacecraft sent to observe the comet Giacobini-Zinner [1]. Again ion sound waves, with a frequency slightly less than 1 kHz, were detected by the spacecraft Sakigake which observed comet Halley.

The study on the low frequency ion waves were motivated by some results on the electrostatic noise in Halley's comet as measured by the Vega probes: the data showed an increase in the noise level, with a peak at $\omega \approx 1-3 \times 10^3 \, s^{-1}$, as the probes travel through a region of increased density of dust particles. This suggested some correlation between the level of electrostatic noise and the presence of charged dust particles. On the other hand, the density of plasma particles in the same region is $n \approx 10^2-10^3 \, cm^{-3}$ corresponding to an ion plasma frequency $\omega_{pi} \geq 10^4 \, s^{-1}$: the peak intensity therefore corresponds to low-frequency (with respect to the electron plasma frequency) ion-acoustic plasma waves at $\omega < \omega_{pi}$ [2,3].

High resolution VEGA 1 and 2 magnetic measurements in the cometary magnetosphere and magnetosheath of Halley reveal the presence of fluctuations with the signature expected for the mirror instability [4]. This instability is a mechanism by which homogeneously produced cometary ions with a large perpendicular temperature anisotropy can be concentrated into discrete linear features. Two stream instability is generated due to the streaming of solar wind into the cometary plasma.

The observed velocity of the solar wind at the comet Giacobini-Zinner by ICE was 400 km s$^{-1}$. This velocity of the solar wind is typical of quiet solar wind conditions and can be expected to be similar at comet Halley also [5]. This velocity of the solar wind can increase upwards to
600 km s\(^{-1}\) during disturbed conditions and hence we chose three values of drift velocity, namely 400 km s\(^{-1}\), 600 km s\(^{-1}\) and 800 km s\(^{-1}\).

The quiet solar wind velocity can thus drive electrostatic instabilities for typical values of densities and temperatures observed at a comet; the source of energy required to drive the instability being the streaming (kinetic) energy of solar wind. Thus the “window” of instability increases with increasing \(V_{\text{drift}}\).

The instability is a “resonant” type instability and is a maximum when the phase velocity of the wave is approximately equal to drift velocity. It decreases in either side when the phase velocity differs considerably from the drift velocity.

2. The thesis deals with the propagation of linear and non-linear waves. But this section 2A deals with instability. What is the reason to select this aspect? (as all other chapter deals with propagating waves)

**Answer:** Section 2A deals with stability of linear electrostatic waves in a multi-ion plasma. In the case of linear waves in plasmas, instabilities is a major area of interest; hence we chose to consider the stability of electrostatic waves and the factors that influence it.

3. Once the dispersion relation (12), which is of order 8 in \(\omega\), is obtained, it is quite natural to study the nature of all the 8 modes (8 real roots) of the wave. It will be more interesting to study such waves, in addition to the instability. Further, a study of the propagating waves for various parameters, will show how a stable wave turns into an unstable wave. Such study will also through light on the critical conditions at which the onset of instability occurs.

**Answer:** Of the eight solutions, only two solutions (which are complex conjugates) have significant real and imaginary parts. Since the solutions are complex conjugates only the solution with a positive imaginary root is
of physical interest. This is the only mode that can exist with a measurable real frequency.

**Section 2B**

1. In page 73, the author states that the dispersion relation (5) is of order 12. But he states that only two are feasible. I don’t understand this statement. Unless it is proved, with detailed discussion and with proof (taken from any article), such statements are not correct. Needs detailed study.

**Answer:** I have stated that only two roots are feasible for the EIC mode. Because, of the twelve solutions, only two roots have frequencies greater than the cyclotron frequency of ions. As proof, the Mathematica code used for solving the dispersion relation (5) is attached.

2. All figures are to be redrawn with proper legend.

**Answer:** EIC modes have a frequency greater than the cyclotron frequency of ions and hence the normalised value of the frequency is greater than 1. So even without using any legend we can clearly distinguish EIC mode from IA mode from the value of frequency. If the frequency is greater than 1 it is EIC mode and if it is less than 1 it is IA mode.

**Chapter 3**

1. The figures in this chapter are referred as Fig.1(A), 2, 3 etc. in the text body. However, the figures are given the caption as Fig 3.1(A), Fig. 3.2, etc. It must be corrected and appended.

**Answer:** The prescribed corrections have been made in the Chapter.
Chapter 4

Section 4A

1. The text in page 119 refers Figure 1, but there is no Figure 1, only Fig.4A.1 is given. This is repeated for the whole section. It must be corrected.

   **Answer:** The prescribed corrections have been made in the Chapter.

Chapter 5

1. The text Figure and the figure label Fig.5.X do not match for all the Figures. All such texts are to be corrected.

   **Answer:** The prescribed corrections have been made in the Chapter.

2. It is very difficult to understand as which equation is computed to get the profile of the soliton/shock wave in this chapter. It must be made explicit.

   **Answer:** KPB equation (24) is used to describe the shock waves. When the wave breaking due to the nonlinearity is balanced by the combined effect of dispersion and dissipation, a monotonic or oscillatory dispersive shock wave is generated in plasma. If the contribution of dissipation is small, shock wave transforms to a soliton which is best described by the KdV equation.
References


\textbf{omega versus obliqueness}

\[\text{ClearAll}["Global`*"]\]
\[\text{ne} = z2 \times n20 - z1 \times n10 + nH0;\]
\[\text{nhe0} := (1/2) \times \text{ne};\]
\[\text{nce0} := (1/2) \times \text{ne};\]
\[\alpha := (\theta \times 3.142 / 180);\]
\[\sigma := \frac{T2}{T1}; \quad \sigma_{H} := \frac{TH}{T1}; \quad \sigma_{ce} := \frac{Tce}{T1}; \quad \sigma_{se} := \frac{The}{T1}; \quad \text{mH} := \frac{mH}{\text{me}}; \quad \text{mce} := \frac{mH}{\text{me}}; \quad \text{mce} := \frac{mH}{\text{me}};\]
\[\omega_{p1} \left( \frac{4 \times Pi \times z1^2 \times q^2 \times n10}{m1} \right)^{1/2}; \quad \omega_{p2} = \left( \frac{4 \times Pi \times z2^2 \times q^2 \times n20}{m1} \right)^{1/2};\]
\[\omega_{pce} = \left( \frac{4 \times Pi \times q^2 \times nce0}{\text{me}} \right)^{1/2}; \quad \omega_{pse} = \left( \frac{4 \times Pi \times q^2 \times nce0}{\text{me}} \right)^{1/2};\]
\[\omega_{ph} = \left( \frac{4 \times Pi \times q^2 \times nH0}{\text{mH}} \right)^{1/2}; \quad \omega_{pse} = \left( \frac{4 \times Pi \times q^2 \times nce0}{\text{mH}} \right)^{1/2};\]
\[\omega_{pce} = \left( \frac{4 \times Pi \times q^2 \times nce0}{\text{me}} \right)^{1/2}; \quad \omega_{pse} = \left( \frac{4 \times Pi \times q^2 \times nce0}{\text{me}} \right)^{1/2};\]
\[\Omega = \frac{q \times B}{\text{m1} \times c}; \quad \nu_{th} = \left( \frac{kB \times TH}{\text{mH}} \right)^{1/2}; \quad \nu_{th} = \left( \frac{kB \times T1}{\text{m1}} \right)^{1/2};\]
\[\nu_{t2} = \left( \frac{kB \times T2}{m2} \right)^{1/2}; \quad \nu_{tce} = \left( \frac{kB \times Tce}{\text{me}} \right)^{1/2}; \quad \nu_{tse} = \left( \frac{kB \times Tse}{\text{me}} \right)^{1/2}; \quad \Omega = \frac{q \times B}{\text{mH} \times c};\]

\[K = 1 + \frac{\omega_{pce}^2 / \Omega^2}{\Omega^2} \times \left( 2 \times \text{xce} - 1 \right) + \frac{\omega_{pse}^2 / \Omega^2}{\Omega^2} \times \left( 2 \times \text{xhe} - 1 \right) + \frac{\rho k^2 \times \sigma_{ce} \times m_{tce}}{(2 \times \text{xce} - 3)} \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right);\]
\[\text{eqn} := \rho k^2 \times \sigma_{ce} \times m_{tce} \times \sigma_{tse} \times (2 \times \text{xce} - 3) \times \left( 2 \times \text{xhe} - 1 \right) \times \sigma_{ce} \times m_{tce} \times (2 \times \text{xhe} - 3) \times \left( 2 \times \text{xhe} - 3 \right) \times \left( 2 \times \text{xhe} - 3 \right) \times \left( 2 \times \text{xhe} - 3 \right) \times (2 \times \text{xce} - 3) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times (2 \times \text{xce} - 3) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right);\]
\[\text{eqn} := \rho k^2 \times \sigma_{ce} \times m_{tce} \times \sigma_{tse} \times (2 \times \text{xce} - 3) \times \left( 2 \times \text{xhe} - 1 \right) \times \sigma_{ce} \times m_{tce} \times (2 \times \text{xhe} - 3) \times \left( 2 \times \text{xhe} - 3 \right) \times \left( 2 \times \text{xhe} - 3 \right) \times \left( 2 \times \text{xhe} - 3 \right) \times (2 \times \text{xce} - 3) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right) \times \left( 2 \times \text{xce} - 3 \right);\]
\[(2 \times xhe - 3) \times \left( \omega^4 - \omega^2 \left( \frac{\Omega H^2}{\Omega^2} + \gamma \times \sigma_k^2 \right) + \gamma \times \rho k^2 \times \sigma_k^2 \right) \times \frac{\Omega H^2}{\Omega^2} \times \cos(\alpha)^2 \right) * \\
\left( \omega^4 - \omega^2 \left( 1 + \gamma \times \rho k^2 \times \sigma \right) + \gamma \times \rho k^2 \times \sigma \times \cos(\alpha)^2 \right) - \\
\frac{\Omega H^2}{\Omega^2} \times \frac{\cos(\alpha)^2}{\Omega^2} \times \rho k^2 \times \sigma_k \times \sigma \times \eta_k \times \eta \right) \times \\
\left( 2 \times xce - 3 \right) \times \left( \omega^4 - \omega^2 \left( 1 + \gamma \times \rho k^2 \times \sigma \right) + \gamma \times \rho k^2 \times \sigma \times \cos(\alpha)^2 \right) * \\
\left( \omega^4 - \omega^2 \left( 1 + \gamma \times \rho k^2 \times \sigma \right) + \gamma \times \rho k^2 \times \sigma \times \cos(\alpha)^2 \right) = 0; \\
solution = NSolve[eqn /. \{n10 \rightarrow 0.05, n20 \rightarrow 0.5, q \rightarrow 4.8 \times 10^{-10}, \}
\{ \text{mH} \rightarrow 1.67 \times 10^{-24}, \text{nH0} \rightarrow 4.95, \text{Tce} \rightarrow 2 \times 10^{-4}, \text{The} \rightarrow 2 \times 10^{-5}, \}
\{ \text{TH} \rightarrow 8 \times 10^{-4}, \text{z1} \rightarrow 1, \text{z2} \rightarrow 4, \text{m1} \rightarrow 16 \times 1.67 \times 10^{-24}, \}
\{ \text{m2} \rightarrow 16 \times 1.67 \times 10^{-24}, \text{me} \rightarrow 9.1 \times 10^{-28}, \text{kB} \rightarrow 1.36 \times 10^{-16}, \}
\{ \gamma \rightarrow 5 / 3, \gamma \rightarrow 5 / 3, \text{B} \rightarrow 8 \times 10^{-5}, \text{c} \rightarrow 3 \times 10^{-10}, \text{T1} \rightarrow 1.16 \times 10^{4}, \}
\{ \text{T2} \rightarrow 1 \times 1.16 \times 10^{4}, \text{xce} \rightarrow 2, \text{xhe} \rightarrow 2, \text{kH} \rightarrow 2 \}, \omega, \text{WorkingPrecision} \rightarrow 4]; \\
\omega1 = \omega /. \text{solution}[1]; \\
\omega2 = \omega /. \text{solution}[2]; \\
\omega3 = \omega /. \text{solution}[3]; \\
\omega4 = \omega /. \text{solution}[4]; \\
\omega5 = \omega /. \text{solution}[5]; \\
\omega6 = \omega /. \text{solution}[6]; \\
\omega7 = \omega /. \text{solution}[7]; \\
\omega8 = \omega /. \text{solution}[8]; \\
\omega9 = \omega /. \text{solution}[9]; \\
\omega10 = \omega /. \text{solution}[10]; \\
\omega11 = \omega /. \text{solution}[11]; \\
\omega12 = \omega /. \text{solution}[12]; \\
\text{Needs["PlotLegends"\]}; \\
\text{Plot[\{Re[\omega1] /. \{\theta \rightarrow 0\}, Re[\omega1] /. \{\theta \rightarrow 45\}, Re[\omega1] /. \{\theta \rightarrow 90\}, \}
\{Re[\omega6] /. \{\theta \rightarrow 0\}, Re[\omega6] /. \{\theta \rightarrow 45\}, Re[\omega6] /. \{\theta \rightarrow 90\}\}, \{\rho k, 0, 1\}, \}
\text{PlotStyle} \rightarrow \{\{\text{Thick}, \text{Black}\}, \{\text{Thick, Dotted, Black}\}, \{\text{Thick, DotDashed, Black}\}, \}
\{\text{Thick, Black}\}, \{\text{Thick, Dotted, Black}\}, \{\text{Thick, DotDashed, Black}\}\}, \}
\text{PlotLegends} \rightarrow \{\"\theta=0\", \"\theta=45\", \"\theta=90\\}\}, \text{Frame} \rightarrow \text{True}, \text{PlotStyle} \rightarrow \text{Thick}, \}
\text{LabelStyle} \rightarrow \{\text{Bold, 14}\}, \text{FrameStyle} \rightarrow \text{Thick}, \}
\text{ImageMargins} \rightarrow 0.01, \text{FrameLabel} \rightarrow \{\\{\text{k}01", \"\frac{\omega}{\Omega}\}\}
\text{ImageSize} \rightarrow 500, \text{RotateLabel} \rightarrow \text{False}, \text{PlotRange} \rightarrow \{-0.2, 3\}] \\
\text{Export["pic01.png", \%, \text{ImageResolution} \rightarrow 500]}
