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Plasma Wave Scenario in Comets

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Abstract

Plasma waves have a universal presence in our solar system – planets, some of their satellites and interplanetary medium. The solar plasma environment of also supports the generation of plasma waves such as electron and ion cyclotron waves, the magnetosonic and Alfven waves which travels a long distance in heliosphere. The plasma environment around a comet is also capable of sustaining plasma waves, some of which are observed in comets Giacobini-Zinner, Halley, Grigg-Skjellerup and Borrelly. Some other comets such as Hyakutake and 67/PChuryumov-Gerasimenko are also supposed to sustain plasma waves but are yet to be observed. This paper presents a brief review on the plasma wave observations in cometary plasma environment carried out so far and some of the unresolved plasma wave issues in comets.

1. Introduction

Plasma waves are omnipresent and thus are a unique feature of space plasmas. Electrostatic (ES) and electromagnetic (EM) plasma waves are observed in almost all the solar system objects, such as planets, some of the planetary satellites [1], Sun [2] and interplanetary medium (IPM) [3]. Plasma waves are predicted to exist in interstellar medium (ISM) [3] and are also believed to exist in many other natural plasma systems such as pulsars, quasars and galaxies.

Plasma waves have significance as they propagate energy across various space regions and transport particles in the absence of collisions and accelerate them to attain higher energies. The study of plasma waves help in having a better understanding of the ionosphere of any planetary body. The plasma waves can be employed as a diagnostic tool for estimating local plasma parameters – density and temperature of the regions which are otherwise not accessible for *in-situ* measurements such as solar corona due to their hostile environment.

A comet is a universal body, primarily made of dust, ice and gaseous matter. In the solar system, a comet can have a large elliptical orbit so that it become visible at Earth periodically such as Halley (76 years) or it can have a parabolic orbit where it passes the solar system once and then get immersed in the interstellar space. The solar radiation upon its interaction with cometary surroundings results in the formation of plasma environment by photoionization. This cometary plasma is modified by the solar wind but is still capable of sustaining basic plasma waves. In this paper such plasma waves, observed in four comets – Halley, Giacobini-Zinner (G-Z), Grigg-Skjellerup (G-S) and Borrelly are discussed.

2. Plasma and Magnetic Environment in Comets

The plasma flow near a comet, where the solar wind encounters a shock front at distance of 10^6 km from the comet nucleus, reduced the supersonic solar wind speed from 400 km/s to about 50 km/s. On moving farther, another shock-transition allows the solar wind plasma to circumvent the cometary nucleus. The cometary plasma here has velocity can be as low as 3 km/s [4].

The cometary tail is the extension of comet in a direction opposite to its movement and has a different plasma environment than that of its coma. The activity of comet and the solar wind conditions decides the overall macroscopic structure of the interaction region as well as the plasma environment around the comet including the magnetic field. The magnetic fields of four comets named in section 1 are displayed in Figure 1 where CA represents the closest approach. The figure shows that at the CA the maximum magnetic field is about 60 nT for G-Z and Halley whereas for G-S and Halley it is 80 nT [5].

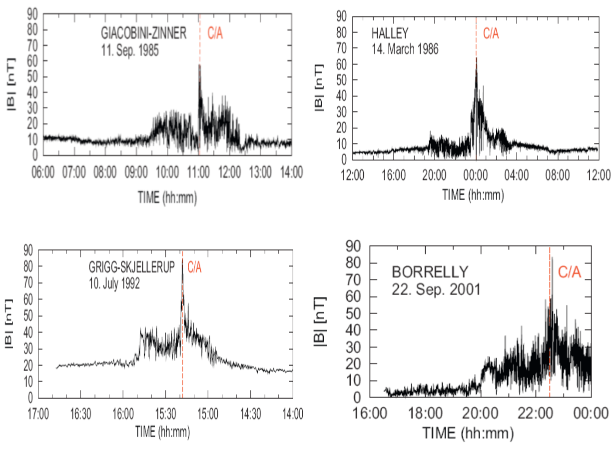

Figure 1: Magnetic field in comets G-Z, Halley, G-S and Borrelly [5].

3. Cometary missions with plasma wave detection instruments

NASA's International Cometary Explorer (ICE, also known as ISEE-3 or ISEE-C) was launched in August 1978 to become first spacecraft to encounter any comet when it encountered G-Z in 1985 and later comet Halley in 1986. ICE was equipped with Plasma Wave Investigation (PWI) having a 90 m long electric dipole, short electric antenna (0.6 m) and search-coil magnetometer to detect plasma waves [6]. A Helium vector magnetometer was also onboard ICE to measure the background magnetic field [7]. The erstwhile USSR launched identical spacecrafts Vega-1 and Vega-2 in December 1984 to reach comet Halley at a closest approach of 8889 km (Vega 1) and 8030 km (Vega 2) with magnetometers, wave and plasma analyzers onboard for plasma and wave studies. The European Space Agency (ESA) launched Giotto in July 1985 to meet comet Halley in March 1986 and G-S in July 1992 with a magnetometer onboard to measure the magnetic field and its time variation due to cometary plasma processes.In October 1998 NASA launched Deep Space-1 (DS-1) to encounter with comet Borrelly in September 2001 and carried a pair of fluxgate magnetometers (FGM), similar to that of present on Rosetta spacecraft, to sample the interplanetary magnetic field (IMF) and its variations prevailing near the comet during encounter with the Plasma Experiment for Planetary Exploration (PEPE), which was an ion mass spectrometer and an electron spectrometer, was also onboard DS-1 [8].

4. Cometary plasma waves

The atmosphere of a comet extends freely into the interplanetary space up to millions of km as it has negligible gravitation field to keep it intact. This atmosphere gets ionized by the ultraviolet radiation from the Sun and the cometary ionized particles form an ion beam in the solar-wind plasma which relaxes due to the impact of plasma waves.

4.1 Plasma waves in comet G-Z

In 1985, the plasma wave instrument on ICE detected a burst of strong ion acoustic waves when the spacecraft was within 4×10^6 km of the comet G-Z nucleus. EM whistlers and low-level electron plasma oscillations (EPOs) were also observed in that vast region which looked to be associated with heavy ion pick-up. As ICE came closer to the nucleus, just beyond the visible coma, the EM and ES wave levels increased significantly [9].

The PWI onboard ICE also detected a burst of strong ion acoustic waves almost continuously when it was within 2×10^6 km of the comet G-Z nucleus. EM whistlers and low-level EPOs were also observed in that region which appeared to be associated with heavy ion pickup. As ICE came closer to the nucleus, just beyond the visible coma, the EM and ES wave levels increased significantly [9].The plasma wave detection by ICE's encounter with comet G-Z are shown in Figure 2 where the EPOs and ion acoustic waves can be seen.

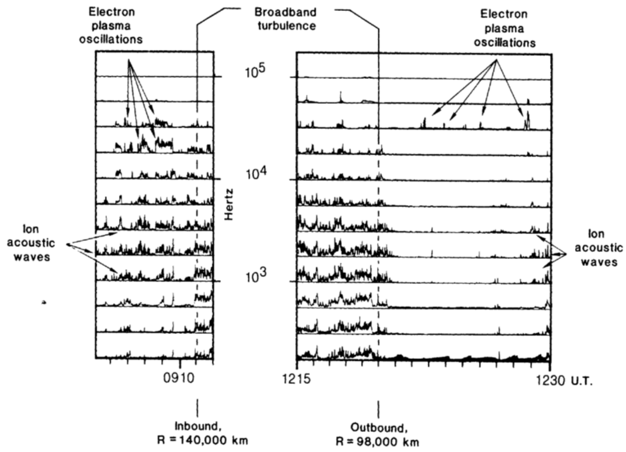

Figure 2: Plasma wave detection near comet G-Z [9].

4.2 Plasma waves in comet Halley

Giotto measured the magnetic field near comet Halley at a distance of ≈ 4500 km from the cometary coma with a maximum of ≈ 50 nT [10]. The first plasma wave observation in comet Halley was carried out by Vega 2 using the high frequency plasma wave analyser (APV-V) having the capability to detect electric fields in the bandwidth 0-300 kHz through a doublesphere antenna with 11 m baseline. The signal spectrum detected by the electric antenna is analyzed in the frequency range 8 Hz – 300 kHz [11].

The low-frequency plasma wave detector (APV-N) onboard Vega 1 and 2 observed increased plasma wave intensity near comet Halley. Vega 1 identified this wave activity with the inbound crossing of a quasi-perpendicular cometary bow shock, Vega 2 observed for quasi-parallel orientation [12].

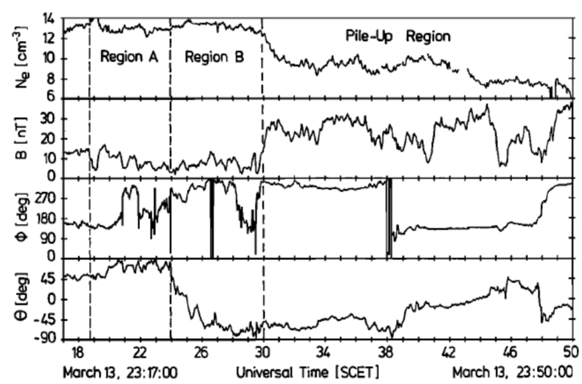

Figure 3: Plasma observations by Giotto during comet Halley flyby. Φ is the azimuth angle and θ is the elevation

of field vector in Halley centered Solar Ecliptic co-ordinate system [13].

Figure 3 shows a series of quasi-sinusoidal, large amplitude magnetic field oscillations of about 6 nT which indicate the presence of a quasi-periodic coherent wave features near the magnetic pileup boundary [13].

4.3 Plasma waves in comet G-S

In July 1992, the Giotto magnetic field and plasma observations established the low frequency EM waves near comet G-S [14]. Waves produced by ion pickup instabilities were observed when Giotto encountered comet G-S as shown in Figure 4 [15].

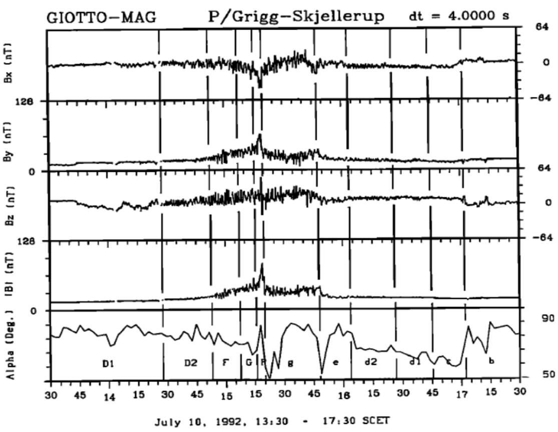

Figure 4: Magnetic field observations overview of the comet G-S. Alpha is the angle between the magnetic field direction and the solar wind flow velocity vector [15].

The magnetic field data indicate a regular wave train with peak-to-peak amplitude 2 nT and a frequency close to the local water group ion gyrofrequency. Wave activity at the smaller periods was also observed around the same time which could have been of solar origin. This is followed by an extended region of disordered IMF in which the wave activity becomes conspicuous. The region g isfurthermore characterized by wave features of peak-to-peak amplitude variation of ~ 10 nT [15].

4.4 Plasma waves in comet Borrelly

Comet Borrelly was encountered by spacecraft DS-1 during its flyby on September 22, 2001 at a solar distance of 1.36 AU. The closest approach between the spacecraft and the comet was at 2171 km. The cometary magnetic field was measured usingthe fluxgate magnetometers onboard DS-1 [16]. The magnetic field pileup region had maximum magnetic field of 83 nT [5]. 1 kHz electron cyclotron waves, predicted to be generated due to plasma instabilities, were observed by DS-1 [17]. Low frequency (10 Hz) whistler waves of mix polarization observed by DS-1 were generated due to the ion pickup process in the cometary plasma environment.The magnetic field measured by magnetometers shows high level of magnetic field fluctuations, after the bow-shock crossing indicating the presence of upstream and downstream waves [18].

Table 1 gives the summary of various plasma wave modes observed in the four comets:

S. No.	Comet Mission Year	Instruments	Observed Plasma Waves
1.	G-Z ICE 1985	Short & Long Electric dipole, Search-coil & Vector Helium Magnetometer	EPOs, UHR emissions, Ion acoustic, lower hybrid (LH) and Whistler waves
2.	Halley Vega-1, Vega-2 1986	Flux-gate Magnetometer, Plasma Wave Instrument	Langmuir,LH, Ion cyclotron and Magnetosonic waves
3.	G-S Giotto 1992	Flux-gate Magnetometer	Whistler, Ion cyclotron and Alfven waves
4.	Borrelly DS-1 2001	PEPE, Flux-gate Magnetometer	Electron cyclotron and Whistler waves

4.5 Plasma waves in other comets

Lower hybrid waves, generated due to the interaction of cometary gas with solar wind, are predicted to exist in the comet Hyakutake which accelerate the electrons resulting in the emission of x-rays from the comet [19]. The plasma environment of comet 67P/ Churyumov-Gerasimenko (C-G), at 1 AU, has typical electron plasma density (n_e) ≈ 10 cm^{-3} which increases on reaching nearer to the nucleus of the comet (≈ 40 at bow-shock); electron plasma temperature, $T_e \approx 8.6$ eV; ion plasma temperature, $T_i \approx 0.9$ eV and the IMF ≈ 7 nT, prevailing there [20] suggesting the existence of ion acoustic waves there [21].

4.6 Unresolved plasma wave issues in comets

There are some unresolved plasma wave issues in comets which are listed as follows:

1. Not all the plasma waves are observed in all the comets. The lower hybrid waves are observed in G-Z and Halley but not in G-S and Borrelly; Ion cyclotron waves are observed in Halley and G-S but not in G-Z and Borrelly; Electron cyclotron waves are observed only in Borrelly and Magnetosonic waves are observed only in Halley and Alfven waves in G-S only. Since the plasma environment of these comets is almost same, this issue needs further investigation.
2. Plasma waves can exist in comets other than the four comets discussed above such as Wirtanen,Hyakutake, C-G, etc. which have plasma wave supportive environment.

5. Conclusion

When the solar radiation interacts with the neutral particle medium it results in the formation of localized plasma or ionization in that region. In cometary environment, this plasma medium extends from the coma around the cometary nucleus to the tail of the comet which is at times a magnetotail. The low density,low temperature plasma around a comet is capable of sustaining plasma waves. A number of such plasma waves are observed in comets G-Z, Halley, G-S and Borrelly. The commonly observed plasma waves in the comets are the electron plasma oscillations, ion cyclotron and lower hybrid waves. Despite these observations, there are still some unresolved issues with respect to the plasma wave observations in comets, which needs to be addressed.

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