



VIPER: A Plasma Wave Detection Instrument onboard Indian Venus Orbiter Spacecraft

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Abstract

Plasma waves are observed in almost all the solar system objects - planets, their satellites, comets, Sun, interplanetary medium, etc. The planetary ionospheres are capable of sustaining plasma waves which are observed there and play an important role in the ionospheric dynamics by propagating energy across different space regions and provide acceleration to particles to attain high energies for transportation. The study of planetary plasma waves also provides information on the solar wind – planet interaction, the energy distribution in the ionospheric plasma of that planet, etc.

Venus does not possess a global magnetic field unlike Earth. The solar EUV radiation ionizes the neutrals and generates a plasma environment around Venus which can sustain plasma waves. Very few attempts are made to observe all plasma waves that can exist around Venus and that too with instruments having a limited dynamic range such as with PVO (Pioneer Venus Orbiter) and Venus Express. However, there are some other plasma waves which can exist around Venus but are yet to be observed.

ISRO is planning to send an orbiter mission to Venus in near future where a suit of instruments named VIPER (Venus Ionospheric Plasma wave detector) is onboard to observe Venusian plasma waves. The plasma wave observations around Venus and VIPER onboard ISRO's Venus Orbiter Spacecraft are discussed in this paper.

1. Introduction

Venus is a terrestrial planet which does not possess a global magnetic field. The solar radiation (dominantly EUV) interacts with the dense Venus atmosphere and ionizes large number of neutral atoms and molecules and the ionosphere gets generated. The magnetic field observed around Venus is a result from the solar wind interaction with the upper atmosphere of the Venus. The induced magnetic field of Venus varies ~ 50 to 150 nT.

The first plasma wave detection around Venus was carried out by PVO in 1978 with a suit of instruments such as magnetometer [1, 2], electric dipole [3] and electron temperature probe, [4].

The electric dipole had an effective length of 0.75 m formed by a pair of electric field sensors having wire circles of diameter 10.5 cm. The electric field sensor had four frequency channels: 100 Hz, 730 Hz, 5.4 kHz and 30 kHz. The automatic gain control amplifiers had a rise time of 50 ms and a decay time of about 500 ms. The Orbiter

Electron Temperature Probe (OETP) was designed to measure the plasma parameters in Venus ionosphere - electron (n_e) and ion (n_i) plasma density, electron plasma temperature (T_e) and the spacecraft potential (V_{sc}). It consisted of two cylindrical sensors – one placed radially at the end of a 1 m long boom and the other placed axially at a distance of 0.4 m away from the spacecraft with a common electronics unit [4, Krehbiel et al., 1980]. The Venus Express in 2005 from ESA also carried two triaxial magnetometer sensors to measure the magnetic field in the Venus ionosphere with one sensor mounted directly on the spacecraft and the other at the end of a 1 m boom. The magnetometer sensors have a dynamic range from ± 32.8 to ± 8388.6 nT with 128 Hz cadence [5]. Table 1 lists different plasma wave detection instruments which have flown onboard various missions to Venus for measurements.

Table 1

Mission	Year	Agency/ Country	Plasma wave Instrument	Other Plasma Instruments
Mariner-10	1974	NASA	Magnetometer	Plasma Ion Probe
Pioneer Venus Orbiter (PVO)	1978	NASA	Orbiter Electric Field Detector (OEFD), Magnetometer (OMAG), Orbiter Electron Temperature Probe (OETP)	Orbiter Ion Mass Spectrometer (OIMS), Orbiter Plasma Analyzer (OPA), Orbiter Retarding Potential Analyzer (ORPA), Orbiter Radio Occultation
Venera 11/12	1978	USSR	Magnetometer	---
Venus Express	2005	ESA	Magnetometer	ASPERA-4

PVO measured the electron plasma density varies from a maximum of $5 \times 10^5 \text{ cm}^{-3}$ at 150 km to about 10^4 cm^{-3} at 900 km whereas the electron temperature has a variation between 1100° K at 150 km to 8000° K at about 900 km. The ion temperature is less than electron temperature at

the same altitude at 500° K at 150 km to 1300° K at 900 km. The typical plasma and magnetic field parameters around Venus [6, 7] are summarized in Table 2.

Table 2

Plasma parameter	Range
Electron number density, n_e (cm^{-3})	$3 \times 10^2 - 5 \times 10^5$
Electron temperature, T_e (eV)	0.1 – 1.7
Ion number density, n_i (cm^{-3})	$10 - 2 \times 10^5$
Ion temperature, T_i (eV)	0.02 – 0.3
Background magnetic field, B (nT)	50 – 165

2. Venus Plasma Wave Observations

PVO was the first best equipped spacecraft to observe plasma waves near the Venus. Its electric field sensors observed a strong and highly variable solar wind interaction with the Venusian ionosphere. PVO observed electromagnetic whistler waves in 100 Hz, lower hybrid waves in 30 kHz range [8] and electron plasma oscillations in 20-54 kHz frequency range [9]. Galileo during its flyby of Venus observed electrostatic Langmuir waves [10]. Venus Express detected proton cyclotron waves in Venus ionosphere with a set of fluxgate magnetometers onboard [11, 12]. Mirror mode waves were also observed in the induced magnetosphere of Venus by Venus Express [13, 14]. Apart from the above mentioned waves, ion acoustic waves (IAW) with frequency $f_{IAW} \approx 100$ Hz are proposed to be present in the Venus ionosphere as a consequence of the ion acoustic beam instability due to O^+ ions [15]. Magnetosonic waves having frequencies between 40-50 mHz (in the spacecraft frame) are observed by Venus Express [16]. A review on plasma waves around Venus is given elsewhere [17]. A summary of various plasma wave observed in the ionosphere of Venus is given in Table 3.

Table 3

Observed Plasma Waves	Spacecraft	Instruments	Frequency
Electron plasma oscillations	PVO, Galileo	OEFD, MAG	≈ 50 kHz
IAW	PVO	OEFD, OMAG, OETP	730 Hz, 5.4 kHz
Whistler waves,			$= < 100$ Hz
Lower hybrid waves			30 kHz
Langmuir waves	Galileo	PWS, MAG	200 Hz - 7 kHz
Proton cyclotron waves	Venus Express	MAG	$= < 0.5$ Hz
Mirror mode waves			30 – 300 mHz
Magnetosonic waves			40 – 50 mHz, < 100 mHz

Table 4 lists all the plasma waves that are expected to be present around Venus and are to be observed by VIPER.

Table 4

Plasma Waves/oscillations	Expected frequency
Hydromagnetic waves	40 – 50 mHz, < 100 mHz
Mirror mode waves	30 – 300 mHz
Proton cyclotron waves	$= < 0.5$ Hz
Whistler waves	$= < 100$ Hz
Ion cyclotron waves	19 – 625 Hz
Mix-mode waves	50 – 1000 Hz
Electron cyclotron waves	1.4 – 4.5 kHz
Ion acoustic waves	730 Hz, 5.4 kHz
Langmuir waves	200 Hz - 7 kHz
Lower hybrid waves	30 kHz
Electron plasma oscillations	≈ 50 kHz

Table 5 list the plasma waves that can exist around Venus but are yet to be observed.

Table 5

Un-observed Plasma Waves	Expected frequency	Importance
Electron cyclotron waves	1.4 – 4.5 kHz	Electron transport from Venus
Ion cyclotron waves	19 – 625 Hz	Particle loss from the Venusian ionosphere
Mix-mode waves	50 – 1000 Hz	Venus ionospheric heating

A hand-made schematic distribution of plasma waves around Venus is shown in Figure 1.

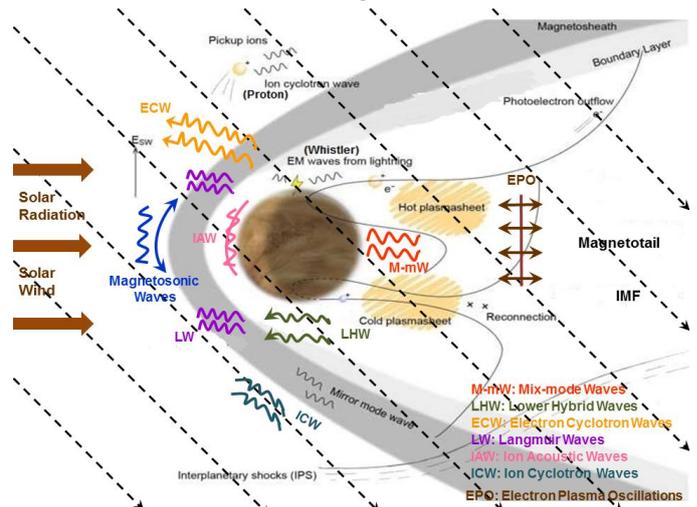


Figure 1. The distribution of plasma waves around Venus (Not to scale in altitude).

It is to be noted that there are only couple of attempts made to observe all plasma waves that can exist in the Venus ionosphere and that too with instruments having a limited dynamic range. However, the limited instrumental capability onboard PVO and Venus Express shows that a number of plasma waves exist in the ionosphere of Venus. There are some plasma waves which may exist in the ionosphere of Venus but are not detected such electron and ion cyclotron waves, mix-mode waves, etc. Although

Langmuir, ion acoustic, whistler and proton cyclotron waves are detected by earlier Venus missions, it shall be prudent to make an attempt again to observe these plasma waves if the dynamic range of the measuring instrument makes it possible so as to verify the earlier measurements and to get some additional scientific information if possible. Electron plasma frequency (f_{pe}) & subsequently electron plasma (Langmuir) wave frequency (f_{EPW}) can be computed as follows: ($n_e \approx 10^3 - 5 \times 10^5 \text{ cm}^{-3}$, $f_{pe} \text{ (min.)} = 0.284 \text{ MHz}$; $f_{pe} \text{ (max.)} = 6.35 \text{ MHz}$).

3. VIPER: Science Objectives

The proposed scientific instruments, in the form of a suit (VIPER) are – a customized Langmuir probe (LP) to measure the electron & ion number density and electron plasma temperature, a triaxial electric field sensor (EFS) to measure the oscillating plasma wave electric field, a triaxial search-coil magnetometer (SCM) to measure the oscillating plasma wave magnetic field around Venus and a triaxial fluxgate magnetometer (FGM) to measure the background magnetic field around Venus. All these sensors shall be mounted on two separate booms thereby keeping them away from the spacecraft to avoid the sheath and shielding effects.

The scientific objectives of VIPER are:

- (i) To study the plasma phenomena around Venus by exploring it in the prevailing localized regions. For this purpose, the electron and ion plasma parameters are going to be measured *in-situ* with LP onboard the orbiter spacecraft around Venus.
- (ii) To study of the interplanetary and induced magnetic field structure around Venus. For this purpose, the background magnetic field is going to be continuously measured *in-situ* with FGM onboard the orbiter spacecraft around Venus.
- (iii) To detect and observe the plasma waves around Venus and to explore their role in modulating the plasma dynamics around Venus. For this purpose, the plasma wave frequency is going to be measured with EFS and SCM.

Table 6 lists the scientific objectives pertaining to the measurement parameters and sampling requirements.

Table 6

Science Objectives	Measurement parameters
To explore the plasma environment around Venus and to study the plasma phenomena prevailing in localized regions.	Continuous measurement of plasma parameters such as electron and ion number density, electron and ion plasma temperature around the Venus.
Study of the interplanetary and induced magnetic field structure prevailing around Venus.	Continuous measurement of background magnetic field around the Venus.
Characterization of Venusian plasma waves and their role in	Continuous detection and measurement of the plasma wave electric and magnetic

modulating the plasma dynamics around Venus.	fields along with the localized plasma parameters around the Venus.
Study of various physical phenomena taking place around Venus such as the plasma energy distribution, plasma heating, particle acceleration and their	Continuous measurements of plasma wave parameters and charge particle distribution measurements along with their number densities and energies around the Venus. Data from VIPER and other onboard instruments to be used.

4. VIPER Plasma Wave Detection

The identification of plasma waves by VIPER is done after detecting the time varying (oscillating) electric field and magnetic field signals. Initially the plasma parameters such as electron and ion number density and electron and ion plasma temperature shall be estimated using the LP along with the background steady state which is going to be measured by the FGM as given in Table 7.

Table 7

Instrument / Scientific Aim	Plasma/Field Parameter & Range	Measurements Required
Langmuir Probe (LP) Plasma parameter measurements	n_e ; [$10^2 - 10^6 \text{ cm}^{-3}$] T_e ; [0.1 - 1 eV] n_i (bulk); [$10^2 - 10^5 \text{ cm}^{-3}$] T_i (bulk); [0.06 – 0.4 eV]	Electron & Ion saturation currents, Complete I-V characteristics
Electric Field Sensor (EFS) Oscillating plasma wave electric field	ω (ES & EM) [1 Hz - 55 kHz]; E_1 ; [mV/m]	Wave electric field at different frequencies.
Fluxgate Magnetometer (FGM) Background magnetic field measurements	B_0 ; [1 – 300 nT]	B_{x1}, B_{y1}, B_{z1} and B_{x2}, B_{y2}, B_{z2}
Search-coil Magnetometer (SCM) Oscillating plasma wave magnetic field	ω (EM only); [1 Hz – 55 kHz] B_1 ; [1 – 300 nT]	Wave magnetic field at different frequencies.

Here, ω is the angular frequency ($= 2\pi f$) of the wave having frequency f , E_1 and B_1 are the time-varying wave electric and magnetic fields respectively. These plasma and field parameters are to be used to estimate the plasma characteristic frequencies such as the electron/ion plasma frequency, electron/ion cyclotron frequency and secondary plasma parameters as given in Table 8.

Table 8

Plasma Parameters	Measured quantities / constants	Value
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Electron cyclotron frequency, $\omega_c = 2\pi (e B_0) / m_e$	B_0, e, m_e	$2.8 \times 10^6 B_0$ Hz
Ion cyclotron frequency, $\Omega_c = 2\pi (Z e B_0) / m_i$	B_0, m_i, m_p, Z $\mu = m_i / m_p$	$1.52 \times 10^3 Z$ $\mu^{-1} B_0$ Hz
Electron plasma frequency, $\omega_{pe} = 2\pi (e^2 n_e / m_e \epsilon_0)^{1/2}$	n_e, e, m_e, ϵ_0	8.98×10^3 $n_e^{1/2}$ Hz
Ion plasma frequency, $\omega_{pi} = 2\pi (Z^2 e^2 n_i / m_i \epsilon_0)^{1/2}$	$Z, e, n_i, m_i, \epsilon_0$	$2.1 \times 10^2 Z$ $\mu^{-1/2} n_i^{1/2}$ Hz
Electron thermal velocity, $v_{the} = (K_B T_e / m_e)^{1/2}$	K_B, T_e, m_e	$4.19 \times 10^5 T_e$ m/sec
Ion sound velocity, $v_s = (\gamma Z K_B T_e / m_i)^{1/2}$	$k, T_e, m_i, Z, \gamma, \mu$ $\mu = m_i / m_p, \gamma = c_p / c_v$	$9.79 \times 10^3 (\gamma Z T_e / \mu)^{1/2}$ m/sec
Ion thermal velocity, $v_{thi} = (k T_i / m_i)^{1/2}$	K_B, T_i, m_e	$9.79 \times 10^3 T_i^{1/2} \mu^{1/2}$ m/sec
Debye length, $\lambda_D = (K_B T_e / e^2 n_e)^{1/2}$	K_B, T_e, n_e, e	$7.43 T_e^{1/2} n_e^{-1/2}$ m
Alfvén velocity $v_A = B_0 / (\mu_0 \rho)^{1/2}$	B_0, μ_0, ρ, μ $\rho = n_i m_i, \mu = m_i / m_p$	$2.18 \times 10^9 \mu^{-1/2} n_i^{-1/2} B_0$ m/sec

Here, B_0 is the background magnetic field, e is electronic charge, m_e is electron mass, Z is the atomic number, m_i is ion mass, m_p is proton mass, c is velocity of light in free space, ϵ_0 is the permittivity of the free space, K_B is the Boltzmann constant, T_e is the electron temperature, γ is the ratio of specific heats, μ_0 is the permeability of the free space, ρ is the ion mass density, n_i is ion number density.

The estimated plasma parameters and measured magnetic field along with the frequency of the oscillating electric and magnetic field shall be fitted in the dispersion relations of various plasma waves that can exist around the Venus and the outcome shall be analysed for proper identification. For example, the dispersion relation of an electron plasma (or Langmuir) wave is $\omega^2 = \omega_p^2 + (3/2) k^2 v_{th}^2$. Here, the variables are ω (measured from EFS), ω_{pe} (estimated from n_e measured by LP), v_{the} (estimated from T_e measured by LP) and k . For a given small range of k , the dispersion relation shall be satisfied and the existence of the wave shall be established.

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