Composition of the Topside Ionosphere Determined from Plasma Wave Measurements Using the Radio Receiver Instrument on e-POP

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Abstract— **Data were collected with Canadian e-POP instruments to measure electric fields (10 Hz to 30 kHz) with the Radio Receiver Instrument (RRI) and the 3-axis magnetometer (MGF) in the 62.5 pt to 65.536 μt range. The electric field measurements showed waves ULF (210 Hz) and VLF (14 kHz) range that varied along the orbit and were disturbed by the firing of the Cygnus satellite rocket motor 50 km away. A number of questions are raised by the observations including: Are the observations attributable to Cygnus? Are the observed harmonics instrumental or physical? What are the plasma wave generation and propagation modes? The observations are used to infer natural and artificial changes in the ionosphere.**

Introduction

Knowledge of the electron density in the topside ionosphere is essential for interpretation of HF radio signals recorded by satellite receivers and validating physical models of the plasma. A new technique has been developed to record the spectrum of natural and spacecraft-induced plasma waves for determination of the local plasma density and ion composition. Possible sources for wave excitation include supra-thermal the electron population associated with photo electrons, quasi-monochromatic electron beams, motion of large antennas across the background magnetic field, and firing of spacecraft thrusters. The e-POP satellite with the wide-band radio receiver instrument (RRI) that should be able to detect a wide variety externally excited plasma waves in situ. Each of these waves has a resonant frequency that is a function of the local properties of the plasma such as electron and ion density, electron and ion mass, electron and ion temperature and background magnetic field. Waves that can be observed in situ include fast MHD (i.e., magnetosonic) mode below the ion gyro frequency, whistler and low-hybrid modes between the ion and electron gyro frequencies, and the electron plasma mode. In a multi-component ion plasma, ion-ion hybrid modes may be observed.
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I. Plasma Waves Yielding Ionospheric Composition

For the e-POP measurement altitudes of 320 to 1500 km altitude, the plasma is mainly composed of electrons, and two ions (e.g. protons and O+). With this composition, four waves have been selected for radio spectrum observations with the RRI sensor flying through the F-Layer during the sunlit hours. For the first plasma wave, the wave spectra of the electron-plasma (Langmuir) will be examined. This mode has been previously seen by in situ and radar techniques with photo-electrons exciting Langmuir fluctuations in the ionosphere. The second wave is the lower-hybrid mode with a resonance that involves the ion-ion hybrid gyro frequency using density weights of the H+ and O+ ion gyro frequencies, and the Pythagorean sum of the electron plasma frequency and the electron gyro frequency. The third wave is the whistler mode whose frequency depends on electron density and propagation angle but not on ion composition. The forth wave is the low frequency two-ion hybrid wave with resonance given by the density and mass-weighted geometric mean of the individual ion cyclotron frequencies; it may be detected by the RRI at low frequency range of the instrument.

This technique relies on external free energy to produce the plasma waves. Electric field fluctuations found in all thermal plasmas because of Cerenkov-like processes that transfers energy from the electron motion to waves at resonance frequencies. The intensity of the induced plasma waves grows as the energy and flux of the electron beam is increased. The wave-particle interactions rely on matching the particle speed of the electrons to the phase speed of the wave. Both Cerenkov and Cyclotron resonances can amplify waves by interactions with electron beams. The electron velocity distribution controls the wave growth process. The electron distribution produced by solar photon ionization yields a supra thermal, but not beam, distribution with a characteristic temperature or energy around 100 times the thermal temperature. The electron distribution for beam driven excitation has a bump at an electron energy that is distinct from the ambient thermal population.

The properties of the plasma are manifested differently with each wave mode. The in situ electron density may be directly inferred from the electron-plasma wave and whistler mode measurements. The relative two-ion plasma composition can be directly determined with ion-ion hybrid frequencies. The lower-hybrid resonance in the plasma can be used to tie together the electron density through plasma frequency and the relative ion composition. This technique has been tested in the ambient ionosphere with daytime operations of the RRI showing strong emissions from the plasma. The measured electron density and ion composition is in good agreement with the SAMI-2 physics based model of the F-layer.

II. TESTS USING NEURAL GAS INJECTIONS

Artificial gas injection is used to test the plasma composition measurements technique. A small, 150 g/s thruster was operated on the Cygnus spacecraft used to service the International Space Station. The nitrogen tetroxide and mono-methyl hydrazine engine is operated to produce a number of molecules including water vapor and nitrogen. These molecules expand into the ionosphere to make water ions (H20+) and molecular nitrogen ions (N2+) by charge exchange with the ambient O+ and H+ ions [1]. Electron-ion recombination leads to a reduction in electron density. The e-POP satellite flies through the modified plasma region measuring plasma oscillations from lower-hybrid, ion-ion hybrid and whistler waves that have frequencies determined by the ion masses and electron densities. The high mass ions and electron density reductions produced by the thruster firing cause the reduction in frequencies for the measured lower-hybrid waves (Figure 1).

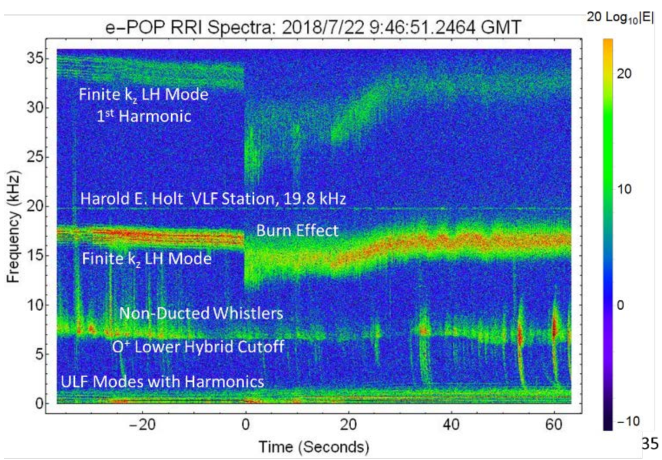

Figure 1. Observations of plasma wave emissions near 530 km altitude in the southern hemisphere ionosphere with the e-POP instruments passing within 50 km of the Cygnus spacecraft engine firing for 30 seconds. The point of closest approach between the satellites is a time zero.

In summary, a new technique has been developed to measure the plasma in the ionosphere. A wide variety of plasma resonances are observed in the F-Layer. The e-POP satellite passing through the 320 to 600 km altitude range yields plasma wave spectra used to measure election density and ion composition.

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