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Electron conic distributions produced by solar ionizing radiation in planetary atmospheres

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Abstract

Electron conic distributions have angular distributions with peak fluxes well separated from the field aligned-direction. They have previously been reported at Earth on auroral field lines and at the Moon and Mars on closed crustal magnetic field lines. Here we report observations of electron conics at Earth on closed magnetic field lines well removed from the aurora. We show how these distributions could be produced without plasma wave interactions when magnetic field lines are illuminated by solar ionizing radiation at relatively high altitudes in the ionosphere. Examination of previous reports of electron conic distributions observed in planetary atmospheres show that there are a variety of physical mechanisms that can lead to their formation, not all of which require wave-particle interactions.
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1. Introduction

Angular distributions of charged particles in the magnetosphere and ionosphere are generally thought of as signatures of plasma energization and acceleration processes. See for example, Shelley (1995). Particle velocity space distributions peaking along the magnetic field direction are called beams. Conical distributions are characterized by a maximum in an angular distribution well separated from the magnetic field line direction. Operationally, the conic angle is defined as the pitch angle at the flux maximum of the distribution. Ion conic distributions are better known and have been shown to be the result of plasma heating or energization processes transferring energy to ions in the plane perpendicular to the local magnetic field. See for example, Klumpar et al. (1984), André (1997), and Collin et al. (1998).

Electron conic distributions are not as well understood and have recently been identified in regions well removed from the Earth's auroral zone. Electron conic distributions may be classified into two distinct types: uni-directional and bi-directional. Menietti and Burch (1985) first identified uni-directional electron conic distributions appearing as enhancements in the electron flux at pitch angles slightly closer to 90° than the loss cone angle. Burch et al. (1990) showed test particle calculations consistent with observations indicating that bi-directional electron conic distributions are observed on auroral field lines within regions of parallel electron acceleration. André and Eliasson (1992) created a model that demonstrated how low frequency electric fields could produce electron conics. Thompson and Lysak (1996) showed that these low frequency waves arise naturally when Alfvén waves reflect from the ionosphere.

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Burch (1995) and André (1997) reviewed the extensive set of electron conic observations from multiple platforms and physical mechanisms thought to create them. Both concluded that electron conic distributions were the result of electron acceleration process but that the exact details of the process were not accessible with existing observations and models. Recently, Brain et al. (2007) identified two-sided or bi-directional electron conic distributions in the Martian ionosphere that are not associated with aurora and Halekas et al. (2012) identified electron conics near the Moon.

Here we report uni-directional electron conic distributions on closed magnetic field lines well equatorward of Earth's auroral field lines and compare and contrast them to the electron conic distributions found on closed Martian magnetic field lines. We demonstrate that there are a variety of physical mechanisms that can lead to the formation of electron conic distributions.

2. Data

Electron energy spectra from the Fast Auroral SnapshoT (FAST) satellite (Carlson et al., 2001) obtained under conditions of solar illumination (solar zenith angle, SZA < 90°) equatorward of the auroral field lines have previously been reported by Peterson et al. (2008, 2009, 2012). Less intense fluxes of photoelectrons are also produced on the nightside of the solar terminator where there is some high altitude illumination when the SZA is larger than 90°. Fig. 1 presents two views of electron energy-angle distributions as a function of time obtained on July 13, 2002 obtained from the FAST spacecraft. During this interval the satellite was at about 3000 km altitude. The feet of magnetic field lines encountered by FAST in the ionosphere below the satellite were in partial sunlight (SZA > 90°).

The top panel (Panel A) presents the color-coded energy-time spectrogram of electrons streaming up magnetic field lines with pitch angles within 18° of the magnetic field direction. Corrections for background noise and varying spacecraft potentials have been applied as described in Peterson et al. (2012). After about 01:07 the satellite entered the auroral region, which is characterized by rapid changes and more energetic electron distributions. The magnetic footprints of the satellite at 100 km altitude entered full sunlight (SZA < 90°) conditions after 01:10. Before 01:07:30 the electrons shown in Panel A are produced by photoionization in the ionosphere below the satellite but above the shadow altitude.

Panel B shows angle-time spectrogram of the angular distribution of the electron flux integrated over the five energy bins between 40 and 60 eV in 360° pitch angle coordinates. The angle between the magnetic field and sensor look direction covers the range from 0 to 360°. For angles less than 180° the calculated pitch angle is used. For angles above 180° the angle reported is 360° minus the calculated pitch angle. In the northern hemisphere, where the data

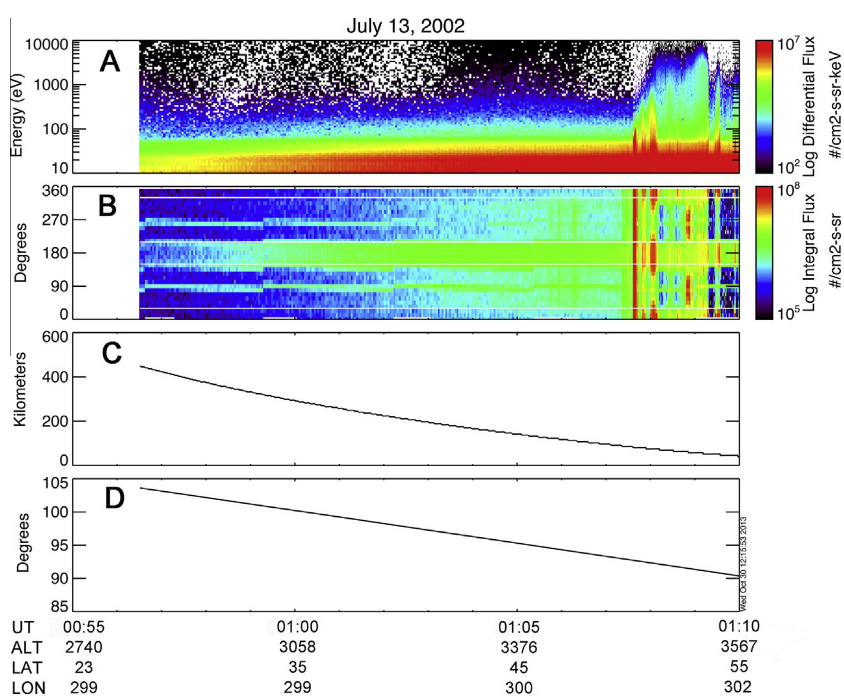

Fig. 1. Data obtained on July 13, 2002. The satellite position in altitude (ALT), latitude (LAT) and longitude (LON) for several universal times (UT) is show at the bottom. (A) Energy-time spectrogram of the differential number flux of upflowing photoelectrons from the ionosphere below encoded in units of $(cm^2\text{-s-sr-keV})^{-1}$ shown in the color bar. (B) Angle-time spectrogram of the flux of electrons integrated over the 40 to 60 eV range encoded in units of $(cm^2\text{-s-sr})^{-1}$ shown in the color bar. (C) The geometrical shadow altitude of the sun on the magnetic field line below the satellite. (D) The solar zenith angle at the magnetic conjugate point in the ionosphere below the satellite. Locations of the magnetic footpoints were determined using the default magnetic field in NASA's Satellite Situation Center (SSCWeb) System (http://sscweb.gsfc.nasa.gov/).

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