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Suprathermal electron fluxes on the nightside of Mars: ASPERA-3 observations

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Abstract

Recently aurora-type UV emissions were discovered on the nightside of Mars [Bertaux, J.-L., Leblanc, F., Witasse, O., et al., 2005. Discovery of an aurora on Mars. Nature 439, doi:10.1038/nature03603]. It was suggested that these emissions are produced by suprathermal electrons with energies of tens of eV, rather than by the electrons with spectra peaked above 100 eV [Leblanc, F., Witasse, O., Winningham J., et al., 2006. Origin of the martian aurora observed by spectroscopy for investigation of characteristics of the atmosphere of Mars (SPICAM) onboard Mars Express. J. Geophys. Res. 111, A09313, doi:10.1029/2006JA011763]. In this paper we present observations of fluxes of suprathermal electrons ($E_e \approx 30$–$100\,\text{eV}$) on the Martian nightside by the ASPERA-3 experiment onboard the Mars Express spacecraft. Narrow spikes of suprathermal electrons are often observed in energy-time spectrograms of electron fluxes at altitudes between 250 and 600 km. These spikes are spatially organized and form narrow strips in regions with strong upward or downward crustal magnetic field. The values of electron fluxes in such events generally could explain the observed auroral UV emissions although a question of their origin (transport from the dayside or local precipitation) remains open.

Keywords: Mars; Ionosphere; Magnetosphere; Aurora

The discovery of a strong localized crustal magnetic field on Mars (Acuña et al., 1998), suggested the existence of a Martian aurora and, indeed, the observations by the European Mars Express spacecraft (MEX), using the ultraviolet spectrometer SPICAM, have identified very localized auroral-type emissions (Bertaux et al., 2005). It was assumed that emissions were due to a flux of electrons precipitating in a narrow cusp-like region (~30 km wide at an altitude of 140 km) at ~178° east longitude and ~ − 50° latitude which well coincides with the location of the strongest crustal source on Mars. It was also estimated that the intensity of the electron flux which is necessary to produce the observed atmospheric emissions is one order of magnitude larger than typical electron fluxes measured by the electron reflectometer (ER) on Mars Global Surveyor (MGS) in the magnetosheath. Bertaux et al. (2005) assumed that the required additional one order of magnitude can be explained if the diameter of the auroral field tube at an altitude of 400 km is about 100 km. Subsequently, Brain et al. (2006) and Lundin et al. (2006) have reported observations of peaked electron energy distributions which were very similar to the inverted 'V' structures related to the aurora on the Earth. Peak energies ranged from 100 eV to >1 keV. Based on this analogy, it was suggested that auroral-like electron acceleration processes operate on Mars too. However, due to higher values of the Pedersen conductivity on Mars, the electric fields can be strongly attenuated (Dubinin et al., 2008) which raises concerns about the existence of small-scale auroral-type flux tubes with parallel electric field potential drops. Reanalysis of the SPICAM observations by Leblanc et al. (2006) has also imposed a strong constraint on the energy distribution of the electrons responsible for the observed emissions. The best agreement with the optical observations is obtained for energy distributions peaking at energies below a few tens of eV. Here we present observations made by the electron spectrometer ELS on

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MEX on the nightside of Mars in the altitude range 250–600 km during the first two years of a MEX operation. The ELS instrument, which is a part of the ASPERA-3 experiment (Barabash et al., 2006) measures 2D distributions of electron fluxes in the energy range 0.4 eV–20 keV ($\delta E/E = 8\%$) with a field of view of $4^{\circ} \times 360^{\circ}$ and a time resolution of ~4 s per energy spectrum.

Fig. 1 shows examples of typical spectrograms of electron fluxes at the nightside near the periapsis. The upper panel corresponds to the measurements obtained on the MEX orbit (August 11, 2004) when the SPICAM instrument has observed the Martian aurora. The emissions were measured at 06:01:21-06:01:28 UT when MEX was in the penumbra at an altitude of 266 km (the s/c

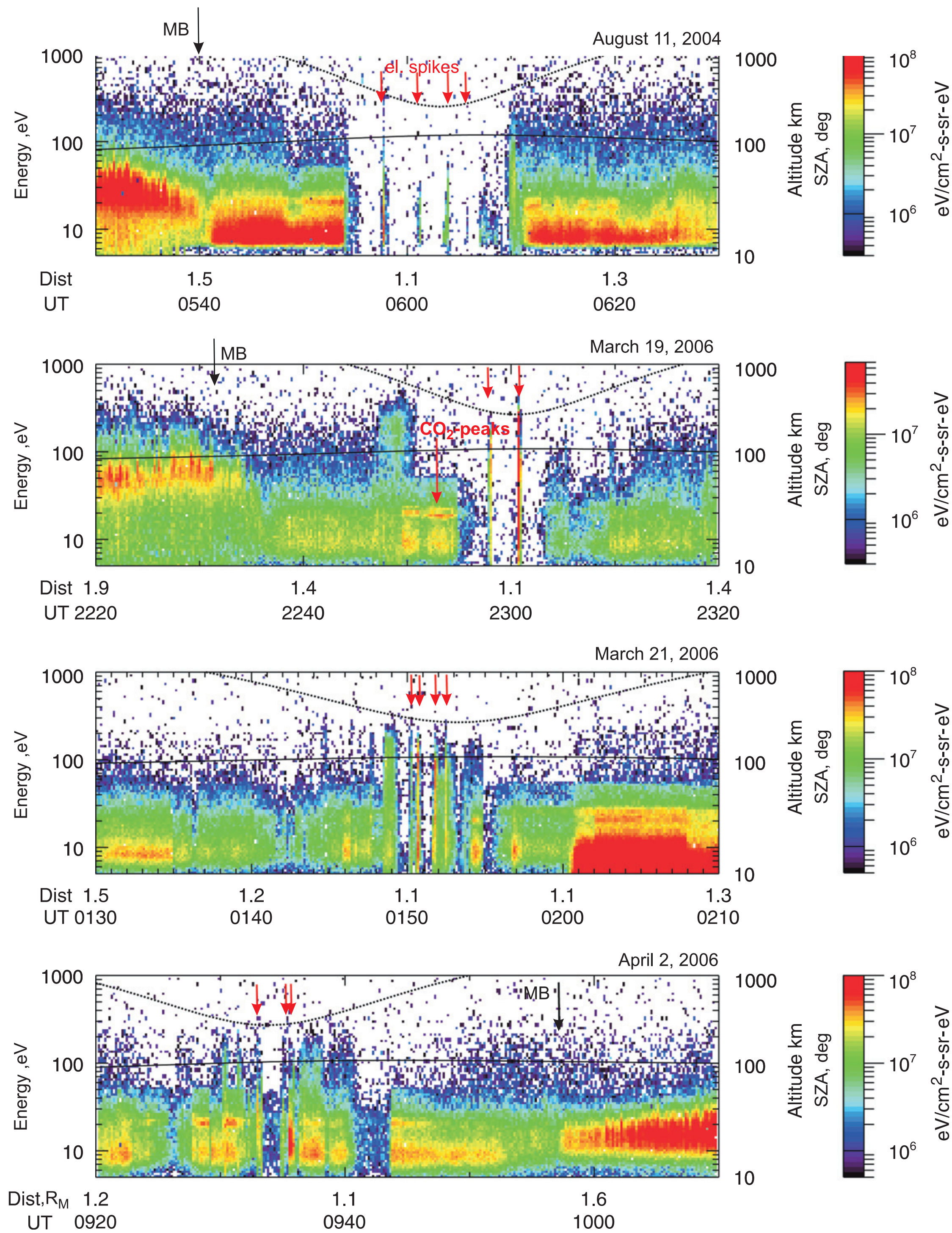

Fig. 1. Spectrograms of electron fluxes on the MEX orbits for which narrow spikes of electrons were observed in the penumbra region close to periapsis altitudes. The location of spikes is marked by the red arrows. The altitude is given by the dotted curves. The solar zenith angle (solid curves) is also shown.

altitude is shown by the dotted curve) and local time $LT \sim 20^h$. The penumbra region is clearly identified by sudden drops of the electron fluxes. Narrow spikes of low energy electrons are observed to occur on the nightside near the same time as the UV observations. The duration of the spikes is of 5–15 s which corresponds to distances of few tens km along the MEX trajectory. Note here that a typical electron gyroradius ($E_e = 50$ ev, $B = 50$ nT) is about of 0.5 km. Spikes of electron fluxes are also observed on other orbits (lower panels) when MEX was in the penumbra region. Their relation to the crustal magnetic fields is discussed below. Narrow flux spikes over time intervals as short as 8 s were also measured on the Martian nightside on MGS (Mitchell et al., 2001).

Fig. 2 compares the electron differential fluxes averaged over all azimuth sectors and measured in the spike (the dashed curves) and in the neighboring region (the solid curves) for two events. Two spectral peaks between 20 and 30 eV (06:01:05 UT on August 11, 2004 and 01:48:09 UT on March 21, 2006) are due to the absorption of the strong solar *HeII* line at 304 Å in the dayside carbon dioxide dominated atmosphere of Mars. Their expected values are 21–24 and 27 eV (Mantas and Hanson, 1979; Frahm et al., 2006). Identification of these peaks strongly reduces an uncertainty in the spacecraft potential. We estimated a potential of −10 and −5 V, respectively, and apply these values while plotting the spectra at other times when the peaks are not well resolved. The first event corresponding to the measurements made few seconds before the SPICAM observations of the aurora shows the flux enhancement and heating of the electrons. In the second event, we observe a much stronger heating of the electrons. Rough estimates show that such electrons can produce emissions similar to the ones observed by SPICAM, although more accurate calculations are required. Note that Leblanc et al. (2006) made a correction for a −4 V spacecraft potential while calculating intensities of the expected emissions and comparing them with the observed values.

Fig. 3 presents typical spectra of electrons on the nightside observed in narrow strip-like structures. The data are given in the same format as in Fig. 3 of Leblanc et al. (2006). A typical auroral-type electron distribution with a peak above 100 eV, measured on MGS, is shown by the thick curve for comparison. Leblanc et al. (2006) have noticed that electron fluxes which may have produced the auroral emissions must be about 10 times higher than those usually observed by the MGS/ER instrument (the thin

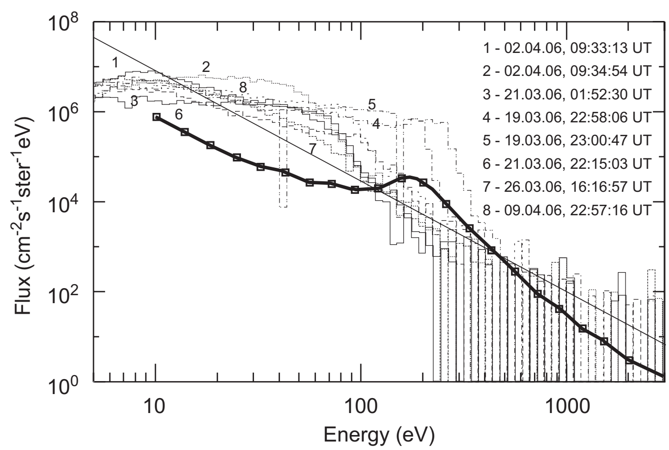

Fig. 3. Examples of electron distributions measured by ASPERA-3 at low altitudes on the nightside (the date is given in day-month-year format). The thick solid curve corresponds to the MGS/ER measurements of an electron auroral-type distribution (Brain et al., 2006). The thin curve gives the typical spectrum of sheath electrons (Mitchell et al., 2001).

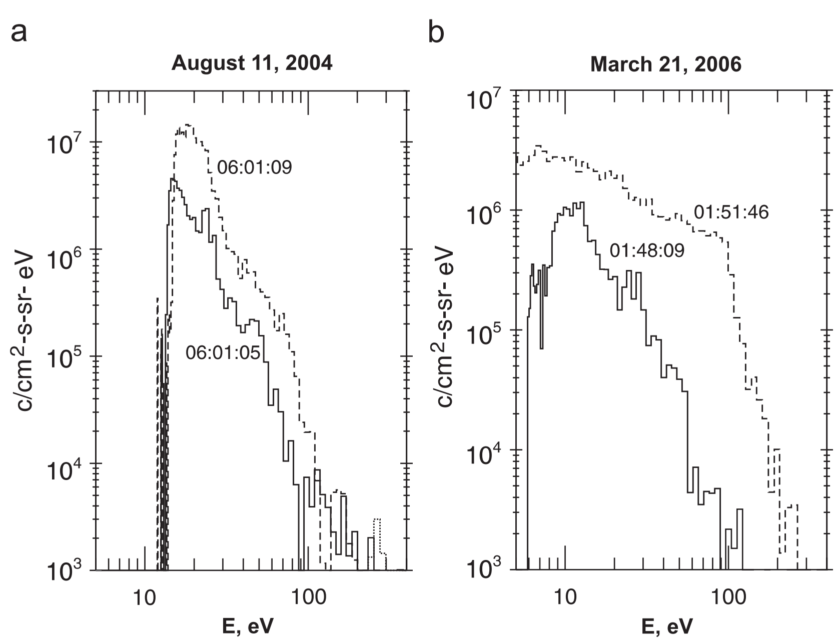

Fig. 2. Differential spectra of electrons in spikes (dashed curves) and in neighboring regions (solid curves) at low altitudes of the nightside magnetosphere. The second event in panel (a) was detected ~15 s before the SPICAM observation of the aurora-type emissions.

curve) in the magnetosheath (Mitchell et al., 2001). The suprathermal electrons with energies $\leqslant 100$ eV measured by ASPERA-3 in these spikes could be good candidates for the parent electron distribution responsible for the aurora emissions.

All MEX orbits during the first two years of the ASPERA-3 operation were analyzed to obtain a statistical pattern of the electron fluxes at the nightside of Mars in the altitude range 250–600 km. Fig. 4 shows the data coverage for the electron measurements between February 1, 2004 and April 30, 2006 as a function of latitude and longitude (panel a) and the sampled solar zenith angles (panel b). Bin sizes are $1^\circ \times 1^\circ$. Although data coverage is rather poor the following maps of suprathermal electron fluxes reveal interesting features.

Fig. 5 presents the mean and max values of the energy flux of electrons with $E_e = 40$–80 eV (the count rate is proportional to the electron energy flux per unit energy) as a function of Mars planetocentric eastern longitude and latitude for the longitude range 160°–240° of the southern hemisphere where the strongest crustal sources of the magnetic field are located (upper panels). Black shaded bins correspond to the regions where electron fluxes are almost absent. The bottom panels depict the radial component B_r of the crustal field at an altitude of 400 km from Connerney et al. (2001). Red and blue shaded bins have values higher (smaller) than ± 100 nT (left panel) and (± 150) nT (right panel). We observe that the regions with strong crustal fields in the latitude range -65° to -30° are almost void of electron fluxes except of several narrow

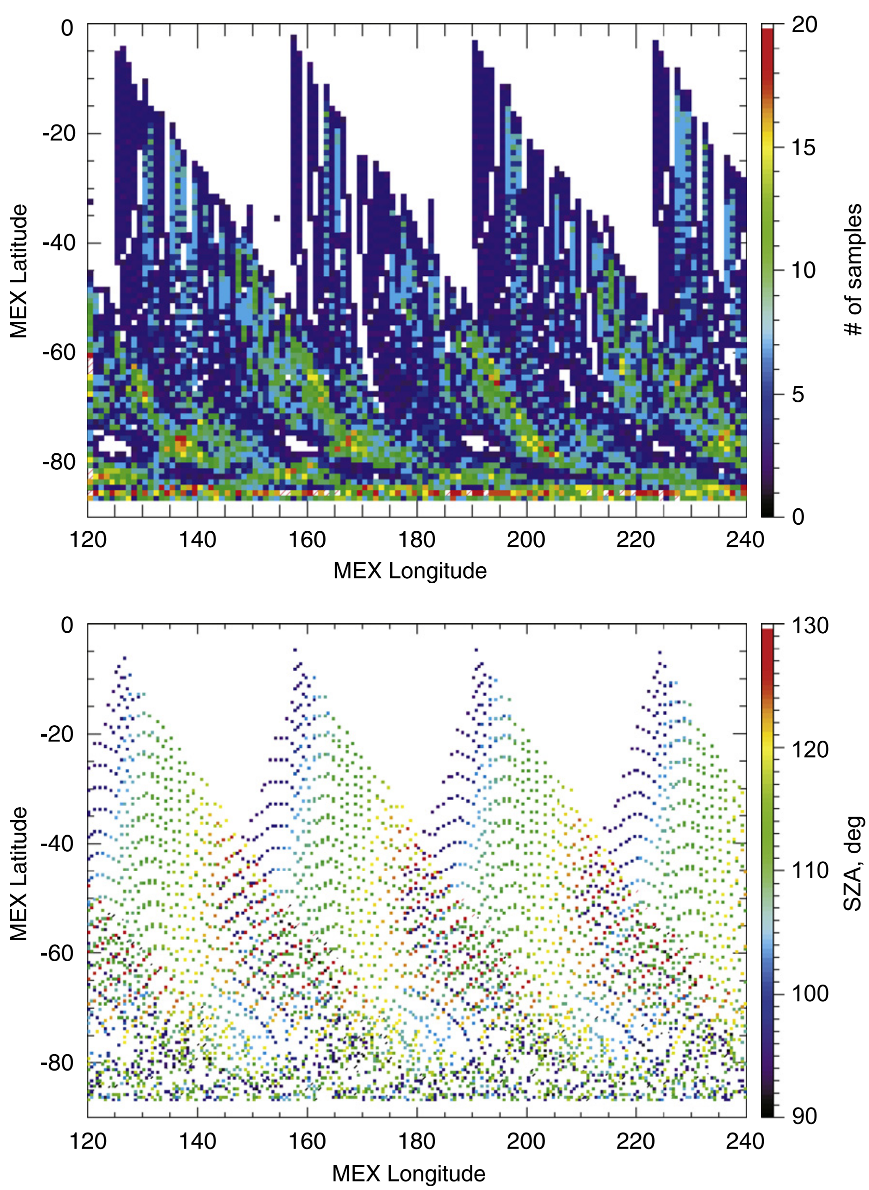

Fig. 4. (a) Data coverage for the electron data of the ASPERA-3 for all orbits between February 1, 2004 and April 30, 2006 crossing the range of altitudes of 250–600 km at the nightside. (b) Solar zenith angles for this sampling.

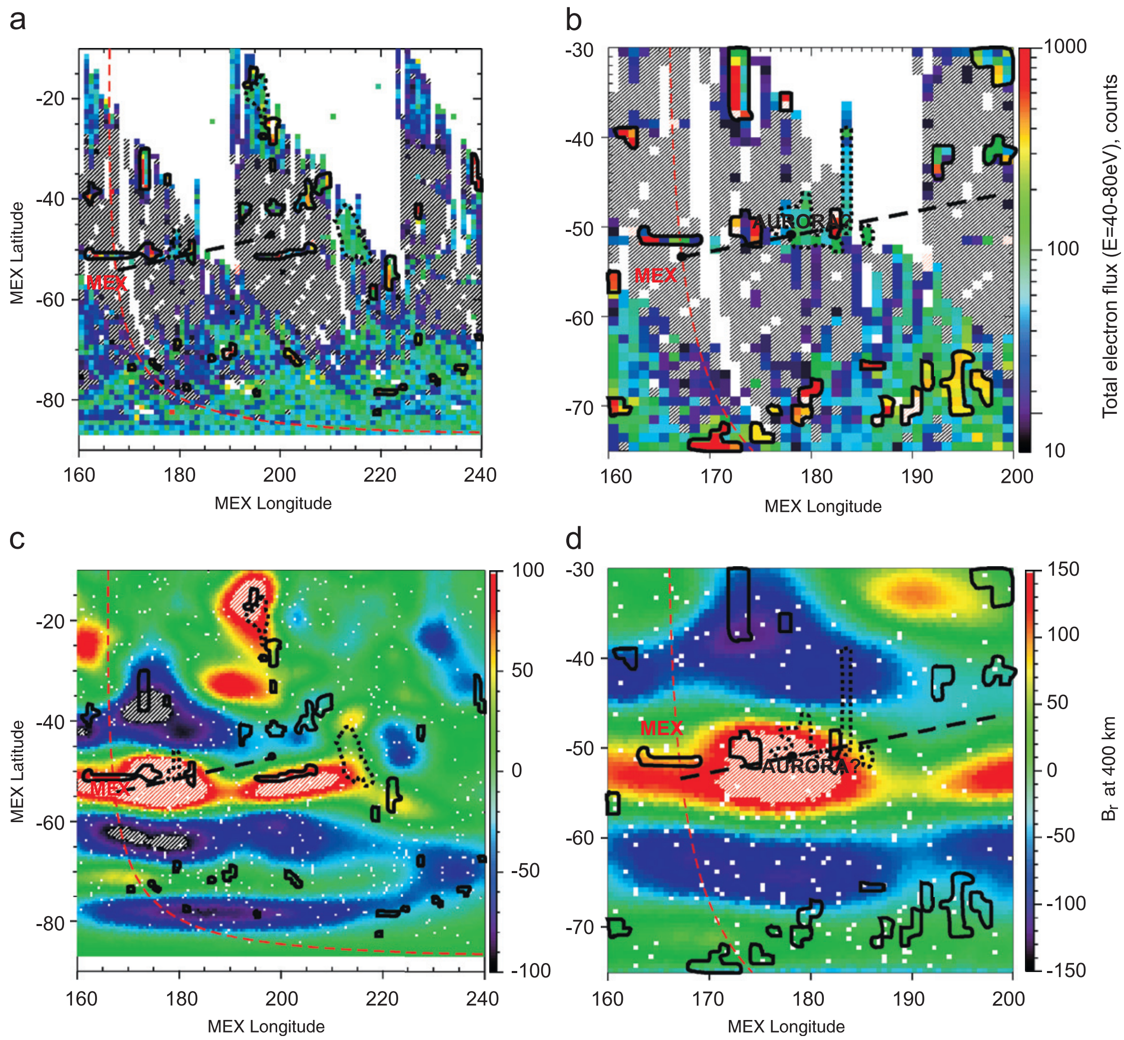

Fig. 5. Maps of mean (panel a) and max (panel b) values of the electron fluxes ($E_e = 40$–80 eV) measured at altitudes of 250–600 km in the regions of strong crustal field on the nightside of Mars. On panel (b) the different scales are used to enlarge the region of the SPICAM measurements. (c, d) Vertical component of the magnetic field at 400 km.

bands, stretched in longitude, or patches in which the fluxes of suprathermal electrons are enhanced. The electron spikes shown in Fig. 1 are localized within such bands. In Fig. 5, these structures are bounded by black curves. One can see that their location at latitudes $> -60^\circ$ mostly coincides with the regions of the crustal patches with large radial magnetic fields. The MEX trajectory (red dashed curve) on which the aurora-type emissions (August 11, 2004) were detected, the position of MEX at the point of emission observations, the line of sight (LOS) of the SPICAM-UV instrument (black dashed line) and the assumed auroral spot are also shown. We observe two spots of enhanced electron precipitation along LOS ($\sim -49^\circ$ Lat., 174.5° Long. and $\sim -59^\circ$ Lat., 182.5° Long.) which could contribute to the observed optical emissions.

In conclusion, the ASPERA-3 observations of fluxes of suprathermal (40–100) eV electrons in the post-terminator region at the nightside of the Martian southern ionosphere, in the regions with strong crustal magnetization, show the existence of narrow 'precipitation' strips, mainly stretched in the longitudinal direction and localized patches. The position of many of these structures coincides with the regions of large vertical magnetic field which can focus the electrons to the altitudes ~150 km where optical aurora-type emissions are produced. Since similar structures of the suprathermal electrons are also observed on the dayside it is not clear yet whether they were produced by local electron precipitation or have been convected from the dayside. The intensity of the electron fluxes could explain the observations by the SPICAM UV spectrometer of aurora-type emissions on the Martian nightside. In most cases spectra of suprathermal electrons observed at low altitudes do not contain peaks above 100 eV which could be attributed to auroral-like electron acceleration processes.

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