ELECTRON LOSS AND METEORIC DUST IN THE MESOSPHERE

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ABSTRACT

The ionosphere is always assumed to contain equal numbers of positive and negative charges in a given volume (quasi-neutrality). Hence fewer electrons than positive charges are an indication of negative charges other than electrons. Theories predict and *in-situ* mass spectrometer measurements confirmed that these negative charges are negative ions, but recent experimental results suggest that other scavengers of free electrons can also be active in the mesosphere. This additional removal of electrons is today assumed to be due to meteoric dust which maximises in the mesosphere. Data predominantly from the recent ECOMA flights are used to test this presumption. Five sounding rockets carried different dust detectors, as well as probes for electrons and ions. With such an instrumental ensemble one can assess whether indeed the existence of meteoric dust removes more electrons than would be expected from gas phase ion chemistry alone. Other factors potentially impacting the electron removal are also discussed in the paper.

1. INTRODUCTION

The ionosphere's plasma is the result of a balance between ionisation from various sources and reverse reactions again leading to neutrals. At high latitudes, notably at night, the most common source of ionisation are energetic electrons precipitating out of the magnetosphere. The ionosphere is quasi-neutral, *i.e.* the number densities of positive and negative particles is equal. Hence the number density of negative charges N^- - other than electrons - can be obtained by forming the difference between positive charges and electrons. The primary products of ionisation are free electrons (N_e) and (primary) positive ions; both these species can not only recombine in the most obvious reaction (dissociative recombination), but may experience several intermediate stages before eventually again leading to neutrals. Fig. 1 shows a simple chemical scheme of the most important ion reactions active in the mesosphere. We will here concentrate on the negative plasma species such as free electrons, negative ions, but also negatively charged larger particles conceivably consisting of aerosols or meteoric dust. In the above scheme the negative species X^- are formed *e.g.*, by three-body attachment β involving the background number density *M*, of electrons to X. The reverse reactions in this simple chemical scenario are *via* atomic oxygen O and by photo

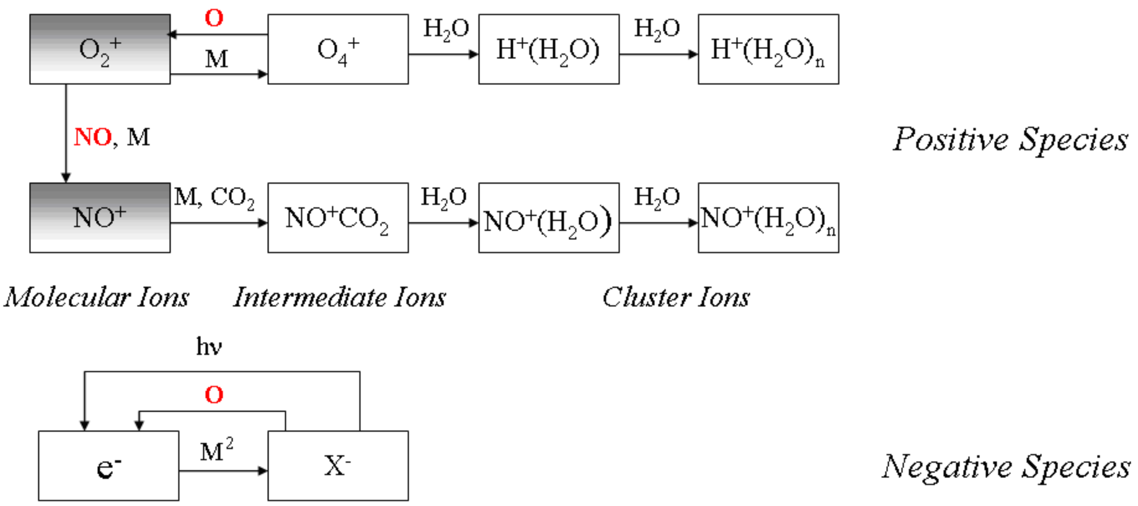

Figure1 Simplified ion-chemistry in the mesosphere (D-region). Ions in the shaded boxes are the ones primarily produced. For graphical reasons the reactions between the negative species (e^- and X^-) to all of the positive species are omitted (O = atomic oxygen, M = background number density, NO = nitric oxide).

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detachment hν with the rate γ. Under normal circumstances atomic oxygen at night only occurs above a pronounced ledge usually located between 83 and 88 km [1]. If the ledge of the O-onset is not very pronounced, but shows structures, they are - as one would expect - indeed reflected in similar structures in the electron densities [2]. Since photo detachment is largely absent at night, the loss of negative charges is primarily by ion-ion recombination (α_i) and the following relation between the number densities of electrons N_e, and positive charges N^+ applies:

$$N_e = \frac{N^+}{1 + \frac{\beta}{\alpha_i}\frac{M^2}{N^+}} \tag{1}$$

In other words, N^+ and N_e should be predictably related provided β/α_i is known and constant. A study of 27 rocket flight where both electrons and positive ions were measured revealed that β/α_i scatters widely about the values expected from laboratory measurements which was tentatively ascribed to additional electron loss by attachment to targets larger than molecules, such as irregularly occurring meteoric dust [3]. At this time the ECOMA flights 7, 8 and 9 are presumably the only ones that can corroborate this hypothesis.

2. DATA AND INSTRUMENTATION

In December 2010 the last three of the series of nine ECOMA payloads were launched. The primary aim of these rockets soundings was to investigate the distribution, properties and abundance of meteoric dust particles which are expected to maximise in the mesosphere *e.g.* [4], [5]. The main instrument on these payloads is the ECOMA detector (= Existence and Charge State of Meteoric Dust Grains in the Middle Atmosphere), essentially a vented Faraday cup with biased grids at the entrance to repell ionospheric plasma. In addition an intermittent UV source ionises neutral particles to make them too detectable [6] (Fig. 2).

Free electrons are continuously produced by ionisation due to various sources mainly orginating from the Sun. At night only scattered solar UV remains, but at high geomagnetic latitudes precipitating particles provide an ionisation source largely independent of the time of the day. In Fig. 3 probably all night-time electron densities from the high latitudes are shown which were ever measured by a rocket-borne radio wave propagation method. The solar zenith angle defining night conditions in this figure is >98°, *i.e.* when the Sun is below the horizon at the height of the mesosphere (*D*-region). The profiles from the flights discussed here are highlighted. We will concentrate on flights ECOMA-7, 8 and 9, but also refer to ECOMA-0 and HotPay-2; the electron densities of all of these flights are everywhere below the median night-time densities, and in fact ECOMA-7 measured the lowest electron profile ever. The ECOMA instrument requires a

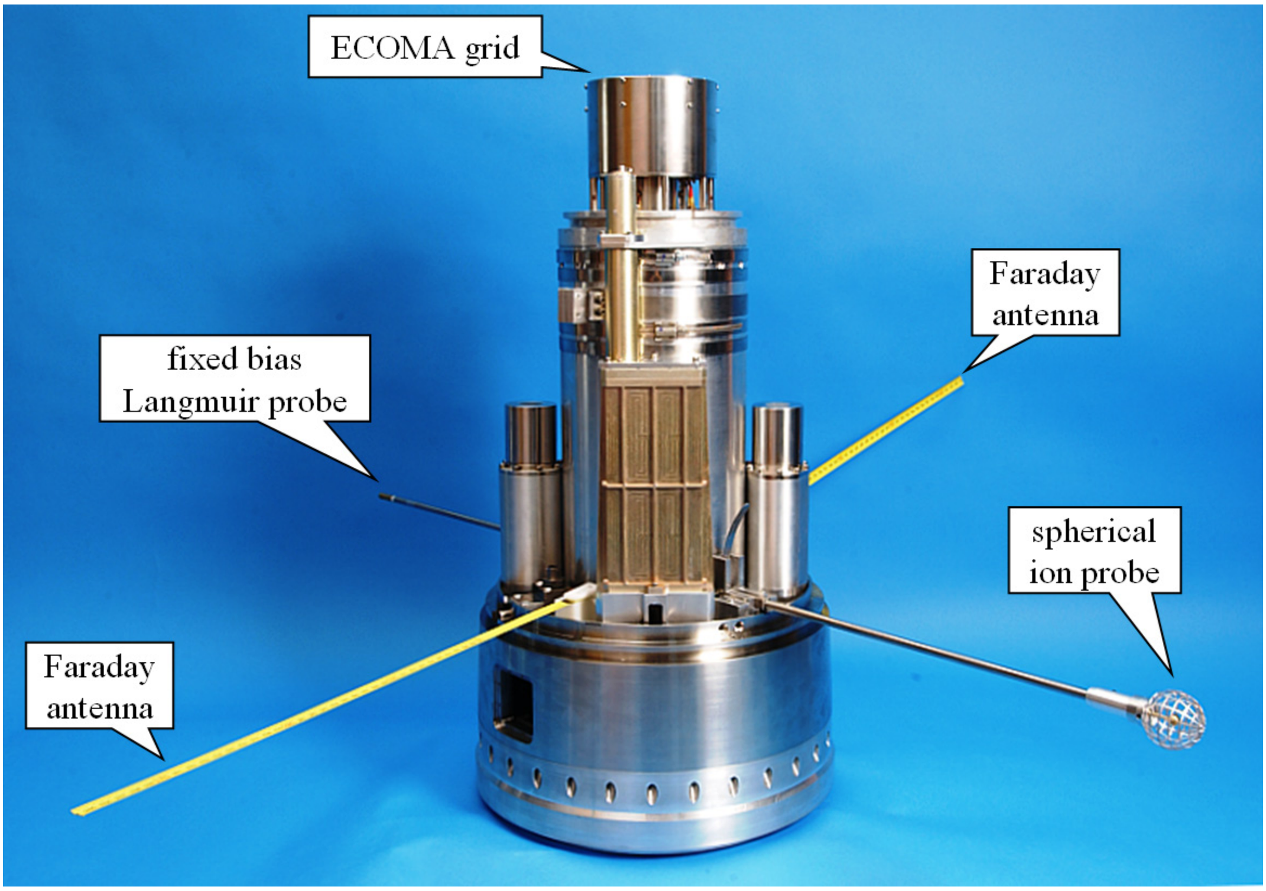

Figure 2 Forward section of an ECOMA payload in flight configuration.

typical velocity of about 1 km s^{-1} into the detector for naturally charges particles to be detectable. Direct Simulation Monte Carlo (DMSC) calculations with the geometry used here [7] have shown that the ram pressure inside the Faraday cup is such that it effectively discrimates lighter masses. Above 80 km the minimum detectable radius of such particles (2 to 3 g cm^{-3}) is about 4 to 5 nm [8]. At higher altitudes (less atmospheric density) the detection threshold of mass or radius of the particles is smaller. Hence the upper part of the height where such an instrument detects particles is quantitively more meaningful than the lower edge of the occurence of detected particles; that limit is more instrumental than geophysical. In Fig. 4 the detected naturally charged particles of ECOMA-7 are shown together with the electron and ion densities of that flight. There is a clear anticorrelation between negative charged particles

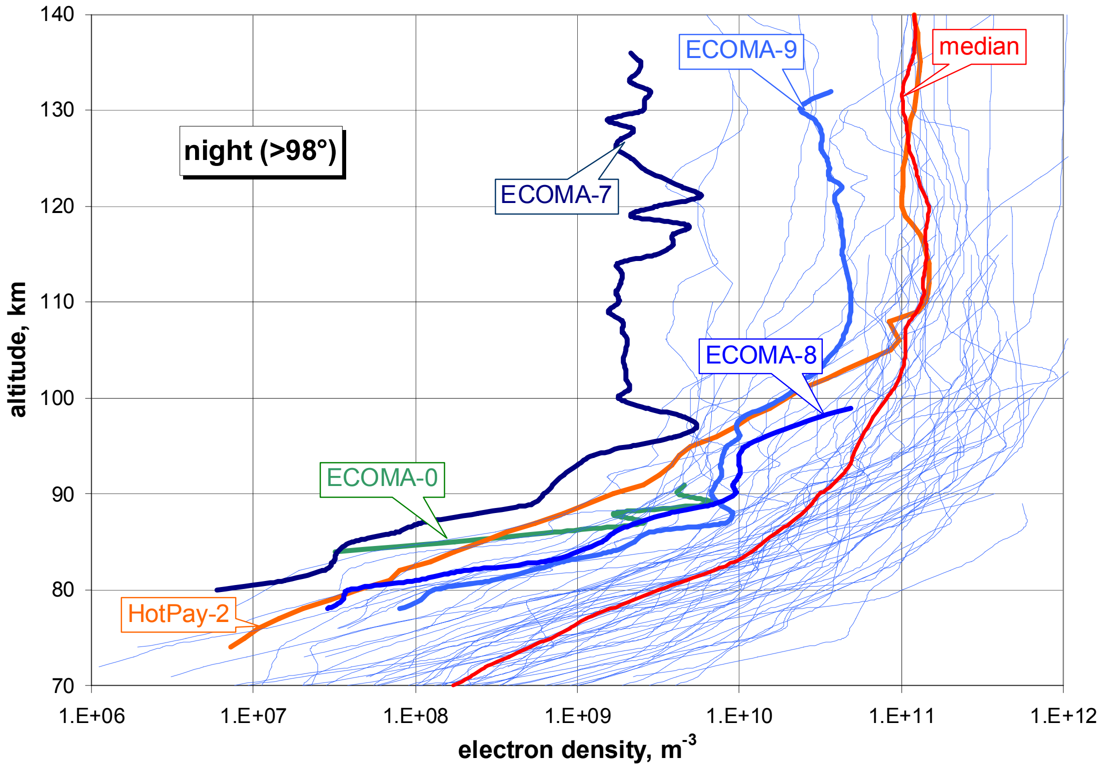

Figure 3 Summary of night-time electron density measurements at high latitudes. The flights referred to in the present context are indicated (primarily ECOMA-7 to -9). Note that these flights are all below the median and furthermore that ECOMA-7 shows the lowest electron densities ever measured.

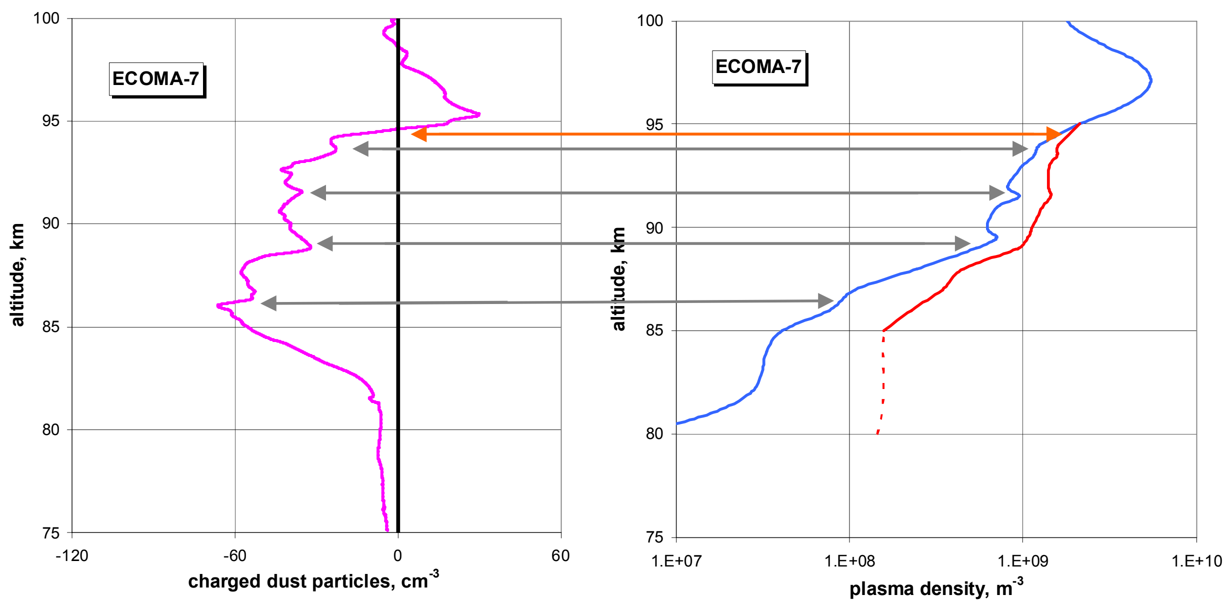

Figure 4 Naturally charged dust collected by the ECOMA instrument in flight 7; the negative sign indicates negative charges (left panel). Electron and ion densities measured in the same flight (right panel). Note the minima of the charged particles coinciding with corresponding maxima in the electron density.

and electrons at 91.7 km, but also - although less pronounced - at 93.8 km. The corresponding comparisons with the data of ECOMA-8 and 9 does not show any discernible correlation in fine structure details, but the altitude of the disappearance of negative charged particle strikingly agrees with the altitudes where electrons and ions converge (Fig. 5). The fact that details of the charged particle densities are reflected in the electrons in flight 7 may be a result of the extremely low electron density. Finally in Fig. 6 we show the β/α_i derived under the provisional assumption that Eq. 1 can be applied. To make the comparison more realistic the values are normalised to a solar zenith angle of 120° and zero Moon albedo using the statistical relation by [3]. ECOMA-7 may be an a-typical case, but the values for ECOMA-9 are somewhat higher than for ECOMA-8. With all due caution this may indeed be due to the Perseid meteor shower which peaked during ECOMA-8, but may have deposited the maximum dust in the mesosphere at the time of ECOMA-9. Tab. 1 list the pertinent details of the present flights together with two flights which carried similar instrumentation. Under "comments" the reasons are listed why these two earlier flights are not considered in the present context; the main reason why we concentrate on the three ECOMA flights is that they carried identical instruments and had (almost) identical trajectories and thus assured comparable aerodynamic behaviour of the particle detectors.

3. CONCLUSIONS

The charge balance observed by the recent night-time, high latitude rocket flights shows negative charges - other than electrons - which are significantly different in the three cases. The charged large particles measured by the same rockets strikingly disappear at almost the same heights as the negative charges obtained by the plasma

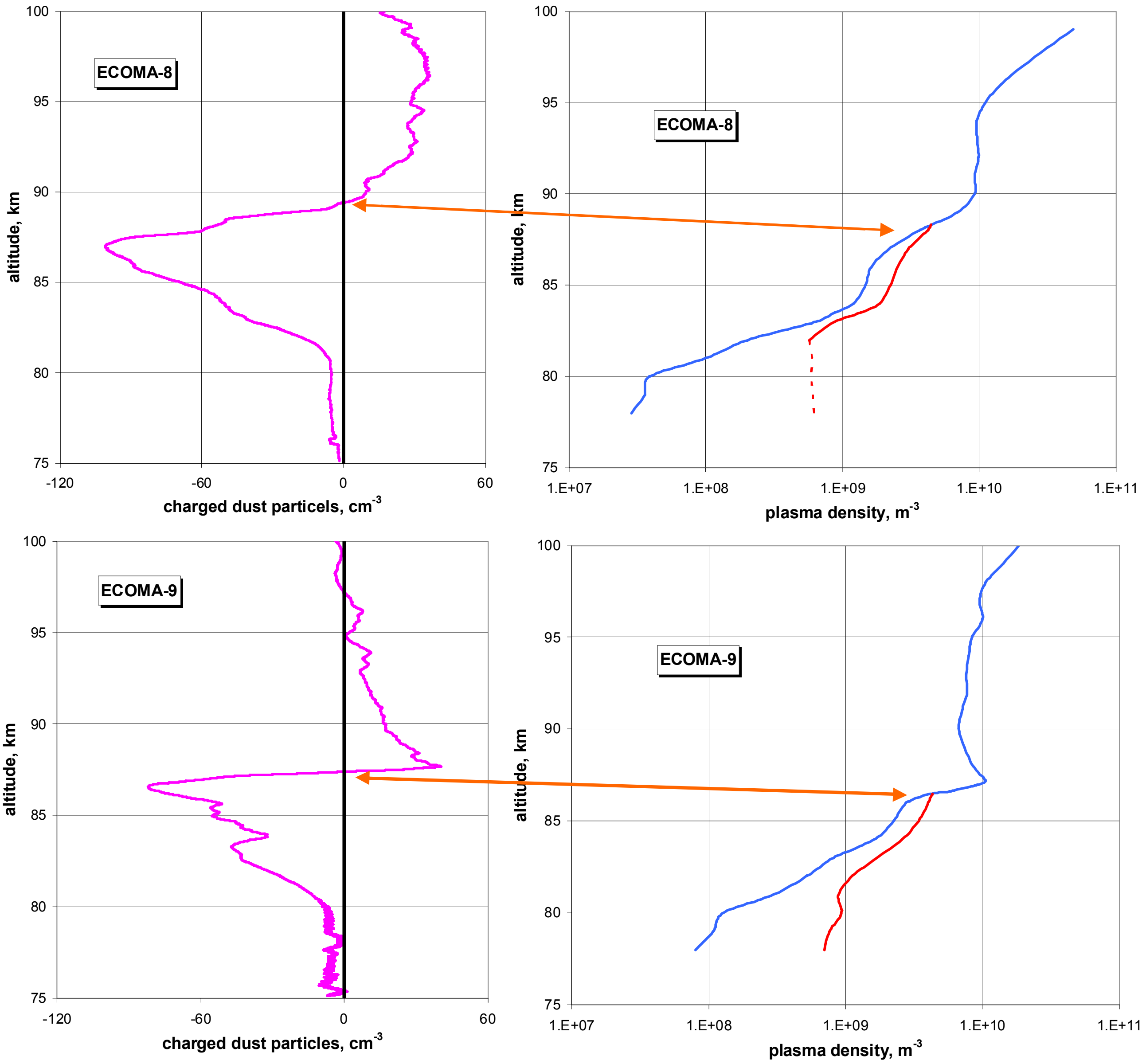

Figure 5 As Figure 4, but for flights 8 and 9. The dotted part of the ion density is due to yet partially unexplained data.

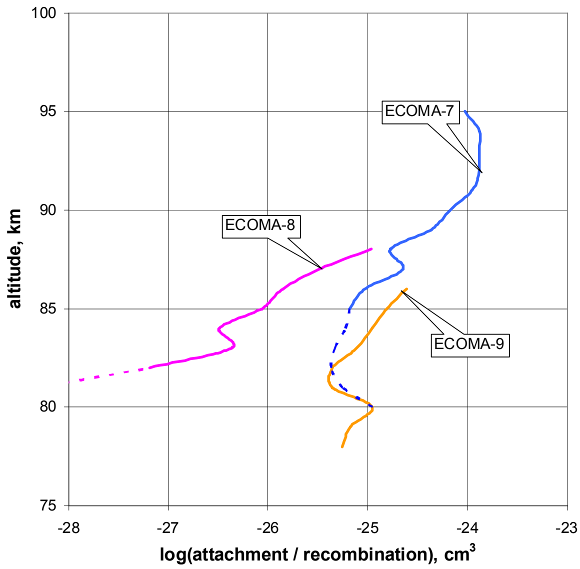

Figure 6 Derived values of β/α_i assuming applicability of Eq. 1. Dotted parts are due to yet uncertain ion densities.

measurements. This strongly suggests that the depletion of free electrons is caused by the large particles in addition to the usual gas phase chemistry by which negative ions in the lower ionosphere are conventionally explained. A similar correlation at the bottom of the particle layer and the electron depletion can not be identified because flow conditions in the denser air are such that only the heaviest particles can be detected. A further indication for electron scavenging by heavy particles is given by the anticorrelation of density structure details between negatively charged particles and electrons.

ACKNOWLEDGEMENTS

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Code	***date***	***time***	χ	$F_{10.7}$	a_p	***riometer***	***range***	***comments***
		UT	*deg*			*dB @ 27.6 MHz*		
ECOMA-0	2004-10-28	19:49	120.1	118.5	3	0.003	Esrange	low apogee; unfavourable flow into the detector
HotPay-2	2008-01-31	19:14	116.6	62.9	23	0.006	Andøya	high apogee; poor height resolution in mesosphere
ECOMA-7	2010-12-04	04:21	112.9	76.4	0	0.000	Andøya	all-time low N_e
ECOMA-8	2010-12-13	03:24	119.1	76.5	23	0.104	Andøya	Perseid showers
ECOMA-9	2010-12-19	02:36	123.6	70.4	5	0.006	Andøya	

Table 1 List of flights with particle detectors together with electron and ion density measurements.