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The Cryo Mass Spectrometer in the Winter Anomaly Campaign

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Abstract. On January 4 and 21, 1976, at 1630 CET two rockets were launched as part of the winter anomaly campaign, both carrying amongst other experiments a cryo mass spectrometer. The mass spectrometers performed measurements of the neutral gas composition in the altitude range from about 80 to 117 km.

Scientific goals, design, and operation of the instruments are described in detail. Preliminary results of the data reduction are presented for the flight of January 4. Number density profiles of N_2, O_2, and Ar show a pronounced wave-like structure.

Key words: Winter anomaly – Mass spectrometer – Mattauch-Herzog geometry – Helium-cooled ion-source – Neutral composition – Trace constituents.

Introduction

On January 4 and 21, 1976, at 1630 CET and 1631 CET, respectively, two rocket-borne mass spectrometers with helium-cooled ion sources were flown above El Arenosillo (Spain) as part of the winter anomaly campaign. The mass spectrometers employed "closed" ion-sources, the walls of which were cooled to about 8 K by means of supercritical helium. As all atmospheric species (except He and H_2) condense on the walls at these temperatures, the formation of background gases within the ion-source is largely suppressed. Moreover, the bow-shock ahead of the instrument is removed down to altitudes below 80 km, the instrument forming the front part of the payload.

The scientific goal of the campaign was the investigation of the meteorological type of the mid-latitutde winter anomaly. Several suggestions have been made so far to explain the processes leading to an enhancement of the electron density in the D-layer, e.g. atmospheric circulations and/or wave motions causing

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changes in the temperature field and in the concentration of minor constituents, which may influence the ion- and neutral-chemistry.

The contribution of the mass spectrometers to this goal was the measurement of the composition of the neutral atmosphere down to about 80 km under shock free conditions and with a good height resolution. Special emphasis was on the determination of atomic oxygen and on specific atmospheric trace constituents which are of importance for the neutral- and ion-chemistry of the D-region. The measurement of inert gases (N_2, Ar) is of interest for the investigation of turbulent and diffusive processes.

A number of atmospheric parameters was measured by redundant experiments during the campaign. Therefore comparison and combination of the data obtained by these different instruments yields a valuable check on the reliability of the measured data. The mass spectrometer measurements described here may thus be especially compared to the data obtained by two other mass spectrometers which were flown on two other rockets with a time shift of about 1 h, and with pitot tube measurements on the same rockets. The Pitot probes were mounted in the payload directly adjacent to the cryo mass spectrometers. The total density derived from the Pitot data allows a check on the sensitivity of the mass spectrometers. On the other hand the height profiles of the N_2 number density measured by the mass spectrometers will complement the total density profiles of the Pitot probes.

Instrument Configuration

A sketch of the instrument is given in Figure 1. Its essential parts are the helium-cooled ion-source, the mass analyzer, and the helium supply system including the storage dewar, valves, and pipes. The instrument was mounted axially in the uppermost part of the payload looking into the flight direction.

During the flight the angle between payload axis and the velocity vector (angle of attack) should be as small as possible to allow the ambient particles to form a properly shaped molecular beam in the ion-source. For this purpose the payload included an attitude control system which kept the angle of attack below $\sim 10°$ (at all altitudes above 80 km). If the ion-source protection cap is ejected at too low altitudes (i.e. around 80 km) the sensitivity of the instrument could be changed because of large amounts of gas condensing on the ion-source walls. Therefore this cap was ejected not earleir than 110 km on the upleg of the flight. Low altitude data were obtained on the downleg thanks to the attitude control of the payload.

Ion Source and Cooling System

The design of the ion source (Fig. 2) was similar to that described by Trinks and Hellenbroich (1973). The ambient atmospheric particles entered the ion source through two circular holes in both the front-plate and the so-called ion-box. Inside the ion-box the particles crossed an electron sheet, emitted

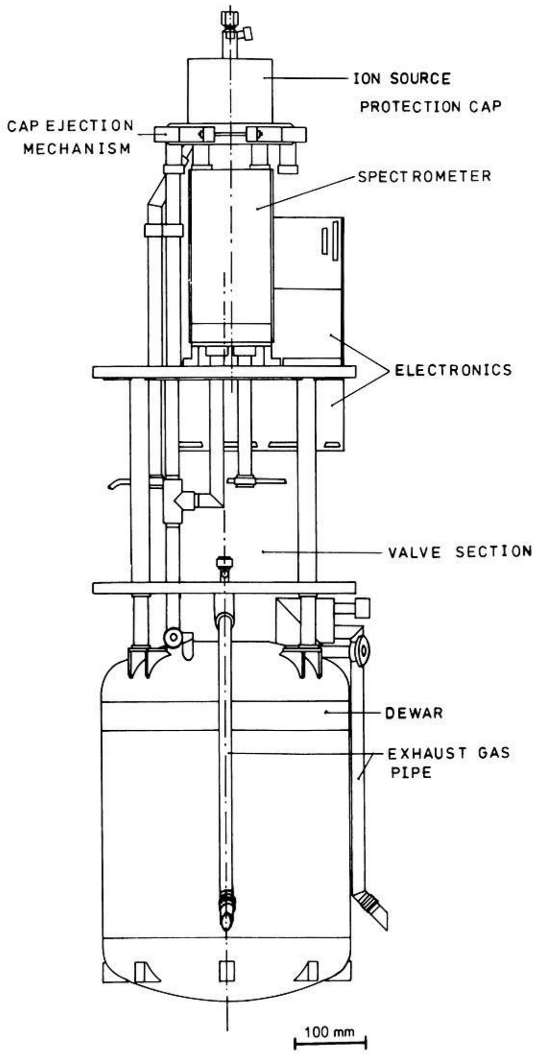

Fig. 1. The cryo mass spectrometer (schematically)

from a hot tungsten-rhenium filament, ionizing part of them. The energy of the ionizing electrons was about 90 eV. The ions were focussed by the ion-lens and a pair of focussing plates onto the "object-slit" of the spectrometer.

The inner parts of the ion source were made of copper with high thermal conductance. Ion-box, ion-lens, and focussing plates were thermally coupled to the heat-exchanger 1 to keep them at temperatures as low as possible during the measurement. This will assure a high sticking probability for gas particles hitting the wall. The wall-temperature normally did not exceed 8 K.

The electron-beam generation system and radiation shield were coupled to the heat-exchanger 3. Their temperature was about 12 K.

In order to avoid the formation of a shock front ahead of the ion-source

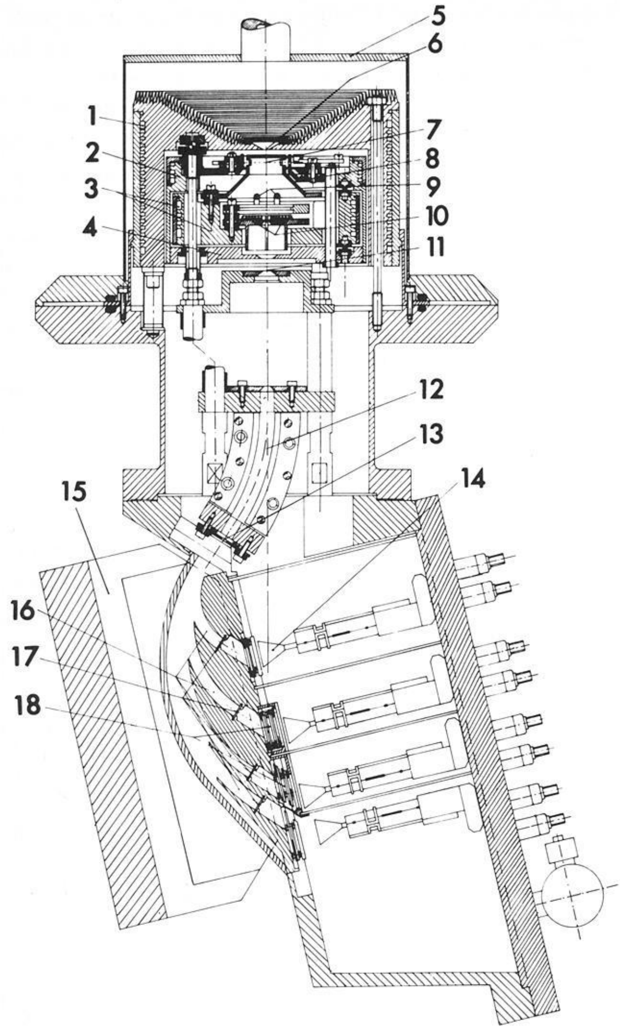

Fig. 2. Cross section of the mass spectrometer. *Legend*: *1* heat exchanger 2 (front plate); *2* heat exchanger 3; *3* heat exchanger 1; *4* radiation shield; *5* ion-source cover; *6* entrance aperture; *7* electron beam; *8* ion-box; *9* ion-lens; *10* focussing plates; *11* object slit; *12* electric field; *13* total ion-current collector; *14* spiraltron; *15* magnet; *16* ion channel; *17* exit slit; *18* ion current collector grid

the temperature of the conical, indented front-plate (heat exchanger 2) should not exceed 20 K (Offermann and Tatarczyk, 1973). A typical value during normal flight operations was about 15 K. To guarantee a high thermal conductance in the front plate it was made from very pure silver.

The heating of the ion source, looking into the flight direction, mainly depends on the solar radiation, the kinetic energy of the impinging particles due to the payload velocity, and on the gas condensation heat. Above about 110 km the heat load mainly consists of the solar input of 0.14 W/cm^2. As the ambient density and payload velocity increase, the heat caused by the impinging particles becomes dominant at lower heights.

Because of the very different heat loads on the front-plate and on the inner ion source two different helium cooling circuits were used for heat exchangers

1+3 and 2, respectively. The cryogen was taken from a 15 liter storage dewar which was filled with liquid helium some time before launch. A few minutes before lift-off the helium was made supercritical (6 K at 5 bars). The flow-rate of the cryogen and thus the ion source temperatures were controlled by several valves and throttles in the exhaust gas pipes. Because of the rapid variation of the heat-loads during the flight, electric feedback circuits were used to control the ion source temperatures and the dewar pressure. These control circuits were blocked during the first part of the flight to avoid accidental cryogen losses.

Mass Spectrometer

Ions which passed the object-slit entered the double focussing Mattauch-Herzog spectrometer which employed a 0.34 T magnetic field (Fig. 2). After mass separation the ions were detected in 4 channels simultaneously by means of 4 spiraltron multipliers operated in the pulse-counting mode. The use of 4 channels allowed a high sampling frequency for the detection of the mass numbers of interest. The dynamical range of the spiraltrons was limited to about 10^6 counts/s which did not allow to measure simultaneously the main atmospheric constituents and the trace gases. The solution to the problem was to determine the main constituents by measuring doubly ionized or isotopic species instead of singly ionized parent molecules.

To further increase the dynamical range, two of the channels were equipped with "ion collector grids". The ion currents intercepted by these grids were fed into logarithmic electrometers.

The mass spectrometer could be operated in two different modes: In the *stepping mode* the acceleration voltage U_a applied to the ion-box was controlled by a programmer selecting 16 fixed voltage steps of a duration of 100 ms each. Thus in 1.6 s – the duration of one measurement cycle – up to 16 different mass lines could be detected per channel. The height resolution for the important constituents, measured twice per cycle, was less than 1 km in the 80 km region and about 100 m near apogee.

In the *scanning mode* U_a was varied continuously from high to low values. The main purpose of this mode was to check whether in the stepping mode U_a was always adjusted to the maximum intensity of the different mass lines. The mass range covered in the scanning mode is given in the following Table 1 for channel 1–4:

Table 1.

Channel	Mass range (amu)
1	1 ... 2
2	7 ... 16
3	14 ... 32
4	28 ... 64

During flight every 4 stepping spectra were followed by 1 scanned spectrum.

Table 2. Flight events

	4 Jan 76	21. Jan 76
Ejection of the protection cap	110.3 km (upleg)	114.1 km (upleg)
Apogee	117.6 km	116.5 km
Deblocking of temperature and helium flow regulation systems	106.5 km (downleg)	105.4 km (downleg)
End of reliable operation of the ion-source	85 km (downleg)	80 km (downleg)

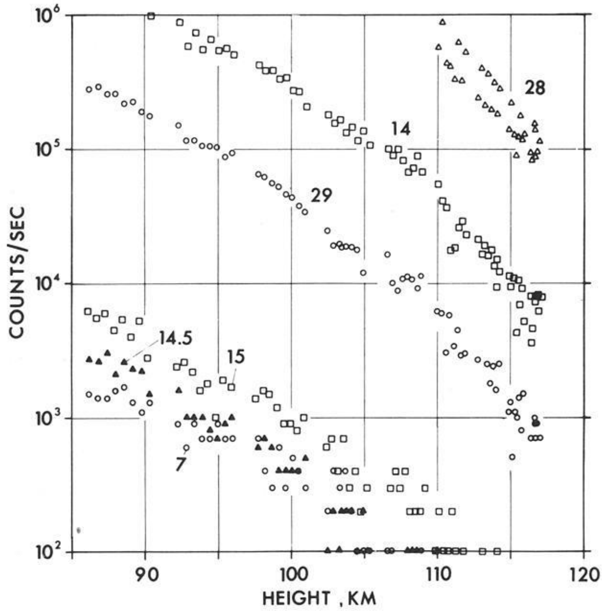

Fig. 3. Ion-counting rates stemming from nitrogen for the flight of January 4, 1976. The numbers labelling the profiles are the respective atomic mass numbers

The Rocket Flights

The essential flight events are summarized in Table 2. To avoid the condensation of large amounts of gas on the ion-source walls, in both flights the protection cap was ejected at heights above 110 km (see above). Therefore low altitude data were taken during the downleg parts of the trajectories. Reliable operation of the instruments on the downleg ceased at altitudes of 85 and 80 km, respectively.

Data Reduction

Typical altitude profiles of the measured ion counting rates are shown in Figure 3. These uncorrected raw data indicate the altitude resolution obtained. The picture also shows how a large dynamical range is obtained by use of

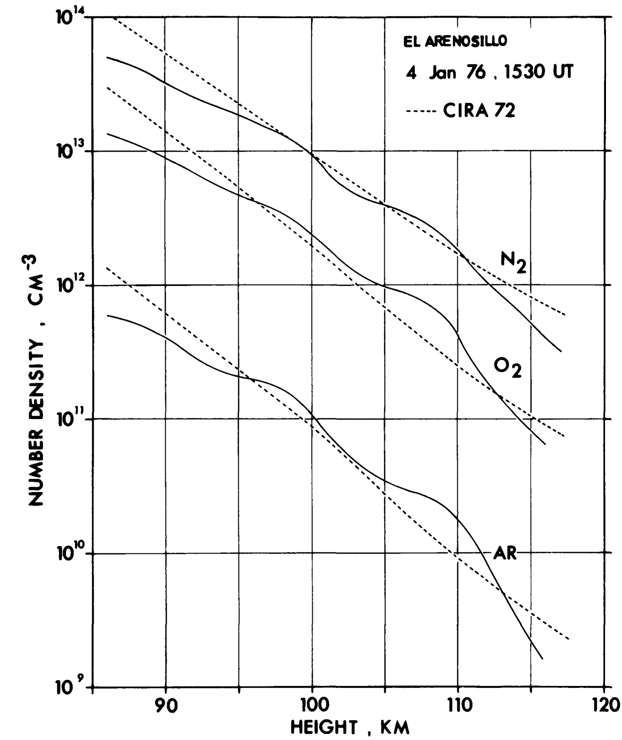

Fig. 4. Preliminary number density profiles of N_2, O_2, and Ar for the flight of January 4, 1976

multiply ionized and/or isotopic molecules. Presented are all measured counting rates versus altitude stemming from nitrogen (averaged over one program step). Molecular nitrogen can be determined by mass number 28 ($^{14}N^{14}N^+$) down to 110 km only. Below 110 km the detection is achieved by the mass numbers 29 and 14.5 ($^{14}N^{15}N$ singly and doubly ionized). The dissociation products of masses 28 and 29 at 14 amu and 15 amu ($^{14}N^+$ and $^{15}N^+$), respectively, and at 7 amu ($^{14}N^{++}$) may also be used.

The altitude profiles in part show large intensity variations. These are mostly due to rocket spin modulation. Below about 10^3 counts/s the statistical scatter becomes considerable.

The ambient atmospheric density N_a is calculated from the ion-counting rate C by the equation:

$$N_a\ (M) = E(M)^{-1} \cdot T_f^{-1} \cdot C(M)$$

where

M = atmospheric species.

$E(M)$ = spectrometer sensitivity for the constituent M as determined during the calibration procedure (Offermann et al., 1972).

T_f = function which takes account of the flight dynamics, i.e. attitude and velocity of the payload.

To obtain T_f an extensive numerical integration method has to be applied (Grossmann und Offermann, 1972; Friedrich, 1975).

Preliminary altitude profiles were obtained in this way for N_2, O_2, Ar, CO_2, and O for the flight of January 4, 1976. Furthermore, signals were observed on mass numbers 18 and 30 corresponding to H_2O and NO, respectively. It is doubtful, however, whether these are due to atmospheric species because both mass lines appear to be contaminated by degassing from the payload. In addition, the isotopes ^{18}O and $^{30}N_2$ were measured on mass numbers 18 and 30, respectively. Therefore further studies will be necessary to clarify whether ambient H_2O and NO-number densities can be obtained.

Figure 4 shows preliminary number densities of N_2, O_2, and Ar versus altitude for the flight of January 4. The N_2-profile was normalized at one point (95 km) to the total density obtained by the pitot tubes mentioned above.

The most striking feature of all curves shown in Figure 4 is a pronounced wave-like structure with a vertical wave-length of about 10 km. Deviations of up to a factor of 2 from the CIRA 72 model are found. Wavelike structures were also found by a number of other experiments during the campaign in atmospheric wind, temperature, and density data. Further studies are needed to determine the nature of these waves.

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