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Contact

Niedersächsische Staats- und Universitätsbibliothek Göttingen
Georg-August-Universität Göttingen
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Germany
Email: gdz@sub.uni-goettingen.de

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The AEROS Neutral and Ion Mass-Spectrometer

D. Krankowsky, P. Lämmerzahl, F. Bonner, and H. Wieder
Max-Planck-Institut für Kernphysik, Heidelberg

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Abstract. A description is given of the mass-spectrometer experiment on both AEROS satellites. The basic design characteristics and the operational capabilities of the instrumentation are explained, as well as the laboratory calibration procedure. A few design modifications were applied to the AEROS-B version which are expected to improve the performance.

Key words: Mass-Spectrometer — Neutral Atmosphere Composition — Ion Composition — Neutral Atmosphere Densities — Quadrupole Analyzer — Semi-open Ion Source.

Introduction

The AEROS mass-spectrometer measures the density of neutral gas constituents and the ion composition which both are important parameters for the mission of this aeronomy satellite. The approach to combine neutral and ion measurements in one mass-spectrometer has been made previously on rockets (Arnold *et al.*, 1969; Balsinger *et al.*, 1971) and on a satellite (Philbrick *et al.*, 1972). Such a combined experiment implies the use of an open-source geometry.

The strong and weak points of open-source and closed-source geometries for neutral gas measurements have been discussed extensively in the literature. Briefly a closed source allows for a straightforward conversion of measured source number densities into ambient densities for non-reactive constituents, whereas reactive species like atomic oxygen are lost or transformed into other species due to the large number of wall collisions inside the source. An open source minimizes the number of wall collisions. Thus, in principle, the open source seems to be a better geometry for a determination of reactive species. However, in practice it was found that even in the open source O atoms recombine to a large extent to O_2. This comes from the fact that at satellite velocities only a few percent of the total particle number density in the ion source is contributed by ambient particles that have not experienced a wall collision in the source. Therefore, other types of ion sources have been proposed and successfully used in recent years. Philbrick *et al.* (1973) proposed and flew on a satellite a velocity mass spectrometer which combined a fly-through ion source and a retarding potential principle thus discriminating between ambient particles without and with wall collisions. The same principle was applied by the Minnesota group (Nier, 1974, private communication) for their mass spectrometer on the AE-C satellite. The method of helium cooled ion sources which has been successfully applied on sounding rockets (Offermann and Trinks, 1971; Offermann and Grossmann, 1973) is at present not feasible on a satellite.

Neutral gas spectrometers on satellites (OGO 6, ESRO 4) have taken advantage of the recombination of O into O_2 in closed sources by determining the atmospheric O concentration from the measured O_2 signal at altitudes where O is much more abundant than O_2 (Taeusch *et al.*, 1971). The NATE experiment on AEROS also employs a closed source and, therefore, provides a good means for a direct intercomparison with the AEROS open source mass spectrometer results.

The relation between source number densities and atmospheric densities is more difficult to assess for an open source than for a closed source, because of possible incomplete thermal accomodation, partial losses of reactive species, and other complications in the kinetic theory prediction of the interaction with the neutral atmosphere at satellite velocities. However, Hedin *et al.* (1964), which flew open and closed source instruments simultaneously on a rocket, demonstrated that in rocket applications both source geometries give consistent densities, a result that was confirmed in later flights (Hedin and Nier, 1966; Kasprzak *et al.*, 1968; Krankowsky *et al.*, 1968; Hickmann and Nier, 1972).

The AEROS experiment determines absolute neutral number densities based on laboratory neutral gas calibration (described in detail in the chapter "calibration") and an appropriate source model that relates source number densities to atmospheric densities. Account must be made for partial losses of atomic oxygen in the source. In order to convert the measured ion currents into ambient ion number densities the mass dependant transmission of the ion source must be known as well as its dependence on the angle of attack. Flight data are used to determine the transmission function by comparing for different angles of attack and different constituents the measured signal strength to the total ion concentration measured by the other plasma experiments on AEROS (RPA and IP).

Instrument Design

The instrumentation on board the AEROS-B spacecraft is only slightly modified with respect to the version that flew on AEROS-A; all essential changes are mentioned in the following description.

The instrument is a quadrupole mass-spectrometer. Its major parts, shown in detail in Fig. 1, are the ion source, the quadrupole analyzer, and the ion detection system.

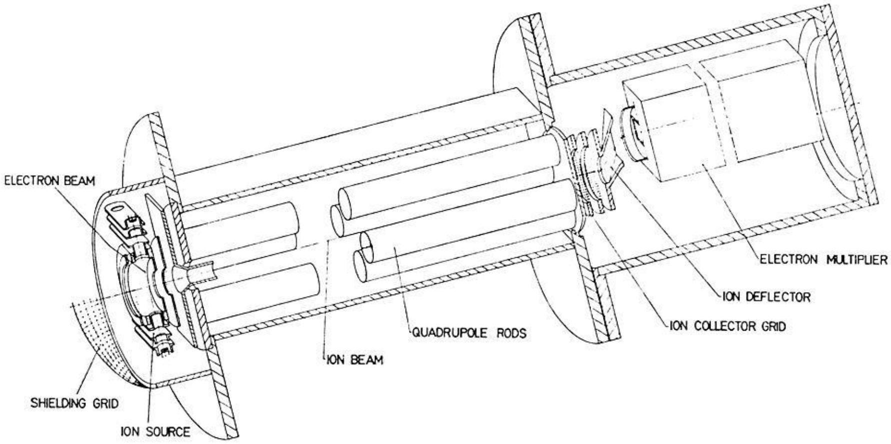


Fig. 1. Configuration of the mass-spectrometer

The ion source is made of stainless steel. In the neutral mode gas particles are ionized by a 75 volt electron beam emitted from either one of two 0.076 mm diameter tungsten-rhenium filaments. The electron beam current entering the ionization box is stabilized to a value of 100 μamp. Ions produced within the ionization box are accelerated into the quadrupole analyzer by an extraction grid and a repeller grid. The positive source potential avoids interference with ambient ions. In the ion mode source potentials are changed to sample atmospheric ions. The electron beam is prevented from entering the ionization box as all source potentials are negative with respect to the filament potential.

In contrast to the cylindrically shaped ionization box of the AEROS-B source (Fig. 1) the AEROS-A version employed a hemispherically shaped ionization box. In the source design care was taken to thermally insulate the heated filament from the ionization box in order to minimize outgassing. Therefore the monitored temperature of the ionization box never exceeds 30 to 35 °C. To avoid disturbances of the plasma experiments the ion source is covered by a hemispherical shielding grid at spacecraft potential. The shielding grid and the planar high transparency repeller grid covering the ionization box which have a total transmission of about 62 % tend to make the ion source perform more like a closed source for neutral gases. This effect is taken into account in the source model.

Within the quadrupole analyzer (length 160 mm, rod radius 9 mm) a filtering of the ions according to their m/e ratio takes place in superimposed electric ac (2 MHz) and dc fields. Individual mass peaks within the mass range 1 to 44 amu are selected by stepping the amplitude of the ac and dc rod voltages.

The ion current leaving the analyzer is deflected by an electrode onto the first dynode of a 16-stage copper-beryllium electron multiplier displaced with respect to the analyzer axis. In the AEROS-A version the multiplier was mounted in the quadrupole axis, but for AEROS-B the modification was introduced to decrease the noise at high ambient pressures.

The electron multiplier output current is recorded by a logarithmic electrometer with a range from 5×10^{-12} amp to 5×10^{-6} amp. About 50 percent of the ion beam to the multiplier is intercepted by an ion collector grid and recorded by a linear electrometer. The full-range sensitivity of the electrometer changes periodically from 10^{-10} amp to 10^{-11} amp. Only the peak current of a mass is sampled by the linear electrometer. A multiplexer combines the logarithmic and linear electrometer readings into one data channel. In-flight calibration of both electrometers is performed once per orbit by feeding currents of 10^{-6} and 10^{-8} amp into the logarithmic electrometer and a current of 10^{-11} amp into the linear electrometer. The main purpose for introducing the linear electrometer is to monitor and correct for possible multiplier gain changes.

The basic sensitivity of the instrument (at the lowest multiplier voltage) is 0.23 amp/torr for N_2 not taking into account the ram pressure increase. In the ion mode for small angles of attack the sensitivity is 10^{-18} amp/ions m^{-3}. By telecommand the multiplier voltage can be selected out of four different levels which provide factors of about 3.8 increase in sensitivity for each step. The maximum signals that can be expected from either ion or neutral measurements at perigee altitudes are of comparable strength. The increase in sensitivity provided by the four high voltage steps is intended for compensation of multiplier gain losses and adjustments of the sensitivity at higher altitudes.

The spectrometer is sealed off by a miniature valve after a last baking at approximately 250 °C and a final calibration and is kept under high vacuum until a week after launch to allow for sufficient spacecraft outgassing. On ground vacuum is maintained by a small titanium sublimation pump and monitored by an ion gauge. The pressure never exceeded 5×10^{-7} torr for the AEROS-B instrument. Most of the residual gas consisted of Ar and He. Once in orbit the spectrometer is exposed to the atmosphere by action of explosive squibs initiated by telecommand breaking a ceramic ring in a titanium cap covering the ion source.

The functional diagram of the spectrometer is shown in Fig. 2. The total mass of the instrument is 7 kg and the maximum operational power 8.6 W.

Data Organization and Modes of Operation

A mass-spectrometer moving at satellite velocity is sensitive to the angle of attack at which it is viewing the flow of particles to be measured.

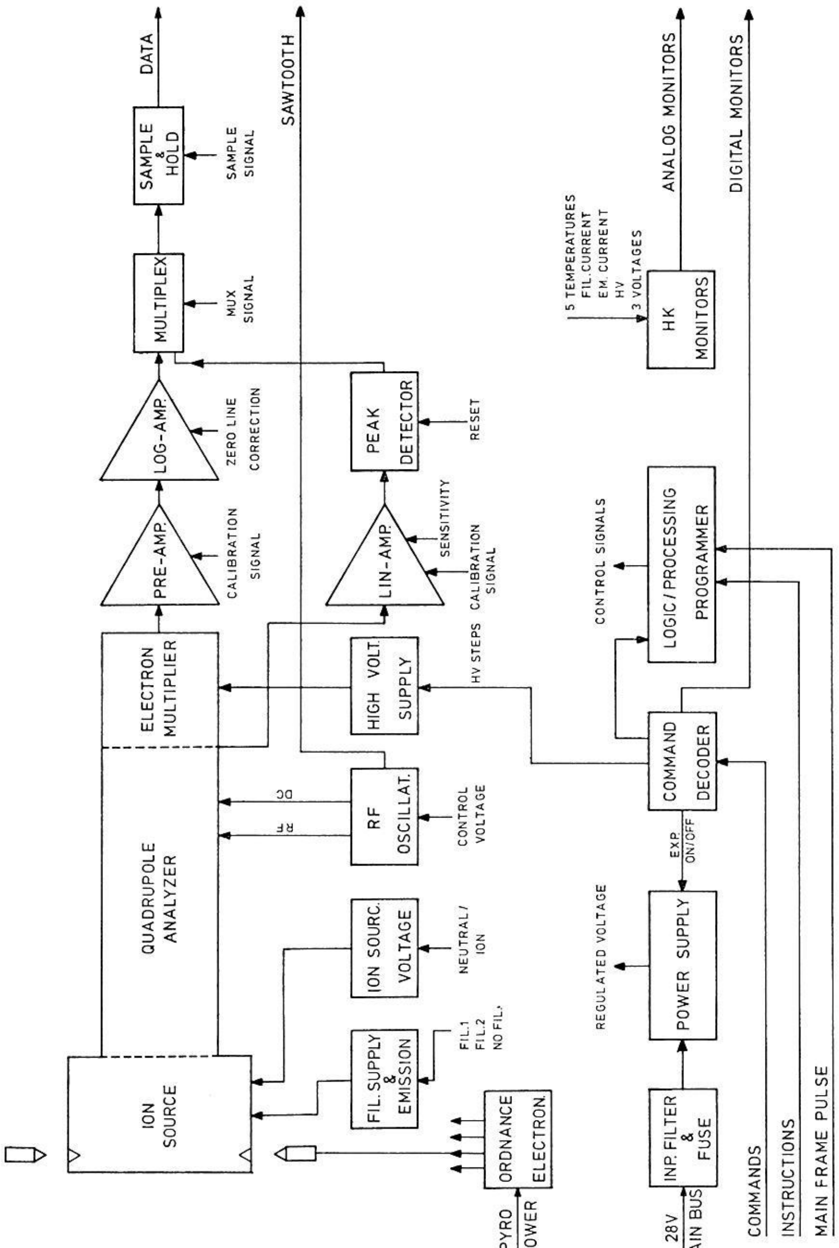


Fig. 2. Functional diagram of the instrumentation

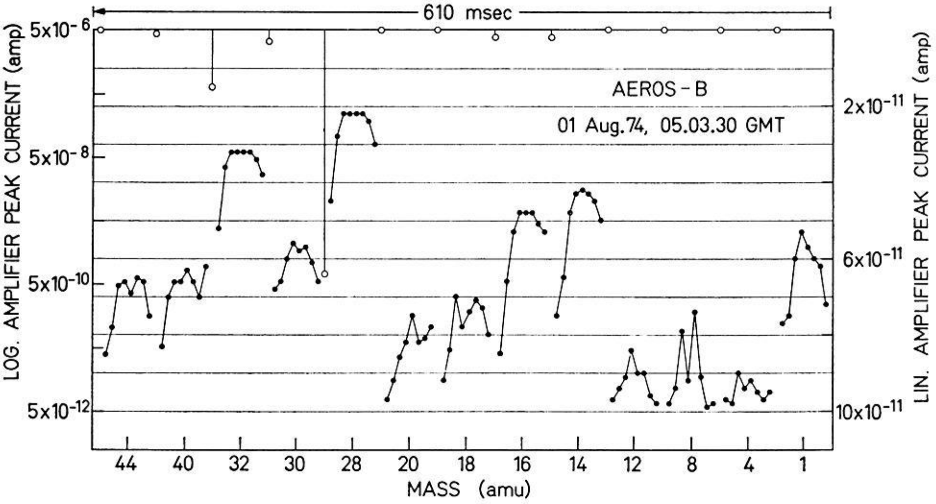


Fig. 3. A neutral gas mass spectrum recorded on AEROS-B, at an altitude of 240 km. Note that every ninth sample represents the peak of the linear electrometer reading during the scan over the preceding mass, in an inverted scale

Thus, the orientation of the spinning spacecraft in its orbit plane puts some basic constraints on the data concept of the experiment as well as of the whole spacecraft.

The spin axis is pointing to the sun which is always approx. 45 degrees off the orbit plane, and the mass-spectrometer is aligned perpendicular to the spin axis. With this configuration the flight aspect angle, and consequently the signal measured, is modulated by the spin with a period of 6 seconds, the minimum angles of attack during a spin revolution ranging from zero degrees at low latitudes to about 45 degrees near the poles.

The AEROS telemetry system can synchronize the data flow with the spin phase and trigger the mass-spectrometer when it is oriented closest to its ram position. Within a time interval of 610 msec which is short as compared to the spin period and during which no significant variation in the flight aspect occurs, the mass-spectrometer analyzer is sweeping over the mass range.

Such a mass sweep is illustrated in more detail in Fig. 3. Altogether 13 different masses are measured, by scanning each peak in 8 equidistant steps covering an interval of 1 amu centered at the peak. The 8 data points are read out from the logarithmic amplifier that follows the electron multiplier, and the intensity of the mass peaks will be determined from the maximum of a curve fitted through these points. Every ninth telemetry word in the main data channel is the output of the linear electrometer and represents the peak current measured when that mass was scanned.

Mass spectra of ions and of neutral gas have the same format. In the standard mode they are alternating every spin revolution, the repetition period for any species being 12 seconds corresponding to a resolution in space of approximately 95 km. For specific investigations requiring higher resolution the density of data points can be doubled by continuous and exclusive measurement of either ions or neutrals. Because of shortage of independent telecommands these program modes are coupled to the filament selection as indicated in Table 1.

The 13 different mass numbers cover all major and measurable minor constituents of the neutral thermosphere (helium, nitrogen, oxygen, and argon) and of the *F*-region ionosphere (H^+, He^+, O^{++}, N^+, O^+, NO^+, O_2^+). Some of the masses measured do not correspond to ambient species but serve to monitor contamination and background gases and ions, or allow to discriminate between atomic and molecular particles (e.g. in the case of oxygen).

The instrument version flown on the AEROS-A satellite obtained one full mass range sweep only within two separate scans at subsequent spins, thus providing only half the resolution in space. The tuning stability of the mass analyzer, however, proved to be sufficient for scanning single mass peaks rather than mass number intervals and, therefore, the mass sequence was rearranged to provide better resolution on AEROS-B.

Two telemetry programs are available on the spacecraft which yield different types of measurements:

The *spinphase controlled telemetry* provides one mass range sweep at every spin revolution, triggered symmetric to the phase of minimum flight aspect. This is intended to be the prime mode, since it gives the highest return of scientific information at the given bitrate combining high spatial resolution with quasi-simultaneity of the measurement of all inherent parameters including those from the other AEROS experiments.

The *clock controlled telemetry* provides consecutive mass range sweeps over one complete spin revolution, but only at every 13th spin. The basic purpose of this mode is diagnostic; it will occasionally be used to investigate contamination and ion-source background at varying angles of attack, to determine the dependence on the angle of attack of the instrument's sensitivity, and to possibly detect fast ions. Since this telemetry mode is independent from the ion-sensor it may also serve as a backup in the event the spinphase control fails. The resolution in space that can be obtained, however, is relatively poor.

On AEROS-A an anomaly in the spinphase control did not allow to use the normal telemetry format routinely, and nearly all the measurements

Table 1. Sequence of measurements in the different modes of operation (AEROS-A in parantheses)

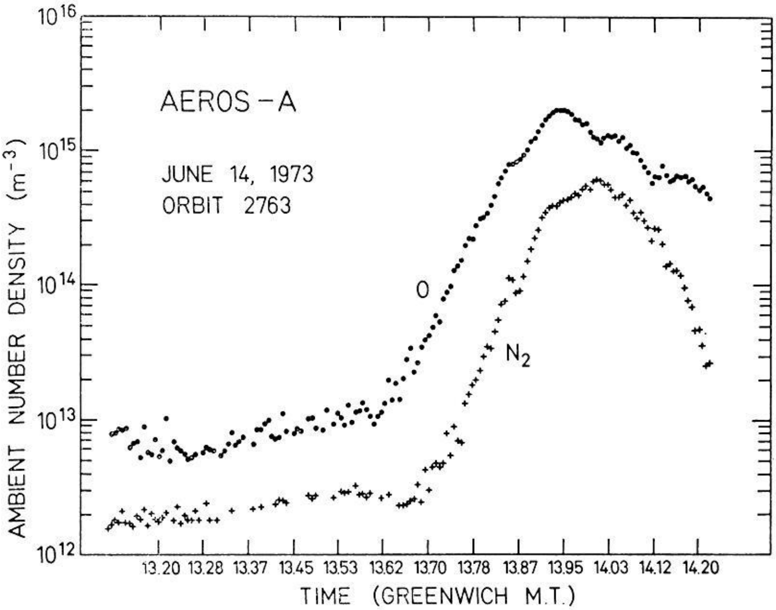
Spin phase controlled telemetry				Clock controlled telemetry			
Spin No.	Instrument modes			Spin No.	Instrument modes		
	Filament 1	Filament 2	No filament		Filament 1	Filament 2	No filament
1	N (N_2)	N (N_2)	I (I_2)	1	10 N (10 N_2)	10 N (10 N_2)	10 I (10 I_2)
2	I (N_1)	N (N_1)	I (I_1)	14	10 I (10 N_1)	10 N (10 N_1)	10 I (10 I_1)
3	N (I_2)	N (I_2)	I (I_2)	27	10 N (10 I_2)	10 N (10 I_2)	10 I (10 I_2)
4	I (I_1)	N (I_1)	I (I_1)	40	10 I (10 I_1)	10 N (10 I_1)	10 I (10 I_1)
5	N (N_2)	N (N_2)	I (I_2)	53	10 N (10 N_2)	10 N (10 N_2)	10 I (10 I_2)
.				.			
.				.			
.				.			
.				.			

$N = 1, 4, 8, 12, 14, 16, 18, 20, 28, 30, 32, 40, 44$ $\quad I = 1^+, 4^+, 8^+, \ldots\ldots$

$N_1 = 1, 2, 3, 4, 5, 6, 7, 8, 12, 13, 14, 15, 16$ $\quad I_1 = 1^+, 2^+, 3^+, \ldots\ldots$

$N_2 = 18, 19, 20, 28, 29, 30, 31, 32, 40, 41, 42, 43, 44$ $\quad I_2 = 18^+, 19^+, 20^+, 28^+, \ldots\ldots$

$10\,N = 1, 4, 8, \ldots, 44; 1, 4, \ldots.; \ldots\ldots; 1, 4, \ldots, 44$ (10 consecutive scans N)



LOCAL TIME	14.20	13.62	12.41	5.53	3.89	3.08	2.85	2.68	2.50	2.30	1.97	0.83	17.84	hr
ALTITUDE	634.1	642.3	625.7	587.2	529.9	453.8	380.0	312.8	257.6	229.3	224.8	245.0	282.6	km
GEOD. LAT.	42.29	59.62	77.41	79.70	63.74	44.19	25.49	6.29	-14.90	-34.66	-54.35	-74.83	-80.65	deg
INV. LAT.	41.07	58.87	77.95	71.02	64.33	44.13	26.83	10.63	18.35	39.08	60.03	80.98	74.78	deg

Fig. 4. Example of neutral densities measured on AEROS-A in the spinphase controlled mode. The N_2 density is obtained from mass 28. The O density is derived from mass 32 assuming complete recombination of atomic oxygen in the ion source; a 10 to 20 percent correction has to be added to account for atomic oxygen not recombined. At altitudes above 400 km the nitrogen data shown reflect the instrumental background whereas the oxygen data are affected by desorption from the walls

were obtained in the backup mode with the low resolution. An example of a measurement in the normal mode of operation, i. e. spinphase controlled, is shown in Fig. 4.

Calibration

Laboratory neutral gas calibration of the spectrometer is done for hydrogen, helium, neon, nitrogen, molecular oxygen, argon and carbon dioxide. A gas flow method (cf. e. g. Schneppe, 1969) is employed using a helium cryopump system. It consists of three parts: the pumping chamber containing the cryopump which is separated from the calibration chamber by an orifice with a conductance of 50.0 liter sec^{-1} for N_2 and the gas inlet system from which gases are introduced into the calibration chamber through calibrated porous leaks. In addition, the system contains noble gas ion getter pumps for maintaining the vacuum during standby periods. The pressure is measured inside the calibration chamber by ion gauges and inside the gas inlet system by Baratron capacitance manometers.

Calibration within the pressure range of 5×10^{-5} to 10^{-9} torr is achieved in two ways. In one method the pressure range is covered by setting the pressure in the calibration chamber at constant values. In the second method an initial pressure of 5×10^{-5} torr is established inside the calibration chamber by filling a volume in the inlet system to an appropriate pressure, and allowing the gas to leak at a constant rate into the calibration chamber. The pressure decays to the background level within about 25 minutes. In both methods spectra are continuously recorded on magnetic tape along with the experiment housekeeping data and calibration system pressure readings. A small computer is used during calibration for limited real time data analysis. The advantage of the calibration system is that based on the Baratron pressure readings and on the accurately calibrated orifice and porous leak conductances well known pressures inside the calibration chamber are established without a need to depend on ion gauge readings. Due to the use of a cryopump behind the 50.0 liter sec^{-1} orifice gas backstreaming is negligible. This is even true for He for pressures up to 10^{-7} torr if care is taken that the pumping surfaces of the cryopump are clean and without gas load. The accuracy of the calibration of the instrument's sensitivity is estimated to be better than 10%.

The instrument is calibrated twice. The first calibration is done with the ion source facing into the calibration chamber and, after mounting the ejectable cap over the source, the second calibration through the miniature valve takes place.

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Dr. D. Krankowsky
Dr. P. Lämmerzahl
Mr. F. Bonner
Dr. H. Wieder
Max-Planck-Institut für Kernphysik
D-6900 Heidelberg 1
Saupfercheckweg
Federal Republic of Germany