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The Giotto RPA-Copernic Plasma Experiment

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Abstract

The RPA-Copernic plasma experiment for the Giotto mission consists of two Sensors, the RPA1-EESA spectrometer and the RPA2-PICCA electrostatic mass analyzer. RPA 1-EESA measures the three-dimensional distributions of electrons between 10 eV and 30 keV. These electron measurements should contribute to defining the properties of the cometary plasma and its interaction with the solar wind. The RPA-2 PICCA sensor is an electrostatic mass analyzer designed to measure the composition and the distribution of thermal cometary positive ions, including clathrate hydrates in the mass range 10 to 203 amu. This instrument should probe the interaction processes producing these ions, and provide information on the spatial distribution and chemical composition of the solid, gas and plasma components of the cometary environment. Such information should allow identification of parent molecules and hence give some knowledge of the composition of the cometary nucleus.

1. Introduction

The RPA-Copernic experiment aboard Giotto is designed to measure the three-dimensional distributions of electrons between 10 eV and 30 kev, and the composition and distribution, close to the comet, of thermal positive ions, including clathrate hydrates, in the mass range 10 to 203 amu. It should help in achieving several of the major scientific objectives of the Giotto mission, by determining:

- the nature of the comet/solar-wind interaction and of comet tails
- the chemical and physical nature of the comet's atmosphere and ionosphere
- the chemical and physical structure of the comet's nucleus.

The electron measurements should contribute to defining the structure of the cometary plasma environment and its interaction with the solar wind (Fig. 1). In addition, these electron measurements may provide detailed information on the magnetic-field structure of the comet nucleus and comet/solar-wind interaction region via electron reflection magnetometry, and information on the role of energetic electrons in ionization of the cometary plasma.

Figure 1. Trajectory of the spacecraft during the encounter with comet Halley. Conceptual solar-wind/comet interaction and cometary atmosphere regions are also indicated, as well as the timing of the different operating modes on the right axis

Before the comet encounter, the electron spectrometer should provide detailed information about the plasma in the interplanetary medium.

Positive ions are produced via various interactions between the comet nucleus, cometary dust, micrometeoroids, cometary and solar-wind plasmas, neutral gas, and solar electromagnetic radiations. As in the Earth’s atmosphere, these ions are expected to be present not only as free ions, but probably also as clathrate hydrates, i.e. bound to water clusters stemming from dissociated icy grains evaporating from the cometary nucleus. Thus measurements of ions, of their clathrate hydrates, and of their mass distribution close to the comet should provide a sensitive probe of these interaction processes, as well as information on the spatial distribution and composition of the solid, gas and plasma components of the cometary environment, and of the chemical composition of the cometary nucleus (parent molecules).

The detailed scientific objectives of the experiment were described in Reme et al. (1981).

In order to achieve electron and thermal ion measurements with optimal performances, the RPA-Copernic experiment consists of two separate instruments (Reme et al., 1981; 1983):

- a symmetric quadrispherical electrostatic analyzer (RPA1-EESA) of novel design (Carlson et al., 1982) which provides 4 pi electron measurements with high sensitivity and high energy, angular and time resolution; it was designed jointly by the Space Sciences Laboratory in Berkeley and the Centre d’Etude Spatiale des Rayonnements in Toulouse and was built by CESR;
- a light electrostatic mass analyzer (RPA2-PICCA), which is designed to detect thermal positive ions with high sensitivity, low background and good mass resolution in the range 10 to 203 amu, close to the comet. This instrument was built by the Max-Planck-Institut fur Aeronomie in Lindau.

These instruments are mounted on the spacecraft’s experiment platform in such a way that the field of view includes the ram direction.

The RPA-Copernic experiment is designed to:

- measure the flux and spectra of electrons from 10 ev to 30 kev, in 39 steps, with a large dynamic range, in the complete 4 pi solid angle, with high time resolution for half a spin period (2 s)
- process the data through a microprocessor, which is programmed to provide the electron pitch-angle distribution around a symmetry direction, i.e. the magnetic-field direction
- detect thermal positive ions incoming from the ram direction and to measure their spatial distribution and their composition from 10 amu to 203 amu with a good mass resolution (Delta m </~ 1 amu)
- perform all measurements with low background. This is particularly important in the cometary environment, due to the presence of the dust and neutral gas, and also of sputtered fragments due to collisions of these particles in the analyzers or with the spacecraft (d’Uston & Reme, 1984).

2. The Electron Electrostatic Analyser (RPA1-EESA)

This sensor (Fig. 2) is designed to measure the fluxes and energy spectra of electrons from 10 eV to 30 keV in order to identify the various cometary plasma regions, to detect any heating or acceleration of particles, e.g. at shocks or in the cometary tail, and to observe any energetic electron population that can be significant for the ionization processes of the cometary plasma. RPA1-EESA has the ability to measure the detailed 4 pi distributions of electrons in all regions of the cometary environment and to be sensitive to flows along either direction of an arbitrarily-oriented magnetic field in order to: (1) detect electrons travelling upstream and downstream of the cometary shocks and in this way provide a remote signal of the presence of the shock, (2) measure any accelerated population in the shock structure, (3) use suprathermal electrons as remote probes or tracers of the magnetic-field topology and intensity (Anderson et al., 1975; Lin et al., 1975). Because charged particles are reflected from regions of stronger magnetic field, the range of electron energies covered by the instrument and its pitch-angle resolution allow the detection of magnetic fields as low as 10**-1 nT. We note here that this technique is also applicable in the absence of a solid surface; for example, if the solar-wind field is compressed as it traverses the cometary ionosphere, incoming electrons must be reflected from the compressed field region.

Figure 2. The Electron Electrostatic Analyser (RPA1-EESA)

2.1 The analyzer

The electrostatic analyzer detector system combines several recent innovations which are particularly applicable to pitch-angle measurements. These innovations include an improved electrostatic analyzer, a fast-counting particle-detection system, and a microprocessor-based data system. Our basic analyzer design is a symmetrical, spherical-section electrostatic analyzer with a uniform 360deg disc-shaped field of view and extremely fine angular-resolution capability, and is protected against dust contamination (Fig. 3). By comparison, there are several shortcomings in a conventional quadrispherical analyzer, which adversely affect pitch angle and three-dimensional plasma measurements: because this analyzer field of view is less than 180deg, there are always look directions that are not sampled, and as Gosling et al. (1978) have shown, its response in azimuth and polar angle is not constant, but becomes broader as the polar angle departs from normal incidence. These problems have been eliminated by the new analyzer design used in RPA1-EESA, which is closely related to quadrispherical analyzers, but has uniform response over 360deg of polar angle.

Figure 3. Cut-away view of the RPA1-EESA spectrometer. The entrance aperture is a plane located at the top of the hemisphere below the top cap, which defines the collimator

Figure 4. Comparison of the symmetrical and the normal quadrisphere. With the normal quadrisphere, the response varies with polar angle. The symmetrical analyzer has no polar-angle dependence and has a complete 360deg field of view. Typical trajectories illustrate the focussing properties

The operating principle of both analyzer types is illustrated by cross-section and top view in Figure 4. The normal quadrisphere consists of two concentric quarter-sphere sections, whereas the symmetric quadrisphere consists of three concentric spherical elements. These three elements are an inner hemisphere, an outer hemisphere which contains a circular opening, and a smaller circular top cap which defines the entrance aperture. This analyzer is classified as quadrispheric, simply because the particles are deflected through 90deg. In both analyzers a potential is applied between the inner and outer plates and only charged particles having a limited range of energy and initial azimuth angle are transmitted. The particle exit position is a measure of the incident polar angle, which can be resolved by a suitable detector system. With a normal quadrisphere, all particles entering at normal incidence focus to a line at the exit aperture, independent of where they cross the entrance aperture. Three paths with identical incident angle but different entrance positions are shown. For all oblique trajectories, the azimuthal response and polar angle focussing depend upon where the particles cross the aperture. This property results directly from the lack of cylindrical symmetry of the planar entrance aperture. The symmetric quadrisphere circumvents this defect by making the entire analyzer, including the entrance aperture, rotationally symmetric. Again trajectories are shown to illustrate the focussing characteristics which are independent of the polar angle for the symmetric quadrisphere. The open character of the entrance aperture makes this symmetrical quadrisphere analyzer immune to both solar and cometary electromagnetic radiations and dust and neutral-gas contamination (fly-through). The acceptance fan is aligned to contain the spacecraft velocity vector so dust and neutral gas particles which pass through the collimator entrance continue through the analyzer top-cap region and pass out of the analyzer on the opposite side (Fig. 5).

The electron detector provides a 360deg X4deg (FWHM) field of view with a uniform angular resolution of 22ù5deg X4deg. Due to the spacecraft spin, the aperture scans the full 4 pi solid angle twice per revolution. It covers the energy range 10 eV - 30 keV with energy resolution Delta E/E ~ 10%.

2.2 Detector assembly

A schematic cross-section of the detection system and the scheme of the sectored collector are shown in Figure 6. Electrons passing through the entrance aperture of the electrostatic analyzer are selected in energy by applying a positive deflection voltage to the inner hemisphere of the analyzer. The selected electrons are detected by a microchannel plate (MCP) ring at the output. The MCP, specially made by Mullard, is made up of two rings, each 1 mm thick with an external diameter of 86.6 mm and an internal diameter of 66 mm. Each ring has a Ni-Cr metallization on the two-face active surface. The total resistance across a ring has a low value (between 12 and 15 mega Ohm) for fast-counting purposes. The 12.5 micro m diameter, straight microchannels are inclined by 15deg and the two rings are chevron-mounted. The collector associated with the MCP is divided into 17 sectors corresponding to 14 bins of 22.5deg, two bins of 19.5deg and one bin of 6deg linked to the ram direction. Hence, the angular position range is divided between 16 bins and the ram sector, and the 4 pi analysis using the rotation of the space probe is made with - 22.5deg X22.5deg elementary sectors.

2.3 Energy sweep

The energy selection of the detected electrons is made by varying the positive deflection voltage of the inner hemisphere of the electrostatic analyzer. The outer hemisphere and the top cap are tied to signal ground. The variation of the deflection voltage is synchronized with the spin period of the spacecraft, via the Sun reference pulse. The sweep of the total energy range is repeated 16 times per spin, i.e. once every 250 ms. Since the 360deg field of view provides full coverage in 1/2 spin period, a full three-dimensional distribution with 22.5deg angular resolution is obtained in 2 s with eight energy sweeps. The deflection high-voltage range is stepped according to an exponential law, each step lasting 1.95 ms. For energies between 80 eV and 30 keV, four high-voltage steps are used for one measurement, and for energies between 10 and 80 eV, only two high-voltage steps are used for one measurement. Four steps are devoted to the high-voltage setting (Fig. 7). During one sweep, 23 measurements for energies greater than 80 eV and 16 measurements for energies smaller than 80 eV are made, and a 39-step energy spectrum is therefore obtained every 250 ms.

2.4 Electronics

For each of the 17 angular bins, MCP signals are passed through individual charge-sensitive amplifiers to seventeen 16-bit counters. A digital front-end system preprocesses the accumulated counts in order to obtain corrected data, taking into account the dead time of the detectors. Electron data are accumulated into 17 angle bins, for every energy, eight times per half spin, and stored in RAM by a main processor. At the end of each half-spin interval, the corrected data are transferred to a pitch-angle calculator for further processing and results from the previous half spin are sent back to the main processor.

Figure 5. Geometrical and electronic characteristics and cross-sectional view of the RPA1-EESA detection system

Figure 6. RPA1-EESA detection system: (a) scheme of the detection system, (b) MCP sectoring

Figure 7. RPA1-EESA deflection high-voltage sweep and data organization (HBR = high-bit-rate telemetry, LBR = low-bit-rate telemetry)

2.4.1 Analogue electronics

The analogue electronics that interface the electron instrument and the data-processing unit are shown in Figure 8. They involve:

- one high voltage to bias the MCP, programmable by ground command between 2000 and 4000 V (16 steps) to accommodate gain changes
- a second high voltage to polarize the electrostatic analyzer, stepping from 3000 V to 1 V (128 steps) exponentially
- the associated analogue electronics to generate the variation laws for the high-voltage supply of the analyzer
- 17 amplifiers (type A 111) associated with the 17 sectors of the MCP
- a special fixed-pattern test-generator circuit, used to check the whole acquisition counter system.

2.4.2 Digital electronics

Three microprocessors are used for data processing:

- one CDP 1802 dedicated to interfacing RPA2-PICCA with RPA1-EESA
- the ’main processor’ (CDP 1802) used for RPA1-EESA instrument control and data processing and to interface with commands and telemetry
- the pitch-angle calculator (NSC 800 microprocessor) which processes the data in order to obtain the electron pitch-angle distribution by computing the magnetic-field direction by means of the diagonalization of the pressure tensors.

The characteristics of these three processors are summarized in Table 1.

Table 1. Characteristics of the three microprocessors used in the data-processing unit

	Main microprocessor	Microprocessor for RPA2	Pitch-angle calculator
Microprocessor	CDP 1802	CDP 1802	NSC 800
Manufacturer	RCA	RCA	NS
Frequency	3.5 MHz	3.5 MHz	5 MHz
Power Supply	10 V internal 5 V external	10 V internal 5 V external	5 V
PROM	6x HM 6641	1x HM 6641	8x HM 6641
Type	CMOS	CMOS	CMOS
Size	3 kbyte	0.5 kbyte	4 kbyte
RAM			
Type	CMOS Hybrid	CMOS Hybrid	CMOS Hybrid
Size	3x (8 kbyte)	8 kbyte	8 kbyte

Figure 8. RPA1-EESA analogue electronics block diagram

The way the three microprocessors work together and how they interface with the analogue electronics and with the spacecraft is shown in Figure 9.

All experiment timing, such as energy sweeping and angle binning, are synchronized via the spacecraft Sun reference pulse and generated from the spin-segment clock pulse (Fig. 7).

Figure 9. RPA1-EESA simplified block diagram

2.5 Onboard data processing

The measurements are accumulated in a memory and passed through a data-processing unit in order to lower the output data range.

As the complete 10 eV to 30 keV electron distribution function over 4 pi can be achieved at each half rotation of the spacecraft, i.e. every 2 s, the amount of information available for every distribution is: 17 sectors (theta) X 8 azimuths (phi) X 39 energy bands (E) = 5304 counts termed CR(theta(i), phi(i), E(k)). These are the input counts (dead-time corrected) corresponding to the 39 energy bands analyzed and the 17 angular sectors (16 sectors + ram sector); the 8 azimuths correspond to the sweeping of the high voltage, which lasts one eighth of a rotation (250 ms), which means 8 sweeps in 2 s.

With 8 bit words, there would have to be 5304X8=42 432 bits,i.e. 21 216 bit/s. It is not possible to transmit such an amount of information through the telemetry and therefore onboard processing is necessary.

This onboard processing must be adapted to the spacecraft real-time telemetry system, which has three different formats for science-data transmission: telemetry Formats 1, 2 and 3 (see Section 4). Formats 1 and 2 can be operated at high bit rate (HBR = total spacecraft bit rate 46 kbit/s) or at half the maximum bit rate (low bit rate = LBR). Independently, the RPA-Copernic data packet lasts 16 s (HBR) or 32 s (LBR). In LBR the same data are produced, but only from every other spin (Fig. 7).

The calculations carried out by RPA1-EESA are the following:

- an estimate of the magnetic-field direction, which is computed from two partial-pressure tensors calculated in two distinct electron energy ranges: in telemetry Formats 3 and 2/2, range 1 is between 3.64 and 0.36 keV and range 2 between 0.36 and 0.08 keV; in telemetry Formats 1 and 2/1, range 1 is between 3.64 and 0.28 keV, and range 2 between 0.28 and 0.08 keV
- the Pitch Angle Distribution (PAD) determination of the electron in the 0-180deg range in eight bins, for several energy bands
- the Omni Directional Energy Spectrum (ODES) for each E-value:

  ODES (E(k)) = Summation(i,j) CR(theta(i), phi(j), E(k)) (for i = 0-15 and j = 0-7).

  For energies E > 80 eV (steps 1 to 23) and steps 24, 26,28 and 30, the calculations are made by the PAD Processor (ODES-B). The calculations for the other steps are made by the main calculator (ODES-A)
- the Low Energy Distribution (LED): in order to search for possible azimuthal anisotropies in the distributions of low-energy electrons (E <80 eV), thereby allowing the possible effects of the asymmetries in spacecraft potential or of predominant streaming directions to be seen, snapshots of the azimuthal distributions are regularly calculated and transmitted. A snapshot is performed in 4 s using one half of the MCP. The next snapshot is performed using the second half of the MCP. Thus, a complete spacecraft rotation is necessary to obtain the snapshot corresponding to all azimuths (16 sectors phi). In the case where there are two snapshots per data packet (Formats 2/1 and 2/2), they are performed with the same half of the MCP:

  LED (phi(j), E(k)) = Summation(i) CR(theta(i), phi(j), E(k))   (for i = 0-7 or i = 8-15).

  In Format 2/2, this calculation is also performed for energies E> 80 eV and is then called the ED (Energy Distribution).
- 2s snapshots of the Distribution Function (DF) are transmitted frequently. Beyond their scientific interest, they also permit the validity of the preceding calculations (principally PAD) to be verified. However, these snapshots are not the most elementary distribution function: the ram and the 128 angular bins

sampled are grouped on only 89 solid angles, following the principle outlined below.
As the directions along the spin axis are oversampled, the high-elevation azimuthal sectors are grouped, whereas the low-elevation ones are transmitted individually. The Distribution Function can be transmitted for selected energy steps or summed over several consecutive steps

- in several bands (of one or more energy steps), the maximum count rate in a spacecraft half-rotation is searched for. The azimuthal as well as the elevation position of this maximum and the corresponding flux are transmitted. For several energy steps, the step corresponding to this maximum is also identified.
- the ram sector in telemetry Formats 2/1 and 2/2 is used to search for an eventual cometary negative ion contribution. Accumulated counts on 32 (Format 2/1) or 8 (Format 2/2) energy spectra are divided into 32 (Format 2/1) or 33 (Format 2/2) energy steps and transmitted.

The operation of the different telemetry formats is given in detail in Section 4.

These data are compressed from 21 bits to 8 bits, according to a special algorithm, such that the precision is always better than 3.3% if the count rate is between 32 and 131 071 s**-1 and 7.2% if the count rate is between 131 072 and 1 996 080 s**-1.

2.6 The Pitch Angle Distribution processor

The Pitch Angle Distribution (PAD) processor is designed to sort the three-dimensional electron distribution data generated by the RPA1-EESA detector into two-dimensional pitch-angle distributions in real time.

The PAD processor hardware consists of an NSC800 CMOS microprocessor together with hardware multiply/divide, ROM, and a pair of dual-ported RAMs. The RPA main processor controls and communicates with the PAD processor via the dual-ported RAMs.

The PAD partial processor computes the PAD in three steps: first, it computes two partial-pressure tensors from the input data over two separate energy ranges (Eqn. 1). Next, each of these tensors is diagonalized under the assumption that the distribution has a two-dimensional symmetry, and the nondegenerate eigenvector is computed. This vector corresponds to the symmetry direction of the distribution, which is presumably the magnetic-field direction. Finally, the three-dimensional input data is sorted into a two-dimensional PAD using the computed symmetry direction for each energy range (Eqn.2).

Pitch-angle distributions of eight angles, summed into 10 or 16 energy steps, are computed every half spin (2s).

The equations used in the computations are:

P(i,j) = Summation (theta, phi, E) [(v(i)v(j)/absolute (v))*(absolute cos(theta))*CR(theta, phi, E

where

CR(theta, phi, E)	-	the count rate sample for energy step E in the theta, phi
v(theta, phi, E)	-	the velocity vector of particles corresponding to data sample CR(theta, phi, E)
v(i)	-	the ith component of velocity vector v
absolute cos(theta)	-	a weighting factor to compensate for the over-sampling at the poles by the analyzer
P(i,j)	-	the i,j element of the pressure tensor =/P (actually =/P is the momentum flux tensor; it is approximately equal to the pressure tensor for plasma bulk velocities that are small compared with the thermal velocities).

PAD (E, alpha) = Summation(theta, phi) [OF(alpha,alpha’) * (absolute cos (theta)) * CR(theta,
/ [16 * Summation(theta, phi) [OF(alpha, alpha’) * (absolute cos(theta))]

alpha (theta, phi) = cos**-1 (B,S(theta, phi)) where

alpha' = the pitch angle of the look direction S(theta,phi) corresponding to data sample CR(theta, phi, E)
B = the symmetry direction computed from the pressure tensor =/P
OF(alpha, alpha') = the fraction of the data sample at pitch angle alpha' that falls into pitch-an bin alpha. Typically, each data sample is summed partially into one pitch-angle bin, and partially into the adjacent bin.

Note that the denominator factor normalizes the PAD to counts per 22.5deg by 22.5deg bin.

2.7 Position on the spacecraft

The configuration of the spectrometer on the experiment platform is shown in Figure 10. The instrument extends beyond the platform in order to get clear of the bumper shield and also of the upper part of the spacecraft body, over the total field of view, which is from -2deg (towards the spacecraft body) to +7deg. It is partly protected by the extension of the rear shield (by a piece of kevlar) and the bumper shield as shown in the figure. The outer hemisphere is made of 0.8 mm-thick aluminium, which is painted on the outside with a white conductive paint. The top cap, which defines the entrance aperture, is similarly made of white-painted aluminium and also grounded to the signal ground. This cap is designed to prevent direct solar illumination at the time of encounter. A portion of the top disc is reduced in the ram direction to minimize the dust-impact problem.

3. The Positive Ion Cluster Composition Analyser (RPA2-PICCA)

3.1 The sensor

The RPA2-PICCA experiment (Fig. 11) is designed to measure the spatial distribution and the composition of positive ions, including large-mass ion-water cluster compounds, in the cometary coma. In the innermost part of this region, these particles are expected to be singly charged (I+ or I+(H2O)n) and rather cold, i.e. their thermal velocity is negligibly small compared with the relative spacecraft velocity (about 69 km/s). These particles are therefore expected to flow with the spacecraft velocity and to be highly collimated in the direction opposite to the spacecraft ram direction. The kinetic energy of these particles will be given approximately by E(kev)

Figure 10. Location of the RPA1-EESA spectrometer on the experiment platform

Figure 11. The Positive Ion Cluster Analyser (RPA2-PICCA)

~ 5.1 X 10**-6 N*V**2, where V is the relative spacecraft velocity in km/s and N the ion mass in amu.

The Giotto space probe is expected to traverse the inner coma in a rather short time, so that the main observations performed by the RPA2-PICCA sensor will begin 15 min before the closest approach of the spacecraft to Comet Halley. In the inner part of the cometary coma the density, and therefore the flux of positively charged particles is expected to be rather high (~ 10**3 cm**-3), and at the same time to be accompanied by a very high flux of 'background radiation'. In the case of the RPA2-PICCA experiment, this background could be caused by one or several of the following components: solar and cometary electromagnetic radiation, incoming dust, neutral gas and sputtered fragments due to collisions of these particles in the analyzer itself, energetic electrons, high fluxes of positive ions interacting with the spacecraft and/or the outer parts of the sensor, and any kind of particles surrounding the spacecraft due to dustmicrometeoroid-neutral gas and cometary plasma interactions with the space probe.

To cope with these constraints and at the same time obtain as large an amount of significant information as possible, the RPA2-PICCA sensor has been optimized in the following way. As Figure 12 shows, the main part of this experiment is mounted behind the backup shield or the second bumper shield, but inside the spacecraft. Only its entrance aperture, which is a 50X50X 150 mm**3 tube, is outside of the spacecraft, but it is attached directly to the spacecraft skin and has a large (+/-6deg) unobstructed field of view in the flight direction of the probe. This aperture is completely open, so that light, micrometeoroids, dust and neutral gas can fly through without penetrating the analyzer system. In addition, the field of view of the analyzer itself is chosen in such a way that it never intersects any part of the aperture, nor the spacecraft skin or shields, but at the same time is still large enough (+/-5deg) to accept all particles to be analyzed, even in cases where their trajectories may differ, due to additional thermal speed of the ions, slight changes in the speed and orientation of the spacecraft, or electrostatic potentials of the space probe. Thus, any kinds of fragments originating from dust, neutral- or charged-particle interaction with the spacecraft and aperture materials is precluded from entering the analyzer system.

As with RPA2-PICCA, a mass analysis of positive ions and their clathrate hydrates will be performed in the mass range 10-203 amu: their kinetic energy will be up to about 5 keV. By applying a steadily increasing deflection voltage (+ HV) between the top and the bottom parts of the aperture, the particles will therefore be deflected from the incoming flow direction into the analyzer system. This analyzer is a 180deg hemispherical electrostatic analyzer, which focusses the particles onto two channeltrons with different sensitive areas in order to increase the dynamic range of the instrument. The overall dynamic range covers ion densities from 10**-3 to 10**3 ions/cm**3. Table 2 gives the geometrical characteristics of RPA2-PICCA. The densities of positive ions and ion-compounds expected at various distances from the cometary nucleus, as determined by Huebner & Giguere (1980) by multidimensional computer simulations, lie within the dynamic range of RPA2-PICCA.

According to the equation E(keV) ~/= k*N*V**2 mentioned above, any energy/charge (E/Q) measurement of this analyzer will actually be a measurement of the mass of the particle, as Q=1. To obtain a good and constant mass resolution, the ions are decelerated before entering the electrostatic analyzer: ions with masses 10 to 50 will have energies after this deceleration of 100 eV, and ions with masses 51 to 203, 250 eV. Using an analyzer with Delta E/E ~/= 10% and operating at two different fixed voltages for the two mass ranges, we obtain Delta E = 10 eV and Delta m ~/= 0.4 for the light ions and Delta E = 25 eV and Delta m ~/= 1 for the heavier ions.

Figure 12. Cross-sectional view of the
RPA2-PICCA sensor

Table 2. Geometrical factor of RPA2-PlCCA in cm**2 (for parallel incidence)

Step numbers	Mass (amu)	G (cm**2) (large CEM)	G (cm**2) (small CEM)
1- 10	10-14	5.3x10**-4	6.2x10**-5
11- 20	14-18	5.2x10**-4	5.2x10**-5
21- 30	18-22	5.1x10**-4	3.0x10**-5
31- 40	22-26	5.1x10**-4	2.0x10**-5
41- 50	26-30	5.0x10**-4	1.5x10**-5
51- 60	30-34	4.9x10**-4	
61- 70	34-38	4.7x10**-4	
71- 80	38-42	4.3x10**-4	
81- 90	42-46	4.0x10**-4	
91- 100	46-50	3.7x10**-4	
101-110	51-60	4.4x10**-4	
111-120	61-70	4.5x10**-4	
121-130	71-80	4.7x10**-4	
131-140	81-90	4.3x10**-4	

141-150	91-100	3.3x10**-4
151-160	101-110	2.5x10**-4
161-170	111-120	1.9x10**-4
171-180	121-130	1.4x10**-4
181-190	131-140	1.1x10**-4
191-200	141-150	9.0x10**-5
201-210	151-160	7.6x10**-5
211-220	161-170	6.5x10**-5
221-230	171-180	5.5x10**-5
231-240	181-190	4.6x10**-5
241-250	191-200	4.0x10**-5
251-256	201-206	3.4x10**-5

The electronics used within the RPA2-PICCA instrument are shown in Figure 13. All high voltages required for the deflection system, lens system, electrostatic analyzer and the two channeltrons are generated within the sensor, so that there are no high-voltage lines between the two RPA-Copernic instruments. The electronics also include one test generator (100 kHz) and one ultraviolet lamp to test the functions of the amplifiers and the channeltrons.

A small negative voltage (-10 V) is applied to the outer part of the sensor in order to repel the secondary electrons of the plasma cloud around the spacecraft, which would otherwise be captured by the positive deflection voltage.

3.2 Associated digital electronics

The electronics associated with RPA2-PICCA are included in the RPA1-EESA box, and are organized around a CDP 1802 microprocessor. These electronics are used to control operation of the RPA2-PICCA detector according to telemetry format and the command status:

- high-voltage stepping
- test generator on/off
- UV lamp on/off.

Synchronously with this task, this microprocessor acquires data from two 16-bit counters, one for the larger CEM and one for the smaller. These data are compressed from 16 bit to 8 bit, according to a special algorithm, such that the precision is always better than 1.2% if the count rate is lower than 255, and better than 3.3% if the count rate is between 255 and 65535. Every 16 s a packet of data is generated and is sent to the telemetry by using a DMA interface. The high-voltage analyzer is monitored through an 8-bit analogue-to-digital converter. The step number and corresponding control voltage are included in the scientific data stream.

Figure 13. Schematic block diagram of RPA2-PICCA

4. Modes of Operation

The initial Giotto telemetry was divided into two formats to allow plasma experiments to get more data far from the nucleus. A third reduced format (Format 3) was also added in order to have some cruise measurements and as complete as possible coverage during the last days before the closest approach to the comet nucleus.

The telemetry allocation for the RPA-Copernic experiment is as follows: 904 bit/s in Format 3, 2530 bit/s in Format 1, 1807 bit/s in Format 2. Format 2 will be used from t(0)-1 hour (t(0) = time of closest approach) until mission end. Format 1 will be used from t(0)-4 h until t(0)-1 h. Prior to that, Formats 1 and 3 will be used in order to obtain complete coverage of the last 24 h before the closest approach to the nucleus and significant coverage during the last five days.

An internal RPA-Copernic switch in Format 2, 15 min before t(0) will modify bit distribution between the two sensors (Formats 2/1 and 2/2). Tables 3,4,5 and 6 give summaries of the measurements and telemetered data for each format (in HBR for Formats 1, 2/1 and 2/2).

RPA2-PICCA is used mainly in the Format 2/2 (encounter phase). Its cycle of measurement is 3.2 s, i.e. less than one spin period, avoiding the analysis of the same masses always in the same sector. This sensor is not used in Format 3 and is in a survey mode in Formats 1 and 2/1.

Table 3. RPA-Copernic measurements in telemetry Format 3

Detector	Data output	Parameters	Time resolution (s)	Bit rate (bit/s)
RPA 1-EESA	Pitch-angle distribution	8 alpha x 10 E 7E> 80 eV* 3E<80eV	2	388
	Omnidirectional energy spectrum	16E> 80 eV	2	64
	low-energy distribution	13e(E<80 eV)** x 16 phi**	Snapshot 4 s every 16 s	104
	Distribution function	6E x 89 Omega	Snapshot 2 s every 16 s	267
	Six maxima and positions for six integrated energy bands***		2	72
RPA2-PICCA		No use		
Housekeeping				9.5
Total				904.5

E = Energy alpha = Pitch angle Omega = Solid angle sector phi = Azimuthal angle

Remarks

* The B-direction is calculated for the 2E bands. In 2 s, the total number of words is (8 alpha x
\+ (6 pressure tensor elements) x (2E bands) + (B direction (2 words)) x (2E bands) + (1 HK word) =
** One snapshot with the first half of the MCP, the following one with the second half of the MCP.
*** Giving the energy (1 word) of each maximum (1 word) and its angular position (1 word) for 6 energy bands, i.e. 18 words.

Table 4. RPA-Copernic measurements in high bit rate (HBR)* telemetry Format 1

Detector	Data output	Parameters	Time resolution (s)	Bit rate (bit/s)
RPAl-EESA	Pitch-angle distribution	8 alpha x 16 E 12E>80 eV 4E<80eV	2	580

	Omnidirectional energy spectrum	11E>80 eV 12E< 80 eV	2	92
	Low energy distribution	12E(E<80 eV) x16 phi	Snapshot 4 s every 16 s	96
	Distribution tunction	15E x 89 Omega	Snapshot 2 s every 8 s	1335
	39 maxima and positions for 39E**	23E>80eV l6E<80 eV	2	312
RPA2-PICCA	l0- 50 amu 51-129 amu	Delta M=0.4(101 steps) Delta M=l (79 steps)	182 steps in 16 s***	90 +6****
Housekeeping	Includes MCP current measurements 16E in 16 s			17.5
Total				2528.5

* The same data are produced in LBR, but from every other spin only.
** Energy information transmission as in Format 3 not needed.
*** Spin-segment clock: 16 384 pulses/spin. Integrated measurement each 360 pulses, i.e. Delta t ~
**** 6 bit/s for status. ADC. high-voltage steps, references of RPA2-PICCA where only large CEM used.

Table 5. RPA-Copernic measurenients in HBR* telemetry Format 2 (Format 2/1)

Detector	Data output	Parameters	Time resolution (3)	Bit rate (bit/s)
RPA1-EESA	Pitch-angle distribution	8 alpha x 16 E 1 2E > 80 eV 4E<80eV	2	580
	Omnidirectional encrgy spectrum	11E>80 eV 12E <80 eV	2	92
	Low energy distribution	12E(E<80 eV) x 16 phi	Snapshot 4 s every 8 s	192
	Distribution function	8Ex89 Omega	Snapshot 2 s every 8 s	7l2
	Seven maxima and positions for seven integrated energy bands		2	84
	Ram direction	32 energy steps 10 eV - 5 keV	8	32
RPA2-PlCCA	10- 50 amu 51-129 amu	Delta M=0.4 (101 steps) Delta M=1 (79 steps)	182 steps in 16 s	90 +6
Housekeeping	Includes MCP current measurements 16E in 16 s			17.5

Total				1805.5

* The same data are produced in LBR, but from every other spin only

Table 6. RPA-Copernic measurements in HBR* telemetry Format 2 (Format 2/2)

Detector	Data output	Parameters	Time resolution (s)	Bit rate (bit/s)
RPA1-EESA	Pitch-angle distribution	8 alpha x 10 E	2	388
	Omnidirectional energy spectrum	16E>80 eV 13E< 80 eV	2	116
	Energy distribution	12E(E< 8 eV) x 16 phi 7E(E>80 eV) x l6 phi	Snapshot 4 s every 8 s	304
	Seven maxima and positions for Seven integrated energy bands		2	84
	Ram direction	33 adjacent energy steps 1O eV -6 keV	2 s	132
RPA2-P1CCA	10- 50 amu 51-203 amu	Delta M=0.4 (101 steps with 50 meas. with small CEM in parallel) Delta M=1 (153 steps)	262 steps in 3.2 s**	760 +6
Housekeeping	Including MCP current measurements 16E in 16 s			17.5
Total				1807.5

* The same data are produced in LBR, but from every other spin only
** Integrated measurement each 50 pulses of the spin segment clock, i.e. 1520 measurements during four spins (Delta t ~/= 12.2 ms).
In four spins we have five measurement sequences; in every sequence we have 262 intervals: 8 are used for resetting the high voltage, 254 with the large channeltron (from 10 to 203 amu) and 50 wi the small channeltron (from 10 to 29.6 amu) in parallel.

5. Conclusion

The main characteristics of the two sensors of the Giotto RPA-Copernic experiment are summarized in Table 7. The experiment operated successfully for the first time in September 1985. RPA2-PICCA is working well, but is not designed to study solar-wind ions, and is therefore not useful during the cruise phase prior to encounter with Comet Halley. RPA1-EESA is regularly providing fine data on the electrons in the interplanetary medium. Figures 14 and 15 show examples of results obtained on day 289 in 1985. Figure 14 contains 5 h of measurements of the interplanetary B-field direction and of the electron density. Figure 15 is an example of the electron Low

Energy Distribution (LED) obtained over one spacecraft spin period (4 s).

Hence, these two sensors, specially designed for the Giotto mission, are ready to study the solar wind - Comet Halley interaction and the environment of the comet nucleus on 13 March 1986. The electron and ion measurements should help to define the basic structure of the cometary plasma, and provide a sensitive diagnosis of the interactions between the various components of the cometary environment: solar wind, cometary plasma, micrometeoroids, cometary dust, the nucleus, neutral gas, electrons and ions.

In addition, important information on the composition of comets should be obtained which, in combination with that from other experiments, should help us to define the chemical and physical nature of comets.

Table 7. Main characteristics of the two sensors of the RPA-Copernic experiment

Function	RPA1-EESA (Suprathermal electron analyzer)	RPA2-PICAA (Positive thermal ion composition analyzer)
Instrumentation		
Analyser	Symmetrical quadrispherical	Hemispherical
Detectors	Microchannel plates	Two channeltrons (one for high count rates)
Energy range	10 eV - 30 keV	
Mass range		10 - 203 amu
Energy resolution	10%	
Mass resolution		Delta M=0.4 if M<50 amu Delta M=1 if M>50 amu
Geometrical factor	2.5x 10**-3 xE (keV) cm**2 . ster . keV	Between 5.3 x 10**-4 and 3.4 x 10** cm**2 for a parallel incidence (Table 2)
Field of view	360deg x4deg (FWHM)	60x6deg
Best angular resolution	22.5deg x4deg (FWHM)	
Dynamic range	(4x10**3x10**9)/E (keV) (cm**2.sec.ster.keV)**-1	10**-3 - 10**3 cm**-3
Background rejection	Fly-through source - UV rejection	Fly-through source - UV rejection
Best time resolution	1/2 spin (2 s) for a complete 3D distribution with 39 energy steps	3.2 s for an ion mass spectrum
Onboard data processing	Pitch-angle sorting	
Physical Characteristics		
Weight	2.3 kg + 0.2 kg (harness from RPA1 to RPA2)	0.78 kg
Power	3.IW	0.6W
Telemetry (high bit rate) (divided by 2 in low bit rate in Format 1, 2/1 and 2/2)	Format 1: 2430 bit/s, Format 2/1: 1709 bit/s Format 2/2: 1039 bit/s. Format 3: 903 bit/s	Format 1: 98 bic/s, Format 2/1: 98 bit/s Format 2/2: 768 bit/s: not used in Format 3

Figure 14. Results of the calculation of the B-field direction on day 289 in 1985 over a 5 h period: B(theta) is given in the lower part and B(phi) in the centre. The electron density is given in the upper sector

Figure 15. Example of the electron low-energy distribution obtained during one spin of the spacecraft on day 289 in 1985 at 08.00:01 UT

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References

Anderson K A, Lin R P, McCoy J E & McGuire R E 1975, Measurement of lunar and planetary magnetic fields by reflection of low energy electrons, Space Sci. Instr., 1,439.

Carlson C W, Curtis D W, Paschmann G & Michael W 1982, An instrument for rapidly measuring plasma distribution functions with high resolution, Adv. Space Res., 2, 67.

Gosling JT, Asbridge J R, Bame S J & Feldman W C 1978, Effects of a long entrance aperture upon the aximuthal response of spherical section electrostatic analyzers, Rev. Sci. Instrum., 49, 1260.

Huebner W T & Giguere R T 1980, Model of comet coma: 2. Effects of solar photodissociative ionization, Astrophys. J., 238, 753.

Lin R P, McGuire R E, Howe H C. Anderson K A & McCoy J E 1975, Mapping of lunar surface remanent magnetic fields by electron scattering, Proc. Sixth Lunar Sci. Conf., 2971.

Reme H, Cotin F, d'Uston C, Sauvaud J A, Korth A, Richter A K, Anderson K A, Carlson C W, Lin R P, Wekhof A, Mendis D A & Johnstone A D 1981, The Copernic experiment to measure three-dimensional electron distribution and the composition of thermal positive ions including water clusters near Comet Halley, ESA SP-169, 29.

Reme H, Cotin F, Cros A, d'Uston C, Sauvaud J A, Bush R, Korth A, Loidl A, Richter A K, Anderson K A, Carlson C W, Curtis D, Lin R P, Mendis D A, Wekhof A & Johnstone A D 1983, An experiment to study the solar wind - Comet Halley interaction and the cometary environment with 3D electron distribution and thermal positive ion measurements onboard the Giotto spacecraft, Cometary Exploration III, 321.

d'Uston C & Reme H 1984, Anticipated impact plasma problems for the Copernic-RPA experiment in the cometary environment, ESA SP-224, 81.