PLAZMAG-1 EXPERIMENT
SOLAR WIND MEASUREMENTS DURING THE CLOSEST APPROACH TO COMET GIACOBINI-ZINNER BY THE ICE PROBE AND TO COMET HALLEY BY THE GIOTTO AND SUISEI SPACECRAFT

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ABSTRACT

The PLAZMAG-1 plasma analyzer, flown on the VEGA 1 and VEGA 2 spacecraft, is described in full detail. When the spacecraft approached comet Halley, the instrument produced informations on the plasma phenomena around the comet.

Keywords: Instrument, Plasma-Observation

1. INTRODUCTION

This presentation will describe the PLAZMAG-1 plasma experiment, intended to study the plasma in the near-comet environment and in the solar wind. PLAZMAG-1 was carried by the VEGA-1 and VEGA-2 spacecraft. Measurements of solar wind parameters were performed also during the closest approach to comet Giacobini-Zinner by the ICE probe in September 1985 and during the closest approach to comet Halley by the GIOTTO and SUISEI probes in March 1986.

The scientific objectives of the PLAZMAG-1 experiment have been already described elsewhere (Ref. 1,2). Here we describe the instrument in more detail.

The PLAZMAG-1 system has sensors to determine the following plasma characteristics:

- basic parameters of solar wind protons and α-particles, using the "ion energy spectrometer", SDA, viewing direction towards the sun;
- mass composition of cometary ions, using the "ion mass-spectrometer", CRA, oriented along the spacecraft-comet relative velocity vector (v_{rv});
- electron energy distribution, using the "electron energy spectrometer", EA, oriented perpendicular to the direction towards the sun and to the v_{rv} vector;
- solar wind ion flux, using the "integral counter" SDFC, oriented towards the sun;
- number density of cometary ions and neutral particles, using the "integral counter", RFC and PID, oriented along the v_{rv} vector.

2. INSTRUMENTATION

The instruments are mounted in a block except the two integral counters RFC and SDFC (see Fig. 1). The three spectrometers were sealed before launch, covers opened 5 days after launch.

Figure 2 shows a schematic of the sensors.

2.1 The Ion and Electron Spectrometers

Two practically identical ion spectrometers using 120° spherical analyzers measured simultaneously the ion component of the solar wind and cometary plasma. The radius of the spheres was $R_1 = 43.75$ and $R_2 = 46.25$ mm. To obtain a larger angular aperture in front of each analyzer a quadrupole electrostatic lense was mounted (Ref. 4,5). By this means the angular characteristic of the spectrometers was increased by a factor of 7 in one direction without reduction of energy-range and geometric factor of the instrument; the high energy resolution also could be maintained.

Figure 3 illustrates the angular characteristic of the SDA spectrometer, where the analyzer was tuned to E = 1000 eV. The angular response in the other direction is given by the properties of the hemispherical analyzer with a knife-edge beam. Ion spectra were taken in 60 steps in the range 50 eV to 27 keV for the SDA spectrometer and in the range 15 to 3500 eV in 120 steps for the CRA spectrometer; this is equivalent to a mass range up to 110 amu. Protecting grids, to which -40 V voltage are applied, were placed in front of the quadrupole lense. This measure was taken to prevent overloading of the lens-bins-supplies near the comet nucleus, where the thermal electron number density was expected to be very high.

The electron spectrometer used a cyclindrical electrostatic 120-degree analyzer. This geometry had to be taken to meet dimensional restrictions, despite the fact, that a spherical analyzer would have been preferable. The mean radius of curvature of the electrodes was $R_m = 45$ mm, the gap between them $\Delta R = 2$ mm. Energy spectra were obtained in 30 log-spaced voltage steps in the 3 eV to 10 keV energy range. To increase the

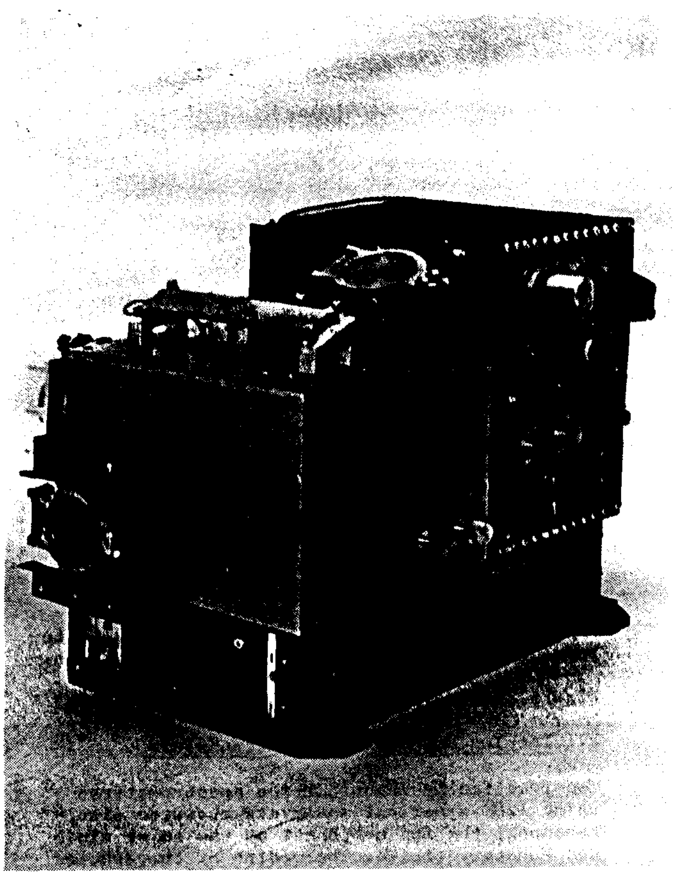


Figure 1. The PLAZMAG instrument.

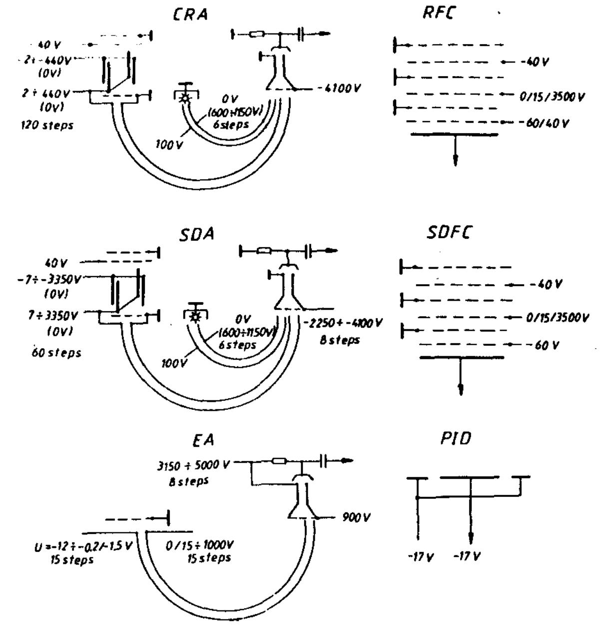


Figure 2. Schematics of the PLAZMAG instrument.
CRA - Cometary Ion Mass Spectrometer;
SDA - Solar Wind Ion Energy Spectrometer;
REC, SDFC, PID - Integral Sensors.

dynamic range, the electron spectrometer had an additional mode, where the sensitivity was lower by 2 orders of magnitude (Ref. 2). This mode was switched on regularly after every fourth spectrum. The spectrometers used commercial Soviet-made channeltrons (CEM's) (VEU-6) as particle detectors. The operating voltage of 4100 V was applied to the CEM's only two days before closest approach to the comet.

In the solar wind measuring mode the CEM-operating voltage for the SDA and EA spectrometers could be commanded to eight specified values in the voltage range 2200 V to 4100 V.

To select the optimum voltage for the CEM's an in-flight calibration mode was introducted. In the ion spectrometers the CEM's were calibrated using a tritium electron source ($E \leq 20$ keV) through a 120-degree cylindrical analyzer. The analyzer could be stepped through some energy range in 6 steps. In the solar wind mode it was blocked by a proper voltage.

The electron spectrometer's CEM's could only be checked by measuring solar wind electrons at different CEM voltages.

All spectrometers were simultaneously calibrated for 20 minutes every 24 hours. Note that during the entire flight (about 1,5 years) the characteristics of all CEM's operating at both spacecraft had not changed considerably; voltages where varied within 2600-3200 V during that time.

2.2 The Integral Plasma

The PID sensor is an open flat, gold-plated collector, biased at -17 V relative to the spacecraft body. The collecting area is 1 cm^2. To reduce edge effects a guard-ring electrode was provided, biased at the same potential. If the collector is bombarded with neutral or dust particles, secondary electrons are released from the surface. Their current is recorded by a DC-amplifier. From the known secondary electron emission coefficient the flux of incoming particles could be estimated.

The SDFC sensor was intended to measure the integral flux of solar wind ions. It consisted of a nickel collector, protected by six grids for shielding. A potential of -60 V on the suppressor grid reduced the photoelectron collector current. The background current was measured by using a grid at variable potentials (0/15/3500 V). At 3500 V practically all solar wind ions were reflected, and the measured current was then due to background radiation. At a potential of 15 V possible effects of the local plasma around the spacecraft could be determined. The third grid, operated at -40 V, prevented thermal electrons from being recorded. The two entrance electrodes where made from metal diaphragm's with several holes; a pair (one hole in the first, one in the second electrode) formed a cone of acceptance. The effective cross-section of the collector was 1.6 cm^2.

The detectors RFC and SDFC are, in principle, identical and have the same electrodes. The RFC-detector had four modes of operation: three similar to the SDFC's modes, plus one mode with a potential of +40 V at the suppressor grid. In this case its operation was identical to that of the PID detector. Details are described in (Ref. 6). The effective cross-section of the collector was 0.93 cm^2, the angular characteristic is a trapezoid with base angles 16° and 26°.

2.3 Electronics

Figure 4 shows a block diagram of the PLAZMAG-1 instrument. The control unit is the central part; it contains a microprocessor, RAM's and PROM's, memories for data storage, and the interfaces to the S/C. All operational programs, also the voltage settings, are stored in PROM's. The channeltrons output pulses are fed towards 19-bit counters through charge sensitive amplifier (8×10^{-14} to 8×10^{-11} Cb, < 10^6 pulses/s) and discriminators. Quasilog compression of the data is used to obtain 8-bit words. Collector currents of the integral sensors are measured by DC-logarithmic amplifiers, followed by conversion into 8 bit (PID) or 9 bit (RFC and SDFC, 1 bit for current polarity) (ranges: PID: $\pm 10^{-11}$ A - $\pm 10^{-5}$ A; SDFC: $\pm 10^{-12}$ A - $\pm 10^{-5}$ A; RFC: $\pm 10^{-12}$ A - $\pm 3 \times 10^{-9}$ A). Data had to be transmitted via two telemetry systems on board of the S/C: a high rate of 65 kbit/s and a low rate of 8 kbit/s. The instrument's power supply also contained a stand-by part which remained on in order to supply the memory, in which commands received from Earth were stored. Most subunits where redundant and could be switched over either automatically or by ground command. During the VEGA-2 cometary encounter - 2.5 minutes before closest approach - PLAZMAG-1 ceased working, probably after the impact of a dust particle into the CRA spectrometer. A command was released to turn on the redundant units. When the command was executed all sensors except CRA operated again normally.

3. PROGRAMME OF OPERATIONS

PLAZMAG had four modes of operation: Cruise Phase Mode I (Trassa I) (1820 bit per 20 minutes); Cruise Phase Mode II (15120 bit/20 minutes) (Trassa II); Realtime (15120 bit/118 s), and High Bitrate Mode (realtime, 2048 bps).

Trassa-I-Mode began 5 days after launch until 2 days prior to encounter. Only the spectrometers EA and SDA operated in this mode; they obtained two spectra every 20 minutes. All detectors were switched on only during the other modes. In Trassa II each spectrometer measured 7 spectra in 20 min. This mode started 2 days prior to encounter and ended about 3.5 hours prior to it. However, this mode was also turned on intermittendly during the Trassa I phase, for example, during the ICE encounter with comet Giacobini-Zinner.

High bitrate mode started only 13 hours prior to encounter and lasted for 4.5 hours. In this mode one spectrum per second was obtained. In the "realtime mode" one spectrum was obtained in 17 seconds only.

After launch, the instrument seals were opened 5 days after launch. The instrument should have remained unpowered for some time to allow for outgassing. Unfortunately, due to an operator's mistake power was switched on on VEGA-1 together with the opening command. This caused a voltage

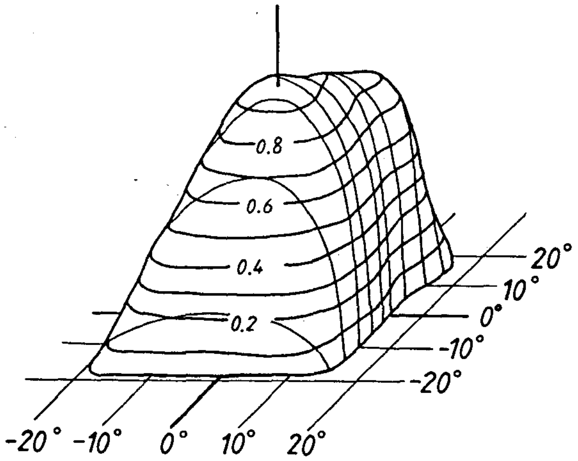


Figure 3. Angular characteristics of the SDA ion spectrometer. Y-axis arbitrary units. Numbers 0.2, 0.4, ... 0.8 denote levels of equal sensitivity.

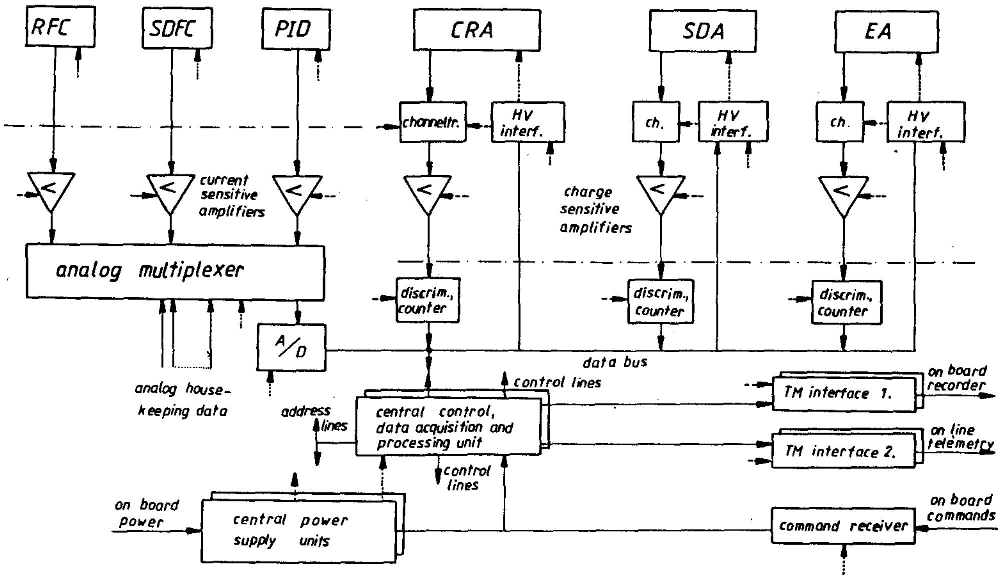
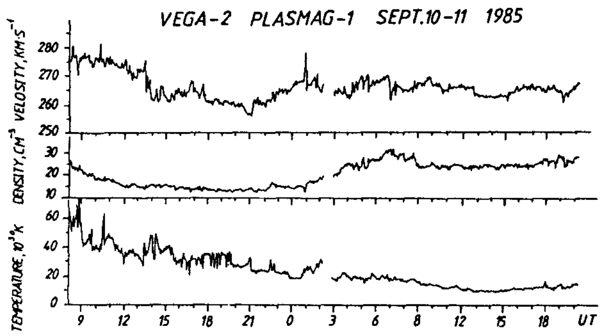


Figure 4. Functional scheme of the PLAZMAG instrument.

Figure 5. Velocity, density and temperature of solar wind protons obtained by the PLAZMAG data during the ICE approach to comet Giacobini-Zinner.



break-down which probably destroyed the charge-sensitive amplifiers of the CRA and EA spectrometers, while the rest remained operational.

PLAZMAG remained operational during almost the entire VEGA-1 flight. On VEGA-2 it was turned on only at encounter (except for short test periods and during some interesting events).

4. MEASURED SOLAR WIND PARAMETERS

During the ICE encounter with comet Giabocini-Zinner in September, 1985, VEGA-1 and VEGA-2 operated in the Trassa 2 mode. Figure 5 shows the velocity, density and temperature of solar wind protons obtained by the VEGA-2 spectrometer SDA on September 10-11, 1985. During this period VEGA-2 was 60° west of ICE at a distance of 1 a.u. from the sun.

Figures 6 and 7 show the same set of parameters obtained by the VEGA-1- and VEGA-2-instruments during the approach of the GIOTTO- und SUISEI-spacecraft to comet Halley. To simplify comparison the solar wind data presented here are plotted taking into account the lag or advance of the ion fluxes arriving at the two spacecraft. The shift was performed by using the solar wind velocities as measured by the PLAZMAG-1 instrument.

During the GIOTTO flyby both VEGA-1 and VEGA-2 operated in the Trassa 1 mode, during the SUISEI flyby VEGA-1 operated in the Trassa 1, the VEGA-2 in the Trassa 2 mode.

At GIOTTO's closest approach VEGA-1 was by 19.6 Million km closer to the sun compared to GIOTTO and 22° (heliographic longitude) west of it. The solar wind delay was 18-22 hours. Relative to GIOTTO VEGA-2 was 13 Million km closer to the sun and 13° west; the solar wind lag was 8 to 10 hours. During the SUISEI encounter VEGA-1 was closer to the sun by 5.8 Million km, and 2° west; the solar wind lag was 9 to 10 hours. VEGA-2 was 18 Million km further out from the sun, 2° east, and the solar wind's advance was 2 to 3 hours.

Table 1.

Parameters	Integral Sensors SDFC	RFC	PID	Spectral Detectors SDA	CRA	EA
Effective Aperture	1.6 cm^2	0.93 cm^2	1 cm^2	$4.6 \times 10^{-3} cm^2$	$1.4 \times 10^{-2} cm^2$	$3.6 \times 10^{-3} cm^2$
Angle of Acceptance	90°x90°	26°x26°	90°x90°	36°x32°	32°x12°	7°x7°
Energy Ranges	>0;15;3500eV	>0;15;3500eV	-----	0.05-27keV	15-3500eV	3-10000eV
Energy Resolution ΔE/E	-----	-----	-----	5 %	5.6 %	7.5 %
Mass Resolution M/ΔM	-----	-----	-----	-----	20	-----
Number of Energy Passbands	-----	-----	-----	60	120	30
Sampling Times: Trassa 1 Trassa 2 High Bitrate				 0.08 s 1.3 s 0.005 s	 1.3 s 0.005 s	 0.16 s 5.2 s 0.02 s

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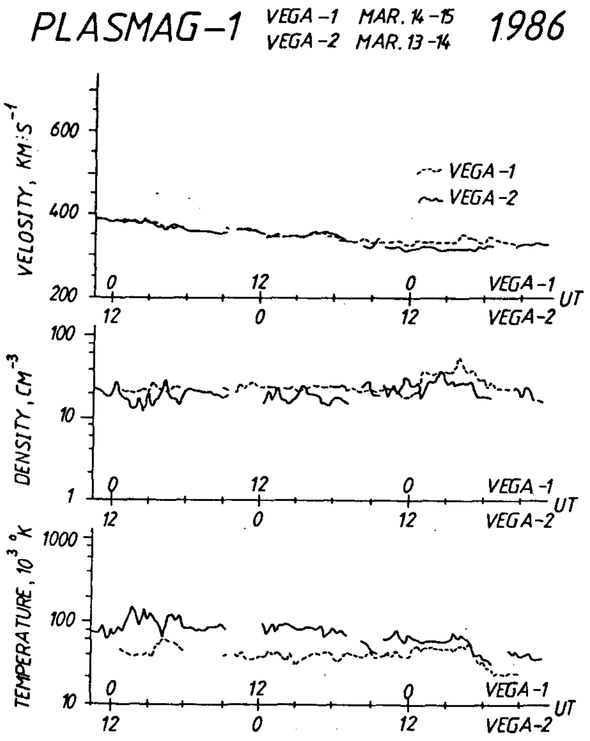

Figure 6. Solar wind proton parameters during the GIOTTO's approach to comet Halley.

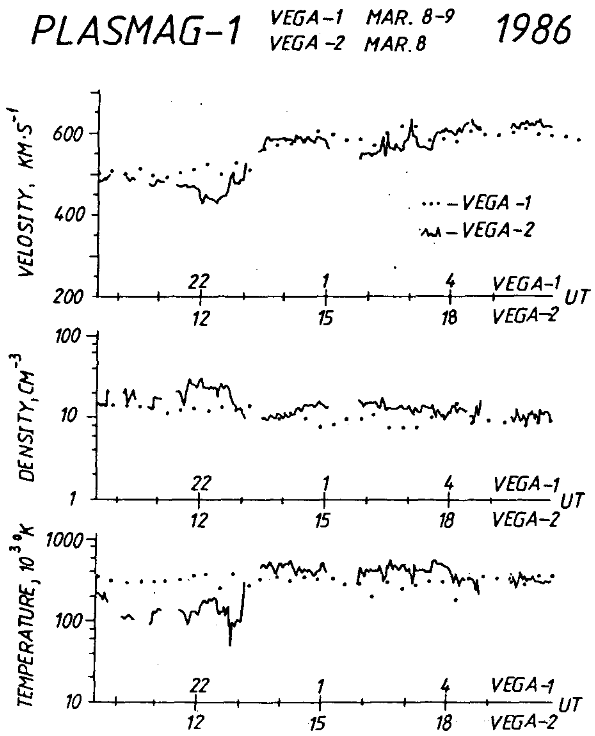

Figure 7. Solar wind proton parameters during SUISEI's approch to comet Halley.