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Auroral photometers aboard the AUREOL-3 satellite : the ALTAIR experiment

by

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ABSTRACT. – *The ALTAIR experiment consists of four photometers for measuring in the upper atmosphere the main auroral emissions excited by electrons and protons, i.e. the oxygen red line at 6 300 Å, the N_2^+ first negative* (0,1) *band emission at* 4 278 Å *and the hydrogen Balmer line H_β at 4 861 Å. Three photometers view the earthward direction at an angle of 20° with respect to the AUREOL-3 satellite's nominal nadir and have identical geometrical factor of 8.8 10^{-3} cm^2.sr. with a total field of view of 1.7°. A fourth photometer is used as a stellar sensor for a more precise determination of the satellite attitude in dark portions of the orbit.*

RESUME. – *L'expérience ALTAIR est composée de 4 photomètres destinés à la mesure dans l'atmosphère supérieure des principales émissions lumineuses excitées par les électrons et les protons : raie rouge à 6 300 Å, émission à 4 278 Å de la bande (0,1) du premier système négatif de N_2^+ et raie de Balmer à 4 861 Å. Trois photomètres visent vers la Terre avec un angle de 20° par rapport au nadir nominal du satellite AUREOL-3 et présentent un facteur de géométrie identique, égal à 8.8 10^{-3} cm^2. ster., ainsi qu'un angle de vue total de 1,7°. Le quatrième photomètre est utilisé comme senseur stellaire dans les portions non éclairées de l'orbite du satellite.*

1. Introduction

The ALTAIR experiment has as its objective the measurements of the main emissions of the upper atmosphere, excited by auroral electrons and protons along dark portions of the AUREOL-3 orbit. The red oxygen line λ 6 300 Å and the N_2^+ $1N$(0,1) band at λ 4 278 Å were selected as indicating the electron-excited aurorae and the hydrogen Balmer line H_β (λ 4 861 Å) was chosen as it is a signature of the so-called proton aurorae.

The onboard apparatus consists of four photometers (Fig. 1). Three auroral photometers with parallel optical axes directed toward the Earth at an angle of 20° from the nominal nadir and at 125° to the right of the spacecraft velocity vector so that the latitudinal profile of the emissions can be measured along a track lying parallel to but at some distance from the satellite trajectory. For a satellite altitude of 1 000 km and an emission height of 150 km this displacement is 300 km. A comparison of optical measurements along such a displaced profile with the "in situ" auroral particle measurements makes it possible to find moments when the satellite crosses extended auroral arcs and to determine their orientation

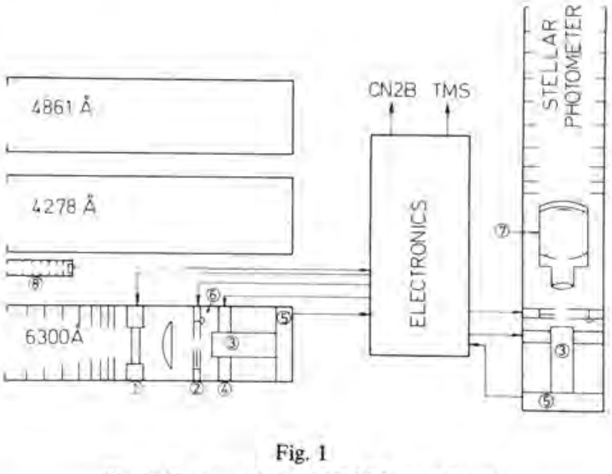

Fig. 1

Block diagram of the ALTAIR experiment

1. interference filter with thermostabilization system ;
2. shutter ;
3. photomultiplier ;
4. cooling system ;
5. preamplifier ;
6. calibration lamp ;
7. objective of the stellar photometer ;
8. sunlight detector.

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in respect to the orbit, i.e. to have a "two-point scheme" for measurements of auroral arcs. All three auroral photometers have identical optical construction with a geometric factor of 8.8 10^{-3} cm^2. ster and an angle of view of 1.7°. Each unit has its own light-protection baffle.

The instrumentation also includes a stellar photometer, used for more precise determination of the satellite attitude along dark portions of the orbit where the onboard solar sensor data are absent. The stellar photometer is directed at an angle of 28° to the vertical. It has a Maksutov objective with a focal length of 500 mm and works in the photometric V system.

2. Instrumental description

The three auroral photometers used interference filters whose parameters are given in Table 1. The temperature drift of the filter passband is 0.2 Å/deg. The satellite temperature can vary over a broad range, but the filter temperature is actively stabilized in the range 20 ± 3°C by means of thermoelectric batteries and a thermoregulator which controls the current through them, using the principle of a thermosensitive impedance bridge. The direction of the current through the thermobattery changes depending on the temperature of the filter, so it is either heated or cooled. The filter temperature stabilization is usually switched on for several hours before switching on the photometers. The temperatures of all filters are checked continuously with thermistors and have been demonstrated to be stable in flight.

Table 1

Passbands and transmission of the interference filters used for the study of the main upper atmosphere emissions

Wavelength, A	Passband, A	Transmission, %
4 278	18	48
4 861	15	45
6 300	16	55

Having passed through the filter and focusing lens, the light goes through an electromagnetic shutter to the photocatode of the photomultiplier. The shutter protects the photomultiplier from scattered daylight along the sunlit part of the orbit. The shutters of the auroral photometers and of the stellar photometer are controlled with individual protection circuits using photoresistors with optical axis parallel to the axis of the photometers (Kozlov and Angarov, 1978). The field of view of the protection photoresistors is about 10°. The shutters are closed when the illumination becomes higher than a predetermined level which corresponds to a source brightness of 150 kR and they are automatically opened for lower illuminations. Each shuttter has a miniature filament lamp for inflight calibration and it is periodically switched on by a command from the instrument programmer.

The detector system is based on a FEU-119 photomultiplier having a multi-alkali photocathode with a focussing magnetic ring and a thermocooling battery (Angarov *et al.*, 1982). The magnetic field of the permanent ring magnet focuses photoelectrons from the operative surface of the photocathode to the first dynode while thermal electrons emitted from the inoperative surface of the photocathode are defocused and deflected away from the first dynode of the photomultiplier (Frommhold and Feibelman, 1967 ; Popov and Utenkov, 1971).

The thermoelectric battery cools the photocathode to temperatures 30 to 35°C lower than the detector body. This allows the photocathode emission level to be decreased by at least an order of magnitude (Angarov *et al.*, 1982 ; Bash *et al.*, 1982). The supply voltage of thermobatteries is switched on by an independent programmable command from the satellite control system at any point of the orbit. This permits the photocathode to be cooled well before the photometric measurements are started. To control the photomultiplier temperature during the flight, thermistors are installed near the photocathode of each photomultiplier.

The photomultiplier used to measure the intensity of hydrogen emission H_β (λ 4861 Å) differs from the three others in that it is used in a circuit with a grounded anode in the photon counting mode. In the selection of the photomultiplier the important criterion was the well-defined single-electron peak in the pulse amplitude spectrum. After the preamplifier and amplifier the shaped pulses are fed to the differential amplitude discriminator adjusted to select one-electron pulses only. Following the discriminator the pulses are counted by an adaptive logarithmic counter with the recalculation coefficient varying automatically as a function of the number of accumulated pulses. The counter capacity is 131 000 pulses and the maximum counting rate is 1 MHz. The accumulation time is determined by the rate of arrival of a telemetry pulse which in turn depends on the chosen telemetry storage regime. The information about the number of pulses is transmitted to a buffer register and then the accumulator is reset to zero. From the buffer the number is transmitted to an eight-bit digital telemetry system. The buffer register is reset to zero before the information from the accumulator is transferred to it.

The three other photometers operate with a grounded anode circuit to measure the average anode current. The electric current from the anode of the photomultiplier is amplified by a logarithmic amplifier ; the output voltage is recorded by the telemetry system. The time constant of the amplifiers is $\tau \approx 0.1$ sec for λ 4278 Å and λ 6300 Å and $\tau \approx 1$ sec for the stellar photometer. Signal smoothing at the stellar photometer output is used to reduce the noise for reliable identification of stellar magnitudes.

To determine the absolute sensitivity of the photometers, a laboratory calibration was done using a standard filament lamp as well as a star calibration. The difference between the results of the laboratory and astronomical calibrations did not exceed 4 %. The threshold sensitivity determined by dark current of photomultipliers is about 100 R. But for in-flight conditions background intensities of more than 1 kR are measured reliably for 6300 Å and 4861 Å and about 200 R for λ 4278 Å for good observing conditions (no moonlight, satellite below radiation belt, etc.) ; for other conditions, the levels are higher. Housekeeping data are taken regularly in flight, controlled by the internal programmer, to verify the correct functionning of the photometers and amplifiers. This includes the calibration of amplifiers, the monitoring of dark current, and the signal from a reference lamp installed in the shutter. The calibration continues 2 minutes after switching on the apparatus and repeats every 90 minutes. When the instrument is switched off an internal command is automatically produced to close the shutters. The programmer unit which controls the cycle is synchronized by pulses from the on-board clock.

3. Inflight operation

Figure 2 shows the intensity variations of emissions at 6300 Å (1a) and at 4278 Å (1b) obtained along orbit 637 on Nov. 9, 1981 between 21 : 45 and 21 : 46 UT. At this time the satellite was in the evening sector of the auroral oval (MLT $\approx$ 22 h). On Figure 2c the intensity profile of 100 eV electrons is shown as measured with RIEP-2802. Reasonable general correspondance is seen between the highest flux of the electrons exciting the red line emission and the measured line intensity maxima, while the 4278 Å band remains very weak, as do harder electron fluxes. It must however be stressed that the measured auroral glow and particle fluxes correspond to slightly different lines of force. The satellite crossed the highest maximum of soft electron flux at $\Lambda_0 = 65.9°$, while along the photometer line of sight trajectory a similar maximum of the 6300 Å emission intensity was crossed at $\Lambda_0 = 66.0°$ (computed for emission altitude of 250 km). This case thus most probably corresponds to a two-point crossing of an intense red auroral arc extending approximately along the auroral oval in the evening sector.

Now let us consider data of the upward directed stellar photometer. Figure 3 gives examples of star signals from the stellar photometer during orbits 639 on Nov. 9, 1981 and 1639 on Jan. 24, 1982. A rather high background intensity level was present so that the lowest reliably measurable stellar magnitude is 3^m on orbit 639 and 5^m on the orbit 1639.

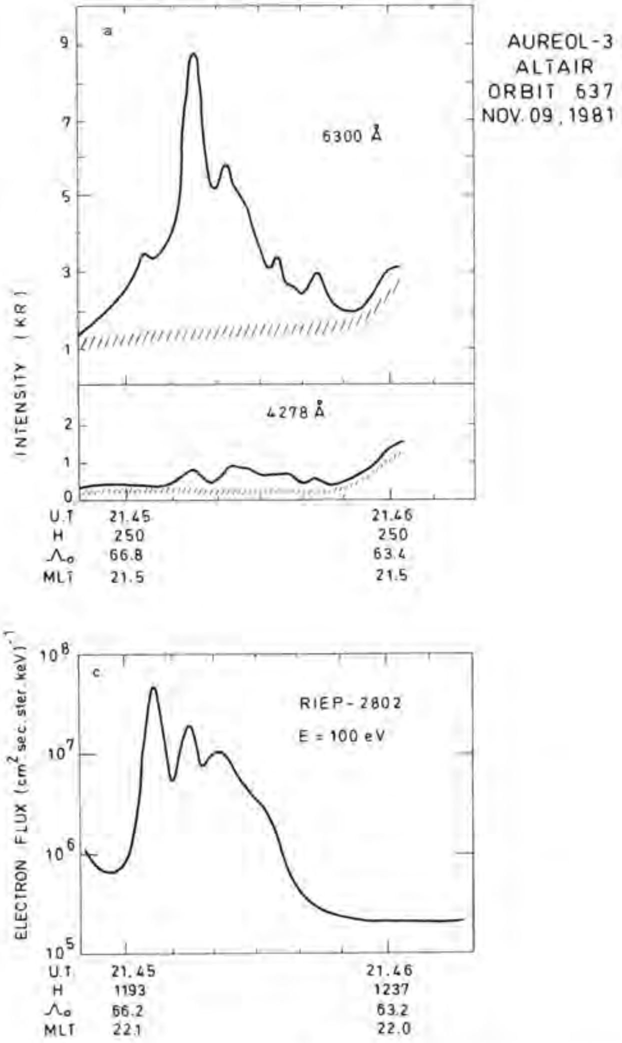

Fig. 2

Intensity profiles of 6300 Å and 4278 Å emissions along the photometer line of sight (displaced about 300 km west from the satellite trajectory) and soft electron flux (E_e = 100 eV) along the satellite's trajectory during orbit 637 on Nov. 9, 1981. An intense red auroral arc was apparently crossed at 65.9-66.0° invariant latitudes in the evening sector. An estimate of a background level for 6300 Å is shown by a hatched band, sharply rising when satellite enters the radiation belt.

The program for the ground-based automatic data processing provides calculations of the intensities of measured upper atmosphere emissions and their ratios which are useful for the identification of the emission sources. This information is presented in compact form on a microfilm. Among the photometric measurements

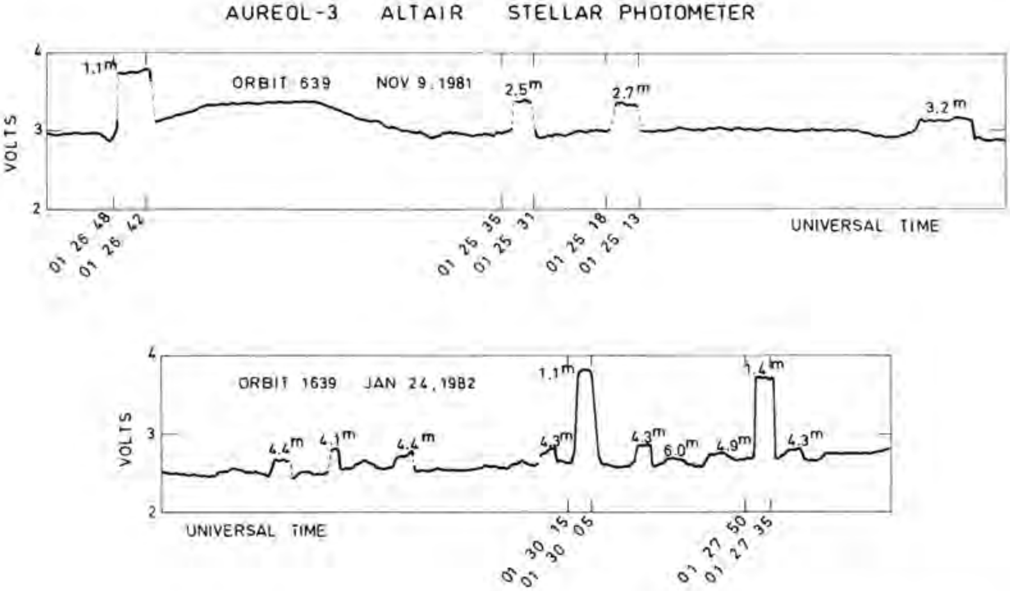

Fig. 3

Star signal from the stellar photometer during orbits 639 and 1639 (Nov. 9, 1981 and Jan. 24., 1982).

by the ALTAIR instrument there are several simultaneous sequences of inflight operations of the AUREOL-3 satellite in conjunction with the INTERCOSMOS BULGARIA-1300 satellite, which includes the EMO-5 airglow and auroral photometer (Petkov *et al*, 1982). This instrument was calibrated using the same technique as for ALTAIR and preflight intercalibration was performed between the two photometer sets. The coordinated data from these two satellites are now being processed.

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