SOLAR RESEARCH FROM SPACE

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1. Introduction

The programme of solar observations from space was initiated in the early 1960's under the original ideas of Professor J.C. Pecker. I had the privilege of carrying out the first elements of this programme at the Service d'Aéronomie du C.N.R.S. as early as 1961, and I have had the opportunity to continue working in this field since then. At that time, the American programme was already well underway. It included a large number of rocket launches per year and the first satellites of the OSO series ware ready to be launched. For a small country like France to undertake research in the same area, was of course very ambitious, and as J.C. Pecker said at that time : "The American have or will very soon do everything which is possible, so we are left with the impossible." So we did it ...!

This paper intends to describe briefly

i. what are the most important results obtained in the not too distant past ;
ii. the programme which is presently underway and finally
iii. the proposed programme for the near future.

The accent will be given to results and programmes which involve the production of hardware and we do not include herein presentations of the numerous results obtained in the framework of Guest-Investigator Programmes. References to the most important publications will be given extensively throughout the text so that the interested reader may find out more details than is possible to give herein, due to obvious editorial limitations. For the same reson, this presentation does not include either the remarkable results obtained in solar radio astronomy by J.L. Steinberg using the very elegant stereoscopic observations from the ground and a spacecraft.

2. An overview of the most important results of the past programme.

As mentioned in the introduction, solar instrumentation designed to carry out observations with the means of space techniques started to be developed in France in 1961. I was in charge of the ultra-violet part of the spectrum and P. Léna was in charge of the infra-red part. Very soon after, P. Lemaire joined our group and increased our task force. The "Impossible" covered mostly the need to reach spatial as well as spectral resolution, since most of the pioneering work had already been done. Our directions of work were therefore twofold and have developed from thereon.

a. Center-to-Limb measurements.

P. Léna and myself have been conducting these measurements in our "respective spectral region. The first measurements in the ultra-violet between 200 nm and 300 nm and the far infra-red (around 10-25 μm) were obtained and are still used now as references (Bonnet, 1968, Léna, 1969). Absolute intensity measurements were also obtained which could fix upper limit to the surface temperature of the sun and served as inputs to the Bilderberg Continuum Reference Atmosphere (B.C.A.), (Léna, 1968, Bonnet and Blamont, 1968). This work has been continued since then by J.P. Baluteau (1970) and D. Samain. Because of its importance, we describe here Samain's work in more detail now.

The technique used by Samain(Samain et al., 1975) was an extrapolation of that used by, and described in, Bonnet et al., 1967 : an image of the sun is formed on the slit of a stimatic spectrography, with the center of the disk positioned on the slit. The spectrum consists in a series of monochromatic and stigmatic images of the slit recorded on photographic film. The photometry of these images allows the measurement of the center-to-limb variation of the ultra-violet solar intensity. Samain's instrument operated between 120 and 210 nm. It was launched successfully on April 17, 1973 on board a Veronique rocket, and provided excellent absolute intensity and center-to-limb measurements. Samain's central intensities (Samain, 1979) are reported on Figure 1 and can be compared to Nishi's similar results. The agreement can be seen to be very good. Samain's data have been analyzed in terms of solar models andwere able to give the first empirical determination of the ultra-violet opacity and of the departures from Local Thermodynamic Equilibrium of Si I in the U.V. They are published in an extensive form in Samain (1980). They also allowed obtaining values of the solar U.V. irradiance which are currently used widely by aeronomists (Samain and Simon, 1976).

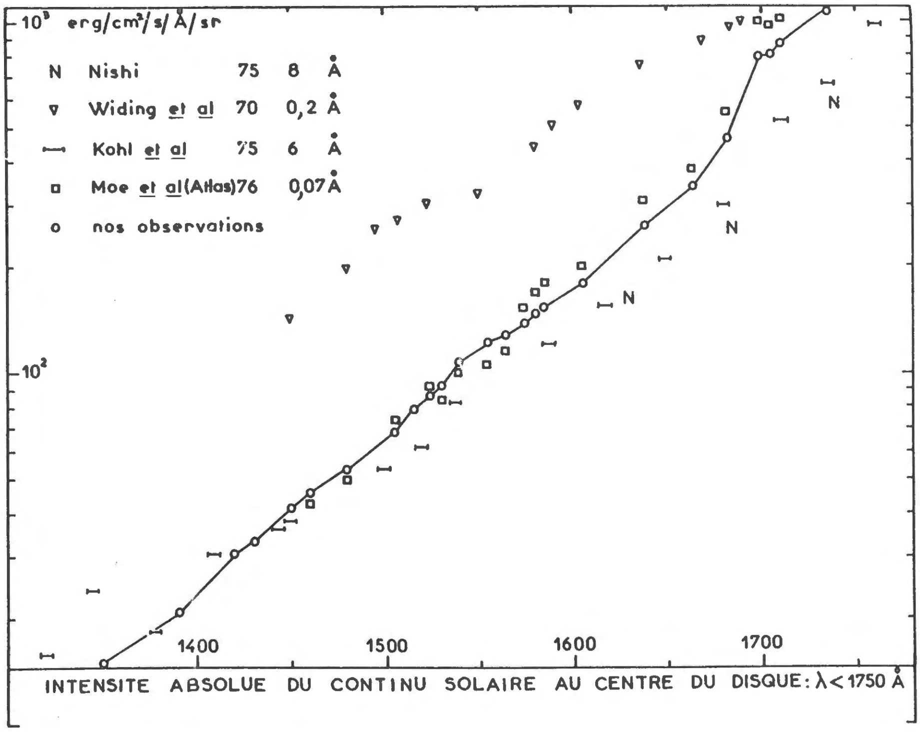

Figure 1 : The absolute spectral radiance of the sun as measured by Samain (1979) between 120 and 210 nm, and compared with other measurements.

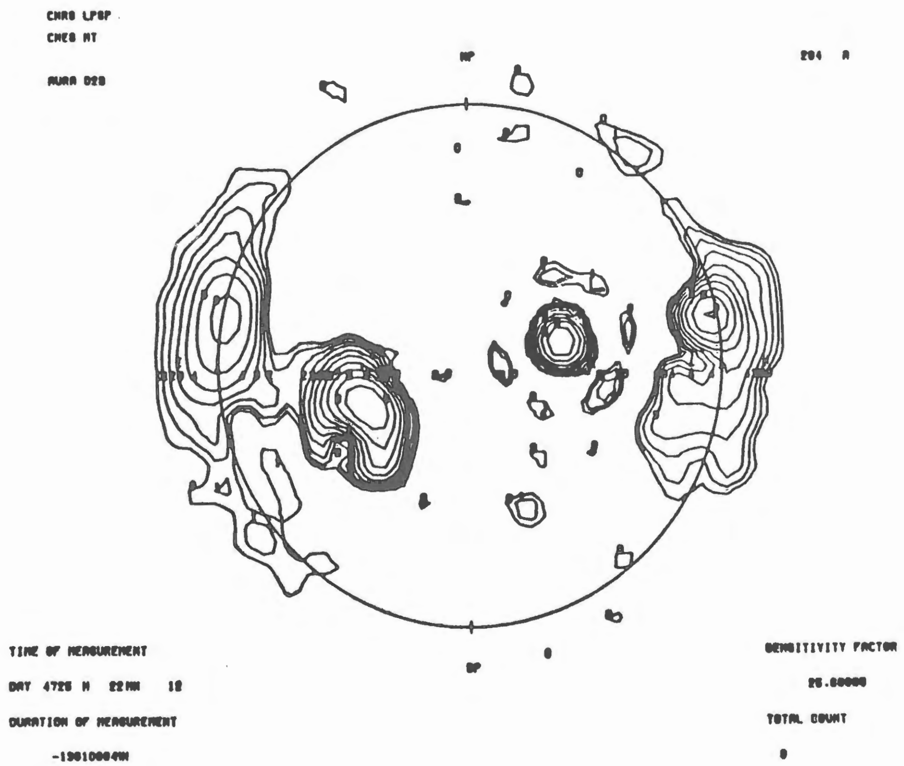

Figure 2 : Spectroheliogram of the Fe XV 28.4 nm EUV line obtained with the LPSP instrument onboard the French D2B Aura Satellite. The angular resolution of that instrument was one arc-min., good enough to show active regions on the disk and the corona at the limb.

Later on M. Hersé (1979) obtained high resolution images in the vicinity of 200 nm with a resolution below one arc-sec using a high resolution balloon borne telescope.

The French D2-B AURA satellite launched on September 21, 1975 had a solar pointing capability and carried a moderate resolution instrument (Delaboudinière, 1973) which could make solar spectra (0.2 to .3 nm)and full sun spectroheliograms (1 arc min resolution) in the region 20 to 125 nm. During the 16 months of operation of the satellite, excellent images of the sun and spectra were obtained (Figure 2), (Delaboudinière and Millier, 1977). The E.U.V. images have been published in Solar Geophysical Data for the period September 1975, December 1976. The main aim of this instrument however was to study the chemical composition of the earth atmosphere by means of extinction measurements at sunsets and sunrises using the active regions on the disk as point sources.

b. High spectral resolution observations.

Using more economic and more easy to work techniques, P. Lemaire was particularly successful in obtaining the first high resolution profiles of the Mg II h and k resonance doublet at 279.5 and 280.3 nm (Lemaire and Skumanich, 1973). Delaboudinière and Crifo (1976) obtained excellent high resolution spectra of the 58.4 nm He I line using a helium resonance cell.

Lemaire's work was a key element in our decision to propose a multichannel high resolution U.V. and visible instrument on board OSO-8. This proposal was accepted in 1970 and the French instrument received its first photons from the sun on 21 June 1975. It operated successfully for more than 3 years and was turned off by NASA in October 1978. The instrument is described in Artzner et al. (1977) and Bonnet et al. (1978). The data obtained consist in high resolution profiles of the Ca II H and K, the Mg II h and k, the H I $L\alpha$ and $L\beta$ lines, observed simultaneously with a spatial resolution as good as two arc seconds. We are still now in the process of data analysis but some important results have already been published from a set which represents no more than ≃ 20 % of the whole quantity of data.

To summarize, three areas have been exploited in more depth :

i. Modelling of active regions.
Figure 3 shows an empirical model of active region obtained by P. Lemaire (1980) through the best fit of computed $L\alpha$, H and K and h and k profiles with corresponding observed profiles. The typical observed profiles are shown on Figure 4 together with the computed ones.

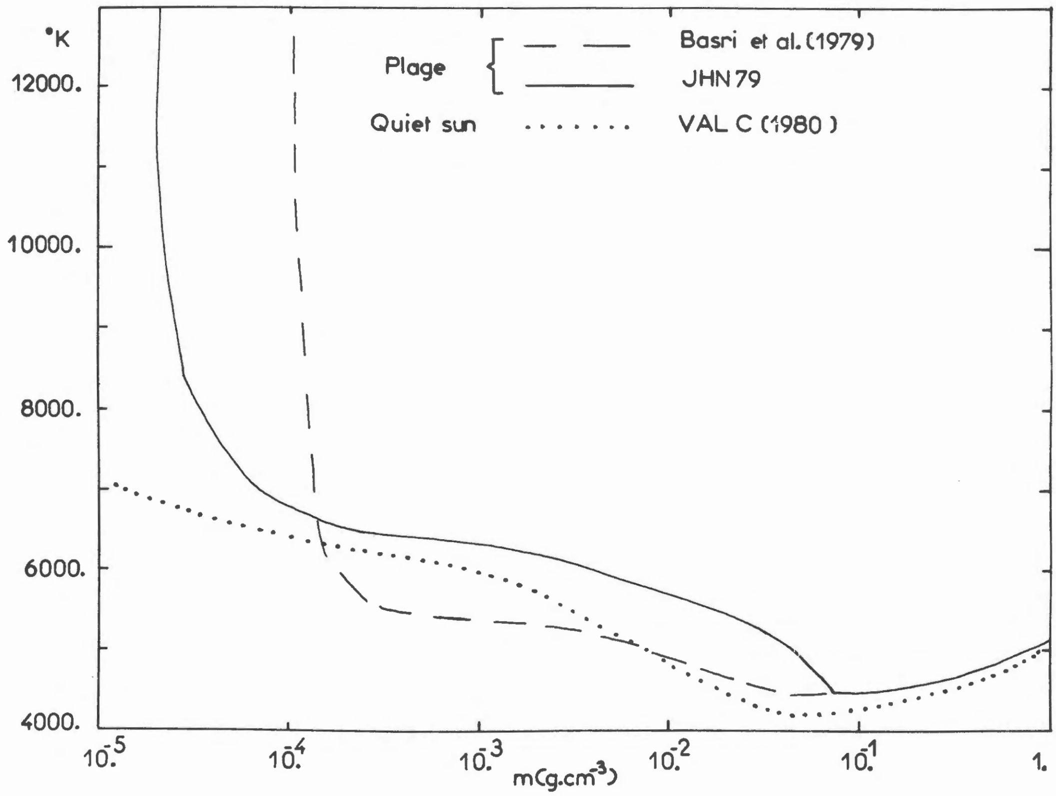

Figure 3 : Active region model JHN 79 derived by P. LEMAIRE (1980) from OSO-8 observations of the Ca II HK , Mg II h and k , Lα and Lβ lines. The model is compared with Basri's plage model and the Quiet sun model of Vernazza Avrettand Loeser.

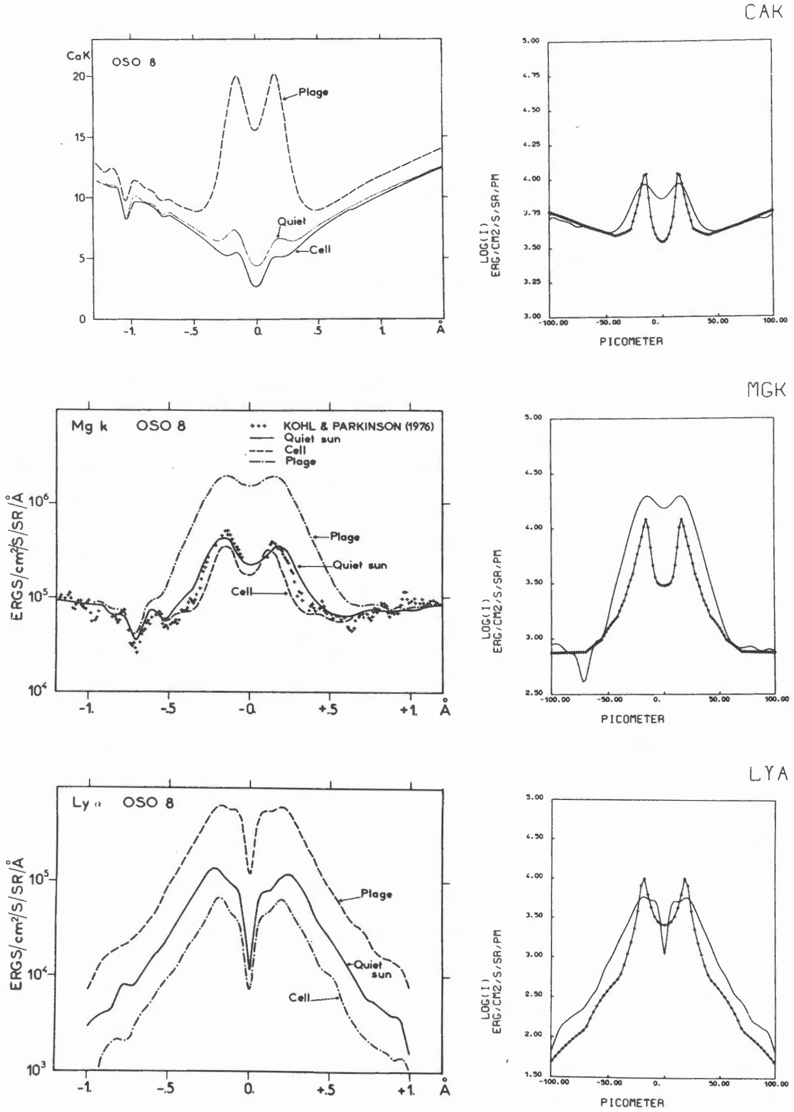

Figure 4 : Comparison between OSO-8 observed and computed Ca II, Mg II and Lα line profiles, using the model of Figure 3. Observations are on the left side, and computed profiles are represented by the dotted line on the right.

ii. Study of chromospheric oscillations.

With its high spectral resolution of 2 pm our instrument was well suited for velocity measurements. Artzner et al. (1978) were able to observe the 200 s chromospheric oscillations in the periodic deformations of the core of the Lα profile. These results compare reasonably well with the computations of Gouttebroze (1980). Any attempt to detect oscillations in the transition region lines (O VI 103.2 nm) have failed within the present limitation of 3 km/s imposed by the spectral resolution of the instrument. Figure 5 is a summary of observations of the 200 s oscillations.

iii. Observations of prominences.

Excellent data on quiet and active prominences have been obtained by Vial et al. (1979, 1980). In Lα the prominences are optically thick with an optical depth at line center of 10^5. In general, as could be expected all six line profiles show complicated time and spatial dependent structures evidencing the existence of strong movements in the prominence (Figure 6). A curious observation is that the ratio $\frac{K}{H}$ is different from $\frac{k}{h}$ in active prominences. Vial is working presently on this problem.

Numerous observations of sunspots, active regions, flares, coronal holes and the chromospheric network have been undertaken but the data analysis is not yet completed.

3. The presently approved space programme.

The decision by the Centre National d'Etudes Spatiales, the French Space Agency to terminate the national sounding rocket programme in 1974 and the national scientific programme in 1975 has had two consequences. First, the number of flight opportunities offered to French scientists has crecreased substantially, and today the national programme is limited stricto sensu to the use of balloons. Balloons however have limited capabilities and do not permit access to the far end of the ultra-violet spectrum. Subsequently we are more and more involved in bi- or multi-lateral cooperative ventures with American institutes or laboratories and also with Soviet and European groups.

a. The Transition Region Camera (T.R.C.).

One of the best illustrations of a cooperative programme is the joint rocket venture between L.P.S.P. and the Lockheed Palo Alto Research Laboratory (L.P.A.R.L.). L.P.A.R.L. kindly offered L.P.S.P. some space on their rockets. They developed a high resolution X-ray spectrometer and spectrograph. L.P.S.P. developed the T.R.C.

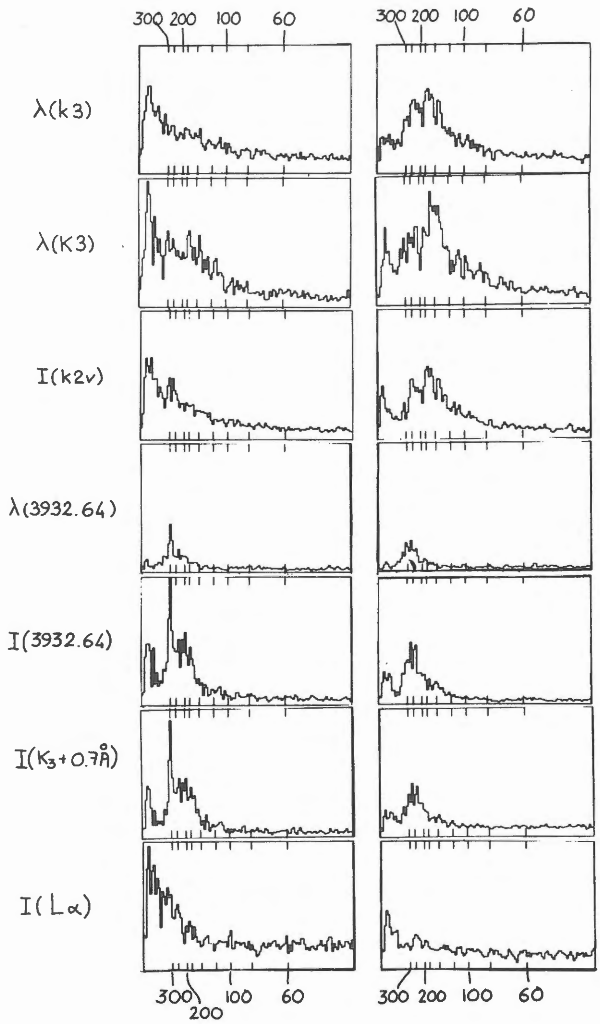

Figure 5 : Power spectra of velocity and Intensity fluctuations in the photosphere and the chromosphere as observed with the LPSP instrument onboard OSO-8 (Artzner et al. 1978). The left row corresponds to observations made in the chromospheric network ; the right row corresponds to dark cell centers. OSO-8 was the first to detect the 200 s line profile oscillation in Lα (line center). However intensity fluctuations in Lα do not evidence any specific well identified period.

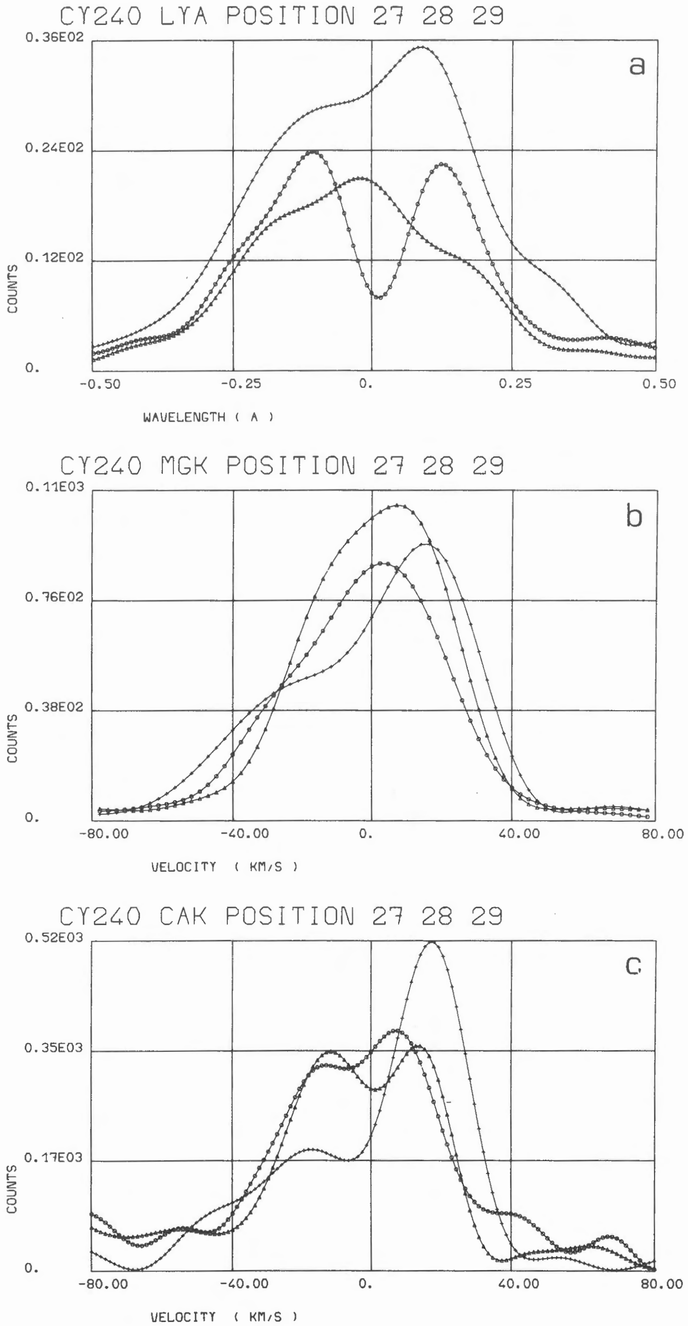

Figure 6 :

Ca II, Mg II, and L α profiles as observed with the LPSP instrument onboard OSO-8 by Vial et al (1979) at various positions across an active prominence.

which consists in a 10 cm Cassegrain telescope, a series of filters and a film camera. This instrument has been launched twice on July 3, 1979 and September 23, 1980. These two flights provided excellent high resolution images in Lyman alpha and at 160 nm. The results of the first launch have been published in Bonnet et al. (1980). They strongly evidence the presence of small scale loops in the chromosphere and the corona. Bonnet and Tsiropoula (1980) have shown that some of these loops are cold (50 000 to 150 000°K), through the absorption of the disk Lα emission by neutral hydrogen. The results obtained during the second launch concern the temperature minimum. As shown on Figure 7 they reveal the fine structure of the network and the numerous bright points already seen in CN and K_2v but with a substantially higher contrast (at 160 nm a 10 % increase in intensity corresponds to $\Delta T = 20°K$).

This programme is intended to continue and another launch of the T.R.C. is scheduled for the summer of 1981.

b. The balloon RASOLBA project.

Following a very successful first generation of balloon spectroscopy by Lemaire and Samain (Lemaire, 1970, Samain, 1971), the L.P.S.P. has defined a second generation instrument aimed at the spectroscopy of the sun between 190 and 300 nm with sub-arc second angular resolution. The characteristics of the instrument are described in Table I.

TABLE I : Main characteristics of the RASOLBA project

Telescope	Cassegrainian, 40 cm diameter Spatial resolution, 0,5 arc sec Inflight focusing.
Slit jaw camera	Hα images displayed in real time for target acquisition.
Spectrograph	λλ : 190-300 nm Spectral resolution, 1.5 pm Detector, photographic film.
Inflight calibration	

The instrument is in its final stage of fabrication and integration proceeds on the telescope and at the sub-assembly level. The first launch is scheduled for October 1981 from the French launching range in South-Western France. Figure 8

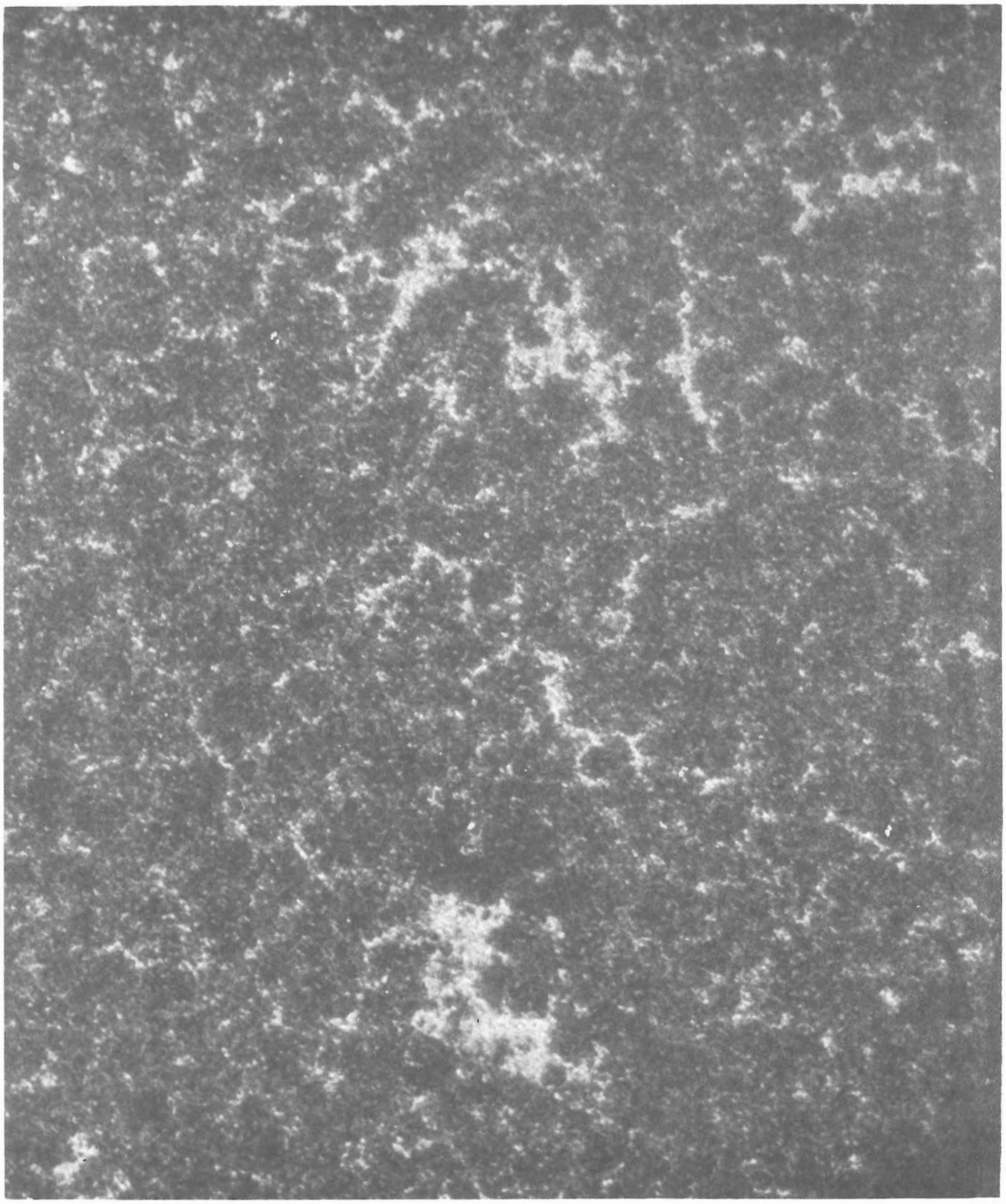

Figure 7 : Detail of a high resolution solar image obtained during the second flight on 23 Sept. 80 of the Transition Region Camera (TRC), (Bonnet et al, 1980) at 160 $\pm$ 10 nm. The 160 nm photons originate at the temperature minimum level. On this picture one easily recognizes the highly contrasted chromosphere network and numerous bright dots inside the chromospheric cells.

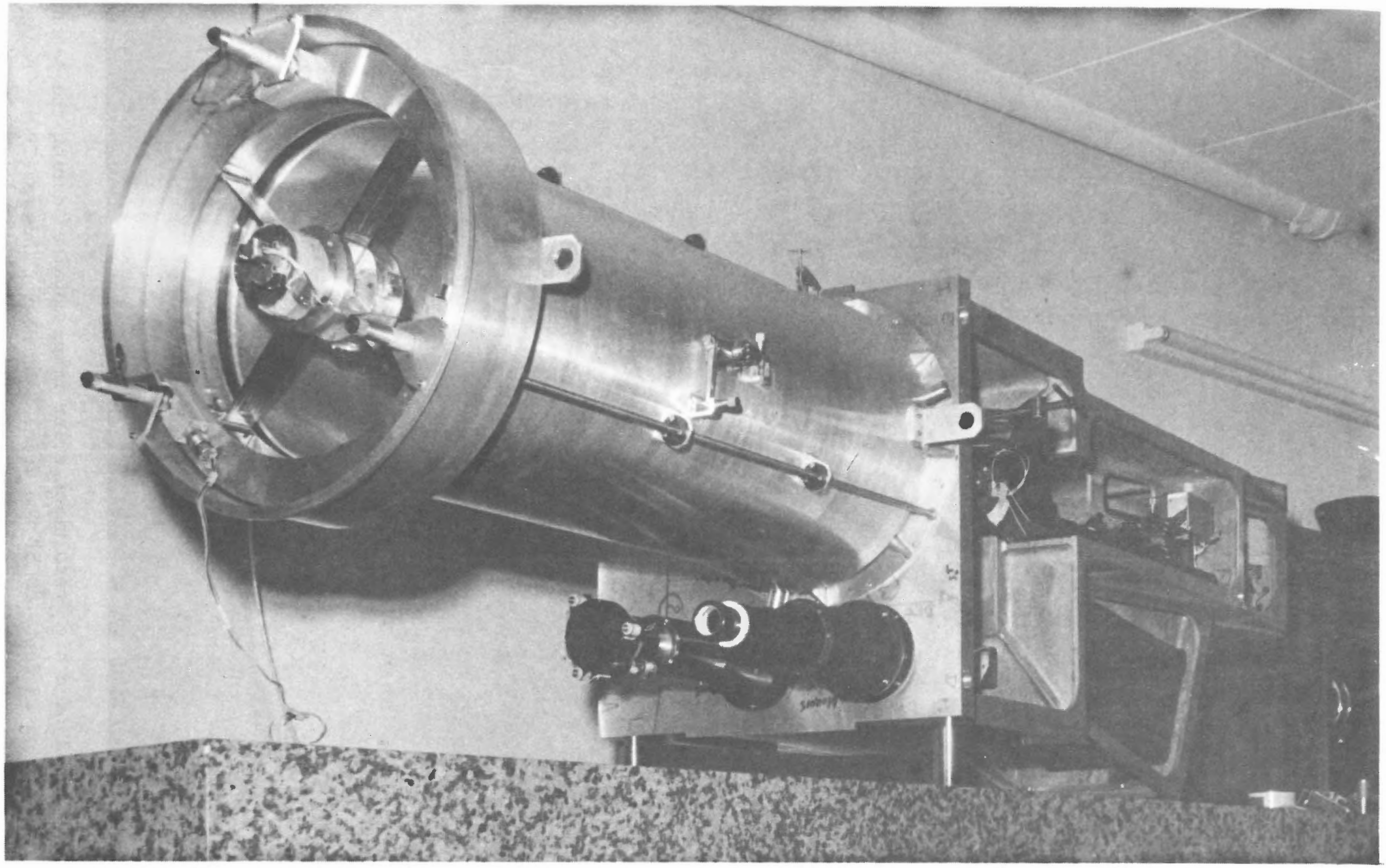

Figure 8 : The main structure and telescope of the balloon RASOLBA project, on the optical bench during mechanical integration. One also the sun sensors and the automatic inflight focussing system on the front face of the main structure. The diameter of the telescope is 40 cm.

represents the telescope and the main position of the spectrometer in the process of mechanical integration.

c. The SCALP project

The Solar Calibration Package (SCALP) is intended to make full sun spectra between 18 and 180 nm, mostly for aeronomy purposes, but it is also well suited to variability studies.

The principle of the instrument is shown in Figure 9. Two identical grazing incidence holographic grating mono chromators cover the ranges from 15 to 62.5 nm and 30 to 180 nm respectively (only one is represented in the figure). The spectrum is analyzed through rotation of the gratings, by a channeltron detector.

The field of view of the instrument is 3° by 1°. Successive diffraction orders are separated by means of broad band thin film filters.

Table II indicates the main characteristics of the two channels :

Channel	Wavelength range (nm)	Grating constant (grooves per nm)	Band pass (FWHM in nm)	Elementary grating step (nm)
A	15-62.5	1100	0.15	0.1
B	30-180	550	0.3	0.2

A rare gas ionization chamber is used in flight for the detection of possible drifts in the sensitivity of the monochromators. The same filters which serve to separate orders in the monochromators are used to define, in conjunction with the appropriate rare gas, narrow sensitivity bands.

In flight calibration will insure that the best photometric accuracy is achieved. We aim at 5 to 1 %. More descriptive details are given in Delaboudinière et al (1976).

SCALP has been proposed to the European Space Agency (ESA) to fly on one of their Spacelab flights. Unfortunately European Spacelab payloads have not been approved yet and have not consequently been assigned a Spacelab flight number. This is the reason why the SCALP instrument is also under negociation between CNES and InterKosmos (the Soviet International Space Organization) to fly on one of their satellites. If approved, the project will be a cooperative venture between LPSP and the Crimea Astrophysical Observatory, and will be rebaptized "OGIS".

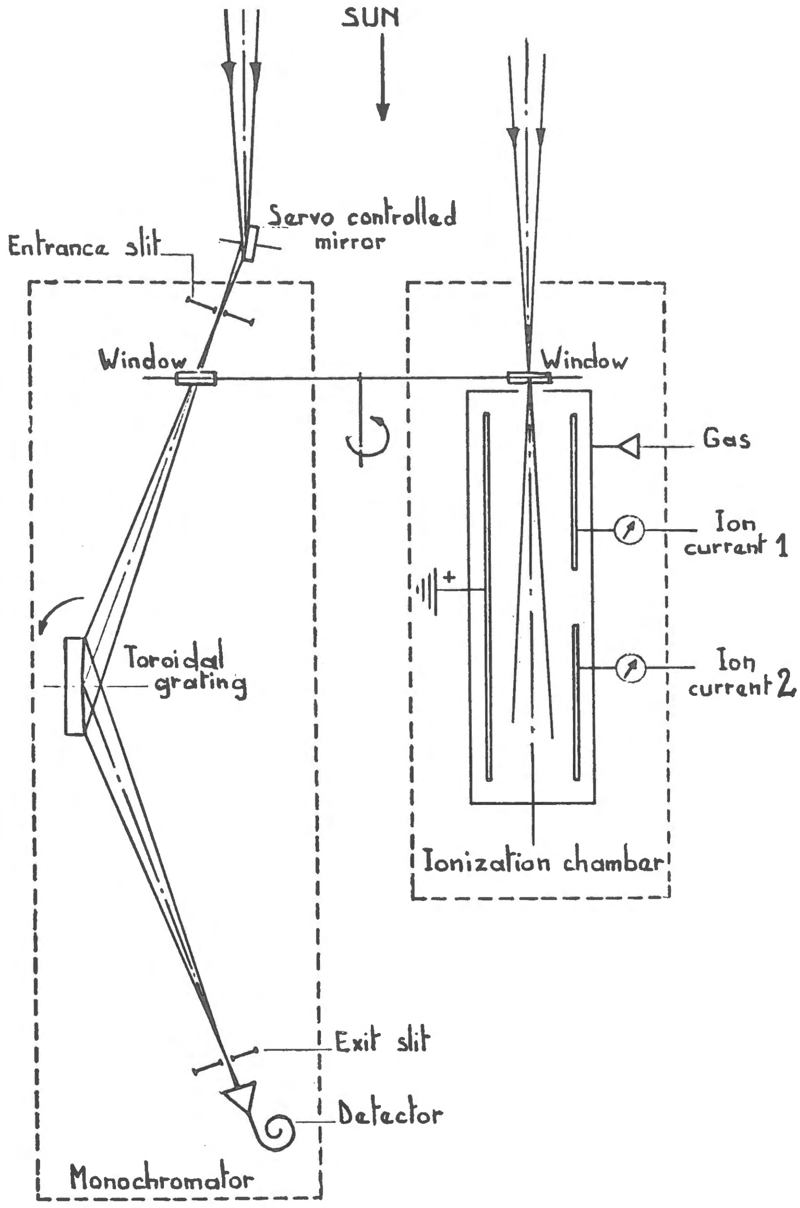

Figure 9 : Schematic diagram of the SCALP instrument (Delaboudinière et al 1976) showing one of the two grazing incidence monochromator and the absolute calibration detector on the right. Each absorbed photon in the ionization chamber produces an electron-ion pair which is collected by two electrodes. Departures from the one to one correspondance between the number of absorbed photons and collected ions are small. The second electrode allows to evaluate which proportion of the incoming flux is absorbed in the first portion of the chamber.

d. The International Solar Polar Mission (ISPM) :

Several French institutes are involved in major investigations of the interplanetary medium on the ISPM, a joint mission between ESA and NASA. The observatoire de Meudon is in charge of fabricating the external occulting disk of the coronagraph on ISPM, an instrument which is built under the responsibility of the High Altitude Observatory.

3. The future programme

The future programme will focus on the availability of the Solar Optical Telescope (SOT) already under development by NASA in the United States. The SOT is a 1.25 m solar telescope, supposed to be diffraction limited at 5000 A, ensuring a resolution of 0.1 arc second (70 km equivalent at the surface of the sun). Various baseline focal plane instruments have been identified such as a visible spectrograph, a magnetograph, a universal filter and an ultra-violet spectrograph. Under the initiative and responsibility of LPSP, two proposals have been submitted to NASA in July 1980, in cooperation with various French, European and American institutes. The selection of these investigations is likely to be announced in mid 1981. We briefly describe here these two proposals.

a. The Ultra-violet spectrograph (UVS).

The UVS provides simultaneously high spatial, spectral and temporal resolution It is made of three main parts :

i. a first spectrograph (1) using a planowadsworth mount and a film camera

ii. a high resolution spectrograph (2A) with an electronographic camera as detector ;

iii. a high resolution spectrograph (2B) with a detector combining the use of a microchannel plate and a CCD for detector.

The characteristics of the three parts are detailed in Table III.

Table III

Spectrograph	1	2A	2B
Spatial resolution (arc-sec)	0.1	0.1	0.3
Spectral resolution (pm)	4.5	1.8	4
Spectral range (nm)	117.5-200	117.5-200	117.5-300
Simultaneous Spectral Coverage (nm).	82.5	3	1

Besides LPSP, the Naval Research Laboratory and the Goddard Space Flight Center in the USA will take important responsibilities in hardware fabrication and data analysis, together with numerous other US institutes or individuals. In France the Observatoire de Meudon have had major involvement in the proposal.

b. The Ultra-violet Imaging System (UVIS).

The excellent results obtained with the TRC (see paragraph II above) have been at the origin of this proposal. The UVIS intends to take high resolution pictures of the largest field of view available at the SOT focus (i.e. 3 x 3 $arcmin^2$), at 6 wavelengths from the near to the far UV, in order to explore the sun from the top of the convective zone (400 nm), up to the middle of the transition region (CIV 154.8 nm) through the temperature minimum and the chromosphere (Mg II 279.5 nm, Lα 121.6 nm).

UVIS is a simple instrument which includes a capability for changing the focal ratio from f/12.5 to f/150. In the latter mode, UVIS should achieve the diffraction limit of the telescope (i.e. 16 km at Lα) using interferometry techniques to overcome the degraded resolution inherent to UV observations. The detection will make use of both a CCD and photographic film .

The Lockheed Palo Alto Research Laboratory and the Center for Astrophysics in the US are the main co-investigators on this proposal. In France, the Institut d'Astrophysique de Paris, the Observatoire du Pic du Midi and the Faculté des Sciences and the Observatoire de Nice have taken part in the proposal.

c. The Grazing Incedence Solar Telescope (GRIST).

The GRIST is not yet an approved project. It is under phase A study at ESA and is supposed to fly together with SOT in one common spacelab flight. The LPSP and the Observatoire de Meudon might be involved in the fabrication of focal plane instrumentation. A decision to include GRIST in ESA's scientific programme will be taken in mid 1982.

d. The South Pole Balloon

The extraordinarily excellent results by Fossat (1980) which he obtained from the South Pole during the austral summer 1979-1980 are still strongly affected by the presence of atmospheric perturbations.
This is why CNES is presently studying the possibility of making this experiment again, from a tethered balloon anchored at the south pole. The result of this study will probably be known in 1981 or 1982 and a decision to go ahead with or to abandon the idea will be taken soon after.

4. Conclusion

As it can be seen from the above description, Solar Physics from space is still a lively activity in France. It is encouraging to observe that more and more institutes and individuals do participate in this programme either as hardware manufacturers or a guest investigators at the level of operations and data analysis.

We wish that the excellent relationships that we entertain with our japanese Colleagues meterialize some day in the future and that several projects will be undertaken in cooperation between France and Japan. The high level of the experiments which are under developement in both countries provides, in addition, the assurance that the highest scientific quality could be reached.

We hope that the present state will not last for ever.

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