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AN INSTRUMENT TO MEASURE THE SOLAR SPECTRUM
FROM 170 TO 3200 NM ON BOARD SPACELAB*

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ABSTRACT

This instrument, at the present time in development, will fly on board Spacelab I in May 1983. Other flights are foreseen during the following missions.

The instrument is composed of three double monochromators covering the range 170 to 3200 nm. The spectrometers have bandpasses of 1 nm up to 900 nm and 20 nm from 850 to 3200 nm with an accuracy 10^{-2} nm. Calibration lamps are included in the instrument to monitor any change of its sensitivity and wavelength scale.

I. INTRODUCTION

The Earth has experienced several climatic changes. Those changes have been observed to have different amplitudes and time scales.

The causes of climatic changes are not as clearly identified as the different processes (thermodynamic, absorption of solar photon...) which act on a complex system composed of the solid Earth, Ocean, and Atmosphere.

It appears that for such a system, the Sun represents the most important external source of energy. Consequently, whatever the feedback processes existing in the Earth-atmosphere system are, a modification of the Sun input should lead to climate changes with a time delay that models could predict.

Some evidences of variation of the sun irradiance have been obtained, mainly at wavelength shorter than 200 nm and recently on the solar constant.

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Then as several processes are wavelength dependent (photodissociation, ...), the scientific aims of the investigation are:

- a. the measurement of the absolute solar spectral irradiance in the wavelength interval 180-3200 nm.

The requested accuracy in general admitted for such measurement is 5% around 200 nm and 1% in the visible and IR ranges.

- b. the measurement of possible long-term variation of the solar spectral irradiances.

In this case, the requested precision is 0.3% in the visible and IR, and 1% in the UV.

Then, the proposed measurements are important in the three following fields:

1. Aeronomy of the middle atmosphere mainly concerned with the solar flux up to 400 nm,
2. Climatology concerned with the wavelength range above 400 nm necessary to establish the radiative budget of the atmosphere,
3. Solar Physics concerned with the full solar spectrum.

The requested accuracy and precision imply that the measurements are not achievable from the ground. Consequently, the measurement must be performed from space.

The vehicle chosen from this investigation is Spacelab launched by the Shuttle on account of:

- the mission is short and limits the time in which the instrument is exposed to space environment, which has always a degrading action,
- periodic missions being foreseen permit study of sun variation,
- the duration of the Shuttle program is compatible with a study conducted along a solar cycle,
- the return of the instrument permits a recalibration after flight which is quite necessary to reach the accuracy and precision needed by the investigation.

II. THE INSTRUMENT

It includes:

- 3 spectrometers
- 3 detectors

- Electronics
- 5 in-flight calibration lamps.

A schematic is given in Figure 1.

2.1 Spectrometers

The instrument includes three double monochromators of 10 cm focal length using concave holographic gratings. Their characteristics are:

- the six gratings are mounted on the same mechanical shaft rotating with a screw and nut system, giving a precision of 2 arc-second at any position. The spectral precision is 10^{-2} nm.
- the UV monochromator range of measurement overlaps with the one of the visible monochromator. Same as for visible and IR monochromators.
- transmitting diffusers (grinds) are placed in front of the three spectrometers.
- filter wheels are placed at the exit slits to remove the second order signal.
- wavelength range and spectral data:

Monochromators	Range	Band-pass	Lines/mm
UV	160 - 365 nm	1 nm	3600
VIS	277 - 889 nm	1 nm	1281
IR	805 - 3160 nm	20 nm	354

The principle of one spectrometer is given in Figure 2. A complete solar spectrum from 170 to 3200 nm is recorded in 15 minutes.

2.2 Detectors

- UV: photomultiplier tube (EMR 641E)
- VIS: photomultiplier tube (EMR 641E) cooled at +5°C
- IR: PbS cell cooled at -10°C with a Chopper working at 512 Hz.

2.3 In-flight Calibration Lamps

The used detectors are not absolute detectors. Hence, the instrument has to be calibrated. But its sensitivity has to remain unchanged all along the ground operations before flight (which may be 1 or 2 years long for the first) and during the flight. Then, rather than maintain all the instrument stable in the above situations (which is difficult to achieve), it is easier to maintain stable a calibration lamp, the distance filament to slit and the lamp power supply. This philosophy has been adopted for this instrument.

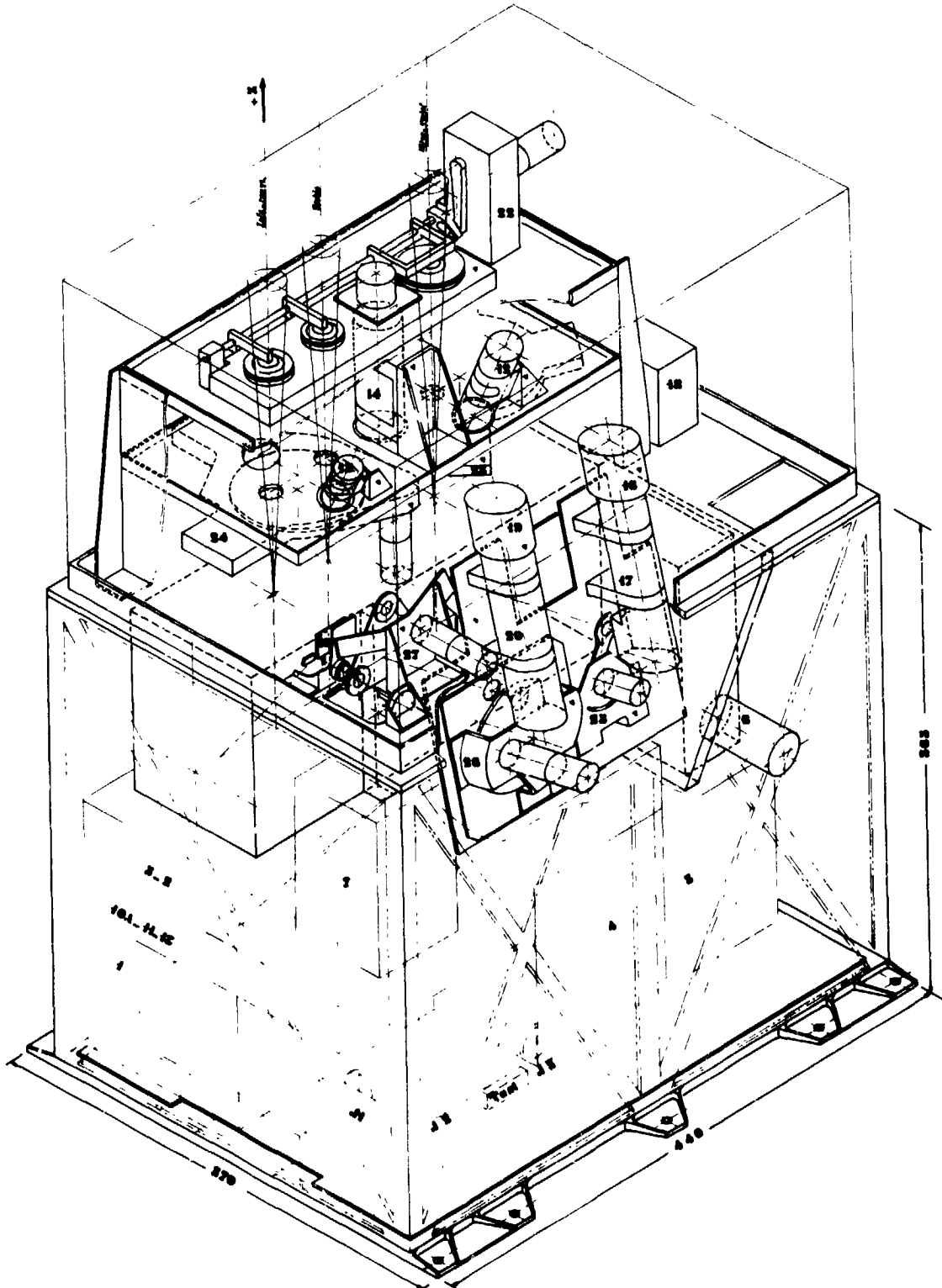


Figure 1. Schematic of the complete instrument

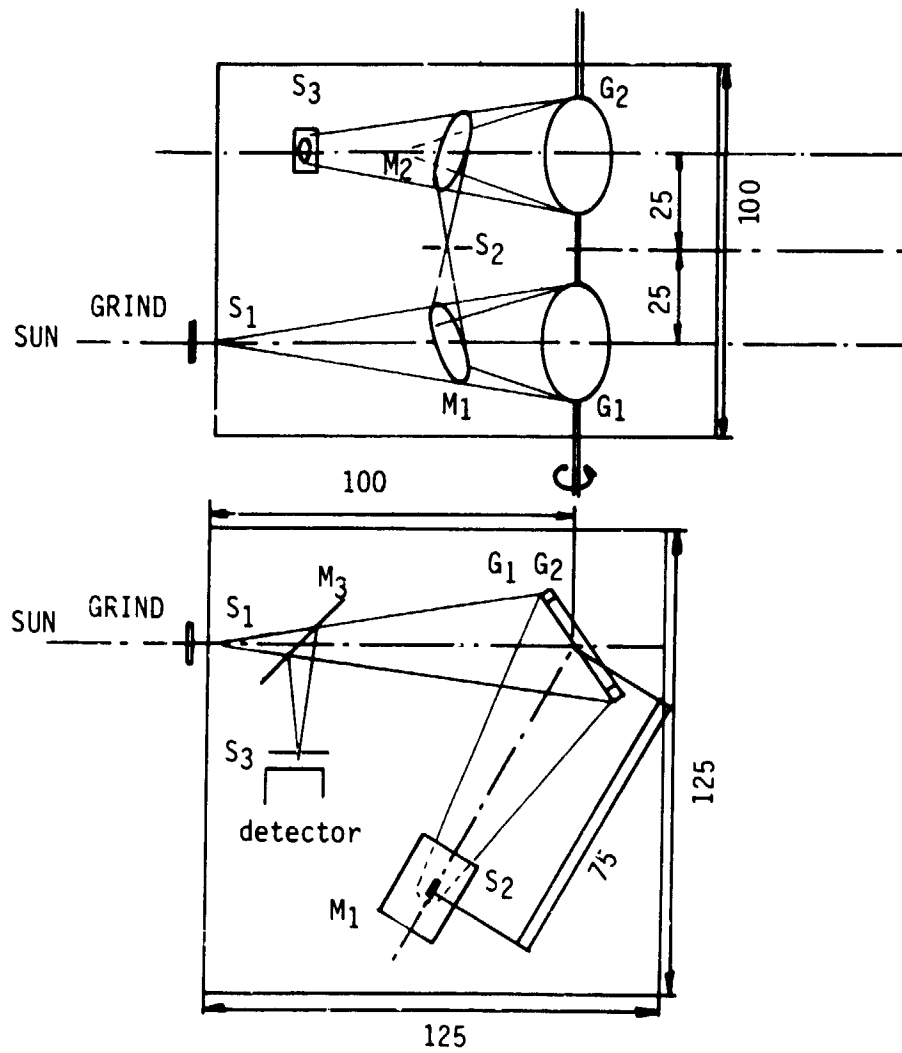


Figure 2. Schematic of one double monochromator. Three same units are mounted on the same mechanical shaft.

The following set of lamps is included in the instrument:

Lamp type	Spectrometer	Purpose	Power	Number
Tungsten ribbon	VIS and IR	Instrument sensitivity	5 W	2
Deuterium	UV		15 W	2
Hollow cathode (filled with He)	UV and VIS	Wavelength scale and band-pass	2 W	1

and has the general characteristics:

- the radiating region (ribbon and anode) is imaged by lenses on the input grinds limited by preslits,
- the diameter and magnification of the lenses are chosen so that the signal due to the lamps is of the order of the one due to the Sun,
- lamps and lenses are mechanically stable with respect to the entrance slits,
- the lamp currents are regulated at 10^{-4} to provide 0.1% stability,
- the lamp currents, voltage and temperature are telemetered,
- other characteristics are given in Ref. 1.

Consequently, we measure in space and at ground all possible change of the instrument sensitivity. The wavelength scale and bandpasses are also determined by use of selected lines emitted by the hollow cathode lamp. In this mode the rotation of the grating is performed by elementary step of 15 arc-second corresponding to 10^{-1} nm.

III. CALIBRATION OF THE INSTRUMENT

3.1 Absolute Calibration

The black body of the Landessternwarte Laboratory is used (3000 K). A linear pyrometer monitors the temperature. This device uses a set of interferential filters and a silicon cell which are temperature stabilized (0.1°C).

The accuracy of the calibration is estimated to be:

$\lambda < 250 \text{ nm}$	5%
$250 < \lambda < 300 \text{ nm}$	3%
$300 < \lambda < 400 \text{ nm}$	2%
$\lambda < 400 \text{ nm}$	1%

3.2 Wavelength Calibration

Its purpose is the measurement of the instrument bandpasses and the calibration of the wavelength scale.

Hollow cathode lamps filled with Argon or Neon are used. Other elements such as N_1 , S_e , R_u , H_g , C_e , S_n , A_s , B_a , T_e , S_i , B_i , C_d permit covering the range from 170 to 3200 nm.

A tunable laser is also used.

3.3 Long Term Standard (LTS)

The scientific aim (b) needs a stable reference during some years, typically a half solar cycle. This requirement can be achieved by use of lamps since they have the needed stability.

The LTS consists of:

10 Tungsten ribbon lamps (W17G from Osram) for $\lambda > 250 \text{ nm}$ and 10 Deuterium lamps (D60 from Hanau) for $\lambda < 250 \text{ nm}$. Five of each are carefully kept in laboratory while the remaining set are on special equipment named LTS box, able to follow the instrument at different sites for integration, preparation to launch and after mission. The LTS box can be placed on the top of the main instrument (Figure 3).

The precision of the LTS is:

1. 0.2% for 100 hours burning time with alternate DC power supply for tungsten lamps as it appears from measurements from 1960's in the Landessternwarte laboratory of Heidelberg.
2. 3% for 100 hours burning time with deuterium lamps (Ref. 2).

But, any change in their irradiance can be monitored by comparison with the tungsten ribbon lamp in the range 280-350 nm.

The set kept in laboratory will not be used more than 10 hours per year.

The sequencing of calibration and LTS use is given in Figure 4, where it appears that the LTS box will be calibrated against the black body using the space instrument itself.

ORIGINAL PAGE
BLACK AND WHITE PHOTOGRAPH

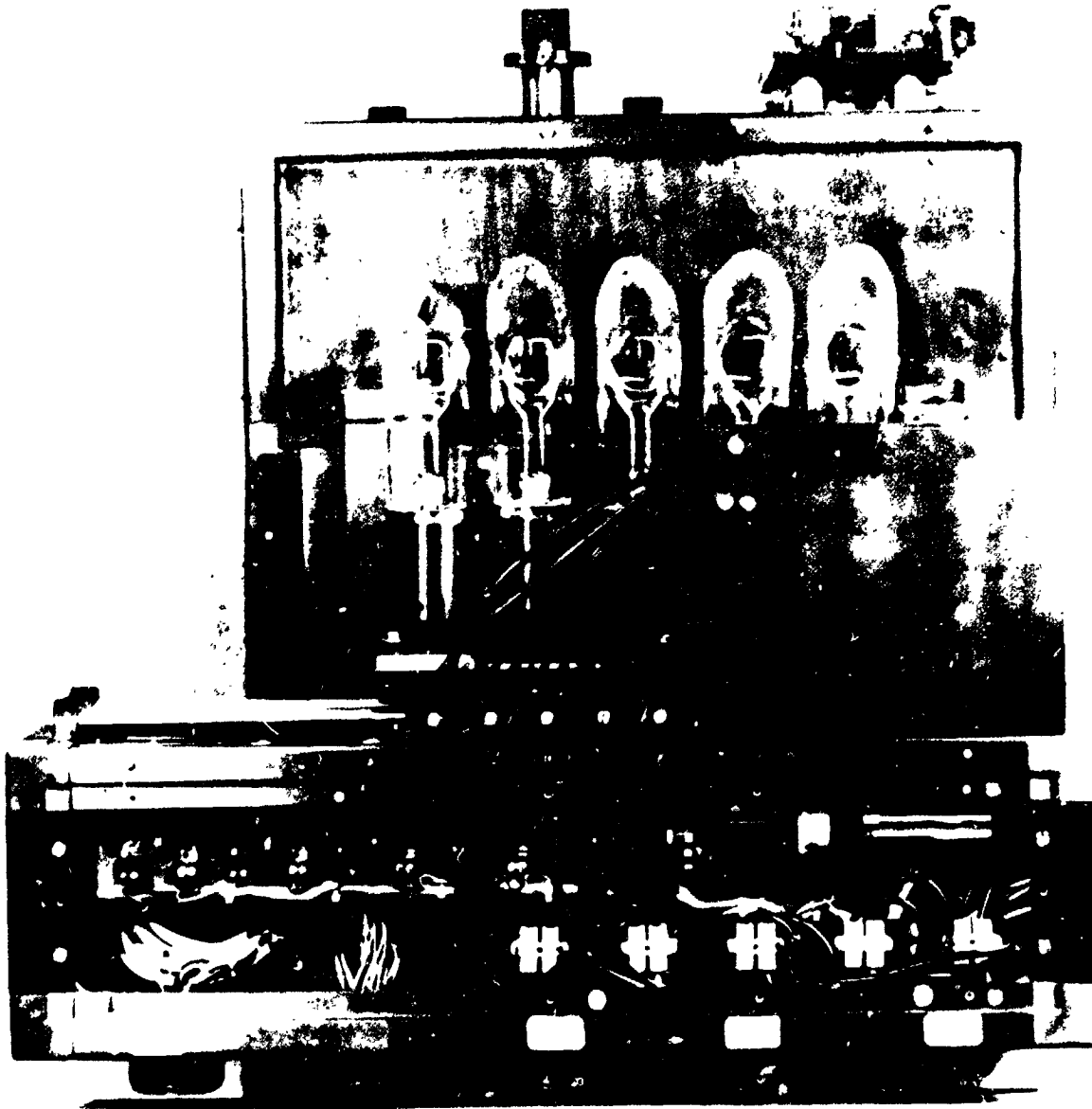


Figure 3. Long Term Standard box showing the five deuterium and five tungsten ribbon lamps. The lamps can be moved to light the three entrance slits of the monochromators.

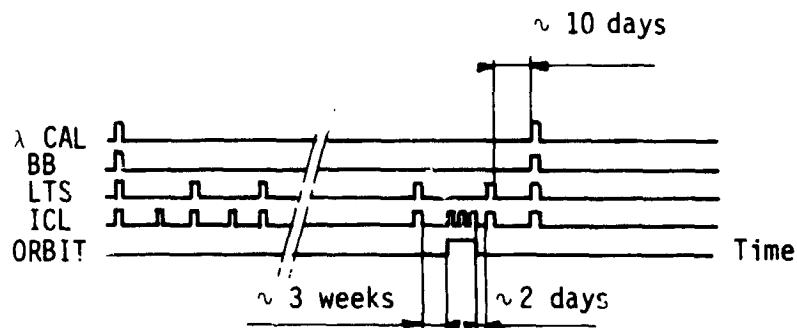


Figure 4. Sequence of calibration and use of LTS box
 λ Cal: Bandpass and wavelength calibration
 BB: Black body calibration
 LTS: Long Term Standard
 ICL: Use of In-flight Calibration Lamps.

3.4 Comparisons

Comparisons before flight with the two absolute radiometers also on-board Spacelab I is foreseen.

Other comparisons with calibrated sources such as the ones existing at the National Bureau of Standards are desired.

3.5 Accuracy and Precision

Accuracy has been given in Section 3.1.

The final precision of the instrument is estimated to be 0.3% taking into account the counting rate, the stability of the in-flight calibration and LTS lamps.

REFERENCES

1. Finkenzeller, U., and Labs, D.: The deuterium lamp as a UV continuum source from 180 nm - 320 nm for space application, *Appl. Optics*, 18, 3938, 1979.
2. Bridges, J. M., Ott, W. R., Pitz, E., Schulz, A., Einfeld, E., and Stuck, D.: Spectral radiance calibration between 165 and 300 nm; an interlaboratory comparison, *Appl. Optics*, 16, 1788, 1977.