HIGH RESOLUTION BALLOON-BORNE SPECTROGRAPH FOR THE NEAR SOLAR ULTRAVIOLET

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Abstract. In order to obtain the solar spectrum of the MgII lines at 2795.5 Å and 2802.7 Å, we built a balloon instrument which consisted of a Cassegrain telescope, with an aperture ratio of $F/20$ and a focal length of 300 cm to give a solar image on the slit of a spectrograph. The theoretical spectral resolution is better than 10 mÅ. In the laboratory, we measured a spatial resolution of 10 μ in the image plane of the spectrograph, which corresponds to 1 arc sec in this mounting. During a balloon flight of 1969, April 30, which used a biaxial pointing system, we obtained a spatial resolution better than 10 arc sec, limited by the accuracy of the pointing system. Lastly, on 1970 June 24, the same instrument with a servosystem inside the telescope, was launched and spectral and spatial resolutions of 25 mÅ and about 3 arc sec, respectively, were obtained.

1. Introduction

Solar spectra with high resolution from rockets were obtained successively by Kachalov and Yakovleva (1962) and Purcell *et al.* (1963) with spectral resolutions of 0.15 Å and 0.03 Å respectively.

These two flights showed the self reversed lines of the ionized magnesium doublet at 2795.5 Å and 2802 Å (K and H MgII lines). This doublet is of great interest to astrophysicists since it can be used to study the solar chromosphere.

A first spectrograph, after an unsuccessful launch which showed the difficulty of obtaining the MgII lines at 33 km, was launched successfully 1967 June 23, using a balloon biaxial solar pointing system developed in the Service d'Aéronomie (Lemaire and Blamont, 1967). This instrumentation could not be used again because of the failure of the recovery parachute.

Soon after, the construction of a new spectrograph was undertaken. The description of this new instrumentation which was launched successfully in 1968, September 22 (Lemaire, 1969a), 1969, April 30 (Lemaire, 1969b) 1969, November 21 and 1970, June 24, is the goal of this paper.

2. Atmospheric Conditions in Balloon Experiments in the near Ultra-Violet

Two external factors must be considered in this experiment:

- temperature environment;
- atmospheric ozone.

(a) The variation of the temperature at altitudes below 40 km is known to a good approximation. The temperature decreases from the ground to −55°C at 10 km; it is constant between 10 and 30 km; then, during the day, it increases slowly to −15°C (*U.S. standard atmosphere*, 1966) at 40 km. During the ascent and after the ceiling of the balloon has been reached, the sun heats instrumentation and introduces a gradient

Labuhn and Lüst (eds.), New Techniques in Space Astronomy, 263–270.

of temperature from the front to the rear of the instrumentation. In order to maintain the optical quality of the instrumentation, it is necessary to have temperature regulation. Our instrumentation is thermostated at 25 °C during both ground tests and flight.

(b) The formation of atmospheric ozone is due to the dissociation of molecular oxygene by the solar ultra-violet radiation (Hunt, 1965). The quantity of ozone between the instrumentation and the sun at the same height of the balloon ceiling varies with the hour of the day, the season, and the geographical location. (Hunt, 1965; *Handbook of Geophysics and Space Environments*, 1965).

By using the absorption coefficients of ozone given by Vigroux (1953) we show in Figure 1 the transmission of the atmosphere obtained from several launchings. The rapid increase in atmospheric transmission with increasing wavelength around 2800 Å causes an increase in stray light of longer wavelengths. This stray light must be significantly reduced to obtain good spectra during a balloon flight.

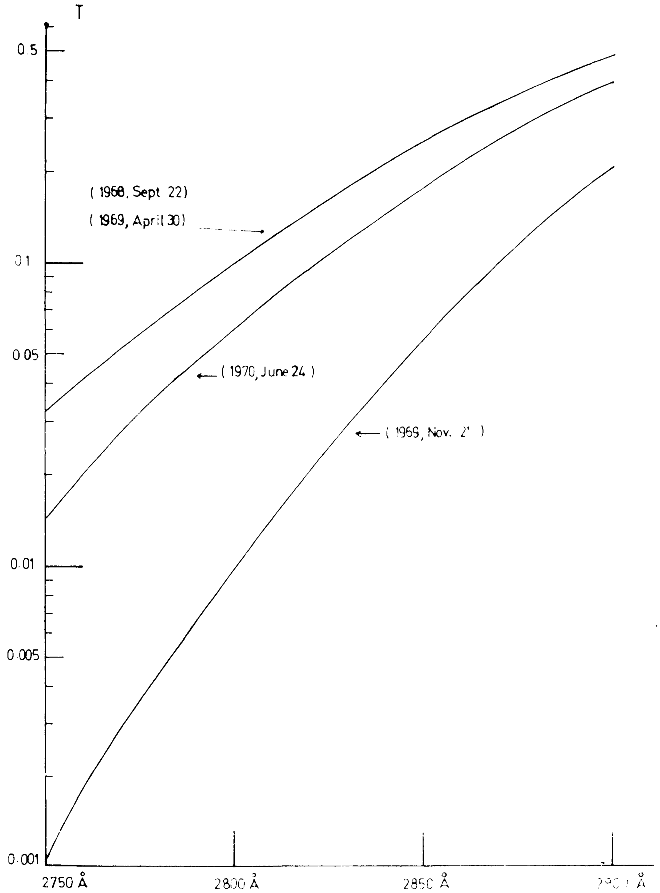

Fig. 1. Atmospheric transmission obtained from several launchings.

3. Instrumentation

The instrumentation and the optical schematic are shown in Figures 2 and 3.

A. TELESCOPE

A Cassegrain telescope is used to image the Sun on the slit of the spectrograph. The diameter of the primary mirror is 15 cm and the equivalent focal length of the telescope is 3 m. The intrinsic spatial resolution at 2800 Å is better than 1 arc sec.

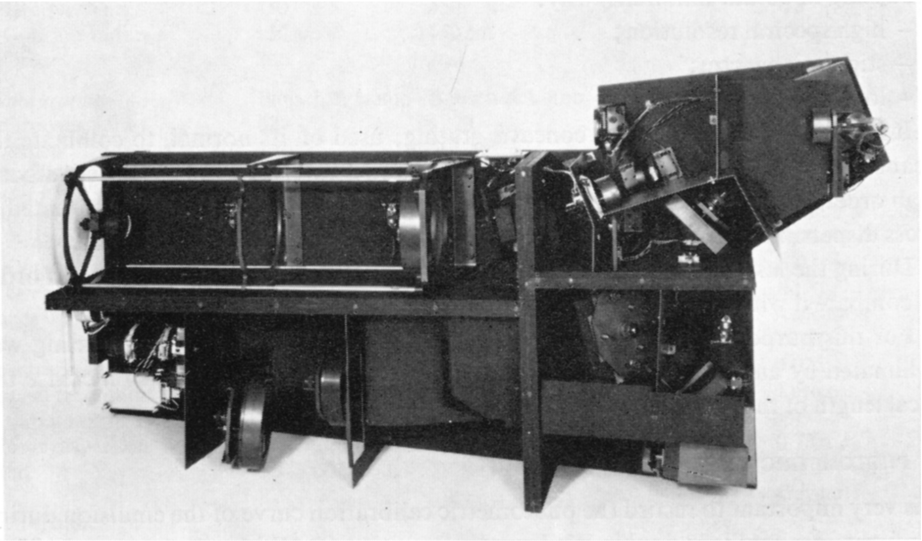

Fig. 2. Optical assembly.

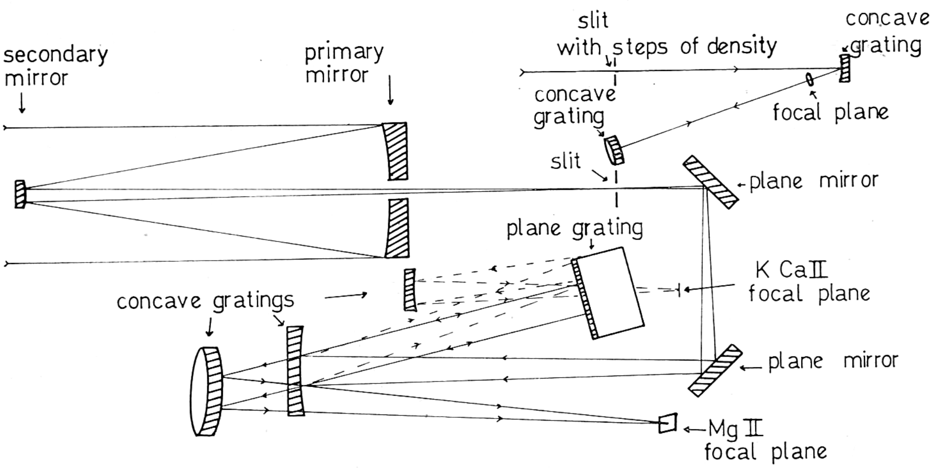

Fig. 3. Schematic of the optical arrangement.

In order to increase the spatial resolution given by the biaxial solar pointing system alone, a servosystem was mounted inside the telescope during the two last flights. This servosystem, developed in the laboratory (Burello, 1970) fixes the solar image in two axes in the focal plane with a theoretical accuracy of better than 1 arc sec. A servo-loop connects two cells, which detect the solar-limb image, with two electromagnets which actuate the secondary mirror of the telescope.

B. SPECTROGRAPH

The spectrograph mounting is a combination of a Czerny-Turner and a Wadsworth mounting to obtain simultaneously:

- high spectral resolution;
- stigmatic spectra;
- low level of stray light.

It is composed of (a) a first concave grating, used on its normal, to collimate the beam leaving the slit; (b) a plane grating, mounted in cross-dispersion and used in high order, to diffract the parallel beam; and (c) a second concave grating, mounted in cross dispersion with the plane grating, to focuse the beam in the camera plane.

During the last two flights, we recorded the K Ca II line with low resolution in order to compare it with the Mg II lines.

For this purpose, the beam diffracted by the third order of the plane grating was collimated by another concave grating mounted with a divergent lens to increase the focal length of this channel

C. PHOTOMETRIC CALIBRATION

It is very important to record the photometric calibration curve of the emulsion during the flight. An auxiliary double Wadsworth mounting (D.W.M.) (Bonnet *et al.*, 1967) is used for this purpose. The slit is directly illuminated by the uniform parallel beam coming from the Sun. A neutral filter with five steps in density is placed close to the slit, giving five plages of different illumination on the slit. The strips of film used in the spectrograph and calibration cameras are cut along the same roll in order to avoid inhomogeneities in the emulsion. The shutters for the spectrograph and the calibration camera are programmed simultaneously by the same timer to obtain the same exposure times.

All the instrumental characteristics for each flight are given in Table I.

4. Performances of the Spectrograph

Before each launching, the quality of the spectrograph is tested in laboratory. The spectral resolution of 25 mÅ measured before the launching of 1970, June 24, is illustrated in Figure 4 which gives a microdensitometer tracing of the emissions lines from zinc.

In order to measure the spatial resolution, a mask with parallel bars having several spacings is put on the slit. The quality of the stigmatic image is given by the quality of

TABLE I

Instrumental characteristics

Flight	9.22.68	4.30.69	11.21.69	6.24.70
Cassegrain telescope				
Equivalent focal length	300 cm	300 cm	300 cm	300 cm
Aperture	1/20	1/20	1/20	1/20
Spectrograph				
Mg II channel				
First concave grating	Bausch & Lomb	Bausch & Lomb	Jobin & Yvon	Jobin & Yvon
Grooves/mm	450	450	915	915
Concave radius	150 cm	150 cm	150 cm	150 cm
Order	2nd	2nd	1st	1st
Plane grating	Bausch & Lomb	Bausch & Lomb	Bausch & Lomb	Bausch & Lomb
Grooves. mm	625	1200	1200	1200
Order	9th	5th	5th	5th
Resolving power	300000	300000	300000	300000
Second concave grating	Bausch & Lomb	Bausch & Lomb	Bausch & Lomb	Bausch & Lomb
Grooves/mm	600	1200	1200	1200
Concave radius	100 cm	100 cm	100 cm	100 cm
Order	2nd	1st	1st	1st
Large bandwidth filter	Transmission	Transmission	Transmission	Reflection
Slit	30 μ	20 μ	20 μ	15 μ
Spectral resolution	0.045 Å	0.035 Å	0.030 Å	0.025 Å
Spatial resolution (laboratory)	3 arc sec	2 arc sec	2 arc sec	1 arc sec
Linear dispersion	0.56 mm/Å	0.73 mm/Å	0.73 mm/Å	0.73 mm/Å
Film	IIIO-UV Kodak	IV E (Kodak)	SA I (Kodak)	39C56(Agfa-Gevaert)
Ca II channel				
First concave grating			Same	Same
plane grating			Same	Same
Order			3rd	3rd
Second concave grating			Bausch & Lomb	Jobin & Yvon
Grooves/mm			600	600
Concave radius			50 cm	50 cm
Order			1st	3rd
Equivalent focal length with the lens			75 cm	50 cm
Spectral resolution			0.12 Å	0.08 Å
Spatial resolution (laboratory)			5 arc sec	5 arc sec
Linear dispersion			0.36 mm/Å	0.32 mm/Å
Film			SA I (Kodak)	39C56 (Agfa-Gevaert)
Calibration Spectrograph				
Step of density	0.5	Linear	0.25	0.25
Range of densities	0–2.5	0.–125	0.–1.25	0–1.25
Concave gratings (B & L)				
Grooves/mm	1200	1200	1200	1200
Radius	50 cm	50 cm	50 cm	50 cm

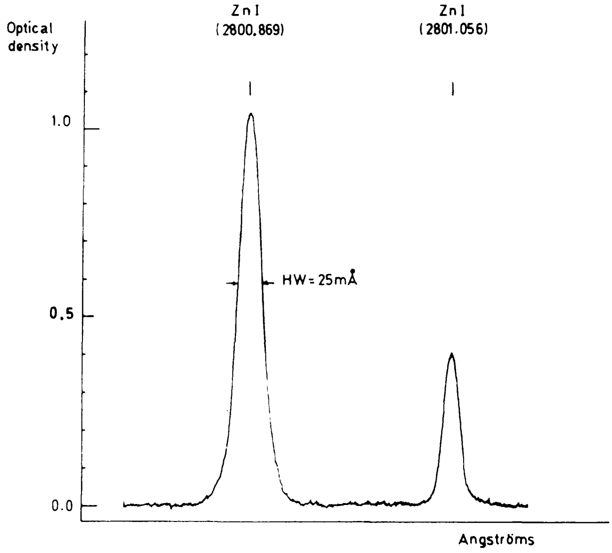

Fig. 4. Microdensitometer tracing of Zn I lines recorded with the spectrograph.

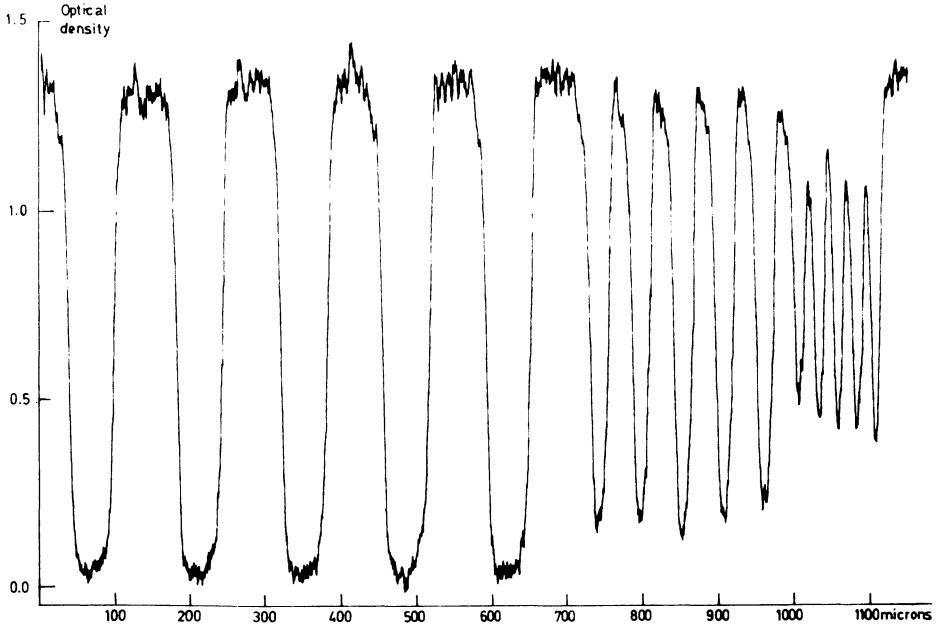

Fig. 5. Microdensitometer tracing of image pattern of square wave intensity distribution: 39C56 Agfa-Gevaert emulsion, area of the scanning spot: 25 μ^2.

the image of each step. Figure 5 shows a microdensitometer tracing of the image of the mask obtained by using a 39C56 Agfa-Gevaert emulsion. The area of the slit of the microdensitometer used to analyse the film is 25 square microns (in the focal plane 10 μ correspond to 1 arc sec spatial resolution or 0.014 Å spectral resolution). Steps of 10 μ are separated. The low granularity and the characteristic slope of 1.4 of the emulsion give an effective resolution of 10 μ (or 1 arc sec).

Figure 6 is a small part of a spectrum obtained during the flight 1970, June 24. The distance between the two dark traces (one is an optical reference and the other is due

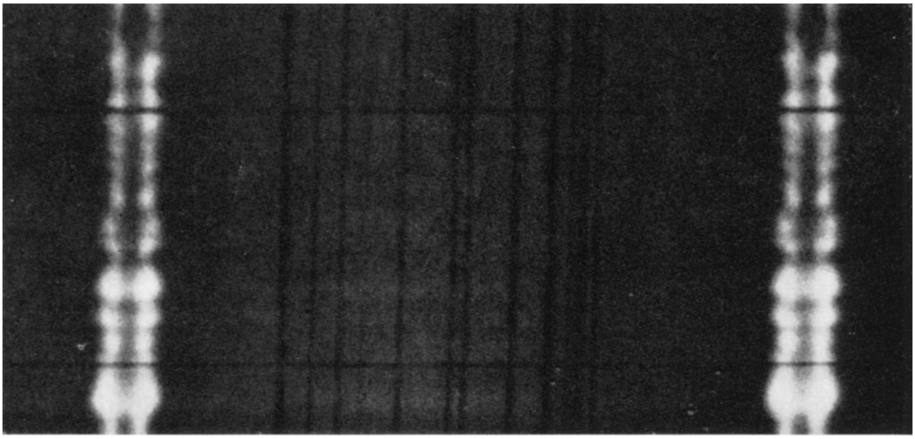

Fig. 6. Small part of spectra obtained during the flight 1970, June 24. The interval between the two dark traces corresponds to 200 arc sec.

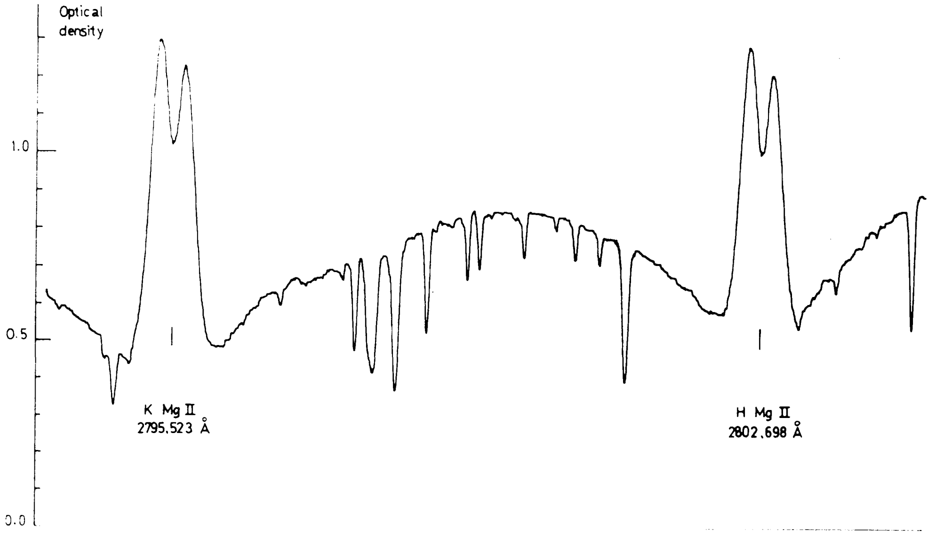

Fig. 7 Microdensitometer tracing of Solar center spectra from flight 1970, June 24.

to a dust on the entrance slit) is 200 arc sec. As can be seen from Figure 6, some features on the K and H lines have 'corn-ear' structure; along the length of the lines the profiles are different and we see a structure similar to the calcium network with cells as small as 10 arc sec. The microdensitometer tracing in Figure 7, for the center of the Sun, in the same flight, shows the Fraunhofer lines between the K and H MgII lines.

Conclusion

To study the MgII resonance lines a spectrograph was built to obtain the limb-darkening variation in these lines with high spectral and spatial resolutions. During the flight 1970, June 24, we obtained a spectral resolution of 25 mÅ and a very good spatial resolution. These results can be improved by using a narrower slit and a finer servo-control inside the telescope. It is very interesting to compare our results obtained with classical spectroscopy with results obtained by Bates *et al.* (1969) with a Fabry-Pérot interferometer.

Acknowledgements

I want to thank Miss N. Lizambert for her help during tests of the instrumentation and Messrs J. C. Barrère, M. Burello and C. Lizambert for technical assistance and realisation of the servo-pointing systems.

This research was supported by the Centre National d'Etudes Spatiales under grants 68-202, 69-224 and 70-252.

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