

Daylight Spectra of Individual Lightning Flashes in the 370–690 nm Region

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ABSTRACT

An optical multichannel analyzer slit spectrometer coupled to a minicomputer was used to record lightning spectra. This is the first successful application of a slit spectrometer to the study of individual lightning flashes and it was accomplished in the daytime. Over 300 spectra were obtained in 1978 and 1979 and are correlated with other experiments in the Thunderstorm Research International Program (TRIP). The spectra duplicate previously published nighttime data but reveal for the first time the relative intensity of H-alpha (656.3 nm) and H-beta (486.1 nm) emissions above their daytime absorption features. These are the characteristic Fraunhofer C and F lines in the solar spectrum. This result suggests that the observation of lightning from space may be accomplished by monitoring the hydrogen emissions from lightning which occur on Earth, or on other planets with hydrogen in their atmospheres, such as Jupiter and Venus where lightning recently has been reported.

1. Introduction

The spectrum of the lightning discharge has been a subject of scientific study for nearly a century. As a result of renewed interest in the physics of lightning, Salanave, Uman and co-workers published numerous papers in the 1960's based on the quantitative analysis of data recorded on film (see, e.g., Salanave, 1961, 1965; Uman, 1966; Orville and Salanave, 1970). These analyses had to cope with the problems of using photographic film as a detector and its inherent nonlinear response to radiation as a function of intensity and wavelength. A careful and very time-consuming process was required to obtain quantitative estimates of the relative intensities of spectral lines (Prueitt, 1963; Orville, 1968). Furthermore, all analyses were limited to data obtained at night, since there was no way to eliminate or compensate for the high background radiation of daylight. Recently, however, the development of silicon intensified targets (SIT) and their successful coupling

to minicomputers and spectrometers has made available highly sensitive and versatile optical multichannel analyzers for the daytime (and nighttime) study of lightning.

The purpose of the present note is to describe the first application of an optical multichannel analyzer spectrometer to the study of lightning. This minicomputer based spectrometer was used on daytime storms and recorded spectra as frequently as every 20 s with a silicon intensified target which responds linearly to radiation. The experiment reported in this note was performed as part of the Thunderstorm Research International Program (TRIP) at the NASA Kennedy Space Center, Florida in the summer of 1978, and at the Langmuir Observatory near Socorro, New Mexico in 1979.

2. Experimental system

The optical multichannel analyzer (OMA) system is schematically shown in Fig. 1. It consists of a

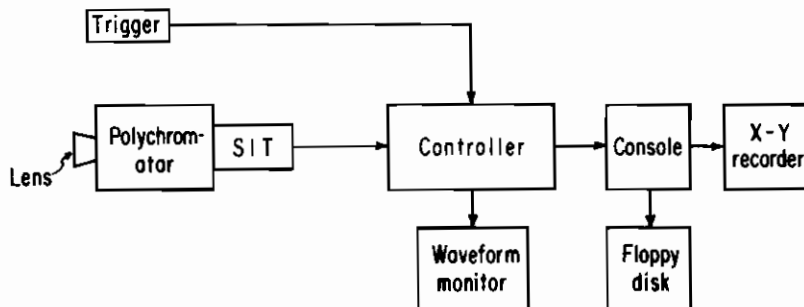


FIG. 1. Schematic of the optical multichannel analyzer spectrometer.

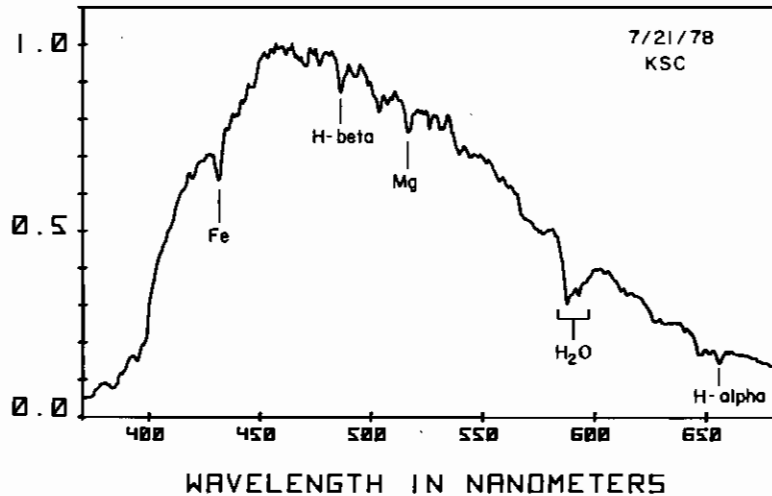


FIG. 2. The scattered daylight spectrum recorded by the optical multi-channel analyzer spectrometer at the Kennedy Space Center (KSC). The plot is normalized to the maximum recorded intensity, but is *not* corrected for the spectrometer-detector sensitivity. A few characteristic absorption features are identified. They include iron, magnesium and hydrogen which absorb in the first 1500 km above the solar photosphere and water vapor which absorbs in the terrestrial atmosphere.

polychromator which is a 0.25 m Ebert spectrometer with the exit slit replaced by the silicon intensified target (SIT) vidicon detector. The polychromator has a 25 μm entrance slit and a 152.5 g mm^{-1} holographic grating which produces a wavelength coverage of 320 nm. For the summers of 1978 and 1979, the wavelength range was set at 370–690 nm to produce survey spectra in the familiar optical range. The spectrum is imaged on the SIT detector which has a square 12.5 mm area that is scanned over 500 channels. Thus, the 320 nm spread over the 500 channels produces an effective dispersion of 0.64 nm per channel. The spectral response of the SIT detector is determined by the S-20 photocathode which is deposited on the vacuum side of the fiber optics faceplate.

The SIT detector is controlled by the multi-channel detector controller which contains all the electronics for the vidicon operation. The controller is triggered by a 2 V pulse from an electronic circuit which is activated by light from the first return stroke. The light is detected by a solar cell, consisting of 2 cm^2 of silicon on a ceramic base and mounted with a field of view of $\sim 35^\circ$. The resulting amplified current signal is used to trigger the controller. The controller has a random access memory for storage of the scan format to be used on the vidicon. At any time the scan format can be viewed on the waveform monitor. Access to the controller is accomplished through the keyboard operation of the console. The console in turn provides for initialization of the detector parameters and its control, data acquisition, data manipulation and reduction, and

data storage. These operations are programmable through a 24k-16 bit internal LSI-11 minicomputer which resides in the console. Data are stored internally on an internal diskette system or on an external diskette drive which can be dedicated to the acquisition of data. The x-y recorder is used to obtain hard copy after a storm.

3. Observations, data and analysis

The type of data obtained by the optical multi-channel analyzer is shown in Fig. 2. It is the spectrum of the scattered solar radiation as modified by the spectrometer-detector system and was obtained on 21 July 1978 at the Kennedy Space Center. The general shape of the spectrum is that of a Planck function for a temperature of ~ 6000 K. Numerous absorption features are apparent of which special note should be made of the Fraunhofer C line at 656.3 nm (H-alpha) and the Fraunhofer F line at 486.1 nm (H-beta). These lines are not particularly prominent because of the low dispersion (0.64 nm per channel) used. The strongest absorption feature is a triangular dip centered approximately at 589 nm and caused by terrestrial water vapor absorption.

In normal operation during a thunderstorm, the system is programmed to respond to a trigger pulse generated by appropriate electronics after the first light pulse from a lightning flash is received. (It was also triggered in other tests in response to a radiation pulse received by a flat plate antenna.) Data are then acquired under program control for 150 ms and subsequently stored on a diskette.

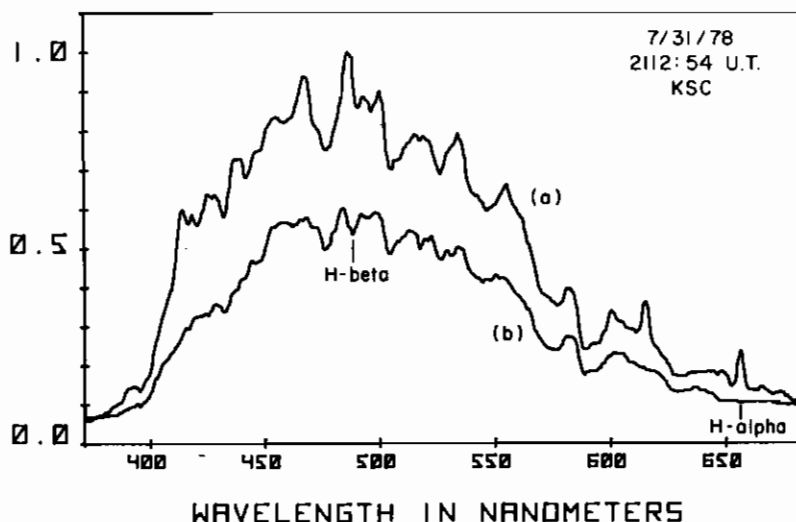


FIG. 3. Two spectra taken approximately 5 s apart. Spectrum (a) was recorded in response to an overhead lightning flash which triggered the spectrometer. The discharge may be an intracloud flash since no channels to ground were observed, but visibility was poor. The observed intensity is composed of the lightning signal and the scattered daylight. Spectrum (b) was recorded 5 s later and displays only the spectrum of scattered daylight.

The system next acquires a background spectrum of the ambient light and stores this in memory. At this point the spectrometer is ready for another flash. All data are obtained under program control and the operator is free to record his observations of the type and time of the flashes.

A sample of the data acquired during an active thunderstorm on the afternoon of 31 July 1978 is shown in Fig. 3. A flash occurred overhead at

2112:54 GMT and the recorded spectrum of the scattered light is graphed as curve (a). Approximately 5 s later, a spectrum of the background ambient light was obtained under program control and this is plotted as curve (b). A significant difference in the relative intensity is immediately obvious. Strong emissions at 486.1 and 656.3 nm are characteristic of lightning and appear in this figure above the Fraunhofer absorption features which are char-

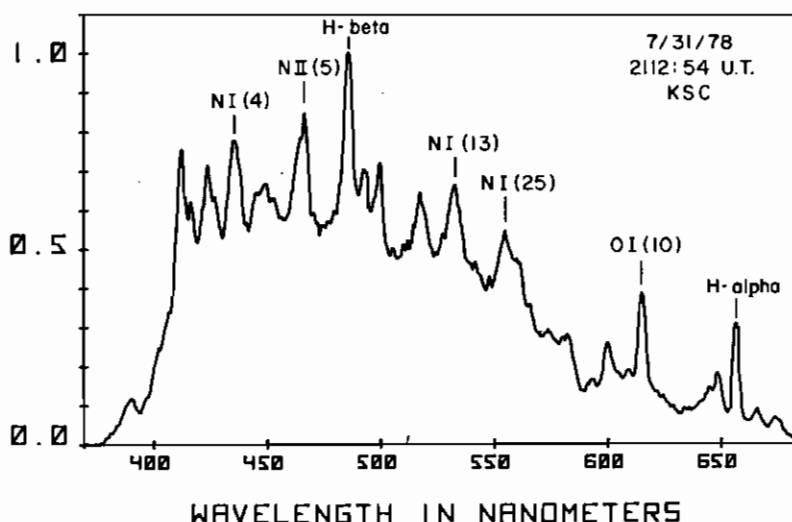


FIG. 4. The difference between curves (a) and (b) in Fig. 3 represents the lightning signal and is graphed here. The emission features can be attributed to neutral nitrogen (NI), oxygen (OI), hydrogen and singly ionized nitrogen (NII). Numbers in parentheses refer to the multiplet designation. A more complete list of identifications is found in Orville and Salanave (1970).

acteristic of the ambient light. The difference between curves (a) and (b) represents the lightning signal.

Fig. 4 was produced by subtracting curve (b) from (a) and displaying the results, a process which takes less than 5 s. The most intense recorded spectral feature is the H-beta line, but this is the result of the greater blue sensitivity of the S-20 photocathode and not a characteristic feature of the lightning spectrum. If a typical S-20 response curve is digitized, and the data in Fig. 4 corrected for the detector sensitivity variation with wavelength, then H-alpha at 656.3 nm is shown to have the highest relative intensity by a factor of approximately 2. These results are not graphed in this preliminary note because the use of a typical S-20 curve provided by a manufacturer does not necessarily represent the response of our tube. Presently we are obtaining an irradiance standard calibrated to the NBS scale which will enable us to correct our data from the spectrometer-detector system to obtain relative intensity values over the full spectral range with errors less than 5%.

The spectral emission lines in Fig. 4 have been previously recorded at night and identified, for example, by Salanave *et al.* (1962). All of the emissions can be attributed to neutral or singly ionized nitrogen and oxygen, and the two hydrogen lines, H-alpha and H-beta previously mentioned. The time resolution in the present data is 150 ms which means that all spectral emissions occurring within this time interval following the trigger were recorded. A time-resolution capability as short as a 100 ns exists within the present spectrometer system but was not used in these preliminary daytime experiments.

4. Conclusion

The results presented here demonstrate the feasibility of recording with a slit spectrograph the spectral emissions from individual lightning flashes in the daytime with good wavelength resolution in the region 370–690 nm. It is apparent that the H-alpha and H-beta emissions are among the strongest lines in these data. When we note that these emissions occur above their respective Fraunhofer C and F lines in the solar continuum, it is obvious that they might be suitable emission features to monitor from an earth satellite for the detection and location of lightning. Furthermore, it

is interesting to observe that the Fraunhofer C and F lines are extraterrestrial absorption features of the solar spectrum. Consequently, on other planets with sufficient hydrogen in their atmospheres, the occurrence of lightning could be detected and studied by monitoring the hydrogen emissions with good time and spatial resolution. Jupiter (Cook *et al.*, 1979) and Venus (Taylor *et al.*, 1979) are the most likely candidates for these studies.

Our present plans include a detailed study of over 300 spectra obtained with the OMA spectrometer of cloud-to-ground and intracloud flashes. In addition, we have recently obtained a lead sulphide detector for the OMA which will enable us to obtain spectral data to 1600 nm, considerably beyond our previous photographic limit of 900 nm (Orville and Salanave, 1970).

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