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The Light of the Night Sky

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ON the surface of the earth, the setting of the sun does not result in so rapid a transition from day into night, as it would on a planet without an atmosphere, such as the moon. After the sun has disappeared below the horizon, the higher layers of the atmosphere, which are still illuminated, scatter the light that they receive and send a small portion of it toward the surface of the earth. But as the layers of air that remain illuminated get higher and higher, and consequently more and more rarefied, scattered light becomes progressively weaker, until finally it becomes practically nonexistent when the sun is 18° below the horizon.

In spite of the fact that night has arrived, the darkness is not complete, even without moon and when the artificial light of the cities is completely avoided. The feeble light produced by the clear and cloudless sky is sufficient to enable a pedestrian to find his way, to see trees, houses and even to read the title of a newspaper. An opaque object placed between the sky and the observer remains visible by contrast. As a matter of fact, the illumination produced by the sky on a horizontal plane is equal to that which a 25-candlepower lamp would produce at a distance of about 300 meters. The impression is entirely different from that which one has in a closed dark room.

These facts were known long ago, but it is only during the last thirty years that the luminosity of the night sky has been systematically studied, from the point of view of its intensity, of its variations and of its composition, with the object of determining its essential characteristics and of discovering its probable origin.[1] With this purpose in view, the simplest conception is quite evidently that of Newcomb who, in 1901,[2] claimed that the light of the night sky was entirely due to the stars, not only to the stars visible to the naked eye and to the telescope, but also to those which escape all present modes of observation. If this were correct, the total light of the sky would indicate the sum of the observable and of the non-observable stars. It would therefore be a very important element with respect to the constitution of the Universe. To evaluate that part of the brightness of the night sky proceeding solely from the weak stars, our statements are based on the investigations made in special regions of the sky, where it has been possible to enumerate the stars of different magnitudes (for instance, up to the 16th magnitude around the North Pole. Such statistics show that the stars of the 10th magnitude contribute the greatest amount of light to the night sky. The nonobservable stars are taken into account by extrapolating the results from the evaluations made on telescopic stars. In the neighborhood of the Pole, for example, we find that the brightness due to the whole of the telescopic and nonobservable stars equals* approximately: 0.009 star of photo-

[1] Chas. Fabry, Réunions de l'Institut d'Optique, Paris, Communic. June 13, 1933, p. 1.
[2] S. Newcomb, Astrophys. J. **14**, 297 (1901).
* Adopting the astronomer's system, we express the brightness of the sky in stellar magnitude, or in the number of stars of unit magnitude for a square degree of the sky.

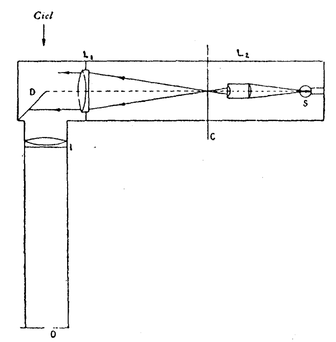

FIG. 1. Photometric scheme for visual measurements.

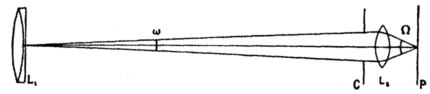

FIG. 2. Photographic method of Fabry.

graphic magnitude unity, for a square degree of the sky.[3]

The brightness thus computed represents only 1/5 of the total brightness measured. The preceding reasoning would be false only if the number of the nonobservable stars were entirely out of proportion to the number of stars of lower magnitudes. This is all the more improbable, because the stars should become less abundant near the boundaries of the galactic agglomeration. To summarize, the brightness of the night sky is much too great to be attributed solely to the sidereal universe.

MEASUREMENTS OF THE BRIGHTNESS OF THE NIGHT SKY

This brightness, measured in comparison with a star of known magnitude, can be obtained visually or by photography. The most exact visual measurements were made by Dufay[3, 4] with the special photometer shown in Fig. 1. The objective L ($f=30$ or 60 cm), which receives the light of the sky directly, is half covered by a diffusing white screen; this is lighted by the parallel beam issuing from L_1 ($f=20$ cm) and proceeding from a small lamp placed behind a microscope eyepiece L_2 ($f=25$ mm). The eye can observe behind the small hole O, at the focus of the lens L, whose halves form two uniformly illuminated portions, no matter what be the source viewed (star of comparison or region of the sky). We produce in the two cases the photometric balance by modifying the illumination due to the small lamp, with the aid of the absorbing wedge C. Before the latter is a colored filter, in order to give to the comparison surface the same tint as to the sky or to the surface receiving the light of the standard star (this filter is made of a dilute solution of ammoniacal copper sulphate). The precision of photometric measurements of very low brightnesses has been discussed in detail by J. Dufay and R. Schwégler.[5] Experience has shown that it is hardly inferior to the one accepted for much greater brightnesses, provided that the angle subtended by the illuminated surfaces is large enough. When this angle is 0.1 or 0.2 radian, the accuracy is rather good as long as the brightness is not below 10^{-8} candles per cm^2 (a hundred times more than the minimum of perceptible brightness), which corresponds nearly exactly with the brightness of the night sky. Under these conditions, the magnitude μ of one square degree of the night sky is measured with an approximation of the order of one-tenth of a magnitude.

The principle of the photographic method, conceived by Charles Fabry in 1910,[6] is extremely simple. The instrument (Fig. 2) includes an objective L_1 ($f=$several cm) in the focal plane of which a circular variable opening limits the field to the useful region of the sky. The objective L_2, having a large aperture (for instance $f/1.5$), gives on the plate P an image of L_1 (exit pupil). No matter what the source, star or portion of the sky, we thus obtain circular spots of the same diameter and uniformly lighted. The plate is calibrated by making several successive exposures on the sky, with the same length of time and different openings of the diaphragm. We

[3] J. Dufay, Réunions de l'Institut d'Optique, Paris, Communic. June 13, 1933, p. 6.

[4] J. Dufay, Thèse de doctorat, Paris, 1928, and Bull. Obs. Lyon **10**, 1 (1928).

[5] J. Dufay and R. Schwégler, Revue d'optique **9**, 263 (1930).

[6] Chas. Fabry, Comptes rendus **150**, 272 (1910).

can also place before L_1 a nearly neutral screen forming four sectors of different densities. This method allows us to measure the photographic magnitude of one square degree of the sky with an approximation of the order of some hundredths of a magnitude.

Between 1923 and 1926, Dufay[3] studied by the two preceding methods the sky region around the North Pole which, on account of its fixity, lends itself particularly well to a carefully followed out photometric study. For this same reason, it is convenient to take the Polar star for comparison. This star is variable, but the amplitude of its variation is small; by using the known light curves, Dufay introduced the necessary corrections into his measurements. The average values relative to one square degree of the clear night sky (Montpellier and Haute Provence) are as follows:

Visual magnitude: $\mu=4.60$ (35 clear nights)
Photographic magnitude: $\mu_g=4.36$ (55 clear nights)

or, expressing the results by the number of stars of unit magnitude, for one square degree of the sky:

0.036 star of visual unit magnitude
0.045 star of photographic unit magnitude.

These results are in good agreement with those of other observers (Newcomb, Burns, Bourget, etc.).[3] We can easily express them in usual photometric units. The brightness of the extragalactic sky is about 10^{-8} candle per cm^2; it is a hundred times greater than the minimum of perceptible brightness (below which an opaque object becomes invisible by contrast). Supposing this to be the brightness of the whole sky, the illumination produced on a horizontal plane is $3\cdot10^{-4}$ lux (or a candle at a distance of 57 meters).

Thus, the light proceeding from one square degree of the sky seems five times greater than the light coming from the weak stars inside. This must undergo an important correction, taking into account the atmospheric scattering, due to the air molecules and to the particles in suspension.[3] In the case of a star, the brightness is reduced both by scattering and by true absorption. Such is not the case for the light of the night sky, which covers an entire hemisphere. In a cone ω containing all the rays received by the observer, the light coming directly from the source is weakened like that of any celestial body but the scattering particles in the cone receive light from other regions of the sky. The scattered light is added to the transmitted light, and the brightness of the sky is therefore less reduced than that of the stars. Laborious computations, based on the laws of molecular scattering, bring out the importance of this effect. They show that above the scattering layers of the atmosphere, the light of the weak stars accounts for about 3/10 of the total brightness of the sky.

This conclusion is confirmed by the study of the distribution of the brightness in the different parts of the sky. For two regions of same zenith distance, the brightness in the Milky Way is at the most twice as great as that outside. If we attribute a purely stellar origin to the light of the night sky, we should expect, from the number of stars, to find the ratio much greater, for example 4 or 5.

Outside the Milky Way and at all the azimuths, the brightness increases with the zenith distance. It is certainly an indication of an atmospheric phenomenon, perhaps resulting in part from scattering. The increase, however, is more marked for visible than for photographically effective light. We are thus led to think that there is an emission of light in the high atmosphere, and that this emission is specially rich in the yellow or the green. It is also necessary to take into account, as we shall later see, the extension of the zodiacal light over a large part, if not indeed over the whole, of the sky.

Polarization of the Light of the Night Sky

With respect to this problem also, the most precise determinations have been made by Dufay,[3,7] accomplished by photographing a circular opening through a double refracting prism. They have shown that the light of the night sky is partially polarized and that the plane of polarization passes constantly through the Sun. But the proportion p of polarized light

[7] J. Dufay, J. de phys. et rad. 10, 219 (1929).

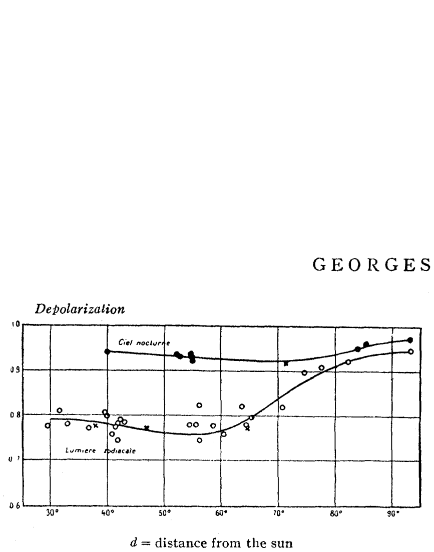

FIG. 3. Polarization of the zodiacal light in the region of the ecliptic.

is always very small (between two and four percent). We obtain a fairly regular curve by plotting as abscissa the angular distance d from the Sun to the observed region, and as ordinate the factor of depolarization ρ, which remains not much inferior to unity ($p=(1-\rho)/(1+\rho)$, Fig. 3). In the case of the zodiacal light, the proportion of polarized light is much greater, as is shown particularly by Dufay's measurements (1924–25), made by photography with the help of the same special apparatus used for the study of the night sky. Near the ecliptic, the values of the depolarization for different angular distances d from the Sun are represented on the lower curve of Fig. 3. This curve indicates a maximum of polarization ($p=0.13$) at 60° from the Sun; it has the same general aspect as the curve for the night sky. We are tempted to attribute the polarized fraction of the night sky light to an extension of the zodiacal light over a large part of the sky. This hypothesis leads up, from the brightness and polarization measurements, to evaluate at about 15 percent the fraction of the brightness of the sky having a zodiacal origin, above the scattering layers of the atmosphere.

SPECTRAL ANALYSIS OF THE LIGHT OF THE NIGHT SKY. GENERAL CHARACTERISTICS OF THE SPECTRUM. OBSERVATIONS MADE BEFORE 1933

The weak intensity of the light of the night sky necessitates the use of spectrographs of great light-gathering power, having one or two prisms, and a camera of very large relative aperture, for instance of the order of $f/1.5$. The exposures must last a very long time, even with a wide slit and highly sensitive plates. The instrument is turned toward one region of the sky, the slit receiving the light directly, without a projection lens. The stars which come into the field play an unimportant part, because they send only very narrow parallel beams into the collimator.

First there was recognized in the spectrum of the night sky the permanent presence of an emission line: the *green line of the aurora* $\lambda=5577$A. This fact was established by Slipher,[8] whose observations were carried out from 1915 to 1919 at Lowell Observatory (35° north latitude), with a single prism spectrograph. The objective of the camera had an aperture $f/1.9$ and the exposure lasted the entire night. This result was confirmed a little later (1922) in England by Lord Rayleigh[9] who worked with a similar instrument. The wave-length of the green line was first measured with fair accuracy by Slipher, then with great precision by H. D. Babcock (1923),[10] who placed an objective of great light-gathering power before a Fabry and Perot interferometer. This exact measurement permits the identification of the green line of the sky with the forbidden line of the neutral oxygen atom ($2p^1D_2-2p^1S_0$) produced in the laboratory the year after by McLennan and Shrum.[11]

The green line is predominant in the spectrum of the night sky (Fig. 4). It is the earliest to appear on an orthochromatic plate; it is easily photographed, even during the full moon. Its variations of intensity, and those of the other spectrum regions, will be discussed later.

Seeking for other radiations in the spectrum of the night sky, Lord Rayleigh (1922–23)[12] used a small spectrograph with one flint prism (aperture $f/0.9$), and exposures of one hundred to two hundred hours. The spectrum measures barely 2 mm from the green line to the solar line K; yet Lord Rayleigh succeeded in seeing a continuous spectrum with the solar absorption lines H and K, and also two emission lines or bands about 4200 and 4450A. During the same period (winter 1922–23), Dufay[4, 7, 13] also photographed the

[8] V. M. Slipher; Astrophys. J. **49**, 266 (1919).
[9] Lord Rayleigh, Proc. Roy. Soc. **A100**, 367 (1922).
[10] H. D. Babcock, Astrophys. J. **57**, 209 (1923).
[11] J. C. McLennan and G. R. Shrum, Proc. Roy. Soc. **A106**, 138 (1924). J. C. McLennan and J. H. McLeod, Proc. Roy. Soc. **A115**, 515 (1927).
[12] Lord Rayleigh, Proc. Roy. Soc. **A103**, 45 (1923).
[13] J. Dufay, Comptes rendus **176**, 1290 (1920).

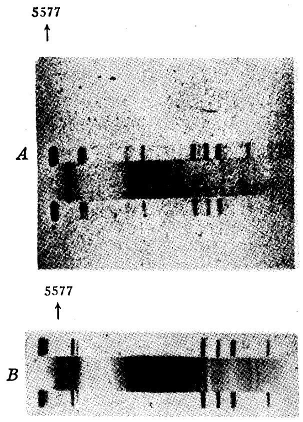

FIG. 4. *A*, Spectrum of the night sky (without moon); *B*, spectrum of the lunar sky (green line visible).

night sky spectrum with a spectrograph having two quartz prisms (aperture $f/3.5$), less luminous but more dispersive than that of Rayleigh. The spectrum thus obtained (wide slit, exposures from 50 to 100 hours) showed, on a continuous ground, numerous clear lines or bands which seem to coincide exactly with those of the sky spectrum at twilight, the two spectra being juxtaposed on the same plate. In the blue, violet and ultraviolet, about 15 Fraunhofer lines or groups of these lines were thus identified by Dufay.

The green line is very intense with respect to the continuous spectrum which surrounds it. In order to determine the ratio of their intensities, it is necessary to compare the line with a broad spectral interval. To succeed in doing this, Dufay[4, 7, 14] devised the following process: The

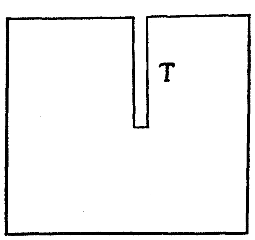

FIG. 5. Rectangular aperture with a narrow rod parallel to the prism *H*.

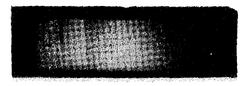

FIG. 6. Spectrogram, one and one-half hour exposure.

slit of the spectrograph is removed and replaced by a large rectangular aperture near the middle of which is a narrow rod parallel to the prism edges (Fig. 5). A continuous spectrum source then gives a very impure spectral band on which the image of the rod is not visible. On the other hand, a source emitting a single monochromatic radiation gives a sharp image of the aperture on which appears the shadow of the rod. If the source emits both a continuous spectrum and a bright line, the shadow of the rod is illuminated by a portion of the continuous spectrum included between two wave-lengths λ_1 and λ_2. The values of λ_1 and λ_2 are determined by working the instrument backwards and substituting for the photographic plate an opaque screen bearing a narrow slit, suitably oriented. Lighting up this slit with a krypton tube, a real spectrum forms itself on the rectangular aperture in the focal plane of the collimator. Then, the narrow slit is moved in order to bring the image of the green krypton line ($\lambda = 5570$A), which is very near the aurora line, into the prolongation of the rod. Other sources can be used in order to find, in the real spectrum on the aperture, the wave-lengths corresponding to the edges of the latter. The study of the plates, by means of a recording microphotometer (after calibration under graduated illuminations) gives the ratio r of the two photographic illuminations produced, respectively, by the bright line together with the portion of the continuous spectrum between λ_1 and λ_2, and by the continuous spectrum alone between the same limits.

This method has been used with a spectrograph having two flint prisms and an objective ($f = 25$ mm) working at $f/1.25$. In this way, good plates were obtained with exposures of one hour to one and a half hours (Fig. 6). In taking into account the spectral sensitivity of the orthochromatic plates used, it was safe to assume that the effective interval of the continuous spectrum illuminating the rod's shadow was included between 4960 and 6000A. Even in moonlight, the green line was still detectable, though of course

[14] J. Dufay, Comptes rendus **185**, 142 (1927).

measurements of the aforesaid type would be meaningless. At Paris, Dufay succeeded by this process in detecting the green line in clear sky, in spite of the illumination of the city.

Dufay's measurements (1926) show that the ratio r varies between 1.4 and 1.6. Then, the photographic brightness produced by the green line is about 0.4 to 0.6 of that due to the continuous spectrum within the mentioned limits, and about 0.28 to 0.38 of the total brightness. The preceding values depend of course on the selective properties of the plates used. In order to deduce the energies from the photographic illuminations, Dufay studied the properties of his plates ("Crumière Aviator"), and he was able to trace the equal energy curve by taking as the source an Ives black body at 1648°K. Supposing that the energy curve of the continuous sky spectrum is exactly that of the Sun (6000°K), it was found that the ratio of the energies, for the green line and the continuous spectrum, varies from 0.25 to 0.38. Supposing that the energy curve of the night sky is that of sunlight scattered by a gas (law in λ^{-4}), the ratio was found between 0.27 and 0.40, that is of the same order as before. In short, the green line carries one-third of the energy of the continuous spectrum, from 4960 to 6000A. Finally, it is possible to pass from the ratio of energies to that of the visual illuminations, taking into account the factor of relative visibility for weak illuminations. Thus, it was found that during Dufay's observations, the green line produced a fraction of the total brightness of the sky varying from 0.06 to 0.09, that is it contributed in the proportion of 6 to 9 percent to the total visual brightness of the night sky. Independently, Lord Rayleigh,[15, 16] using an entirely different method, obtained the ratio 0.069.

We have already mentioned that in addition to the continuous spectrum with solar absorption lines, Lord Rayleigh had observed in 1922–23, two emission lines or bands about 4200 and 4450A, which were also found by Slipher. Great importance was attached at that time to the absence, in the night sky, of the nitrogen bands, which accompany the green line in the spectrum of aurora borealis. In the south of England, Lord Rayleigh had been unsuccessful in finding the nitrogen bands; he could photograph them only in Scotland and in the Orkneys, where auroral displays are often seen. In the south of France, Dufay observed the strong negative band $\lambda = 3914$A, by pointing the spectrograph toward the northern horizon, but he attributed its presence to distant flashes of lightning. Thus, the absence, or at least the extremely weak intensity, of the nitrogen bands in the night sky enabled Lord Rayleigh to distinguish clearly the "permanent aurora" or nonpolar, from the polar aurora itself. The two phenomena might have entirely different causes.

In 1928, Sommer[17] observed at Göttingen an emission spectrum much richer than those of Rayleigh and Slipher. It includes, between 5130 and 3578A, forty bright bands or lines; about thirty of them seemed to belong to the spectrum of polar aurora, and 22 could be identified with nitrogen bands. But this rich spectrum was only observed one night out of forty-eight (exposures from 8 to 9 hours), with a not very luminous instrument ($f/5$). Dufay then assumed that it was a question of an exceptional night, with perhaps auroral activity. In 1931, at the Observatory of the University of Lyons (45° 42′ latitude), Dufay[3, 18, 19] again took up his research work with a new spectrograph, having two flint prisms 11 cm on each side and an anastigmatic objective ($f = 90$ mm) working at $f/1.5$. The spectrum furnished by this new instrument measures about 1 cm from red to near ultraviolet (K line). Exposures of 22 to 80 hours gave a complex emission spectrum in the blue and violet regions (Fig. 4). The simultaneous use of a second spectrograph, less dispersive but more luminous than the former (aperture $f/1.25$) proved the daily presence of this emission spectrum superposed upon the continuous one. Besides, several bands were detected by Dufay on old spectrograms obtained between 1922 and 1925. It is necessary to note also that Dufay's early observations which disclosed only the continuous spectrum with Fraunhofer lines had been made by pointing the instruments toward the zenith, whereas during the observations of

[15] Lord Rayleigh, Proc. Roy. Soc. **A129**, 458 (1930).
[16] Lord Rayleigh, Proc. Roy. Soc. **A101**, 312 (1922).
[17] L. A. Sommer, Zeits. f. Physik **57**, 582 (1929).
[18] J. Dufay, Comptes rendus **193**, 1106 (1931).
[19] J. Dufay, J. de phys. et rad. **4**, 221 (1933).

1931, the studied regions were south or west, at a small height above the horizon (10 or 20°). Dufay's emission spectrum was similar but not identical with that of Sommer; it was also comparable to a spectrum obtained in India by Ramanathan,[20] in February 1932 at Poona (18° 30′ latitude).

In the long wave-length regions of the visible spectrum, the study of the night sky presents even greater difficulties, especially because of the extremely weak dispersion of spectrograms. Certain of Lord Rayleigh's[21] and Dufay's[3, 4, 7] observations, made through colored filters had shown that the light of the night sky is relatively richer in red radiations than the solar light. In particular, Dufay established a great difference in spectral composition between the day and the night sky. The latter would be more like the solar light, from which however it would differ by a relatively greater intensity in the red and in the violet, if for purposes of comparison we suppose the intensities of the two kinds of light made equal in the yellow-green. The light of the night sky is then not blue, like that of the day sky, nor reddish like that which would be scattered by meteors; it is at the same time blue and red. In agreement with these observations, Slipher[22] discovered (1929) a group of emission lines in the red and orange regions of the spectrum, up until that time unexplored. He attributed to the most intense the following wave-lengths:

5892 6315 6530 6870 and 7270A

A few weaker lines were observed in the green by Dufay.[19, 23] On the other hand, Sommer[24] published in 1932 a list containing more than twenty radiations between 5265 and 7280A, revealed by the help of an extremely luminous spectrograph used at Mount Wilson Observatory for the study of extragalactic nebulae. Thus, beyond 5000A, towards larger wave-lengths, the night sky spectrum seems as rich and complex as in the blue and the violet.

If we compare the emission spectrum of the night sky to that of the polar aurorae, we observe,

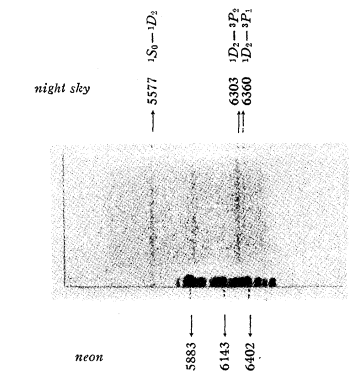

FIG. 7. O I lines in the night sky.

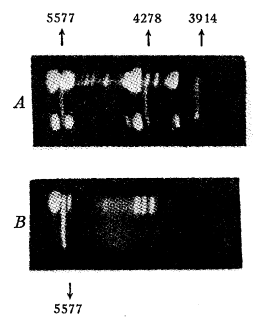

FIG. 8. *A*, Spectrogram of the aurora at Louiseville, province of Quebec, August 28, 1932 (exposure one and one-half hours). *B*, Spectrogram of the night sky photographed at Lyons with the same instrument as used in *A*, November 7, 1931 (exposure ten hours and 55 minutes).

in spite of evident similarities of spectral composition, striking differences especially with respect to the relative intensities of the radiations occurring in both. We find in the two spectra the three forbidden lines of O I: $\lambda=5577A$ $(2p\,^1D_2-2p\,^1S_0)$, $\lambda=6300A$ $(2p\,^3P_2-2p\,^1D_2)$, $\lambda=6363A$ $(2p\,^3P_1-2p\,^1D_2)$. These last two form together the "red line" of the polar aurorae. They seem to have been separated in the sky spectrum by Sommer; they are very distinct on the plates reproduced in a recent paper by Slipher[25] (1933) and on the spectrogram of Fig. 7, obtained in April 1935 by Cabannes.[26] The observations de-

[20] K. R. Ramanathan, Ind. J. Phys. **7**, 405 (1932).
[21] Lord Rayleigh, Proc. Roy. Soc. **A106**, 117 (1924).
[22] V. M. Slipher, Pub. Astronom. Soc. of the Pacific **41**, 262 (1929).
[23] J. Dufay, Comptes rendus **194**, 1898 (1932).
[24] L. A. Sommer, Zeits. f. Physik **77**, 374 (1932).

[25] V. M. Slipher, Monthly Notices of the Roy. Astronom. Soc. **93**, 657 (1933).
[26] J. Cabannes, Comptes rendus **200**, 1905 (1935).

scribed up to this point place beyond doubt the presence of certain nitrogen bands in the night sky spectrum, but with respect to this there exists an essential difference between the sky and the aurora borealis. In the case of the aurora, the bands 4278 and 3914A of the negative system of nitrogen have generally, on orthochromatic plates, an intensity comparable to that of the green line. Such is not the case for the night sky, as is seen immediately by comparing the two spectrograms of Fig. 8, obtained with the same instrument (two prisms, objective focus = 25 mm $f/1.25$). The first, A, is that of an aurora photographed by Dufay[3, 19] at Louiseville (Province of Quebec), August 28, 1932, with an exposure of $1\frac{1}{2}$ hours. It shows the green line and, with an intensity of the same order, the bands 4278 and 3914A. The second, B, was obtained at Lyons by exposing the plate one night to the night sky; outside of the very intense green line, we distinguish in the blue only a weak continuous spectrum. In short, we can say that in the night sky spectrum, all the observed bands between 3900 and 5100A are much weaker than the line 5577A. Moreover, after Dufay's observations lasting up until 1933, we could affirm that the most intense bands of this region do not belong to the positive and negative systems of nitrogen. Contrary to Sommer's opinion, the distinction established by Lord Rayleigh between the polar aurora and the general nonpolar aurora possesses a certain amount of truth.

Recent Researches on the Spectrum of the Night Sky (1933–1935)

The spectral composition of the night sky light has been for two years the object of researches made under the direction of Cabannes and of Dufay at the Lyons Observatory and at the University of Montpellier. To simplify the exposition of the results, we divide the spectral intervals studied (8000–2950A) into three regions.

A. Region 8000–5000A

In order to study this region which is particularly difficult to explore, Cabannes[27, 28] caused to be built an especially luminous instrument, characterized not only by its large aperture ($f/0.7$), but also by the considerable size of the camera objective ($f = 80$ mm), which was particularly free of aberrations and was associated with a large flint prism of 115 mm in height with a base of 205 mm. The spectral domain 5265–7280A occupies on the plates a length of 4.6 mm, but the spectrograms are sufficiently good to allow wave-length measurements (after calibration with iron or neon lines) with an approximation varying from several A to some tenths of an A, between the green and the infrared. The bands or lines were distinguished either directly with the help of the microscope comparator, or on the registered curves given by a recording microphotometer. On these curves appear many supplementary details which the microscope cannot reveal. Simultaneous examination of enlarged records also permits one to compare with ease the spectra obtained during different nights.

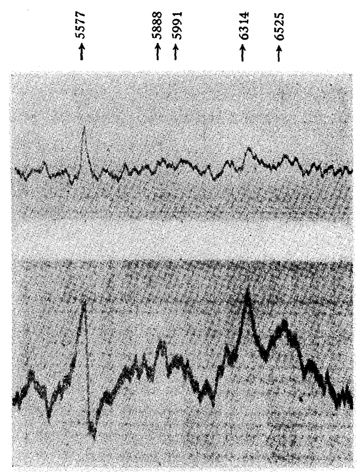

FIG. 9. Microphotometer curves of spectra taken by Cabannes.

For the detailed study of the long wave region, Cabannes used six spectrograms taken in 1933–34 (Montpellier and Pic du Midi), in very fine weather, with a slit of 0.2 mm and exposures varying from 6 to 17 hours. When these plates are examined under a magnifying glass, no continu-

[27] J. Cabannes, Comptes rendus **198**, 2132 (1934).
[28] J. Cabannes, J. de phys. et rad. **5**, 603 (1934).

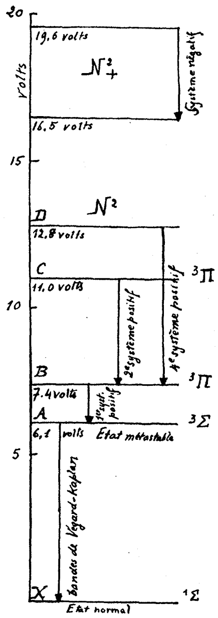

FIG. 10. Energy diagram of the nitrogen bands.

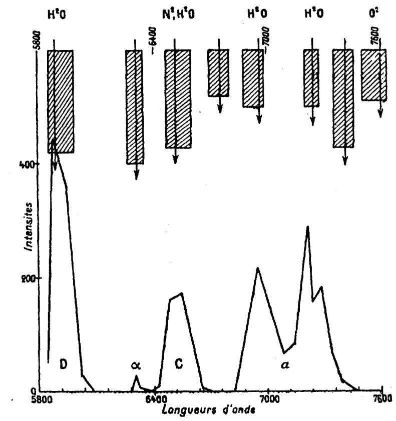

FIG. 11. Sky bands compared with water vapor bands.

ous impression is visible, but only a small number of emission lines or bands. Two different separate microphotometer curves of the same plate are reproduced in Fig. 9. We can distinguish immediately on these curves the characteristic green and red lines of the sky and of the aurorae. A complete study of all the plates and records enables the affirmation of the existence of 70 radiations (lines, bands, distinct maxima) between 5016 and 8330A. Apart from several secondary divergences, the agreement is striking between the measurements Sommer had already made and those of Cabannes, these last being however more reliable and more complete. Moreover, contrary to that which happens in the blue and the violet where the strong intensity of the nitrogen negative bands gives to the spectrum of the aurora a very distinctive aspect, there exists in this region 5000–8000A a great similarity between the spectrum of the sky and that of the aurora according to the observations of Vegard and of Vegard and Harang (1933). This should be considered as a proof of the atmospheric origin of the selective emission of the night sky. This emission, particularly strong in the red, is superposed upon the solar light scattered by interplanetary particles, which is the probable cause of the continuous spectrum with Fraunhofer lines observed by Dufay in the violet and the ultraviolet. In the region analyzed by Cabannes, the continuous spectrum must evidently be very weak in relation to the selective spectrum, since it does not show on the spectrograms. Dufay's photometrical measurements show effectively that in the red the selective emission of atmospheric origin must be considerable by comparison with the continuous spectrum of probable interplanetary origin.

By a very thorough analysis and discussion Cabannes arrives at the following identifications of emission lines or bands, other than the forbidden line of O I, observed on the plates or microphotometer curves:

(1) The principal emission groups of the night sky spectrum between 5000 and 8000A belong to the first positive system of the nitrogen bands (see energy diagram, Fig. 10). Thus, the luminous particles are, for the most part, very rarefied nitrogen molecules previously carried to the level $B(^3\Pi)$, with a vibrational quantum number in the neighborhood of 15 or of 7.

(2) We find in the night sky light the principal

vibration bands (telluric bands) of water vapor a, C, α and D. The best argument for radiation from water vapor is the exact coincidence of certain sky bands with the bands a, C and D of water vapor. Fig. 11 represents according to Mecke the number of lines of water vapor that are met with in each interval of 50 Angstroms, between 5800 and 7600A. This graph gives an idea of the aspect of the bands photographed under low dispersion. Above are shown by rectangles the emission bands of the night sky, whose centers of gravity are indicated by arrows. We see that each water vapor band corresponds exactly with a sky band. The following list also shows this correspondence:

	Water Vapor	*Night Sky*	*Aurora*
a	7330–7160	7278–7200	7243
	7020–6920	6966–6877	
C	6600–6430	6607–6468	6608–6440
D	6000–5850	5990–5861	5975–5867

(3) In conformity with Sommer's opinion, the telluric bands A, B, α, α' (and perhaps α'') of oxygen exist in the emission spectrum of the night sky.

Cabannes' conclusions were recently questioned by Vegard and Tonsberg[29] who, having failed to confirm in their observations the numerous radiations discovered by Sommer and Cabannes, beyond $\lambda = 5577$A, suppose that most of the accidents revealed by the records are purely the result of mere chance, and proceed from photographic-emulsion irregularities. These criticisms seem to be unfounded. For instance, Dufay has studied both with the comparator and on the microphotometer curves, the low dispersion spectrum of a small lamp containing impure neon. The number of the lines that can be distinguished on the record is double the number directly visible through the microscope of the comparator.

On a new spectrogram (Fig. 7), obtained by Cabannes[26] in April 1935, the red line $\lambda = 6300$A has a remarkably great intensity and outshines the green line. Outside of the three forbidden lines of O I (5577, 6300 and 6360A), this spectrogram reveals only the presence of ten bands among those which were previously observed on the long wave-length side of the green line.

[29] L. Vegard and E. Tonsberg, Zeits. f. Physik **94**, 413 (1935).

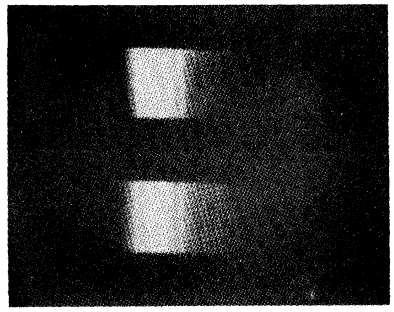

FIG. 12. Six hours exposure to the night sky.

B. Region 5000–3800A

In this region, Cabannes and Dufay[30, 31, 32] used the two spectrographs previously described, having camera objectives working at $f/1.5$ and $f/0.7$. With the most luminous ($f/0.7$), the spectra measure 5.7 mm from 3900 to 5000A, but the images are sharp and the wave-lengths can be determined to within 2A, near 4400A. An exposure of six hours, during a clear night, gives a satisfactory plate (Fig. 12). A hundred or so of plates were got together by Cabannes and Dufay during the period from August 1933 to January 1935 (Pic du Midi, Montpellier, Forcalquier, Lyons). A large number have been studied directly with the comparator or with a microphotometer. About 125 radiations were thus found in the interval 5000–3800A. Aside from a small number of radiations which could not be attributed with certainty to any known spectrum,* they consist of the following groups, whose importance is very unequal.

(1) We find in the first place several bands of the first negative system (4708, 4278, 4236, 4199 and 3914) and of the second positive systems of nitrogen (4574, 4059, 3998).

All are quite weak, even 3914, the intensity of

[30] J. Cabannes and J. Dufay, Comptes rendus **198**, 306 (1934).

[31] J. Cabannes and J. Dufay, Communication au Congrès des Sociétés Savantes, Lyon, 1935.

[32] J. Cabannes and J. Dufay, Comptes rendus **200**, 1504 (1935).

* A few of these radiations can be attributed with some probability to the neutral nitrogen atom N I (for example: 4153, 4110, 4101A).

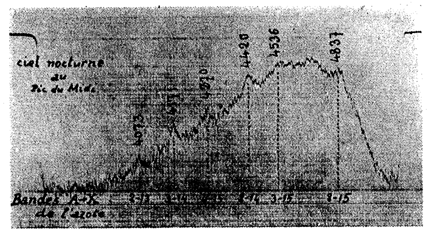

FIG. 13. Spectrogram showing the Vegard-Kaplan bands (nitrogen).

which in the aurora spectrum, as we have seen, is comparable to that of the green line.

(2) Certain intense lines of the red spectrum of argon A 1 coincide practically with feeble radiations of the night sky (4700, 4632, 4592, 4345, 4337, 4301, 4259, 4193, 4181 and 4160A).

(3) The most typical lines of the spectrum (of unknown origin) of cometary nuclei: 4724, 4669, 4329, 4314, 4301, 4292, 4068, 4052, 4040, 4020, 4014 and 3988, are all very near certain radiations of the sky.

(4) The preceding attributions do not include the most intense and characteristic radiations of the night sky, among which are the two bright lines on bands first discovered by Lord Rayleigh and Slipher ten years ago, toward 4200 and 4450A. In 1934, Hamada had proposed to identify these radiations with two Goldstein bands of the nitrogen molecule, but this interpretation is scarcely compatible with the maxima of intensity which appear toward 4200 and 4450A on Cabannes and Dufay's spectrograms. More recently, Kaplan thought that these were two of the bands of the new system he had just excited in active nitrogen. In spite of certain numerical discordances, these new bands do not differ from those which Vegard had previously observed by bombarding with cathode rays a solidified mixture of argon and nitrogen dioxide. The Vegard-Kaplan bands have been classified by Herzberg; their frequencies in cm^{-1} are given by the formula:

$$\nu = 49{,}774.4 + (1446.46\, v' - 13.93\, v'^2) - (2345.16\, v'' - 14.445\, v''^2).$$

The first parenthesis shows that the initial state is the metastable A ($^3\Sigma$); on the other hand, if we make $v''=1$ in the second parenthesis, we find 2331 cm^{-1}, which is the Raman frequency of nitrogen; the final state is then the normal one $X(^1\Sigma)$ of the molecule. The frequency obtained for $v'=v''=0$ shows that the energy of the metastable level A is 6.1 volts, instead of 8.2 volts as was believed up until now. It was then impossible to compute *a priori* the wave-lengths of the Vegard-Kaplan bands. We kept account of this correction on the energy diagram of Fig. 10.

In trying to verify the Kaplan suggestion, after assembling all their observations of the night sky, Cabannes and Dufay concluded that a great number of the sky radiations are very close to Vegard-Kaplan bands. The agreement is even more satisfactory if we subtract 21 cm^{-1} from the constant term of the Herzberg formula, but this correction is perhaps only apparent and due to the fact that the bands are degraded toward the red. The principal bands of the sky in the interval 3500–5000A are so explained in a very satisfactory way which seems definitive for most of them. The record of Fig. 13 permits the recognition of six Vegard-Kaplan bands, among the most intense of the sky. In the whole, 32 radiations of the sky mentioned in the following table, and included between 3400 and 5400A, can be identified with Vegard-Kaplan bands, the most intense belong to the sequences: $v''-v'=10$, 11, 12 and 13.

Vegard-Kaplan bands in the night sky

5324	4603	4252	3936
5062	**4536**	4220	3889
4962	4493	**4171**	3855
4838	**4425**	4144	3769
4768	4382	**4073**	3669
4719	4363	4046	3582
4650	4321	3979	3501
4616	**4270**	3950	3426

In using Vegard's measurements, Cabannes and Dufay found also several Vegard-Kaplan bands (13 bands, among which 4424 and 4218A) in the spectrum of the aurora, but the bands of the second positive and negative systems of nitrogen have an intensity so strong that they hide certain of the bands $A \rightarrow X$. These attributions, which seem much more reasonable than those of Vegard (O II, N II) leave only a small number of radiations unexplained in the spectrum of the aurora described by Vegard.

We are now able to return to the essential difference between the night sky and the auroral spectra; it consists especially in the *degree of excitation*. In the sky, the Vegard-Kaplan bands (6.1 volts) are the most intense, then come the bands of the first and second positive systems (7.4 and 11.0 volts); lastly the negative bands (19.6 volts) have a much reduced intensity. *The order of intensities is exactly reversed in the auroral spectrum.*

C. Ultraviolet region

According to a spectrogram obtained in 1925 with a quartz instrument open to $f/3.5$, Dufay[33, 34] was able to establish in the region between 3900 and 3000A, the existence of an emission spectrum superposed on the continuous one, itself presenting about 10 Fraunhofer absorption lines, easily identified; these are used as standards for measuring the wave-lengths of the 40 lines or bands of the emission spectrum. Most of them belong very probably to the negative and second positive systems of the nitrogen bands; these last are the most intense, contrary to that which occurs in the polar aurora. Several other radiations are very near the cometary nucleus lines (Morehouse 1908 c). Finally, the continuous spectrum with Fraunhofer lines becomes weaker below 3500A, while the emission lines or bands remain intense up to the limit of atmospheric transparency. This explains the great intensity of the night sky ultraviolet spectrum mentioned some time ago by Dufay.

The study of the sky in the ultraviolet has been followed out by Gauzit[35, 36] with a quartz spectrograph opened at $f/2$. Ten spectrograms obtained at Montpellier in 1933 and 1934 were studied directly with the comparator or from their microphotometer records. This detailed analysis, which confirms and extends Dufay's observations and measurements, permitted Gauzit to recognize between 4175 and 2963A, more than 100 emission lines or bands, for which Gauzit gives the most reasonable attributions (negative and second positive systems of nitrogen, A I, comet and helium lines). At the present time, it seems difficult to decide definitely about these attributions, which should be reviewed by taking into account the existence of the Vegard-Kaplan bands in the visible region of the spectrum. Dufay* has already found a good number of coincidences between certain wave-lengths measured by Gauzit and those of bands $A \rightarrow X$ derived from the Herzberg formula. On the other hand, Kaplan[37] has calculated long wave-length members of the Schumann-Runge system of oxygen which fall in the region above $\lambda = 3000$A and has found that the agreement is quite good. One of the most curious and interesting inferences from Gauzit's analysis is the presence of emission radiations in the region occupied by the great absorption band of the atmospheric ozone (Hartley band), which sharply limits the spectrum of the sun and stars to about 3000A. The reality of the radiation of the night sky seems proved up to 2963A.

In conclusion, we have come to recognize in the night sky light the existence of a continuous spectrum with Fraunhofer lines, of which the intensity is relatively very weak in the long wave region. On this continuous background appear a great number of lines or bands among which are predominant the forbidden lines of the oxygen atom (5577, 6300 and 6363A). The other radiations are manifestly related to the various systems of nitrogen bands, which in order of intensity are arranged in the following manner: Vegard-Kaplan bands $A \rightarrow X$; bands of the first and second positive systems, negative bands. In the region of the long wave end of the visible spectrum, Cabannes' analysis confirms the provisional attributions of Sommer and tends to prove the presence of certain telluric bands of oxygen, and also vibration bands of the water molecule. Lastly, the greater part of the other radiations are very near the most intense comet nucleus lines (unknown origin) and several A I lines. The presence of lines of nitrogen atom or of helium should be considered very doubtful.

In a lecture delivered in May 1933 before the Royal Astronomical Society, Slipher[25] has given a short general account of the spectrographical

[33] J. Dufay, Comptes rendus **198**, 107 (1934).
[34] J. Dufay, J. de phys. et rad. **5**, 523 (1934).
[35] J. Gauzit, Comptes rendus **199**, 29 (1934).
[36] J. Gauzit, J. de phys. et rad. **5**, 527 (1934).

* Private communication.
[37] J. Kaplan, Pub. Astronom. Soc. of the Pacific **47**, 257 (1935).

observations of the night sky light, undertaken at Flagstaff since 1915. He found that the negative bands of nitrogen, typical of the auroral spectrum and very faint in the normal spectrum of the night sky, are usually present in the morning and evening skies, if brief exposures are made when the first and last traces of sunlight touch the high atmosphere. The day seems to begin and end with a sort of auroral flash. In the common spectrum of the night sky are present many radiations distributed from the ultraviolet to as far as $\lambda = 10{,}000$A. Near 8600A appear the strongest of these, which doubtless outshine the green-yellow line. On the beautiful spectrograms reproduced in Slipher's paper, the two forbidden red lines of O I (6300 and 6360A) are to be noted, and it is also possible to identify the principal Vegard-Kaplan bands.

Spectra obtained recently in India (1933) by Karandikar[38] are also practically identical with those obtained by the French investigators both as regards the principal radiations and their relative intensities. But from 3700 to 5900A, thirty radiations only were discovered and measured by Karandikar.

Variations of the Light of the Night Sky

The measurements of brightness made by Dufay in 1924 and 1925, either visually or by photography, indicate a seasonal variation with a maximum about the summer solstice and a minimum about the winter solstice.[3, 39] On the other hand, since 1923, Lord Rayleigh[21, 40, 41] made a long series of measurements on the brightness of the sky through colored filters, taking as source of comparison a luminous preparation of double sulphate of uranyl and potassium. According to Rayleigh and his collaborators, important variations occur from one night to another in certain spectral regions. However, Dufay claims that these variations have very little influence on the measurements of integral brightness. This fact agrees with the presence of emission lines and bands, which varies in intensity, in the green and the orange. On account of the Purkinje phenomenon, the region 4700–5300 is almost the only one to contribute to the total light in the visual measurements. From 1923 to 1927, Rayleigh's measurements with a green filter indicated a seasonal variation with a minimum of brightness in December, and two maxima less pronounced in March and in October. In addition, Lord Rayleigh found an increase of the average light from 1923 to 1927. In spite of certain discrepancies there exists an irrefutable parallelism between these slow variations established by Rayleigh and those observed by Dufay for radiations of shorter wave-lengths.

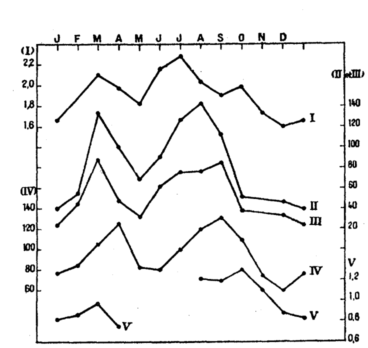

FIG. 14. I, brilliancy of the night sky in the neighborhood of the north pole measured photographically (1924–1925), (in stars of photographic magnitude 5 per degree squared); II, intensity of the radiation λ4425 (in arbitrary units); III, intensity of the radiation λ4171 (in arbitrary units); IV, frequency of the aurora at New York (over 25-year period); V, intensity of the line λ5577 (in arbitrary units).

During the winter 1931-32, Dufay[3, 23] found a simultaneous weakening of the green line and also of the blue and violet regions, in which at that time the continuous spectrum with Fraunhofer lines was the only one discernible (December 1931–February 1932). This question was taken up again by Cabannes and Dufay[42] who studied quantitatively, by photographic photometry, the variations of intensity of the bands 4425 and 4171A (belonging to the Vegard-Kaplan system), which are the most intense and the most easily isolated from the continuous spectrum between 3900 and 5000A. They thus observe from one night to the next unsystematic

[38] J. V. Karandikar, Ind. J. Phys. **9**, 245 (1935).
[39] J. Dufay, Bull. Obs. Lyon **2**, 46 (1929).
[40] Lord Rayleigh, Proc. Roy. Soc. **A109**, 428 (1925).
[41] Lord Rayleigh, Proc. Roy. Soc. **A119**, 11 (1928).
[42] J. Cabannes and J. Dufay, Comptes rendus **200**, 878 (1935).

variations of intensity, sometimes as high as from 2 to 1. But these variations do not prevent us from distinguishing a more slow and regular one, of which the amplitude is greater. The monthly average values of the intensities of the two radiations have been plotted on the diagram of Fig. 14 (curve II: 4425; curve III: 4171). The observations cover only 14 months (68 plates corresponding to as many clear nights), but it seems probable that the fluctuations they indicate recur from year to year, at least in general aspect. These variations are very similar to that of the curve I, which represents the monthly average values of photographic brightness, obtained by Dufay in total light (1924–25). If it is right to assume that the continuous spectrum has a constant intensity and that all the radiations vary together in the same ratio, the comparison of the amplitudes of the preceding curves permits the evaluation of the part which belongs to the whole of the blue and violet lines or bands, in the total brightness of the night sky. We thus find that the discontinuous spectrum should produce a fraction of the total brightness measured by photography, which varies, according to the period of the year, between 0.15 and 0.4 (average: 0.25). The variations of the bands 4425 and 4171A resemble that of the green line (curve V, according to Lord Rayleigh, 1922–1928) and that of the frequency of the aurorae of low latitude, during 25 years of observation at New York (curve IV). These similarities allow us to think that the emission of the Vegard-Kaplan bands is connected with that of the green line and also that the polar aurorae and the night sky light could have a common origin.

In a recent paper, Lord Rayleigh and H. Spencer Jones[43] have given a complete analysis of the intensity variations at Terling (England, 1923–1934), Canberra (Australia, 1925–1934) and Cape Town (1925–1933), in three regions of the spectrum selected by appropriate colored filters. One of them transmits a narrow interval around the auroral line $\lambda = 5577$A, and the others transmit red and blue regions to the exclusion of this line. The observations at each station indicate that there is a well-marked variation with a six-month period, in addition to the annual variation and the secular change previously found by Lord Rayleigh. The annual variation is largest at Terling and smallest at the Cape. The yearly component appears to be dependent both upon magnetic and geographical latitude, and near the equator it would presumably be negligibly small. On the other hand, the amplitude of the semi-annual variation shows little variation from one station to another. In the auroral and red regions, the amplitudes of the annual variation are approximately equal and larger than the amplitude in the blue region. The amplitude of the six-monthly variation is largest in the auroral region and smallest in the blue region. A slow variation and irregular fluctuations are superposed on the periodic terms. The slow variation, which is most clearly defined in the auroral region, indicates a correlation between the mean early values and the mean early sun-spot areas. The Terling observations, which extend over a complete sun-spot cycle, show a general rise from 1924 to 1929 followed by a progressive fall continuing to 1933. During the same period, there was a sun-spot minimum in 1923, a maximum in 1928, and a further minimum in 1933. Some attempts to find a connection between the night sky brightness and magnetic activity have not proved very successful. However, the mean values to the Cape, in the auroral region, appear at indicate a systematic tendency to a greater brightness on disturbed days than on quiet days. The mean absolute intensities at the three stations, in any one spectral region, are comparable in magnitude, but are probably highest at Terling and lowest at the Cape.

The variations which occur during a single night have been studied by Lord Rayleigh (1929)[44] by means of a rubidium photoelectric cell, particularly sensitive to blue radiations. These variations seem systematic, the brightness passing in general through a maximum around midnight. For the green line studied by photography, McLennan, McLeod and Ireton (1928)[45] were led to the same conclusion. A new confirmation has been recently given by Dobrotin, Frank

[43] Lord Rayleigh and H. Spencer Jones, Proc. Roy. Soc. **A151**, 22 (1935).

[44] Lord Rayleigh, Proc. Roy. Soc. **A124**, 395 (1929).

[45] J. C. McLennan, J. H. McLeod and I. C. Ireton, Trans. Roy. Soc. Canada **22**, 397 (1928).

and Čerenkov,[46] and also by Chvostikov and Lebedev[47] who, in Russia observed a rapid increase of the green line intensity during the first hours of the night, a maximum toward 1 A.M. followed by a slower decrease until the end of the night. In the center of Asia, Eropkin and Kozirev[48] found also the green line fainter before the dawn than at midnight, the ratio of intensity being about $\frac{1}{2}$. But the night sky during the hours before the dawn seems to be bluer than at midnight. In contrast, the results of Karandikar (1934),[49] obtained in India by the photographic method (orthochromatic plates and colored filters) are absolutely different. They indicate, for all spectral regions, the following general tendency: a progressive weakening during the first part of the night, a minimum between midnight and two A.M. followed by an increase of intensity during the end of the night. At Flagstaff, the same order of variation was observed on the green line by Slipher,[25] but it is not always the case for all the nights. The phenomena seem then to depend on the latitude and on other causes.

At the Physics Laboratory of the University of Lyons, Grandmontagne* has just designed a photoelectric recording photometer for the study of the variations of the night sky brightness, during a single night or from one night to another. The receiver is a caesium oxide photocell giving an extremely weak current in a resistance of 10^{11} ohms. The potential difference at the ends of the latter is measured by means of a Dolezalek electrometer, associated with a recording device, and sufficiently sensitive to indicate the hundredth of a volt. The apparatus was first installed in a nearly completely darkened room, where a very weak diffuse light is admitted by special curtains. This light produces on a photographic plate an impression like that which results from an exposure to the night sky during the same time. In this manner, it was found that the sensitivity necessary for the study of the night sky is greatly increased. Moreover, it is easy to distinguish on the record all the details (passage of clouds, nightfall, etc.) of the curves given simultaneously by the solarigraph at the Lyons Observatory. By combining the receiving cell with colored filters, or using cells of various types of color sensitivity, it will be possible by means of this instrument to study directly and without difficulties the variations of intensity in different spectral regions. The first results, obtained since July 1935 and corresponding to some clear moonless nights, indicate a maximum of intensity (caesium oxide photo-cell) occurring about five hours after the setting of the Sun.

Most experimenters[50, 51] have noticed the occurrence of exceptional nights characterized by a brightness particularly great which, according to Lord Rayleigh, cannot be attributed to aurora displays covering a large part of the sky. In India, Karandikar[49] brought attention to the fact that, when the variations of intensity are abnormal, they remain analogous for the different spectral regions, and that under these conditions, the intensity is always exceptionally high compared with that of normal nights.

Theories of the Origin of the Night Sky Light

The results which have just been exposed show that the night sky light is a very complex phenomenon, whose origin still remains to a great extent mysterious. We will summarily indicate the hypotheses which seem acceptable for explaining, at least provisionally, the presence of the continuous spectrum of the solar type and the selective emission of which we know now the principal characteristics.

(1) Continuous spectrum[3]

It is impossible to evaluate at present the portions of the sky brightness attributable to the discontinuous and to the continuous spectra. The weak stars certainly produce a portion of the latter and, in this respect, the statistical researches of Seares, on the average color index of the stars of each magnitude, show clearly that the whole ought to give approximately a

[46] N. Dobrotin, I. Franck and P. Čerenkov, Comptes rendus U. S. S. R. **1**, 110 (1935).
[47] I. Chvostikov and A. Lebedev, Comptes rendus U. S. S. R. **1**, 118 (1935).
[48] D. J. Eropkin and N. A. Kozirev, Poulkovo Observatory Circular **13**, 21 (1935).
[49] J. V. Karandikar, Ind. J. Phys. **8**, 547 (1934).
* Private communication.

[50] Chas. Fabry, Bull. Soc. Astronom. France **32**, 22 (1918).
[51] Lord Rayleigh, Proc. Roy. Soc. **A131**, 376 (1931).

spectrum of the solar type, like that observed in the night sky. If the emission of weak stars were sufficient to explain completely the presence of the continuous spectrum, this would correspond to $\frac{1}{3}$ at the most of the brightness of the sky, measured by photography on an ordinary plate. But the contrast between the bright bands and the continuous background is too weak for such to be true, and it has to be conceded that the continuous spectrum only partially proceeds from weak stars. Besides, the observed polarization indicates the presence of a certain proportion of sunlight scattered outside of the earth atmosphere, at least at a distance of the order of the earth radius. By attributing this effect to an extension of the zodiacal light, it is possible to explain another ten to fifteen percent of the brightness of the sky. The spectrum of the zodiacal light includes evidently the radiations emitted by the superposed sky background. Spectrophotometric comparisons between this complex spectrum and that of the normal sky light have shown (Eropkin and Kozirev,[48] Cabannes and Dufay[52]) that the emission lines or bands do not exist in the spectrum of the zodiacal light itself, which is essentially a continuous spectrum with Fraunhofer lines.

Moreover, it is possible to postulate a scattering of light in interstellar space. It is admitted now that there exists in the neighborhood of the galactic plane an absorbing layer relatively thin and very much spread out; the absorption is said to be greater for the violet than for the red, so that it could be consistent with scattering according to Rayleigh's law in λ^{-4}. The scattering of the light from the stars by this layer being greater than that of the sunlight, there would be practically no polarization. In computing the brightness that such a layer would give to the night sky, it is found that it could double that which should be attributed to the stars themselves; this is an acceptable order or magnitude. Lastly, outside of the zodiacal light customarily so called, one can think of the scattering of sunlight by interplanetary particles. There surely exist in the space around us a great number of minute asteroids, which become shooting stars in penetrating the higher atmosphere; if they escape this fate, they reflect toward us a little sunlight without perceptible polarization. Furthermore, traces of gases, coming from planetary and solar atmospheres should exist in the entire solar system.

(2) Selective emission spectrum

We have seen that the selective emission of atmospheric origin is manifestly similar to the radiation of polar aurorae. It differs only in the degree of excitation (the relative intensities of the various systems of nitrogen bands being reversed), and in a greater richness in radiations of unknown or doubtful origin.

In order to estimate roughly the altitude of the luminous layers, Cabannes and Dufay use the following process. A total reflection prism is placed so as to cover half of the spectrograph slit, in order to photograph simultaneously the zenith and the horizon, and afterwards to compare the intensity of the radiations proceeding from these two regions of the sky. For the emission spectrum, it is found that the intensity is always greater in the north and in the south than at zenith. The ratios found, variable from one radiation to another, are of the order of 1.5. The atmospheric absorption intervening in a complex manner, it is difficult to ascertain accurately the altitudes of the layers whence the light comes. However, by trying to take account of the absorption, Cabannes and Dufay[30, 53] computed values decidedly higher than 100 km, perhaps between 200 and 300 km, that is much greater than for the majority of the aurorae. This approximate localization seems in agreement with the fact mentioned by Vegard that, in the auroral spectrum, the intensity of the radiations of doubtful or unknown origin, relative to that of the nitrogen bands, increases with the altitude.

The spectral analysis of the aurorae and of the night sky shows that at very high altitudes, and apparently as far as the confines of the atmosphere, this is mainly composed of oxygen and nitrogen, in contradiction with the classic theories which tend to make us suppose the exclusive presence of very light gases (hydrogen,

[52] J. Cabannes and J. Dufay, Comptes rendus **201**, 696 (1935).

[53] J. Cabannes, Helv. Phys. Acta **8**, 405 (1935).

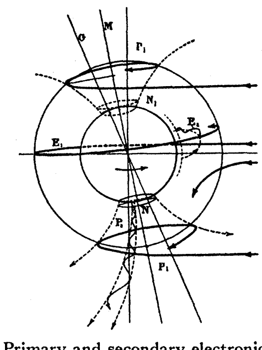

FIG. 15. Primary and secondary electronic paths in the earth magnetic field: P_1, polar primary paths; E_1, equatorial primary path; P_2, secondary path producing the Nordenskjöld corona; E_2, secondary path producing the general nonpolar aurora.

helium). At 100 km of altitude, the pressure then would not be 13 baryes as these theories predicted, but only of the order of one barye. The presence of water vapor under these conditions, revealed by the observations of Sommer and of Cabannes, is not very surprising, no more than is that of a trace of argon. Besides, we know that auroral displays bring out nearly always the formation of cirrus which imitates curtains or rays, thus made visible during the day, or which takes on the form of the polar arc of Nordenskjöld. No doubt, it is the result of condensation of water vapor on the negative ions which are produced during aurorae. On the other hand, very high clouds (80 km, according to Störmer) can be observed at the end of twilight, while the very high layers of the atmosphere are still receiving sunlight. Their presence also reveals the possibility of a condensation of water vapor in the higher atmosphere.

In 1932, Dauvillier[54] suggested an extremely attractive theory which tries to interpret simultaneously all the phenomena of the high atmosphere, by attributing them to the electronic emission of the sun. The electrons having a velocity (corresponding to an energy of 10^{10} electron volts) not much less than that of light, are assumed to be projected mainly by the faculae in the neighborhood of the equatorial plane of the sun. Their paths, made visible by the scattered sunlight, form the solar corona and the zodiacal light, considered simply as an extension of the corona to the region of the earth's orbit. According to this theory, the zodiacal light should be minimum at the solstices and maximum at the equinoxes. Dauvillier claims that such will be the case for all geocosmic phenomena, such as the polar aurora, the night sky light, the telluric or magnetic disturbances and their periodical variations. The hypothesis of a purely electronic origin of the zodiacal light seems to agree very well with its strong polarization and its rapid variations of extent and of intensity during magnetic storms; these last are presumably related to the variations of density of the coronal electronic flux at the earth's level.

When the solar electrons come into the neighborhood of the globe (Fig. 15), their paths curve into the earth's magnetic field and take a radius which near the poles is of the order of that of the earth and is approximately double this value at the equator. The earth is then surrounded at a distance of the order of its radius by a quasi-spherical enclosure of paths, whose electrons always manage to escape because of their oblique incidence, the magnetic axis being always inclined to the ecliptic plane. Dauvillier assumes that gas molecules (oxygen, nitrogen) exist even at this distance from the earth. These molecules will then be ionized by the primary electrons which thus produce much less rapid secondary electrons. These are going to wind themselves in helices having a rapidly decreasing radius, around the lines of the magnetic field. They go in the direction of the poles of the two hemispheres, crossing the atmosphere in which they undergo an increasing absorption, up to the point where they have exhausted all their energy in ionization work. Their paths will then be indicated by a rapidly increasing luminosity toward the bottom, sharply limited at the lower edge. This luminosity is due to the neutralization of the pairs of ions formed during their journey. It takes in the sky the form of the lines of magnetic force and constitutes the polar aurorae.

Considering the primary polar paths (such as P_1, Fig. 15) it is possible to show that the poles will be constantly surrounded by a luminous

[54] A. Dauvillier, Rev. gén. de l'électricité **31**, 303, 443, 477 (1932).

ring whose intensity will depend on the solar activity and on the solar equatorial distribution of the coronal intensity. In fact, this phenomenon is none other than the steady auroral arc of Nordenskjöld, whose characteristics are in good agreement with the initial hypothesis which attributes to the solar electrons an average energy of about 10^{10} electron volts. The Nordenskjöld arc corresponds to the average electronic emission of the sun. The fluctuations of the solar activity, from the point of view of the energy and intensity of the electronic rays, correspond to bright and rapidly changing aurorae, that can be called storm aurorae to distinguish them from the quiet aurora of Nordenskjöld. We have previously seen (Fig. 14) that the frequency of these storm aurorae presents a maximum at the equinoxes and it is known besides that it undergoes the influence of the solar activity.

The primary equatorial paths (such as E_1, in Fig. 15) also liberate secondary electrons, but these, following the lines of the magnetic field, arrive in temperate regions. As a result, there is the production of a general aurora, permanent and diffuse, weak at the equator and of increasing intensity with the magnetic latitude. This must correspond to the selective emission of the night sky. In fact, it has been seen that the law of annual variation of the intensity, for the green line and for the bands 4425 and 4171, is closely similar to that which governs the frequency of the aurorae of low latitude. To summarize: Dauvillier's theory attempts to explain the brightness of the night sky by adducing: (1) the scattering of sunlight by the primary electrons, beyond the radius of the earth, which is identified with the zodiacal light extending nonuniformly over the whole sky; (2) the luminescence excited by the secondary electrons in the atmospheric strata of altitude higher than 100 km. Moreover, the production of ozone is ascribed to the secondary electrons of the present theory and not to the action of ultraviolet solar radiations which would be expected to have the opposite effect (direct destruction of ozone molecules, or else destruction resulting from the increase in temperature due to the absorption of the radiations of wave-lengths shorter than 2900A). Ozone would then be produced at an altitude of more than 100 km, thence descending slowly and assuming the distribution known at present (center of gravity about 20 km up).

Of course, this theory does not tell anything about the transformations which take place in the high atmosphere, under the action of the "rain" of secondary electrons. Sommer proposed to explain the emission of the oxygen bands, in the region of the great wave-lengths of the visible spectrum, by the decomposition of ozone. Cabannes[26, 53] postulates both metastable molecules of nitrogen A and metastable atoms of oxygen ^1S, the formation of which would be attributed to the secondary electrons of the Dauvillier theory. Assuming that the probability of excitation is roughly the same in the two processes, the numbers of metastable molecules $N_2(A)$ and atoms $O(^1S)$ are proportional to those of the normal molecules N_2 and atoms O present in the high atmosphere. Then, estimates of the relative intensities of the green line and of the Vegard-Kaplan bands show that the molecules N_2 are about three times more numerous than the atoms O. In the luminescent layer, at least $\frac{2}{3}$ of the oxygen must be in atomic state, resulting from dissociation of molecules O_2 by the secondary electrons. The average life of the molecules $N_2(A)$ is quite long, but in the higher strata, on account of the rarety of molecular encounters, the spontaneous transitions to normal state become possible, and are accompanied by the emission of the forbidden bands $A \rightarrow X$ (Vegard-Kaplan bands). The phenomenon may be compared to the excitation of the forbidden lines O I, the green line corresponding to the transition between the two metastable $^1S_0$ and $^1D_2$ and the two red lines to the return from the metastable state $^1D_2$ to the levels $^3P_2$ and $^3P_1$. In lower layers, the encounters between particles capable of exchanging energy (for example: $O(^1S)$ and $N_2(A)$, or $O(^1S)$ and H_2O) must generate a second type of luminescence phenomena (second positive system of nitrogen bands, vibration spectrum of water vapor, etc.). The atmospheric ozone does not apparently play a part in the emission. In fact, the annual variation of the night sky light and that of the amount of ozone do not follow the same law.

Attempts at Reproducing in the Laboratory the Spectra of the Aurora and of the Night Sky

The attempts made by Vegard (1923) to identify the spectrum of the aurora with that of the solidified nitrogen bombarded by cathode rays may be mentioned only because of their historical interest. McLennan and Shrum proved shortly after that the wide yellow-green band so obtained is really composed of three components (5556, 5619 and 5654A), perfectly distinct from the aurora line at 5577A. This line, produced in the laboratory by the same workers, should be definitely identified with the forbidden oxygen line. The bands of solid nitrogen, observed since by McLennan and his collaborators, seem to be related to the various positive systems of nitrogen (Kaplan) and we now understand why Vegard tried to identify the luminescence spectrum of the solidified nitrogen with that of the aurora borealis.

Since 1928, J. Kaplan has accomplished interesting and important experiments with the object of reproducing in the laboratory the auroral spectrum and investigating the conditions of excitation that must exist in the high atmosphere. Kaplan used as source the afterglow observed in a discharge tube containing nitrogen or a mixture of this gas and oxygen. The luminescence which subsists after the end of the discharge is due to the presence of active nitrogen in the atmosphere of the bulb, and generally its spectrum differs notably from that of the discharge itself, from which it can be separated by means of a revolving light interrupter. This method made possible in the first place the excitation of the aurora green line in the afterglow,[55] the nitrogen containing a very feeble proportion (for instance, several percent) of oxygen. In 1932, Kaplan[56] obtained active nitrogen in an uncondensed discharge, after having made the tube undergo a preliminary treatment under the action of the discharge lasting several days. Under these conditions, he found in the spectrum of the afterglow, with a relatively high pressure (several mm) the bands of the ionized nitrogen molecule (negative bands) unaccompanied by the N^+ lines which are, on the contrary, always present when the N_2^+ bands are excited at low pressures. In this regard, the spectrum shows the same characteristics as those of the aurora. Kaplan was led to infer the presence, in the mixture which gives the afterglow, of metastable molecules $A(^3\Sigma)$, of which the direct excitation by electronic impact is responsible for the strong intensity of the negative bands. Further, he proposed to interpret the aurora light as that of an electric discharge in a mixture of nitrogen and oxygen containing numerous metastable molecules. The spectrum of the aurora might also result from the superposition of those of the exciting discharge and of the afterglow. Kaplan[57] has studied conditions corresponding to weak current intensities and for which these two spectra, including the negative and the first and second positive systems of nitrogen, are not much different and are both analogous to that of the aurora.

Continuing with the same method, Kaplan[58] succeeded in 1934 in exciting in the active nitrogen afterglow (suitable pressure: 0.1 mm) a new band spectrum which was recognized to be identical with that discovered by Vegard in the luminescence spectrum of solid nitrogen. The new bands were, as already mentioned, classified by Herzberg and the level from which they originate is none other than the metastable state $A(^3\Sigma)$. Consequently, their appearance is an absolutely convincing proof of the presence of metastable molecules A in the active nitrogen afterglow. In June 1934, Kaplan[59] brought to notice that the night sky light can best be explained as bands belonging to the first and second positive systems of nitrogen, as well as to the new system $A \rightarrow X$ recently discovered (see above). Use of active nitrogen makes possible the excitation of a spectrum of this type, which is obtained when using the lowest current intensities capable of producing a rather intense afterglow. We can then consider the selective emission of the night sky as being that of a very weak afterglow in the rarefied nitrogen of the high atmosphere.

In 1935, Kaplan[60] briefly described some new experiments during which the green line and the

[55] J. Kaplan, Nature **121**, 711 (1928); Phys. Rev. **33**, 154 (1929).
[56] J. Kaplan, Phys. Rev. **42**, 807 (1932).
[57] J. Kaplan, Phys. Rev. **45**, 671 (1934).
[58] J. Kaplan, Phys. Rev. **45**, 675 (1934); **45**, 898 (1934).
[59] J. Kaplan, Nature **133**, 331 (1934); **134**, 289 (1934).
[60] J. Kaplan, Nature **135**, 229 (1935).

nitrogen bands were excited simultaneously, under conditions which reproduce, in its principal features, the selective emission of the night sky. Instead of trying to separate the spectrum of the afterglow, Kaplan photographed the spectrum of a discharge periodically and quite frequently interrupted, so that the current could not attain to its maximum value. Under these conditions were observed together the emission of the green line, that of the new bands $A \rightarrow X$ and that of the second positive system of nitrogen. In the visible region, the red line O I and the bands of the new system were not recognized with certainty. Nevertheless, the whole of the observations clearly indicates that the complex light thus produced presents great similarities with that of the night sky. In June 1935, Kaplan[37, 61] described the spectrum of an afterglow produced by a very feeble discharge; the negative bands of nitrogen are not present, and the new bands $A \rightarrow X$ have a much greater relative intensity compared with that of the second positive system. Moreover, in the case of the periodically interrupted discharge, the intensity of the green line is considerably increased when the current is lowered to the convenient value for enhancing the Vegard-Kaplan bands in the new afterglow.

In collaboration with Miss Schwégler, G. Déjardin[62] studied in 1934 the luminescence excited by the rolling of a mercury drop on the inside wall of a glass bulb containing an impure rare gas. In the case of neon with a trace of nitrogen (and perhaps helium) there is thus obtained a spectrum very similar to that of the polar aurora, in respect of the spectral composition as well as for the relative intensities of the emitted radiations. These last include the principal bands of the negative and second positive systems of nitrogen, and also several weak radiations of doubtful origin, attributed to N I, N II (?) or He I. The analogy is much less pronounced with the spectrum of the night sky. When the luminescence of argon is excited under the same conditions, a spectrum is obtained including, in addition to the A I lines, a large number of A II lines of the ionized atom; this gives an idea of the degree of excitation attainable by this method. The same spectra are produced without any mercury by applying a continued friction (with cloth or cardboard) on the outside wall of the bulb while it is being rotated by means of an electric motor. A more complete examination of the impure neon plates has revealed the presence of certain radiations (λ measured: 4540, 4218, 3981, 3845 and 3772) which are probably Vegard-Kaplan bands (λ computed: 4535, 4219, 3979, 3844 and 3768). With the exception of the last, these bands are among those which also seem to exist in the spectrum of the aurora, according to Vegard's observations. The spectrograms corresponding to impure argon also show three radiations very near Vegard-Kaplan bands (λ measured: 4317, 4220 and 3981).

On the other hand, at the Physics Laboratory of the University of Lyons, R. Bernard[63] studied the emission obtained in submitting to a controlled electronic bombardment (in a three-electrode tube) a mixture of argon and a very small proportion of nitrogen or air (total pressure between 0.1 and 0.6 mm; proportion of nitrogen varying from 10^{-1} to 10^{-5} of the total pressure). The spectra photographed under these conditions, for accelerating potentials between 15 and 20 volts, show great analogies with that of the night sky, except for the excitation of strong lines A I. In addition of the bands of the first and second positive systems of nitrogen, we can distinguish a large number of Vegard-Kaplan bands belonging particularly to the following sequences: $v''-v'=10$, 11, 12 and 13. Their wave-lengths, measured on the microphotometer records, are given in the following table, with (between parenthesis) the wave-lengths computed by the Herzberg formula modified by Cabannes and Dufay.

5326	(5327)	4535	(4535)	3889	(3889)
5060	(5061)	4495	(4495)	3855	(3856)
4960	(4962)	4320	(4320)	3769	(3768)
4837	(4838)	4219	(4219)	3750	(3753)
4718	(4718)	4171	(4171)	3683	(3684)
4650	(4651)	4144	(4147)	3664	(3666)
4616	(4614)	4072	(4073)	3603	(3603)
4605	(4605)	3979	(3979)	3582	(3582)
		3940	(3940)	3503	(3502)

The excitation of the bands of the first positive system indicates the presence of metastable

[61] J. Kaplan, Nature **135**, 1034 (1935).

[62] G. Déjardin and R. Schwégler, Comptes rendus **199**, 1110 (1934); J. de phys. et rad. **6**, 110 f. (1935).

[63] R. Bernard, Comptes rendus **200**, 2074 (1935).

molecules $A(^3\Sigma)$. As the partial pressure of nitrogen decreases, the relative intensity of the Vegard-Kaplan bands increases, and that of the second positive bands on the contrary weakens progressively. The rarefaction of nitrogen therefore increases the probability of the transitions $A \rightarrow X$, corresponding to the emission of the Vegard-Kaplan bands.

On the matter of the forbidden oxygen lines, we are at last able to establish an interesting comparison between the spectra of the aurora and the night sky, that of the novae and that of the planetary nebulae. Grotrian showed in 1931 the presence of the three forbidden lines O I in the spectrum of novae. In the case of Nova Herculis 1934, these three lines presented a considerable intensity, which varied in an irregular manner. At Lyons Observatory, the three green and red lines were observed from December 30, 1934 onward; the two red lines became very intense in March while the green line was already much weakened. March 11, 6300 appeared as strong as H_β and came immediately after H_α in the order of intensities. In the spectra of the aurorae and of the night sky, 5577 is much more developed than the red lines. On the contrary, the latter are frequently observed without the green line in the spectrum of planetary nebulae. The novae then seem to present intermediary conditions. In the nebulae, the dominant intensity of the red lines is due to the extreme scarcity of encounters, which makes more probable the return to the fundamental levels of O I. We are thus led to admit that in the novae atmosphere, the pressure should be weaker than in the high earth atmosphere. The gradual enhancement of the lines $D \rightarrow P$, compared to the line $S \rightarrow D$, seems to indicate a progressive decrease in pressure, in agreement with the present ideas about the evolution of the novae.

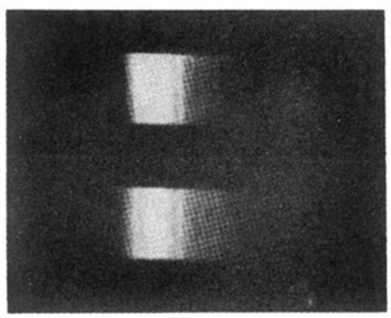

Fig. 12. Six hours exposure to the night sky.

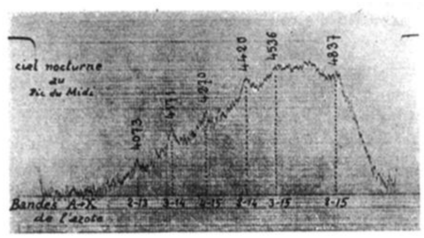

FIG. 13. Spectrogram showing the Vegard-Kaplan bands (nitrogen).

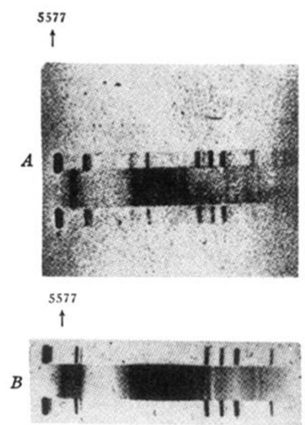

FIG. 4. *A*, Spectrum of the night sky (without moon); *B*, spectrum of the lunar sky (green line visible).

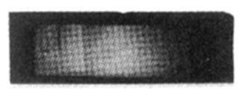

FIG. 6. Spectrogram, one and one-half hour exposure.

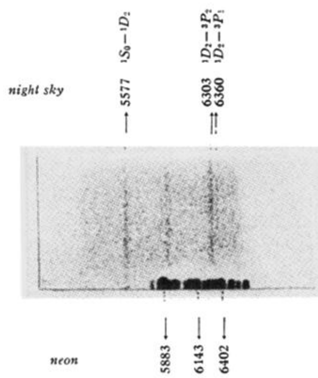

FIG. 7. O I lines in the night sky.

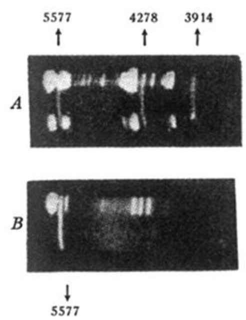

FIG. 8. *A*, Spectrogram of the aurora at Louiseville, province of Quebec, August 28, 1932 (exposure one and one-half hours). *B*, Spectrogram of the night sky photographed at Lyons with the same instrument as used in *A*, November 7, 1931 (exposure ten hours and 55 minutes).

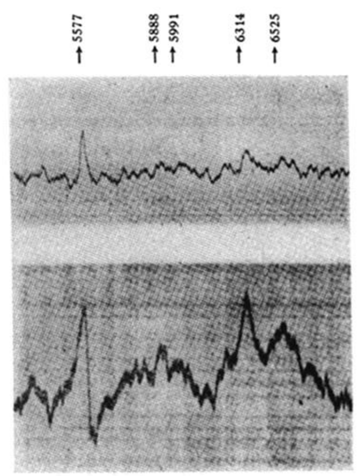

FIG. 9. Microphotometer curves of spectra taken by Cabannes.