Daytime Optical Aeronomy

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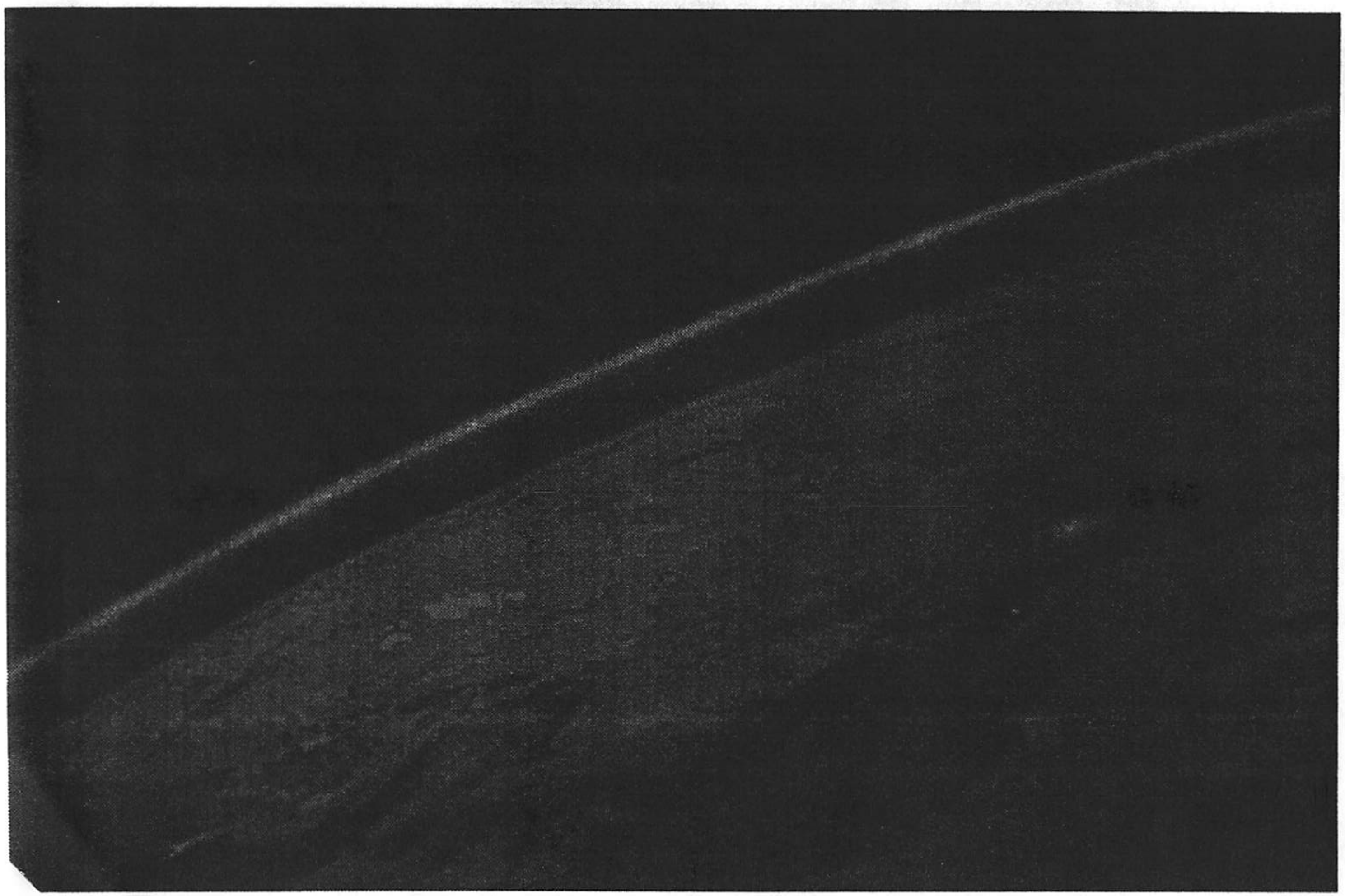
Motivation

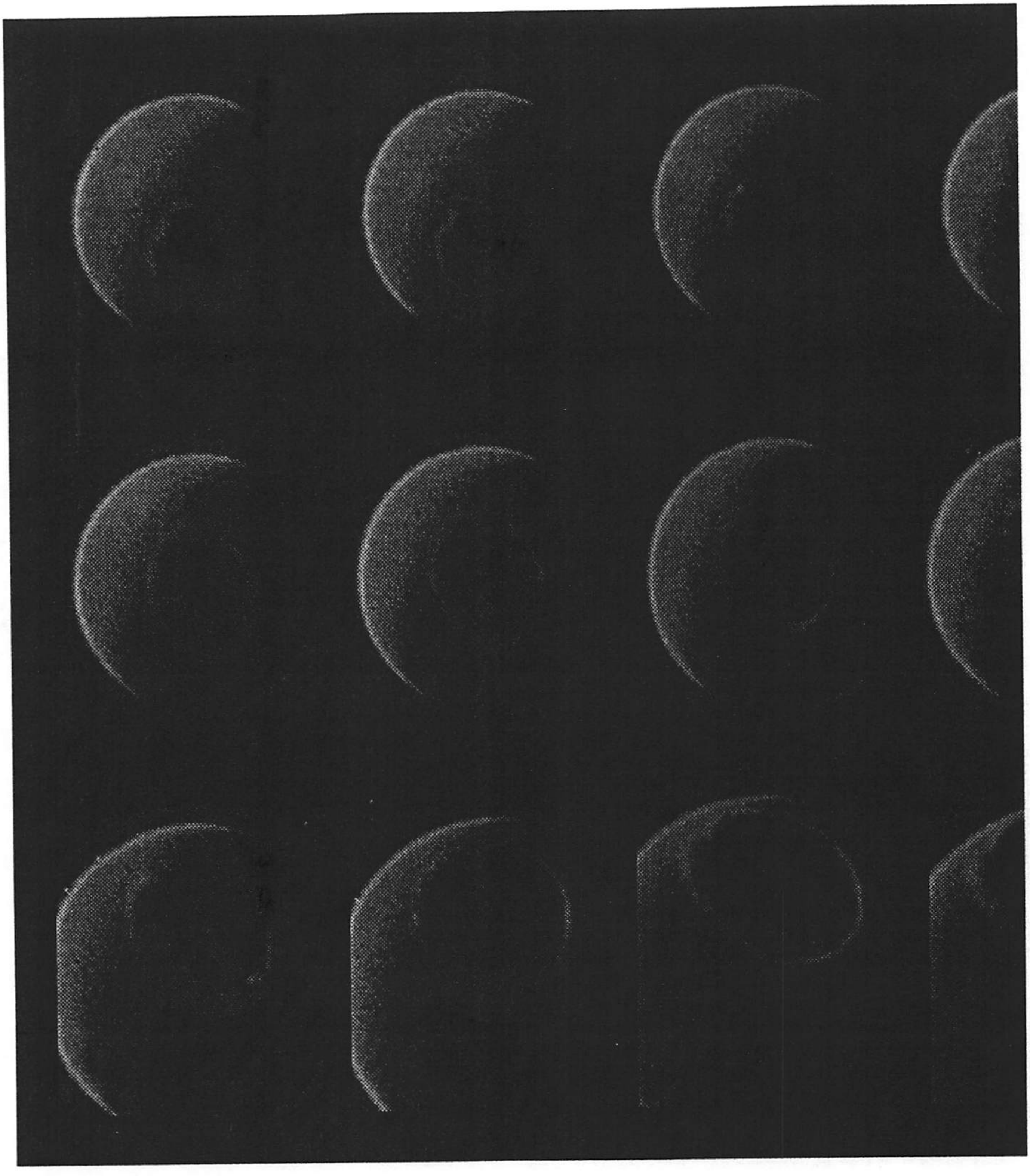
- At any given time, the Earth is
  - 42 - 45% Sunlit
  - 33 - 35% Dark (night)
  - 20 - 25% twilight

Most CEDAR related optical observations are limited to clear nights during 2 weeks centered around the new Moon

More on Motivation

- Continuous observations like RADAR
- Equatorial Spread F triggers
- Observations of cusp emissions under sunlit conditions
- Observations of Stable Auroral Red Arcs under sunlit condition
- Conjugate auroral emissions





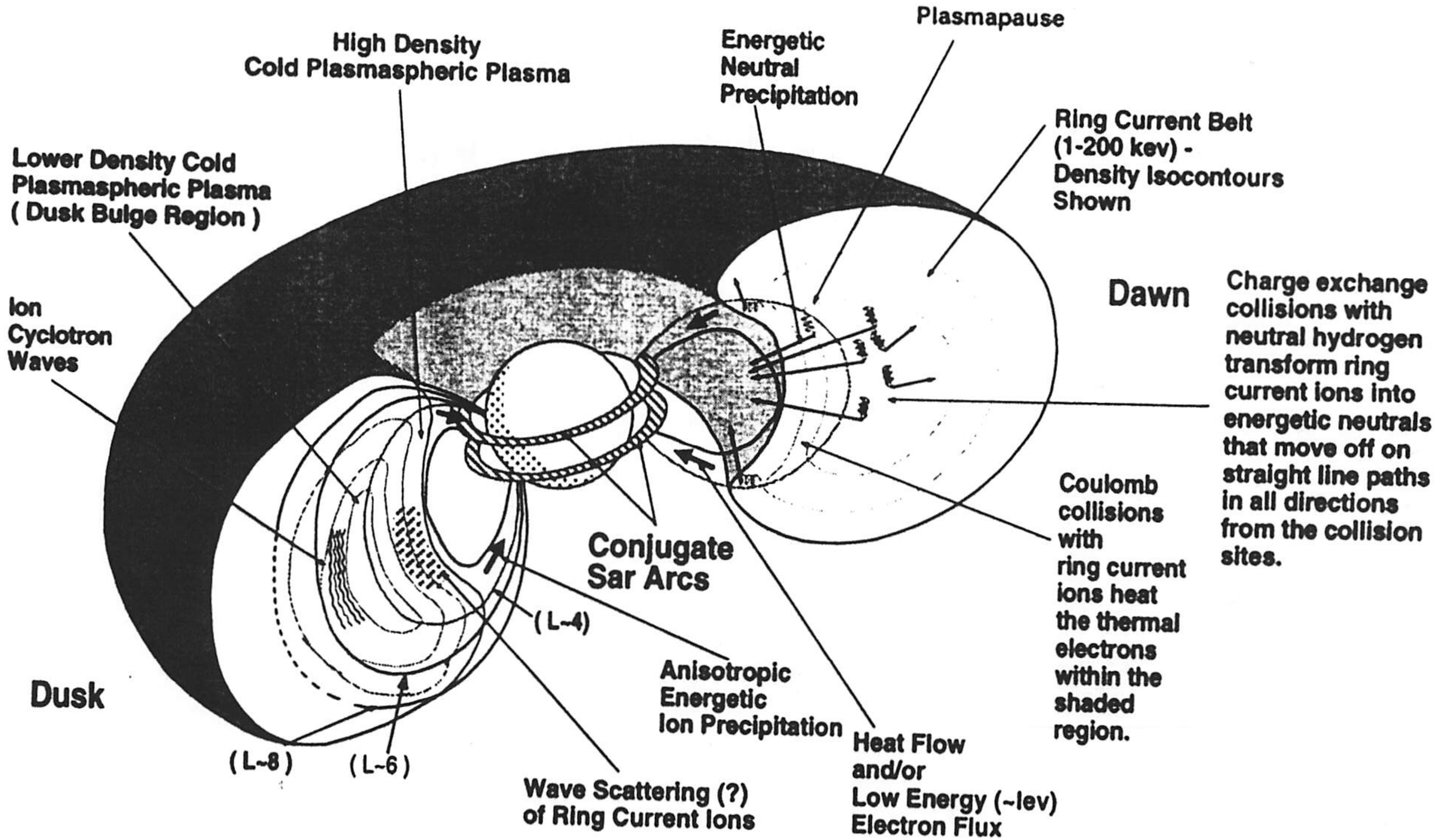


Figure 5. Blowup of the inner magnetosphere showing the overlap between the ring current and plasr
and the position of conjugate SAR arc emissions. Major ring current loss processes are summarize

Observe when the Sun is up

What can we do to increase the observing time?

(when we were grad students......

we did not complain about working nights and weekends)

Early Observations

- In the 11th Century, Persian born Egyptian mathematician, physicist, and astronomer Ibn al-Haytham (îb´en äl-hìthäm´) or Alhazen (àlhezen´)
  - Colors of twilight was due to the optical properties of the atmosphere
  - Measured the height of the atmosphere by measuring the duration of twilight (52,000 paces)

Early Observations (contd.)

- First quantitative measurement of day sky undertaken by Swiss physicist de Saussure (late 18th century)
- Systematic photometry of the Celestial Sphere started by Jensen in 1898 (Jensen, 1928)

Early Observations (contd.)

- Yntema (1909) - first photometric measurements of the night sky light
  - Called it Earthlight
  - Variable from night to night
  - Scattered starlight could not account for the zenith angle distribution of the intensity
  - Noted similar earlier observations dating back to 1788

Early Observations (contd.)

- Spectroscopic Observations of Auroral Green Line (5577A) [Campbell (1895)]
  - Present all the time
  - Permanent aurora (due to Yntema)
  - Non-Polar Aurora (due to Rayleigh, 1924)

This is what today we call *Airglow* (due to Elvey, 1950)

Terminology

Airglow: Non-thermal radiation emitted by the Earth's atmosphere with the exceptions of auroral emissions and radiation of cataclysmic origin such as lightning and meteor trains - Chamberlain (notes that essentially same as Elvey's)

Twilightglow: Sunlight shining on the emitting region from below

Dayglow: Sunlight enters from above the atmosphere

So what is the challenge?

Day sky is about 10^9-10^{10} brighter than night

Brightness of the Full Moon is 10^{-6} of the Sun

Brightness of the New Moon is 10^{-9} of the Sun

Ice, water, land - all contribute to the brightness of the sky near an observatory

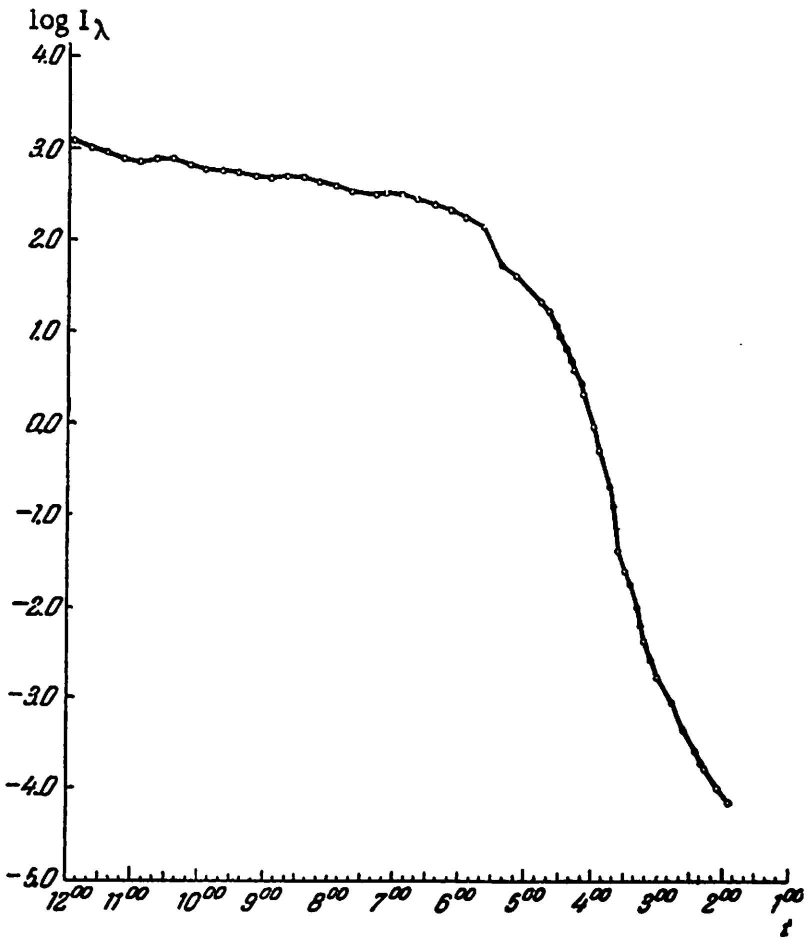


Fig. 2. A sample record of the sky brightness at the zenith as a function of time from measurements in a narrow spectral band ($\lambda \approx 0.5\ \mu$, $\Delta\lambda = 6$ A) on a July day that was not very clear.

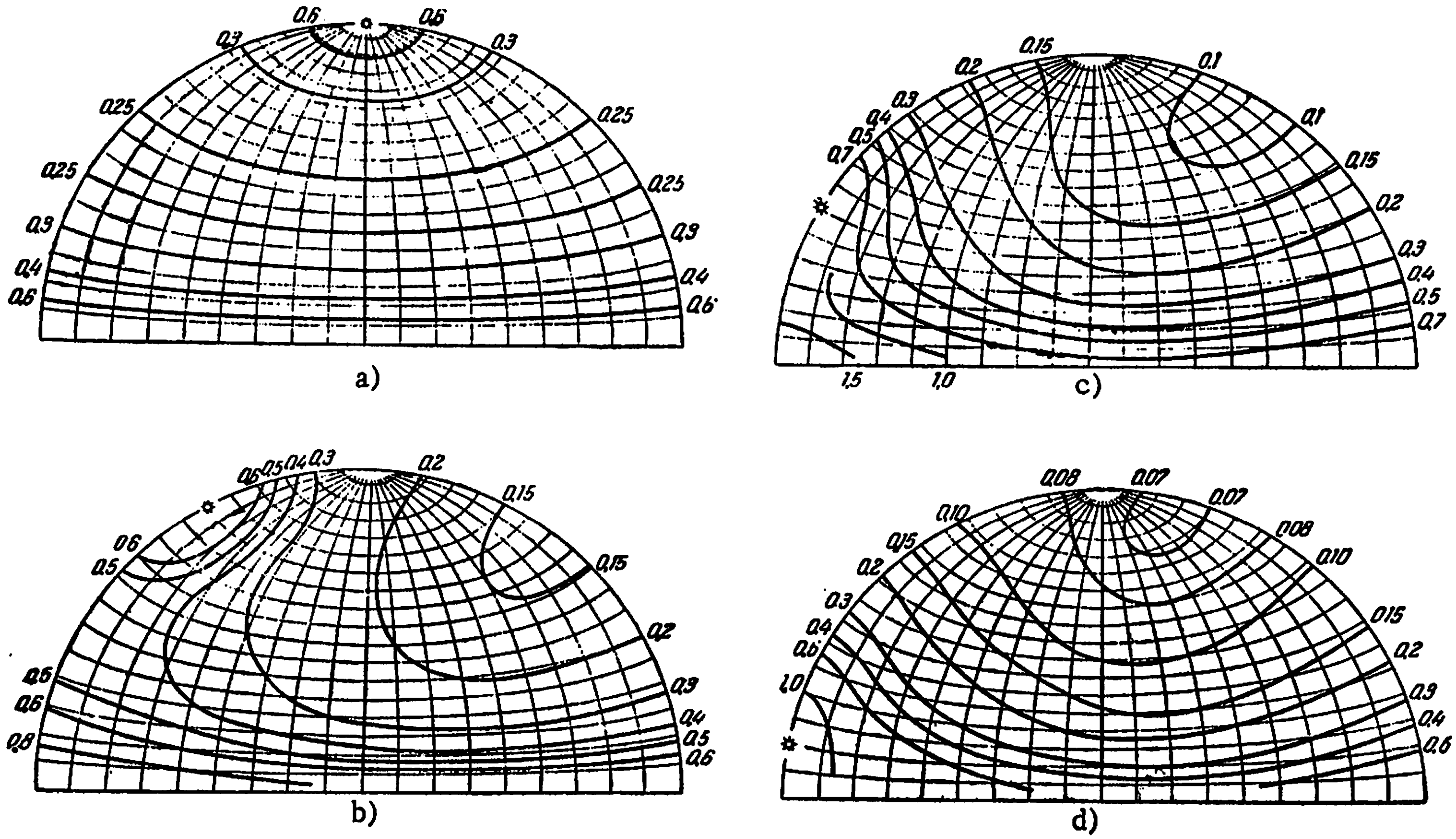


Fig. 1. Smoothed isophotes of the daytime sky for a highly transparent atmosphere (P = 0.87) and various zenith distances ζ of the sun. The surface brightness of the sky is expressed in stilbs. a) $\zeta = 0°$; b) $\zeta = 30°$; c) $\zeta = 60°$; d) $\zeta = 80°$.

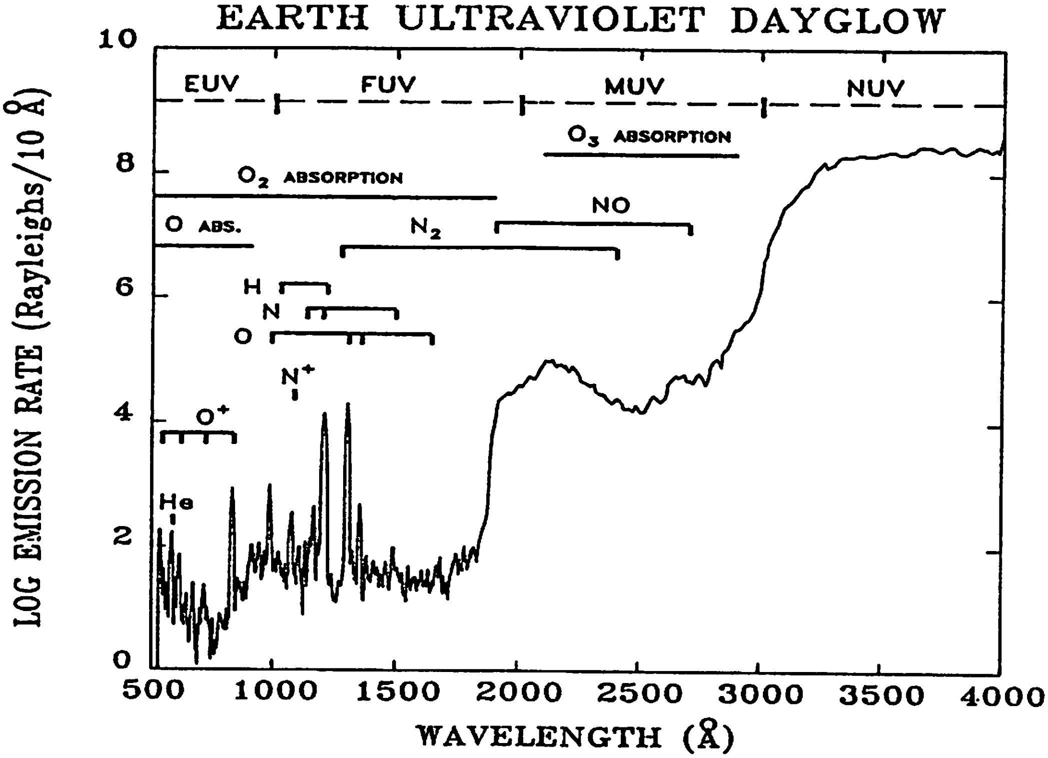


Fig. 3. Complete Earth dayglow spectrum, adjusted to nadir viewing from 200 km at midmorning. The various spectral bands defined at the top of the figure are the extreme, far, middle, and near-ultraviolet. Regions of absorption by oxygen species are indicated by thick horizontal lines; emission band intervals are shown for N_2 and NO, and the stronger emission lines of atomic and ionic species are shown. The NUV emission rate was calculated assuming an Earth albedo of 0.3 and a smoothed solar irradiance, the MUV was taken from Barth (1965), the FUV from Huffman *et al.* (1980), and the EUV from Gentieu *et al.* (1979).

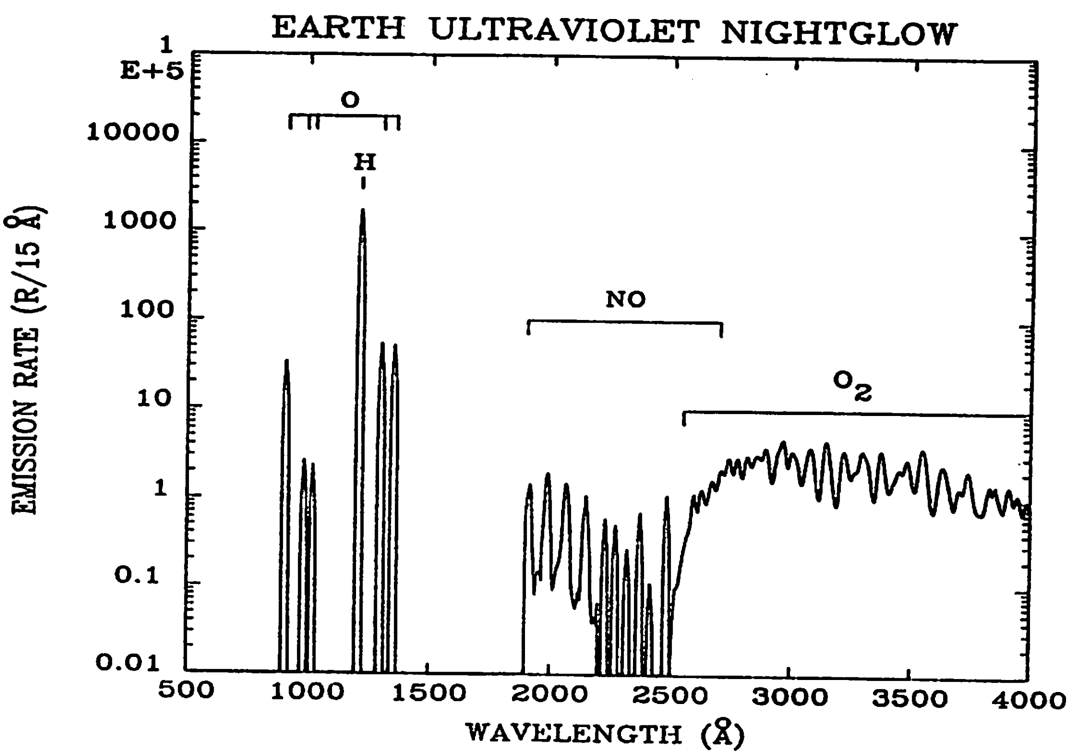
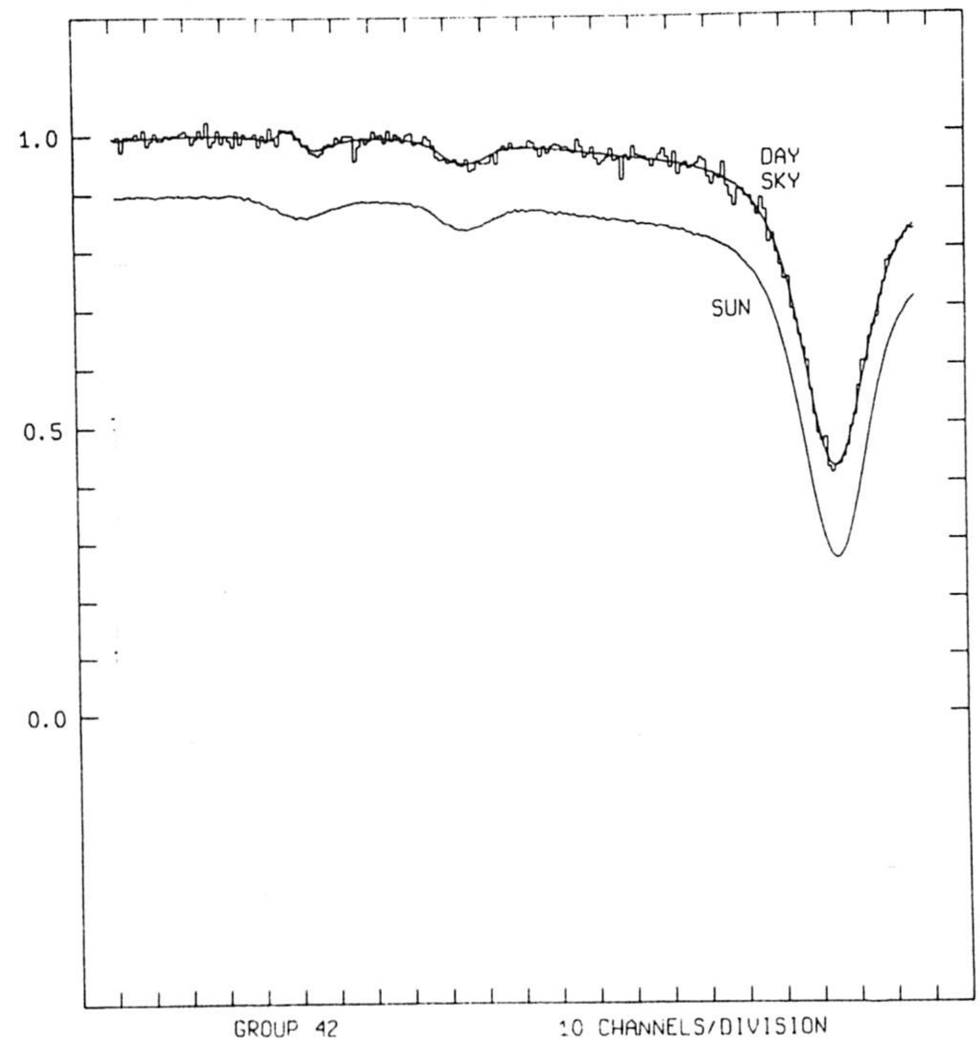
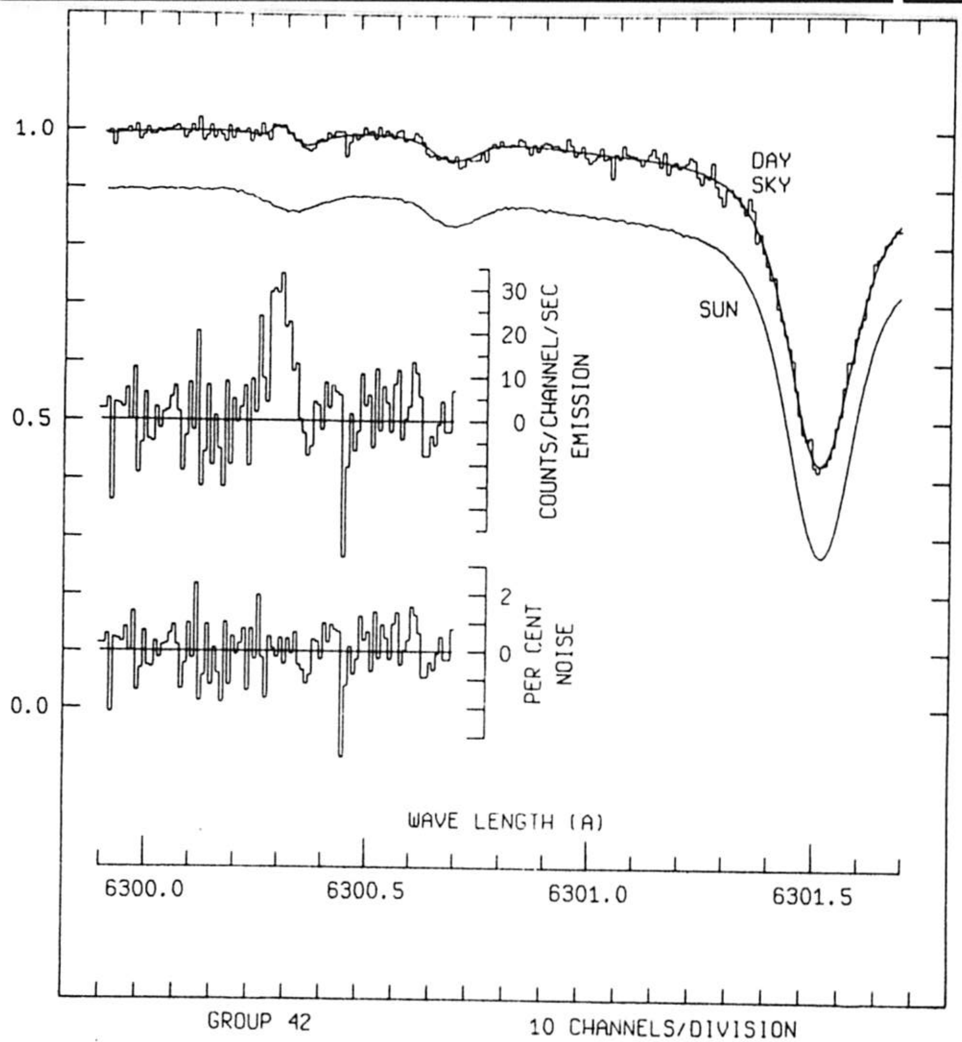


Fig. 9. Composite UV nightglow spectrum adjusted to nadir viewing from 600 km in equatorial region. All spectral features have been smoothed to 15 Å resolution. The O_2 and NO molecular, the H geocoronal resonant scattering, and the $O^+ + e \rightarrow O$ recombination emissions are indicated. The O_2 spectrum was taken from the Hennes (1966) rocket experiment, the NO spectrum from the Sharp and Rusch (1981) rocket data, and the O I and H I lines from the STP 78-1 satellite data of Chakrabarti *et al.* (1984). The absolute values of the O_2 and NO bands were obtained by normalizing to the Huffman *et al.* (1980) S3-4 equatorial spectrum (after converting the S3-4 data to absolute units). The nightglow varies strongly with geographic position, local time, and solar activity.

Find the airglow signal

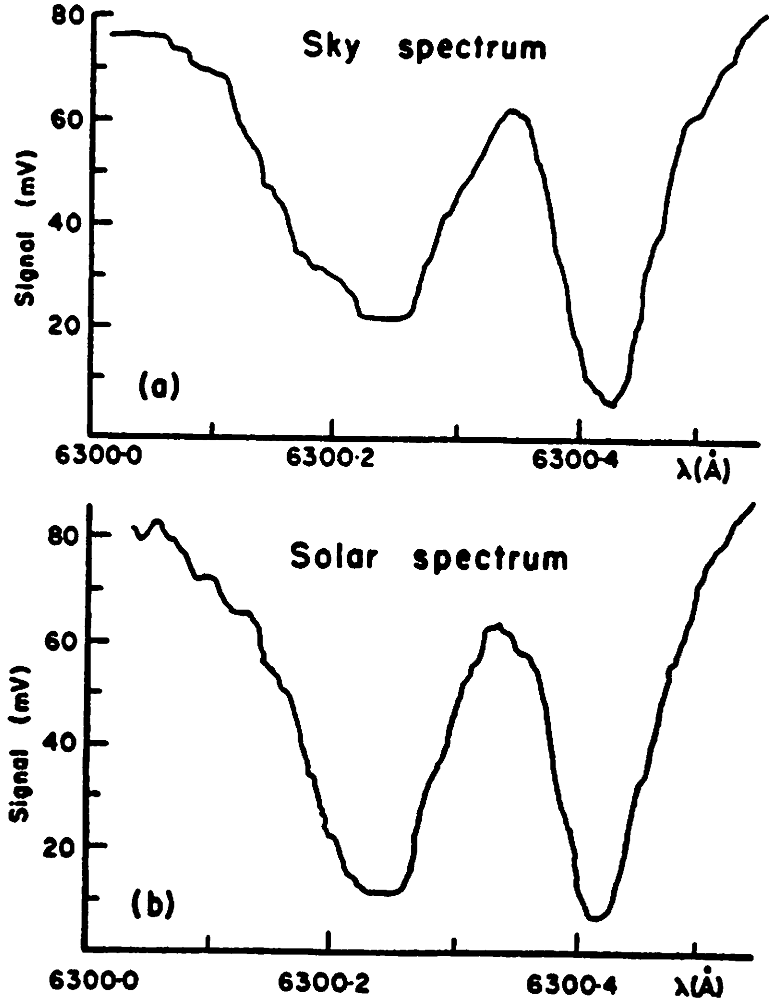


Dayglow measurement by FPI

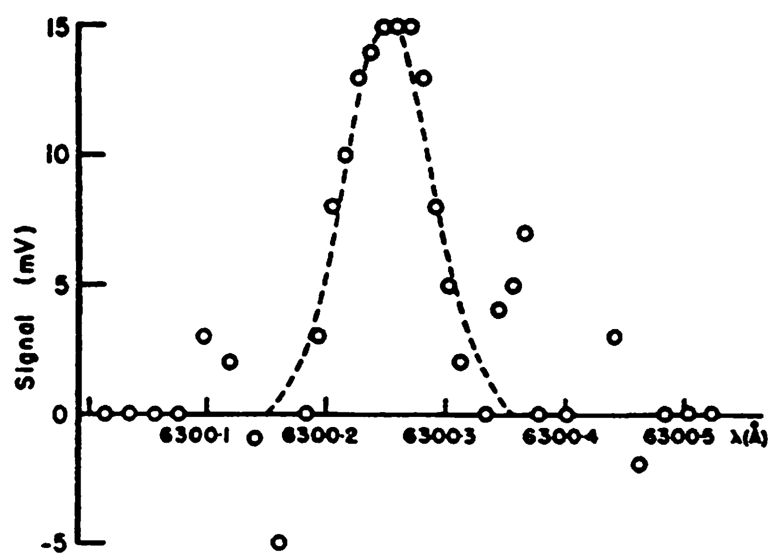


SPECTRA OF THE ZENITH DAY SKY AND THE SUN NEAR 6300 Å AS SEEN THROUGH THE SPECTROMETER.

(Barmore, 1977)



High-resolution spectra of sky and sun obtained by Bens, Cogger, and Shepherd (1965). The true zero level would actually be at about −1000 mV.



The result of subtracting the two spectra in Figure 2; the difference shows the 6300.3 Å oxygen line in the dayglow.

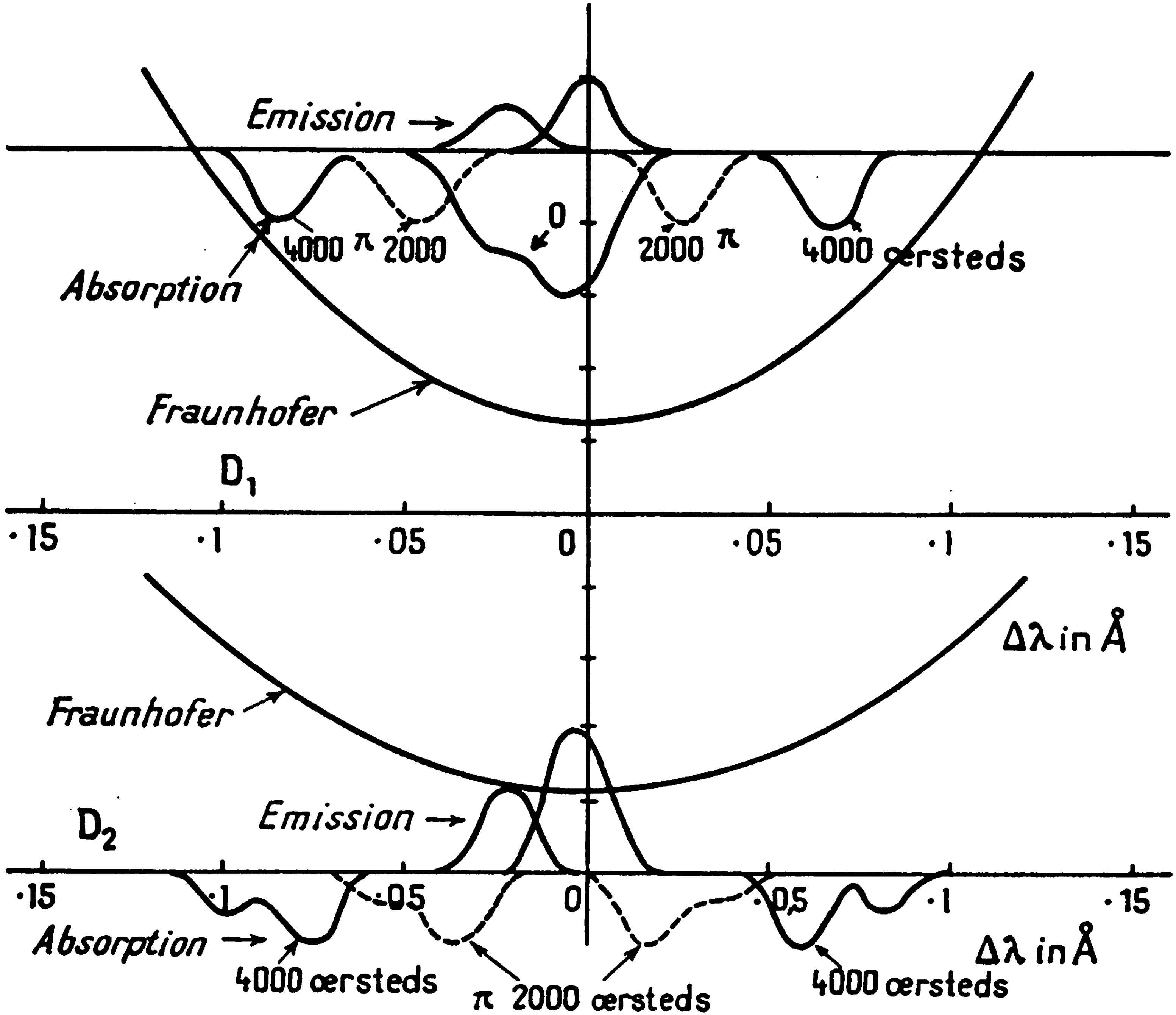


Fig. 3. Profiles of D_2 and D_1 Fraunhofer lines as computed from Priester's observation: and D_1 terrestrial lines are shown for an autumn evening. The absorption lines are those o cell at 160° with 0 field and the π components at 2000 and 4000 oersteds.

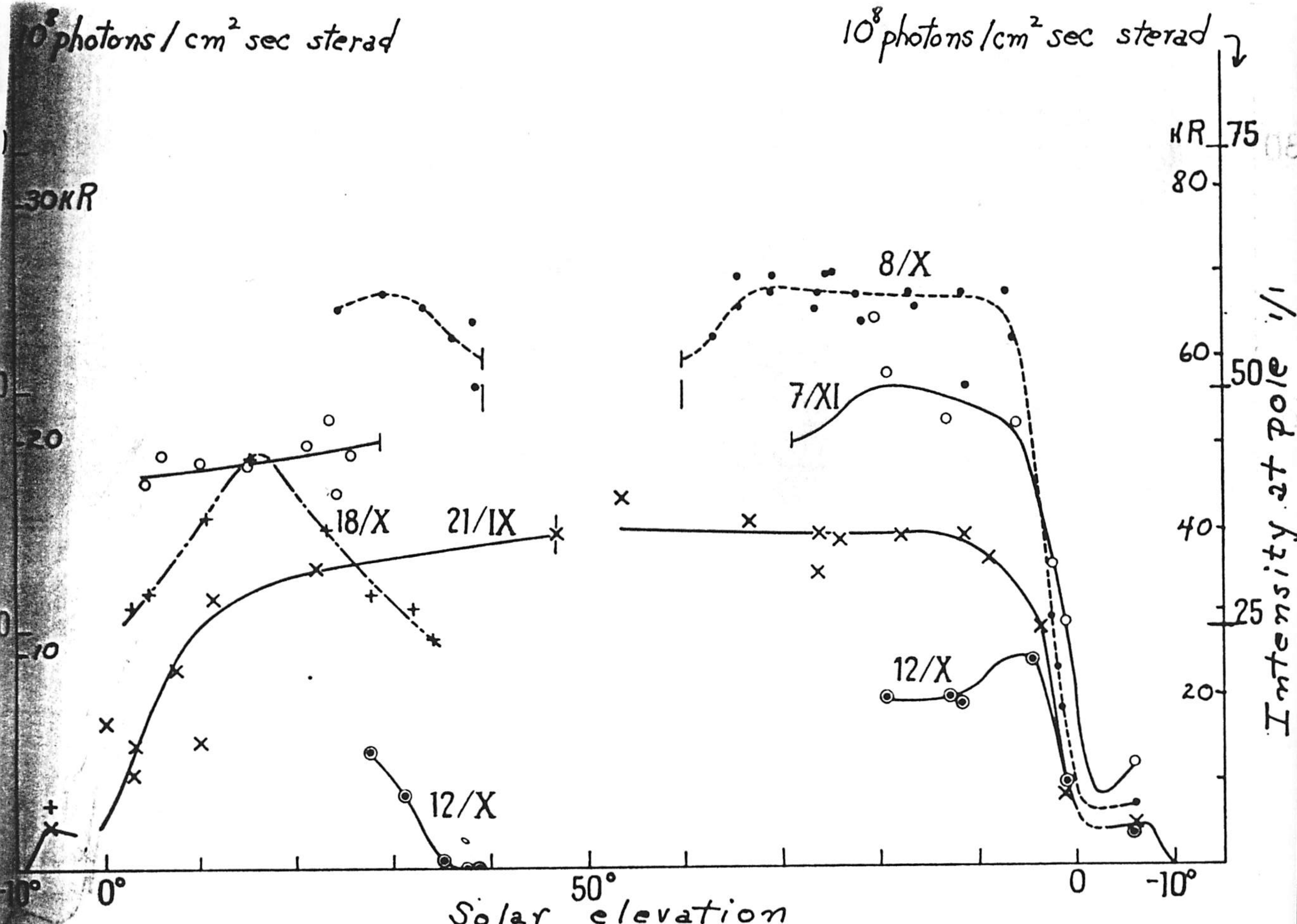


Fig. 7. Observed sodium dayglow and twilight intensities.

Visible Dayglow Observations

Dayglow Observations[a]

Emission	Wavelength	Altitude	Zenith Intensity
Lyman-α	1216 Å	> 100 km	5–12 kr
O I $^3P-^3S$	1304 Å	> 100 km	2–6 kr
[O I] $^5P-^5S$	1355 Å	> 100 km	0.4 kr
NO-γ	2000–3000 Å	80–140 km	1 kr
N_2 2PG	3000–4000 Å	obs > 170 km	0.4 kr
N_2^+ 1 Neg	3914 Å 4278 Å	100–400 km	2–5 kr
[N I] $^4S-^2D$	5200 Å	> 100 km	0.1 kr
[O I] $^1D-^1S$	5577 Å	80–250 km	2 kr
Na D	5893 Å	85–95 km	5–40 kr
[O I] $^3P-^1D$	6300 Å	> 125 km	2–60 kr
[O_2] $^1\Sigma g-^3\Sigma g^-$	7600 Å 8640 Å	40–130 km	300 kr
[O_2] $^1\Delta g-^3\Sigma g^-$	1.27 μ	40–90 km	~25 mr
OH	2.8–4.0 μ	not measured, probably 50–90 km	~5 mr

[a] References and details on these emissions are given in the text. Several features show a wide range of intensity; the true range may be less than is shown. The NO- and second positive N_2-intensity applies to the strongest band.

(As summarized by Noxon, 1968)

Strategy for Ground based optical airglow and auroral observations

- Since the signals are line emissions, and the dominant background is continuum, use small bandpass instruments
  - High spectral resolution spectrometers or photometers
  - Fabry-Perot Interferometers
  - LIDARs
- Use conventional instruments from high altitude
  - Aircrafts, balloons, rockets, spacecrafts
- Exploit the difference in polarization characteristics of the signal and background
- Exploit unusual observing conditions
  - Eclipses, dayside aurora (local winter)

Strategy (Contd.)

- Use new technology to improve SNR
  - Detector
    - » CCDs have > 10 times QE of PMTs
  - New optical configurations
    - » DGP, Hi-TIES, SCARI
  - New observation geometry and analysis
    - » Application of tomography

Examples

- High Resolution Photometer
  - First reported observation of Dayglow by Blamont and Donahue (1961) used a sodium vapor cell (as the bandpass selector) which was periodically subjected to a magnetic field perpendicular to the optical axis (to further discriminate the airglow signal from Rayleigh scattered component)

Works for resonance lines of selected species

Examples (contd.)

- High resolution Spectrometer
  - So far, the airglow measurements have been carried out by interferometers e.g., Jarrett and Hoey, 1963 (*controversial*); Bens et al., 1965; Barmore, 1977 and Sridharan et al., 1992, 1994, 1995.
- LIDARS
  - Gibson and Sandford (1972) found that sodium abundance enhancement smaller than dayglow observations reported by Blamont and Donahue (1961)
  - Clemesha et al. (1982) studied diurnal variations
  - Yu et al. (1997) obtained tidal temperature

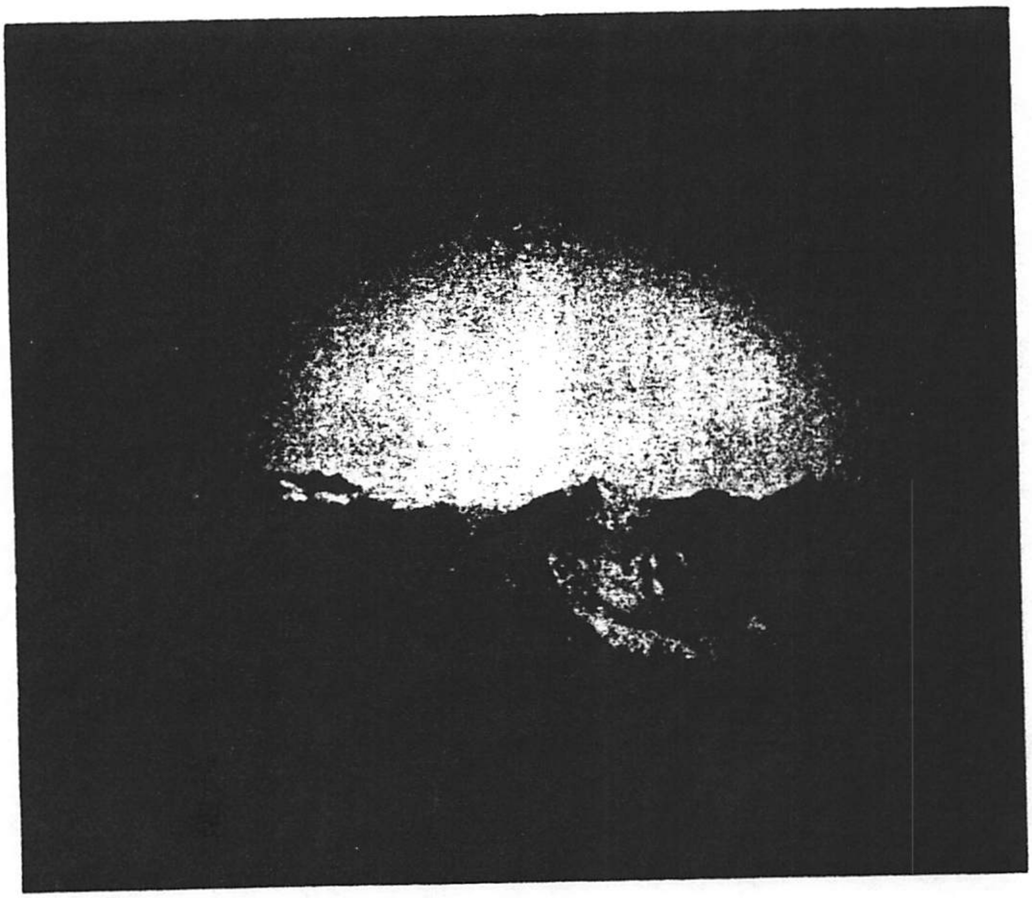


Fig. 1. Fabry-Perot interference fringes of the dayglow 6300 Å OI radiation photographed at l'Observatoire du Pic du Midi (altitude 2877 m) on 30 August 1963 at $18^h.00$ G.M.T. Exposure 5 sec, f/2 camera, with a single plate Fabry-Perot interferometer and 15 Å half-width interference filter. Azimuth due south over Pyrenees with zero degrees elevation.

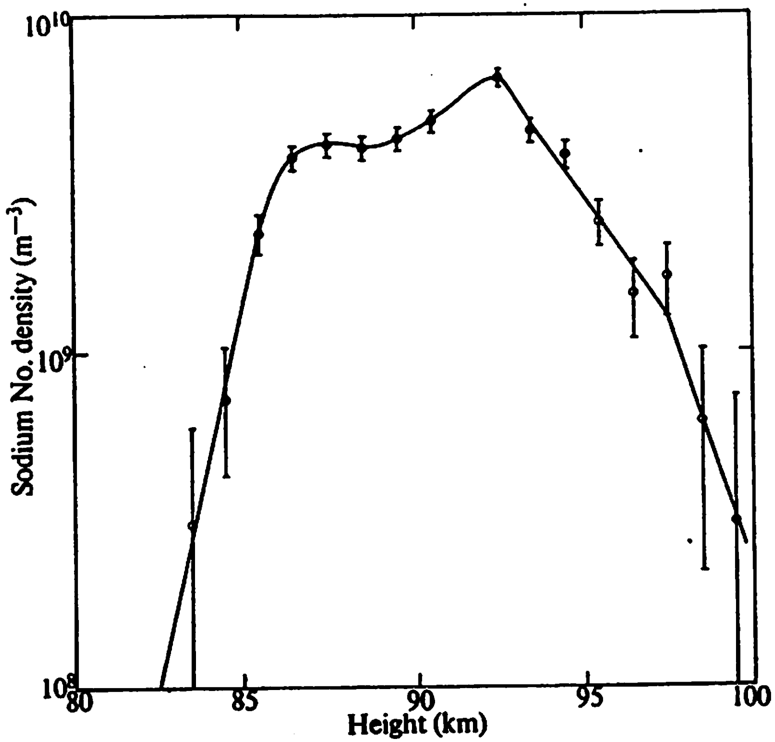


Fig. 1 Height distribution for 1,000 laser shots between 1205 and 1257 UT, October 27, 1971. The bars are the standard errors due to the limited photon count. The absolute density scale is uncertain to ±30% because a night-time calibration was not possible on this date.

Table 2 Day/Night Abundance Ratio

Date	Time of observations (UT) Day	Night	Mean abundance during day / Mean abundance during night	Mean abundance within 3 h of noon / Mean abundance during night
October 6, 1971	1300–1800	1800–2200	1.06	0.82
October 7, 1971	1300–1800	1800–2200	1.10	1.04
November 2, 1971	1100–1700	1700–2200	0.97	0.95
November 14, 1971	1200–1300	1900–2100	1.42	1.42
July 12, 1972	1800–2100	2100–2400	0.95	—
July 13, 1972	0500–0900	0000–0300	0.92	—
July 15, 1972	1100–2100	2100–2300	1.04	0.82
	Mean over all dates		1.07±0.06	1.01±0.11

TABLE 1. Specifications for the Lidar

	Nighttime Value	Daytime Value
Transmitted energy	30 mJ	60 mJ
Pulse duration	2 μs	2 μs
Repetition rate	0.4 s^{-1}	0.4 s^{-1}
Wavelength	589 nm	589 nm
Total transmitted bandwidth	10 pm	12 pm
Receiver area	0.39 m^2	0.39 m^2
Receiver bandwidth	800 pm	30 pm
Transmitter beamwidth	0.15 mR	0.15 mR
Receiver beamwidth	0.4 mR	0.2 mR
Receiver efficiency	2.4 %	0.7 %
Height interval	1 km	1 km

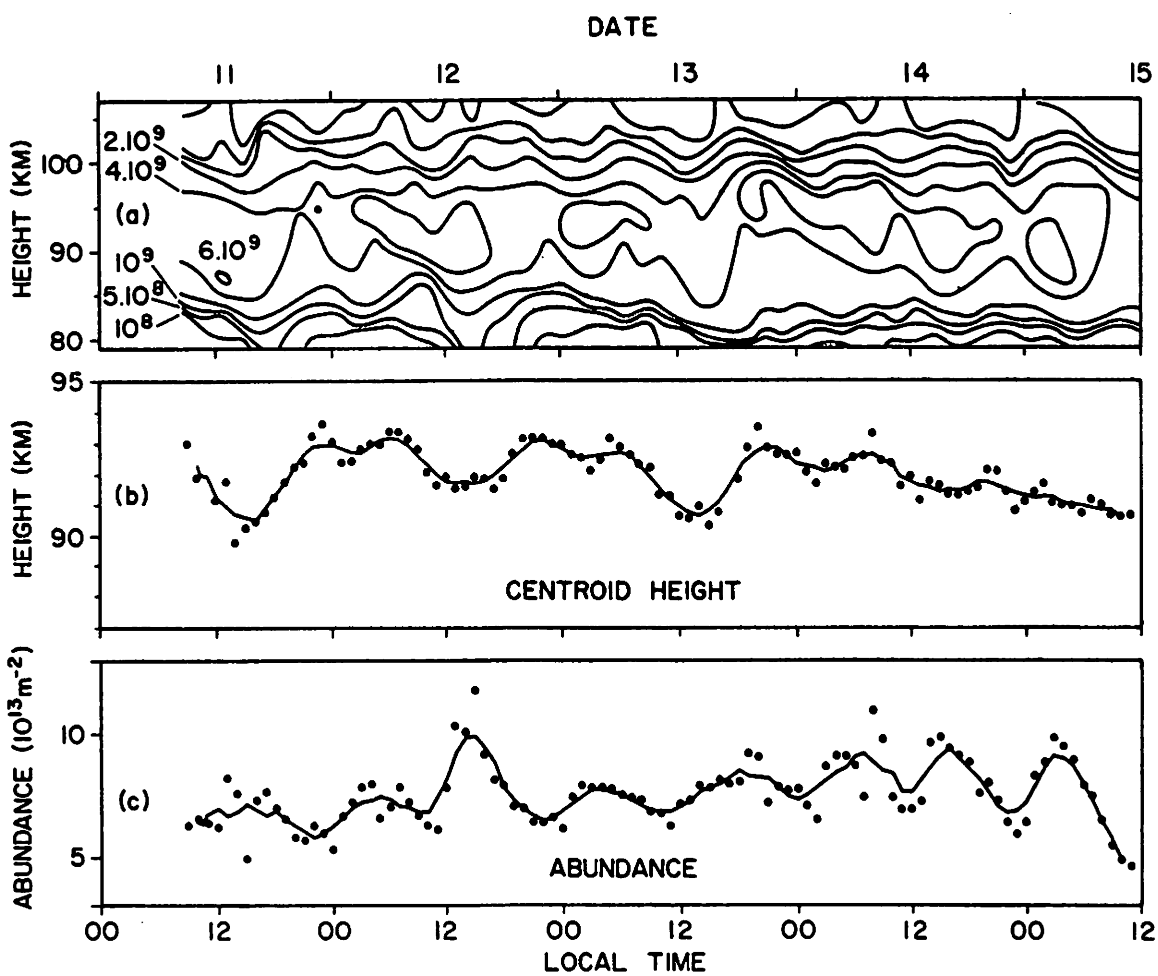


Fig. 2. Sodium variations for period May 11-15, 1981. Density isopleths are in units of m^{-3}. The continuous curves in (b) and (c) are 5-hour running means.

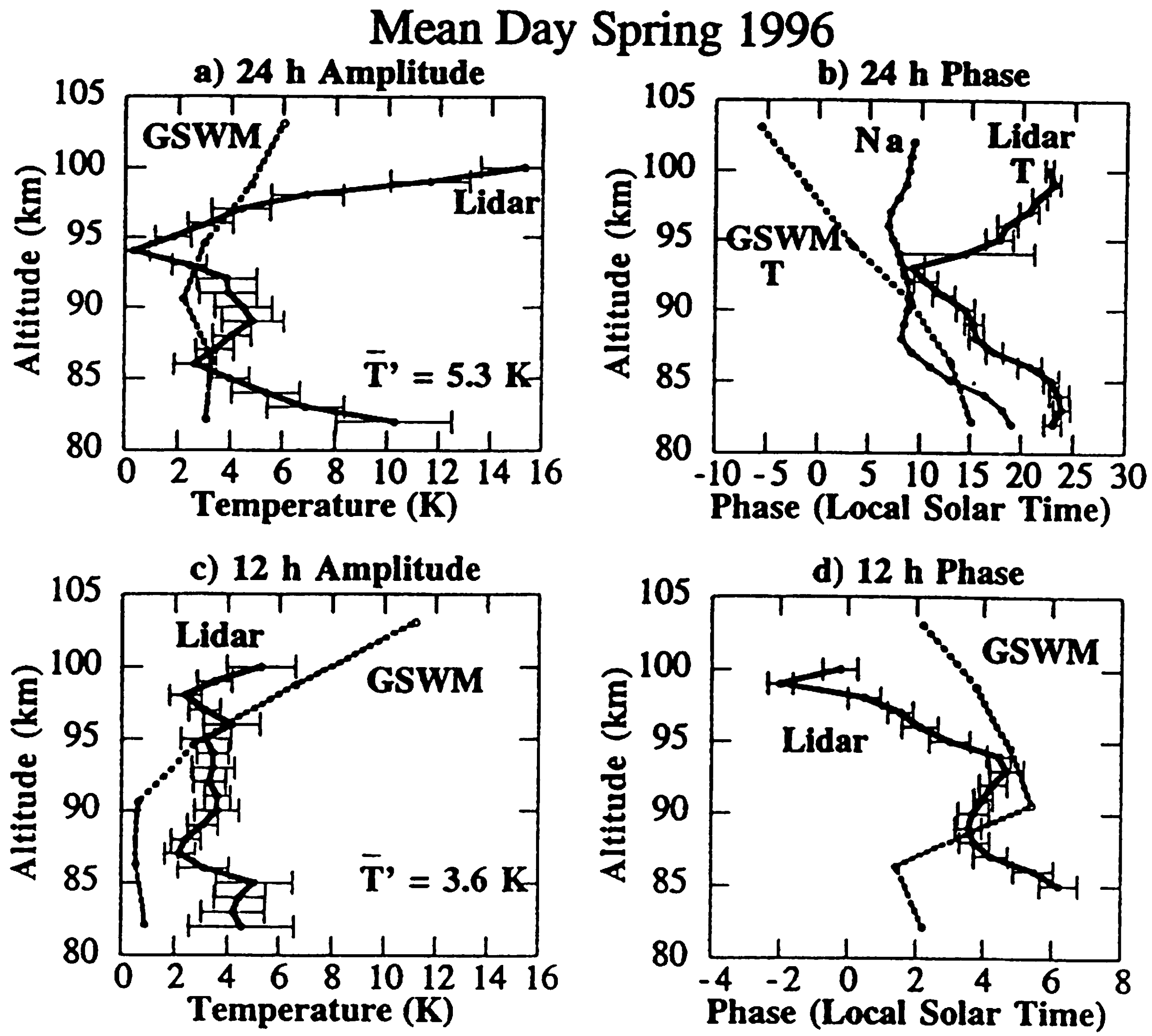


Figure 2. Amplitude and phase profiles of the 24 and 12 h components of the temperature perturbations for the 1996 Spring Mean Day at Urbana.

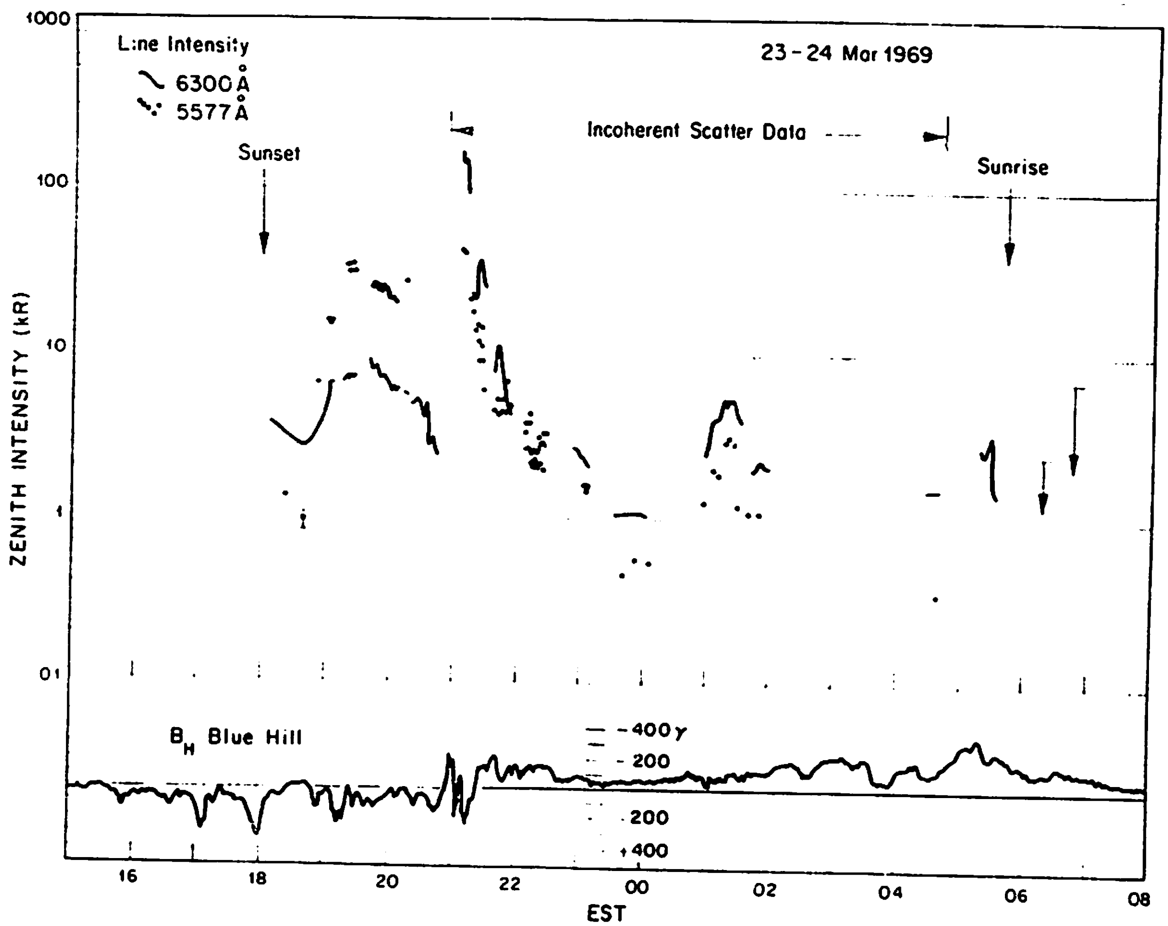


Fig. 4.31. Absolute values of $I(6300)$ and $I(5577)$ observed by Noxon and Evans (1974) from Blue Hill Observatory (geomagnetic latitude about 56°N) during the type-d display of March 23–24, 1969. The gaps are at times when the photometer was directed away from the zenith. The lower trace is the magnetometer H-component. I am very much indebted to Dr J. F. Noxon for providing these data in advance of publication.

Examples (contd.)

- High altitude measurements
  - Aircrafts
    - » Noxon and Vallance Jones (1962) - O_2 1.27 μm
  - Balloons
    - » Wallace (1962) - OI 6300 A
  - Rockets
    - » Wallace and McElroy (1966) - OI 5577 A
  - Spacecrafts
    - » Hays et al. (1978); Solomon and Abreu (1989)

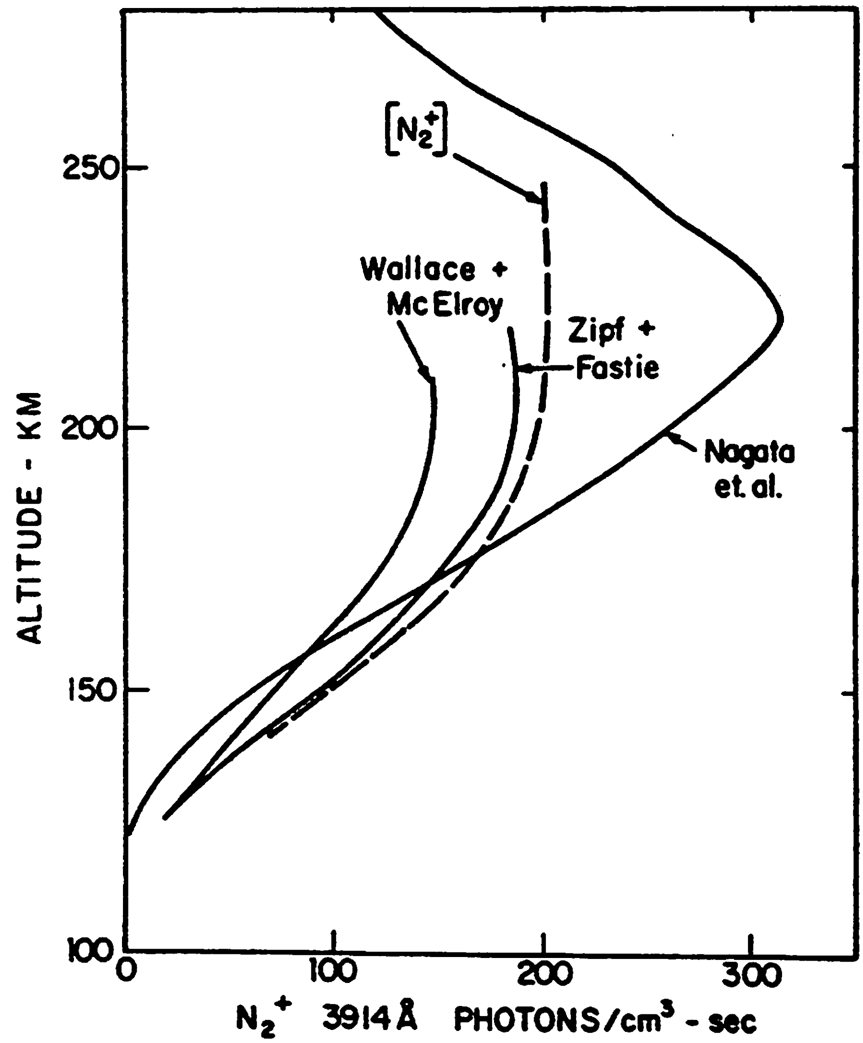


Fig. 12. Rocket measurements of the 3914 Å N_2^+ dayglow volume emission rate. The dotted line is proportional to the N_2^+ ion concentration measured by a mass spectrometer.

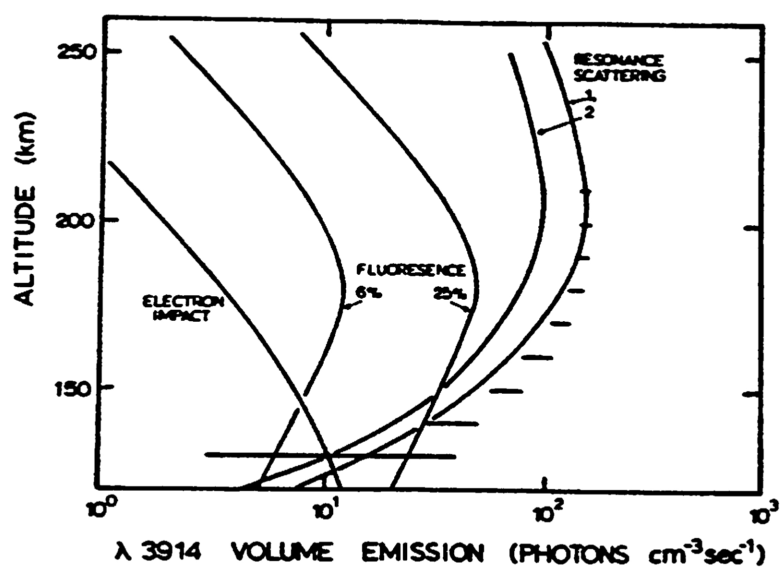


Fig. 13. Theoretical contribution of several excitation mechanisms to the N_2^+ dayglow, taken from Wallace and McElroy (1966). Two assumptions were made concerning the efficiency of solar UV in simultaneously ionizing and exciting the ion. The horizontal lines correspond to the Wallace and McElroy measurements.

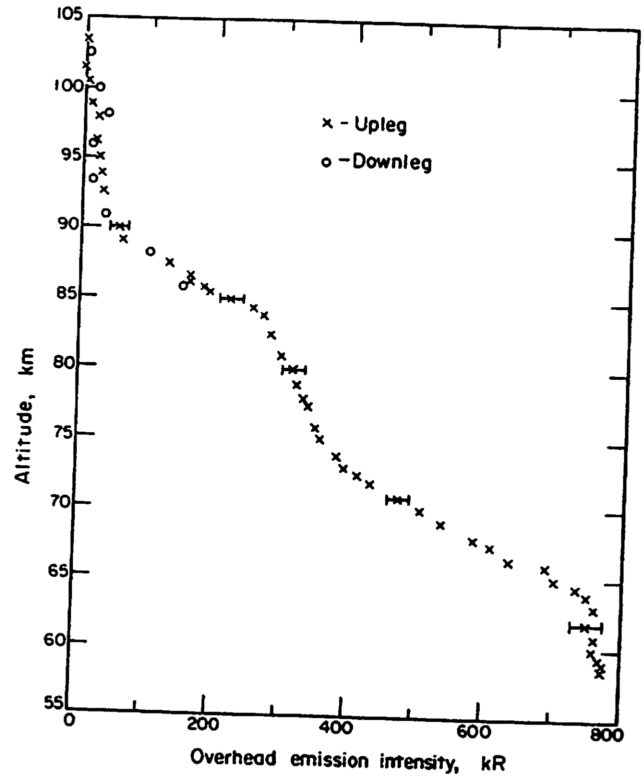
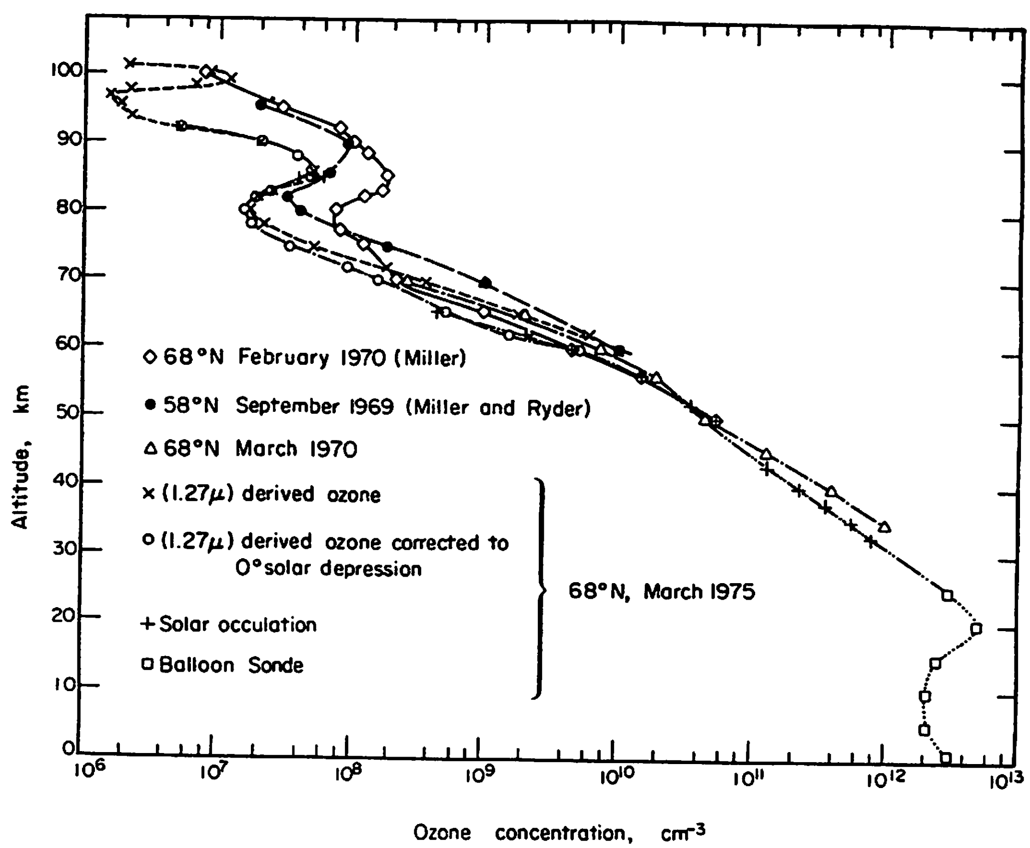


FIG. 1. $O_2(^1\Delta_g)$ OVERHEAD EMISSION INTENSITY CORRECTED TO THE ZENITH.



A COMPARISON OF THE MEASURED OZONE PROFILE WITH THAT OBTAINED FROM OTHER EXPERIMENTS.

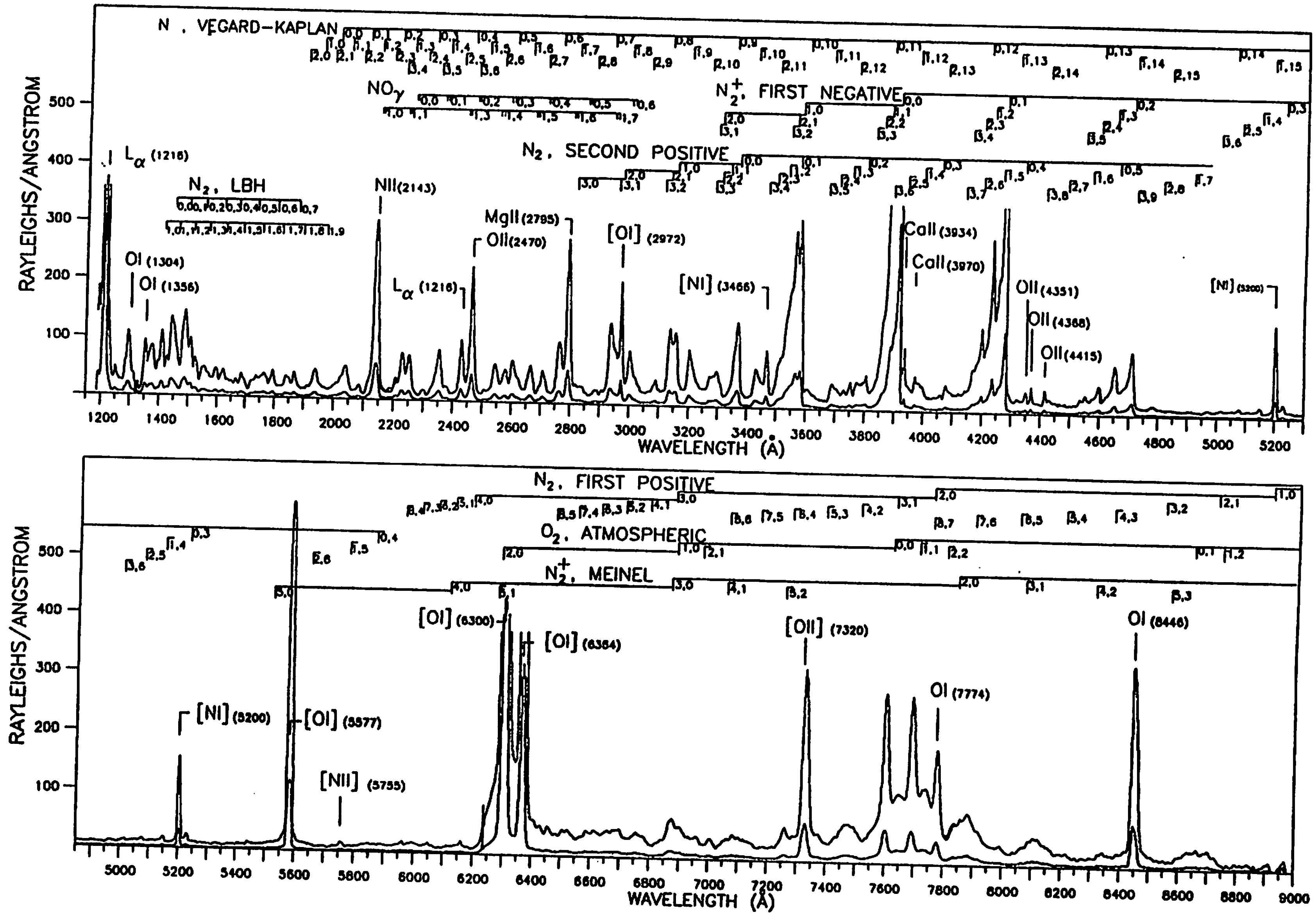


Figure 2. Typical dayglow spectrum recorded by the Arizona Airglow Experiment (GLO) spectrographs. The spectrum was recorded simultaneously from one column of gas in eight overlapping segments.

TABLE 1. Rate Coefficients and Branching Ratios

Reaction	Rate Coefficient ($cm^3 s^{-1}$) or Yield	Reference
$O_2^+ + e \rightarrow O + O$	$1.6\times10^{-7}(T_e/300)^{-0.55}$, $T_e>1200$	*Walls and Dunn* [1974]; *Torr et al.* [1976]
	$1.95\times10^{-7}(T_e/300)^{-0.7}$, $T_e<1200$	*Mehr and Biondi* [1969]; *Alge et al.* [1983]
$N(^2P)+O \rightarrow N+O$	1.2×10^{-11}	*Zipf et al.* [1980]
$N(^2P)+O_2 \rightarrow NO+O$	2.0×10^{-12}	*Zipf et al.* [1980]
$N(^2P)+NO \rightarrow N+NO$	1.8×10^{-10}	*Rees and Jones* [1973]
$O_2^+ + N \rightarrow NO^+ + O$	1.2×10^{-10}	*Fehsenfeld* [1977]
$O^+ + N(^2D) \rightarrow N^+ + O$	1.3×10^{-10}	*Constantinides et al.* [1979]
$O(^1S)+O_2 \rightarrow O+O_2$	$4.0\times10^{-12}\exp(-865/T_n)$	*Slanger et al.* [1972]
$O(^1D)$ from $O_2^+ + e$	1.2	*Abreu et al.* [1983]
$O(^1D)$ from $O_2^+ + e$, alternate	$-0.2\log_{10}[(T_e/300)^{-0.7}e/O]$	approx. to *Yee et al.* [1989]
$O(^1S)$ from $O_2^+ + e$	$0.12+0.02\log_{10}[(T_e/300)^{-0.7}e/O]$	approx. to *Yee et al.* [1989]
$O(^1S)$ from $N_2(A^3\Sigma_u^+)+O$	0.75 (v=0 only)	*Piper* [1982]
$N_2(A)(v=0)$ / $N_2(A)$(all v)	0.25	*Cartwright* [1978]
$O(^1D)$ from $N(^2D)+O$	0.03	*Olson and Smith* [1974]
$O(^1D)$ from $N(^2P)+O_2$	0.0	assumed
$O(^1D)$ from $N(^2P)+O$	0.0	assumed

Examples (contd.)

- Polarimetry
  - Noxon and Goody (1962); Noxon (1963, 1964). Primarily investigated OI 6300 A in dayglow and also in daytime aurora
- Special geometry
  - Total solar eclipse
    - » Sharp et al. (1966)
  - Dayside cusp
    - » Many

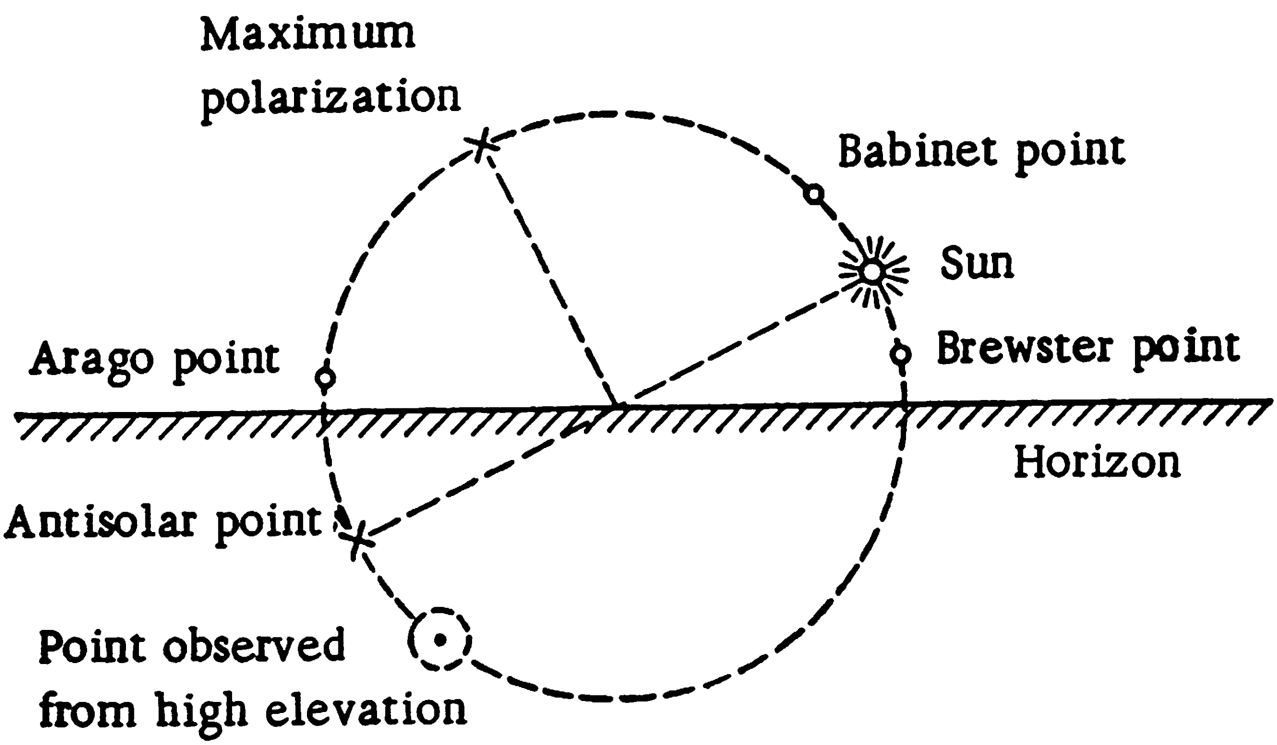


Fig. 10. Diagram of the neutral points.

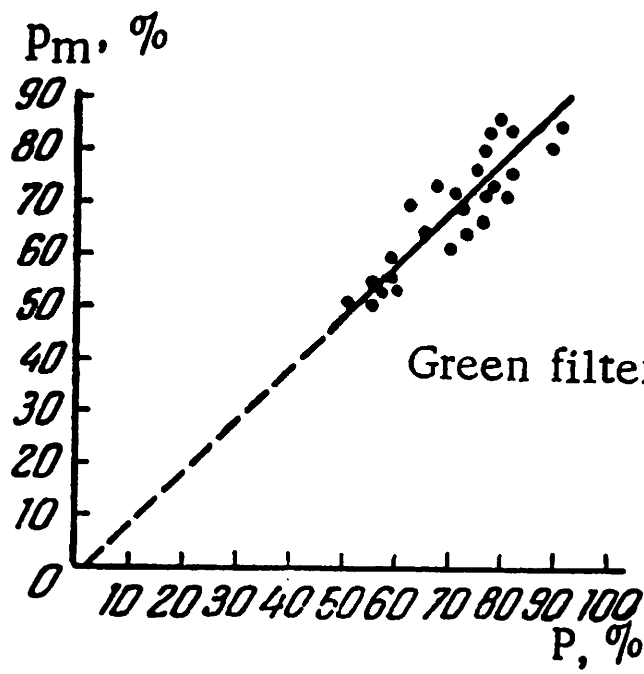


Fig. 8. Maximum degree of polarization of the light from the daytime sky as a function of the vertical transparency of the atmosphere.

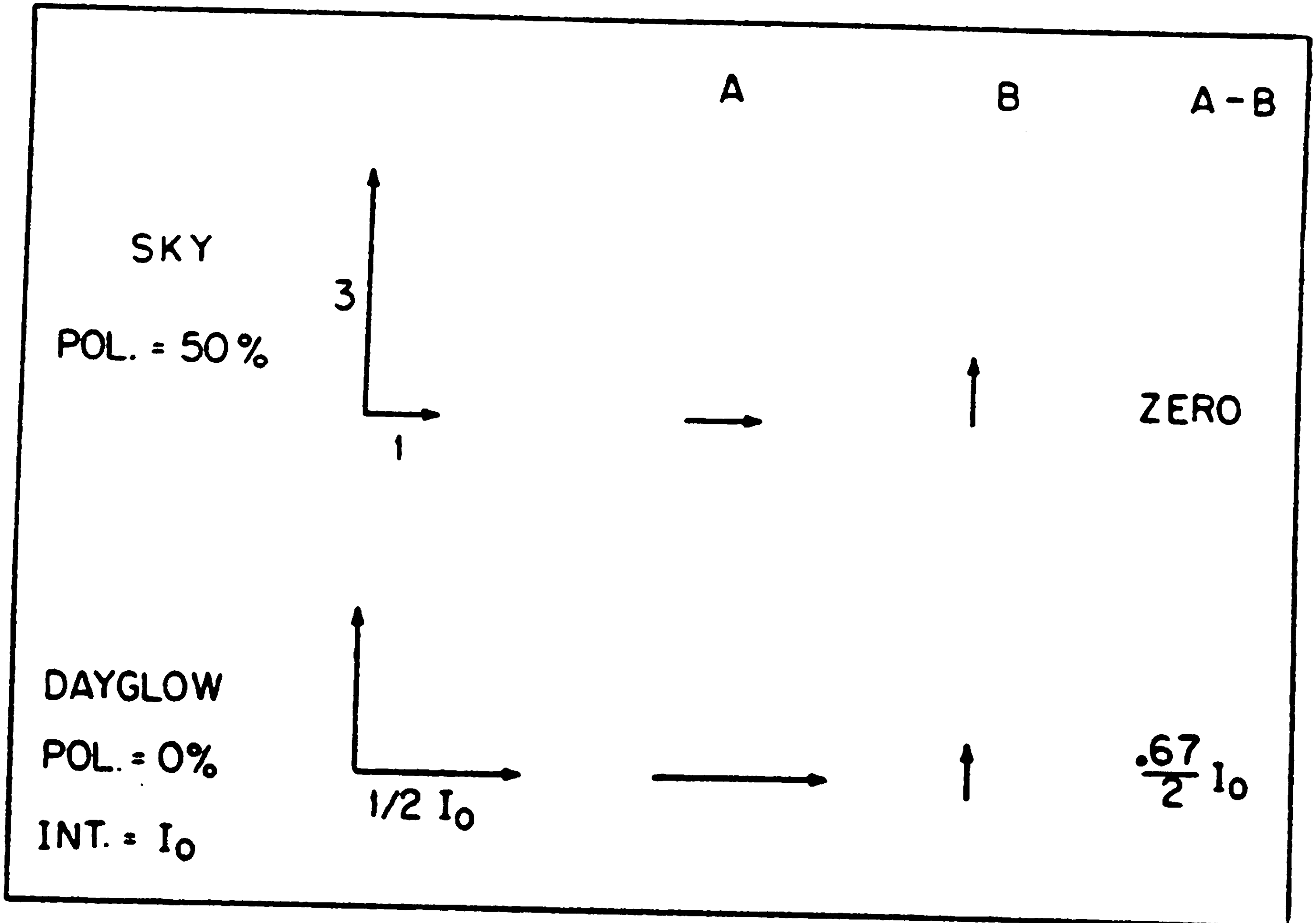


Fig. 4. Cancellation principle in the dayglow polarimeter. Optical channel *A* contains a polaroid set to transmit the minimum signal from the sky background. Channel *B* transmits an attenuated signal from a polaroid set to maximize the signal from the sky background. When the two are equalized for the background a strong out of balance component remains for an unpolarized dayglow emission feature; the actual sky signal through one channel is several orders of magnitude greater than the dayglow signal.

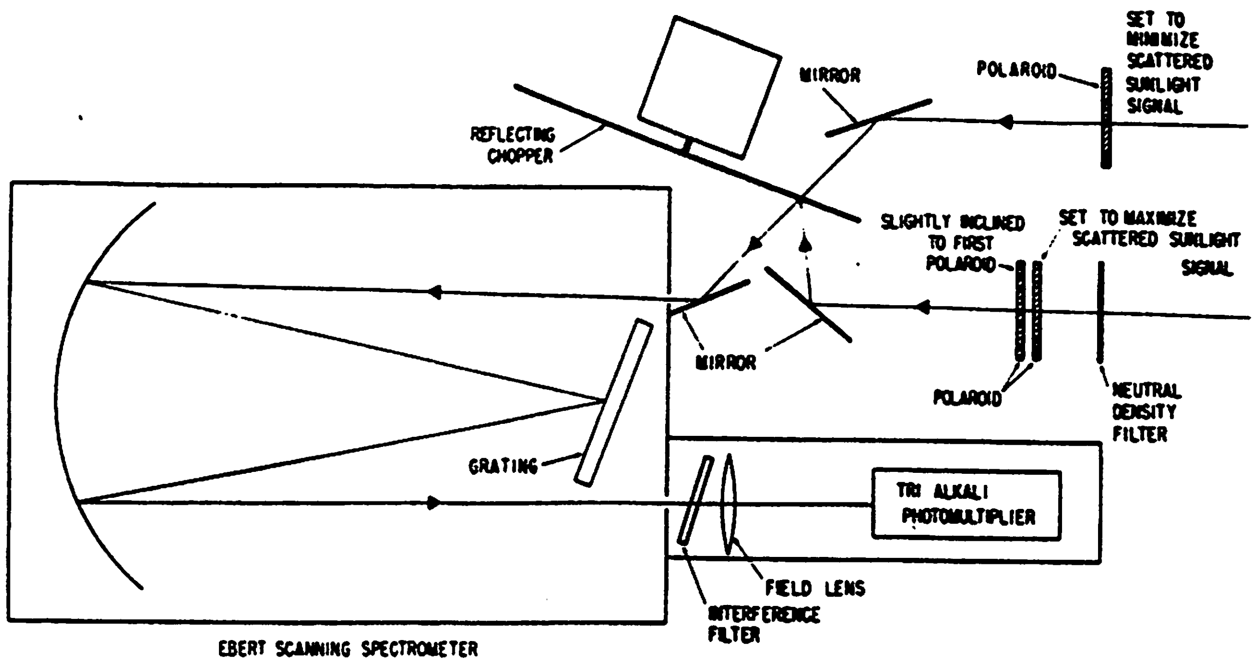
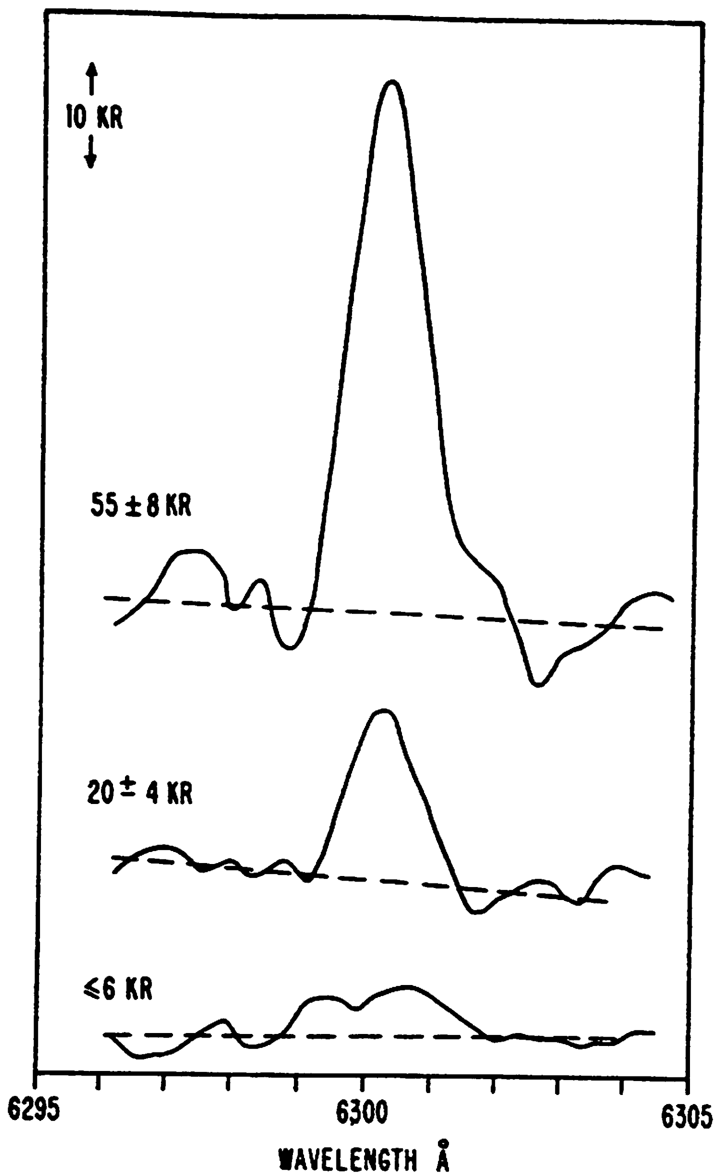


Fig. 5. An early version of the scanning polarimeter indicating how the spectrometer is made to rapidly alternate between the two optical channels; channel *A* is at the top. Later versions avoid the polarization introduced from mirror reflection although its existence does not upset the principle of operation.



Spectra of the 6300 Å line in the dayglow showing the wide range of intensity observed.

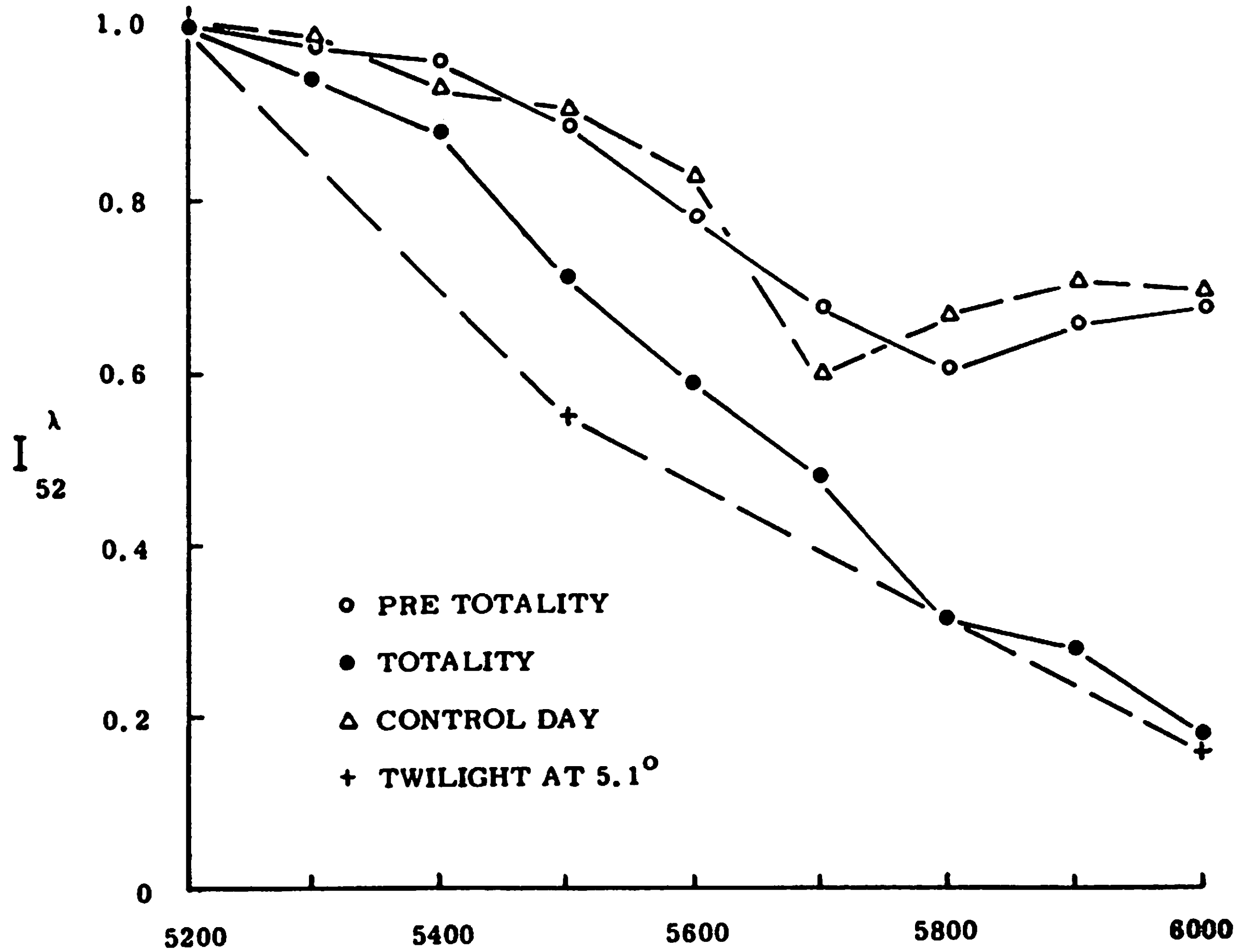


Fig. 5. A plot showing that the relative spectral distribution of the day sky is the same as that of the zenith sky just before totality, and also that the distribution at totality is similar to that of the twilight at 5.1° solar depression.

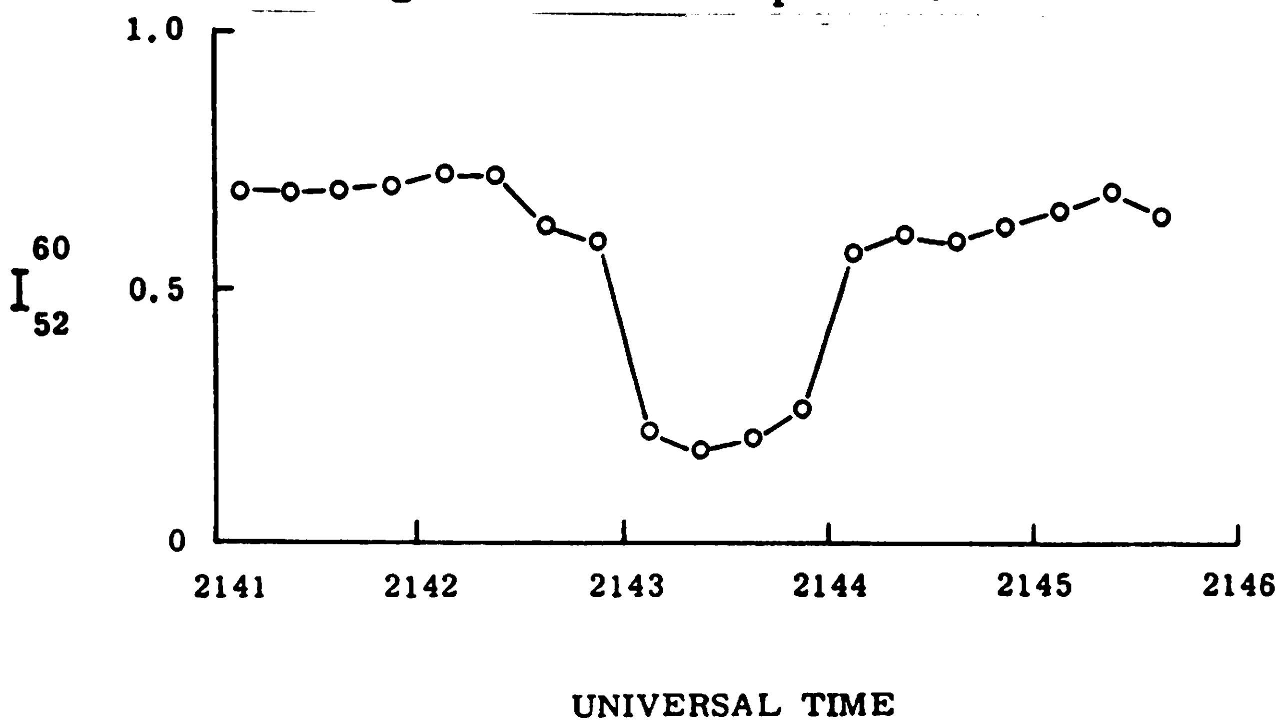


Fig. 4. The color change around totality expressed as the ratio of the intensity at 6000 Å to that 5200 Å

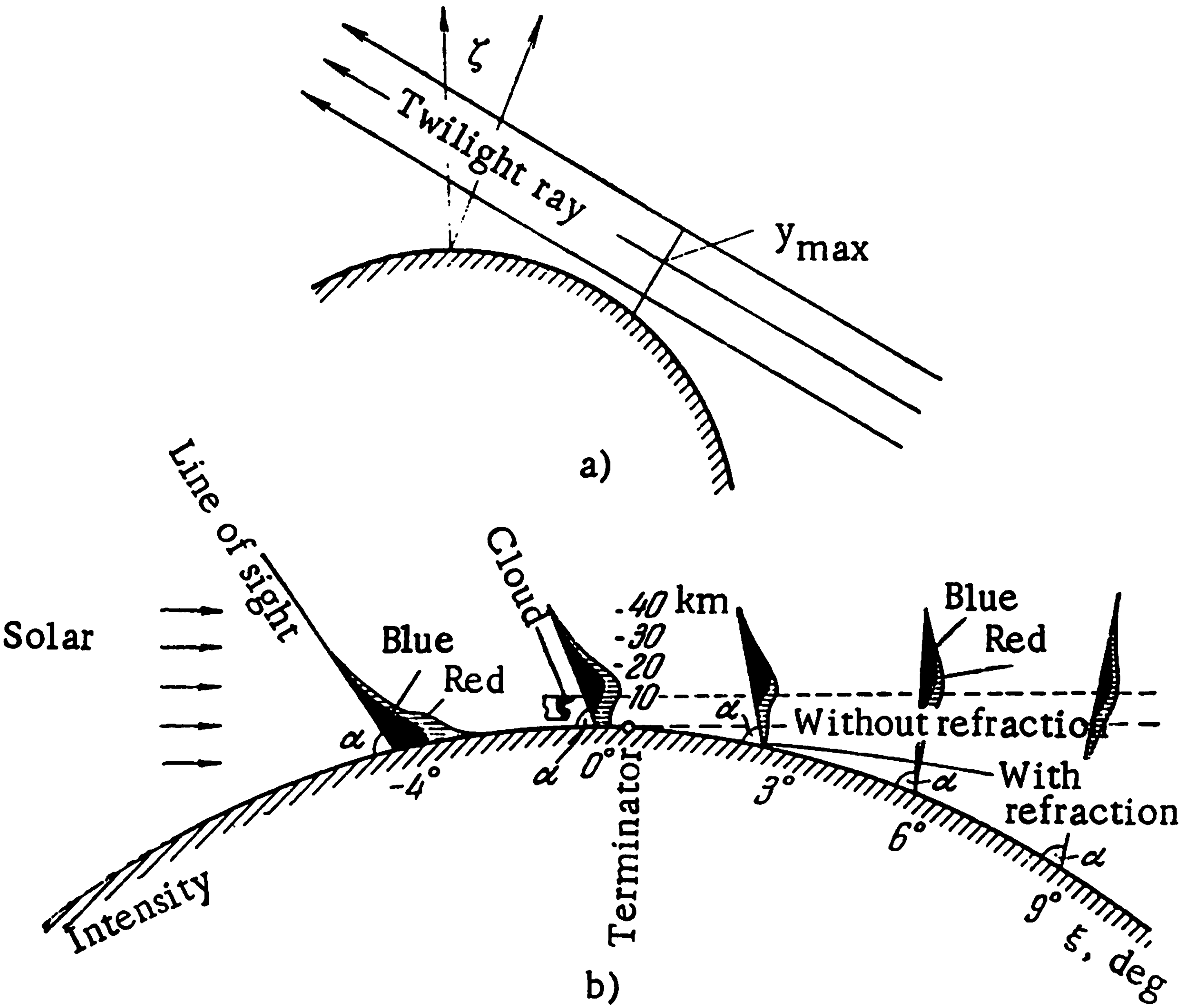


Fig. 118. The twilight ray.

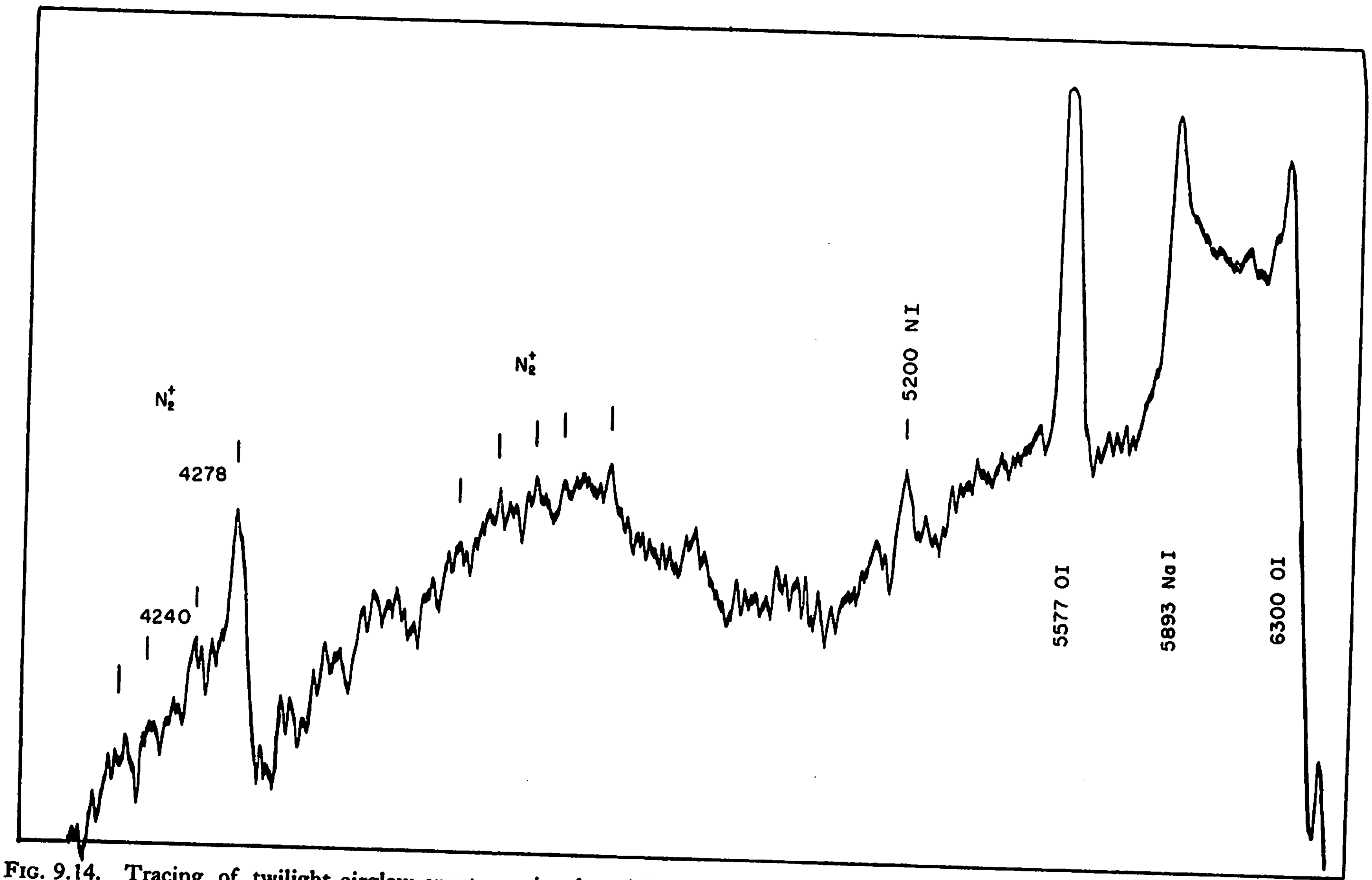
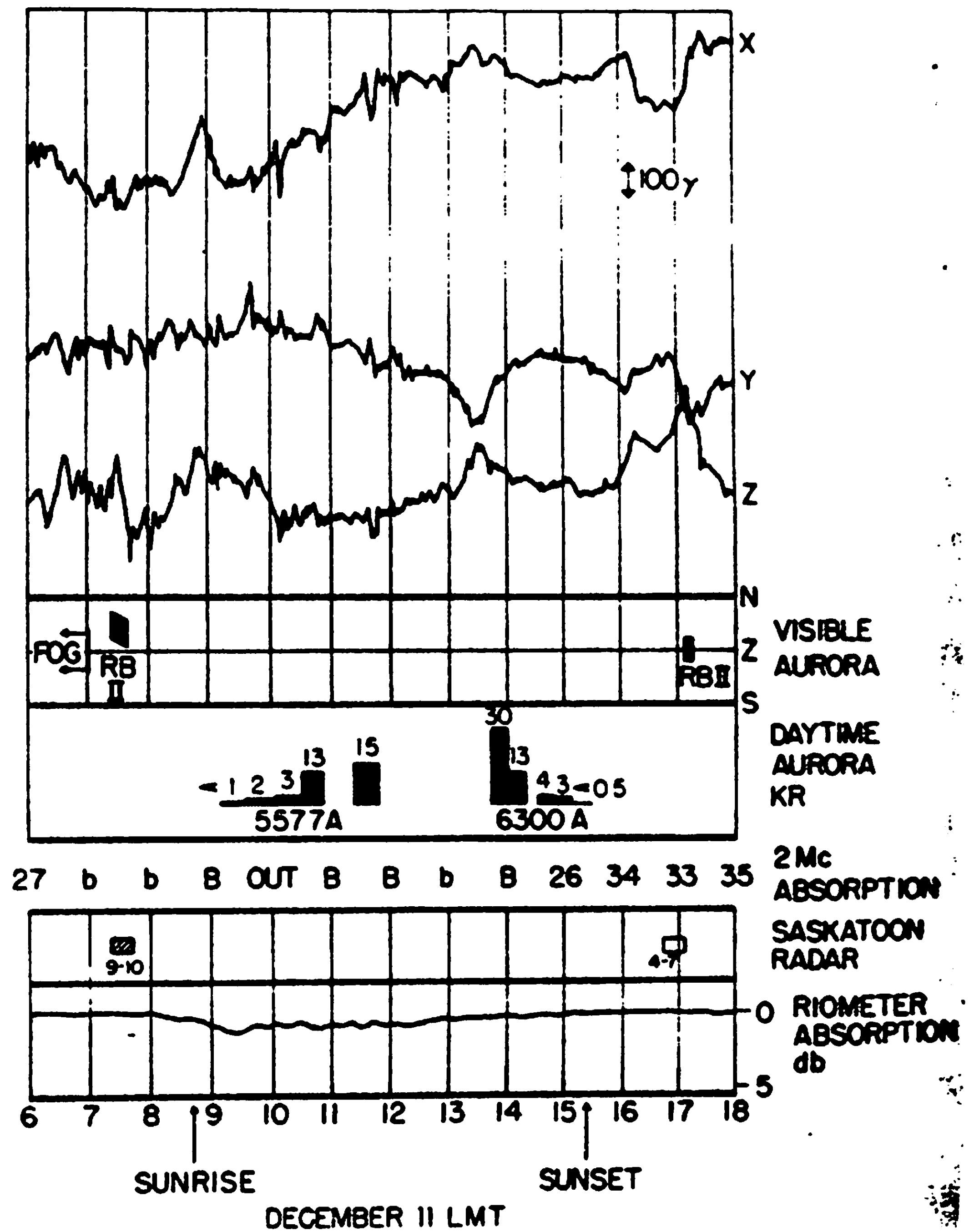


FIG. 9.14. Tracing of twilight airglow spectrum in the visible region. The N_2^+ bands and $[NI]_{21}$ line are abnormally strong, suggesting an auroral effect. After Nicolet [1954*b*]; courtesy University of Chicago Press.

Fig. 3. Records similar to those shown in Fig. 2 obtained during the late night, daytime, and early evening of December 11, including the record of optical emission from daytime aurora. Details of the material are given in the text.



MULTI-WAVELENGTH DAYTIME PHOTOMETER

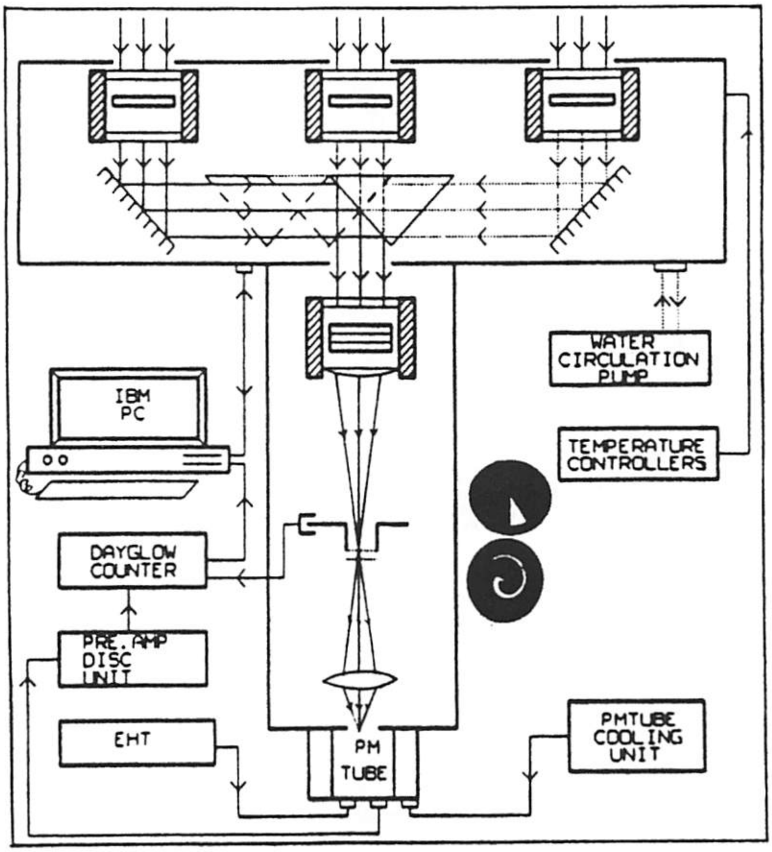


Fig. 1. Schematic diagram of the Multiwavelength Daytime Photometer along with the novel mask system. Temperature stabilized interference filters are shown at the front end of the instrument. The Fabry–Perot etalon can be seen in the optical unit.

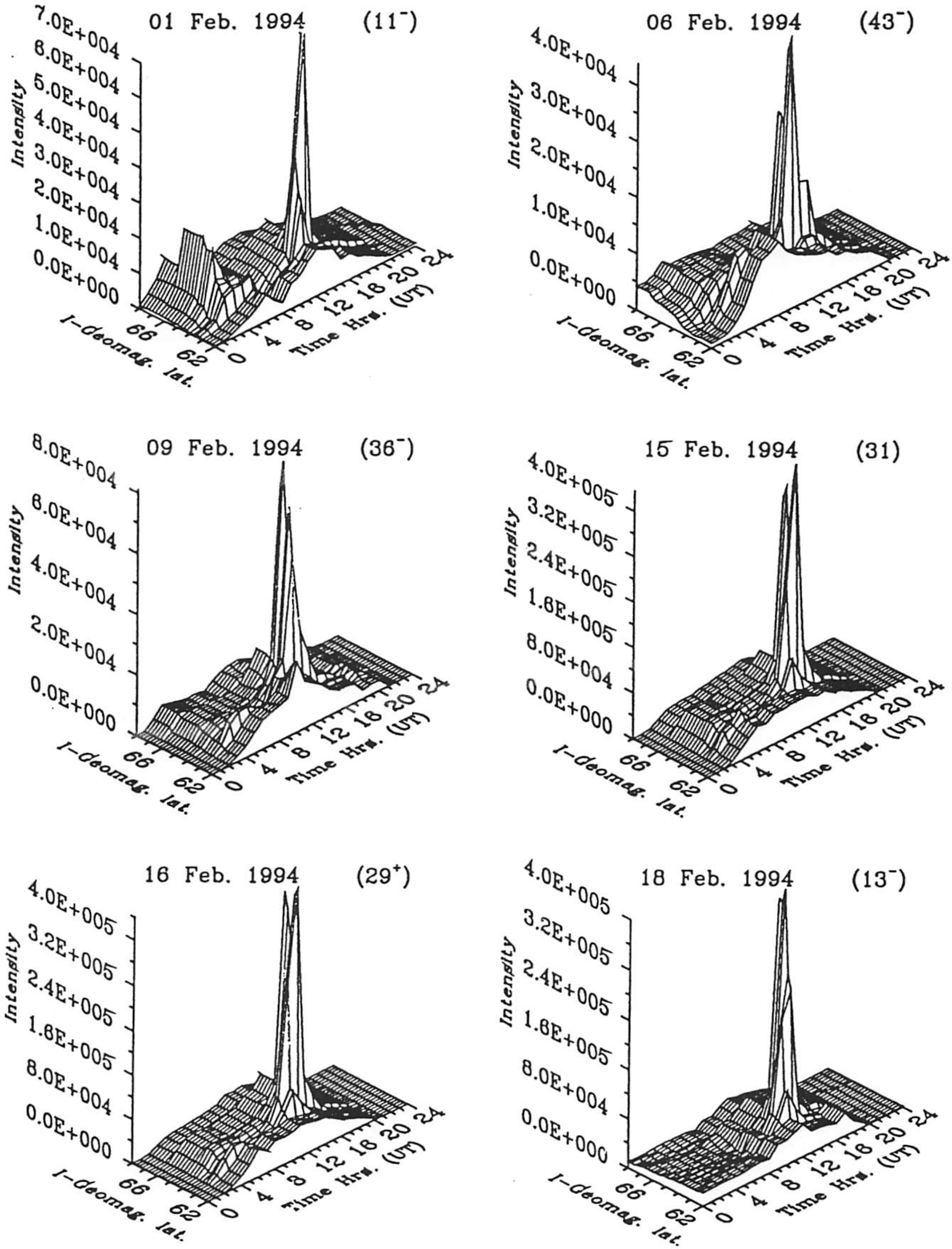


Figure 6.8a. Surface plots of 557.7 nm emission intensities as observed from Maitri during February 1994. The X, Y and Z axis represent the universal time, I- geomagnetic latitude and the relative intensities in photon counts respectively.

Future

- New Instruments
  - Hi-TIES
  - SCARI
  - Application of LCD FPIs
- New Techniques
  - Application of tomographic techniques for 2-D imaging spectroscopy applications

7 Traits Common to Many Discoveries
(In *Cosmic Discovery* by Martin Harwitt)

- The most important observational discoveries result from substantial technological innovation in observational astronomy
- Once a powerful new technique is applied in astronomy, the most profound follow with little delay
- A novel instrument soon exhausts its capacity for discovery
- New cosmic Phenomena frequently are discovered by physicists and engineers or by other researchers originally trained outside astronomy
- May of the discoveries of new phenomena involved use of equipment originally designed for military use
- The instruments used in the discovery of new phenomena often have been constructed by the observer and used exclusively by him
- Observational discoveries of new phenomena frequently occur by chance - they combine a measure of luck with the will to pursue and understand an unexpected finding

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