21. LIGHT OF THE NIGHT-SKY (LUMINESCENCE DU CIEL)

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I. INTRODUCTION

The subject of Commission 21 is of a heterogeneous nature and the borderlines to other Commissions are not very well defined. The light of the night-sky comprises a variety of components which are due to various kinds of physical processes taking place at very different distances from the Earth.

In the present report less emphasis is placed on airglow problems as in previous ones in accordance with a recommendation of Commission 21 of 1970. During recent years airglow research became an important subject of geophysics and the new tools offered by rockets and satellites have enormously expanded the observational side. This report tries to concentrate upon aspects of astronomical interest. The review papers on airglow and connected atmospheric problems mentioned in the beginning of Chapter II on the other hand contain valuable information on progress in all sections of this wide field.

Besides new valuable results deduced in the last triennium on the extraterrestrial components of the night-sky light (Chapter V–VII) considerable progress is to be expected within the near future due to observations from the Earth-orbiting Skylab and from deep space probes which are already in space, as Pioneer 10, or being in preparation for launch, as Pioneer G and Helios A and B.

Many of the references to Soviet studies were taken from a report prepared by Dr Truttse and Dr Shefov. References to U.S.A.-studies were contributed by Dr Weinberg.

II. NIGHTGLOW

The phenomenology of the night airglow is reviewed by S. M. Silverman (04.082.077) with particular emphasis on the work of recent years. The major topics discussed are the spectrum, latitudinal dependency, diurnal variation, correlations in time and space, effects of magnetic and of solar activity, and conjugacy and the airglow.

At several symposia review papers and new results on atmospheric emissions have been presented: Parallel with the twelfth COSPAR meeting (1969) in Prague a symposium on 'Thermospheric Properties Concerning Temperatures and Dynamics with Special Application to Hydrogen and Helium' was held. The invited and contributed papers are included in the proceedings of the COSPAR plenary meeting (Ed. T. M. Donahue, P. A. Smith, L. Thomas, 05.012.007). A Symposium 'Aurora and Airglow, 1970' was organized by the Summer Advanced Study Institute in Kingston, Ontario. The lectures presented there including a summary by D. M. Hunten are contained in the book *The Radiating Atmosphere* (Ed. B. M. McCormac, 06.012.021.) Also in 1970 a ESRIN-ESLAB symposium on 'Mesospheric Models and Related Experiments' took place in Frascati, the proceedings of which (Ed. G. Fiocco, 06.012.024) contain different papers related to atmospheric emission effects. Papers presented at the IAGA symposium on 'Aurora and Airglow' in Moscow 1971 are published in *Ann. Geophys.*, **28** (1972).

A special research report on 'Atmospheric Optics' (Ed. N. B. Divari, 05.003.031) translated from Russian, contains a number of papers within the field of Commission 21. The Russian text was al-

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ready published in 1968. Work on similar topics is compiled in Vol. **18** of *Trudy Astrofiz. Inst. Alma Ata* (07.082.113–133).

A popular article 'The Spectrum of the Airglow' was written by Ingham (07.082.009).

O I 5577 Å

Using observations obtained during and since the IGY at several stations in Japan, Sawado and Tanaka derived composite isophote maps for a wider area than can be covered by a single station. They show 5577 Å-intensities during 9 nights for every half hour and demonstrate the linear scale and the motion of patches. (1970, *World Data Center C2*, Tokyo) Another study evaluating IGY-observations in order to derive diurnal variations of the 5577 Å-emission for a large range of latitudes was published by Brenton and Silverman. Data of 22 stations have been analyzed. Statistically significant variations are not found at the highest latitudes. Midlatitude stations show the well known maximum during the night whereas in a large belt including the equatorial latitudes a pronounced minimum sometime during the night occurs. Definite seasonal effects where found for the 13 stations for which sufficient data were available. No sunspot cycle effect was found (03.082.040).

Seasonal and diurnal variations of the 5577 Å-nightglow in the period of 1958–1967 in Ashkabad were derived by Korobeynikova and Nasirov. They found maxima in June and October and a minimum in January. The diurnal variation shows a maximum between 02 and 03 hr. Spatial inhomogeneities with periodic variations in size were observed. (1972, *Ann. Geophys.*, **28**, 483) Short period fluctuations observed with two photometers placed several kilometers apart can be interpreted in terms of turbulent transport under the control of horizontal wind according to Barat *et al.* (1972, *Ann. Geophys.*, **28**, 145). For a summary of recent results on diurnal variations see also Silverman (04.082.077).

The intensity of the 5577 Å-emission in Ashkabad exhibits a lunar time variation, the same effect reported formerly by other investigators. Forbes and Geller (07.082.101) came to the conclusion that the atmospheric dynamics of the lunar tide are sufficient to produce a lunar variation of the green line intensity similar to the observed effects.

Rocketborne measurements of the 5577 Å-emission were made by Dandekar and Turtle (06.082.-015) and discussed with respect to the alternative excitation mechanisms. Their results show in accordance with former experiments that this emission originates from two layers, one around 100 km and the other above 150 km. The peak concentrations of atomic oxygen determined from the Chapman and the Barth concentrations differ from each other by an order of magnitude; the profiles from the two mechanisms are very similar in shape. The authors conclude that the Chapman mechanism is adequate for explaining the green line emission around 100 km.

O I 6300 Å

The comprehensive investigations of the 6300 Å-emission at the Zvenigorod Observatory were continued. New material on the nocturnal variation during the 1968–1971 period with predawn effects is included in a paper of Truttse (1972, *Ann. Geophys.*, **28**, 169) together with a discussion of excitation problems. The close correlation between the intensity of this emission, the solar activity index $F_{10.7}$ and the index D_{St} characterizing geomagnetic disturbances found by Truttse earlier were confirmed by new observations (04.084.054). The Doppler width of the 6300 Å-profile increases with the local K-index and demonstrates the correlation between upper atmospheric temperature and geomagnetic activity (05.082.077). New information on the morphology of the 6300 Å-emission at lower latitudes was obtained by Nasirov *et al.* in Ashkabad. Seasonal features in the diurnal variations of the 6300 Å emission are discussed by Pal on the basis of observations at Mt. Abu over a period from 1965 to 1967 (1972, *Ann. Geophys.*, **28**, 51). The nocturnal variation near the magnetic equator was determined by Kulkarni and Rao in March 1970 and in March/April 1971 by observations near Thumba (India). It was found as distinctly different from that at mid- or low-altitude stations. The 6300 Å-emission shows a midnight maximum which is explained by special conditions within the F-layer near the magnetic equator (1972, *Ann. Geophys.*, **28**, 475).

At Abastumani the predawn enhancement was studied in the winter 1968/69 and 1969/70 by Fishkova and Mateshvili (1972, *Ann. Geophys.*, **28**, 497). The observations indicate that onset and amplitude of the enhancement depend on solar and geomagnetic activity. The problems of predawn airglow enhancement are reviewed by Carlson; his paper contains many references related to this subject (1972, *Ann. Geophys.*, **28**, 179). Wickwar discusses new Arecibo Observatory data of 6300 Å-intensities in connection with excitation by photoelectrons from the magnetic conjugate point (1972, *Ann. Geophys.*, **28**, 187). With respect to conjugacy and nightglow Silverman (04.082.077) came to the conclusion that the phenomenology is in accord with the predictions resulting from the hypothesis of the transport of low energy electrons from a sunlit to a magnetically conjugate hemisphere.

Nightglow observations at Mt. Abu during 1964-1967 show for some nights covariant enhancements of the 6300 Å- and 5577 Å-emissions as reported by Pal. He discusses these features in relation with the changes in the height of ionization in the night time *F*-layer (06.082.027). The relationship between 6300 Å-emission and changes in the electronic loss rate in the *F*-layer was investigated by Brown and Steiger at Hawaii by means of simultaneous measurements of nightglow intensity and total electron content of the ionosphere (07.083. 015).

Mullaney *et al.* found that fluctuations in the intensity of the 6300 Å-line are considerably higher during periods of enhanced ionospheric scintillation. But it was not possible on the basis of their data to choose between particle precipitation and travelling compressional waves as the cause of these fluctuations (07.082.014).

Observations of mid-latitude arcs of 6300 Å emission and their relations to geomagnetic disturbances are discussed in several papers by Okuda, Old, and Kim (05.084.039; 1971, *Ann. Geophys.*, **27**, 205; 1971, *Radio Sci.*, **6**, 887).

1304 Å-, 1356 Å-*Emissions*

By OGO 4 spectrometer at tropical latitudes Barth and Schaffner (04.082.020) could verify that the prominent ultraviolet nightglow emissions are the 1304 Å- and 1356 Å-lines of atomic oxygen. The presence of UV nightglow in the tropical zone was discovered by Hicks and Chubb at altitudes of less than 500 km (04.084.029). The maximum intensity and frequency of occurrence are correlated with a local time of 21 hr. The most likely source of excitation appears to be an ionospheric recombination mechanism which was studied by Knudsen (04.082.013). Meier and Prinz summarize the main features of the 1304 Å-airglow as observed from OGO 4. Long term variations correlate with solar activity (06.082.003).

The emission at 1304 Å was also recorded by the satellite Cosmos-215 in the region of $\pm 12°$ from the geomagnetic equator with an average intensity of 150 *R*. A daytime maximum at altitudes of about 250 km and noticeable variations in the intensity as a function of solar activity are reported by Scheffer (05.082.007,039).

OH-*bands*, O_2-*Herzberg bands*

The extensive measurements of OH-emission made for many years by Soviet scientists have permitted to derive reliable information on various regular features in the diurnal and seasonal behaviour of intensity, vibrational and rotational temperatures as well as in latitude effects. Summaries of these valuable results which confirm earlier findings (see 1970 Report of Commission 21) are given in two papers by Shefov (05.082.043; 1972, *Ann. Geophys.*, **28**, 137). Nocturnal and diurnal variations have been determined also in the (5,1) and (9,4) bands by Yano and Takahashi (1971, *Rept. Ionosph. Space Res. Japan*, **25**, 301) and in the (8,3) band by Fiocco (04.082.178) and by Dick (1972, *Ann. Geophys.*, **28**, 149). The Japanese investigation showed a remarkable nocturnal change in the intensity ratio of the two bands on several occasions. This is of interest since the 9th vibrational level is the highest one identified from the nightglow OH-bands.

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By use of a scanning Ebert spectrophotometer aboard NASA's Convair 990 Airborne Laboratory intensity measurements of OH (6,1) (7,2) bands, O I 6300 Å, Hα and several O_2 Herzberg I bands were performed by Dick *et al.* Along the same line-of-sight O I 5577 Å and 6300 Å were monitored photometrically. The results represent geographical variations over a wide range of latitudes (10°–80°N). In contrast to the findings of Shefov for the OH-intensities no clear latitude variation is evident. But this may be masked by seasonal effects over the duration of the expedition (03.082.065). For the relationship between OH, 5577 Å and O_2 Herzberg I bands and their latitude distribution see also Dick and Sivjee (06.082.048), Sharp and Rees (04.082.065), and Shefov (06.082.014). Whether diurnal variations of OH are of large geographical extent shall be determined by the coordination of observations at Kitt Peak by Dick and near Rio de Janeiro by Christensen, as Dick reports.

Against the background of systematic diurnal variations Krassovsky (1972, *Ann. Geophys.*, **28**, No. 4) found periodic changes in the OH rotational temperature which permit studies of the propagation of infrasonic and gravitational waves in the atmosphere. Airborne and groundbased measurements showing short-term temporal variations in OH rotational temperature were presented by Sivjee *et al.* (07.082.021) and interpreted on the basis of a dynamic model of the OH emitting region.

Huruhata refers to some recent activities in Japan: Makino observed the nightglow OH-bands at 1–2 μm and the O_2 (0,0) band at 1·27 μm with a balloon-borne spectrometer with a resolution of about 250 Å. The intensity distribution of the OH-bands is in favor of uniform distribution among the vibrational levels in excitation. In the visible region the OH bands and the O_2 bands were observed by Nakamura and in the near infrared by Makino on a rocket in 1971. Their preliminary results show that the peak height of OH-emission is about 90 km. Harrison (04.082.114) found a peak at 95 km for the OH (6,2) band emission.

After geomagnetic disturbances the intensity of OH-emission is correlated with the radio wave absorption in the lower ionosphere according to measurements in the U.S.S.R. An analysis of the vibrational excitation of OH molecules in the upper atmosphere and in laboratory has shown an essential role of vibrationally excited components taking part in reactions. (Krassovsky, 1971, *Ann. Geophys.*, **27**, 211).

Nightglow continuum

Progress in this difficult subject was achieved by a careful investigation by Ingham and Sternberg (1972, *Mon. Not. Roy. Astron. Soc.*, **159**, 1 and 21). They completed a programme of spectroscopic observations of the airglow continuum which had been begun in 1968 at the Observatoire de Haute Provence. The observations, which covered the wavelength range 4100–8200 Å, and which were carefully corrected for the presence of zodiacal light and starlight, confirmed the existence of a continuous component in the spectrum of the nightglow, showed evidence of discrete structure at certain wavelengths and a large increase in brightness in the near infra-red. Sternberg made an exhaustive examination of possible photochemical processes and concluded that two independent mechanisms are responsible for the continuum; (1) the classic reaction

$$NO + O \rightarrow NO_2 + h\nu \ (4000\text{–}5500\ \text{Å})$$

and (2) collision induced transitions of the O_2 molecule from bound states close to the dissociation limit,

$$O_2^*(^1\Sigma_g^+) \rightarrow O_2^*(^3\Sigma_g^-) + h\nu \ (5000\text{–}9000\ \text{Å})$$
$$O_2(^1\Delta_g) \rightarrow O_2^*(^3\Sigma_g^-) + h\nu \ (7000\ \text{Å}\text{–}2{\cdot}2\mu).$$

On the other hand Fishkova (04.082.080) found on the basis of observations made at Abastumani in 1958–1969 that the main portion (65–70%) of the nightglow continuum in the region 4700–6700 Å is due to multiscattered solar light.

Dumont and Sánchez-Martinez refer to new observational material obtained at the Teide Observatory which they consider as a reliable proof of the long discussed 5577 Å line/5200 Å continuum correlation.

III. HYDROGEN AND HELIUM GLOW

Studies of Hα-emission in the night-sky were continued intensely in the U.S.S.R. At Abastumani Fishkova *et al.* investigated the nocturnal variation in Hα-intensity and found that at the end of night-time it is greater than at the beginning almost by a factor 2. The reduced Hα-intensity is almost independent on latitude and longitude within the belt of $\pm 50°$ geomagnetic latitude $\emptyset$. For $\emptyset > 50°$ it grows up to a maximum over the auroral oval and then decreases towards the geomagnetic pole. Theoretical models explaining the observations have been derived (04.082.087, 06.082.025, 1972, *Bull. Abastumani*, No. 42). On the basis of spectral observations of Hα in twilight Megrelishvili *et al.* obtained information on the vertical distribution of H I. The number of H I-atoms near 200 km was found as $2 \times 10^7 cm^{-3}$ and near 300 km as $9 \times 10^5 cm^{-3}$ (04.082.081, 04.082.181).

During the last three years a number of investigations concerning Lα-observations and the H I-distribution within the geocorona have been performed. Different papers on this problem were presented at the COSPAR meeting in Prague (05.082.103–109). New empiric data on Lα and other emissions due to rocket and satellite observations were published by Meier and Mange (03.082.063), Meier *et al.* (04.082.018), Sheffer (05.082.019), Buckley *et al.* (05.082.047), and Young *et al.* (05.082.139). Simultaneous measurements of the hydrogen emissions Lα, Lβ, and Hα were discussed by Weller *et al.* (06.082.076) and interpreted with a variety of multiple scattering hydrogen models of the geocorona. The observations can be reproduced with a theoretical model consisting of a combination of the Kockarts and Nicolet and the Chamberlain density distributions at an exospheric temperature of 950 K and normalized such that the hydrogen column density is 2×10^{13} atoms cm^{-2} above 215 km. This density is equivalent to an optical depth of about 3·6 at Lα and 0·6 at Lβ. A polar-equatorial departure from spherical symmetry in the H-distribution is indicated. From the Lβ- and Hα-rates of emission the authors conclude that the reported value of the solar Lβ-flux is lower than required by a factor of 5. More observations of the solar Lβ-profile are required to explain this anomaly.

Sheffer (l.c.) reports a correlation between Lα-emission and solar activity. Shefov (05.082.108) points out that the migration of H-atoms from one hemisphere to the other may affect the spatial H-distribution. Deviations from the average behaviour indicate that besides the H I geocorona also clouds in the thermosphere are present, as Krassovsky found on the basis of Hα observations from Zvenigorod, Abastumani, and Alma Ata and by a comparison with known data about orthohelium and hydrogen Lα-emission (06.082.026).

Hydrogen Lα-measurements on OGO 5 from 1968 to 1971 provided information on the outer geocorona and the sky background emission. The paper of Thomas and Bohlin (07.082.098) presents selected data and an interpretation of three phenomena, (1) a pronounced antisolar enhancement of the geocoronal scattering beyond 70000 km which seems to be due to a geotail produced by solar Lα-radiation pressure, (2) a clear correlation of periodic variations with solar activity associated with solar rotation, and (3) an annual variation caused by the earth's orbital motion within the cavity created by the solar wind in the nearby interstellar hydrogen.

The altitude distribution of the He 584 Å- and the He^+ 304 Å-emissions was measured with a rocket experiment by Ogawa and Tohmatsu (06.082.032). On ascent the 584 Å-intensity increased from 40*R* to 100*R* between 250 and 720 km and then decreased gradually to 30*R* at 1600 km. The 304 Å-intensity decreased from 12 to 4*R* on ascent from 420 to 1200 km. The excitation of the 584 Å-glow is ascribed to resonance fluorescence of atmospheric helium by solar 584Å-radiation. The observed distribution is consistent with a diffusive equilibrium distribution of He at a thermopause temperature of 1180 K having a baseline density of 1×10^6 atoms cm^{-3} at 720 km. The 304 Å-radiation was at least 2·5 times greater than expected. This may be due to extraterrestrial helium. The observations of Young *et al.* (05.082.039) suggest similar conclusions. See also Tohmatsu (05.082.107).

Simultaneous observations at Abastumani by Toroshelidze of the He-emission at 10380 Å and O I-6300 Å during 1969/70 showed predawn enhancement for both emissions due to photoelectron flux from the illuminated magnetically conjugate point. Measurements during the period 1964–1967 made it possible to derive a regular seasonal variation in the 10830 Å-emission with a winter-maximum and a summer-minimum as well as the predominance of morning intensities over evening ones. In addition the behaviour during dawn was revealed (04.082.147, 06.082.091).

Observations of helium 10830 Å-radiation with a grille spectrometer at Socorro, New Mexico from 1967 to 1970 were presented by Christensen *et al.* together with new computations of the excitation and emission profiles (05.082.030). The observations show an intensity increase of a factor 3 during this period that is closely related to a corresponding change in the solar EUV radiation below 380 Å. A large seasonal variation is discussed with respect to a seasonal variation in the conjugate electron flux.

IV. TWILIGHTGLOW

By systematic observations of the oxygen 6300 Å line from 1962 to 1969 at Abastumani information on diurnal, annual, and seasonal variation in the intensity at various altitudes of the atmosphere were obtained and several separate layers have been singled out due to different excitation mechanisms (Megrelishvili, 1972, *Bull. Abastumani*, No. 42). Results on 6300 Å morning twilight measurements up to 96° solar zenith angle with a new high dispersion Ebert-type monochromator are reported by Suzuki and Ogawa (GRL Tokyo). Ground-based photometry of the O_2 1·27μm band in twilight which is strongly absorbed in the lower atmosphere was performed by Evans *et al.* (04.082.007). Graham *et al.* measured sodium, lithium, and potassium twilightglow at Moscow, Idaho/U.S.A. during 1967/68. Taking into account new calculations of transmission functions they derived heights of maximum densities near 90 km and total vertical abundances of about 10^{10} atoms cm^{-2} for sodium, $3\times10^{6}cm^{-2}$ for lithium, and $10^{8}cm^{-2}$ for potassium (1971, *Ann. Geophys.*, **27**, 223; 483). A study of atmospheric sodium was also published by Toroshelidze (1970, *Indian J. Meteor. Geophys.*, **21**, 211; 1971, *Bull. Abastumani*, No. 41). He investigated further an emission band at 5610 Å in twilight which was identified as due to barium iodide of probably artificial origin (03.082.081).

The results of extensive spectrographic observations of the scattered dusk light during 1962–69 were presented by Megrelishvili (1971, *Bull. Abastumani*, No. 41). Irregular variations caused by aerosol particles of terrestrial and extraterrestrial origin were found. He claims that scattered solar light of second order is small compared to that of the first order. Dust in the upper atmosphere by twilight observations was also investigated by Divari who found two layers of scattering maxima at heights near 50 and 100 km (06.082.051). Calculations of twilight brightness and polarisation as well as ph. e. measurements were made by Divari, Zaginayilo, and Samsonova (1970, *Atmosphernaya optika*, Nauka Moscow). See also 05.003.031.

New evidence indicating the influence of meteor showers on the brightness of the twilight sky was presented by Link and Robley (06.082.045; 1972, *Space Res.*, **XII**) and by Fehrenbach *et al.* (05.082.027; 1972, *Ann. Geophys.*, **28**, 363). They made observations from high mountains and by use of a balloon-borne photometer. The results of six flights in October 1970 show clearly an effect of the Orionids on the optical properties of the upper atmosphere near 5100 Å.

V. ZODIACAL LIGHT

Review papers on the zodiacal light and interplanetary dust were presented by Greenberg, Weinberg, and Elsässer (05.106.017–019) dealing with ground-based and space observations, dust particles and cloud models, and particle fluxes near the Earth.

Photometry and polarimetry

New observational results were presented within the last three years by some researchers. Brightness, color, and polarization at elongations between 25° and 50° from the Sun were derived by Vande Noord (04.106.004) from measurements with balloon-borne equipment. Sparrow and Ney (07.106.024) published brightness and polarization data gained from the satellite OSO-5 at elongations close to 90° from the ecliptic to the poles. Lillie (Boulder, Univ. Colorado) reports on OAO-2 observations of the zodiacal light at twelve wavelengths between 1000 Å and 4300 Å. Leinert *et al.* (*IAU-Coll.*, No. 23) measured brightness, color, and polarization at 15° and 21° elongation at daytime by use of a rocket. Photometric results of ground-based observations were presented by Dachs (03. 082.044), Sánchez (04.106.041), and Divari and Krylova (*IAU-Coll.*, No. 13.) Papers of Staude and Schmidt (1972, *Astron. and Astrophys.*, **20**, 163) and of Wolstencroft and Kemp (1972, *Astrophys. J.*, **177**, L 137) deal with the circular polarization of the zodiacal light.

The results of Vande Noord are in good agreement with the average of the results of other recent investigations. His observations suggest that a difference exists in the brightness distribution along the ecliptic between the evening and the morning, but it may be due to improper correction of airglow. According to Lillie at wavelengths shorter than 2500 Å the zodiacal light is considerably bluer than the Sun and has the energy distribution of an early B-star. At wavelengths between 2500 Å and 4300 Å he finds it redder than the Sun and similar to a G8-star. The other investigators found no significant deviations from the color of the Sun in the visual part of the spectrum.

Sparrow and Ney as well as Lillie obtain the zodiacal light intensity at the ecliptic pole as about $35S_{10}$ (blue). Values derived from ground-based observations by Dumont and by Divari and Krylova are about 30% higher. So with regard to former determinations a tendency to lower values is obvious.

The rocket measurements of Leinert *et al.* yielded a higher degree of polarization at 15° and 21° elongation than one would expect on account of former data for larger distances to the Sun. This experiment used an elaborate baffle system to suppress sunlight scattered by the photometer and by the sunlit Earth. Fractional circular polarization q of the zodiacal light in the range $-0{\cdot}3\%$ to $+0{\cdot}5\%$ was found by Wolstencroft and Kemp in several directions along the ecliptic. The dependence of q on elongation appears to be consistent with partially overlapping measurements made by Staude and Schmidt who found q very near to zero. These results are in disagreement with former ones which claimed higher q values. Wolstencroft and Bandermann believe that the new observations indicate the presence of elongated and partially aligned dust grains.

On the basis of extensive observations at the Teide Observatory Sánchez looked for variations in brightness correlated with solar activity. He reports on brightness decreases in correlation with the appearance of solar flares and a variation covariant with the eleven-year-cycle. These phenomena are discussed with regard to a lower limit in particle size of about $0{\cdot}1\mu$m.

Up to now infrared observations of the zodiacal light are a scarcely used source of information on interplanetary dust. Hayakawa *et al.* (05.106.020) presented results of observations made by means of a rocket-borne infrared photometer for the J-, H-, and K-range ($\lambda < 2{\cdot}5\mu$m). They found an energy distribution which is not inconsistent with a solar type curve. Preliminary results of the Heidelberg group obtained by balloon-borne equipment are of the same kind. Evidence for the thermal emission of the interplanetary dust is indicated in the results of Soifer *et al.* (06.106.009) at three wavelengths between 5μm and 23μm. This radiation was recorded by a rocket-borne-detector at an elongation of 160° near the ecliptic against a relatively bright background. A blackbody curve representing the observed fluxes corresponds to a temperature of 280K.

Gegenschein, libration clouds

The gegenschein has been observed in a four-year program by Roosen. The center of the gegenschein was found to lie precisely at the antisolar point. The results of his observations are interpreted with the help of model calculations. The only one of all previous explanations found tenable is that the gegenschein is caused by light reflected from particles of dust in heliocentric orbits (04.106.030, 05.106.022). On the basis of his observations Roosen argues against a concentration of interplanetary dust near the Earth, the socalled geocentric dust cloud (05.106.015). Roosen further published a valuable annoted bibliography on the gegenschein. It contains all references that have come to the author's attention during a thorough study. Also presented are position and brightness measurements from individual papers in tabular and graphical form (1970, *Icarus*, **13**, 523).

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Data from the OSO-6 zodiacal light experiment for the region near the gegenschein have been published by Rouy *et al.* (05.016.034). The equipment is operable only during satellite daytime and scattered light enters the photometer when the Sun or the sunlit Earth is at an elongation 90° or less with respect to the line of sight. The gegenschein region is free of photometric contamination from this effect. These measurements are in accord with former ground-based results and the studies of Roosen.

First results from the Pioneer 10 spacecraft (see below), as Weinberg reports, concern also the gegenschein. Principal result to date are observations when the Earth-Sun-spacecraft angle was 3°.4 and the spacecraft was 9·2 million km from the Earth. The brightness relative to 180° elongation is also found to be similar to ground-based results.

Whether the libration clouds are real is discussed in a letter by Roosen and Wolff (02.091.032). They call attention to theoretical difficulties and to observational evidence against the existence of dust clouds at the L_4 and L_5 libration points of the Earth-Moon system. With regard to dust-counting experiments on space probes they suggest that clouds of observable brightness may pass through interplanetary space causing fluctuations and an occasional erroneous report of a 'libration cloud'.

Current programs, space projects

Some colleagues are referring to current programs and observational material which is still being analyzed. A large body of observations made in recent years with a photoelectric polarimeter at the Haleakala Observatory, Hawaii by Weinberg and co-workers is being reduced at Albany. Included are coordinated observations from Hawaii and Pioneer 10.– Maps of the polarized intensity and polarization orientation of the night sky radiation over most of the two ecliptic hemispheres have been prepared by Wolstencroft from observations made at Chacaltaya, Bolivia at five wavelengths between 3650 Å and 9515 Å. The influence of tropospheric scattering has been closely studied and carefully eliminated. – The program of Dumont and Sánchez has been pursued at the Teide Observatory, part of the material is reduced at the Bordeaux Observatory. A re-examination of all photometric data since 1964 has been made with special care on minimizing the errors. The result shows that the zodiacal brightness can be obtained from ground with rms-errors less than 10% in the bright cones and 25% in the dark off-ecliptic regions.

The reduction of brightness and polarization measurements of the zodiacal light at large elongations conducted by the Heidelberg group within the last two years by use of a balloon-borne telescope in the visual and near infrared region is nearly completed. – Tanabe, Tokyo, observed polarization of the inner zodiacal light at 5200 Å and 6000 Å with a photoelectric polarimeter by a rocket in 1971. He also tried to detect the circularly polarized component by a balloon-borne instrument in 1972. Both rocket and balloon data are in the process of reduction.

Photographs taken from the Apollo 14–17 Command Modules in lunar orbit with the spacecraft in umbra and out of Earth-shine are analyzed by Mercer, Dudley Observatory. Under these perfect occulting conditions measurements can be made to within one degree of the Sun. So far photometrically calibrated data have been acquired on the *F*-corona, zodiacal light, and Gegenschein region. The gap from a couple of degrees on either side of the sun to about twenty degrees elongation in the ecliptic has been photographed. From the lunar position there is a parallax of some thirteen degrees between the L_1 Lagrangian point of the Earth-Sun system and the antisolar direction. Preliminary results show a relatively strong counterglow with no noticeable contribution from the L_1 region.

In order to obtain further information on the zodiacal light in the ultraviolet, Lillie is presently working with data from Fastie's UV-spectrometer experiment on Apollo 17 which has a 12° × 20° field of view and is sensitive in the 1180–1680 Å spectral range. With this instrument it was possible to look within three degrees of the Sun using the Moon as an occulting disk. A preliminary examination of the data indicates that the UV enhancement is much smaller at 1500 Å than at 1900 Å (see above). Although many alternative explanations are possible, it is consistent with scattering by small (200 Å) graphite grains.

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Measurements of zodiacal light, starlight, *F*-region airglow, and the spacecraft corona will be made with a photoelectric polarimeter from the Earth-orbiting Skylab. Launch is scheduled for April 1973. Various fixed-position and scanning programs will be used to observe the sky to within 15° of the Sun at ten wavelengths between 4000 Å to 8200 Å, the same wavelengths as used for observations from Haleakala. The polarimeter and a parallel camera system are positioned on an altazimuth mounting which is extended by an astronaut 6 m from the spacecraft to insure that the instrument does not see the large solar panels associated with the Apollo Telescope Mount. Principal investigator is J. L. Weinberg of Dudley Observatory.

Another important experiment of Weinberg and his group is carried by Pioneer 10 which was launched in March 1972. Zodiacal light and integrated starlight are measured in two broad spectral regions (blue and red). This deep-space probe is on the way to Jupiter and offers the opportunity to determine the spatial distribution of interplanetary dust between 1 and 5 AU and to map the night sky at large heliocentric distances where the zodiacal light is negligible. First results on the gegenschein are mentioned above. Encounter with Jupiter is in December 1973. The second Asteroid Jupiter probe Pioneer G which is scheduled for launch in April 1973 will carry a polarimeter identical to that on Pioneer 10.

Helios is a deep space probe for the investigation of the inner part of the solar system and will also carry a zodiacal light experiment which is prepared by the Heidelberg-group. This German-American spacecraft is designed to approach the Sun down to a distance of 0·25 AU. Brightness and polarization of the zodiacal light are measured in three colors which are close to the *UBV*-system. Due to the spin of the spacecraft two photometers will scan the circles of 15° and 30° ecliptic latitude while a 90°-photometer is monitoring the ecliptic pole region. The instruments are provided with extended baffle systems for straylight suppression. Helios A is scheduled for launch in fall 1974. A second Helios B probe with identical equipment will follow about one year later in 1974. For details see 05.106.019 and Leinert *et al.* (*IAU-Coll.*, No. 23). Cooperative programs of Dudley and Heidelberg Observatories are devoted to intercomparison of calibration standards for these space experiments.

The interplanetary dust cloud

Various models of the interplanetary dust distribution were considered by Giese. In preparation of an analysis of space experiments catalogues of basic single-component models predicting brightness and polarization of the zodiacal light for a wide range of particle sizes, spatial distributions, and material were computed (1972, *Rept. Dudley Obs.*). Predictions were made concerning the appearance of zodiacal light as it will be observed from space probes at positions in and out of the ecliptic. The degree of polarization at higher ecliptic latitudes and especially at the pole is found to be an important observable quantity. (06.106.020; 1972, *Space Res.*, **XII**, 437)

Model computations on how the zodiacal light will look like as seen from the Pioneer F/G and Helios probes were published by Hanner and Leinert (1972, *Space Res.*, **XII**, 445) with special emphasis on the effects of a dust free zone near the Sun and a particle concentration in the asteroid belt. These probes provide an unique opportunity to determine the spatial distribution of interplanetary dust throughout the region from 0·1 to 5 AU and its concentration towards the ecliptic plane.

On the basis of observations of the polarized component of the zodiacal light between 30° and 180° elongation Jameson derived a model with a density varying as $1/r$ in the ecliptic plane (r distance from the Sun). Outside the ecliptic plane the density is found to vary approximately as $1/r \exp(-2{\cdot}5 \sin\gamma)$, where γ is the heliocentric ecliptic latitude (04.106.007).

Thermal emission of the interplanetary dust for the *F*-corona region was calculated by Kaiser (03.106.001). His paper demonstrates how new information on the particles' nature can be gained by infrared observations. By comparison with former measurements of Peterson and MacQueen at wavelengths of 2·2μm and 3·5μm which show different emission peaks of the *F*-corona indications for the presence of different stony materials near the sun are derived. – Another analysis of Mac Queen's observations is done by Beard and Calbert (07.074.042). The vaporization temperature of

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dust near the Sun was determined by Peterson (07.106.005) on the basis of new infrared measurements. At 4 $R_{\odot}$ distance from the Sun he finds relatively high temperatures near 2200K.

During recent years the fluxes of dust particles measured by rockets and satellites have shown a tendency to approach the values derived from zodiacal light data. The problem of transforming particle densities as they follow from zodiacal light observations into fluxes was discussed by Elsässer (05.106.019) and Leinert (06.106.019). They come to the conclusion that due to the uncertainties of the models the fluxes calculated from zodiacal light data are not better defined than to a factor of about ten. Differences between the zodiacal light fluxes and fluxes measured on spacecrafts of less than one order of magnitude are therefore meaningless at present. That there is no longer a serious discrepancy between flux measurements and zodiacal light data was recently confirmed by Giese (1972, *Space Res.*, **XII**, 437).

The capture of dust particles by the Earth has been studied by Komarnitskaya. Orbits of particles in the plane of the ecliptic and near to it have been calculated taking into account the cooperation of three gravitational bodies. Corridors from which the capture of particles by the Earth takes place and the effective radii of capture were determined (07.105.060).

Results of a new attempt to observe the motion of the interplanetary dust cloud by measuring the Doppler shift of Fraunhoferlines in the spectrum of the zodiacal light were published by James and Smeethe (04.106.008). From the variation of the Doppler shift with elongation it is possible in principle to deduce also the spatial density law of the particles. By use of a Fabry-Perot etalon the authors were able to extend the curve of Doppler shift derived by Reay and Ring in 1968 in the region of elongations from 45° to 28°. The observations have been made at the Haleakala Observatory, Hawaii in the spectrum region around the b_1 component of the Mg II Fraunhoferline at 5183·6 Å. They found that the Doppler shift increase markedly with decreasing elongation. The magnitude of the shift is such as might be expected if the particle size index were less than three. It follows then that radiation pressure does not play an important part in the short term dynamics of the dust cloud. There is no evidence for a component in retrograde orbit around the Sun.

VI. INTEGRATED STARLIGHT, DIFFUSE GALACTIC LIGHT

The background brightness of the milky way near 2500 Å between $l = 72°$ and 126° has been derived by Sudbury and Ingham (03.155.008) from four scans across the galactic plane by means of a rocket experiment. Qualitatively the data show the general features of milky way brightness maps. A comparison with those for the visual give some hints of the distribution of interstellar dust and early type stars. The brightness in the galactic plane indicates in comparison with other data a maximum of extinction in the 2200–2500 Å region due to a true absorption rather than a peak of scattering. – Isophote maps of the milky way for the *U*-color of the *UBV*-system, except the northern region from Per to Cep/Cyg, were presented by Pfleiderer and Mayer (06.113.025). The brightest areas coincide with OB associations and Hα regions. – Tanabe of the Tokyo Observatory is continuing the measurements of star fields on the *Palomar Sky Atlas* using the star-counting device, which was introduced at the *IAU-Colloquiem*, No. 11. Measurements in the regions of the north celestial, ecliptic and galactic poles have been almost completed.

Linear polarization of the integrated light from the milky way amounting to a few percent has been determined by Wolstencroft (*IAU-Symp.*, No. 52) at several galactic longitudes using two independent methods of correcting for foreground zodiacal light. Similar results were obtained by Staude *et al.* (*IAU-Symp.*, No. 52). They measured linear and circular polarization of the southern milky way at the Boyden Observatory, South Africa. At several points a nonzero circular component is indicated.

Remarkable progress has been achieved in recent years in the investigation of the diffuse galactic light: Photoelectric measurements in the Coalsack and a dark nebula in Libra have been carried out by Mattila. The brightness of the diffuse light reaches 80, 50, and $60S_{10}$ in *V*, *B*, and *U* respectively in the most opaque regions of the Coalsack. The diffuse light in the Libra nebula was found to be polarized, the polarization direction is perpendicular to the galactic equator (04.131.029). The

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observational results were interpreted by Mattila in terms of the albedo and the form of the scattering function of interstellar particles in a theoretical study on radiative transfer in spherical dust clouds. The albedo was found as 0·65 and the asymmetry factor g as 0·85. A reinterpretation of Witt's observations of the diffuse galactic light in Cygnus and Taurus/Auriga gave support for these values (04.133.044). In another paper the diffuse light in the galactic plane is interpreted by Mattila taking into account the discrete cloud structure of the dust and it is shown to have considerable effects on the determination of the grain properties. The albedo is derived in the range 0·3–0·7 and g again as greater than 0·75 (06.155.028).

New determinations of the diffuse galactic light by observations across the galactic equator in the right-ascension domain 257°–336° have been made by Roach *et al.* (07. 155. 036). They found intensities up to about 150 S_{10} in V. An attempt to determine diffuse galactic light at larger galactic latitudes was undertaken by Dumont *et al.* (04.155.019).

From surface brightness measurements of the night sky made with the stellar photometers of the OAO-2 in 29 of Kapteyn's Selected Areas at ten wavelengths between 1500 Å and 4250 Å Witt and Lillie (*Astron. and Astrophys.*, in press) derived a component of increasing intensity towards the galactic equator which is interpreted as diffuse galactic light. Their results suggest a wavelength dependent albedo of the interstellar grains with a pronounced minimum around 2500 Å and a rapid increase towards values near unity at wavelengths below 2000Å. Between 3000 Å and 4000 Å the albedo lies near 0·5. The scattering function is strongly forward scattering for wavelengths longer than 1900 Å and appears isotropic for wavelengths shorter than this limit. Preliminary results of OAO observations of reflection nebulae show also an increase in the albedo below 2000 Å. These results are also of great interest with regard to Lillie's findings on interplanetary particles (see above).

It should be pointed out still that from the different experiments on spacecrafts which are described above (Chapter IV) many new measurements of integrated and diffuse galactic light are to be expected.

VII. EXTRAGALACTIC BACKGROUND

It is an old question whether extragalactic contributions to the night-sky light can be ascertained. Again and again attempts have been made to measure it without convincing results so far. Of fundamental significance is the chance to find a contribution to the background light by very distant young galaxies, the radiation of which is displaced toward the infrared as a consequence of their large cosmological redshifts. Therefore information on the history of the universe could be obtained by measuring the night-sky background in the infrared. This topic was discussed from a theoretical point of view on different occasions by Peebles, see for instance 05.162.024. To know the brightness of the infrared night-sky is also of interest in connexion with the 3K-background radiation.

Recently some researchers tried to measure the infrared background by means of rocket experiments at different wavelengths (McNutt *et al.*, 03.082.014, 06.082.149; Muehlner and Weiss, 03.066.024; Pipher *et al.*, 05.082.132; Blair, 06.082.044). Their results demonstrate that is is very difficult so far to separate contributions of instrumental, atmospheric, interplanetary, galactic and extragalactic origin. Therefore up to now only upper limits to the background intensities could be derived. Satellite experiments have their specific problems because measurements above about 3 μm wavelength have to be made at liquid helium temperatures. So far no results of background observations in the infrared from satellites became known.

VIII. PRIORITIES AND EXPECTED DEVELOPMENTS

Since in the future increasing efforts will concentrate upon the infrared spectrum of all components of the night-sky light, from the astronomer's point of view better knowledge of the infrared emissions of atmosphere and ionosphere, the foreground, is highly desirable. In the middle and far infrared the airglow is not well investigated so far. Regarding the airglow continuum even in the visual part of the spectrum controversial questions have to be solved still.

Nothing which could be relied on is known at present about composition of the interplanetary dust. Also our knowledge of its spatial distribution is very limited. Basic data for a theory of dynamics and evolution of the interplanetary dust cloud are missing therefore. From deep space probes important information on the density law is to be expected within the next years. The thermal radiation of the dust cloud contains unknown information on the particles as well as on their spatial densities. Because its main part is to be expected at wavelengths beyond 3 μm measurements have to be done outside the earth's atmosphere. The ultraviolet is of the same interest.

Spectroscopy of the zodiacal light and exploration of the kinematics of the heliocentric dust cloud are still in the initial stage. Careful photometric programs from spacecrafts as well as from ground in order to learn more about the correlation between zodiacal light brightness and solar activity, that means about the interaction of corpuscular radiation of the sun and interplanetary dust, are a promising task.

Deductions of the integrated starlight intensity by means of star counts are an important problem, not at least with regard to determinations of extragalactic background light. At higher galactic latitudes where other night-sky components are brigther than the galactic light this is the only way to derive reliable results. Modern data obtained by use of good photometric sequences at weak magnitudes are not available at present, but programs are going on in this direction at some observatories. With regard to measurements of the surface brightness of the integrated star light remarkable uncertainties due to photometric and atmospheric effects are still present. Relatively little is known about polarization of the diffuse galactic light. By its investigation new information on interstellar grains could be gained.

New activities in order to identify extragalactic contributions to the night-sky light have been initiated. It is to be hoped that efforts in this complex field will succeed in the near future.

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