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Monitoring of Earth's atmosphere by astrophysical means

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Abstract.
For the last twenty years new methods of recording of radiation from astrophysical objects have been developed and adopted. In most cases their efficiency is much higher than the possibilities of the classical ground-based techniques of investigation of spectral and photometric characteristics of the Earth's atmosphere. A number of features (important for observing astronomers) of behaviour of emission and absorption characteristics of the Earth's atmosphere spectrum are presented. Some ways of creation and use of astrophysical apparatus for solving the problems of geophysical and ecological monitoring are discussed.

Key words: Earth's atmosphere: monitoring– Astrophysical database

1. Introduction

The study of chemical composition of the Earth's atmosphere is a base of a number of scientific and applied fields. Let us enumerate some of them: formation and evolution of the atmosphere, planetary gaseous exchange of the current epoch, photochemistry of the upper atmosphere layers, interaction between the atmosphere and interplanetary medium, investigation of the aerosol component, backwarming effect, and the problem of changing the conditions of management in consequence of global rise in temperature, degradation of the ozone layer as a protection screen, atmosphere pollution over the urban regions, overboundary transfer of the principal atmospheric component and admixtures of anthropogenic origin.

One of the main objects of inquiry in ecology is the "biosphere". The concept comprises the layers of atmosphere, water and litosphere (geological medium). The biosphere includes the upper part of the atmosphere up to the height of the ozone layer (about 20-25 km).

The ecological significance of air as the biosphere element is determined by its chemical content, which is affected considerably by technogenic factors. Analysis of air pollution, inspection of chemical catastrophes, of their ecological consequences are extremely vital and define integrated approach to investigation of the problem. In the last few years industrial development has increased anthropogenic load per unit area, and led to an essential change in the air content. The change has manifested, first of all, as depletion of oxygen reserves, destruction of the ozone layer, accumulation of carbon dioxide, methane and pollutants: nitrogen oxides, sulphur, soot and dust, increased amount of radionuclear products.

Understanding of present-day climate changes depends on the data of biological sciences on the situation in vegetation and soil. Analysis (from the point of view of sciences about the natural medium) of consequences of increase in concentration of carbon dioxide and dust in the atmosphere as a result of industrial pollution is of great importance (Kondrat'ev, 1980). The purposeful decisions on changing the character of anthropogenic effect on the atmosphere needs primarily a full description of the efficiency of all sources and sewers of principal components and admixtures of the atmosphere, their regional, seasonal and secular features. It is on the basis of this description in combination with the information on the efficiency of long-term natural reservoirs of different chemical elements and compounds that one can evaluate by means of numerical simulation, the character of current evolution of the atmosphere.

Information on the chemical composition of the atmosphere arrives from both different monitoring systems and individual experiments. The systems of global monitoring of the atmosphere are designed so as to be economical and technological simplicity of perfomance of every element of a monitoring systems to be provided. The system sensitivity is, as a rule, adequate to the main problems for the moment of its formation. The latter presents difficulties in formulating new problems for the available monitoring systems.

The principal information accumulated for dozens of years of investigating optical properties of the Earth's atmosphere refers to it's dayly state or twilight airglow. The study of mechanism producing night stratosphere was inhibited until recently by the sensitivity of photographic techniques and low photometric accuracy of the procedure of photographic recording in combination with image tubes (IT). As early as two dozen years ago most astrophysical observations were carried out through the transparent window in the Earth's atmosphere for 300-600 nm with photographic recording and using IT. In such observations, made with moderate signal–to–noise ratio the amount of information on the Earth's atmosphere remain minimal. Lines and bands recorded on the spectra of faint astronomical objects were far from falling always within the linearity range of light detectors.

That is why quite recently practically the only technology that jointed astrophysics and atmospheric optics was the use of one-channel photoelectric light detectors. Photoelectric photometry was done, as a rule, using broadband filters, which reduced to a certain degree the unambiguity of quantitative interpretation of results in both the problems of studying the Earth's atmosphere characteristics and the problems of investigation of stellar atmospheres. Certain problems would arise in the attempts to meet the conditions of simultaneousness of multichannel photoelectric observations.

The situation has changed over the last twenty years. Firstly, the introductions of the methods of investigation of the terrestrial atmosphere with the use of orbiting platforms and development of techniques for optical and microwave ground based probing were accompanied by lowering of attention to improving the technology of ground based optical monitoring of the atmosphere by the network facilities. The network facilities developed in the late 1960's and early 1970's do not comply with the present-day accuracy requirements. Secondly, observational astrophysics has obtained the windows of the infrared (IR) range, where the number of the Earth's atmosphere spectrum details is large. Thirdly, the costs of large telescopes and the increased demand for their use have made the unit observing time more informative, and special attention is being paid to the creation of multichannel systems for recording of radiation. Fourthly, the improved light-gathering power of large telescopes has increased the number of the interesting objects investigated by high-resolution spectroscopy. The certain technological boom was started, and for the last ten years unique spectrometers have been made. Fifthly, the modern numerical methods of interpretation of stellar spectra allow the concentration of chemical elements up to the level 10^{-12} on the number of particles in the stellar atmosphere to be determined. At last, part of astronomical observatories, which were once built well away from cities, are enveloped now by megapolises or industrial centers, staying under the conditions (night sky illumination, dust) which make it impossible to perform priority investigations of faint distant astrophysical objects. The developed infrastructure of such observatories may facilitate their reorientation to other directions (including atmosphere monitoring).

Therefore we consider the problem contained in the head of our paper to be up-to-date. Below we will be concerned with some principal possibilities of examining the main components of the Earth's atmosphere. In parallel we will enumerate the principle characteristics of secular, latitudinal, daily (longitudinal) variations of content of molecules, atoms and ions in the atmosphere, relating them to one or another measurement procedure.

2. Atmosphere composition and variation of its components

The present-day knowledge of the atmosphere processes permitted a thesis on tight evolutionary interrelation of the Earth's atmosphere with the neighbouring media — the Earth's crust and the World ocean on the one hand and the interplanetary medium on the other hand. In Table 1 is indicated the number of particles in a column of standard atmosphere with a base of 1 cm^2. Mixing keeps this relation constant within the troposphere, and only for the light fractions (hydrogen, helium) a barometric increase in the relative content with height is noticeable. Strictly speaking the distribution of concentration with height is determined by dynamical equilibrium between formation and destruction of a given component in a given elementary layer and the rate of matter exchange with the neighbouring layers. The deviation from the barometric law is most distinct in the case of ozone. A principal distinguishing feature of the Earth's atmosphere is the diversity in relative concentration of the components defining its average molecular weight, and the components that determine its radiation balance. In a first approximation this allows part of the processes in the atmosphere to be treated disregarding the interrelation, however, on the other hand complicates self-consistent atmosphere modelling. The cause is that the thermodynamical characteristics and the characteristics of mass transfer processes are determined by the components dominating in mass, while the radiation characteristics are defined by minor admixtures whose state depends on a great number of competing processes

Table 1: *Main atmosphere components*

nitrogen	$0.16 \cdot 10^{26}$	krypton	$0.24 \cdot 10^{20}$
oxygen	$0.45 \cdot 10^{25}$	xenon	$0.19 \cdot 10^{19}$
argon	$0.20 \cdot 10^{24}$	hydrogen	$0.11 \cdot 10^{20}$
carbon dioxide	$0.67 \cdot 10^{22}$	nitrogen oxide	$0.11 \cdot 10^{20}$
neon	$0.39 \cdot 10^{21}$	methane	$0.43 \cdot 10^{20}$
helium	$0.11 \cdot 10^{21}$	ozone	$0.10 \cdot 10^{19}$

in the atmosphere itself and in the adjacent media. A similar condition occurs in the atmospheres of cool stars of the oxygen sequence, where we hardly observe (but for hydrogen series) spectral evidence of the main atmosphere components, while the radiation balance in the visible and near-IR region of the spectra is due to minor admixtures (titanium oxide, water vapour, etc.), which account as mass for no more than 10^{-7} of the stellar atmosphere.

2.1. Oxygen and carbon dioxide

The basic components of the atmosphere are involved in the process of gaseous exchange. The system of reservoirs of movable fund of the atmosphere affected by geological processes of a time scale of $10^6 - 10^8$ years. The principal process in which carbon is supplied to the atmosphere (including one via the ocean) is degassing of the mantle and metamorphized rocks of the crust. The main process of withdrawal of carbon is burial in sedimentary as suboxided organic carbon and carbonates. Oxygen is supplied to the atmosphere from formation of sedimentary rocks and as a result of photodisintegration of water vapour in the upper atmosphere layers. Because of the difference in the geochemical cycles of carbon and oxygen, both long-term and short-term actions upon the geosphere tell on the carbon content in the movable fund and have practically no effect on the abundance of oxygen, the amount of which in the movable fund is dozens of times as great (Byutner, 1986). A characteristic time of variation of equilibrium oxygen content in the atmosphere due to bioprocesses occurring on dry land is 10^4 years, which is many times the characteristic time of global mixing of the atmosphere. That is why the concentration of O_2 in the atmosphere practically does not depend on the latitude and shows no seasonal variations. This allows, in particular, the oxygen band to be used for determining the upper boundary of the cloud cover from the artificial Earth satellites. On the other hand, the lines of rotational transition of molecular oxygen of the Earth's atmosphere, which are recorded in stellar and solar high-resolution spectra, may serve indicators of rotational temperature of oxygen molecules in the atmosphere layers where the lines are effectively formed. In Fig. 1 are shown fragments of the stellar spectra we obtained, which contain the band heads of atmospheric oxygen.

The carbon content is characterized by the seasonal cycle caused by the relative shift of seasonal variations of the processes of formation and destruction of organic mass on land. As a consequence of anthropogenic disturbances (effects on the biomass and burning of fossil fuel) the balance is upset between the processes of formation and destruction of organic substance, which results in global changes of CO_2 content in the atmosphere. The characteristic life-time of CO_2 in the atmosphere is longer than the atmospheric mixing characteristic time. Hence the general thesis on the latitudinal uniformity of the global field of CO_2 concentration arises. However, the concentration of CO_2 over different regions of the Earth surface still undergoes essential variations. One isolates three characteristic scales of the variations: synoptical (several days), seasonal and interseasonal (Shashkov and Faber, 1991). To these time scales correspond geographical scales of order hundreds, thousands and ten of thousands kilometers. In order to study synoptical variations, which are mainly due to the round-the-clock cycle of vegetation breathing, the procedure of taking samples of air (Brounstein et al., 1984) is desirable to be added by the spectroscopic technique, the latter must be as sensitive as to ensure night observations as well. In this case the ground-based facilities can be used to investigate the character of decrease in amplitude of the synoptical variations in the CO_2 concentration with height. In studying the seasonal and interseasonal global variations in the CO_2 concentration it is suffice to use only day-time spectroscopic technique. In the equatorial regions the processes of yelding and absorption of CO_2 are practically unaffected during a year, since these are controlled mainly by the temperature of air and soil. Due to the seasonal disbalancing of these processes in moderate latitudes the amplitude of seasonal variations of CO_2 rises smoothly with latitude, the amplitude being lower in low latitudes, where the contribution of the ocean to the formation of seasonal variations is comparable with that of the land biota. The stations of seasonal and global monitoring are so located as to avoid the influence of synoptical fluctuations, and, at best, samples are taken several times per month. That is why the synoptical variations turn out to be insufficiently studied.

Regular CO_2 measurements were initiated in 1958, but as a result of analysis of gaseous composition of air bubbles in glaciers the variation of CO_2 (20 % increase) for the last two centuries has been reconstructed (Neftel et al., 1985). The principal characteristic of global CO_2 concentration is its secular trend which is associated with permanent anthropogenic sources (forest extermination and fossil fuel burning). As a result the atmosphere receives much more carbon than it does from the deep layers of the Earth (Budyko, 1995), however contribution of biota to this trend is still the subject of discussion. In investigation of the global carbon cycle a decisive part is assigned to investigation of variations of isotopic composition of CO_2, since the processes of isotopic fractioning in absorption and yelding of CO_2 by vegetation lead to different yield of the ratio C_{13}/C_{12} for the gas liberated by ocean, biota of land, and gas, evolved from fossil fuel burning. Analysis of isotopic composition of CO_2 is performed only in samples of air and it will be a good idea to complement the analysis by spectroscopic measurements, which places extremely stringent requirements upon the experiment.

The anthropogenic effect on the CO_2 variations can be evaluated by studying the inhomogeneities of its distribution above the continents, the vertical inhomogeneities and daily variations should also be taken into account. Here too the spectroscopic methods may turn out to be decisive. Unfortunately there are actually no regular measurements of CO_2 above the continents (note that model calculations show that the most powerful source of CO_2 is the East-Siberian taiga).

The results of spectroscopic measurement of integral CO_2 content in the atmosphere for many years are consistent with the aircraft measurement in the same regions. The assumption about the uniform mixing of CO_2 in height is well supported. The root mean-square error of a single spectroscopic measurement of CO_2 is 2 % (Arefiev et al., 1990). Further increase in accuracy is associated with allowance for the water vapour lines blending effect.

2.2. Ozone

Altitudinal profile of the atmospheric gas temperature displays that there are three atmospheric gas heating sources: the heating of the Earth's surface, stratosphere ozone layer and solar radiation effect upon the ionosphere.

External, cosmic effects on the ozone layer characteristics occur mainly through the influence of solar flares. Changes in the concentration of ozone in the upper stratosphere occurs 1-2 days after the flare, in the troposphere these variations are delayed by another 2-3 days. With these changes the total ozone content increases by about 7 %. With the rise in solar activity the height of the ozone layer maximum grows too.

In the troposphere and stratosphere hundreds of chemical reactions take place, which have a direct or indirect effect upon the ozone content. The contribution of a given chemical component to destruction of the ozone layer is difficult to determine. Complete information on all chemical compounds that take part in reactions, on conditions of reactions and their constants is lacking. That is why in any calculation the situation has to be simplified and there is no guarantee that important processes are not disregarded in the simplification. The activity of mankind continuously changes the troposphere and stratosphere by introduction of million tons of new agents. This can affect also the conditions of proceeding of the reactions of ozone destruction, which are accepted to be basic presently, and it is possible that the processes that were of little importance yesterday will have to be taken into account tomorrow. Only the result of versatile observations can control the results of modelling the dynamics of ozone in the atmosphere. One differentiates photometric and spectrophotometric techniques of measuring the total ozone content. We will describe the most common from them.

As early as in the 1940's ozonometers with interference filters were developed in the USSR. The bandwidth did not exceed 2 nm, and the angle of view of the apparatus was 2°. This allowed an accuracy of measurement of no less than 10 %, and at minimum aerosole influence — up to 5 % (Mizun, 1993). The ozonometers were simple but requiring regular calibration because of their changing characteristics. Up to the present time, however, most of the devices, the home ozonometric stations are equipped with, have employed sets of wide-band glass filters. The most commonly used in the late 1950's was the ozonometer M-83 (Gushchin, 1974). In the 1980's the number of ozonometric stations equipped with this device in the USSR, whose results were published, amounted to 44. The kind of glass (UFS-2) used in one of the filters suffers from considerable solarization even in its latest modifications (Gushchin and Sokolenko, 1985), that is why it needed to be calibrated every year by higher precision ozonometers of Dobson's system (Dobson, 1957). Calculation of errors for the net ozonometers showed that the relative marginal error for the Dobson's ozonometer was 6-20 % (depending on the selected pair of wavelengths), whereas for the ozonometer M-83 – 50 %. The mean precision of M-83 turned out low (down to 30 %), which devaluated the funds allocated for quite a few years to stationary and expedition (including seabased) observations with this apparatus. The accuracy achieved proved to be insuf-

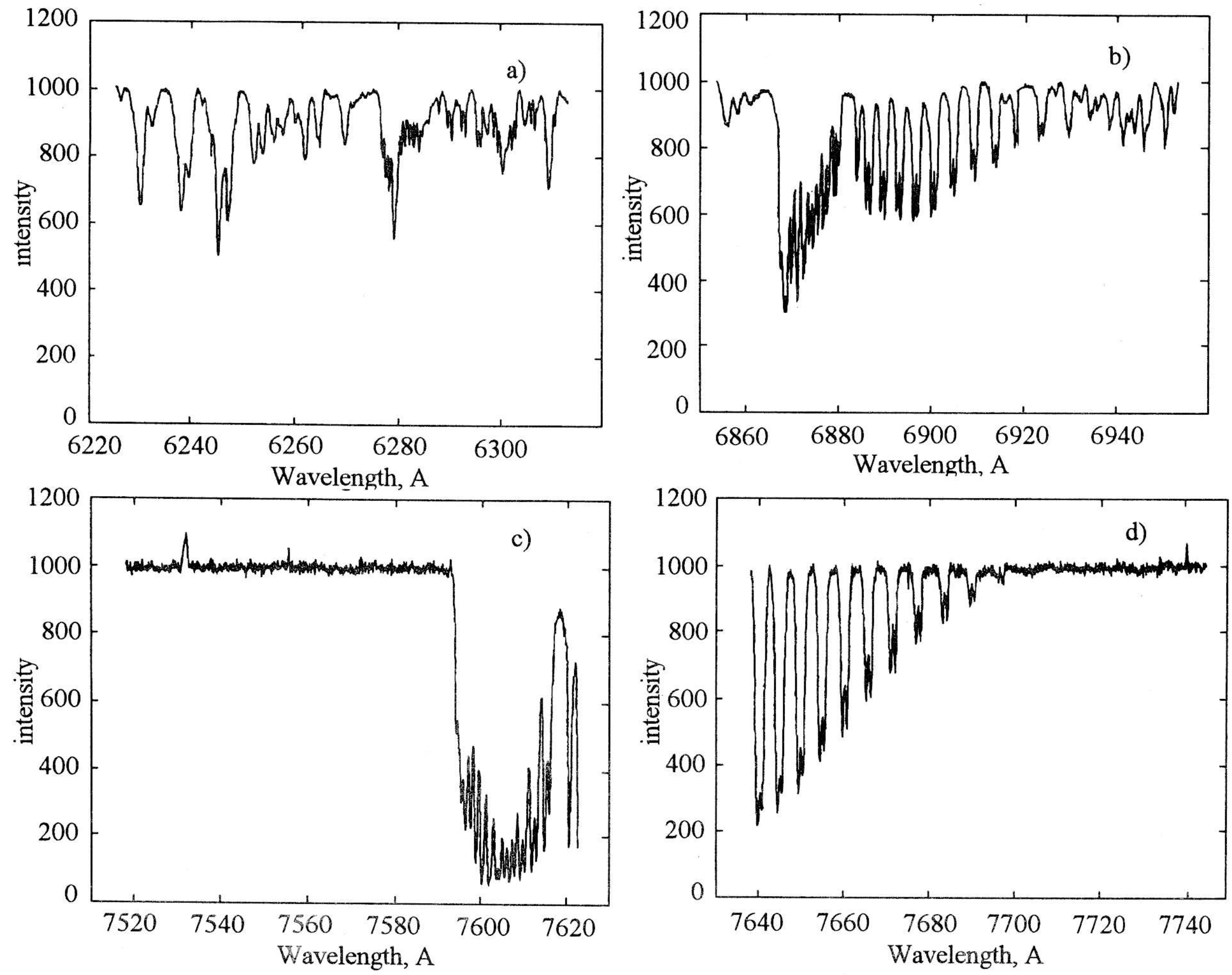

Figure 1: *Fragments of stellar echelle spectra that contain oxygen bands: a) with the band λ6288 Å, transition (0,2); b) with the band λ6884 Å, transition (0,1); c) and d) with the band λ7621Å, transition (0,0).*

ficient for investigation of the global time distribution of ozone. Later, M-83 was modified but this too did not save the situation: the relative limiting error amounted to 20 % (Shalamyansky and Romashkina, 1980).

If the filter halfwidth at the entrance of the ozonometer is varied from 10 to 40 nm, then the measurement error may reach 40 %. That is why the ozonometers by Dobson have a width (0.9 and 3 nm) that diminishes the error down to 2-3 % when measuring solar radiation and reduction to 5 % when observing scattered light at the zenith. The device is a dual quartz monochromator and measures at two wavelengths simultaneously. The difference in modulated fluxes in the two channels is compensated by moving the neutral wedge. Reading of the wedge position is the result of the measurement.

One of the principal difficulties in determining the ozone content by the photometric technique is the necessity of allowing for the influence of aerosol, which requires fulfillment of simultaneous measurement in the set of passbands (Gushchin, 1988). Cardinal solution of the problem is the use of spectrophotometers. In the ozonometer of Biewer the dispersion unit is a diffraction grating. In the focal plane there are four slits, however the switching of channels is performed on the one photomultiplier. The accuracy of ozone content measurement may reach 1 %. The home-made devices, DMR-1 and DMR-4 are based on monochromators. A device operating in the range 300-800 nm was also developed. Measurements are made at 9 wavelengths. This enables better correction for aerosol influence. The accuracy of ozone measurement can be brought to 2 % (Sokolenko, 1983).

The effect of errors in setting wavelengths in the spectrophotometer upon the accuracy of determination of the total ozone content in the atmosphere as dependent on the spectral resolution of the device was investigated. It is shown that for high-resolution devices (this is about 0.1 nm in ozonometry) there are possible ways of reduction of these effects of errors (including one through determination of extraatmospheric solar constants by extrapolation to a zero air mass). For the wide-band ozonometer M-83 the relative error in the total ozone content is larger than 10 % provided that the wavelength setting error (or the measure of departure of the used passband contour from the real one) totals 2 nm, i.e. 0.1 passband (Lyudchik et al., 1988). The absolute error of the device M-83, as has been mentioned, exceeds 10 %.

The altitudinal ozone distribution is determined by the method of reversing. The method consists in the following. When the Sun is low above the horizon, and the device is pointed to the zenith, the radiation scattered from different altitudes is recorded. The rays that pass above the ozone layer are not attenuated and from the scattering regions they run down vertically threading the ozone layer by the shortest route. The rays passing the ozone layer obliquely are absorbed largely and then scattered at the zenith beneath the ozone layer and reach the device. The lower the Sun above the horizon, the greater is the portion of the radiation scattered above the ozone layer in the overall radiation recorded by the apparatus, i.e. predominantly the shorter wavelength radiation. From the comparison of short- and long-wavelength fluxes the altitudinal ozone distribution is computed for each of the moments of time (the profile is, however, rough: the elevation of the center gravity, halfwidth of the layer, and the slope of the curve over the maximum ozone concentration).

2.3. Carbon oxide, methane and nitrogen monoxide

The CO content is estimated from IR spectra 2160 – 2150 cm^{-1}. The single measurement error is defined by the equivalent width measurement inside the instrumental profile and makes 10 %. Taking into account errors in the determination of corrections from the effect of temperature and humidity, the total random error is estimated to be 20 %. At this accuracy level of longitudinal variations in the CO content are not revealed. But latitudinal variations, which in the southern hemisphere is 3–4 times as small as in the northern, are revealed. No 24-hourly variations have been observed in unpolluted regions. A seasonal trend has been revealed: a rise of CO content is observed in the cold months, which is superseded by a fall in spring, in summer it is practically constant (Dianov-Klokov et al., 1978). A conclusion is drawn that CO is distributed uniformly in the northern hemisphere in the zone of latitudes 45 – 85°.

The contents of methane CH_4 and nitrogen monoxide N_2O did not show spatial and seasonal variations. within the measurement error of 5-8 % (Grechko, Dzhola, 1990). It should be noted that the possibility of studying the vertical distribution of methane by astrophysical techniques was demonstrated as far back as the middle of the century (Goldberg, 1951).

2.4. Water vapour

The humidity distribution in the ground layer represents, apart from the seasonal atmospheric phenomena, the geographical characteristics of vegetation. The correlation of ground-layer humidity with value of precipitated water layer is low. Alongside the methods of aerological probing, photometric and spectrophotometric techniques of integral measurements of humidity have been developed. The calibration accuracy of photometric humidity measures from the data of aerological probing is restricted by sluggishness of aerological methods. Note that ground-based investigation of precipitated water layer by the method of measuring integral absorption of solar radiation in a selected band of the vibration-rotation spectrum of water vapour (Bergner et al., 1978) is essentially limited in accuracy since the band consists of numerous lines of different intensity which are located in different portions of the curve of growth. If each of these numerous lines is recorded separately, then the troposphere humidity profile can be reconstructed, allowing for the different effective line-formation regions in the atmosphere. In the Fig. 2 are displayed the fragments of stellar spectra that contain water vapour lines.

The atmosphere components above itemized are available for daily spectroscopy. The sensitivity of the present-day astrophysical devices allows the behaviour of these components to be followed at night as well (Figs. 1 and 2), but the methodological and analytical basis must be different since the techniques based on the scattering of solar light in the atmosphere, e.g. ozonometric method of reversing, is inapplicable in the night time.

Now refer to some results of geophysical investigations performed only at twilight and at night.

3. Stratosphere emission spectra

In the day-time atmosphere reactions of dissociation of water and oxygen molecules under the action of UV radiation take place. At night the molecular oxygen is restored, the energetic states of a sample of different atoms, ions, molecules and molecular ions are being affected by the restoring reactions. Therefore the night atmosphere radiation is an indicator of various chemical and dynamical processes in the middle and upper atmosphere. Here both the dynamical action, coming from the Earth's surface, and the processes, associated with active regions on the Sun and solar wind take effect (Fishkova, 1983). We will now enumerate (in order of decreasing intensity) the

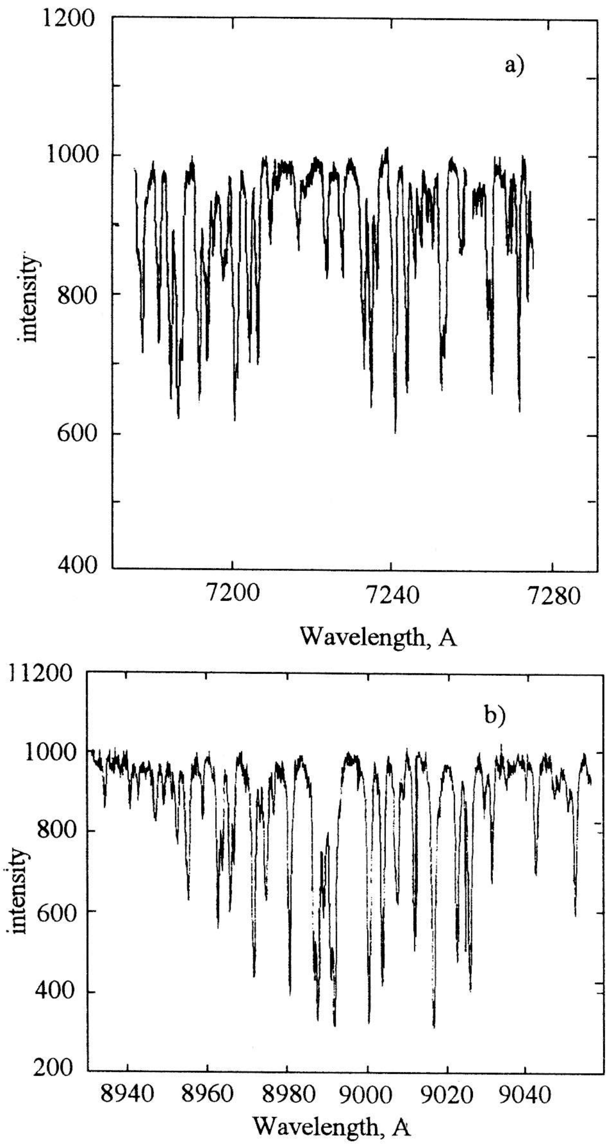

Figure 2: *Fragments of stellar spectra that contain water vapour lines: a) with the band λ7200 Å, transition (000,301); b) with the ρ-band λ9100Å, transition (000,003). These spectra are also obtained with high resolution echelle-spectrometer of the 6 m telescope.*

mean characteristics of the stratosphere components that are reflected in emission spectra.

3.1. Hydroxyl

The intensity summed over the bands totals 4500000 rayleighs and increases at twilight. In Fig. 3 are presented the fragments of stellar spectra we obtained, which contain hydroxyl bands. Under stationary condition, when exciting OH emission, the intensity of OH bands will be dependent on the concentration of hydrogen at the beginning of the night, H_0, and variation of ozone concentration. During the night the band intensities will be determined by the nightly variation of O_3, but the nightly trend, its type will depend on the value of H_0, which varying according to the season, will define the seasonal variation of the frequency of occurrence of the nightly behaviour type. With a sufficiently high spectral resolution accurate estimates of rotational temperature for OH are possible too.

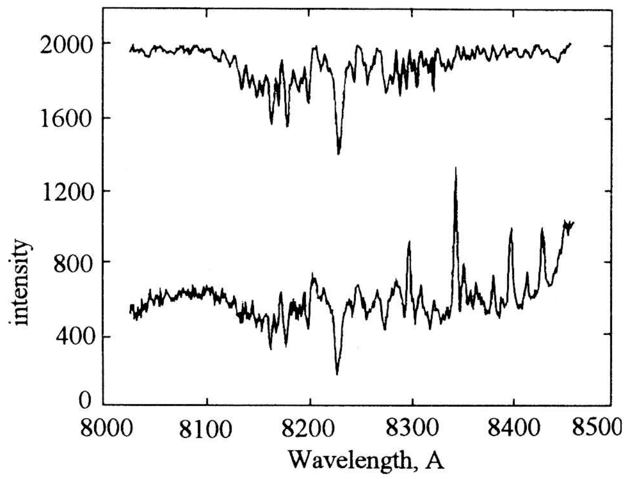

Figure 3: *Fragments of stellar echelle–spectra containing water vapour and hydroxyl lines. The spectrum of a bright object containing only water vapour absorption lines in the band (000,211) (top). The spectrum of a faint object containing hydroxyl emission lines in the band (6,2) and water vapour absorption lines.*

The longest series of observations were obtained in Abastumani (Fishkova, 1983), where a hydroxyl radiation was recorded to rise gradually during thirty years. This may be due to the increase in humidity of the middle atmosphere resulting from anthropogenically induced growth of carbon dioxide content and hence from heating of the atmosphere and strengthening of turbulence.

3.2. Molecular oxygen

The infrared 1200 nm system of bands has an intensity of 80000 rayleighs, while the intensity of the bands 761.9 nm (0.0) and 864.5 nm (0-1) is 6000 rayleighs. The molecular oxygen luminosity increases at twilight. The intensity of Hertzberg bands (260-380 nm) is 600 rayleighs. The radiation is formed at a height of 80-90 km.

3.3. Nitrogen dioxide

The intensity of radiation in the range 500-650 nm is 250 rayleighs. This stratosphere component is the major contribution to the "continuum" of the night glow.

The nitrogen oxide and nitrogen dioxide present in the atmosphere originate predominantly in the natural processes: volcanic eruptions, atmospheric discharges etc. Human activity of man also makes an essential contribution to their content. And if the nitrogen oxide and nitrogen dioxide are sufficiently uniformly distributed in the atmosphere, the increase in their content is then chiefly due to industry.

3.4. Atomic oxygen

The intensity of radiation is 250 rayleighs, it increases at twilight, originates at a height of 90 km. When comparing results of observations performed at different stations it turned out that the nightly behaviour of the 557.7 nm line emission is coincident in type for the given latitude, if plotted as a function of local time. The latitudinal intensity variation shows maxima at medium latitudes. The region of diagnostics by the 557.5 nm line is the interval of heights 70-120 km. Irrespective of the excitation mechanism, the intensity of the green oxygen line is proportional to the cubed concentration of atomic oxygen.

The temperature minimum in the stratosphere is located, on the average, at 85 km. The surrounding region, which contains temperature gradients of different sign, is characterized by intensive turbulent transfer and average vertical motions both upward and downward. The propagation of oscillations of different periods – both disturbed short-period of type of internal gravitational waves and regular variations, associated with atmospheric tides, planetary waves, long-period fluctuations, which represent the global circulation and solar activity effects is of great importance (Fishkova, 1983). As compared to the line 630 nm, which originates, on the average, at a height of 300 km, the time intensity variations of the line 557.7 nm have a smaller amplitude. At medium latitudes, where the ionospheric disturbances are not so well-defined, glow intensity variations are evidence of the presence of wind driven discrete structures with characteristic sizes of tens and hundreds of kilometers. The resolved lines of atomic oxygen 777.2, 777.4 and 777.5 nm are characterized by low intensity.

3.5. Atomic oxygen in reactions with ions

The 630 nm (100 rayleighs) and 635.4 nm line emission represents the character of ionospheric disturbances. The growth of concentration of ionized components leads to a several-fold increase in intensity. The glow is more intensive at twilight. The emission lines 630 and 636 nm are the most intensive indicators of the ionospheric F-region. The theoretical intensity ratio of the lines is equal to 3.1:1 and remains constant. Maximum intensity is observed near the peak of electron concentration at a height of 250 – 270 km. At the beginning and at the end of winter nights additional excitation gives rise to processes connected with injection of photoelectrons that came from the magnetic–connected ionosphere illuminated by the Sun. This emission is known to be highly sensitive to geomagnetic and ionospheric disturbances.

During a year regular vertical displacements of layers having large values of concentration of oxygen atoms take place. Variations of the annual average intensity correlated with solar activity were revealed.

3.6. Atomic sodium

The mean glow intensity is 50 rayleighs. At twilight glow flare is observed. The glow in the lines of the sodium resonance doublet does not show pronounced longitudinal variations. So far it is believed that sodium emission is nearly latitude independent. This suggests that the main source of sodium atoms is injection of cosmic matter into the atmosphere. The variation of relative intensity of the components allows sodium content to be estimated. Examining the intensity ratio of the components as a function of zenith distance, one can obtain information on the location of the maximum of the emission intensity in the lower atmosphere and mesosphere. The average height of emission formation is 90 km.

The emission of Na in the nocturnal lower thermosphere depends on both the initial concentration of sodium atoms and the relative concentration of oxygen and ozone at the consistent levels. However the main part is played by ozone. The nightly behaviour of sodium intensity represents mainly the nightly behaviour of ozone since the content of free sodium in the lower thermosphere remains constant within 5 % from evening twilight to morning twilight.

3.7. Hydrogen of the upper atmosphere and geocorona

Higher than 1000 km the neutral atmosphere is all-hydrogen. The vertical distribution profile is determined by the dissipation rate as well as by the character and intensity of the processes of hydrogen formation in the mesosphere, where water vapour dissociates. The emission line H_α in the spectrum of night glow is excited as a result of resonance scattering of solar L_α line emission in atomic hydrogen of the upper atmosphere and in the circumterrestrial hydrogen cloud, named geocorona by I. S. Shklowsky. A relationship between the amount of hydrogen and solar activity (the former decreases with rising activity) has been detected. The intensity of hydrogen emission increases at twilight.

3.8. Other components

The intensity of 1083 nm helium line emission, which is excited in the geocorona, increases at twilight seasonal intensity variations have been revealed. The line emission of the nitrogen doublet 519.99-520.33 nm is difficult to isolate from the OH spectrum at a medium spectral resolution.

4. Vitality of ground-based investigations of atmosphere optical characteristics

Prediction of the atmosphere state for the nearest decades is presently one of the most important problems. Here one observes paradoxically conflicting points of view of specialists. One of them insist on being careful in taking atmosphere control measures, on the vagueness of the prospects and complexity of global effects. The others believe that the judgement of the existing hazard of irreversible changes in the atmosphere and the inheritance for the future generations is correct even now. The principal objective is to evaluate the rate of rise in temperature and ultraviolet radiation reaching the Earth. The positive trend of the global atmosphere temperature around 1963 was discontinued by opalescence of volcanic origin. During the period from 1975 to 1985 the temperature of the medium and upper stratosphere in the western part of the northern hemisphere fell by 1.5° C. During the same time the lower stratosphere of the northern hemisphere cooled down by 0.5° C, while the troposphere became 0.2° C warmer, i.e. the vertical temperature gradient increased. There is no time left to fixation of secular trends, while the realistic model forecasting is possible only with allowance for the dynamics of all backwarming effect components.

Results of numerical modeling suggest that decrease in ozone concentration at heights over 30 km results in increasing the global-mean ground air temperature (increase in the ozone concentration at heights below 30 km has the same effect), the variations of ozone content in the troposphere and lower stratosphere being the most effective from the point of view of influence upon the climate, since the backwarming efficiency (on a per - molecular basis) is maximum for changing the ozone concentration near the tropopause (Kondrat'iev, 1989). The lack of adequate ozone-probing data calls for further development of satellite observations. Their employment is complicated by the fact that the reconstruction of the vertical profile of ozone concentration in the troposphere and lower stratosphere is a very complicated problem and the "Nimbus-7" satellite data, for instance, allow the ozone concentration profile to be reconstructed only at heights greater than 25 km.

By 2010 a considerable elevation of temperature in the arctic region and a smaller rise in the zone of desert, a more powerful response on the CO_2 rising of the climate of land as compared to ocean are predicted. This will lead to a 40–60 % decrease of moisture content in soil in the region of steppe of the northern hemisphere and to a considerable reduction of cloud cover in latitude 40 – 50° north, which amounts to 12 % in summer. Out of the agents that are still accumulated in the atmosphere, but for CO_2, an essential contribution to the backwarming effect is made by freons and carbon tetrachloride. Prediction of the level of UV radiation is complicated by the fact that addition of methane and carbon dioxide to air increases the quantity of ozone, while accumulation of freons decreases it, especially in the main part of the ozone layer — below 23 km. The model prediction of ozone decrease by 2030 is 6.5 % (up to 18 % at high latitudes). The following biological effects of increasing UV radiation are expected: appearance of eye cataract and damage of retina, photosynthesis rate drop and crop capacity reduction. On the contrary, the increase of CO_2 content accelerates the growth and increases crop capacity. In 1995 the Viennese convention on ozone layer control was signed (20 countries took part in its development and signing). A number of topics concerned with ozone and its monitoring, with observation of minor admixtures of type $HO_x, NO_x, ClO_x, CO, CH_4$ (Khrgian, 1989) were recommended.

The possibilities of satellites are presently restricted by the few component recorded simultaneously and the low resolving power of the methods for the lower atmosphere. The satellite means, however, is indispensable for investigating the variability of solar UV radiation in the region 110–140 nm when studying its influence upon the upper atmosphere.

At the present time complex monitoring is needed of the main components of the planetary gaseous exchange and atmosphere pollutants. To correctly judge the role played by the sources of gaseous exchange and transfer effects the monitoring should be executed by a ramified net. The first steps of the complex monitoring of selected atmosphere components have already been made – regular observations of CO_2, ozone, aerosol, water vapour, methane, chlorfluorinecarbons, and nitrogen oxides concentrations are being carried out at four stations (Alaska, Hawaii, Samoa, South Pole).

The problem of forecasting climate variations is followed by the problem of relatively short–term effects on the atmosphere. The regular nightly behaviour of emission features of hydroxyle, sodium, and atomic oxygen intensities is interpreted as a result of atmospheric tides. The amplitude of gravitation tide is small at the Earth's surface, however in the upper atmosphere it increases, as a result of decreasing density, so that at a height of 100 km it is 1000 times as high. Observations of irregular variations of night radiation is a sensitive technique for investigation of both interaction of individual atmospheric layers and development of different kinds of disturbances in the Earth's atmosphere associated with the solar activity.

The third problem is the one of early diagnostics of earthquakes. Here it is important to find methods capable covering a considerable territory. Disturbances in the Earth's crust in seismically active regions affect the variations of night radiation of the medium and upper atmosphere: the atomic oxygen and hydrogen radiation intensity variations starting in the period of the earthquake incipience have been revealed which permits the data to be used in the complex of electromagnetic heralds of earthquakes (Kharadze and Fishkova, 1988).

5. Problems of ground–based geophysical techniques

From the theory of stellar atmospheres one important condition is known: the lower the spectral resolution the more ambiguous becomes the quantitative interpretation of observations. We will emphasize that in the case of stellar atmosphere we deal with steeper temperature gradients per unit optical depth than in the case of planetary atmosphere, i.e. in the case of stellar atmosphere the exploration in depth using the means of low spectral resolution is still possible.

The geophysical facilities intended for passive monitoring of the atmosphere are predominantly a collection of production–type devices of low and moderate resolution. For this kind of devices, where an individual spectral line is impossible to isolate, calibration is of paramount importance. But if even the resolving power of an apparatus used for calibration is higher than that of a production–type device, in this case too the calibration accuracy is strongly restricted, which is due to ambiguity of interpretation with a low and medium spectral resolution.

The net devices created to comply with the requirements of definite servicing, cost, and possibility of multiplication provide, as a rule, the accuracies that allow monthly average and seasonal characteristics to be investigated. Due to the great difference between the night and day radiation fluxes, one and the same net device can not be used to investigate round–the–clock processes. The greater part of apparatus was created before the present–day problems were formulated and measurement accuracies were provided which could enable solution of a new problem. For instance, errors of measurement with production–type ozonometers are comparable with the value that characterizes the trend of long–term annual average ozone concentration. All the more these devices are unsuitable for investigation of the ozone concentration behaviour with height. The net monitoring implies that the stations located in towns and at the periphery (background stations) are equipped with apparatus of the same type, whose complexity is defined by performance of a background station.

For the last two decades the ground–based geophysical techniques have suffered pressing from the competing extraatmospheric techniques, which caused not only cessation of a considerable part of ground–based observations, but also to disappearance of a number of stations (background, first of all). Then followed an abrupt reduction of funding the extraatmospheric techniques...

In atmospheric physics day–time methods are most commonly used, but for a few station where the night atmosphere glow is systematically investigated. These stations, having a relatively more complex (obsolescent, however) equipment, are located, as a rule, near populated areas. The increased anthropogenic portion of night atmosphere glow causes efficiency reduction of broad–band techniques used to study natural emissions.

6. Ground–based astrophysical facilities

The principle reason for closing down the home net of ground–based monitoring is the necessity of performing definite observations only on clear days, which are not numerous. The equipment of net monitoring has become outdated and is unusable in solving any of the above geophysical problems. The low engineering level is unattractive to active researchers and apparatus designers.

On the other hand replacement of monitoring methods would involve an increasing sophistication of the net facilities, which could result in the necessity of solving an additional problem – development of the infrastructure of net stations and highly trained attendance.

The use of the potential of modern astrophysical observations with a developed infrastructure may be considered as one of the intermediate solutions. The global net of astronomical observatories even now compare favourably in power and funding with the net of geophysical observatories. We will characterize in brief the methods of observation in the optical and near IR ranges, which can be used directly or be adapted for the problems of atmosphere control. Then we will briefly consider the possibilities of creation (based on astrophysical techniques) of systems designed to be used directly for atmosphere control.

6.1. Monitoring of the atmosphere in astrophysical observations

In spectroscopic observations of the solar photosphere details with a high spectral resolution ($R > 10^5$) the absorption spectrum of the Earth's atmosphere gaseous component (including admixtures) is also recorded. The signal/noise ratio (S/N) of these observations may be brought up to several thousands and is actually restricted by the way of allowance for the multielement detector response "relief". The optics of the solar telescopes and spectral devices are mirror, so the accessible wavelength range is wholly defined by the responsivity of the detector and by the short-wave boundary of the atmosphere transparency window.

In high resolution spectroscopic observations of stars, bright fast–rotating stars, whose atmospheres do not generate narrow absorption features, are necessarily observed. All narrow absorption features (but for the interstellar medium lines) in the spectra of these stars originate in the Earth's atmosphere. These observations are then used to clear the spectra of other objects from the details of telluric origin. The spectral resolution is $10^5 > \mathrm{R} > 2 \cdot 10^4$, $100 < \mathrm{S/N} < 1000$. In spectroscopic observations of faint stars and galaxies spectra of the night sky glow at different azimuths and zenith distances are recorded at the same time. To correctly subtract the night spectra from the spectra of a faint object the night sky background spectrum is generally recorded (simultaneously, as a rule). The spectral resolution in this kind of observations is $10^4 > R > 10^3$, the S/N ratio is $10 < \mathrm{S/N} < 100$. The specimens of the night sky spectra taken with different R and S/N can be found in (Vlasyuk and Spiridonova, 1993; Osterbrock et al., 1996). To allow for atmospheric extinction, in broad–band, medium–band and narrow–band observations standard stars at different azimuths and elevations are observed.

In spectroscopic and photometric (using CCD photometers) observations effective diameters of star images blurred by turbulent motions in the Earth's atmosphere are recorded. Part of this information is estimated subjectively, part — in an objective form – is contained in the two–dimensional images of stellar spectra. The matter is that the height of the spectrum across the dispersion contains information on the diameter of star images and guiding quality, the latter can be neglected at short exposures of bright standard stars. It should be emphasized that this makes it possible to measure monochromatic diameters of star images. By measuring the seeing at different zenith distances, one can estimate atmosphere turbulence characteristics at different heights. Thus, even by the present time astronomical observatories have stored a wealth of information on the processes in the day– and night–time atmosphere.

6.2. Target–oriented monitoring by astrophysical facilities

At the multiprogram status telescopes several kinds of spectral devices are used. High–resolution spectrographs are used for about 30 % of calendar time in the period when the sky background brightness makes it impossible to perform observations of faint objects with low and moderate spectral resolution. The cost of these spectrographs is high, that is why three most powerful of them are equipped with additional telescopes of smaller diameter, which are located to the south of the domes of the main telescopes. The small telescopes feed the spectrographs on moonless nights, when the main telescopes are used to observe faint objects. In principle such small telescopes can be used during the daytime too for recording of atmospheric absorption spectra with high spectral resolution in the scattered light. Another way of feeding the idle spectral devices may be their connection to specialized feeding optics through fiber optics. One should take into account the depth changeability of Frauenhofer lines in the direct solar light and the Ring effect (Grainger and Ring, 1962) in the twilight spectrum. Thus the extension of time of using spectrographs is a powerful reserve of acquisition of data on the daylight and night atmosphere. The role of these spectrographs played in calibration of techniques is evident even if they are used for individual experiments.

Let us enumerate briefly the properties of the atmospheric components detectable by astronomical procedures. In addition to daylight measurements the broad–band and medium–band photometry technique can be used for investigation of the atmosphere aerosol component at night and twilight. It should be emphasized that present–day photometers are frequently furnished with polarimetric attachments. The medium resolution spectroscopy methods can be used to study the night and twilight atmosphere glow, investigating at the same time the relation between the components (hydroxyl, oxygen, ionosphere oxygen, sodium, helium, and geocorona hydrogen).

High resolution spectroscopy allows one to study atmospheric absorption features in the spectra of bright stars. First of all the spectra of oxygen, water vapour, carbon dioxide, carbon monoxide, ozone are accessible for measurements. By reaching a high S/N ratio and going to the IR range one can measure other minor admixtures as well. It should be noted that the behaviour of selected absorption features of the atmosphere spectrum has so far been investigated during daylight. The superhigh resolution spectroscopy techniques can be used to investigate the velocity field in selected lines of selected atmosphere components.

6.3. Some prospects of creation of ground–based new generation geophysical devices

We believe that the development of the methods of investigation of radiation from astronomical objects is bound to have an effect on the techniques of ground–based investigation of the Earth's atmosphere.

The widespread introduction in astronomy of solid–body detectors (CCDs) and abundoning the photographic methods caused revision of the ideology of designing spectral apparatus. Multiobject systems have been developed that form a collection of spectra of different objects located in the field of view of the telescope on a CCD chip. Systems of high spectral resolution (echelle spectrometers) have been developed, in which the CCD chip format is filled with a collection of high spectral orders belonging to the spectrum of one object. With a spectral resolution of 20000–70000 this technique makes it possible to measure simultaneously a portion of spectrum as long as 200–300 nm.

The systems of mechanical scanning of the twilight and night sky, developed for study of spectra of the upper atmosphere glow can be replaced by poliaperture systems. For instance, a set of like elements of the feeding optics oriented at different azimuths and zenith distances can be connected to the entrance of a spectral device via fiber optics. This will permit to simultaneously record spectra of the glow of different regions of the vault, i.e. to carry out the multiobject method over to geophysics.

The technology of manufacturing diffraction gratings with extremal blaze angle values allows compact echelle spectrometers with a spectral resolution amounting to 10^5 to be made. In this case the echelle may be covered with an immersion medium increasing the spectral resolution, while the immersion medium in turn must be shielded with a prism functioning as the order separating element. This kind of protected dispersion unit combined with the spectrograph autocollimation optics can be a basis of a new generation spectral devices designed for investigation of absorption spectra, including expedition conditions too.

The procedure of packing a high–resolution spectrum on a detector of small format liberates the large camera mirrors of high–resolution spectrographs, where a spectrum was recorded on one or several plates. For instance, the long–focus camera of the Main stellar spectrograph of the 6 m telescope recorded the spectra of the brightest stars using 4 plates each 300 mm long at the same time. The diameter of the camera mirror is equal to 2 meters. The long–focus cameras incorporated in the spectrographs installed at the Coude focus of small and moderate diameter telescopes have similar diameters. The large camera mirrors of old spectrographs, which practically unused presently, could be employed as optics for lidar air sounding (Zuev, 1970; 1974).

It is evident that the use of astrophysical methods of spectrum recording in Earth's atmosphere physics will entail the employment of systems of storage and reduction of spectra of astrophysical orientation. Note that the collection of methodological solutions implemented in practice of astrophysical spectroscopy makes it possible to measure lines whose equivalent widths are as small as a few milliangstroms. It can be suggested that astrophysical observatories with powerful spectroscopic facilities, but for their main functions, can be considered a connecting link between the field statistical methods of monitoring and refined complex experiments in the investigation of the Earth's atmosphere.

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