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# FROM SPECTROSCOPY TO THE CHEMICAL EVOLUTION OF THE GALAXY. PART 1.

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ABSTRACT. A brief review of the results obtained at Odesa Astronomical Observatory based on the stellar spectra analyses from 1892 to 2000 is presented. The review begins with the first observations of emission lines in solar prominences carried out in 1892 under the direction of Alexander Kononowitsch and includes an overview of spectrophotometric studies performed at the observatory using instruments and telescopes designed in-house; theoretical consideration of the issues of modelling physical conditions in stars and spectra simulation. It also describes the main results of the research of stars of various types, including cool giants K-, M spectral types, stars with various peculiarities of chemical composition, having enhanced lines of metals and CN bands, eclipsing binaries and binaries of different types, semi-regular and long-period variable stars, RR Lyraes, δ Scuti and λ Boötes stars, the diversity of Cepheids, blue stragglers in field and cluster populations, hot B Main-Sequence stars, etc., and finally, the enrichment with neutron-capture elements in the galactic stars.

**Keywords:** stars: abundances – stars: atmospheres – stars: different types – techniques: spectroscopic.

АНОТАЦІЯ. Подано короткий огляд результатів, отриманих в Одеській астрономічній обсерваторії за аналізом спектрів зірок з 1892 по 2000 рр. Огляд починається з перших спостережень емісійних ліній у сонячних протуберанцях, здійснених у 1892 році під керівництвом Олександра Кононовича, і включає огляд спектрофотометричних досліджень, проведених в обсерваторії за допомогою інструментів і телескопів, розроблених власними силами; теоретичний розгляд питань моделювання фізичних умов у зірках та моделювання спектрів починаючи з 60-х років 20-го століття. Також описані основні результати дослідження зірок різних типів, включаючи холодні гіганти K-, M спектральних класів, зірки з різними особливостями хімічного складу, який проявляється посиленими лініями металів і смуг молекули циану CN, подвійні системи різних типів та їх моделювання, напів-правильні та довгоперіодичні змінні зірки, зірки типів RR Ліри, δ Щита та λ Волопаса, різновиди цефеїд, блакитні страглери поля та скупчень, гарячі зірки B Головної Послідовності тощо, і, нарешті, збагачення галактичних зірок елементами захоплення нейтронів.

**Ключові слова**: зірки: хімічний склад – зірки: атмосфера – методи: спектроскопічний.

## 1. Introduction

The first spectral observations started in 1892 under the leadership of Alexander Konstantinovich Kononowitsch (1850-1910), the Director of Odesa Astronomical Observatory and Head of the Department of Astronomy of Odesa University, and they continued till 1895. Those were observations of solar prominences with a double-prism spectroscope for visual observation of the radiation spectrum (constructed in the workshop by Mr Toepfer, Potsdam) donated to Odesa observatory by the Academy of Sciences after Fedor A. Bredikhin, the Director of Pulkovo Observatory, arrived in Odesa in 1891. It was due to his direct involvement that systematic observations of the solar chromosphere with a prominence spectroscope began so early. The observations yielded drawings of solar prominences, marks of the width of the prominence base and height, as well as an indication of the presence of emission in the lines of hydrogen (Hα, Hβ and Hγ) and helium. Alexander Kononowitsch, Nicolas Zwetinowitsch, Artem Orbinsky and Aleksey Hansky participated in the observations. The observation results obtained over two years (1892-1893) were published in the Notes of Odesa University (Kononowitsch *et al.*, 1893). Later, there was a break in the spectral research until the 1960s, when throughout the globe an enormous interest in physics and space emerged, and young vigorous students and researchers joined the Department of Astronomy and Astronomical Observatory of Odesa University. Spectrophotometric and spectral studies of different types of stars, including variable stars, began to develop at the Astronomical Observatory, which traditionally dealt with astrometry, meteors and visual observations of variable stars.

## 2. Spectrophotometric investigations

Valentin Karetnikov and Yuri Medvedev started experimenting in this area of research as early as in 1964. They converted (adapted) an ordinary photoelectric photometer for spectroscopy (Karetnikov & Medvedev, 1966). Spectral energy distributions in the continuum of stars α And, β Ari and α Cyg were obtained, with α Lyr being observed as a reference standard, and then compared with those available in the literature. Noticeable chromatic aberrations in the red and especially blue regions due to the primary lens did not allow the researchers to obtain more accurate results or use the tool in their further research.

In the same years, Vladimir Pozigun and Nikolai Komarov created an electrospectrophotometer for observations in the near infrared region of the spectrum and, for the first time in the Soviet Union, they carried out observations and studies of stars by their energy distributions in the IR region of the spectrum (Komarov & Pozigun 1968). As a radiation receiver they used a photomultiplier, which had been semilegally brought back from a business trip to the USA (according to the legend, it was brought in a pocket) by Vladimir Platonovich Tsesevich, the Director of the observatory. The studies of energy distributions in the spectra of stars were performed at Odesa Astronomical Observatory (OAO) with a 17” telescope with an objective (4°) prism and an RCA7102 photomultiplier using evaporative cooling with carbon dioxide; the spectra were presented on a recorder. In September 1966, trial observations of Vega (α Lyr) and χ Cygnus were carried out. The IR electrospectrophotometer functioned at the observation station of the Astronomical Observatory in Mayaki village till 1970. The first observation station outside Odesa was arranged in the village Vannovsky (near Ashgabat, Turkmenistan) with a 17” telescope and an IR spectrometer transported and installed there; the station operated from 1970 to 1975.

In subsequent years, several telescopes were created at the Astronomical Observatory under supervision of its Chief Engineer, Leonid Paulin. Different equipment, spectrophotometers and photometers were also made by the Astro-Instrument Engineering Department and further employed in various observations at new observing stations and other observatories, where the new telescopes were installed or the existing ones were used. In particular, in the North Caucasus (Peak Terskol, during that period of time – at MAO of Academy of Sciences of Ukraine), they installed 80-cm AZT-7 telescopes (constructed at Odesa observatory) and spectrometers operating in the visible and infrared regions. Then, Seya-Namioka type spectrometers were installed on telescopes in Abastumani (Georgia, 1973-1974) and in the village of Mondy (Sayan mountains, Solar Observatory of the Siberian Branch of the USSR Academy of Sciences), at the stations of the MAO of the USSR Academy of Sciences (Bezymyanny (Nameless) Pass, Armenia and Murgab, Pamir, a 80-cm telescope); on the mount Dushak-Erekdag (Turkmenistan, a 80-cm telescope), etc.

## 3. Spectral investigations

After a brief report of the spectrophotometric studies conducted at the observatory, now let me focus our attention on the studies and analyses of both variable and non-variable stars, performed using spectra with low, medium and high dispersion (resolution), as well as on the studies related to the modelling of spectra, which have been carried out at OAO since the late 60s.

The first researcher who showed his interest in spectral research was Nikolay Komarov; his graduation research was devoted to the spectra of meteors and carried out under the guidance of Efim Naumovich Kramer, the graduation thesis was entitled *Spectra of Meteors*. In 1961, N. Komarov became a graduate student of Vladimir Platonovich Tsesevich with the research task to study variable stars. However, Sergei Rublev’s actively developing theoretical studies of radiation transfer in stellar atmospheres and observations of stellar spectra appealed to Nikolay Komarov. Rublev directed Komarov to the Crimean Astrophysical Observatory in order to obtain spectra for his dissertation, and Nikolay Komarov conducted spectral observations with a 50(48)-inch reflector. Actually, the primary mirror of that refractor is 48 inches in diameter, but among astronomers it has been dubbed a “fifty inch” one. Ivan Kopylov, the Vice-Director of the Crimean Astrophysical Observatory and an outstanding scientist, suggested that N. Komarov deal with poorly studied so-called "metal" stars, the Main Sequence stars with enhanced metal lines. Among the stars belonging to the A2-F2 spectral types, there is a large group of stars with enhanced metal lines. These are the lines of such elements as Ca, Zr, Sc, Mg, Ti, V and H. The first PhD thesis that used stellar spectra and spectrum modelling and was successfully defended in Odesa was that one by N. Komarov entitled *Kinematic and Morphological Properties of Stars with Enhanced Metal Lines* (1969).

In his dissertation research, N. Komarov used spectrograms of 29 stars obtained with a spectrograph attached to the 122-cm (50”) telescope of the Crimean Astronomical Observatory (CrAO). The following models of stellar atmospheres in the spectral interval of A0-F0 near the MS were constructed: LTE, plane-parallel, radiative and hydrodynamic equilibrium. The temperature distribution was found in the gray approximation and with the Chandrasekhar intensity averaging over direction. Metals were used to be a source of opacity. Subsequently, the temperature distribution was corrected for the non-gray atmosphere by the Swihart method assuming a constant flux of radiant energy at different optical depths. The grid of models was calculated on the Ural-2 computer at the Computing Centre of Odesa State University with different hydrogen content relative to metals for Teff = 9000, 8000, 7000 and 6000 K; log g = 4 and 3. The models with stellar envelopes were calculated (Golinko *et al.* 1969). A catalogue of 380 "metal" stars was compiled. It was the most advanced and up-to-date research performed at that time.

### *3.1 Analysing and modelling spectra*

Analysing spectra provided new opportunities and gave a new tool in the examination of physical conditions in stellar atmospheres, thus enabling to determine the temperature and gravity on the surface of stars, the chemical composition, the relationship between various parameters and the physics of the different processes occurring in stars and manifesting themselves in the stellar spectra, etc. Stars of late spectral classes (cool stars) were of particular interest at the time. The interpretation of their spectra, streaked with molecular bands and lines, required new approaches both in determining parameters of such stars and in calculating the molecular spectra as such, as well as analysing their effects on the parameters and structure of atmospheres. A progress in that area of research could be made by in-depth studies of physical processes that enabled to model stellar atmospheres and spectra. An important role in studies of cool stars was played by the *Stellar Atmospheres* Working Group founded by Nikolay Komarov, Nail Sakhibullin, Arved Sappar and Yanis Straume in the early 1970s.

The first study devoted to modelling atmospheres and envelopes of stars was the afore-mentioned research performed at OAO by N. Komarov in collaboration with V. Golinko and Zh. Krasnova (1969); it yielded model atmospheres and envelopes of A0-G5 stars. Theoretical modelling of processes in the atmospheres of cool stars was initiated by several investigations conducted by Vladimir Panchuk. He considered the propagation of a shock wave and convection in M-stars (Panchuk, 1970; 1972), and also calculated absorption spectra of titanium oxide molecules in the atmospheres of M-stars (Panchuk, 1974). Vladimir Panchuk constructed model atmospheres of stars of late spectral classes and deliberated *Equations of state. Part I* (Panchuk, 1974), *Sources of opacity. Part II* (Panchuk, 1975), and *The Possibility of Constructing Model Atmospheres of R CrB type Stars* (Panchuk, 1975). Blanketing effects in the radiation of cool M stars were studied by Alina Dragunova and Vladimir Panchuk using spectra with a dispersion of 37 A/mm (Dragunova & Panchuk, 1978).

Vadim Tsymbal, Vladimir Panchuk and Nikolay Komarov played a significant role in developing methods for analysing and modelling stellar spectra (computation of the synthetic spectrum). Vadim Tsymbal presented an important work entitled *Synthetic Spectra of Late-Type Stars* (Tsymbal, 1980). The programme code STARSP developed by Tsymbal to calculate the atomic and molecule synthetic spectrum with several subsequent modifications has been used by many scientists involved in studying chemical compositions of stars of different types up till now. Tsymbal calculated and reported *Column Densities of Opacity Particles in Cool Stars* (Tsymbal, 1980) and presented the tables of Franck-Condon factors with account for vibrational-rotational interaction for astrophysically important molecules ZrO, SiO, C2 and LAO (Tsymbal, 1980). Nikolay Komarov together with V. Tsymbal considered the thermochemical equilibrium of atoms, ions and molecules in the atmospheres of cold stars (Komarov & Tsymbal, 1980; 1987), calculated the effective depths of line formation and improved the growth curve method (Komarov *et al.,* 1979; Komarov & Mishenina, 1983). The effects of chemical composition in the atmospheres of M-, S- and C-stars were considered by Tsymbal & Panchuk (1980). To study those effects, the system of ionisation and dissociation equations was solved using an ES-1040 computer by the Newton-Raphson method; 94 chemical elements and 227 molecules were taken into account. The carbon content was a calculation parameter, O/C: 1.82, 1.2 and 1.02, which corresponded to M-, S- and C-stars, respectively. It was shown that the function of the number of M-, S- and C-stars should be monotonically decreasing over the whole range of spectral types and that one should expect a noticeable dispersion of the O/C ratio among M stars.

### *3.2. The equipment, telescopes and spectrographs*

Since the 1960s, spectral studies have been carried out at OAO using spectra with high and low dispersion (to obtain parameters and chemical composition and to make spectral classification, respectively), obtained by the observatory staff using telescopes and spectrographs at other observatories in the Soviet Union and throughout the globe. High dispersion spectra have been obtained with the following telescopes: a 50 (48) inch or 122 cm reflector of the Crimean Astrophysical Observatory and an echelle spectrograph (Cassegrain focus, inverse dispersion (14 A/mm and 37 A/mm)); a 6-m Large Azimuthal Telescope (BTA) of the Special Astronomical Observatory of the Academy of Sciences of the USSR with the main stellar spectrograph (OZSP, inverse dispersion 5 A/mm) and NES (a high-resolution echelle spectrometer, R = 60 000), which are in the focus of Nasmyth-2; a 1-m telescope (Zeiss-1000) of the SAO RAS with a coudé-echelle spectrometer (R = 30 000); a 1.52-m telescope at the Observatoire de Haute Provence (France) with spectrograph AURELIE ( R= 110 000); a 2.7-m telescope at McDonald Observatory, USA. In order to obtain low dispersion spectra, telescopes and prism spectrographs of Abastumani and Shamakhy observatories have been used.

## 4. Spectral studies (main results)

Now let me present the main results obtained by different groups of scientists at the observatory from the late 1960s to the year 2000.

### *4.1. Cool stars*

Based on high-dispersion spectra (a dispersion of 5 A/mm), an analysis of the chemical composition of cool long-period and semi-regular variable stars was carried out by N. Komarov (Komarov *et al.,* 1973; Komarov *et al.,* 1977). The temperature was determined from the ratio of the intensities of the titanium oxide band heads. That made it possible to reliably determine elemental abundances from the lines of atoms and ions for cool variable stars. To analyse the chemical composition, a part of the spectrum in a narrow wavelength range free from strong absorption in molecular lines and the growth curve method were used. The studied stars were found to contain elements at levels close to the solar ones.

Applying the differential method of growth curves to the study of the chemical composition of stars (Komarov *et al.,* 1979; Komarov & Shcherbak, 1979) made it possible to determine the relative abundances of elements in atmospheres of stars with an accuracy of about ±0.1dex; to demonstrate by an example study of 12 galactic open clusters that the matter in the spiral arms of the Galaxy was distributed irregularly and might differ in the chemical composition (Komarov & Shcherbak 1980a) and to estimate the value of the radial metallicity gradient in the Galactic disc d[Fe/H]/dR = -(0.07±0.03), which was close to the modern value (Komarov & Shcherbak, 1980b). Moreover, N. Komarov and A. Shcherbak investigated elemental abundances in the atmospheres of cool stars of different ages (Komarov & Shcherbak, 1980c), determined abundances of chemical elements in the atmospheres of cool giant stars (Komarov &

Shcherbak, 1980d) and in K-giants (Komarov & Shcherbak, 1980e).

In the 1980s, the research continued with studying the abundances of chemical elements in the atmospheres of K-giant of fields (Komarov *et al.,* 1985) and the Hyades cluster (Komarov *et al.,* 1986). An interpretation of spectra of K and M giants with low resolution was considered (Komarov & Motrich, 1987) and Catalogue of fundamental characteristics of stars of late spectral classes (Motrich, 1988) was created. Of particular note is to mention the study on the determination of the sodium abundance in the atmospheres of K-giants performed at OAO for the first time using the synthetic spectrum method developed by V. Tsymbal (Komarov *et al.,* 1985); the first works focused on studying neutron-capture elements, molybdenum and ruthenium in K-giants (Komarov & Mishenina, 1988), the abundances of barium and lanthanides in the Hyades giants (Gopka *et al.,* 1990) and abundances of heavy elements in Aldebaran (Gopka & Komarov, 1990). Moreover, the methods of research and modelling spectra were improved: a method for the simultaneous determination of atmospheric parameters was developed by Oleksandr Yushchenko, and the first study of the effects of deviations from Local Thermodynamic Equilibrium (LTE) on the sodium abundance was performed at OAO by Korotin & Komarov (1989).

In the 1990s, the advancement in the studies of possible sources of the origin of chemical elements, calculations of theories of nucleosynthesis, modelling the Type I and II supernovae and creating models of the chemical evolution of the Galaxy required the list of the studied elements to be expanded. To a large extent, that was due to the attention to the elements formed in neutron capture processes. The abundances of a number of elements formed in neutron capture processes (strontium, yttrium, zirconium, niobium, molybdenum, ruthenium, rhodium, barium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, dysprosium, thorium, tellurium and erbium) were measured in K-giants, standard stars (Arcturus, Aldebaran and Procyon) and the Sun (Gopka *et al.,* 1991). Vera Gopka and Oleksandr Yushchenko carried out research on the identification of absorption lines of dysprosium in the solar spectrum (Yushchenko & Gopka, 1994a), determined and analysed the abundances of iron and light lanthanides in the atmospheres of Arcturus and Aldebaran (Gopka & Yushchenko, 1994), the thorium abundance in the atmosphere of Procyon (Yushchenko & Gopka, 1994b), the erbium content from the spectra of the Sun and Procyon (Gopka & Yushchenko, 1995), the abundances of rhenium and tellurium in Procyon (Yushchenko & Gopka, 1996a), the abundances of heavy elements in the atmosphere of Procyon (Yushchenko & Gopka, 1996b), as well as the abundances of thorium and uranium in the atmosphere of Arcturus that were determined in collaboration with A. Shavrina and A. Perekhod (Gopka *et al.*, 1999). The abundances of magnesium isotopes – $^{24}$Mg, $^{25}$ Mg and $^{26}$ Mg – in the atmospheres of G-K giants were studied by Kovtyukh *et al.* (1999).

The investigation of giant stars of late spectral types also continued. Fundamental characteristics of cool giant stars were determined from photometry in the Geneva and Gildenkern systems using a large number of standard stars for the calibration; the catalogues of $T_{eff}$, log g and Fe/H were obtained in the two afore-mentioned systems for 1,000 and 600 stars, respectively. The metallicity data of stars belonging to dynamical groups and open clusters did not confirm the presence of a linear metallicity-age relationship. A conclusion about the existence of two age groups among disc giants was drawn (Komarov & Korotina, 1992). Absolute apparent magnitudes, absolute bolometric magnitudes, luminosities, radii and masses were found for 1,370 giants in the vicinity of the Sun. The metallicities were determined for giants in 27 open clusters and moving groups of various ages. The velocity of mixing in the interstellar medium has been increasing in the course of evolution of the Galaxy. The age of cool giants, especially of metal-deficient ones, in the solar neighbourhood can be compared to the age of globular clusters (Komarov *et al.,* 1996). The chemical composition of two Praesepe stars was found via atmospherical modelling. The abundances of chemical elements in the atmospheres of K-giants were found to be close to those of the Sun (Komarov & Basak, 1993). The chemical composition of atmospheres of cool giant stars (Komarov, 1994), the effects of the diatomic molecules on the structure of the outer layers of cool giant stars (Komarov & Dulapchi 1994), the structure of the outer atmospheres of cool giant stars (Komarov & Shevchuk, 1995), the problems of determination of abundances in the atmospheres of K giant stars (Komarov *et al.,* 1997a), the chemical abundances in the atmospheres of K giant stars (Komarov *et al.,* 1997b) were investigated. The data on energy distributions in the spectra of 555 stars were reduced and used to compile the Spectrophotometric Star Catalogue in the wavelength range of 320-1080 nm for the B-M spectral types (Dragunova *et al.,* 1994); the mean stellar spectra of cool giant stars were obtained (Dragunova *et al.,* 1997) and mean energy distributions in stellar spectra were determined for 555 stars (Komarov *et al.,* 1998). The studies were aimed at the investigation of the low dispersion synthetic spectra of cool giant stars (Belik *et al.,* 1997), the energy distributions in the spectra of stars in the region of λλ320-750 nm (Komarov *et al.,* 1997c) and the determination of characteristics of F-, G- and K-type stars. The effective temperatures were determined (Komarov *et al.,* 1999), and the catalogue of fundamental characteristics of cool giant stars was compiled (Komarov *et al.,* 2000).

In the 1990s, the Galactic disc, open and globular clusters, as well as metal-poor stars, were included in the scope of research at OAO with active participation of Tamara Mishenina. Based on the studies of clusters and dynamical groups, it was shown that the chemical homogeneity of the Galactic disc was observed in the solar vicinity, within 1.5 kpc from the Sun (Klochkova *et al.,* 1989). The obtained oxygen abundance in the Hyades K-giants was close to the solar one; the determination was performed through the synthetic spectrum method in the LTE approximation (Komarov *et al.,* 1990). The behaviour of elemental abundances in metal-poor stars differed from that of the scaled solar abundance. It related, first of all, to various abundances of CNO elements, an excess of α-elements and elements formed in the slow neutron capture processes (Mishenina *et al.*, 1995; Mishenina *et al.*, 1997). An evidence of mixing in giants of the M13 globular cluster was found based on the examination of five stars in the M13 globular cluster and two halo stars, using data taken from the literature (Mishenina & Kutsenko, 1994) and obtained in spectral research of some stars in the M13 globular cluster, including the II-90 giant (Klochkova *et al*., 1994), an RGB giant and an AGB giant (Klochkova & Mishenina, 1998). A comparison of elemental abundances in GC with those in halo stars showed a difference in the abundances of Na, Mg and elements of the rapid (r-) and slow (s-) neutron capture processes in the studied stars. The model atmospheric parameters and chemical abundance curve were derived for the infrared source IRAS 09276+4454 and identified with the peculiar supergiant HD 82040 (M6). The effective temperature was determined from the hand head intensity relations of the TiO α-system. The abundances of 11 chemical elements in the atmosphere of IRAS 09276+4454 were estimated. The chemical abundance pattern was found to be close to the solar one (Klochkova *et al*., 1997).

An important study performed by Mishenina *et al.* (2000) turned out to be a decisive argument in the astrophysicists' dispute about the oxygen enrichment of the Galaxy, in particular concerning the trend of oxygen and its abundance in low metallicity stars. In the study, oxygen abundances for 14 halo stars were derived from the O I 7774 A triplet using high-resolution spectra (R = 25 000; S/N > 100) obtained with the echelle spectrometer attached to the 6-m telescope of the SAO RAN. The effective temperature was determined from the wings of the Hα line using photometric indices. The oxygen content was analysed using both LTE and non-LTE approaches. To this end, a model of the oxygen atom was created by Sergei Korotin. The average value of [O/Fe] turned out to be 0.61 ±0.21 when determined in the non-LTE approximation. It was found that the oxygen abundance was increasing with decreasing iron abundance. The relationship between [O/Fe] and [Fe/H] was linear: [O/Fe] = -0.370 x [Fe/H] + 0.047. In addition to the sample of programme stars, 24 stars from the study by Cavallo *et al.* (1997) were also involved in the analysis after all necessary non-LTE corrections. The study may be called a reference one, because it was carried out by the authors representing an independent group of astrophysicists, using independent spectral observations, and received about 100 citations so far.

As a part of the study of the Galactic disc stars with specific features in the spectra, among the stars of late spectral types (giants and sub-giants), a special attention was drawn to those with enhanced metal lines, referred to as Super Metal Rich (SMR) stars, as well as to the stars with enhanced CN indices, which were characterised by enhanced CN molecular bands. Based on the high-dispersion coudé-echelle spectra obtained with the 1-m telescope at the SAO RAS, a number of parameters and chemical composition were determined for five stars with enhanced CN indices (Mishenina *et al.*, 1995), three stars with enhanced CN2 indices (Mishenina & Kutsenko, 1996) and 31 Aquilae (Mishenina, 1996). Four stars – namely, HD 176411, HD 181984, HD 190940 and HD 207130 – were found to be normal giants in the post first dredge-up phase; the star HD 222404 (γ Cep) was considered to be unmixed star. HD 181984 (τ Dra), being presumably a metal-rich star, exhibited a metallicity of [Fe/H] = +0.10 dex. It appeared to be deficient in C and O while overabundant in Na, Al and Mn. Three stars – HD 176411, HD 190940, and HD 207130 exhibited near-solar metallicity, they were deficient in C and O while overabundant in Na and Al. The derived abundances of O, Na (and Al) might be an evidence for anomalous mixing in those stars. The chemical composition of HD 222404 was close to that of the Sun. The programme stars had, on average, solar abundances of Y, Zr, Ba, La, Ce, Pr and Nd within the errors of determination. Three stars with enhanced CN2 indices turned out to be typical giants of the Galactic thin disc with an overabundance of Na and solar abundance of neutron-capture elements. The star HD 188056 (presumably, a SMR star) had [Fe/H] = 0.14 and was overabundant in C, Al and Mn.

31 Aquilae is the only evolved star for which the SMR status has been confirmed. This is why a new determination of the environmental parameters and chemical composition of 31 Aql was carried out (Mishenina, 1991). The new [Fe/H] value was +0.32±0.15 dex, which was close to the [Fe/H] limit for dwarf stars belonging to the thin disc of the Galaxy. The value of the Li abundance log A(Li) = 1.35. The value [C/H] obtained in the study was -0.05±0.11 dex. Within the errors, solar scaled values of [Element/Fe] were obtained for Na, Y, Zr, Ba, La, Ce, Pr and Nd. The age of 31 Aql and its location in the Galaxy were estimated, and a thorough analysis of the abundance determination errors was carried out. 31 Aql was found to be in the evolutionary stage when the convective envelope begins to extend. Two stars with the likely SMR status and an excess in metallicity – HD 121370 (8 Boo) and HD 218640 (89 Aqr) – were studied on the basis of spectra obtained with the echelle spectrometer of the 6-m telescope at the SAO RAS. Atomic and molecular spectra were used to determine abundances of 25 elements, including Li and elements of the CNO group. The metallicities [Fe/H] for the stars were +0.23±0.15 (8 Boo) and +0.19±0.19 (89 Aqr). Such values were close to the upper limit of [Fe/H] for dwarf stars in the Galactic disc (Mishenina, 1998).

To clarify the evolutionary status and spectral classification, the abundances of Li and CNO in the atmospheres of nine peculiar giants (eight CN-strong stars and the SMR star 31 Aql) were estimated through the method of model atmospheres (Mishenina & Tsymbal, 1997). The derived Li and CNO abundances were close to the mean values for the disc G-K giants; it suggested that the stars had gone through the mixing phase (were in the phase after the first dredge-up). For the CN-strong stars, the C/O ratios implied a slight carbon overabundance in their atmospheres, but it was insufficient to substantiate the hypothesis of Keenan & Heck (1994) that the CN-strong stars could be marginal R stars belonging to a special class of carbon stars. The sodium abundances in 12 peculiar disc stars with Na excesses were determined taking into account deviations from LTE. In some cases, the non-LTE corrections reached 0.2 dex; however, on average, it did not exceed 0.1 dex, and the Na excesses for most of the stars were not eliminated by taking non-LTE corrections into account (Korotin & Mishenina, 1999).

### *4.2. Eclipsing binaries*

The first spectrophotometric studies carried out by Valentin Karetnikov were focused on the Pleiades cluster stars (Karetnikov & Vykhrestyuk, 1973), the eclipsing star RZ Scuti on low-dispersion spectrograms (Karetnikov, 1967; 1972), the eclipsing binary V367 Cygni **(**Karetnikov & Perekresny, 1973) and the determining of the electron density in stellar atmospheres (Karetnikov *et al.*, 1973). Later, the results of a spectral study of Nova Cyg 1975 based on diffraction spectrograms obtained from August 30 to September 26, 1975 were presented (Karetnikov & Medvedev, 1977). The depths and intensities of the absorption and emission lines in the spectrum of Nova, as well as the velocity of the envelope of new absorption components based on the displacement and the half-widths of the emission lines were calculated (Karetnikov *et al.*, 1986), and spectroscopic observations of Nova Vul 1976 = NQ Vul were carried out (Karetnikov *et al.*, 1977).

Studying spectra of eclipsing stars, establishing spectral types of components, examining the behaviour of hydrogen and helium lines with the revolution period and phase, the presence of emission in the lines of metals and hydrogen, the "mass loss-envelope mass" relation, etc., made it possible to detect gas flows and envelopes in such systems and construct relevant models. The stars RY Per, V367 Cyg, V448, RY Gem, TX Uma and XZ Cep were studied. RY Per had a complex spectrum, and the spectral lines also changed in a complex way. The hydrogen lines showed a change in the equivalent width with the revolution period, while the helium line profiles changed markedly with the phase. The emission lines of metals were also found in the spectrum. The electron pressure was calculated from hydrogen lines, and the RY Per model was built from observational data (Karetnikov & Kutsenko, 1979). Based on diffraction spectrograms with a dispersion of 37 A/m in the wavelength range of 3700-4700 A, physical characteristics of the atmospheres of both stars in RY Per were determined by the method of growth curves. The results obtained were consistent with the spectral classes B5V and F61V for the two stars. It was suggested that gas streams and a common envelope were present in RY Per (Karetnikov *et al.*, 1979).

Spectral observations of the eclipsing binary star V367 Cyg reported that the structure of the spectrum was of the envelope type with emission in Hα and Hγ lines. The Mg II line at 4481 Å, as well as the wings of the hydrogen lines, was found exclusively in the main star. The structure and velocity of the gaseous medium in V367 Cyg were studied from the emission components in the Hγ line. A gas flow of the secondary component was observed passing through the Lagrange point L(1). The outflow of matter from V367 Cyg was estimated to be about 0.0000323 solar masses per year. A line showing the structure of the stellar envelope was presented (Karetnikov & Menchenkova, 1985). A spectroscopic study of the massive close binary system V448 Cyg was conducted. Based on spectrograms with dispersions of 9 and 28 Å/mm, the spectral types were determined as B1.2Ib+O8.9V. Hydrogen and helium line profiles had anomalies. The model of the eclipsing system V448 Cyg was discussed in detail (Glazunova *et al.*, 1986). The RY Gem binary system was also studied. The spectral type and luminosity, excitation temperature, turbulent velocity, electron pressure in the atmosphere and envelope, as well as concentrations of atoms of some chemical elements in the star were determined. It was noted that the concentrations of chemical elements were systematically lower than the "solar" concentrations (Karetnikov & Menchenkova, 1987).

Motions in circumstellar gaseous structures and rotations of the TX Uma stars were determined from the detected emission and absorption components of the profiles of the Hβ, Hγ, K Ca II and Mg II λ4481 Å lines. The value of the mass loss rate of the system was found (Karetnikov & Kovtyukh, 1987). For the RY Sct binary star system, the dependence "mass loss-envelope mass" was constructed on the basis of the data on the masses of the eclipsing binary star envelopes, derived using polarimetric and spectral methods, as well as on the mass losses calculated from the variations in the periods of those stars. The dependence was confirmed by the data on the RY Sct eclipsing star with an envelope (Karetnikov, 1987). The spectrum of the XZ Cep star turned out to be composite, with a complexly changing line profile, a phase change in the equivalent widths of hydrogen and helium lines, and a change in the electron concentration in the shell. The system consisted of the main star B1.5 II-III and the satellite B1.1 III-V, between which a gas flow was observed. Stars were surrounded by envelopes, the heavier of which surrounded the secondary component (Glazunova & Karetnikov, 1985). At that time, the studies aimed at modelling the flow of matter in the investigated close binary systems were carried out actively: for instance, the formation of a gaseous flow in the vicinity of the inner Lagrangian point for XZ Cep (V. Nazarenko 1992); the matter flow formation in W Serpentis-type binaries (Karetnikov *et al.*, 1995a), W Draconis binary stars (Karetnikov *et al.*, 1995b), semidetached AO Cassiopeiae-type eclipsing binaries (Karetnikov *et al.*, 1995c), W UMa contact close binaries (Karetnikov & Nazarenko, 1996a) and R CMa-type systems (Karetnikov & Nazarenko, 1996b).

### *4.3. Variable pulsating stars of the RR Lyr and δ Sct types and Cepheids*

**The RR Lyr and δ Sct type stars**. Many magnetic stars are located within the instability band of short period δ Scuti type variable stars. Photometric periods of changes in the brightness of magnetic stars, obtained by different authors, often turn out to be close to the known periods of stars of the δ Scuti type. Therefore, it was of interest to study magnetic fields of pulsating stars. Magnetic fields in pulsating variable stars of the RR Lyr and δ Sct types were first studied at OAO. The magnetic field in variables of the RR Lyr type was first mentioned in the study by Romanov & Udovichenko (1981); later on, there were attempts to determine the magnetic field of the stars V474 Mon, $\alpha^2$CVn and β CrB (Romanov, 1985; Romanov *et al.*, 1984; 1985), and variations in the depression in the 5200 Å region depending on the value of the magnetic field for $\alpha^2$CVn and β CrB were presented (Udovichenko, 1987). The spectra obtained with the 6-m telescope at the SAO RAS were employed to study variations in the magnetic field strength and its polarity. It was found that the average value and polarity of the magnetic field changed with a period of 41 days (the Blazhko effect). It was suggested that long-period variations of the magnetic field with the Blazhko effect could be explained by the rotation of a star with the same period (Romanov *et al.,* 1987). A study of five stars – RR Lyr, V474 Mon, X Ari, TU Cas and VW Dra – as well as their rotational velocities and parameter ΔS was carried out on the basis of spectral research. The dependences of the decrease in the half-width of the Mg II λ448.1 nm and Fe I λ447.6 nm lines on the rotational velocities of the standard stars were found. Those relations were used to determine the rotational rates of the variable stars RR Lyr, V474 Mon, X Ari, TU Cas and VW Dra (Zaikova & Udovichenko, 1988). Based on the spectra with a dispersion of 37 Amm, the ΔS parameter of RR Lyrae stars was revised and rotational velocities of some pulsating SW And stars were determined (Zajkova & Romanov, 1988; Zajkova *et al.,* 1992). Based on the profiles of the hydrogen lines for 28 Be stars and Be stars with stellar envelopes, it was established that the origin of the envelopes in those stars was associated with the mass loss due to rotation, which corresponded to the presence of a rotating equatorial disc (Udovichenko & Konchagina, 1997). The radial velocities were determined for RZ Lyr (Romanov, 1977) and V474 Mon (Udovichenko, 1994).

Studying chemical composition of permanent and variable stars required knowledge of a certain reference chemical composition for stars - it related, first of all, to the chemical composition of the Sun, as well as chemical compositions of selected standard stars and the standard (unified) composition of stars of certain spectral classes. The standard chemical composition of the atmospheres of A1-G0 stars based on 14 chemical elements was determined for 12 stars of the A1-G0 spectral classes. The results obtained by the method of quantitative spectral classification were compared with the results obtained by the method of growth curves (Fenina & Romanov, 1980; 1982). Investigation of the spectral features of the variable stars RR Lyr and XZ Cyg showed a change in the spectral characteristics with the phase of the Blazhko effect (Romanov, Fenina and Vasilieva, 1981). A spectrophotometric study of the atmosphere of the yellow semiregular variable star VW Dra was carried out (Andrievsky *et al.,* 1985). The pulsating variable SW Andromedae and magnetic variable stars AF (73) Dra and β CrB were studied (Fenina & Romanov, 1985; Fenina & Zaikova, 1988). β CrB was analysed by the growth curve method (Zgonyaiko & Fenina, 1988). The system of equivalent widths of Fe I absorption lines was applied to determine regional (local) temperatures in physically variable stars and to analyse the two-component structure of the spectrum-forming metal layer in the Cepheid type star T Vul (Fenina *et al.,* 1990; 1991), as well as to study variations of parameters with phase in three Cepheids – RT Aur, T Vul and κ Pav (Fenina *et al.,* 1994). Based on several spectrograms of β CrB with opposite external characteristics, new independent determinations of the temperature of the spectrum-forming levels from the lines of neutral iron Fe I were carried out, and some physicochemical characteristics were determined by the methods of the growth curve and atmospheric models (Romanov *et al.,* 1998).

A series of studies focused on the δ Sct and RR Lyr type variable stars and Cepheids, based on the spectra obtained with the 50(48)" telescope at CrAO, were carried out by Gennady Garbuzov. An emission in the Hα line was deemed to be associated with the passing of a shock wave in the δ Sct type star VZ Cnc (Garbuzov & Mitskevich, 1984). Variations in the Hα line in the spectra of RR Lyrae stars - DH Peg and RZ Cep – were studied. Weak short-lived emission and splitting of the Hα absorption line into two components were found. The observed phenomena were compared for the RRab and RRc type stars, and it was concluded that the shock waves were formed in the atmospheres of RRc stars at higher layers than in the atmospheres of RRab stars (Garbuzov & Zaikova, 1986). A mechanism of excitation of chromospheric radiation from δ Sct stars was studied. It was suggested that such a mechanism could explain the occurrence and variability of chromospheric emission at the centre of the h and k Mg II lines in the spectra of pulsating δ Scuti stars. According to the model, the radiation was associated with the radiation of gas heated by a shock wave propagating in the outer layers of the star's atmosphere at phases close to the brightness maximum. Flux variability in the Mg II h and k lines was due to the motion of a shock wave in an inhomogeneous medium with decreasing density (Garbuzov & Andrievskii, 1986). The Hα line in the spectrum of the unique Cepheid V473 Lyr was studied. Variations in the Hα profile in the HR 7308 spectrum Cepheid were compared to those in beat Cepheids. It was concluded that the rapid Ha profile variations observed in HR 7308 were not characteristic of Cepheids. The qualitative similarity of those variations with the spectral manifestation of non-radial pulsations was emphasised (Andrievskij & Garbuzov, 1987). To search for and identify high-frequency radial oscillations in pulsating stars of the δ Scuti type, it was proposed to use information on variations in the equivalent widths and radial velocities on spectral lines formed in the outer layers of atmospheres (for example, Hα). The spectrograms revealed a fast variability of the Hα line in τ Peg, which was interpreted as a manifestation of radial vibrations in the 3rd and 5th overtones (Garbuzov *et al.,* 1987). Further studies focused on the Hα variability in τ Cyg (Andrievskii & Garbuzov, 1987) and a shock wave front in a continuum (Garbuzov & Paramonova, 1987).

**Bimodal and multimodal Cepheids** are stars that pulsate in two or more different modes. If the pulsation periods are close, then beats appear in the pulsations of Cepheids. Atmospheric parameters and abundances of a number of elements were determined in several studies of bimodal Cepheids. Deficiencies in iron and carbon, along with an excess of nitrogen, were obtained. Oxygen, α-elements and elements of the iron group, showed the solar ratios. The dependence of metallicity [Fe/H] on the period ratio $P_1/P_0$ was obtained. The value [Fe/H] = -0.43 indicated that the TU Cas star was poorer in metals than other bimodal Cepheids (Andrievsky *et al.,* 1993). For three bimodal Cepheids – EW Sct, VX Pup and BQ Ser – the abundance analysis showed that a deficiency in carbon was accompanied by an excess of nitrogen and a normal (near solar) oxygen content. Alpha-elements and elements of the iron group, with few exceptions, showed the solar ratio [M/Fe]. Near solar iron abundance for EW Sct ([Fe/H] = -0.08) and metal deficiency for VX Pup ([Fe/H] = -0.39) and BQ Ser ([Fe/H] = - 0.36) strongly supported the existence of the $P_1/P_0$ to metallicity ratio (Andrievsky *et al.,* 1994). The abundances of helium and other chemical elements in the atmospheres of classical Cepheids were determined (Kovtyukh *et al.,* 1994).

The designation **s-Cepheid** is used for Cepheids with a short pulsation period and a small brightness amplitude with a sinusoidal light curve. It is reckoned that such objects pulsate in the first overtone. They are located near the red edge of the instability band. Studies of s-Cepheids with a short pulsation period show solar-like abundances of α- and iron-group elements, some Na overabundance; majority of these stars are deficient in carbon and overabundant in nitrogen which indicates that these s-Cepheids are not crossing the instability strip for the first time. But among them there are stars with different chemical composition, for instance, the unique Cepheid α UMi (Polaris), unique galactic Cepheid V473 Lyr and the s-Cepheid EV Sct binarity. An important factor in studying s-Cepheids is the idea to use barium lines as an indicator of luminosity. The s-Cepheids α UMi (Polaris) and HR 7308 (V 473 Lyr) were analysed. The unique Cepheid α-UMi exhibited a small overabundance of most elements relative to the Sun. A larger value of gravity as compared to the data of other authors could be due to a decrease in the Polaris pulsational amplitude. The analysis showed that light elements demonstrated a small overabundance while the Fe group elements were slightly deficient in the HR 7308 atmosphere (Andrievsky *et al.*, 1994).

Eight s-Cepheids and V1162 Aql (earlier classified as an s-Cepheid) were studied. All Cepheids (with the only exception of EU Tau) had solar-like abundances of α- and iron-group elements, and they all were overabundant in Na. The carbon deficiency found in EU Tau, DT Cyg and V440 Per and nitrogen overabundance (in DT Cyg) indicated that those s-Cepheids were not crossing the instability strip for the first time. The s-process elements were slightly enhanced in the programme stars. V1162 Aql did not show any changes in C and N abundances, the star known as a normal Cepheid (Cδ) was crossing the instability strip toward the giant branch for the first time. Such a conclusion was also confirmed by its position on the evolutionary diagram (Andrievsky *et al.,* 1996). A hypothesis about s-Cepheids' crossing the instability strip for the first time was verified by spectroscopic testing for seven s-Cepheids. V473 Lyr, IR Cep, UY Mon, BY Cas and V636 Cas had solar iron abundance whereas V526 Mon and V924 Cyg showed a moderate iron deficiency. The absolute carbon deficiency (relatively to the solar C/H value) found for all programme stars (with the exception of V636 Cas) and a nitrogen overabundance suggested that those s-Cepheids were not crossing the instability strip for the first time. V636 Cas also demonstrated a rather high abundance of carbon; perhaps, the star was crossing the instability strip for the first time. Na and Al were overabundant in all programme stars for which the two elements were estimated. The sodium overabundance was also observed in two Cepheids crossing the instability strip for the first time. Abundances of α-elements and iron-group elements were close to the solar ones, while those of s-process elements appeared to be slightly enhanced (Kovtyukh *et al.,* 1996).

The data for the unique galactic Cepheid V473 Lyr were revised. Results were obtained for 38 species of 32 chemical elements. The authors confirmed a slight underabundance of metals ([Fe/H] = -0.16). Carbon was deficient, and no significant overabundance was detected for sodium. Other elements with determined abundances did not show any marked anomalies (Andrievsky *et al.,* 1998). Spectroscopic manifestations of the s-Cepheid EV Sct binarity were reported. All lines in the spectrum of the Cepheid were noticeably asymmetric or even split, indicating that the system consisted of two components. Both components had similar effective temperatures; the difference in apparent values seemed to be small. Together with the preliminary results of the frequency analysis based on the published photometric data, such findings meant that the secondary was probably within the instability band as well, being a very short period Cepheid with P ~ 1.2 days (Kovtyukh & Andrievsky, 1999). The Ba II lines were proposed as indicators of the luminosity of yellow supergiants. In particular, it was shown that the equivalent width of the Ba II 5853.6 line correlated well with the luminosity for s-Cepheids (Andrievsky, 1998).

### *4.4. Blues stragglers, λ Boötes stars, B-stars and rapidly oscillating Ap stars (roAp)*

**Blue stragglers** are Main Sequence stars in star clusters that are located above and to the left of the turnoff point on the Hertzsprung-Russell diagram. They have higher temperatures, luminosities and masses as compared to the other cluster stars. In several studies at OAO, the parameters and chemical composition of open-cluster and field blue stranglers were investigated. Blue stragglers in open clusters showed the same chemical peculiarities as ordinary cluster and Galactic field stars of the same spectral type. The modern view about the origin of blue stragglers states that they are the result of mergers of stars through mass transfers from an evolved star onto a main-sequence companion.

A spectral study of seven blue stragglers of the Galactic field was conducted. The iron abundance values for the studied stars varied from [Fe/H] = -0.9 dex to [Fe/H] = -0.3 dex. A preliminary interpretation of such findings was that the group of the field blue stragglers consisted of stars of different ages. Mg and Ca abundances (relative to iron) exceeded solar values (Andrievsky *et al.,* 1995). A spectroscopic investigation of 15 Galactic field blue stragglers and one normal F-dwarf showed that all stars were metal deficient. The mean value of [Fe/H] for 13 stars was -0.31±0.13 (two stars of the sample, namely HD54073 and HD88923, were likely to have a more pronounced iron deficiency); the estimated (C/H) and

(O/H) ratios were close to the solar values (i.e. those elements were slightly enhanced with respect to iron: [C/Fe] = ~[O/Fe] = ~0.3dex); sodium and α-elements in the field blue stragglers were slightly enhanced as well. Only magnesium showed practically the solar ratio: [Mg/Fe] was near solar one; as regards the iron group elements, Sc showed the solar ratio [Sc/Fe]. Cr and Ni were slightly overabundant; a rather great age of the investigated stars estimated from their metallicity was in contradiction to their locations in the evolutionary diagram. The problem could be eliminated by assuming that field stragglers were old objects with delayed evolution, similarly to blue stragglers in stellar clusters (Andrievsky *et al.*, 1996).

A spectroscopic study of four blue stragglers in old Galactic open cluster NGC 2632 (Praesepe) was carried out. The LTE analysis using Kurucz's atmospheric models and synthetic spectra technique showed that three stars, including the hottest star of the cluster HD73666, exhibited a uniform chemical composition: they showed a solar-like abundance (or a slight overabundance) of iron and an apparent deficiency in oxygen and silicon. Two stars exhibited a remarkable barium overabundance. The chemical composition of their atmospheres was typical for Am stars (metallic-line stars representing a type of chemically peculiar stars of spectral type A). One star of the studied sample did not share such a uniform elemental distribution, being generally deficient in metals (Andrievsky, 1998).

A spectroscopic study of blue straggler and Main Sequence B- and A-type stars in the open clusters NGC 3496, NGC 6475, NGC 6633 and IC 2602 was based on observations collected at the European Southern Observatory. A detailed analysis through Kurucz's atmosphere models showed that the MS stars rotated rather rapidly and exhibited abundances different from normal (solar) metallicity for only few light elements. The blue stragglers had significantly smaller projected rotational velocities. As a group, they showed the same chemical peculiarities as ordinary cluster and Galactic field stars of the same spectral type. Two blue stragglers and one MS star had a rather low content of helium. All investigated stars for which the C abundance could be measured showed a moderate-to-strong deficiency in carbon (Andrievsky *et al.*, 2000).

**λ Boötes stars** represent a rare type of peculiar stars. These stars are characterised by weak metal lines, indicating a lack of heavy elements, and extremely slow rotation. Most of them exhibit variability of the δ Sct type. The abundances of C, O, Na and S seem to be nearly solar ones for all investigated stars. There is a wide range of underabundances of all other elements in individual stars. Such results are consistent with the accretion/diffusion model adopted to explain the λ Boo phenomenon.

A new approach to the problem of the origin of λ Boo stars was discussed in the study by Andrievsky (1997). It was suggested that at least some of those stars might originate from contact binary systems of W UMa type. Simple estimations based on such hypothesis could account for the present-day number of λ Boo stars in the solar neighbourhood, their masses and spectral classes. What is also important is that the proposed scenario did not exclude circumstellar envelope formation, which was considered to be responsible for the chemical peculiarities of λ Boo stars. The atmosphere of VW Ari A ($T_{eff}$ = 7200 K, log g = 3.7), the primary component of the visual binary system, was analysed. The synthetic spectrum technique applied in the analysis enabled to reveal that the atmosphere of the star was severely deficient in some metals whereas light elements were abundant at levels similar to the solar ones. Taking into account such results, VW Ari A could be assumed to be a lambda Boo type star. Another argument supporting such assumption could be found on the photometric diagrams. VW Ari A fell exactly in the region occupied by the λ Boo stars (Chernyshova *et al.*, 1998).

Seven well established λ Boo stars (a group of A to F type stars severely underabundant in Fe-peak elements while appearing to be solar abundant in C, N, O and S) – HD 31295, HD 125162, HD 142994, HD 149303, HD 192640, HD 204041 and HD 221756 – were studied. The abundances of C, O, Na and S seemed to be nearly solar ones for all investigated stars. There was a wide range of underabundances of all other elements within individual stars. No correlation between individual abundances and astrophysical parameters, such as $T_{eff}$, log g and vsini, was found. The results were consistent with the accretion/diffusion model adopted to explain the λ Boo phenomenon (Paunzen *et al*., 1999). Having analysed the accretion-based model of the dust-gas separation, which is regarded to be the most promising for the explanation of anomalous properties of λ Boo stars, we can conclude the following: (i) for any reasonable density profiles of the envelope, dust grains appear to be decoupled from the gaseous background within the region where the temperature drops below the condensation temperature of heavy elements, such as Mg, Ca, Fe, etc.; (ii) it is most likely that only small dust particles (of less than ~10-6cm in size) can be formed in the envelope of λ Boo-type stars; (iii) significant alteration of the initial atmospheric chemical composition can take place in the case when the density in the envelope changes as $r^{-2}$ (Andrievsky & Paunzen, 2000). With regard to pulsation characteristics of λ Boötis-type stars for the star BD Phe (HD 11413): in-depth astroseismological studies have been carried out so far only for four members of this group of stars, and the number of identified frequencies for these stars varies from four to seven. In the relevant study, the authors presented a 30-hour UBVRI time-series photometry along with a 14-hour high signal-to-noise ratio high dispersion spectroscopy for the star BD Phe. At least seven frequencies were detected. Since they were all present in independent sets of observations, it was argued that the frequencies were fairly well defined despite the limited data. The results may be useful in the context of recently published models of δ Sct pulsations that take into account diffusion effects (Koen *et al.*, 2003).

**B-stars** hotter than the Sun are the MS stars located in a region close to the Cepheid region. A series of studies of B stars with the allowance for deviations from the Local Thermodynamic Equilibrium (NLTE) was carried out under the leadership of Sergei Korotin. To that end, he modified the complex programme MULTI (Carlsson, 1986), created models of the carbon and nitrogen atoms, and employed models of oxygen and sodium constructed earlier. The carbon abundance in the atmosphere of the B star γ Peg indicated a slight deficit of [C/H] = -0.25 (Korotin *et al*., 1998), so did the nitrogen content ([C/H] = -0.30) (Korotin *et al.,* 1999a), which did not substantiate the hypothesis of turbulent diffusion in massive MS stars. The abundances of C, N and O in the sample hot MS stars appeared to be sub-solar and probably unaltered by stellar evolution. A comparative analysis of elemental abundances in hot MS B stars, the Cepheid U Sgr and two cool supergiants belonging to young OC M 25 detected disagreement between abundances of carbon, oxygen and other elements in those stars; it might be due to the fact that chemical anomalies observed in B stars were caused by different mechanisms operated in those stars. It could indicate that turbulent diffusion in massive MS stars (discussed in Maeder, 1987) and the related appearance of the CN-processed material at the stellar surface could hardly be operating in γ Peg. Abundances of carbon and nitrogen in the sample hot MS stars were determined in the NLTE approximation and, in most cases, those abundances appeared to be sub-solar and probably unaltered by stellar evolution (Anrievsky *et al.*, 1999). The analysis was based on the spectra collected with a 1.52-m telescope at Haute Provence Observatoire (France). A non-LTE analysis of O II lines in a sample of hot MS B stars was performed. The derived oxygen abundances for the programme stars appeared to be sub-solar. A brief comparison between the oxygen abundance in B stars and those in stars of other related types was presented (Korotin *et al.,* 1999b). The chemical composition of B stars determined spectroscopically might not reflect correctly their true chemical composition or the chemical composition of the interstellar medium. On the other hand such abundance anomalies were not expected for F-G supergiants which had suffered the large scale mixing in the red giant phase (Luck *et al.,* 2000).

Investigation of non-radial pulsation of **Ap stars** was performed by David Mkrtichian. Rapidly oscillating Ap stars (roAp) belong to the class of non-radial pulsating stars oscillating in low-degree modes (l = 1–3) with a period of 4-15 minutes. A study of radial velocity (RV) and pulsation mode was carried out using a 2.7-meter telescope with an iodine cell at the McDonald Observatory (USA). For Ɵ Uma, variability was detected in radial velocities of the Hα hydrogen line with a period of 0.063 d. The variability had amplitude of 2K = 12.3 km/s and was reckoned to be caused by oscillations in the third radial overtone (Mkrtichian, 1990). Precise radial velocity (RV) measurements were carried out for five roAp stars (33 Lib, γ Equ, HR 1217, HD 134214 and HD 122970). Pulsational RV variations were detected in all five stars with amplitudes ranging from 50 to 400 m/s. For the roAp star HR 1217, the authors managed to detect 5 of the 6 known pulsation modes present in the star. A detailed line-by-line analysis of radial velocities revealed that the pulsational amplitude depended not only on atomic species, but on the line strength as well. It was deduced that the surface distribution of elements could act as a spatial filter thus enabling us to detect high degree modes, which was deemed to be not possible in stars with a more uniform distribution of elements due to cancellation effects. Precise RV measurements proved to be a powerful tool for probing both the vertical and horizontal structure of the pulsations in roAp stars (Hatzes, *et al.* 1998).

## 6. Conclusions

The first spectrophotometric observations in the near IR region of the spectrum were conducted at Odesa Astronomical Observatory in 1966. In the 70-80s, 28 telescopes with a primary mirror diameter from 30 cm to 1 m were constructed at the observatory under the general direction of Vladimir Platonovich Tsesevich and thanks to the developments of the Chief Engineer, Leonid Stepanovich Paulin. The mirrors were made and polished under the guidance of Nikolay Nikolayevich Fashchevsky. The Astro-Instrument Engineering Department, under the leadership of Vitaliy Nikonovich Ivanov, developed and constructed photometers and spectrophotometers for observations carried out in the Department of Astrospectroscopy under the leadership of Nikolay Sergeyevich Komarov. A large number of employees of the Department participated in spectrophotometric observation expeditions. In 1988, Valentin Karetnikov and in 1989, Nikolay Komarov successfully defended their doctoral theses entitled *Properties of Eclipsing Binary Stars at the Stage of the First Mass Exchange* and *Structure of the Atmospheres of Cool Giant Stars*, respectively.

Since the late 60s, the observatory has also been actively engaged in modelling spectra and radiation transfer in stellar atmospheres; the first calculations of atmospheric models were made by Nikolai Komarov and colleagues in 1969. The monograph *Cool Giant Stars* by N. Komarov summed up the results of work on modelling, as well as on spectrophotometric and photometric studies over the considered years (Komarov, 1999). The *Photometric and Spectral Catalogue of Bright Stars* was compiled in 1979 (Komarov *et al.*, 1979). Spectrophotometric observational data were partially included in the catalogue *Spectrophotometry of Stars in the Wavelength Range λλ 550 – 900 nm*" (Komarov *et al.*, 1983) and the spectrophotometric star catalogue (Komarov *et al.*, 1995), they were also presented in the final reports on 52 topics of the funded projects. A number of projects were carried out on spectral studies, modelling the structure of binary stars and the transport of matter in binary stars under the leadership of Valentin Karetnikov. Yuri Romanov and Sergei Udovichenko were practically the first to measure the magnetic field in RR Lyr type stars. A significant contribution to spectral research was made by Vladimir Pozigun, Vadim Karamysh, Alina Dragunova, Vadim Tsymbal, Zemfira Fenina, Tamara Mishenina, Svetlana Kutsenko, Stanislav Belik, Valery Motrich, Vera Gopka, Oleksandr Yushchenko, Elena Menchenkova, Lyudmila Glazunova, Tatiana Gorbaneva, Viktor Nazarenko, Sergey Korotin, Sergey Andrievsky, Valery Kovtyukh, Gennady Garbuzov, David Mkrtichyan and many others employees of the observatory. Successful research conducted at OAO in subsequent years proved that the scientific foundation laid in the 60-90s worked perfectly.

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