From spectroscopy to the chemical evolution of the Milky Way. Part 1.

To mark the 150th anniversary of
Odesa Astronomical Observatory

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**22nd Gamow International Astronomical Conference
August 22, 2022**

The first spectral observations

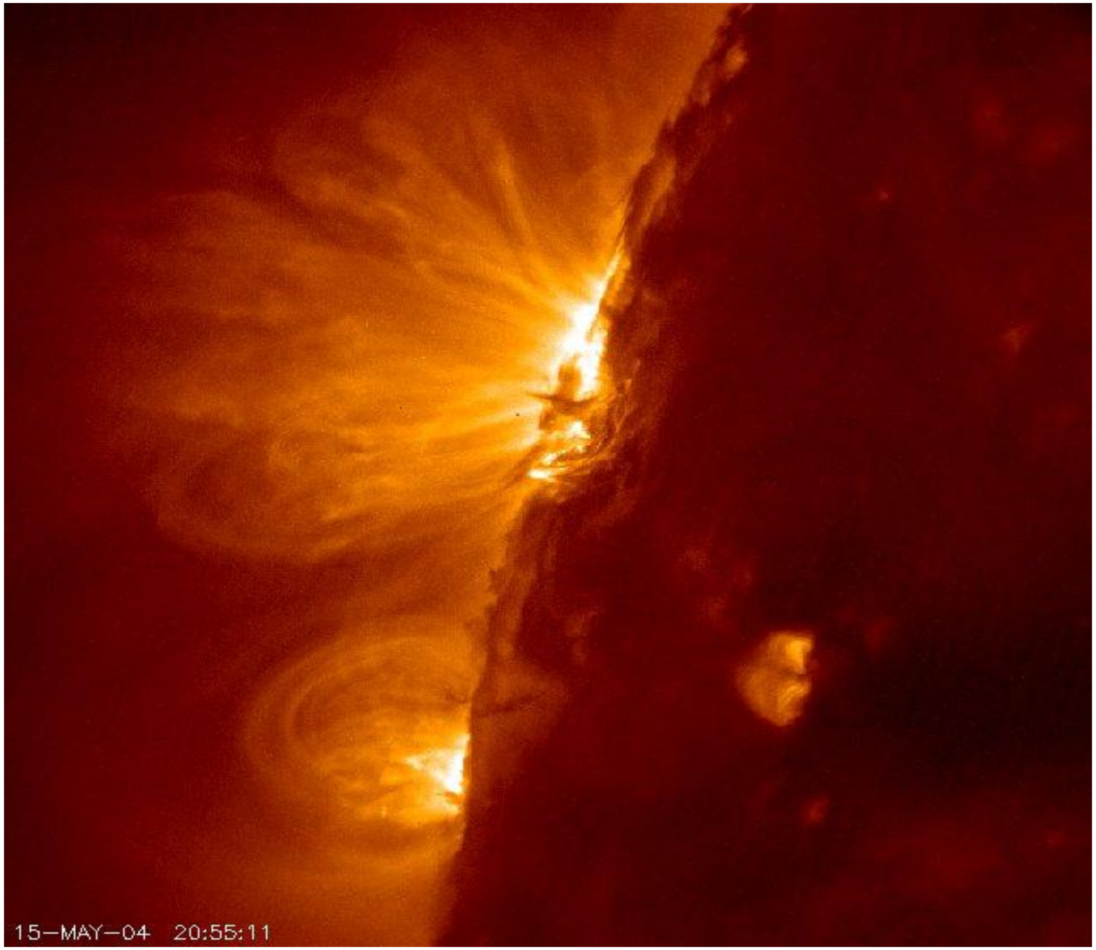
Observations of emission lines in solar prominences started in 1892 under the leadership of Alexander Kononovich (Kononowitsch) (1850-1910), the Director of the Observatory and Head of the Department of Astronomy of Odesa University. The observations continued till 1895.

- Solar prominences with a double-prism spectroscope (a workshop by Mr. Toepfer, Potsdam) donated by the Academy of Sciences to Odesa Astronomical Observatory
- Sketches of prominences, marks of Sketches of prominences the width of the base and height of the prominence, as well as indications of the presence of emission in the lines of Hydrogen (Hα, Hβ and Hγ) and Helium
- A. Kononovich (Kononowitsch), N. Zwetinowitsch, A. Orbinsky, P. Hansky

Observations des protuberances solaires faites a l'observatoire d'Odessa du mois d'aout 1892 jusqu'au mois d'aout 1893

par A. Kononowitsch, N. Zwetinowitsch, A. Orbinsky

(Notes de l'Université d'Odessa, 1893, V.68, P.225-262)



In the 1960s, throughout the globe there was an enormous interest in physics and space.

- 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 variable stars (visual observations). It was also the time when the development of photometric observations started, but it is beyond the scope of our discussion.

1966

1966, AJ 43, p. 873

A Photoelectric Spectrophotometer at Odesa Observatory

A block diagram of the spectrophotometer

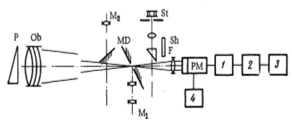


Fig. 1. Block diagram of the photoelectric spectrophotometer. P) Prism; Ob) telescope objective; M_1) diaphragm microscope; M_2) field microscope; MD) mirror diaphragms; St) standard; Sh) shutter; F) Fabry lens; PM) photomultiplier; 1) preamplifier; 2) amplifier; 3) recorder; 4) photomultiplier supply.

mounted on a "Cactus" microroentgenometer base. The spectra are recorded on an ÉPP-09 recorder and the tape is wound at a rate of 40 mm/min. The photomultiplier is supplied by a BAS-80 battery. Figure 1 shows a block diagram of this photoelectric spectrophotometer.

The setting of the spectrum on the slit and the guiding are accomplished by using the inspection microscope M_1 on the set of obliquely oriented photometer diaphragms. The micrometric screws are used to hold the spectrum on the slit at its red end, and then to scan it in both direct and reverse directions by reversing the motor. Before and after recording each spectrum a phosphor is recorded; all measurements are made relative to the phosphor. Figure 2 illustrates a tracing of the spectrum of α And; the phosphor is recorded on the left, the sky background on both sides of the spectrum, and the Hβ line is the first line on the right in the spectrum. The scanning rate and the winding rate of the recorder tape were so selected that the spectrum was recorded on the tape at 30-power magnification.

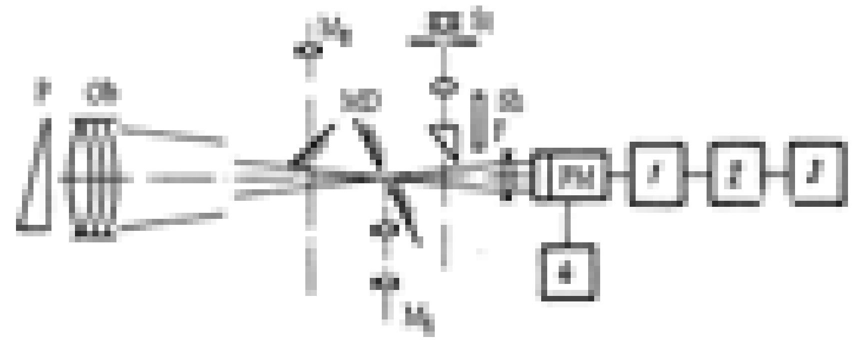
The wavelength calibration of the spectrum tracings was made by means of spectral lines and bands – the Balmer lines for early-type stars and the titanium oxide bands for red stars. Identification of the spectral lines and bands presents no difficulty if the spectral sensitivity of the system and the dispersion curve of the instrument are known.

To investigate the quality of the spectrograms that were obtained, we have made a comparison between the spectra of α And, β Ari, and α Cyg as observed with our instrument, and data obtained by Kharitonov [2, 3] and Code [4]. As a standard star we have used α Lyr, whose spectrum was recorded before or after the spectrum of each star investigated, depending on the zenith distance. The spectrograms were reduced by customary procedures, using photoelectric observations in the reduction. After allowance for atmospheric extinction both spectra of each star were averaged and the difference in the monochromatic magnitudes of the investigated star and the standard star was found for some tens of wavelengths. Then the difference was added to the absolute energy distribution in the spectrum of α Lyr, expressed in m_λ. As a result the absolute energy distribution in the spectra of α And, β Ari, and α Cyg was obtained in relative magnitudes by means of relative spectrophotometry. These data are presented in Table 1 and are illustrated in Fig. 3. Evidently for β Ari and α Cyg the agreement of the results is very good, while for α And there is a slight difference, perhaps because a mean extinction coefficient was used. The rms error for a single pair of measurements is 1.5%, and in the short-wave spectral region it increases to 4% for the same reason.

The good agreement between our results and other authors' observations permits us to conclude

TABLE 1

λ(Å)	α And	β Ari	α Cyg	λ(Å)	α And	β Ari	α Cyg
3860	$-0^m.955$	$-0^m.417$	$-0^m.836$	4590	$0^m.660$	$0^m.506$	$0^m.423$
3950	1.066	0.542	0.742	4800	0.507	0.407	0.339
4040	1.014	0.732	0.700	5060	0.367	0.268	0.217
4190	0.921	0.677	0.654	5300	0.247	0.092	0.088
4400	0.785	0.585	0.521	5560	−0.150	−0.020	−0.020



Valentin Karetnikov and Yuri Medvedev started experimenting in this area of research as early as 1964.

They converted (adapted) an ordinary photoelectric photometer for their spectroscopic studies.

The block diagram of the spectrophotometer is shown in figure.

1966, AJ 43, p. 873

A Photoelectric Spectrophotometer at Odesa Observatory

An example of observations of energy distributions in the spectrum of a star

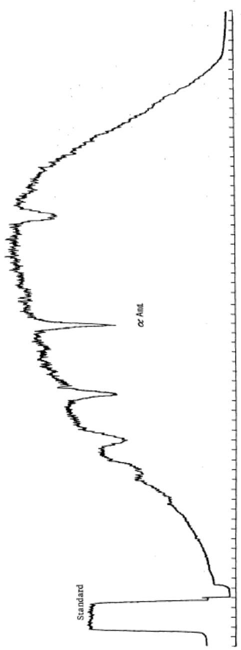


Fig. 2. A record of the spectrum of α And. The first spectral line on the right is Hδ.

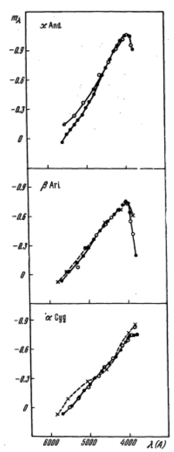


Fig. 3. Comparison between the spectral energy distributions for α And, β Ari, and α Cyg according to our measurements (circles) and those of Kharitonov (dots) and Code (crosses, broken curves).

The energy distributions in the continuum of stars α And, β Ari, α Cyg were obtained with α Lyr observed as a reference standard and then compared with the energy distributions available in the literature.

Noticeable chromatic aberration in the red and especially in the blue regions due to the primary lens did not allow the researchers to obtain more accurate results.

- In the same years, Vladimir Pozigun and Nikolay Komarov created an electrospectrophotometer for observations in the near infrared region of the spectrum. For the first time in the Soviet Union they carried out observations and studies of stars by energy distributions in the IR region of the spectrum.
- 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.

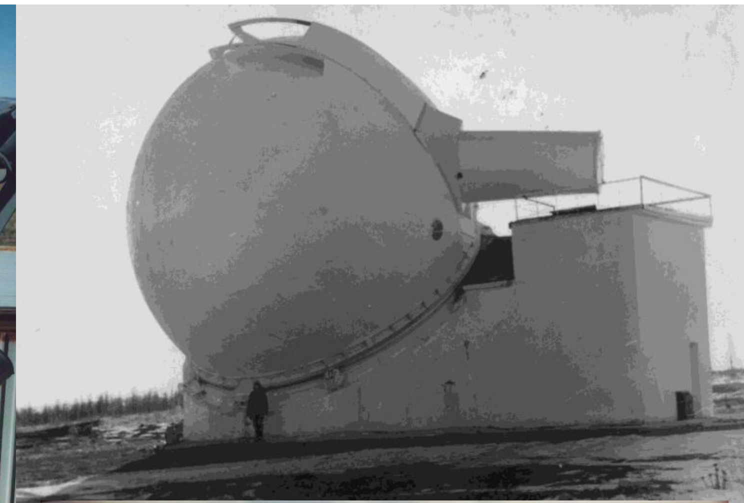
Komarov, N. S.; Pozigun, V.A. 1968AZh....45..133
Stellar Energy Distribution at Infrared Wavelengths

The studies of energy distributions in the spectra of stars were performed at OAO on 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 Cyg were carried out. The IR spectrophotometer in the observation station in Mayaki village functioned 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.







Stations, telescopes and equipment

In the subsequent years, several **telescopes** were created at the Astronomical Observatory under the general supervision of V.P. Tsessevich and its Chief Engineer, **Leonid Paulin.** Different equipment, **spectrophotometers and photometers** were also made by the **Astro-Instrument Engineering sector** 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 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 in Odesa observatory), spectrometers operating in the visible and infrared regions; on the mount **Dushak-Erekdag** (Turkmenistan, 80 cm), at the stations of the MAO of the USSR AS (**Bezymyanny (Nameless) Pass**, Armenia and **Murgab,** Pamir, 80 cm);
- 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), etc.

Interest in spectra at Odesa Astronomical Observatory (*Nikolay Komarov*)

- Graduation thesis entitled *Spectra of Meteors* successfully defended by N. Komarov (the research adviser – Efim Naumovich Kramer).
- In 1961, N. Komarov became a graduate student of Vladimir Platonovich Tsesevich with the research task to study variable stars.
- However, Sergei Rublev attracted Nikolay Komarov to theoretical studies of radiation transfer in stellar atmospheres and observations of the spectra of stars. 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. (in fact, the reflector is 48 inches in diameter, but among astronomers it is 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.

1967AZh....44..110K, Komarov N.S.

Kinematic and Morphological Properties of Stars with Enhanced Metal Lines

Distribution of metallic stars

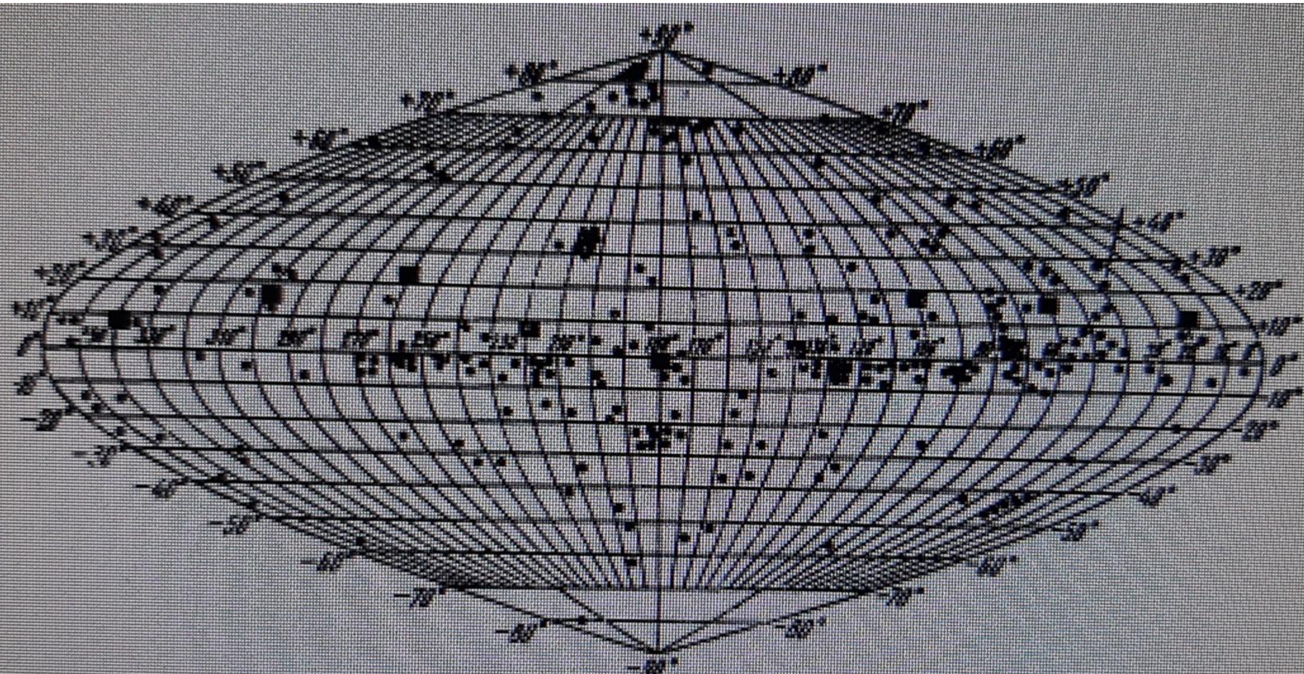


Fig. 2. Distribution of metallic stars in galactic coordinates. The squares represent the mean galactic latitudes of stars brighter than 6ᵐ5, as computed at 40° longitude intervals.

1967AZh....44..110K, Komarov N.S.

Kinematic and Morphological Properties of Stars with Enhanced Metal Lines

List of parameters

TABLE 1

No.	HD	m_v	Sp(H)	Sp(M)	M_v^0	$(B-V)^*$	$(U-B)^*$	A_V^0
1	2628	5.26	A 7.9	A 7.5	1.12	0.06	—	0.16
2	3883	5.98	A 2.8	F 2.8	1.17	—	—	0.20
3	8374	6.60	A 7.9	A 5.6	1.47	0.19	0.19	0.11
4	12869	5.08	A 3.8	A 7.1	1.08	0.06	0.13	0.20
5	13372	6.20	A 2.7	A 5.0	1.57	0.04	0.15	0.20
6	18769	5.91	A 2.3	A 7.8	1.50	0.10	0.15	0.14
7	20320	4.90	A 7.6	A 7.2	1.52	0.20	0.11	0.09
8	27045	4.80	A 7.2	F 5.0	2.16	0.21	0.07	0.10
9	27628	5.76	A 7.2	F 2.0	2.23	0.25	0.09	0.14
10	27749	5.68	A 7.2	F 5.0	2.25	0.26	0.12	0.14
11	27962	4.24	A 3.3	A 3.0	1.10	0.02	0.12	0.13
12	28226	5.74	A 7.6	F 2.0	2.20	0.22	0.14	0.15
13	29140	4.38	A 2.7	A 7.0	1.50	0.15	0.15	0.11
14	29479	5.15	A 5.1	F 0.0	1.50	0.08	0.19	0.11
15	30210	5.43	A 5.1	F 0.0	1.71	0.18	0.21	0.11
16	33254	5.42	A 7.8	F 2.0	1.58	0.19	0.19	0.11
17	40932	4.19	A 7.5	A 7.0	1.14	0.13	0.16	0.04
18	63589	6.02	A 5.2	F 0.0	1.52	0.13	0.13	0.07
19	102660	5.95	A 5.2	F 2.5	1.23	0.22	0.14	0.11
20	116657	3.96	A 3.9	A 3.5	1.83	—	—	0.04
21	136403	6.14	A 5.2	F 0.0	1.60	0.20	0.09	0.11
22	141675	5.79	A 3.8	F 2.0	1.84	—	—	0.10
23	141795	3.75	A 3.6	A 3.9	1.60	—	—	0.05
24	144197	4.84	—	—	0.43	0.18	0.13	0.14
25	145570	4.91	A 2.2	A 5.4	0.83	—		0.23
26	148367	4.68	A 5.4	A 7.4	1.20	—	—	0.19
27	159541	4.98	A 5.8	F 0.3	2.07	0.24	0.06	0.06
28	159560	4.95	A 5.9	A 7.9	2.04	0.27	0.10	0.06
29	161321	6.13	A 2.0	A 7.4	1.00	—	—	0.13
30	173648	4.29	A 2.5	F 0.8	1.15	0.16	0.17	0.04
31	173880	4.37	A 3.6	A 7.4	2.16	0.14	—	0.05
32	189849	4.74	A 3.5	A 3.0	1.67	0.03	—	0.06
33	195725	4.28	A 5.2	A 5.9	1.75	0.06	—	0.05
34	198743	4.80	A 7.4	F 2.2	0.85	0.23	—	0.10
35	206088	3.80	A 7.6	F 2.2	1.12	0.16	—	0.06
36	207098	2.98	A 7.3	A 3.8	2.02	0.14	—	0.03
37	209625	5.23	A 3.8	A 7.6	1.00	0.19	—	0.11
38	209790	4.57	F 2.0	F 5.3	2.27	—	—	0.08

PhD Thesis by Komarov N.S. (1969)

Kinematic and Morphological Properties of Stars with Enhanced Metal Lines

The following materials were used in the thesis research:

- Spectrograms of 29 stars obtained with a spectrograph attached to the 122-cm (50”) telescope of the Crimean Astronomical Observatory, the access to which had been provided to N. Komarov by I. Kopylov.
- Models of stellar atmospheres in the spectral type interval of A0-F0 near the MS were constructed: LTE, plane-parallel, radiative and hydrodynamic equilibrium. The temperature distribution was in the gray approximation and with the Chandrasekhar intensity averaging over the direction. Metals are 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 Center of Odesa State University with different hydrogen content relative to metals for Teff = 9000, 8000, 7000, 6000 K; log g = 4, 3.
- The envelopes of the star were calculated.
- A relevant paper was published: Golinko, V. I.; Komarov, N. S.; Krasnova, G. S. Model atmospheres and envelopes of A0-G5 stars. 1969AAfz....8...35

The PhD thesis by N. Komarov was the first one that used spectra and spectrum modeling and was successfully defended in Odesa.

Main results

A catalogue of 380 "metal" stars was compiled and the following conclusions were made:

1) There is no difference between “metallic” and normal stars;
2) There is a deficiency in the UV radiation of “metallic” stars;
3) The masses of “metallic” stars do not differ from those of A stars;
4) Kinematic characteristics are slightly different from those of A stars;
5) ”Metallic“ stars are belonging to the flat component (disk) of the Galaxy;
6) Parameters derived from metal lines correspond to those of supergiants, whereas parameters determined from hydrogen lines are similar to those of MS stars;
7) Axial rotation velocities are lower than those of MS stars;
8) An increase in the abundance of metals leads to a decrease in the coefficient of continuous absorption, and
9) The model is a star with a envelope.

Analyses of spectra

- Analyzing spectra provided new opportunities and gave a new tool in the examination of physical conditions in the 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 different processes occurring in stars and manifesting themselves in the stellar spectra, etc.
- Stars of **late spectral classes** 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 and analyzing their effects on the parameters and structure of atmospheres. A progress in this area of research could be made by in-depth studies of physical processes that enable to model stellar atmospheres and spectra.
- An important role in studies of cool stars was played by the **Working Group *Stellar Atmospheres*** founded by Nikolay Komarov, Nail Sakhibullin, Arved Sappar and Yanis Straume in the early 1970s.

Working group *Stellar Atmospheres*

Founders:
(Yuriy Borisov), Nail Sakhibullin,
Nikolay Komarov and Arved Sapar

Modeling

- **The first study** devoted to modeling atmospheres and envelopes of stars was performed by N. Komarov in collaboration with V. Golinko and Zh. Krasnova (1969) and yielded **model atmospheres and envelopes of A0-G5 stars.**
- Theoretical modeling 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** (1970, 1972) and also calculated absorption **spectra of titanium oxide molecules** in the atmospheres of **M-stars** (1974). V. Panchuk constructed **model atmospheres of stars of late spectral classes** and deliberated Equations of state (Part I issued in 1974), Sources of opacity (Part II issued in 1975) and the possibility of **constructing model atmospheres of R CrB type stars** (1975).
- Blanketing effects in the radiation of **cool M stars** were studied by Alina Dragunova and Vladimir Panchuk (1978) using spectra with a dispersion of 37 A/mm.

Vadim Tsymbal, Vladimir Panchuk and Nikolay Komarov played a significant role in developing methods for analyzing and modeling stellar spectra (computation of **the synthetic spectrum**).

- In 1980, Vadim Tsymbal presented an important work entitled **Synthetic spectra of late-type stars**. The software 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 composition of stars of different types up till now.
- V. Tsymbal calculated and reported “”Column Densities of Opacity Particles in Cool Stars” (1980) and presented the “Tables of Franck-Condon factors with account for vibrational-rotational interaction for astrophysically important molecules. I. Titanium Oxide. II. N, ZrO, SiO. III. C2, IV. LAO (1977-1980).
- N. Komarov together with V. Tsymbal considered the **thermochemical equilibrium of atoms, ions and molecules** in the atmospheres of cool stars (1980, 1987), calculated **the effective depths of line formation** and improved the growth curve method (N. Komarov, V. Tsymbal, A. Shcherbak 1979; N. Komarov and T. Mishenina 1983).
- Deviations from thermochemical equilibrium in the atmospheres of long-period variables (V. Tsymbal and V. Panchuk 1980).

N. Komarov, V. Tsymbal (1987):
Thermochemical equilibrium of atoms, ions and molecules in the atmospheres of cool stars

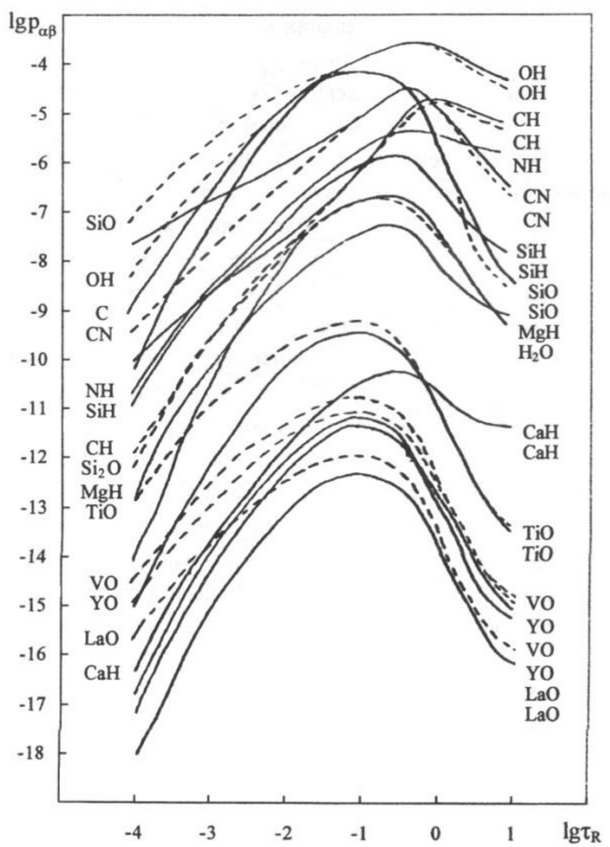


Рис.3.5. Ход величин $\log p_{\alpha\beta}$ для моделей атмосфер [121] с разным содержанием химических элементов: пунктирная линия – [231], сплошная линия – [277].

Partial pressures of molecules in the atmospheres of cool stars

M-star

Tsymbal V.V., Panchuk V.E.

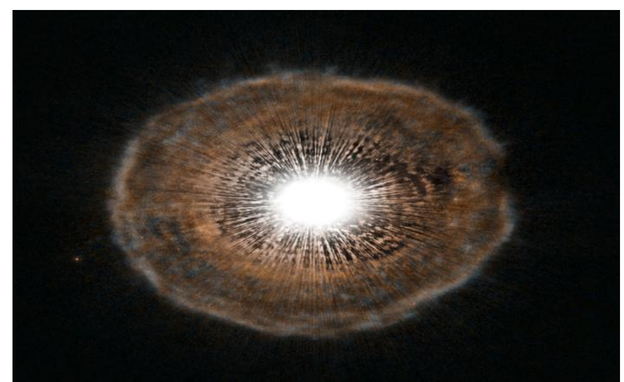
The Effects of Chemical Composition in the Atmospheres of M-, S- and C-Stars

1980AZh....57..881

- The system of ionization and dissociation equations was solved on a ES-1040 computer using 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, 1.02, which corresponds to M-, S-, C- stars, respectively.
- It has been shown that the function of the number of M-, S,- C- stars must be monotonically decreasing over the whole range of spectral types; moreover, one should expect a noticeable dispersion of the O/C ratio among M stars.

S-star:
Chi Cygni

C-star:
U Giraffe and its gaseous envelope



All photos from the Hubble Space Telescope

Observations

Spectral studies (telescopes and spectrographs)

- **High dispersion spectra:**
  - **50"(48") or 122 cm reflector** of the Crimean Astrophysical Observatory and **an echelle spectrograph** (Cassegrain focus, inverse dispersion (14 A/mm and 37 A/mm));
  - **6-m Large Azimuth Telescope (BTA**) of the Special Astronomical Observatory of the Academy of Sciences of the USSR; the **main stellar spectrograph (OZSP**, inverse dispersion 5 A/mm) and **NES (high-resolution echelle spectrometer, R = 60 000**), which are in the focus of Nasmyth-2;
  - **1-m telescope (Zeiss-1000)** of the SAO RAS with a **coudé-echelle spectrometer (R = 30 000);**
  - **1.52-m** telescope at Observatoire de Haute Provence (**France**) with **spectrograph AURELIE (R = 110 000**);
  - **2.7-m telescope** at McDonald Observatory, USA;
  - **Atlases of Sun and Stars** (Arcturus, Aldebaran, Procyon etc.) R =
- **Low dispersion spectra:**
  - **Telescopes and prism spectrographs of Abastumani and Shamakhy** observatories.

The 60s, 70s, 80s

50(48)-inch reflector (Carl Zeiss Jena, 1915)
of the Crimean Astrophysical Observatory
with an echelle spectrograph, inverse dispersion
(14 A/mm, 37 A/mm), 2 gratings

Observers:

M-type giant stars	Komarov N.S., Medvedev Yu.A. , Dragunova A.V.
RR Lyr	Romanov Yu.S., Fenina Z.N., Zaykova L.P. , Paramonova O.P., Sakharova R., Bachina L., Udovichenko S.N. , Vasilieva S.V., Lemeschenko N.D.
K, M giants	Shcherbak A. N., Mishenina T.V.
Binary stars	Karetnikov V.G., Kutsenko S.V., Glazunova L.V., Menchenkova E.V.
δ Scuti	Garbuzov G. A.

6-m telescope in SAO

Observers: Komarov N.S., Romanov Yu.S., Medvedev Yu. A., Makarenko E.N., Mishenina T.V., Motrich V.D., Glazunova L.V., Kutsenko S. Menchenkova E.V., Udovichenko S.N., Andrievsky S.M., Kovtyukh V.V., Mkrtichian D.

1.52-m telescope, OHP
Observer: S. Andrievsky

2.7-m Harlan J. Smith telescope
McDonald observatory
Observer: D. Mkrtichian

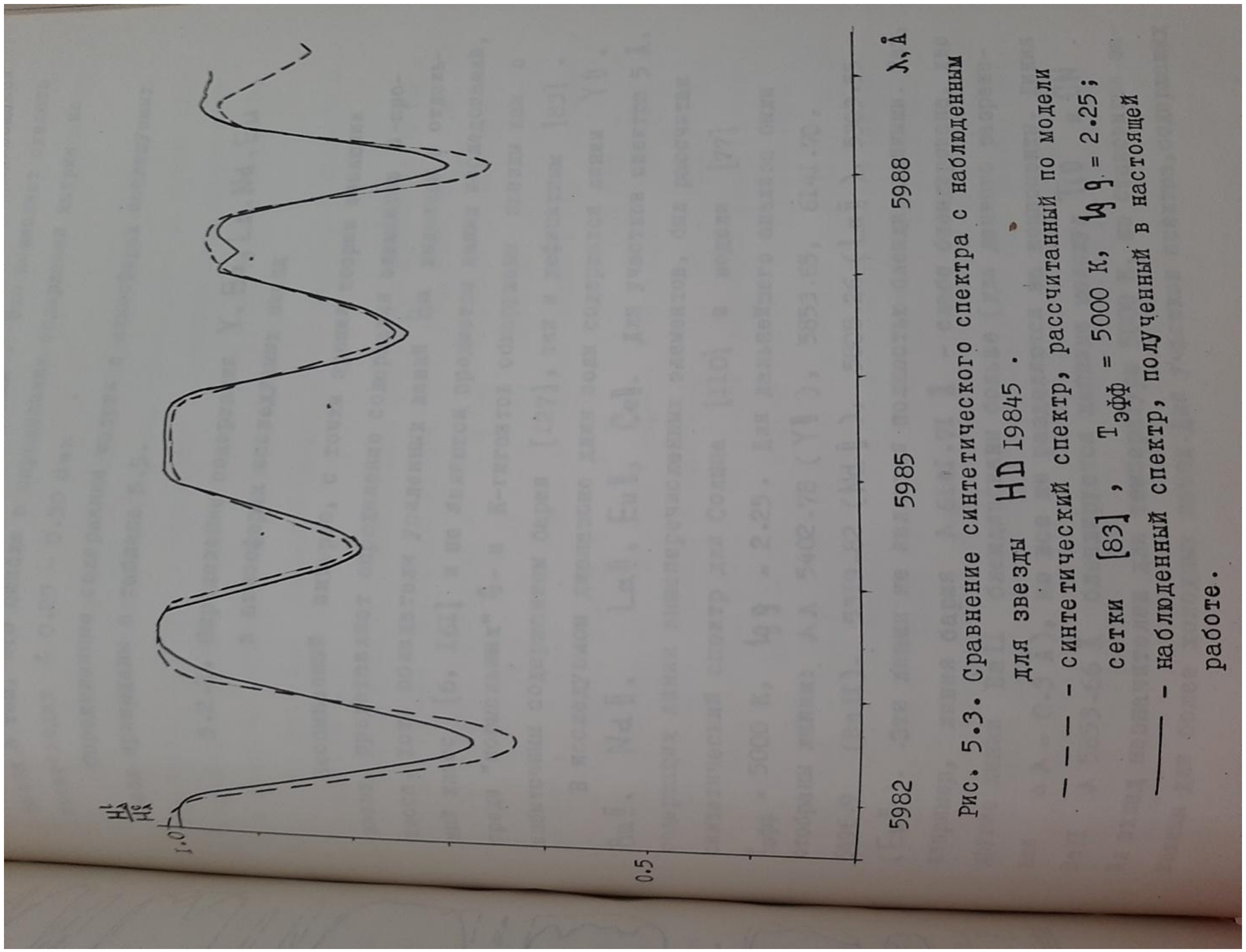
Spectral studies - main results

- 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, Yu. Medvedev, T. Mishenina and N. Gladushina (1973, 1977). The temperature was determined from the **ratio of the intensities of the heads of the titanium oxide bands.** To analyze 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 abundances**.
- Applying the **differential method of growth curves** to the study of the chemical composition of stars (N. Komarov, A. Shcherbak) made it possible to determine the relative abundances of elements in the atmospheres of stars with **an accuracy of about ±0.1 dex**; to demonstrate by an example study of 12 galactic open clusters that **the matter in the spiral arms of the Milky Way is distributed irregularly and may differ in the chemical composition (1980)** and to estimate the value of **the radial metallicity gradient in the Galactic disk d[Fe/H]/dR = -(0.07±0.03), which is close to the current value**.
- Moreover, N. Komarov and A. Shcherbak investigated elemental abundances in the atmospheres of cool stars of different ages (1980), in cool giant stars (1980) and in K-Giants (1980).

In the 1980s, the research continued under the leadership of N. Komarov with Tamara Mishenina, Vera Gopka, Valery Motrich, Svetlana Kutsenko, Sergey Korotin

- The abundances of chemical elements in the atmospheres **of K-giants of fields** (1985) and **the Hyades cluster** (1986) were studied by N. Komarov, T. Mishenina an V. Panchuk. **For the first time at OAO**, the sodium abundance in the atmospheres of K giants was determined **using the synthetic spectrum method** developed by V. Tsymbal (N. Komarov, T. Mishenina and V. Motrich 1985).
- Intense studying the abundances of elements formed **in neutron capture processes** began in that decade, with the first works focused on determining the abundances of **molybdenum and ruthenium in K-giants** using the synthetic spectrum method (N. Komarov and T. Mishenina 1988), abundances of **barium and lanthanides** in **Hyades** giants (V. Gopka, N. Komarov, T. Mishenina and A. Yushchenko 1990) and abundances of heavy elements in **Aldebaran** (V. Gopka and N. Komarov 1990).
- During that decade the work on **the methods** of research and **modeling** spectra continued as well. A. Yushchenko developed a method for **the simultaneous determination of atmospheric parameters** (temperature, gravity and metallicity). With the development of atmospheric modeling, **the first study** performed at OAO (S. Korotin and N. Komarov 1989) aimed at investigating t**he effects of deviations from Local Thermodynamic Equilibrium (LTE) on the sodium abundance** in the atmospheres of K-giants showed **insignificant** deviations from LTE .

Sodium abundance



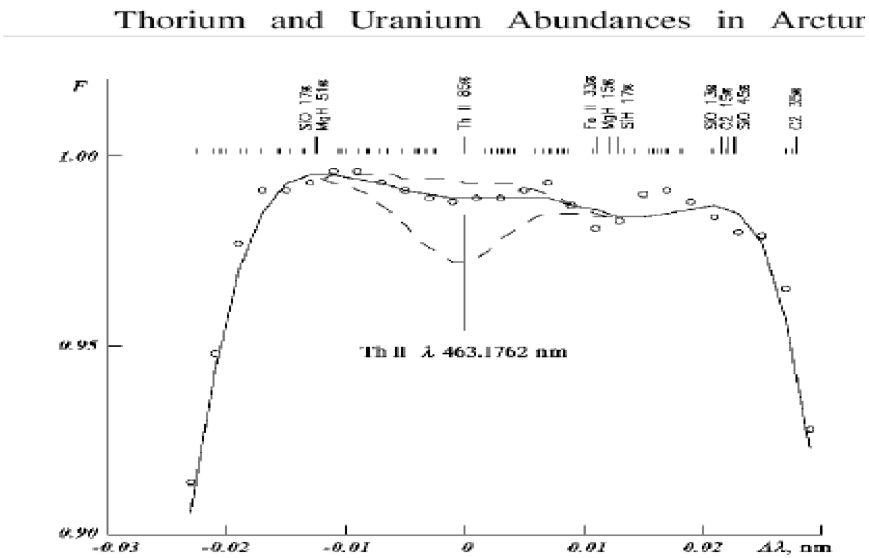
In 1989, Nikolay Komarov successfully defended his doctoral dissertation entitled

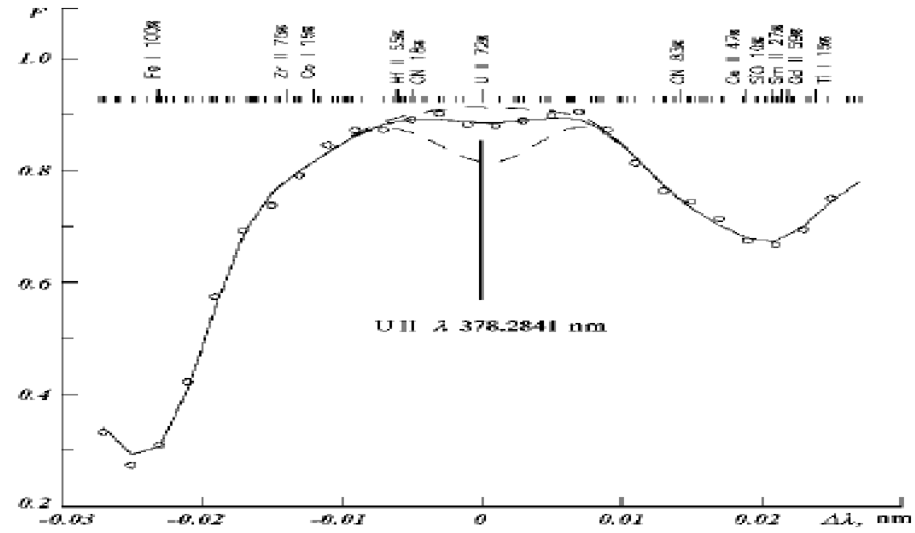
Structure of the atmospheres of cool giant stars

In the 1990s (n-capture elements)

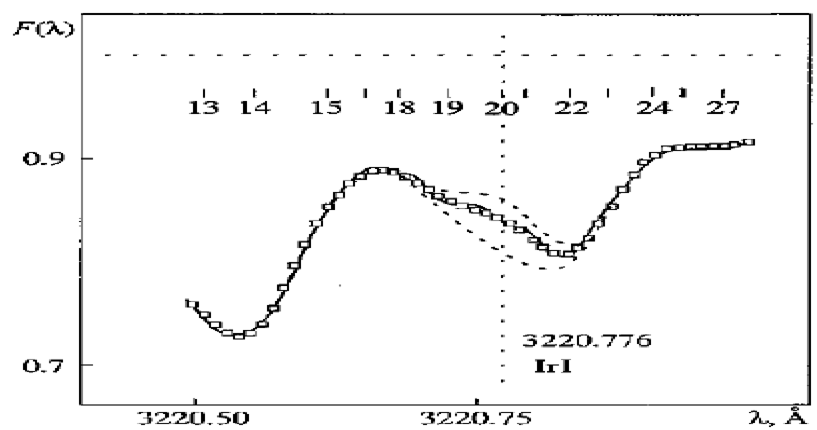
- The abundances of a number of **elements formed in neutron capture processes** (strontium, yttrium, zirconium, niobium, molybdenum, ruthenium, rhodium, barium, lanthanum, cerium, praseodymium, neodymium, samarium, europium, gadolinium, dysprosium, thorium, tellurium and erbium) were measured in K-giants, standard stars (Arcturus, Aldebaran and Procyon) and the Sun (Gopka V.F., Komarov N.S., Mishenina T.V. and Yushchenko A.V. 1991).
- **Vera Gopka and Alexander Yushchenko were leading** experts in these studies. They carried out research on **the identification of absorption lines** of dysprosium in the solar spectrum (1994), determined and analyzed the abundances of iron and light lanthanides in the atmospheres of Arcturus and Aldebaran (1994), the thorium abundance in the atmosphere of Procyon (1994), the erbium in the spectra of the Sun and Procyon (1995), abundances of rhenium and tellurium in Procyon (1996), abundances of heavy elements in the atmosphere of Procyon (1996), and abundances of thorium and uranium in the atmosphere of Arcturus that were determined in collaboration with A. Shavrina and A. Perekhod (1999).

Figures related to the n-capture abundance determinations





Ir I in Procyon



1990s: Spectral studies led by Tamara Mishenina

The Galactic disk, open and globular clusters and metal-poor stars

- Studying clusters and dynamical groups. **The chemical homogeneity of the Galactic disk** was observed **in the solar vicinity**, within 1.5 kpc from the Sun (V. Klochkova, T. Mishenina and V. Panchuk 1989).
- The obtained **oxygen abundance in the K-giants** of the Hyades was **close to the solar one** (N. Komarov, T. Mishenina and V. Panchuk 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, excess of alpha elements** and elements formed in **the slow neutron capture** processes. (T. Mishenina, V. Klochkova and V. Panchuk 1995; T. Mishenina, V. Klochkova and V. Panchuk 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 (T. Mishenina and S. Kutsenko 1994) and obtained in spectral research of some stars in the M13 globular cluster, including **the II-90 giant** (V. Klochkova, T. Mishenina and V. Panchuk 1994), **an RGB giant and an AGB giant** (V. Klochkova and T. 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 r- and s-processes** in the studied stars.

The oxygen enrichment of the Galactic disk

Mishenina, T.V.; Korotin, S. A.; Klochkova, V. G. and Panchuk, V. E.

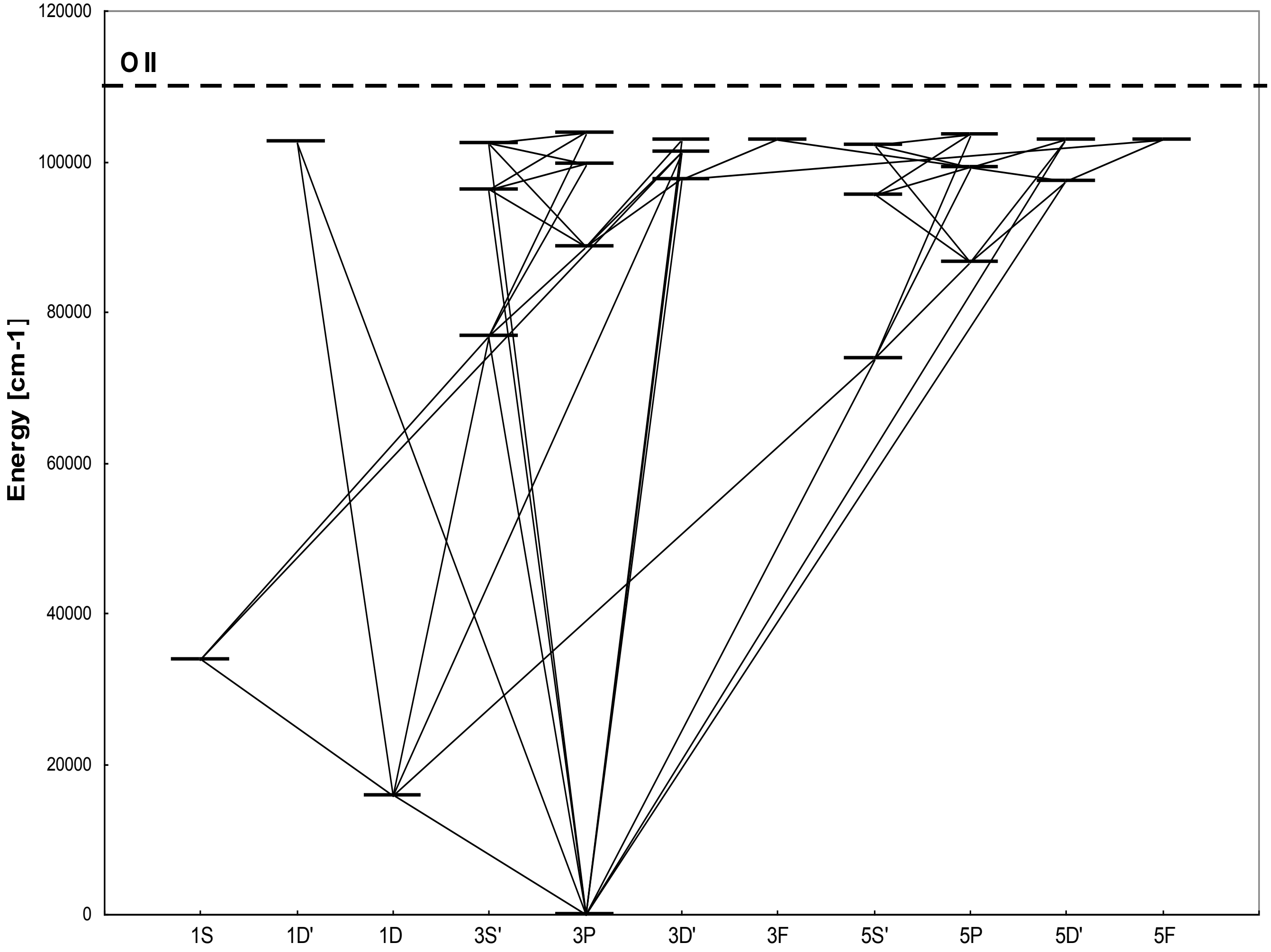
Oxygen abundance in halo stars from O I triplet

Astronomy and Astrophysics v.353, p.978-986 (2000)

An important study, which turned out to be decisive in the astrophysicists' dispute in 2000 concerning **the trend of oxygen and its abundance value in low metallicity stars**. In the study, oxygen abundances for **14 halo stars** were determined from the O I 7774 A triplet using high-resolution spectra (R = 25,000; S/N>100). The oxygen content was analyzed using both LTE and non-LTE approaches. To this end, a model of the oxygen atom was created by S.A. 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] = -0.370x[Fe/H] + 0.047. In addition to the sample of program stars, 24 stars from the study by Cavallo *et al*. were also involved in the analysis after all necessary non-LTE corrections.

The study can be called a benchmark because it showed **clear evidence of a trend in oxygen** in the Milky Way; it was carried out **by authors outside** the two astrophysicist groups debating the evolution of the oxygen content, and which used **independent spectral observations.**

Model of an oxygen atom by S. Korotin



Studying SMR stars with enhanced metal lines and CN indices (CN-strong). Part I.

- **Five stars with enhanced CN indices. 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**. Three stars – **HD 176411, HD 190940** and **HD 207130** – exhibited near-solar metallicity, they were deficient in C and O and overabundant in Na and Al. The derived abundances of **O, Na** (and **Al**) **might be an evidence for anomalous mixing in those stars**. The stars had on average solar abundances of n-capture elements. (T. Mishenina, S. Kutsenko and F. Musaev 1995).
- Three stars with **enhanced CN2** indices turned out to be **typical giants of a thin Galactic disk** with an overabundance of Na and solar abundance of n-capture elements (T. Mishenina and S. Kutsenko 1996) .
- **31 Aquilae** is known as a **Super Metal Rich (SMR)** star with the SMR status confirmed. The new **[Fe/H] value** was **+0.32±0.15 dex**, which was **close to the [Fe/H] limit for stars belonging to the thin disk** 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 [El/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. 31 Aql was found to be **in the evolutionary stage** when the **convective envelope begins to extend** (T. Mishenina 1996) .

Li, CNO and Na abundances as peculiarities in giants (SMR and CN-strong). Part II.

- **Two SMR** stars – HD 121370 (8 Boo) and HD 218640 (89 Aqr) – exhibited excess metallicity. 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 disk.** (T. Mishenina 1998)
- **Li and CNO** content in the atmospheres **of nine peculiar giants** (**eight CN-strong stars** and **the SMR star 31 Aql**) estimated through the method of model atmospheres were **close to the mean values for disk G-K giants**; it suggested that the stars had gone through the mixing 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 unlikely substantiating the hypothesis of Keenan and Heck (1994) that the CN-strong stars could be marginal R stars (T. Mishenina and V. Tsymbal 1997).
- The **sodium abundances** in **12 peculiar disk stars** with **Na excesses** were determined taking into account deviations from LTE. In some cases, the non-LTE corrections reached 0.2 dex, but, on average, it did not exceed 0.1 dex, and the **Na excesses for most of the stars were not eliminated by taking NLTE corrections into account** (S. Korotin and T. Mishenina 1999).

Spectral studies led by Valentin Karetnikov

1970s : the Pleiades and RZ Scuti, Nova Cygnus 1975 and NQ Vul

- Spectrophotometric studies carried out by Valentin Karetnikov were focused on the stars in **the Pleiades** cluster (V. Karetnikov and T. Vykhrestyuk 1973) and the eclipsing star **RZ Scuti** on Low-Dispersion Spectrograms (V. Karetnikov 1967, 1972).
- The results of a spectral study of **Nova Cygnus 1975** based on diffraction spectrograms obtained from August 30 to September 26, 1975 were reported. **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 on the half-widths of the emission lines were calculated (V. Karetnikov and Yu. Medvedev 1977; V. Karetnikov, Yu. Medvedev and M. Yasinskaya 1986). Moreover, spectroscopic observations of **Nova Vulpequlae 1976 (NQ Vul)** were carried out (1977).

1980s: eclipsing binaries

with the participation of Lyudmila Kantsen, Svetlana Kutsenko, Elena Menchenkova, Lyudmila Glazunova and Valery Kovtyukh

- The target stars: **RY Per, V367 Cyg** and **V448**.
- **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 (V. Karetnikov and S. Kutsenko 1979). Physical characteristics of the atmospheres **of both stars** 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 an envelope** were present in RY Per (V. Karetnikov, L. Kantsen and E. Kutsenko 1979)
- **V367 Cygnus:** 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, were 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 Hg 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**. A line was drawn to show the **structure of the stellar envelope** (V. Karetnikov and E. Menchenkova 1985a, 1985b).
- The massive close binary system **V448 Cyg**. 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 (L. Glazunova, V. Karetnikov, S. Kutsenko 1986).

1980s: eclipsing binaries, RY Gem, TX Uma, RY Sct and XZ Cep

- The **RY Gem** binary system. The spectral type and luminosity, excitation temperature, turbulent velocity, electron pressure in the atmosphere and envelope, and 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** (V. Karetnikov and E. Menchenkova 1987).
- **TX Uma.** Motions in **circumstellar gaseous structures** and rotations of 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 (V. Karetnikov and V. Kovtyukh 1987).
- **RY Sct.** Based on the data on the **masses of the envelopes of eclipsing binary** stars, derived using polarimetric and spectral methods, as well as on the mass losses calculated from the variations in the periods of the stars, the **dependence "mass loss - envelope mass"** was constructed. The dependence was confirmed by the data on the eclipsing star with an envelope RY Sct (V. Karetnikov 1987)
- **XZ Cep.** The spectrum of the star turned out to be composite, with a complexly changing line profile, with 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** (L. Glazunova and V. Karetnikov 1985).

1988: The thesis for the degree of Doctor of Physical and Mathematical Sciences entitled

Properties of eclipsing binary stars at the stage of the first mass exchange

Valentin Karetnikov

Studies of variable stars under the leadership of Yuri Romanov

The research group included: Zemfira Fenina, Sergey Udovichenko, Lyudmila Zaikova, Svetlana Vasilyeva, Nina Zgonyaiko, Nina Lemeshchenko and Alexander Yushchenko

- The **magnetic field** in pulsating variable stars. The magnetic field in variables of **the RR Lyrae type** was **first mentioned** (Yu. Romanov and S. Udovichenko 1981); later on, there were attempts to **determine** the magnetic field of the stars **V474 Mon, α2 Canum Venaticorum** and **β CrB** (Yu. Romanov, S. Udovichenko and M. Frolov 1984, 1985; Udovichenko 1994). A search for **magnetic fields** was carried out in several **δ Scuti type** stars (S. Udovichenko, V. Shtol‘ and G. Valyavin 1996). Sergey Udovichenko (1987) presented variation in the depression in the 5200 Å region depending on the value of the magnetic field for **α2 Canum Venaticorum** and **β CrB.**
- **RR Lyr**. The average value and polarity of **the magnetic field change with a period of 41 days (the Blazhko effect)** were reported**.** It was suggested explaining **long-period variations** of the magnetic field with the Blazhko effect **by the rotation of a star** with the same period (Yu. Romanov, S. Udovichenko and M. Frolov 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. 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 (L. Zaikova and S. Udovichenko 1988). The **ΔS parameter** of RR Lyrae stars and **rotational velocities** of some pulsating **SW And stars** were determined (L. Zaikova, Yu. Romanov 1988; L. Zaikova, S. Udovichenko and Yu. Romanov 1992).
- The profiles of the Hα and Hβ lines for **28 B and Be with stellar envelopes. The origin of the envelopes in the stars was associated with the mass loss due to rotation**, which corresponded to the presence of a rotating equatorial disk (S. Udovichenko and E. Konchagina 1997).

The chemical composition of the Sun, as well as the chemical composition of selected standard stars and the standard (unified) composition of stars

- **Standard chemical composition of atmospheres of A1-G0 type stars**. The relative abundance of atoms of 14 chemical elements was determined in 12 stars of the **A1-G0** spectral class. The results obtained by the method of quantitative spectral classification were compared with the results obtained by the method of growth curves (Z. Fenina and Yu. Romanov 1980, 1982)
- 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** (Yu. Romanov, Z. Fenina and S. Vasilieva 1981).
- A spectrophotometric study of the atmosphere of **the yellow semiregular variable star VW Dra** was carried out (S. Andrievsky, E. Makarenko and Z. Fenina 1985).
- The pulsating variable **SW Andromedae** and magnetic variable stars **AF (73) Dra** and **β CrB** were studied (Z. Fenina and Yu. Romanov 1985; Z. Fenina and L. Zaikova 1988); **β CrB** was analyzed using the growth curve method (N. Zgonyaiko and Z. 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 analyze the **two-component structure of the spectrum-forming** metal layer in the Cepheid type **T Vul** (Z. Fenina, N. Zgonyaiko and N. Lemeshchenko 1990, 1991) and also to study variations of parameters with phase in three Cepheids – **RT Aur**, **T Vul** and **κ Pav** (Z. Fenina, N. Zgonyaiko and S. Vasilyeva 1994).
- **β CrB: 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 (Yu. Romanov, Z. Fenina and N. Zgonyaiko 1998).

Studies of the δ Scuti type stars, RR Lyr type stars and Cepheids carried out under the direction of Gennady Garbuzov

- The existence of an extended atmosphere in the **δ Sct type** star **VZ Cnc** was reported. An **emission in the Hα line** was deemed to be associated with **the passing of a shock wave** (G. Garbuzov and A. Mitskevich 1984).
- **Variations in the Hα line** in the spectra of **RR Lyr stars - DH Peg** and **RZ Cep** – were studied. Weak short-lived emission and splitting of the Hα absorption line into two components were compared for the RRab and RRc type stars, the **shock waves were formed in the RRc stars in higher layers than in the RRab star**s (G. Garbuzov and L. Zaikova 1986)
- **A mechanism of excitation of chromospheric** radiation from pulsating **δ Sct stars** was suggested to explain the occurrence and variability of chromospheric emission at the center of the h and k Mg II lines in the spectra of pulsating δSct stars. **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 (G. Garbuzov and S. Andrievsky 1986)
- **Variations in the Hα profile** in the **HR 7308** spectrum of classical and unique **Cepheid V473 Lyr.** The qualitative similarity of **those variations in V473 Lyr** with **non-radial pulsations** was emphasized (S. Andrievsky and G. Garbuzov 1987)
- A **fast variability of the Hα line** in **τ Peg** as a manifestation of radial oscillations in the 3rd and 5th overtones (G. Garbuzov, S. Andrievsky and V. Malanushenko 1987).
- **Hα** Variability in **τ Cyg** (S. Andrievsky and G. Garbuzov 1987) and a shock wave front in a continuum (G. Garbuzov and O. Paramonova 1987) were studied.

Studies of different types of variable stars

under the leadership of Sergei Andrievsky and Valery Kovtyukh, involving Igor Usenko, Irina Chernyshova, Lyudmila Kostynchuk, Yuriy Beletsky, Irina Yegorova and Sergey Korotin

- **Bimodal** and **multimodal Cepheids** are stars that pulsate in two or more different periods. Deficiencies in iron and carbon, along with an excess of nitrogen, were obtained. Oxygen, α-elements and elements of the iron group showed a solar ratio. **The dependence of metallicity [Fe/H] on the period ratio P1/P0** was obtained. The value [Fe/H]=-0.43 indicated that the **TU Cas** star was poorer in metals than other bimodal Cepheids (S. Andrievsky, V. Kovtukh, E. Makarenko and I. Usenko 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 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 P1/P0-ratio vs. metallicity** (S. Andrievsky, V. Kovtukh, I. Usenko, V. Klochkova and G. Galazutdinov 1994).

S-Cepheids (with a short pulsation period)

- The **s-Cepheids α Ursae Minoris (Polaris)** and **HR 7308** (**V 473 Lyr**). **α UMi (Polaris)** exhibited a **small overabundance** of most elements **relative to the Sun**. A **decrease in the Polaris pulsation amplitude** was found. Light elements showed a small overabundance and Fe group elements were slightly deficient in **HR 7308** (S. Andrievsky, V. Kovtyukh and I. Usenko 1994).
- **Eight s-Cepheids** and **V1162 Aql** (earlier classified as a s-Cepheid). All Cepheids (with the only exception of EU Tau) had **solar-like abundances of α- and iron-group elements** and **Na overabundance**. 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 program stars. **V1162 Aql** did not show **any changes in C and N** abundances, the star is a normal Cepheid (Cδ), but **it was the first time that it crossed** the instability strip toward the giant branch (S. Andrievsky, V. Kovtyukh and I. Usenko 1996).
- A hypothesis about **s-Cepheids' first time crossing of the instability strip** was **checked** for seven s-Cepheids. V473 Lyr, IR Cep, UY Mon, BY Cas, V636 Cas had **solar iron abundance**, while V526 Mon and V924 Cyg showed moderate iron deficiency. The absolute **carbon deficiency** found for **all program stars (excepting V636 Cas**) and a nitrogen overabundance suggested that those s-Cepheids **were not crossing the instability strip for the first time**. **V636 Cas was crossing the instability strip for the first time**. Na and Al were overabundant for all program stars. Abundances of α-elements and iron-group elements were close to the solar ones. The s-process elements appeared to be slightly enhanced (V. Kovtyukh, S. Andrievsky, I. Usenko and V. Klochkova 1996).

Cepheids: binarity and luminosity

- The unique Galactic Cepheid **V473 Lyr** revisited. 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** (S. Andrievsky, V. Kovtyukh, D. Bersier, R. Luck, V. Gopka, A. Yushchenko and I. Usenko 1998).
- Spectroscopic manifestations of the **binarity** of the s-Cepheid **EV Sct** 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 close effective temperatures, the difference in visual 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 also within the instability band, being a **very short period Cepheid (P ~ 1.2 days)** (V. Kovtyukh and S. 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** (S. Andrievsky 1998).

Blue stragglers form a rare class of MS stars in globular and open clusters, as well as in the field of the Milky Way

- **7 blue stragglers** in the Galactic **field**. The iron abundance values for the studied stars **varied from [Fe/H]=-0.9dex to [Fe/H]=-0.3dex**. It was suggested that **the blue stragglers in the field population represented stars of different ages** (S. Andrievsky, I. Chernyshova and O. Ivashchenko 1995).
- **15 Galactic field blue stragglers** and one normal F-dwarf. All stars were **metal deficient**. The mean value of [Fe/H] for 13 stars was -0.31±0.13; C and O were slightly enhanced [C/Fe]=[O/Fe]=0.3dex) as well as Na and α-elements. Mg and Sc showed solar ratio [El/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** (long to leave the MS) (S. Andrievsky, I. Chernyshova and V. Kovtyukh 1996). **Modern view - mergers of stars and the exchange of masses between them.**
- **Four blue stragglers** from **old Galactic open cluster NGC 2632 (Praesepe**). Three stars, including the hottest star of the cluster HD73666, exhibited a **uniform chemical composition: they showed a solar-like abundance 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** (S. Andrievsky 1998).
- **Blue straggler and MS B and A type stars** in the **open clusters NGC 3496, NGC 6475, NGC 6633 and IC 2602**. **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. All investigated stars were **moderately-to-severely deficient in carbon** (S. Andrievsky, D. Schönberner and J. Drilling 2000).

λ Boötes stars

- A new approach to the problem of **the origin of λ Boo stars** suggested that some of those stars **might originate from contact binary systems of W UMa type**. The scenario did **not exclude circumstellar envelope** formation, which was responsible for chemical peculiarities of λ Boo stars (S. Andrievsky 1997).
- **VW Ari A** (Teff =7200, log g = 3.7), being the main component of the visual binary system, was analyzed and found to be **severely deficient in some metals** whereas **light elements** were abundant at levels **similar to the solar ones**. **VW Ari A** was assumed to be a **λ Boo type star**. The **VW Ari A's** photometric data confirmed the assumption (I. Chernyshova, S. Andrievsky, V. Kovtyukh and D. Mkrtichian 1998).
- **Seven well established λ Boo type stars** – namely, 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 for all investigated stars**. There was a **wide range of underabundances of all other elements** in individual stars. The results were **consistent with the accretion/diffusion model** adopted to explain the **λ Boo** phenomenon (E. Paunzen, S. Andrievsky, I. Chernyshova, V. Klochkova, V. Panchuk and G. Handler 1999).
- An analysis of **accretion-based model of the dust-gas separation**, which is the explanation of anomalous properties of λ Boötis-type stars, showed that (i) for any reasonable density profiles of the envelope**, dust grains appeared to be decoupled from the gaseous background** within the region where the temperature dropped below the condensation temperature of heavy elements such as Mg, Ca, Fe, etc; (ii) it was most likely that only small dust particles (of less than ~10-6cm in size) could be created in the envelope of λ Boötis-type stars (S. Andrievsky and E. Paunzen 2000).

B-stars located in a region of H-R close to the Cepheid region

- A study of **B stars** with the allowance for deviations from Local Thermodynamic Equilibrium (NLTE) was carried out under the leadership of **Sergei Korotin**.
- **γ Peg** revealed a slight deficiency of carbon ([C/H] = -0.25) (S. Korotin, S. Andrievsky and L. Kostynchuk 1999a) and nitrogen ([N/H] = -0.30) (S. Korotin, S. Andrievsky and L. Kostynchuk 1999b). 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 **C** and **N** in a sample of **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** (S. Korotin, S. Andrievsky, R. Luck and L. Kostynchuk 1999). The analysis was based on the spectra collected with a 1.52-m telescope at Haute Provence Observatoire.
- In a sample of **hot MS B stars**, the derived NLTE **oxygen** abundances 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 (S. Korotin, S. Andrievsky and R. Luck 1999).
- A comparative analysis of chemical 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 the mechanism of radiative diffusion in the upper atmosphere layers**. 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 (R. Luck, S. Andrievsky, V. Kovtyukh, S. Korotin and Yu. Beletsky 2000).

Studies of non-radial pulsation by David Mkrtichian

- **Ɵ Uma**, variability was detected in radial velocities of the Hα hydrogen line with a period of 0.063 d. The variability had an amplitude of 2K = 12.3 km/s and was reckoned to be caused by **oscillations in the third radial overtone** (D. Mkrtichian 1990)
- 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. Measurements of precise radial velocity (RV) were carried out for 5 roAp stars, namely 33 Lib, γ Equ, HR 1217, HD 134214 and HD 122970. Pulsational RV variations were detected in all five stars with amplitudes ranging from 50-400 m s(-1). For the roAp star HR 1217, the authors were able 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 on 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 (A. Hatzes, D. Mkrtichian and A. Kanaan 1998, 2000).

PhD thesis

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OAO - 2000

Thank you

for your attention!