REVIEWS

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Supergiants with large IR excesses

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Abstract.
Evolutionary status of peculiar supergiants with large IR excesses, candidates for protoplanetary nebulae (PPN), has been considered.
Results of spectroscopy of supergiants with IR excesses obtained with the 6 m telescope in 1994–1996 are presented. Using high spectral resolution CCD spectra taken with the echelle spectrometer LYNX, a sample of 14 supergiants, PPN candidates, having large IR flux excesses has been studied. In the atmospheres of three metal–poor objects, IRAS 04296+3429, IRAS 07134+1005 and IRAS 22272+5435, overabundances of nuclei of s–process elements are reliably detected. In the atmospheres of these stars large overabundances of carbon and nitrogen are also revealed. A similar chemical abundance pattern is also derived for AC Her, one of four pulsating RV Tau type variables investigated. At the same time for the greater part of PPN candidates excesses of heavy nuclei, whose synthesis in neutronization reactions and subsequent dredge–up to the atmosphere of a post–AGB star is predicted by the stellar evolution theory, are not revealed. For the star RV Tau the abundance of iron group elements is obtained to be solar, carbon and s–process elements are estimated to be underabundant.
It is shown that the sample of high luminosity stars with IR excesses is not homogeneous: these are mostly low–mass halo post–AGB objects, but at the same time it includes stellar objects of a different nature, e.g. the IR source IRC+10420. The metallicity we have determined, which is close to solar, and the detailed chemical composition of the supergiant IRC+10420 verify the hypothesis of its membership in the not numerous population of massive stars evolving towards WR. Spectral monitoring has been started of the unique Sakurai's object, which is classified as a post–AGB star in the stage of the final helium flash from the results of 1996 observations. The radial velocity variability of the object IRAS 07134+1005 is confirmed and radial velocity oscillations of the peculiar supergiant UU Her are revealed.

Key words: stars: evolution — stars: post–AGB — stars: chemical composition — stars: dynamical stage of atmospheres

1. The problems of evolutionary status of supergiants with IR excesses

1.1. Post–AGB evolution stage

The IRAS telescope launched in 1983 opened up a view of infrared sky to astronomers. This made it possible to select objects that represented circumstellar envelopes with temperatures from 200 to 1000 K at high latitudes of the Galaxy. Later (Pottash & Parthasarathy, 1988; Hrivnak et al., 1989; Oudmaijer et al., 1992; Oudmaijer, 1996) part of these objects were identified with high luminosity stars, being assumingly at the post–AGB stage of evolution, a small fraction of which were observable spectroscopically with a high spectral resolution. Immediately after the optical identification of the first IRAS source a boom in investigation of these objects was started. The results of the first decade are presented in the survey made by Kwok (1993).

The objects at the transition post–AGB stage (hereafter referred to as PPN, IRAS sources, post–AGB–stage stars) offer a unique opportunity to examine detailed chemical composition which has undergone changes as a result of nucleosynthesis pro-

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cesses in the course of evolution of a given star. This problem has been traditionally studied using spectra of planetary nebulae, however in this case as a result of ground–based observations one can obtain only data on the light element abundances. The details of the abundance curve caused by nuclear processes at late evolution stages remain insufficiently studied. The spectra of the post–AGB–stage stars, which are late (F, G) supergiants, allow one to estimate abundances of both light elements and heavy metals synthesized in the process of neutronization of nuclei. Apart from this classical problem of investigation of chemical composition of stars at non–trivial evolution stages, the study of processes of matter exchange between the star's atmosphere, the search for mechanisms responsible for the peculiarities of chemical composition of stars surrounded by dust envelopes are of independent interest.

From the general idea of evolution of the Galaxy and stars we are to expect at high latitudes the presence of only low–mass objects, representatives of old–type populations, including low–mass supergiants at final stages of stellar evolution. However, over the last few years it has become clear that in the Galaxy halo a population of obviously young massive B stars is observed (see e.g. Conlon et al., 1988; 1992). A possibility of existence of massive high luminosity stars in the halo of the Galaxy needs ascertaining. The age, the large distance from the galactic plane, z, and kinematics of a number of such objects are inconsistent within the frames of the mechanism of ejection from the disk and require the hypothesis of formation of these stars in the halo of the Galaxy to be involved. We cannot reject a possibility of recent star formation because at high galactic latitudes clouds have been discovered with masses and densities sufficient for stars to be formed in collisions of the clouds (Van Woerden, 1993).

The situation with supergiants at high latitudes is similar. A number of hypotheses have been put forward that explain their existence at high latitudes: ejection from the disk in the supernova outburst in a binary system, formation in collisions of high latitude clouds, accretion of intergalactic gas, formation of stars in the halo through phase transitions in low–density gaseous clouds. The hypothesis of ejection from the disk do not explain the large observed values of z and kinematics of stars as in the case of B stars.

The mechanism of phase transitions was considered by Tohline (1985) and developed by him later with his coauthors (Christodoulou et al., 1993). The phase transition of low density diffuse gas to compact "disk–like" structures occurs in a stochastic manner inside the clouds without thermodynamic equilibrium, and may be efficient enough at mass values essentially lower than those required by Jeans criterion. Such a collapse calls for supersonic perturbations

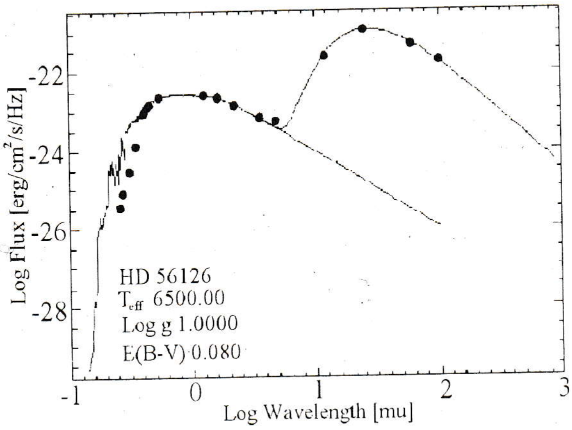

Figure 1: *The spectral energy distribution of HD 56126 (figure is borrowed from the paper by Bakker et al. (1996b).*

in a non–equilibrium medium and may be effective at very low densities, $n \approx 0.1\,cm^{-3}$ and low temperatures, $T \approx 20\,K$, as those, that have been measured at high latitudes in the Galaxy.

1.1.1. Post–AGB stars in globular clusters and other galaxies

Part of the questions raised by the uncertainties in the evolutionary status, distances and luminosity of PPN candidates in the galactic field can be eliminated if one turns to investigation of similar stars inside globular clusters. However, because the post–AGB stage is of short duration, there is rather a limited sample of such objects in globular clusters. PPNe in globular clusters, which are accessible to high–resolution spectroscopy, are still less numerous. By the present time the detailed chemical composition has been investigated for the post–AGB stars in the nearest globular cluster ω Cen (Gonzalez & Wallerstein, 1992; 1994). The supergiant ROA 24 (Gonzalez, Wallerstein, 1992) is a reliable representative of the post–AGB stage owing to its ω Cen membership. The abundance of chemical elements in the atmosphere of ROA 24 is treated as a primary standard for the post–AGB stage and is used in the study of the objects suspected to belong to this stage.

But in this case too, which is the most favourable for observations, the S/N ratio of the spectra obtained with the CTIO 4 m telescope is generally insufficient for measurement of weak absorption lines. It is apparent that mass high accuracy observations with a high spectral resolution of stars in globular clusters is a priority programme for telescopes with a mirror diameter over 4 m.

An independent problem is search for and study of extragalactic stars, PPN candidates. For the selection of candidates, IR spectroscopy and two-colour IRAS diagrams are used to advantage. For instance, in the Small Magellanic Cloud Van Loot et al. (1997) have selected post-AGB stars of subclasses II – III (by classification of Van der Veen & Habing, 1988).

In the past years along with classical cepheids, RV Tau and RR Lyr type stars, the post-AGB stars have come to be treated as a standard candle in determination of distances to galaxies. The post-AGB stars have a number of advantages over the enumerated objects (Bond, 1996): high absolute luminosity in the narrow range of luminosities, possibility of their selection using low-resolution spectra (from the non-standard peculiar H_α profile and anomalously high Balmer jump values), membership in population II, reliable enough calibration of luminosities by objects inside our Galaxy, insignificant light variability.

1.2. Observational manifestations of the PPN stage

At the AGB stage, stars represent a dense C–O core surrounded by an extended envelope (Iben & Renzini, 1983; Schönberner, 1983). A strong wind with a rate of $10^{-5} M_\odot$/yr and even $10^{-4} M_\odot$/yr is inherent in this configuration, which eventually results in an optically thick envelope, and a star ceases to be observed in the optical range. Stars at the late stages, which lose matter through the wind, resemble a candle burning at both ends (Masevich & Tutukov, 1988). When the mass of the hydrogen shell drops to $0.001\,M_\odot$, the wind stops and the star moves into the blue region of the Hertzsprung–Russel diagram because of rising $T_{\rm eff}$. This stage may last to $T_{\rm eff}$ values as high as about 30000 K, at which ionization of the circumstellar nebula is initiated. Recombination hydrogen lines and forbidden metal lines make the object readily observable as a planetary nebula (PN). Most of the time the luminosity of the star is provided by shell hydrogen burning.

The term AGB indicates that for low-mass stars ($1 - 2\,M_\odot$) the relationship $T_{\rm eff} - L$ at this evolutionary stage is very close to that on the first giant branch (RGB) but slightly shifted blueward (the two branches are well seen on the H–R diagrams of globular clusters). For MS stars with a mass from 2–3 to $8 - 9\,M_\odot$ (these objects are called intermediate mass stars, helium burning in their cores proceeds in the absence of electron degeneration) the term "asymptotic" has no morphological sense and is used to denote stars with a degenerate C–O core. After helium in the core is exhausted, the degenerate C–O core is originated surrounded by energetically active He and H burning layers, i.e. a configuration – analog of an AGB star — is formed.

1.2.1. Gaseous-dust envelope manifestations

Thus, from the general ideas of the stellar evolution theory it follows that objects at the transition post-AGB stage, having undergone the AGB phase with a considerable mass loss, are stellar remnants of high luminosity surrounded by a dust envelope with a temperature of about 200 K. From the point of view of the theory and observations the transition, very short (about 10^3 years) phase from the AGB stage to a planetary nebula, is little studied. The theoretical study of evolution of PPNe is impeded due to the complexity of their structure including at least two components: a cooling down envelope, which may be of composite structure and a star continuing its evolution. However, a number of papers is available in which modelling of radiation of the expanding cooling down dust envelope is made (see, for instance, the papers by Volk & Kwok, 1989; Szczerba & Marten, 1993; Lopez et al., 1997) and tracks for the evolution of the central star (Schönberner, 1983) have been computed, including the evolutionary tracks with allowance made for the mass loss (Vassiliadis & Wood, 1993; 1994; Blöcker, 1995 a,b). In the papers by Blöcker (1995 a,b) the evolutionary tracks have been calculated for stars with initial masses of $1 - 7\,M_\odot$, taking into account the mass loss at the RGB, AGB and post-AGB stages. The author emphasizes that the mass loss rate in the course of evolution of a star is the most important parameter along with the initial mass on the main sequence, and it determines not only the final mass after the AGB phase but the internal structure of the star and time scales of evolution at the final phases as well as the chemical composition variations of the surface layers of the star.

Nonvariable OH/IR stars are likely to be the youngest post-AGB objects. Habing et al. (1987), Van der Veen and Habing (1988), and Kwok et al. (1987 a,b) have proposed to call this transition evolution phase the late-AGB (LAGB). Since the phase is short, the object preserves many properties of its predecessors — stars at the AGB stage. At the beginning of this stage the object is observed only in the IR and radio ranges and not identified with objects visible in the optical range (Kwok et al., 1987 a,b; Volk & Kwok, 1989). The carbon star CW Leo (IRC+10216), the brightest source in the sky at $\lambda = 5\mu m$, serves a prototype of an OH/IR star with an optically thick expanding envelope created through the strong stellar wind at the preceding phases of the star evolution (Olofsson et al., 1982; Groenewegen, 1997). Delfosse et al. (1977) have modelled emission profiles of CO observed in 5 of this kind of objects. Rotational transitions of CO are widely used in determination of the matter loss rate for long-period variables. However, in the case of young (optically thick) OH/IR stars the mass loss rate corresponding to the integral IR flux turned out to be an order of magnitude higher than the value which is obtained from the intensity of the weak CO emission (this inconsistence is especially pronounced for the CO line corresponding to the transition J = 1 – 0) (Heske et al., 1990). Such a behaviour distinguishes young OH/IR stars from Mira variables and OH/IR stars with an optically thin envelope, for which the mass loss rate estimates from the CO line and from the IR radiation are consistent.

The optical thickness of the dust envelope during expansion decreases, as a consequence of which the ratio of IR flux to the total flux will decrease. For young PPNe it is 1/3. Volk and Kwok (1989) have performed modelling of energy distribution evolution in the spectrum of PPN as the envelope cools down and expands. When the effective temperature of a star reaches a value of about 5000 K, the phase of LAGB terminates and an object becomes a PPN (Schönberner, 1983).

The objects AFGL 618 and AFGL 2688 (Egg Nebula) may be an example. AFGL 618 is an IR source with $T_{eff} = 300$ K which is located between two optical components separated by 7″ (Westbrook et al., 1975). On the radio images small (0.4″) ionized regions embedded into the IR source are revealed. At a distance of up to 20″ a molecular envelope expanding at the velocity V = 20 km/s, like circumstellar envelope of an AGB star, is observed. The optical component of AFGL 618 is a faint star (Sp = B9, $V = 19^m$) due to high absorption: the absorption in the visible range, A_V, reaches 70 – 100 magnitudes under the assumption that the circumstellar absorption affects IR lines in a manner similar to the interstellar absorption (Lequeux, Jourdain de Muizon, 1990). The IR and molecular emission arise in the asymmetric envelope. The remnants of the envelope are concentrated towards the equatorial plane, the lower optical density at the poles allows the optical radiation to pass, and the scattered light creates a bipolar nebula. In consequence of asymmetry of such a structure the observed image is dependent on the observer's view angle.

The mass of the ionized part of the PN envelope is 0.2 $M_\odot$; if the age is about 5000 years, the mass loss rate at the AGB stage must then be about $4 \cdot 10^{-5} M_\odot$, whereas from Reimers (1975) for a star of such a mass it may be by 1–2 orders of magnitude lower. Therefore, to explain the formation of a PN a hypothetic "superwind" with $10^{-4} M_\odot$ per year is introduced (Renzini, 1981; Baud & Habing, 1983). At a certain moment of the life time of an AGB star its mass loss rate suddenly increases. This rapid increase in the mass loss rate finds its reflection on the diagram of IR colours as a gap between non–variable AGB stars, which have actually no IR excesses, and post AGB star (see e.g. Van der Veen & Habing, 1988, Figs. 3a and 5a). These authors suppose that one of the causes of the abrupt rise in mass loss rate may be the pulsating instability of supergiants since on both sides of the gap mentioned the numbers of variable stars differ essentially. Besides, in the extended atmospheres of super– and hypergiants a complex pattern of turbulence exists, which creates turbulent pressure on matter and may cause a high rate mass loss (de Jager, 1992). The "superwind" stage in low and medium-mass stars terminates when the hydrogen envelope is exhausted. The duration of the "superwind" stage is not large, $10^2 - 10^3$ years (Baud & Habing, 1983; Delfosse et al., 1997).

Several stars at the post–AGB stage, in particular the above mentioned AFGL 618 and AFGL 2688, had been known before the IRAS satellite was launched. Besides in the paper of 1951 Bidelman drew attention to the presence of F,G supergiants located in high galactic latitudes. However, as a result of observations with the IRAS devices a population of F,G supergiants with large IR excesses was revealed (Lamers et al., 1986; Parthasarathy & Pottash, 1986; Hrivnak et al., 1989; Trams et al., 1991), which were interpreted to be caused by radiation of circumstellar envelopes. It is from the results of identification of this population in the optical range that a sample of peculiar supergiants with large IR excesses mostly in high galactic latitudes ($b > 10°$) was formed.

The IR flux maximum lies at about 25 – 60 μm. The flux up to 5 μm is mainly determined by a reddened star, and over 10 μm — by dust. Colour characteristics (flux ratios at the wavelengths 12, 25, 60, 100 μm) are caused by the circumstellar envelope properties, therefore, they are dependent on the wind parameters at the AGB stage. On the infrared colour diagrams the late AGBs and young PNe are clearly distinguished (Van der Veen & Habing, 1988; Volk, Kwok, 1989).

In addition to the cool dust envelope with a temperature of several hundred degrees in several PPNe a hotter inner envelope (up to 1000 K) is observed. It is important that the integral IR flux for a number of stars is comparable (and even exceeds) with the flux in the optical range, in consequence of which the energy distribution in the spectrum of PPNe has a two–peaked character (Volk & Kwok, 1989; Van der Veen et al., 1994; Oudmaijer, 1996). As a typical example, in Fig. 1 is presented the distribution of energy in the spectrum of the PPN, HD 56126 (the figure has been taken over from the paper by Bakker et al., 1996b). It follows from the figure that the flux in the visible range is consistent with the Kurucz's model with $T_{eff} = 6500$ K and surface gravity $\log g = 1.0$. Note that the excitation temperature we have determined from a large set of neutral iron lines (Klochkova, 1995 a) equals 7000 K and is in fair agreement with the data of energy distribution modelling. It should be borne in mind that T_{eff} of the given object may change (Oudmaijer & Bakker, 1994) because the colour indices are observed to vary.

It should be noted that at high latitudes of the Galaxy F, G supergiants have been selected (Bond et al., 1984; Sasselov, 1984), which, by all indications, may be considered as post–AGB stars (UU Her type stars), however, they have no IR excess. It is assumed that these are the objects with a low mass of the core, in consequence of which their evolution is hindered. As a result, the envelope has time to dissipate leaving no trace, since the dynamic life time of the nebula is much shorter than the transition stage of the star from the AGB to the post-AGB stage, hence these objects will never get PNe. On the other hand, in the case of a more massive central star, which evolves faster, the PN will be ionized earlier, when the dynamic age is still small, the ratio of the IR flux to the flux in the optical range is still higher. Thus, there are IR objects that have no optical counterpart identification, as, for instance, the IR source IRAS 18530+0817 (Walker et al., 1997).

The envelopes of the greater part of the AGB objects are of extended asymmetric shape (Bujarrabal et al., 1992), which is indicative of the non-sphericity of the mass loss process and the likely presence of a companion. Optical images of PPNe obtained in the last time with a resolution as high as the diffraction limit of large telescopes point to a complex morphology of these objects. For instance, Cruzalèbes et al. (1996), having adapted the bispectral analysis method (Weigelt, 1977) of speckle images and conducted CFHT observations in the near IR, drew a conclusion of the bipolar structure of the PPN HD 44179 (Red Rectangle nebula). Some later Osterbart et al. (1997) confirmed this result using optical speckle-observations. From observations of IRC+10216 (CW Leo) with a high spatial resolution by the method of speckle masking performed at the 6 m telescope Osterbart et al. (1996) have drawn a conclusion of the presence of a resolvable central peak surrounded by condensations of matter. The authors infer that the character of the matter outflow process is stochastic. From radio images of CW Leo in emission at a wavelength of 1.3 mm the extended dust envelope of this star is traced up to a distance of 50″ (Groenwegen et al., 1997). At distances of about 5 and 20″ together with the monotonic decrease in density of the envelope the authors have detected rises in its density associated, apparently, with the enhanced (2–7 times) mass loss by the star during the earlier evolution stage.

From CFHT observations Kwok et al. (1996) have obtained images of 20 PPN candidates and detected a bipolar structure in the visible range for 2 of them. Analysis of subsequent images of the 2 selected objects obtained by those authors at the telescopes CFHT and UKIRT in the visible and IR wavelength ranges with a high spatial resolution led to the conclusion of the presence of circumstellar disks, which obscure the central zones of the objects under investigation.

A qualitatively new level of understanding the structure and dynamics of the envelopes around far evolved stars is ensured by observations with the Hubble space telescope. For example, very complicated picture has been obtained for the young nebula Egg (STSI, 1997). The non–uniform asymmetric image of this nebula obtained with a wide–angle camera in the IR range represent a hierarchy of different scale details with a set of velocities: clouds of molecular hydrogen, arcs, jets.

1.2.2. Spectral features in the IR spectrum

In the spectrum of a number of PPNe in the near IR range Hrivnak et al. (1989) have detected the Brackett H I series lines, the absorption feature 1.54 μm, which is ascribed to Mg I; absorption (may change over to circumstellar emissions, as in the case of IRAS 22272+5435) bands at 2.4 μm due to rotation transitions of the CO molecule; emission features at about 3 μm similar to those found in the spectra of PNe and H II regions, which have not yet been reliably identified.

O–rich post–AGB stars (for the photosphere O/C > 1) have in IR spectrum strong details of 9.7 and 18 μm caused by silicates such as for O–rich AGB stars (Van der Veen & Habing, 1988). The line of 9.7 μm changes from emission for early AGBs (Mira type) to absorption in the evolved AGB (OH/IR) objects with optically thick envelopes. C–rich PPNe have a strong IR detail at 11 μm (Van der Veen & Habing, 1988; Chan & Kwok, 1990). It may be due to graphite. This is assumed to be a likely vibrational band of some symmetric molecule.

A small number of PPNe (Kwok et al., 1989; Henning et al., 1996) have in the IR spectrum an unidentified emission band of about 21 μm, which is found neither in the spectra of their predecessors, AGB stars, nor in the spectra of PNe. Buss et al. (1990) have supposed that this band may be caused by the molecules of polycyclic aromatic hydrocarbon. Goebel (1993) has identified the 21 μm band with the vibrational band of the SiS_2 molecule, the presence of which is consistent with the temperature of the envelope. As has been noted in the paper by Kwok et al. (1989) the objects whose spectra contain the 21 μm band are extremal carbon stars. It is important to note that the sources IRAS 07134+1005 (Klochkova, 1995a), IRAS 22272+5435 (Začs et al., 1995), IRAS 04296+3429 (Klochkova et al., 1997c), for which we have obtained the values of C/O > 1 and the excess of s–process elements, using the spectra of chemical composition investigation carried out at the 6 m telescope, belong exactly to this kind of PPNe. An interesting thing is the detection of the band near 21 μm in the spectra of the very young stars with IR envelopes (Hebbing et al., 1996), which apparently points to the similarity of physical and chemical processes in the envelopes of these objects at so different stages of evolution. The resemblance of these two types of objects shows up in morphology (bipolar structure) and in the details of kinematics of the envelope (Henning et al., 1996).

The broad emission band at 30 μm is observed as rarely in PPNe spectra. Omont (1993) and Omont et al. (1995) have found this band in the spectra of four PPNe. The authors of these papers have inferred that the intensity of the 30 μm band does not correlate with the presence of the band at 21 μm. Besides, in contrast to the 21 μm, the 30 μm band occurs in the spectra of stars at the neighbouring evolutionary stages, AGB and PN. In the spectra of IRAS 22272+5435 the 30 μm band intensity amounts to 20 % of the bolometric source luminosity, while in the spectrum of IRAS 07134+1005, whose atmosphere is also rich in carbon (Klochkova, 1995a), the intensity of this band is not high. Szczerba et al. (1997), when modelling the detailed energy distribution in the spectrum of IRAS 22272+5435, concluded that the 30 μm band is caused by pure magnesium sulphite, MgS, condensed on carbon grains of dust.

1.2.3. Spectral features in the UV range

One of the PPNe puzzles is the combination of the large IR excess with the object bright enough in the visible and UV regions. Despite the large amount of dust around PPN candidates, no essential absorption is observed in the UV and visible wavelength ranges. For instance, for HD 44179 the ratio of the UV luminosity to the optical luminosity is large, about 33 (Leinert, Haas, 1989), the colour excess therewith is as low as $E(B-V) = 0.4$, which can be explained according to Waelkens et al. (1996) by the geometry of a binary system surrounded by a gaseous–dust disk.

The energy distribution in the UV spectra of IRAS objects does not show, as a rule, any peculiarities which could point to the presence of hot companions or considerable reddening. In this sense the energy distribution in the spectrum of the supergiant HD 161796 having a large IR excess (Parthasarathy & Pottash, 1986) and possessing no distortions in the visible and UV ranges is typical (Humphreys & Ney, 1974; Parthasarathy et al., 1988). The distribution of energy in its spectrum is suggestive of a small deficiency of metals in the atmosphere, which is confirmed well by the data of the chemical composition of HD 161796 (Luck et al., 1990, see also Table 1 of this paper).

In a general case the absence of considerable absorption in the UV can be explained by the fact that the dust envelope is spatially separated from the central star and has an insignificant effect on its radiation.

In a number of supergiants unusual spectral details in the UV region have been observed. For instance, in the IUE spectrum of the supergiant HD 187885 Parthasarathy et al. (1987) have found an intensive broad absorption line of about 1657 Å (C I or C_2) and the emission line N IV, 1487 Å.

High resolution UV spectra (IUE) near the chromospheric lines Mg II 2800 Å obtained for a sample of high–latitude supergiants have signs of stellar wind and mass loss. These objects are weak for IUE, that is why the spectra are noisy. Emission profiles of P Cyg type and extended absorptions shifted towards short wavelengths have been found, which is indicative of matter loss. The velocity may reach 200–300 km/s. The results obtained by Bakker et al. (1996a) for the peculiar supergiant HD 101584 from the IUE high and low spectral resolution spectra may be an example.

The UV monitoring has revealed in 89 Her an 80-day variability of the Mg II profiles (photometric cycle about 65 days), which confirms the effect the pulsations have on the process (rate) of mass loss (Dupree, 1993).

1.2.4. Spectral peculiarities in the radio wavelength range

Observations of PPNe in the radio range have provided a wealth of information about the physical conditions in circumstellar envelopes. It is of importance that objects with high (interstellar and circumstellar) absorption in the optical range, including objects in the galactic plane, are observable by radio methods. Radio observations in molecular bands (thermal radiation of the molecules CO, SiO, H_2O in the centimeter range and nonthermal maser radiation of OH, H_2O, SiO) point to the presence of huge, frequently bipolar, molecular envelopes in a lot of post–AGBs (Likkel et al., 1987, 1991; Likkel, 1989; Trams et. al., 1990; te Lintel Hekkert, 1991; te Lintel Hekkert, Chapman, 1996; te Lintel Hekkert et al., 1992; Van der Veen et al., 1993; Engels & Lewis, 1996). The non–thermal character of emissions in the radio wavelength range follows from comparison of the brightness temperature (usually $\leq 10^8$ K) and line widths, which point to the kinetic temperature $T \approx 100$ K. The powerful maser radiation is an effective means for the study of circumstellar envelopes, which permits the detailed spatial structure to be revealed and even molecular envelopes in other galaxies to be observed (Wood et al., 1986).

The existence of molecular envelopes and their optical thickness is determined by the mass loss rate at AGB–stage and by the rate of following evolution.

Prior to the IRAS observations, the existence of an expanding envelope was the principal distinguishing characteristic of a post–AGB star. Objects with OH emission are likely to essentially differ from objects with close IRAS parameters, but with no OH emission (Likkel, 1989). For quite a few IRAS sources a variability of OH profiles has been revealed (te Lintel Hekkert, Chapman, 1996), which may be due to temporal variable interaction between the stellar wind and the circumstellar dust (Balick et al., 1987), to mass transfer in a binary system (Waelkens, 1995). Besides, as noted by te Lintel Hekkert and Chapman (1996), the dynamic and geometric conditions in the system may be modulated by the star's magnetic field, which will involve variation of the OH profile.

The CO lines in the millimeter range, along with the IR data, are widely used to study the history of mass loss (Omont, 1996) owing to the interrelation of the intensity of these lines and the mass loss rate.

The total widths of the CO profiles reach 300 km/s. On the CO profile discrete peaks are occasionally observed, which are suggestive, for example, of repeat events of matter dredge–up (Trams et al., 1990).

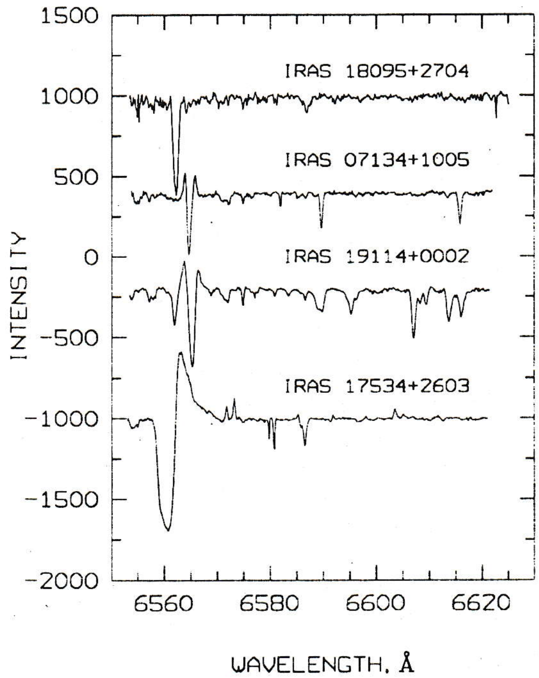

Figure 2: *Comparison of the spectra of some PPNe near* H_α.

1.2.5. Spectral peculiarities in the optical spectra

If a post AGB star, a PPN candidate, is observed in the optical range, it cannot at once be distinguished from an ordinary massive supergiant. Most frequently this star is of spectral class F (Waelkens et al., 1989), however, there are objects of earlier spectral classes. For instance, McCausland et al. (1992) investigated hot (11000–27000 K) post–AGB stars at high galactic latitudes. With the application of MK–classification criteria a very high absolute luminosity of these objects is obtained — luminosity classes Ia, b, II, $-7 < M_V < -5$. However, such a high absolute luminosity obtained with the MK–classification criteria points only to a low value of $\log g$ in the atmosphere (or pseudophotosphere) of a star, and objects at high galactic latitudes are generally not massive supergiants. For a number of stars the high luminosity follows from the distribution of energy in the optical range as well.

The spectrum of a PPN is distinguished from the spectra of classical supergiants basically by the anomalous behaviour of the line profiles (H I, Na I, He I) and, first of all, of the neutral hydrogen H_α line, which is also observed in low spectral resolution spectra. The presence of H_α emission, along with the IR excesses, is the main criterion for the selection of PPN candidates. In the spectra of typical PPNe the H_α line has composite (emission + absorption) variable profiles with asymmetry of the core, P Cyg or inverse P Cyg type profiles, profiles with emission asymmetric wings. It is not infrequent that a combination of such details is also observed. The H_α emission profile is known to be a sign of matter outflow processes and/or pulsations. The shift of the core is, as a rule, smaller than that corresponding to escape velocity, i.e. we can speak rather about the outflow (expansion) of the outer layers of the extended atmosphere than about the wind (Dupree, 1993). To illustrate the variety of the profiles, in Fig. 2 are displayed some H_α profiles we have obtained in the course of fulfilment of the spectroscopic programme at the 6 m telescope. The differences in the shape of the H_α profiles are caused by the differences in dynamic processes that occur in the extended atmospheres of individual PPN candidates: spherically symmetric outflow at a constant rate or variable with height in the atmosphere, accretion of matter onto the photosphere, pulsations. The peculiarity of the PPN spectra also manifests itself in that the spectral features of an F–K class supergiant are not uncommonly combined in them with numerous absorptions of molecules. For instance, in the spectrum of HD 56126 with $T_{eff} > 6500$ K Bakker et al. (1996a) have identified the bands of the Phillips, Swan system of the C_2 molecule and of the red system of the CN molecule, which, in the opinion of those authors, are formed in the envelope, in a confined region closest to the star. A comparison of the envelope expansion velocity determined from the C_2 and CN lines with this parameter from CO observations will make it possible to trace the process of mass loss by the star at the AGB stage.

Klochkova et al. (1997c) have detected **emission** features in the optical spectrum of the source IRAS 04296+3429 taken with the echelle spectrometer of the 6 m telescope and identified with bands (0.0) and (1.0) of the Swan system of the C_2 molecule. Similar spectral features (but with a different intensity ratio) we have also revealed with the same spectral devices in the core of the Hale–Bopp comet (Fig. 3). The detected analogy has enabled Klochkova et al. (1997c) to conclude resonance fluorescence to be a mechanism that excites emission of the two objects in the molecular bands indicated.

When analyzing the spectra of the variable supergiant with an IR excess, IRAS 07331+0021, for the different phases of the light curve, Klochkova and Panchuk (1996) have obtained for the "cool" phase the effective temperature $T_{eff} = 4100$ K from the neutral iron lines and $T_{eff} = 3500$ K from the α–system spectrum of the TiO molecule. The authors have proposed a number of likely explanations to this discrepancy: the upset of the dissociative equilibrium in the upper layers where the TiO bands are formed: underestimation of blanketing in the upper layers of the used model atmosphere, which leads to overestimation of temperature in these layers; large–scale inhomogeneity of the flux over the star's surface.

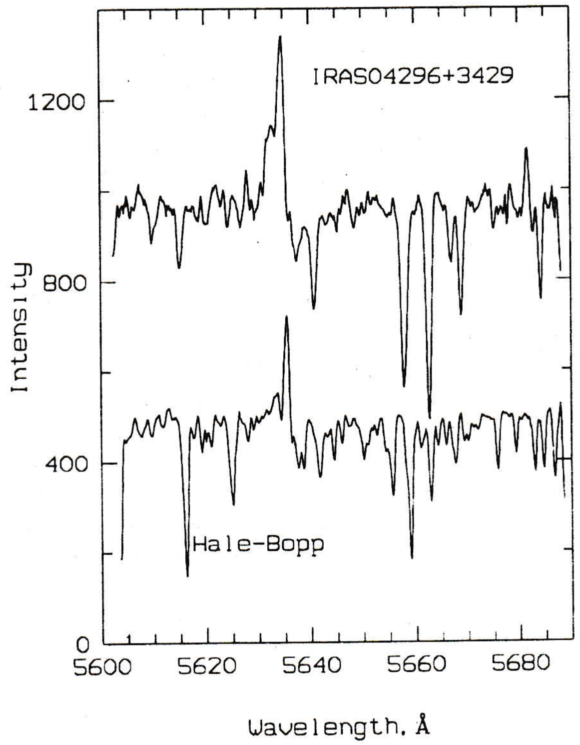

Figure 3: *Comparison of the spectra of PPN IRAS 04296+3429 and Hale-Bopp comet nuclei near head band C − 2 (figure is borrowed from the paper of Klochkova et al., (1997c).*

1.2.6. Binarity, pulsations

A considerable part of PPN candidates demonstrate a variability of the radial velocity V_r (Waelkens and Waters, 1993; Waelkens et al., 1993; Waters et al., 1993) with a characteristic time of the process of several hundreds of days, which may suggest their binarity. Indeed, for several optically bright objects with IR excesses conclusive evidence of orbital motion has been found. For example, the binarity has been proved, elements of the orbit have been determined and a model of a system for the high-latitude supergiants 89 Her (Ferro, 1984; Waters et al., 1993) and HR 4049 (Waelkens et al., 1991b) has been proposed. Van Winkel et al. (1995) have shown the stars HR 4049, HD 44179, surrounded by the Red Rectangle nebula, and HD 52961 to be spectral binaries with an orbital period of about 1–2 years. These authors conclude that all the investigated extremal metal-deficient PPN candidates (HR 4049, HD 441179, HD 52961, HD 46703, BD 39°4926) are binaries.

The nature of the companion for the post–AGB stars, suspected to be binaries, is so far unknown for lack of its manifestations in the continuum and spectral lines, all the known binaries among post–AGBs are SB1. This may be either a very hot object or a very low luminosity object on the main sequence, a white dwarf, as in the case of Ba II stars (McClure, 1984), cannot be excluded.

The observed correlation between the binarity and the presence of a dust envelope (Waters et al., 1991) suggests that the binarity favours the formation of an envelope.

The temporal variability of the H_α profiles is significant: for months the intensity ratio of the emission components in the wings of H_α may change to reverse. In Fig. 4 is shown the variation of the H_α profile in the spectrum of one of the IR sources, IRAS 07331+0021 (Klochkova & Panchuk, 1996). However, the character of V_r variability is not always consistent with the hypothesis of binarity. For example, for some objects periodic (and quasiperiodic) V_r variations are observed, which are apparently due to pulsations. The pulsation instability is inherent in many objects at the post–AGB stage, this follows already from the fact of their location in the instability band on the Hertzsprung–Russel diagram.

A similar variability of the H_α profiles is observed in the spectra of yellow pulsating supergiants — RV Tau and W Vir types stars. For the given types of objects the H_α profile variability is due to the propagation of a shock wave in an extended atmosphere of a pulsating star (Lebre & Gillet, 1991, 1992; Fokin & Gillet, 1994; Gillet et al., 1994). Pulsation peculiar to many post–AGB objects may facilitate mass loss

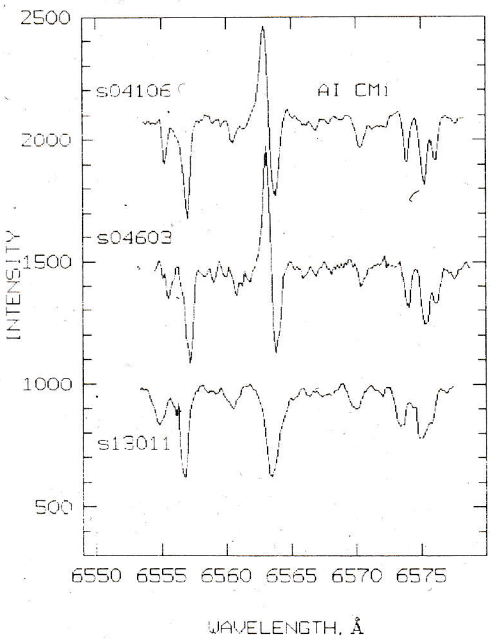

Figure 4: *The spectrum of the infrared source IRAS 07331+0021 (AI CMi) near the* H_α *for different observing moments (for details see Klochkova, Panchuk, 1996).*

by heating and expanding the atmosphere. Note that RV Tau type objects are also post–AGB objects, but, as Jura (1986) has emphasized, these "lazy" (called by Jura) stars are likely to be the least massive, which results in their slow evolution, and they will never become PNe. Their low–dispersion spectra are like those of carbon stars. The observed fact of O–rich envelopes in C–rich stars of RV Tau type is a puzzle (Kwok, 1993). Several sufficiently bright RV Tau type stars we have included into the spectroscope programme at the 6 m telescope to obtain a detailed chemical composition pattern.

The H_α variability is naturally explained for post–AGB stars with the signs of binarity and mass loss (HR 4049): in such systems the H_α profile changes because of the orbital motion in the system. However, in the case of post-AGB objects H_α varies also for those of them for which no signs of V_r and brightness variability have been revealed (HD 133656, van Winkel et al., 1996a). The brightness variability would allow a shock–wave mechanism to be involved as in RV Tau stars for which a probable mechanism stimulating outflow of matter is dissipation of shock waves in the atmosphere. Convection in envelopes gives rise to a flux of mechanical energy to the chromosphere and corona. The pressure of radiation upon grains can also provide the conditions necessary for material loss. For the radiative mechanism of initiation of the wind, which is effective in the case of hot massive supergiants, the radiation flux in post–AGBs is insufficient.

The variability pattern of V_r caused by the binarity is not infrequently complicated by differential motions in the extended atmospheres of the objects under study. A detailed analysis of V_r made from high spectral and temporal resolution spectra for the selected, brightest PPNe has allowed the differential behaviour of the V_r derived from lines of different excitation, which are formed at different depths in the atmosphere of a star, to be detected. For instance, Bakker et al. (1996a) have revealed in the spectrum of the IRAS source, identified with the peculiar supergiant HD 101584, 8 categories of spectral lines for which the temporal behaviour of the profiles, widths and shifts (hence V_r values) is essentially different. In particular, most highly excited UV absorptions which are formed in the photosphere of the star, show the variability caused by the orbital motion in the binary system. At the same time the low excitation lines with the P Cyg profiles are formed in the stellar wind region and represent outflow of matter. The velocity of the system has been surely determined from radio emissions of the CO and OH molecules.

A similar complex dynamic state of the atmosphere is observed in the case of the unique object IRC+10420 (IRAS 19244+1115) studied from the spectra obtained at the 6 m telescope (Klochkova et al., 1997a). The spectrum of IRC+10420 contains numerous absorptions formed in the photosphere layers, which are immovable with respect to the star's mass centre and emissions formed in the expanding envelope. The velocity of the centre of mass we have obtained is 60–66 km/s from a set of "pure" absorption and emission details, which is consistent with a velocity value, 61–65 km/s derived by other authors (Jones et al., 1993; Oudmaijer, 1995). From the shifts of the absorption components of P Cyg type profiles with respect to the emission components the envelope expansion velocity is about 40–50 km/s, which is in a good agreement with the data of Oudmaijer et al. (1996) obtained in the radio wavelength range from the line profiles of the CO molecule and with the expansion velocity values obtained from the widths of forbidden emission lines and reported by Klochkova et al. (1997a).

Examination of the radial velocity variability of the object IRAS 07134+1005, one of a few post–AGB objects in the atmospheres of which the products of the 3-d dredge–up have been revealed (Klochkova, 1995a), is of importance. From a comparison of the available IRAS 07134+1005 radial velocity data with the 6 m telescope results we have obtained, a variability of its radial velocity has been suspected (Klochkova, 1995a). Later Lebre et al. (1996) have carried out a detailed spectral monitoring of IRAS 07134+1005. On the basis of the Fourier analysis of a collection of radial velocity data with the brightness variability data involved, those authors have drawn a conclusion about the similarity of the dynamic state of the IRAS 07134+1005 and the pattern peculiar to pulsating variables of RV Tau type. The H_α variability is interpreted by them as a result of shock wave propagation. From a large collection of spectrograms with a high temporal resolution and S/N ratio Oudmaijer & Bakker (1994) have also analyzed the V_r variability of this object and concluded that the object is variable on a scale of several months and has no variations with a characteristic time of minutes–hours. It is obvious that the complex dynamic state similar to that observed in the atmosphere of the objects HD 101584 or IRC+10420 is caused by a recent or continuing process of matter loss and is therefore inherent in those PPNe with the emission component of the H_α profile which have large IR excesses (especially in the near IR range). For the peculiar supergiant UU Her without apparent excess of the IR flux, no V_r gradient in the atmosphere has been found from the 6 m telescope spectra (Klochkova et al., 1997b), however, oscillations of V_r with an amplitude of about 15 km/s have been revealed.

The possible binarity of PPNe is a key point for interpreting peculiarities of their chemical composition since the prevailing hypothesis for explanation of anomalous chemical composition is the formation of a circumstellar envelope (disk) in a binary system (Trams et al., 1993) and subsequent selective fractioning of chemical elements. The presence of a companion is required only for stimulation of the process of mass loss by the primary star, therefore the nature of the companion (its mass and evolutionary stage) is not crucial.

2. Spectroscopy of PPNe at the BTA

The programme of spectral observations of supergiants with large IR excesses is a part of a more general project of spectroscopic study of stars at advanced evolutionary stages that has been carried out at the 6 m telescope for the last decade. The aim of this project is a comparative analysis of details of chemical composition of stellar atmospheres at successive phases of evolution of stars of different masses (see e.g. Klochkova, 1991, and references therein). As a result of such a comparison one can detect in the outer layers of stellar atmospheres the products of nuclear reactions produced at the preceding stages of evolution and dredged up to the surface layers, which is necessary for specification of the current knowledge about the evolution of stars at the advanced stages.

Using the 6 m telescope, since 1982 we have been carrying out a programme of spectroscopy of stars belonging to different types of Galaxy populations and observed at different stages of nuclear evolution. These were normal B, A, F stars, members of open clusters and stellar associations of the Galaxy; massive supergiants, members of open clusters; classical cepheids of the disk; stars of the red, blue and extended parts of the horizontal branch of globular clusters (in the field of the Galaxy and inside globular clusters); metal–deficient red giants, members of globular clusters and their analogs in the Galaxy field; peculiar supergiants at high galactic latitudes (UU Her type stars); pulsating halo cepheids (stars of W Vir type). In the course of fulfilment of these programmes we adhered to two main principles: firstly, for each type of stars a representative sample of objects was examined, secondly, comparison was made of the obtained results on chemical composition with those for stars at other evolutionary stages. For instance, when comparing the mean chemical composition of a representative group of disk A stars and a sample of halo A stars (members of the blue part of the horizontal branch), one can hold to a minimum the influence of systematic temperature effects (the mean T_{eff} values for the two groups are practically the same). Or, when comparing the chemical composition of F supergiants at high galactic latitudes and F supergiants, members of open clusters, one can rid the results of differential determination of chemical composition of the effects of luminosity.

Since 1994, spectroscopy of candidates for proto-planetary nebulae, i.e. stars with large IR excesses, assumingly at the post–asymptotic giant branch, has been the central goal of our programme. First of all the programme is directed towards the study of the fundamental problem of stellar evolution associated with the investigation of nuclear synthesis of chemical elements in the interior of low- and medium mass stars (under 8–9 solar masses). At the final evolutionary stages these stars supply the interstellar medium with matter enriched in heavy elements. That is why the programme bears a direct relationship to other fundamental problems of astrophysics — origin of chemical elements in the Universe and chemical evolution of matter in the Galaxy.

The detection of chemical composition anomalies of stars at the evolutionary stages "asymptotic giant branch" and "post–asymptotic giant branch" is our basic area of research within the programme mentioned. It is known (Iben & Renzini, 1983) that at these stages two sources of energy release are operative in the envelopes of stars: helium and hydrogen burning in the shells surrounding a degenerate carbon–oxygen core. Most of the time the energy release is provided by the hydrogen layer, however at certain moments, as the hydrogen burning products add the helium shell, a short–time helium ignition occurs in it. At this point the hydrogen burning in the hydrogen convective shell ceases. This structure of a star is unstable and the theory predicts a sufficiently effective mixing and dredge–up of matter (through the penetration of convection), altered in nuclear reactions which accompany the processes of energy production mentioned, into the atmosphere of a star. The dredge–up of matter caused by multiple change of energetically active layers is customarily called a third dredge–up (see for details, for example, Smith & Lambert, 1990).

For stars with a sufficiently massive core ($\approx 0.96\,M_\odot$) about 1/3 of matter altered in the core may be dredged–up to the surface. In rapid transition to the phase of a white dwarf (with a mass no larger than 1.4 of solar) these stars (having an initial mass of $8-9\,M_\odot$) lose matter of the envelope, delivering into the interstellar medium material enriched in elements synthesized in the processes of thermonuclear burning and neutronization reactions.

Thus, these stars are the only supplier of all nuclei of heavy elements produced in the reactions of electron capture at a low density of electron flux, which are observed in the Universe.

The investigations of IRAS sources were initiated in the early 1990s by the author at the 6 m telescope of SAO and by a group of European astronomers at the 1.4 m telescope of ESO. It goes without saying that we were able to observe fainter objects, i.e. with a higher circumstellar extinction, i.e. with a higher (on the average) mass loss rate. As a result of the observations and their analysis, the first objects were detected that demonstrated in their atmospheres material having undergone the neutronization phase in the interiors of a given star. Judging by the number of investigated objects of this type (and by the number of reveals of changed chemical composition) SAO is the leader. More than half of the detections of chemical abundance changes of both light and heavy s–process elements have still been made in these objects with the 6 m telescope by the high resolution spectroscopy technique with the use of model atmospheres (Klochkova, 1995a; Klochkova & Panchuk, 1996; Začs et al., 1995, 1996; Klochkova et al., 1997c).

Spectral material of high accuracy is also used along with the study of chemical composition for the detailed analysis of the velocity field in the atmospheres of these stars with mass loss, which represents a separate astrophysical problem.

2.1. Observations

In the frames of the programme of investigation of PPNe we have managed to obtain observational data for a number of IRAS sources identified with sufficiently bright in the optical range supergiants. In Table 1 are listed the numbers of the objects in the IRAS catalogue, the name of the star (or the number in the HD catalogue), the spectral class, the apparent V magnitude, main parameters of the atmosphere model (effective temperature, surface gravity), and the metallicity with respect to solar.

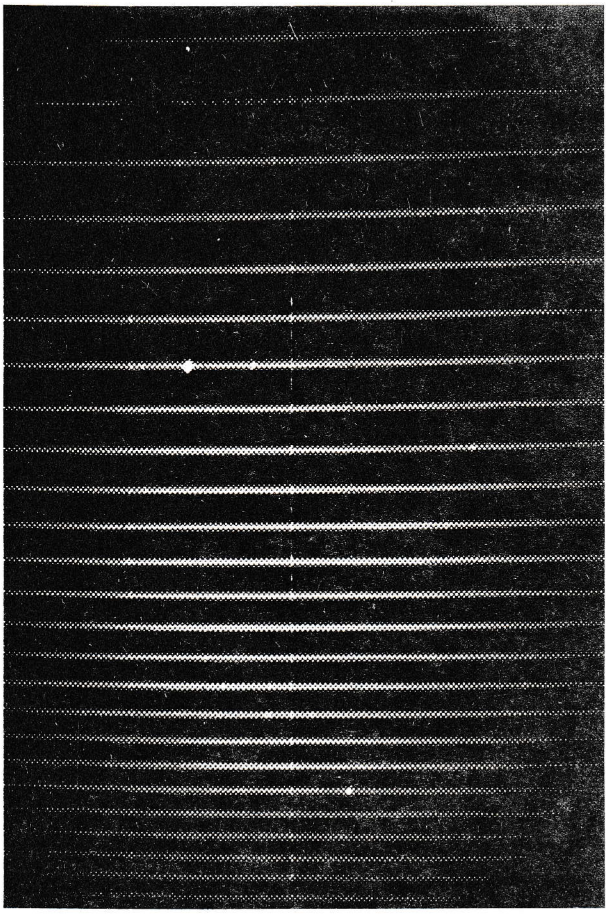

Figure 5: *Spectrum in the interval from* $\lambda\,4330$ Å *to* $\lambda\,8300$ Å *of the source IRAS 18062+2410 we obtained with the echelle-spectrometer PFES. The most strong emission line is* H_α.

Observations were obtained with the 6 m telescope, at the Nasmyth–2 focus. The echelle spectrometer LYNX was used (Klochkova, 1995b) in conjunction with a CCD of 1040 × 1170 pixels developed by the Advanced Designs Laboratory (ADL) of SAO RAS. For each star at least two spectra were taken with the spectral resolution R = 24000 and a signal–to–noise ratio higher than 100 in the wavelength range 4700–7200 or 5200–8800 Å. Since 1996, the echelle spectrometer PFES (Panchuk et al., 1998) placed at the BTA prime focus has been used to observe the faintest programme objects ($V > 12^m$). For the objects as bright as $V \leq 14.5^m$ the device ensures the $S/N \approx 100$ wanted for our purpose with a spectral resolution $R \approx 15000$.

For illustration in Fig. 5 is presented a copy of the echelle frame for one of the programme objects, IRAS 18062+2410, identified with the peculiar supergiant HDE 341617 (b = 20°). Arkhipova et al. (1996) have come to the conclusion that the apparent brightness of this supergiant has decreased by 1.5^m as compared with the first half of our century and that the present–day spectral class value (B5I) is inconsistent with the value A5 available in the HDE catalogue. The same authors have revealed this object to have a photometric variability from night to night with an amplitude of up to 0.3^m in the V band.

During the first years of the observations the software package LIMA (in the environment DOS + WINDOWS) developed by I.V. Afanasieva in the ADL of SAO RAS was used. Since March 1996 the observations have been carried out in the environment OS Linux with the application of the NICE context (Knyazev & Shergin, 1995) of the MIDAS–ESO system (version NOV 95).

To select in the spectra the lines of the telluric spectrum, on every observing night we obtained an echelle spectrum of a fast–rotating star. The quality of spectra of the programme stars allowed us to measure the equivalent widths, W, with an accuracy of 2–4 mÅ, which is consistent with the accuracy estimates made by Cayrel's formula (Cayrel de Strobel, 1985).

2.2. Spectral data reduction and analysis techniques

For the processing of two–dimensional echelle images (summation and averaging of spectra, cosmic particle traces removal, dark–frame subtraction, extraction of echelle orders, linearization of spectra) the context ECHELLE of the MIDAS system in the environment OS Linux was used. To measure the characteristics of individual spectral details (equivalent widths W, radial velocities V_r, profiles), the software DECH (Galazutdinov, 1992) in the environment Linux in combination with the DOS emulator was used.

For determination of the main parameters of the model atmospheres, effective temperature T_{eff}, surface gravity log g, and for the computation of chemical composition the grids of Kurucz's (1979, 1993) and Bell et al's. (1976) models were applied. The details of the procedures we have used in determining the parameters T_{eff}, log g and microturbulent velocity ξ, as well as the errors of the obtained chemical element abundances, which were caused by inaccuracies of model approximation and by errors in the choice of model parameters and equivalent widths measurement, are presented in the papers by Klochkova (1995a) and Začs et al. (1995).

3. Chemical composition

For more certain conclusions concerning the relation between peculiarities of chemical composition and binarity of the objects, repeated spectral observations are needed. Because of the obvious inhomogeneity of chemical composition of the objects, it is important to obtain it for large sample of objects so that the principal trends and relations can be revealed. This makes the problem of observations still more complicated. Accurate high resolution spectral observations are presently available only for the brightest PPNe, their observations baving been performed with CCD–equipped echelle spectrometers at large telescopes. A low metallicity (10–100000 times as low as solar) and non–typical proportions of abundances of other elements have been obtained for these objects.

In the course of hydrogen burning in the core and then in the shell the helium abundance increases. At the advanced stages of evolution of a star, after the AGB stage, when the process of the 3-d dredge–up terminated, and after departure of the hydrogen envelope the layers enriched in altered matter became uncovered, the helium abundance might be expected to essentially enhance. In the spectra of two best studied stars (HR 4049, HD 44179) helium lines were detected, which allowed its abundance to be estimated. For HD 44179, the central star of the nebula Red Rectangle, Waelkens et al. (1992) have obtained helium abundance slightly higher than the solar value. A nearly solar helium abundance (within the errors) has been obtained for the extremely metal–poor object HD 4049 (Waelkens et al., 1991a). Conlon et al. (1992) have obtained a normal helium abundance for the sample of hot post–AGB stars with T_{eff} of 11000–27000 K. This is especially important since for such an advanced stage of evolution an essential proportion of hydrogen was expected to be replaced by helium. So far only one of the PPN candidates, the star HD 187885 investigated by Van Winkel et al. (1996a), has helium excess.

For most of the PPN candidates studied interrelation of the CNO–group element changed in the course of their evolution is observed, the C/O ratio is varied from C/O < 1 to C/O > 1 (Luck et al., 1983; Bond & Luck, 1987; Lambert et al., 1988; Klochkova, 1995; Začs et al., 1995, 1996; Van Winckel et al., 1996a, 1996b; Van Winckel, 1997). Analysis of the behaviour of different chemical elements (Fe, CNO, S, Zn, s– and r–process elements) for the complete sample of the investigated PPN candidates shows that by chemical composition they should, apparently, be divided into two types: stars with an extremely low metallicity, $[Fe/H]_{\odot} < -4$ dex, are attributed to the first type, stars with a less pronounced metal deficiency — to the second. The most likely and effective mechanism that has produced the anomalous chemical composition in the case of extremely metal–poor stars studied is not the nucleosynthesis but the processes of chemical separation of elements in the gaseous–dust envelope.

In the case of a single post–AGB star the gaseous–dust envelope may have been created by a slow stellar wind at the AGB stage. Grains of dust may be accelerated outwards by the radial pressure, absorbing radiation. At the same time gas with the altered chemical abundance patterns may fall back onto the surface since, because of the great distance from the star to the inner boundary of the gaseous–dust envelope, its gaseous component is staying in a neutral state, that is why there is no significant absorption (no active absorbers — singly ionized metal atoms) of optical radiation of a star.

The existence of dust grains and processes of condensation is hard to assume under the condition of stellar photospheres, these processes are most likely to occur in the circumstellar envelopes. However Whitney et al. (1992) have shown the formation of dust near the photospheric layers to be possible in the case of R CrB type stars. The main arguments: amorphous graphites may be formed at 4000 K, condensation of dust may occur due to departure from thermal equilibrium.

Bond (1991) has first proposed a scenario of selective separation and subsequent reaccretion for a single star, assuming that dust is formed in its atmosphere. The main reason is the dependence of the element abundance on the temperature of condensation in dust grains (Bond, 1992). The abundance of Fe, Mg, Si, Ca in its atmosphere is decreased by a few orders of magnitude, while CNO, S and even an iron group element, Zn, have the solar abundances (Waelkens et al., 1991a, 1992, 1996; Van Winckel et al., 1992). It should be noted that this picture is similar to chemical abundance behaviour in the gaseous component of ISM.

Currently one more group of stars is known: the stars of λ Boo type (Veen, Lambert, 1990) in the atmospheres of which anomalies are observed that may also arise through selective separation into dust particles. A young λ Boo type star may be surrounded by dust as a remnant of protostellar material the star has been formed from.

It is obvious the star's atmosphere must be stable enough, so that the mixing of the stellar wind would not disturb the picture of distribution of chemical elements. However there is evidence that the atmospheres of post–AGB stars are not as stable: for most of these objects pulsations and outflow of matter have been noted, which manifests itself in the presence of variable H_α emission.

Models have been proposed of formation of stars with a chemical composition modulated by selective separation on grains of dust through accretion in a binary system. Mathis and Lamers (1992) have considered a case of formation of the envelope of a star through interception of matter being lost by the companion as a strong, up to $10^{-4} M_\odot$/year, wind. They have shown that as low as $10^{-6} M_\odot$ of "purified" gas is enough to ensure the selective depletion observed in the atmosphere. The main problem of this scenario is the low probability of the configuration (post–AGB + AGB). At the same time, 100–1000 years ago the two stars have to be at the AGB stage. Waters et al. (1992), and Trams et al. (1993) have suggested that the presence of a companion is needed only to stimulate the process of mass loss in a primary (AGB) star. In such a model the accretion of matter may be varied depending on the location of the primary in the orbit (if the eccentricity is not equal to zero). It is important that this model is valid only to some stars (the stars must be binaries with fitted parameters of the orbit), which ensures the low occurrence of post-AGBs with high deficiency and anomalous chemical composition. As is noted by Waters et al. (1992), analogous processes of separation in the gaseous–dust circumstellar envelopes may occur in the case of λ Boo stars. However the selective depletion of the atmosphere is less effective for these stars than for post–AGB stars. The differences may be caused, for instance, by the differences in duration of the processes for these two types of objects.

It is apparent that from the point of view of studying the stellar nucleosynthesis and mixing processes, the PPN candidates, having a moderate metal deficiency, appear the most attractive, in this case the chemical abundance pattern is likely to be not significant distorted by the processes of separation.

3.1. Abundances of s–process elements

As a whole, based on the sample of PPN candidates we have studied, and on the data available in literature, their chemical composition can be stated to be inhomogeneous. Now we present the most important inferences we have made for individual investigated objects (see Table 2 and 3).

In particular, from the 6 m telescope spectra for the metal–poor ($[Fe/H]_\odot = -1.0$) supergiant IRAS 07143+1005, we (Klochkova, 1995a) have reliably revealed excess (relative to metallicity) of heavy metals synthesized in the processes of neutronization (Y, Zr, Ba, La, Nd). Along with excess of heavy metals, very large (over an order of magnitude) excesses of CNO–group elements were found. Thus, from the collection of parameters the source IRAS 07143+1005 is a classical representative of post-AGB stars. The fact of excess of s–process elements in the atmosphere of IRAS 07143+1005 had repercussions among astrophysicists concerned with stellar evolution since the excess of s–process elements expected for post

AGB stars as a consequence of previous evolution of a star and a third dredge–up has been observed very rarely. For example, we (Klochkova, 1995a) have not revealed excess of s–process elements for the IR source IRAS 18095+2704, which is called an excellent PPN candidate by all its observational characteristics (Hrivnak et al., 1988).

Later we (Začs et al., 1995) have revealed reliable excesses of carbon, oxygen and heavy metals in the atmosphere of the cool supergiant SAO 34504, which is associated with the IR source IRAS 2272+5435. Our "spectroscopic" value for the effective temperature of SAO 34504 is in a good agreement with the result obtained by Szczerba et al. (1997) by modelling the energy distribution. From the radial velocity value $V_r \approx 40$ km/s and the slight decrease in metallicity as compared to the solar value $[Fe/H]_{\odot} \approx -0.5$ dex we refer this object to the population of the old disk.

Začs et al. (1996) have drawn less certain conclusions for the source IRAS 19114+0002 identified with the bright star HD 179821, which is classified by the spectrum as a high–luminosity object with uncertain (or variable) spectral class: F8Ib (Volk & Kwok, 1989) and G5Ia (Kwok, 1993); with signs of mass loss and presence of an envelope expanding at a velocity of 30 km/s (Van der Veen et al., 1993). Based on the analysis of the spectrum of HD 179821 by the model atmosphere method, in the paper by Začs et al. (1996) two sets of parameters of the model were obtained which led to two essentially different values of metallicity and chemical element abundances. The low value of temperature, $T_{eff} = 5000$ K leads to the version of metal–poor star, which is in good agreement with the high radial velocity of the object: $V_r \approx 90$ km/s (Začs et al., 1996). Therewith the s–process elements have been found to be considerably underabundant. It is obvious that in order to draw unambiguous conclusions concerning metallicity, chemical composition and evolutionary status of the given object, independent estimates of T_{eff} should be involved. For HD 179821 Van der Veen et al. (1994) have estimated $T_{eff} = 5000$ K by modelling the observed integral flux in the optical range. Thus, for HD 179821 the low temperature value can be considered more reliable, hence the star has the status of a low–mass supergiant with decreased metallicity and overdeficiency of the s–process elements.

Thus, by the present time excess of s–process elements has been reliably found in three objects investigated at BTA: IRAS 04296+3429, IRAS 07134+1005 and IRAS 22272+5435. Besides, similar conclusions have appeared for another two PPN candidates: HD 158616 (Van Winckel et al., 1995) and IRAS 19500-1709 = HD 187885 (Van Winckel, 1997).

In the atmospheres of PPN candidates overdeficiency (with respect to their metallicity) of heavy nuclei is generally observed (Klochkova, 1995a; Van Winckel et al., 1996a, 1996b; Klochkova & Panchuk, 1996; Van Winckel, 1997), whose existence in the atmospheres of post–AGB low–mass supergiants has not yet found an unambiguous explanation. Luck & Bond (1989) have considered a number of physical (hydrogen underabundance in the atmospheres; overionization of atoms having a low potential of the second ionization) and methodical (errors in parameters) effects which could explain the observed overdeficiency of the s–process elements in the atmospheres of low–mass supergiants. But none of the proposed explanations is consistent with the full pattern of chemical composition of these objects.

3.2. The problem of UU Her type supergiants

The programme of spectroscopy of PPNe at the BTA includes the peculiar supergiant UU Her, which has served as a prototype for selection of a new type of semi–regular variable stars (Sasselov, 1984). As a rule, supergiants of UU Her type are located at high galactic latitudes and have spatial velocities typical of the halo population. These objects may be both young massive stars that have recently been formed at high latitudes and old low–mass stars advanced in the course of evolution as far as the post–AGB stage. Our results for UU Her have not removed contradictions of the situation since for this metal–poor object ($[Fe/H] = -1.32$ from our data) we have obtained excess only for nitrogen, while carbon and the s–process elements in the atmosphere of UU Her are essentially underabundant.

We have thus detected the manifestation of only the first episode of mixing and dredge–up of matter to the surface. From a set of properties (high luminosity, radial velocity value typical of the halo, chemical abundance pattern) the object has been concluded to belong to low–mass halo stars but its belonging to post–AGB stage has been called in question. It is likely that in the paper of Van Winckel (1997) an object very close to UU Her in its set of characteristics is examined — the supergiant HD 107369 having a high galactic latitude ($b = +30°$) and a radial velocity typical of old populations of the Galaxy. This object, being in a number of characteristics close to post–AGB stars, has no IR excess and third dredge-up signs, as in UU Her.

The predecessor of the variable star UU Her may be assumed to have a mass lower than $2 - 2.3\,M_{\odot}$ on the MS. A star of such an initial mass, at the AGB stage, has a low-mass core and does not provide in the core a temperature ($T \approx 3 \cdot 10^8$ K) necessary for the reaction $^{22}Ne(\alpha, n)^{25}Mg$, which is the main provider of neutrons. This reaction occurs in cores of $M > 0.95\,M_{\odot}$. However one should bear in mind that there exists an alternative process: $^{13}C(\alpha, n)^{16}O$ that occurs at a lower temperature ($T \approx 10^8$ K), and can, in principle, ensure a neutron flux for synthesis of heavy metals.

The hypothesis on the low initial mass of UU Her is confirmed by the absence of IR excess in this star and hence the dust envelope, which even in the event of being at the AGB, has had time to dissipate because of the slowed–down evolution of the object. This star is likely to belong to "lazy" post-AGB stars that evolve ten times as slow (Schönberner, 1983). The rate of evolution at the post-AGB is determined by the mass of the core, the dependence being very strong: a core of 0.565 $M_\odot$ evolves about an order of magnitude faster than of 0.546 $M_\odot$!

Several years ago Klochkova and Panchuk (1988, 1989, 1992) examined a sample of peculiar supergiants at high galactic latitudes (UU Her type stars), which, by the set of their characteristics, are with high probability old objects at the post–AGB stage and for which we also obtained a significant underabundance of s–process elements. As previously, we (Klochkova & Panchuk, 1992) are apt to consider the observed underabundance of heavy nuclei to be real and explain it by the absence of results of the third dredge–up products. It is most likely that because of the low mass of the star its mass loss rate at the AGB stage was insufficient for the uncovering of the surface layers with the chemical composition changed in the course of evolution. This assumption is also confirmed by the low carbon abundance in the atmosphere of UU Her.

Having studied a sample of post–AGB stars it can be assumed that the abundance of s–process elements depends on the detailed evolution at the post–AGB stage, which, in turn, is determined by the initial mass of a star since it is the mass that has an effect on the pulsation activity and mass loss rate. It can be assumed that most likely the overabundance of s–process elements can be expected in the atmospheres of the stars lying above the evolution track "AGB–OH/IR" on the two–colour IR diagram. Van der Veen and Habing (1988) have paid attention to the existence of such objects and to their radiation near 60 μm, which is so strong that can not be caused by ordinary loss of matter. As Van der Veen and Habing believe, these objects have passed through the "thermal pulse", as a result of which the pulsations and the wind have been suppressed. It is in the course of the "thermal pulse" that inversion of C/O value could occur through the dredge–up to the surface of matter enriched in carbon and heavy metals. After the end of the "thermal pulse" and restoration of dynamical pulsations the stars' location on the diagram is shifted due to the dust radiation in the wavelength region 40 to 80 μm, the star becomes a carbon star.

3.3. Chemical composition of pulsating supergiants

Several RV Tau type supergiants have been included into our PPN spectroscopy programme at the 6 m telescope since it is customary to assume that they are passing the post–AGB stage (Gingold, 1985). The understanding of the role of pulsations in the process of mixing and dredge–up of altered matter is an additional stimulus in the study of the detailed chemical composition of RV Tau type supergiants. However, it is so far little known about the chemical composition of these objects to draw definite conclusions (Luck & Bond, 1989; Giridhar et al., 1994 and references therein).

Pulsating stars of this type have unusual photometric and spectroscopic properties that distinguish this class of objects from related W Vir type stars and semi–regular variable supergiants. The main distinguishing characteristic of the stable enough periodical pulsations of stars of RV Tau type is the presence of two minima on the phase light curve. RV Tau type stars with minimum luminosity (mass) and periods (shorter than 20 days) are close to W Vir stars. From the presence of RV Tau type stars in globular clusters and from the kinematic characteristics and distance from the galactic plane of their analogs in the galactic field it follows that these objects belong to old stellar populations (population II and thick disk). RV Tau stars, members of globular clusters, apparently have masses below solar and evolve to the stage of planetary nebula and a white dwarf.

From the spectra with classification dispersions RV Tau type stars are peculiar supergiants of luminosity classes Ib, II. The spectral peculiarity is caused by the appearance at certain phases of strong variable spectral details, identified with the bands of TiO, CN, CH molecules, in a spectrum of an F–K supergiant, which is evidence of an appreciable inhomogeneity of their extended atmospheres.

Luminosity classes Ib, II for RV Tau type stars have been confirmed with the application of the IR triplet of oxygen OI, λ 7773 Å (Mantegazza, 1991), whose equivalent width is a good luminosity criterion for A, F, G stars.

RV Tau type stars, as a rule, have excess radiation in the IR range, the spectral index for the IR flux being close to unity (Jura, 1986). The density of particles in the dust envelope decreases with distance from a star approximately as r^{-1} (Jura, 1986), which confirms the presence of a strong (up to $10^{-5} M_\odot yr^{-1}$) stellar wind at the preceding moment of evolution.

It should be noted that RV Tau type stars satisfy four criteria of belonging to the post–AGB stage, which have been stated by Trams et al. (1991): a) spectral characteristics of a supergiant, b) location off the galactic plane (outside the layer 100 pc),

c) presence of high IR excess caused by dust, d) photometric variability.

As it follows, for instance, from the low–dispersion survey of Wahlgren (1972), the sample of the galactic field RV Tau stars he has studied is rather heterogeneous in metallicity: [Fe/H] from −0.3 to −1.7, which may suggest that they belong to galactic populations of different age.

The deficiency of information on the chemical composition details of RV Tau stars does not allow a comparative analysis of the behaviour of different chemical elements in the case of pulsating stars of different types (UU Her type peculiar supergiants, long–period variable stars, W Vir stars) and stable supergiants at close evolutionary stages to be made. Such a comparison could provide radically new conclusions about the distinctions of the evolution of stars of different masses at their final phases, the structure of the atmospheres of pulsating supergiants, the effectiveness of mixing processes.

The results of our chemical composition determination for 4 pulsating stars with IR flux excess, U Mon, AC Her, RV Tau (Klochkova & Panchuk, 1998) and AI CMi (from the paper by Klochkova & Panchuk, 1996), are given in Table 3. It is seen from Table 3 that the chemical abundance pattern for pulsating supergiants is not uniform. Only in the case of AC Her it is consistent with the expected one for a post–AGB halo star: underabundance of iron group elements, overabundance of CNO and s–process elements. At the same time in the case of metal–poor star U Mon with large carbon excess we have found no excess of s–process elements. The solar metallicity and the proportion of CNO elements for RV Tau conforms to the status of a young supergiant.

3.4. Fast–evolving post–AGB objects

The results we have obtained for the abundance of chemical elements in the atmosphere of the source IRAS 19114+0002 are of importance from the point of view of comparison of its characteristics with those of the unique IR source IRC+10420 (IRAS 19244+1115) since these two objects are customarily considered analogs (Kastner & Weintraub, 1995). The peculiar supergiant IRC+10420 has first of all attracted interest by its marginally high absolute luminosity typical of hypergiants (Jones et al., 1993). What is more, this object occupies peculiar position on the IR colour diagram (Volk & Kwok, 1989) and is a source of strong variable maser OH radiation (Lewis et al., 1986; Nedoluha & Bowers, 1992), which suggests the presence of an extended gaseous–dust envelope. From observations in OH the source shows a composite spatial structure (Nedoluha & Bowers, 1992).

The totality of the observed characteristics for this peculiar supergiant is not contrary to two basic hypotheses on its nature: IRC+10420 may be a low–mass object at the evolution stage of a protoplanetary nebula, or else a massive object, predecessor of a Wolf-Rayet star. That is why some researchers (see e.g. Hrivnak et al., 1989) rank it among candidates for protoplanetary nebulae, others consider it to be a massive supergiant (Humphreys, 1991; Jones et al., 1993). It is difficult to decide between the two cases because the observational manifestations in both of them are alike: the effective temperature rises with time, a gaseous–dust envelope inherited from a red giant or a supergiant is present. A good criterion for a more certain choice of the evolutionary status may be the metallicity in combination with a large set of chemical element abundances. The task is, however, complicated by the low optical brightness of the object (see Table 1).

An analysis of the IRC 10420 spectra taken with BTA in 1994–1996 made it possible to draw a number of conclusions (Klochkova et al., 1997a). Using the intensities of absorption spectral lines an effective temperature value, T_{eff} = 8500 K, has been derived. This result suggests that the effective temperature has increased for the last 20 years: its spectral class has changed from F8 (Humphreys et al., 1973) to A5 (Klochkova et al., 1997a), which is indicative of commencement of fast evolution. Oudmaijer et al. (1996) have also inferred that the temperature of IRC+10420 has increased by about 1000 K since the time of observations by Humphreys et al. (1973). This spectral class change is likely to have occurred for an essentially shorter period of time, since Jones et al. (1993) write about the observed reduction of IR flux at a constant energy distribution in the optical range. The abundance of the iron–group elements is the same as in the atmosphere of the Sun, while carbon has been found to be underabundant and nitrogen overabundant, which is typical of massive supergiants of the disk. Preliminary estimation of the abundance of the elements synthesized in the processes of slow neutronization has shown their normal (solar) content.

Note that we have first managed to estimate the metallicity and some details of the chemical composition of IRC+10420. These results combined with the high luminosity, close to the limit of Humphreys–Davidson (Jones et al., 1993) confirm the hypothesis that most likely IRC+10420 is a massive star (up to 40 $M_\odot$) at a short and therefore rarely observed evolutionary stage, transitional from OH/IR star to a LBV or Wolf–Rayet star. It should be pointed out that the value log g = 1.0 we have obtained by the model atmosphere method also confirms the high luminosity of the object, which is close to the luminosity of the brightest hypergiant η Car. Comparing the obtained chemical composition of the atmospheres of two supergiants, IRAS 191114+0002 and IRC+10420, we see that the details of chemical element abundance indicate that their masses, metallicities and, eventually, the evolution history are different. Thus, the inference (Kastner & Weintraub, 1995) that the two supergiants are analogs has not been confirmed.

For more certain conclusions as regards the evolutionary status of IRC+10420 we are plannig to obtain additional high–quality spectra with a S/N over 100, including the blue region, primarily to estimate reliably the helium abundance. A long–duration monitoring of this rapidly evolving object, which is most likely being observed at a short (as short as 10^4 years) and therefore rarely observed transitional stage from massive red supergiants to predecessors of SN, seems to be of importance too. At the present time this transitional evolution phase of massive stars is little studied both theoretically and observationally.

Spectral monitoring is also needed for the peculiar object in Sagittarius, whose flare was detected in February, 1996 by the Japanese astronomer Y. Sakurai (Green, 1996). During 1996 the stellar magnitude of the object changed from 12.5 to 11.2. Classified by the rate of brightness change during the flare as a slow Nova, it was referred to peculiar objects after the first spectra were obtained with the ESO 3.6 m telescope, since the spectrum did not correspond to the expected spectrum of a Nova. In March, 1996 on the direct CCD images of the Sakurai's object obtained with the ESO 0.9 m telescope a planetary nebula around the object was detected. Using low resolution spectra Duerbeck and Benetti (1996) have concluded that the neutral hydrogen line is significantly weakened while strong carbon and oxygen lines are present. Based on the collection of distinctions, they classified the flare object among R CrB type stars.

The first high–resolution spectra of Sakurai's object were obtained with the 2.7 m telescope of the McDonald observatory (Asplund et al., 1997) and by us with the 6 m telescope in 1996. As a result of analysis of these spectra and calculation of chemical composition by the model atmosphere method (Asplund et al., 1997; Kipper & Klochkova, 1997), a 3 dex reduction of hydrogen abundance (moreover, it reduces by 0.7 dex from May to October 1996), carbon excess and Li, Sr, Y, Zr increase have been revealed. Apparently, the object had undergone the final shell helium burning and began to evolve rapidly similar to FG Sge (Kipper, 1996; Blöcker & Schönberner, 1997).

From the evolution model of the star as a result of the helium shell flash (Iben, McDonald, 1995), one should expect an increase in luminosity as high as 10 times and a change in T_{eff} from 40000 K to 6300 K for 17 years. The model parameters derived by Asplund et al. (1997) and Kipper and Klochkova (1997) allow to state that Sakurai's object is rapidly evolving (for a half–year its temperature dropped by 600 K).

It should be emphasized that the scenario of formation of hydrogen–deficient supergiants of R CrB type proposed by Iben (1984) is not single. Apart from the mechanisms of shell helium burning Iben et al. (1996) have considered a number of other scenarios realized, in particular, in the course of evolution of binary systems.

The body of the first observational data obtained for Sakurai's object permits it to be considered a unique object being observed at a fast final evolutionary phase and providing a rare chance of testing theoretical modelling of the processes of evolution of the cores of planetary nebulae and circumstellar envelopes, loss of matter, convection, stellar nucleosynthesis and alteration in the surface chemical composition. In this respect Sakurai's object can be placed on a level with FG Sge, which demonstrates, as is known, a maximum rate of evolution (Van Genderen, Gautschy, 1995; Kipper, 1996) and is called by right "Rosetta stone" of stellar evolution (Kraft, 1974).

3.5. Conclusions

In the present paper are briefly considered the most important problems and observed facts concerning the evolution stage of transition from AGB to a planetary nebula, and principal results are summed up that have been obtained in the course of spectroscopic study at the 6 m telescope of a sample of peculiar supergiants assumingly at the PPN stage, which are associated with galactic IRAS sources.

The basic point of our programme is analysis of spectral manifestations of the dynamic state of extended envelopes of PPNe as well as search for evolutionary variations of chemical composition of stars having passed the AGB stage and a third dredge–up. The most significant result of the programme is the discovery of 3 post–AGB objects in the atmospheres of which real overabundances of s–process elements have been revealed.

We consider it worthwhile to emphasize that all the basic ideas of the nature of protoplanetary nebulae as a particular stage of stellar evolution, which is undergone by the overwhelming majority of stars with masses ranging from 3 to 8 $M_{\odot}$ in the course of their evolution, were stated as early as 40 years ago by I.S. Shklovsky (1956). It is in that paper that he drew conclusions about the relation between red giants (supergiants), planetary nebulae and white dwarfs; about the discrete formation of an extended envelope as a result of departure of the outer layers of a red giant; about the evolution of a star core which leads to formation of a white dwarf. Questions were considered concerning morphology and dynamics of envelopes and their connection with the type of the central core, the presence of multiple envelopes and double (multiple) cores, the duration of separate phases of formation of a young PN on the basis of stellar statistics, the problem of chemical composition evolution.

The decades that have passed since the paper by Shklovsky (1956) was published have appeared very fruitful for investigations of PPNe, primarily because astrophysics has become "all-wave" (Shklovsky, 1982), in particular, effective (ground–based and space) observational techniques in the IR and radio ranges have been developed, which are the most informative for the study of PPNe, a considerable part of energy of which is released in these very ranges.

In parallel, due to the advanced computing technologies and rapid growth of computer capacity, the development of techniques of theoretical analysis and modelling of observational data has become as intensive. Combination of progress in observations and in data analysis has led to the present–day knowledge of origin, structure and evolution of PPNe, the principal points of which are briefly outlined in the present review.

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Table 1: *Peculiar supergiants we have observed at BTA with the echelle spectrometer*

IRAS	Ident	Sp	V	T_{eff}, K	log g	$[Fe/H]_{\odot}$	IR-excess	Remarks
IRAS 04296+3429		G0Ia	14.2	6300[a]	0.0	-0.86	yes[1]	
IRAS 04440+2605	RV Tau	G2Iae	9.2	5600[b]	1.0	+0.07	yes	puls[2]
AFGL 915[4]	HD 44179	A0	8.8				yes	
	HD 52961[4]	FI	6.4				yes	bin?, puls
IRAS 07134+1005	HD 56126	F5I	8.4	7000[c]	0.1	-1.00	yes	bin[3], puls
IRAS 07284-0940	U Mon	F8Ibe	5.7-6.6	4950[b]	0.0	-0.69	yes	bin?, puls
IRAS 07331+0021	AI CMi	G5Iab	8.0-9.3	4500[d]	0.0	-1.13	yes	puls
IRAS 09276+4454	SAO 42901	K7II	8.1	3400[e]	1.0	-0.34	yes	
IRAS 15465+2818[4]	R CrB	G0Iep	5.8-15					puls
	UU Her	F5Ib	9.0	6000[f]	0.7	-1.32	no	bin?, puls
IRAS 17436+5003	HD 161796	F3Ib	7.0	7100[g]	0.5	-0.25	yes	
	Sakurai's object	F2Ia	11.4	7250 [h]	1.0	-1.54		
IRAS 18062+2410[4]	HDE 341617	B5I	11.4				yes	var
IRAS 18095+2704		F3Ib	10.4	6700[c]	1.0	-0.78	yes. SiO	
IRAS 18281+2149	AC Her	F2Ipe	6.8-9.0	6100[b]	1.5	-0.82	yes	bin, puls
IRAS 19102+0329	FN Aql	F8-G2	9.1	5700[g]	2.0	+0.17		puls
IRAS 19114+0002	HD 179821	G5Ia	8.0	6800[k]	1.3	-0.10	yes, SiO	bin?
				5000[k]	-0.75	-0.98		
IRAS 19244+1115	IRC+10420	A5Ia	11.2	8500[l]	1.0	-0.12	yes	
IRAS 20004+2955[4]	V1027 Cyg	G7Iab	8.9				yes, SiO	
IRAS 21153+6842[4]	SAO 19283	A0p	8.0				yes	
IRAS 22272+5435	HD 235858	G5Ia	9.3	5600[m]	0.5	-0.49	yes, SiO	

[1] - there is an IR-excess
[2] - pulsating star
[3] - binary star
[4] - data for this object are now in preparation
Values of T_{eff}, K, log g and $[Fe/H]_{\odot}$ are from the following papers:
[a] - Klochkova et al., 1997c
[b] - this paper
[c] - Klochkova, 1995a
[d] - Klochkova & Panchuk, 1996
[e] - Klochkova & Mishenina, 1998
[f] - Klochkova et al., 1997b
[g] - Klochkova et al., 1998
[h] - Kipper & Klochkova 1997
[k] - Začs et al., 1996
[l] - Klochkova et al., 1997a
[m] - Začs et al., 1995

Table 2: *a. Chemical composition for IRAS sources studied* $\log\epsilon(X) \pm \sigma$ *($\log(H) = 12.0$). n - number of lines used for calculation*

	Sun[1]	IRAS07134+1005[2]			IRAS18095+2704[2]			IRAS17436+5003			IRAS04296+3429[3]		
X	logϵ	logϵ	n	σ	logϵ	n	σ	logϵ	n	σ	logϵ	n	σ
LiI	3.31							2.85	1		3.23	1	
CI	8.55	8.63	3	0.04	8.27	4	0.04	8.52	5	0.07	8.55	21	0.10
NI	7.97	8.00	3	0.09	7.66	3	0.06	8.39	3	0.25	7.95	4	0.05
OI	8.87	8.50	3	0.06	8.74	3	0.02	9.15	2	0.09	8.21	3	0.03
NaI	6.33	5.87	4	0.17	6.02	4	0.15	6.40	4	0.07	5.93	3	0.14
MgI	7.58	7.55	5	0.28	7.42	5	0.16	7.26	1				
MgII					7.52	2					8.06	2	0.02
AlI	6.47	6.95	3	0.29	5.81	3	0.30	6.20	2	0.06	6.86	3	0.08
SiI	7.55	7.50	17	0.11	7.48	22	0.04						
SiII								8.76	1		6.96	1	
SI	7.21	6.84	2	0.18	6.96	1							
KI	5.12										5.04	1	
CaI	6.36	5.81	12	0.19	5.84	18	0.06	6.02	17	0.04	5.75	19	0.07
ScII	3.17	2.24	8	0.09	2.25	9	0.08	2.43	6	0.12	2.52	10	0.09
TiII					4.05	1					4.05	5	0.15
VII		2.97	4	0.16	3.45	3	0.12				3.24	4	0.14
CrII					4.98	7					4.94	10	0.09
MnI	5.39	5.40	3	0.34	5.12	8	0.13						
FeI	7.50	6.50	39	0.06	6.71	62	0.04	7.25	63	0.02	6.66	82	0.04
FeII		6.50	10	0.04	6.73	12	0.05	7.27	13	0.04	6.65	18	0.05
NiI	6.25	6.49	21	0.16	6.13	22	0.12	6.28	12	0.11	6.30	9	0.08
CuI	4.21	4.24	1		4.06	1		4.23	1		3.64	1	
ZnI	4.60				4.60	1		4.63	1		3.87	1	
YII		2.94	2	0.24	1.42	7					2.44	3	0.19
ZrII											2.39	1	
BaII	2.13	2.12	1		1.13	3	0.11	1.62	3	0.07			
LaII	1.22	1.81	4	0.10	0.83	4	0.15				1.49	6	0.18
CeII	1.55										1.53	5	0.07
PrII	0.71				0.50	2					0.63	1	
NdII	1.50	1.80	3	0.16	1.56	3	0.08	1.58	1		1.75	12	0.09
SmII	1.01												
EuII	0.51	0.57	2	0.30	0.96	2		-0.42	1		0.03	2	0.03

1 – data from (Grevesse, Noels, 1993)
2 – Klochkova (1995a)
3 – Klochkova et al. (1997c)

Table 2: *b. Relative chemical composition* $[X/Fe]_\odot$

X	IRAS07134 +1005	IRAS18095 +2704	IRAS17436 +5003	IRAS04296 +3429	α Per [1]	ROA24[2]
LiI			1.94	0.77		
CI	1.08	0.50	0.22	0.85	-0.17	0.67
NI	1.03	0.47	0.67	0.83	0.65	1.02
OI	0.63	0.65	0.53	0.19	-0.27	1.01
NaI	0.54	0.47	0.32	0.45	0.23	0.71
MgI	0.97	0.62	-0.07		0.22	0.31
MgII		0.72		1.33		0.09
AlI	1.48	0.12	-0.02	0.46	0.05	-0.88
SiI	0.95	0.71	1.46		0.19	0.80
SiII				0.26		
SI	0.63	0.53			0.55	1.03
KI				0.77		
CaI	0.45	0.26	-0.09	0.24	0.15	0.60
ScII	-0.07	-0.30	-0.49	0.20	-0.36	-0.13
TiII		-0.19		-0.12	0.00	0.33
VII	-0.03	0.23		-0.09	-0.28	0.15
CrII		0.09		0.12	0.08	-0.01
MnI	1.01	0.51			-0.06	0.35
FeI	0.00	-0.01	0.00		-0.01	0.00
FeII	0.00	0.01	0.02	0.00	0.02	0.00
NiI	1.24	0.66	0.28	0.93	-0.01	0.23
CuI	1.03	0.63	0.27	0.28	0.53	
ZnI		0.78	0.28	0.12		0.56
YII	1.70	-0.04		1.05	0.02	0.37
ZrII				0.64		0.57
BaII	0.99	-0.22	-0.26		0.01	0.96
LaII	1.59	0.39		1.12	-0.02	0.54
CeII				0.83		
PrII		0.57		0.76		
NdII	1.30	0.84	0.33	1.10	-0.52	0.67
SmII						
EuII	1.06	1.23	-0.68	-0.37	0.09	0.25

[1] – Klochkova, 1995a
[2] – Gonzales, Wallerstein, 1992

Table 3: *a. Chemical composition of pulsating stars studied* $\log\epsilon(X) \pm \sigma$ *($log(H) = 12.0$). n - number of lines used*

	Sun[1]	AC Her			U Mon			RV Tau						AI CMi [2]		
								s15411			s17910					
X	logε	logε	n	σ	logε	n	σ	logε	n	σ	logε	n	σ	logε	n	σ
LiI	3.31	2.39	1					2.20	1					0.19	1	
CI	8.55	8.59	21	0.05	8.63	6	0.12	8.47	10	0.10						
NI	7.97	8.50	2	0.50				8.20	1							
OI	8.87	8.40	2	0.06	8.73	2	0.55	9.20	2	0.24				8.63	1	
NaI	6.33	5.91	4	0.02	6.34	4	0.18	6.93	3	0.09				5.50	3	0.1
MgI	7.58	7.03	6	0.16	6.78	1					7.51	1		6.71	4	0.1
MgII								7.63	1							
AlI	6.47	5.52	3	0.06	5.82	1		6.42	4	0.14	6.64	2	0.26	5.62	3	0.1
SiI	7.55	6.84	11	0.05	7.04	17	0.09	7.69	20	0.05	7.72	18	0.07	6.85	20	0.1
SiII		6.72	2	0.14				7.66	2	0.18						
SI	7.21	6.96	8	0.03	7.12	7	0.11	8.10	10	0.10	8.12	7	0.16			
KI	5.12	4.68	1													
CaI	6.36	5.32	20	0.04	5.65	18	0.05	6.32	12	0.09	6.29	8	0.10	5.18	12	0.2
ScII	3.17	2.05	12	0.06	2.28	10	0.11	2.98	8	0.08	2.88	6	0.15	1.83	6	0.1
TiI	5.02				4.76	13	0.06	4.85	10	0.07	4.96	29	0.06	4.47	19	0.1
TiII		3.89	8	0.09	4.26	5	0.15	4.76	4	0.08	4.86	4	0.10	3.63	2	0.0
VI	4.00				2.89	5	0.16	4.10	10	0.05	3.94	15	0.04	3.29	14	0.1
VII		3.32	2	0.14	2.61	3	0.18	3.83	4	0.14	3.62	4	0.13	2.60	3	0.1
CrI	5.67	4.87	10	0.11	4.78	7	0.10	5.72	9	0.07	5.67	12	0.09	4.59	8	0.2
CrII		4.78	12	0.06	4.78	7	0.04	5.66	8	0.08	5.72	7	0.06			
MnI	5.39	4.59	3	0.07	4.53	7	0.19	5.80	10	0.15	5.54	9	0.11	3.96	3	0.0
FeI	7.50	6.69	148	0.02	6.80	133	0.02	7.56	131	0.02	7.58	147	0.02	6.38	80	0.0
FeII		6.67	19	0.05	6.83	13	0.06	7.58	12	0.08	7.60	15	0.07	6.34	17	0.1
NiI	6.25	5.87	28	0.08							6.23	29	0.08	5.04	22	0.1
CuI	4.21	3.60	2	0.01	2.95	1		4.42	2	0.40	4.94	2	0.18	2.82	2	0.2
ZnI	4.60	4.48	1		4.11	1		4.76	3	0.18	4.78	1		4.17	1	
YII	2.24	1.16	5	0.14	1.29	4	0.17	1.67	7	0.08	1.77	5	0.09	1.06	3	0.4
ZrI	2.60										1.50	1		1.52	4	0.1
ZrII		1.36	1		2.00	1		1.91	1					1.05	1	
BaII	2.13	1.15	2	0.22										0.97	2	0.1
LaII	1.22	0.84	4	0.06	0.32	6	0.10	1.24	6	0.11	0.94	3	0.10	-0.03	4	0.1
CeII	1.55	0.94	4	0.08	0.39	4	0.03	1.17	3	0.17	0.74	4	0.09	-0.24	1	
PrII	0.71	0.57	1											-0.89	1	
NdII	1.50	0.65	7	0.08	0.26	5	0.18	1.08	6	0.10	1.13	8	0.09	0.35	1	
SmII	1.01	0.54	1		-0.57	1		0.67	1							
EuII	0.51	0.14	2	0.16	-0.25	3	0.08	0.64	3	0.13	0.51	3	0.12	-0.31	2	0.3

[1] – solar abundances (Grevesse, Noels, 1993)
[2] – averaged data for AI CMi (Klochkova, Panchuk, 1996)

Table 3: *b. Relative chemical composition* $[X/Fe]_{\odot}$

X	AC Her	U Mon	RV Tau		AI CMi
			s15411	s17910	
LiI	-0.11		-1.18		-2.02
CI	+0.85	+0.77	-0.15		
NI	+1.34		+0.16		
OI	+0.34	+0.55	+0.26		+0.85
NaI	+0.39	+0.70	+0.53		+0.26
MgI	-0.26	-0.11		-0.16	+0.22
MgII			-0.02		
AlI	-0.14	+0.04	-0.12	+0.08	+0.24
SiI	+0.10	+0.18	+0.07	+0.08	+0.39
SiII	-0.01		+0.04		
SI	+0.56	+0.60	+0.82	+0.82	
KI	+0.37				
CaI	-0.23	-0.02	-0.11	-0.16	-0.09
ScII	-0.31	-0.20	-0.26	-0.38	-0.25
TiI		+0.43	-0.24	-0.15	+0.54
TiII	-0.31	-0.07	-0.33	-0.25	-0.30
VI		-0.42	+0.03	-0.15	+0.30
VII	+0.14	-0.70	-0.24	-0.47	-0.31
CrI	+0.01	-0.20	-0.02	-0.09	+0.01
CrII	-0.07	0.20	-0.08	-0.04	
MnI	+0.01	-0.17	+0.34	-0.04	-0.35
FeI	+0.00	-0.01	-0.01	-0.01	-0.03
FeII		+0.02	+0.01	+0.01	-0.07
NiI	+0.43			-0.11	-0.12
CuI	+0.20	-0.57	+0.14	+0.62	-0.30
ZnI	+0.69	+0.20	+0.09	+0.09	+0.66
YII	-0.27	-0.26	-0.64	-0.56	-0.09
ZrI				-1.59	-0.03
ZrII	-0.42	+0.09	-0.74		-0.46
BaII	-0.17				-0.07
LaII	+0.43	-0.21	-0.09	-0.37	-0.16
CeII	+0.20	-0.47	-0.45	-0.90	-0.70
PrII	+0.67				-0.51
NdII	-0.04	-0.55	-0.49	-0.46	-0.06
SmII	+0.34	-0.89	-0.41		
EuII	+0.44	-0.07	-0.20	-0.09	+0.28