Session I

SURVEYS

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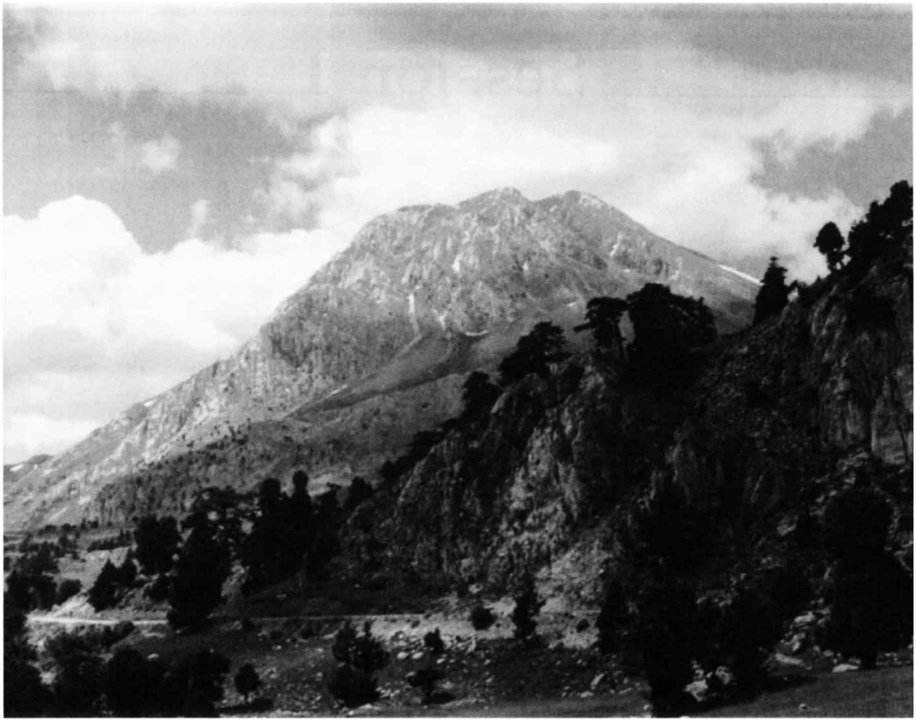

Bakırlıtepe, a 2485-m (8150 ft) peak in the Toros range, is the site of the new Turkish National Observatory, headed by Zeki Aslan.

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DEEP IV–N AND YELLOW–RED SPECTRAL SURVEYS FOR CARBON STARS

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Abstract. We present the results of the First and Second Abastumani Objective Prism Spectral Surveys along with other surveys for carbon stars carried out in recent years.

1. Introduction

Theoretical models for Asymptotic Giant Branch (AGB) stars indicate that the carbon-star phase may last up to 10^6 years. It is strongly limited by rapid mass-loss rates of up to 10^{-4} $M_\odot$ yr^{-1} (Kleinmann 1989), and it is critical in their evolution since it determines their fate as planetary nebulae and white dwarfs. This lifetime is consistent with the analysis of Claussen et al. (1987), who used the space distribution of high-luminosity carbon stars and their main-sequence progenitors to argue that the lifetime of carbon stars lies between 10^5 and 10^6 years (Jura 1991).

Carbon stars are also the most likely sources of carbon grains, PAHs, and any carbon-cage molecules and *s*-process species that may be found in the interstellar medium. Furthermore, a few of them are super-rich in lithium and these objects may be important in synthesizing lithium in the Galaxy. The low effective temperature of carbon stars means that their atmospheres are molecular and hence their winds are primarily in molecular form, and consequently they develop an extensive, cold, molecular circumstellar envelope due to mass loss (Knapp et al. 1990). Not all carbon stars lie on the AGB. The hottest R-type stars may have luminosities of only 100 $L_\odot$.

Carbon stars are promising standard-candle tracers of large-scale galactic structure. They are intrinsically bright and numerous, so they can be identified anywhere in the Galaxy despite dust extinction. Carbon stars

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with known distances and velocities are powerful indicators of disk dynamics, providing an opportunity to probe the evolutionary history of the Galaxy (Weinberg 1993). They can also play an important role in the estimation of galactic dark matter out to 5 $R_{\odot}$ (Schechter 1993).

Interest in obtaining an accurate census of these stars by various types of surveys is stimulated by the goals of measuring their range of lifetime in the AGB phase and the extent to which they dominate the chemical evolution of the Galaxy.

Numerous spectral surveys have been carried out in the past several decades. Some of them have been analyzed by Mavridis (1971), McCarthy & Blanco (1978), Blanco & McCarthy (1981), and MacConnell (1995). We will limit our attention to extensive spectral surveys of the galactic plane carried out by means of objective prisms.

2. Objective-Prism Surveys

The Henry Draper catalogue, produced at Harvard by Annie J. Cannon and her assistants, was the primary source of data on carbon stars until the 1940s. Starting with the pioneering work of Lee et al. (1940), low-dispersion objective-prism spectra have been widely used for the identification of red stars. Nassau & Velghe (1964) introduced the use of the near-infrared (6800–8800 Å) spectral range for the detection and classification of late-type stars. They showed that carbon stars could be easily identified by their pronounced cyanogen (CN) bands at 7945, 8125 and 8320 Å nearly to the limit of their plates.

2.1. THE I–N SPECTRAL SURVEYS

A near-infrared spectral survey of the northern part of the galactic belt was carried out in Cleveland by Nassau and his collaborators (1949, 1950, 1954; 1954a,b,c; 1957, 1964) to a limiting magnitude of about $I = 10.5$, and the distribution of M, C and S stars was studied. All these near-infrared (Kodak I–N + Wr 89 filter), low dispersion (1700 and 3400 Å mm^{-1} at the A-band) spectral surveys were carried out with the 24/36-inch Schmidt telescope of the Warner and Swasey Observatory equipped with 4° or 2° prisms. The area in galactic longitude from $l = 333°$ through 0° to $l = 210°$ and $b = 0°$, $\pm 4°$ was covered and more than seven hundred carbon stars were found, among them six hundred new ones. An extension to southern declinations was carried out by Blanco & Münch (1955, $200° \leq l \leq 270°$, $|b| \leq 2°$) at Tonantzintla Observatory and by Smith & Smith (1956, $180° \leq l \leq 360°$, $|b| \leq 1°.5$) at Bloemfontein. They identified 172 and 186 carbon stars, respectively. The limiting near-infrared magnitude of these surveys was $I \approx 10.2$.

To extend the galactic belt surveys to fainter magnitudes, a complete low-dispersion spectral survey (2100 Å mm^{-1} at the A-band) of the southern Milky Way, covering a 10° equatorial belt from $l = 235°$ to $l = 7°$, was carried out by Westerlund (1971) with the 50-cm Schmidt telescope at the Uppsala Southern Station at Mount Stromlo Observatory to a limiting infrared magnitude $I = 12.5$. On the basis of the spectral material obtained, 1124 carbon stars were discovered including more than 950 new ones.

Statistics of these surveys are summarized in Table 1, which gives the approximate area of the sky covered in sq. deg., the limiting magnitude in I or V, the number of C stars recorded, and the number of these that were new.

TABLE 1. Spectral Surveys of the Milky Way

Observer	Area	I	V	All	New
Nassau et al.	3,700	10.5		700	600
Westerlund	1,320	12.5		1,124	950
Fuenmayor	644	13.0		283	123
MacConnell	1,200	13.0			600
Maehara, Soyano	1,325	13.0		884	259
Alksne, Alksnis et al.	1,200		14.5		318
Kurtanidze, Nikolashvili	1,500		16.5	1,503	862
Kurtanidze, Nikolashvili	350	15.5		496	384
Nikolashvili, Kurtanidze	150	15.5		257	196
Aaronson, Blanco et al.	400	15.0		921	423
Stephenson	2,400	14.0		2,100	

In the early 1970s, MacConnell (1988, 1995) began taking infrared plates of dispersion 3400 Å mm^{-1} at the A-band with the 61/91-cm Curtis Schmidt telescope at Cerro Tololo Inter-American Observatory to search for cool supergiants and carbon stars. Plates were taken along the full southern galactic half-circle, from $l = 230°$ to $l = 30°$, covering a band 13° wide. His deep plates were ammonia-sensitized and reach $I = 13.5$. The discovery of more than 600 new carbon stars has been reported to date.

During nearly the same period (1978–1985), Maehara and Soyano were making a deep survey for cool carbon stars along the galactic plane with the 105/150-cm Schmidt telescope of the Kiso Station of the Tokyo Astronomical Observatory. They used hypersensitized Kodak I–N plates behind a Schott RG 695 filter and the 4° prism, giving a dispersion of about 1000 Å mm^{-1} at the A-band. Direct IIa–D plates were taken to determine the positions and V magnitudes of the objects discovered. The limiting magnitude

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of the survey is $I = 13.0$. In a series of papers (Maehara & Soyano 1987a, 1987b, 1988, 1990; Soyano & Maehara 1991, 1993) they published accurate positions, visual magnitudes and finding charts for 884 carbon stars found in the Cassiopea ($l \sim 120°$), anticenter ($l \sim 180°$), Cygnus ($l \sim 90°$), Serpens-Aquila-Scutum ($l \sim 30°$), Perseus-Camelopardalis ($l \sim 150°$) and Monoceros ($l \sim 210°$) regions. The survey covers about 1300 sq. deg. and 272 new carbon stars were identified.

To study the center-anticenter asymmetry in the surface and space distributions of carbon stars in the Galaxy, Fuenmayor (1981) carried out a spectral survey at 1700 Å mm^{-1} on Kodak I–N plates hypersensitized in a bath of distilled water at 5°C for 2 minutes. This procedure resulted in a limiting infrared magnitude of $13^{m}_{\cdot}0$. Each survey area of 322 sq. degrees located in the galactic center and anticenter directions was observed with similar Schmidt-type telescopes located in the southern and northern hemispheres. As a result, 283 carbon stars were identified, of which 123 were new.

2.2. THE YELLOW–RED SPECTRAL SURVEYS

Using the 80/120-cm Schmidt telescope of the Radioastrophysical Observatory at Baldone near Riga, Alksne and collaborators (1989) carried out a green-yellow (A600 films, 600 Å mm^{-1} and 1130 Å mm^{-1} at H_γ) and near-infrared (Kodak I–N + RG 1, 2500 Å mm^{-1} at the A-band) objective-prism spectral survey of strategically selected northern Milky Way regions ($168° < l < 200°$, $b = \pm 7°$; $84° < l < 96°$ and $172° < l < 180°$, $|b| < 2°.5$; $128° < l < 140°$, $b = +7°$; $80° < l < 96°$, $|b| < 9°.5$). As a result of these surveys they discovered 318 new cool C stars.

In the beginning of 1975 we began laboratory tests at Abastumani Astrophysical Observatory for hypersensitization of the Kodak emulsions 103a–O, IIa–O,D and IIIa–J,F by baking in dry air for 4–10 hours at 50–70°C. Applied to types IIIa–J,F this technique yielded speed gains of a factor of 3 to 5. At first these hypersensitized plates were used for direct photography of nearby clusters of galaxies ($z < 0.05$, $B = 21.5$), and later on at the end of 1977 they were used for low-dispersion spectroscopy for the identification of different kinds of stars. Carbon stars were identified on these plates to a limiting magnitude of $V = 16.5$, which is equivalent to the limit of Westerlund for objects having $V - I \approx 3$. Therefore, in the middle of 1978 we undertook an extensive low-dispersion spectral survey of the northern equatorial belt of the Milky Way for the identification of OB, B8–A3, M, and C stars (Kurtanidze & Nikolashvili 1981). Our principal objective was the extension of Westerlund's southern galactic belt survey to the northern Milky Way.

The spectra obtained for this survey have a dispersion of 1250 Å mm^{-1} at H_γ. They were taken with the 2° objective prism attached to the 70/98/210-cm meniscus telescope of the Abastumani Observatory. Kodak IIIa–J,F plates hypersensitized in dry air or in nitrogen and exposed for 20 and 50 min yielded an approximate limiting magnitude of $B = 18.5$ (A0 V).

The plate material covers the region of the Milky Way from $l = 30°$ to $l = 165°$ and $l = 195°$ to $l = 210°$, $b = 0°$, $\pm 3°.6$. A survey of the region $165° < l < 196°$ was carried out by Fuenmayor (1981) in the near-infrared. On these plates the groups of OB, B8–A3, M, and C stars are easily distinguished. Carbon stars are identified by the presence of C_2 bands at 4737 Å, 5167 Å (IIIa–J,F), and 5635 Å (IIIa–F).

It must be noted that the survey of the region $195° < l < 210°$, $|b| < 5°$ was carried out on Kodak I–N + RG 5 but is included here because the limiting magnitudes of the I–N and J,F surveys are nearly the same for late-type stars.

As a result of the First Abastumani Survey for early and late-type stars, more than 1500 C stars were identified, including more than 860 new ones (Nikolashvili 1987a,b; Kurtanidze & Nikolashvili 1981, 1988b, 1989a,b,c; 1994, 1995), and their distribution was studied.

2.3. THE IV–N SPECTRAL SURVEYS

Thanks to all these low-dispersion spectral surveys carried out in the near-infrared (I–N) and yellow-red spectral regions, the Milky Way equatorial ten-degree belt is now uniformly covered to a near-infrared magnitude of $12\overset{m}{.}5 - 13\overset{m}{.}0$.

To probe the outermost parts of the galactic plane we initiated a still deeper spectral survey in the mid-1980s. It covers the region from $l = 50°$ to $l = 115°$ and $b = 0°$, $\pm 3.5°$. The area covered by 12×12 cm plates is equal to ~ 12 sq. degrees. All observations have been carried out with the 70-cm meniscus telescope equipped with the 2° prism giving a reciprocal dispersion of about 7000 Å mm^{-1} at the A-band. Fine-grained Kodak IV–N plates hypersensitized in silver-nitrate solution ($AgNO_3$) in combination with a 2-mm Schott RG 8 filter yielded a passband from 6800 to 8800 Å. Carbon stars are identified on the infrared-sensitive spectral plates by the presence of an easily noticeable dip nearly in the middle of the spectra, due to unresolved CN bands at $\lambda\lambda$ 7945, 8025, 8320 Å. Despite the very low dispersion used, and consequently the low resolution of ~ 200 Å (R = 40), they are easily distinguished from M–type stars, the TiO bands of which are well separated in these spectra. On plates obtained with the 1° prism ($\sim$15000 Å mm^{-1} at the A-band, $\Delta\lambda = 400$) carbon stars are indistinguishable from other late-type stars. As a result of the survey of about 500 sq. degrees, 752 carbon stars were revealed to a limiting near-infrared magnitude of $15^{m}_{\cdot}5$, among them 580 new ones (Kurtanidze & Nikolashvili 1988a; Nikolashvili & Kurtanidze 1989). The limiting magnitude was estimated on spectral plates of IC 5146 (Forte & Orsatti 1984).

In an excellent and unique project to measure the rotation of the Milky Way at large galactocentric radii, Aaronson, Blanco et al. (1989, 1990) carried out a very deep spectral survey in 16 regions of low absorption. All observations were obtained using the Curtis and Burrell Schmidt telescopes equipped with objective prisms giving reciprocal dispersions of about 1800 Å mm^{-1} at 8000 Å. Silver nitrate hypersensitized IV–N plates were used with an RG 695 filter. Each of the plates obtained covers an area of 25 sq. deg. They identified 498 known and 487 probable C stars. Spectroscopic observations of the latter with higher resolution show that there are 423 new discoveries and 64 misidentifications including 13 new S stars. Radial velocities and *JHK* photometry have been obtained for more than 800 and 1000 objects, respectively.

Stephenson (1989) used the Burrell Schmidt telescope of the Warner and Swasey Observatory on Kitt Peak to conduct the extensive spectral survey of the Milky Way from $l = 0°$ to $l = 240°$, $|b| < 6°$. The spectral dispersion provided by the 4° prism was close to 1700 Å mm^{-1} at the telluric A-band. A near-infrared magnitude $I = 13.5$ was reached using Kodak IV–N emulsion hypersensitized in $AgNO_3$. As a result about 2100 carbon stars were identified.

The data on all the surveys described were compiled by Stephenson (1989) in *A General Catalog of Cool Galactic Carbon Stars* containing 5987 entries, the faintest of which are as faint as $15^{m}_{\cdot}5$ in the near-infrared spectral region.

3. Further Prospects

While carbon stars are usually identified on the basis of optical surveys, they are so cool (except for the warmer carbon stars of the R0–R3 or C0–C2 subclasses) that they emit most of their radiation at wavelengths longward of one micron, at which the Galaxy is almost transparent. Therefore, the DENIS and 2MASS surveys will play a very important role in studies of the space distribution of carbon stars and the variation of their characteristics with galactocentric distance, as well as in other galactic problems. Thanks to the very faint limiting magnitude reached ($K = 14$), practically all galactic giant carbon stars will be detected including the warmer ones, although the separation of those having $J–K < 1.5$ from other kinds of objects will not be possible (Wood 1994). Therefore, spectral surveys in the optical region will still play an important role for the identification and classification of the warmer carbon stars. These surveys could be carried out at 10 Å resolution and should be as deep as possible.

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Discussion

Frogel: Can you comment on the *relative* number of C stars you find, i.e. relative to the number of M stars or to the overall stellar density?

Kurtanidze: The $C/M5^+$ ratios along the galactic plane are presented by M. Nikolashvili (these proceedings). As regards the other Natural Groups that can be detected by the meniscus J,F survey, the work is still in progress, although the penetration would differ for different groups of stars. Early estimates indicate a space density of C stars of the order of 10^{-7} pc^{-3}, or about 25 C stars within 400 pc of the sun. On the other hand if the surface density of disk dwarf C stars to $V = 18$ is 1.3 deg^{-2} (de Kool & Green 1995, *ApJ*, 449, 236), then at least $900 \times 1.3 \ / \ 4 = 300$ C stars of the deepest IV–N surveys (Table 1) should be dwarfs.

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