PROFILE OF A KEY PROGRAMME:

Investigation of the Galactic Distribution and Physical Properties of Carbon Stars

T. LE BERTRE, ESO*

N. EPCHTEIN and P. FOUQUÉ, Paris Observatory, France

J. HRON and F. KERSCHBAUM, Vienna Observatory, Austria

J. LÉPINE, São Paulo University, Brazil

After leaving the main sequence, stars of intermediate mass ($1 < M/M_\odot < 8$) evolve through various stages controlled by helium and hydrogen combustion. In one of these stages, called the asymptotic giant branch (AGB), hydrogen and helium burn alternately in shells around an electron degenerate carbon-oxygen core [1]. This core results from the complete combustion of helium during previous phases. Due to the high electronic thermal conductivity, its temperature is insufficient for carbon ignition. At the beginning of the evolution through the AGB, helium burns through triple-alpha reaction in a shell around the core which thus increases its mass (early AGB). This shell disappears progressively leading to the ignition of hydrogen in the surrounding shell. This second source of energy becomes progressively dominant.

As a consequence, the mass of the helium shell increases until helium is reignited violently in it (thermal pulse), then burns quietly while hydrogen in the upper shell stops burning. The star may experience 10 to 20 such cycles of $\sim 10^5$ years duration. During 10% of each cycle, the dominant source of energy is helium combustion, and, during the remaining 90%, hydrogen combustion. When helium is burning, the output luminosity of the star should be lower by 0.5–1 magnitude than when hydrogen is burning. This phase of the AGB – when helium and hydrogen are burning alternately – is referred to as the thermally pulsing AGB (TP-AGB) and often, by ellipsis, the AGB. After the AGB, the star evolves quickly (in $\sim 10^3$–10^4 years) toward the planetary nebula stage at approximately constant luminosity and then dies out as a white dwarf whose temperature and luminosity steadily decrease.

The shells in which nuclear combustion occurs are surrounded by a large convective hydrogen envelope. Following a thermal pulse, material processed by the triple-alpha reaction can be convected upward leading to an enrichment in carbon of the stellar surface. The carbon to oxygen (C/O) abundance ratio being normally inferior to 1, the surface composition is in general oxygen-rich and the stars are said to be of M-type. However, at each thermal pulse, the surface C/O ratio increases and, in some cases, can reach a value larger than 1, meaning that the surface composition becomes carbon-rich (C-type). This mechanism is thought to be responsible for most of the carbon stars (at least those on the AGB) in our Galaxy.

The hydrogen envelope is unstable and more or less regular pulsations develop in it. Stars on the AGB are classified, sometimes arbitrarily , as irregular, semi-regular or mira variables. It is thought that the regular pulsations of miras appear during the quiet phase of hydrogen burning; in general, their periods range from 100 to 500 days, but in some extreme cases may be larger. Following a thermal pulse, the star is thought to become an irregular pulsator of lower luminosity.

Also, through a mechanism which is still not well understood but which appears related to the pulsations, the stellar atmosphere is extended well above the photospheric radius ($R_{phot} \sim$ 1 A.U.). In some cases, it can reach such a large dimension ($\sim 10\ R_{phot}$) that, in its upper layers, refractory elements condense into dust. Dust formation has drastic consequences. Radiation pressure on grains accelerate them away from the central star and, in their motion, they drag the gas outwards. In these conditions, the star becomes surrounded by an expanding envelope of gas and dust. This mass loss phenomenon occurs preferentially during the Mira phases; however, some irregular and semi-regular pulsators are known to be also losing mass, whereas some miras, especially among those of short period (< 350 days), do not appear to be undergoing significant mass loss.

The TP-AGB corresponds to a relatively short stage of the stellar evolution (10^6–10^7 years). However, its study is very important, because stars are reaching their maximum luminosity ($\sim 10^4\ L_\odot$) and experience most of their mass loss during this phase. Although we understand in broad lines the evolution of the stars through the AGB, our knowledge is often only qualitative and many relevant points stay unclear. For instance, the formation and evolution of carbon stars are still the subject of different interpretations. Also, the mass loss phenomenon is not well understood quantitatively; numerical models show that the stellar evolution through the AGB and later is strongly dependent on the mass loss history. Parameters such as helium abundance and metallicity (and in general individual element abundances) might have a strong influence on stellar evolution and, in particular, on carbon star formation; however, there is a lack of observational data in that field.

Finally, these objects during their phases of mass loss appear to be major contributors to the replenishment of the interstellar medium. The knowledge of the composition and of the total return rate of the matter that they are injecting into the interstellar medium at different galacto-centric distances is of basic importance for describing the chemical evolution of the Galaxy. This requires an accurate census of the AGB stars as a function of their location, type and mass loss rate.

In our approach of these problems, we concentrate on galactic carbon stars which are presently undergoing mass loss. Optical surveys are known to be biased against mass losing carbon stars; also, due to the interstellar absorption, they are limited to the solar neighbourhood. However, we have developed a selection method of such objects which is based on near-infrared (1 to 5 μm) and IRAS (12 and 25 μm) photometric data and which has been shown to be efficient and safe [2]. Starting from the IRAS LRS data base, we have then studied the carbon stars in the solar neighbourhood [3]. We now want to extend our study to several locations in the Galaxy, namely the disk at different galacto-centric distances and height above the galactic plane, by surveying, in an unbiased way, the mass losing AGB population in the galactic

* Present address: DEMIRM, Observatoire de Paris, 92195 Meudon Principal Cedex, France.

centre and anti-centre directions, and at different galactic latitudes.

For every sub-sample, the distributions of objects in function of their bolometric luminosities and mass loss rates will be evaluated. As the samples contain stars of different pulsational behaviours, the relationships between type of variability, luminosity and mass loss rate will be investigated. Initial masses of carbon star progenitors will be derived through their distribution perpendicularly to the galactic plane. Because metallicity depends on the galacto-centric distance, its effect on the formation and evolution of carbon stars will be sorted out. Also, the mass-return rate from carbon stars will be determined as a function of the distance to the galactic centre.

This investigation will thus cast new light on the physical properties of carbon stars in different physical and chemical environments, and on the chemical evolution of the interstellar medium throughout the Galaxy.

References

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PROFILE OF A KEY PROGRAMME:

High Precision Radial Velocity Determinations for the Study of the Internal Kinematical and Dynamical Structure and Evolution of Young Stellar Groups

H. HENSBERGE, E. L. VAN DESSEL, M. BURGER, Royal Observatory of Belgium

P. T. DE ZEEUW, J. LUB, R. S. LEPOOLE, University of Leiden, the Netherlands

W. VERSCHUEREN, M. DAVID, T. THEUNS, C. DE LOORE, University of Antwerp, Belgium

E. J. DE GEUS, University of Maryland, USA

R. D. MATHIEU, University of Wisconsin, USA

A. BLAAUW, Universities of Leiden and Groningen, the Netherlands

Purpose

Presently observable sites of star formation corroborate the viewpoint that the birth of stars occurs in groups. Such groups remain gravitationally bound for a shorter or a longer time interval and are catalogued as open star clusters or associations depending on their compactness. As far as the dynamical state of these groups is governed by the conditions in the initial phases of cloud fragmentation, star formation and nebular gas expulsion, they contain valuable information about the star birth processes and the early dynamical evolution of a star forming region (1). Evidently, the younger the groups, the more the present state reflects the initial characteristics.

An important key to the progress in such studies is the availability of information on the internal kinematics in stellar groups: the internal velocity dispersion, and its spatial and stellar mass dependence (2). That purpose imposes an accuracy of the order of a few km/s on empirically derived kinematical quantities for a considerable number of stars covering a large range in stellar mass (3). Nowadays, instrumental technology is at the point that makes such observational efforts feasible. CCD echelle spectroscopy on ground-based telescopes offers the opportunity to record good quality (S/N >50) spectra over the extended wavelength range required in order to acquire sufficient spectral information in early-type stars. CASPEC at the 3.6-m ESO telescope provides the stability and efficiency to obtain a reasonably large set of radial velocities (RVs) with an accuracy that is limited by stellar atmosphere physics or standard system calibration rather than by the instrument. We concentrate on the 3 subgroups in the Sco-Cen OB association and on the more distant young cluster NGC 2244 in the Rosette nebula, aiming at a detailed survey of about 500 O-F type respectively 50 O-A0 type stars. The radial velocity study is part of a continuing observing programme on nearby clusters and associations, including Walraven photometry (4, 5, 6), astrometry from HIPPARCOS, mapping of molecular gas (7), and spectroscopy for classification (6). The theoretical side of our study consists of N-body hydrodynamical simulations of stars embedded in gas (8). Reliable empirical information on the dynamical state of young stellar systems is essential as input in such numerical experiments and in theoretical models.

Interpretation of the Data

The determination of RVs in early-type stars with the required precision is, for several reasons, a challenge. The application of CORAVEL in RV work has opened new frontiers in the study of late-type stars, based on a high quality RV standard system. The use of the CORAVEL technique is unfortunately not extendable to earlier types. The establishment of a better standard system at early spectral types is still essential and our observations are expected to contribute to this task (9). RVs will be measured by the cross-correlation technique (10), although attention will have to be paid to discern systematic effects possibly originating from subsystems of spectral lines; systematic atmospheric motions in OB stars might bias the apparent RVs and could be detectable from lines formed over different atmospherical depths. As a by-product, this should almost certainly lead to addition-