

The evolution of galactic carbon stars

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Abstract. Based on a comparison of observations with new synthetic AGB evolution calculations we propose a revised evolutionary scenario for carbon stars in the solar neighbourhood. From observations we derive that the lowest initial mass from which carbon stars form is about $1.5 M_{\odot}$. This constraint combined with four other constraints (the observed initial-final mass relation, the birth rate of carbon stars, the observed abundance ratios in planetary nebulae (PNe) and the number ratios C/M and S/C of AGB stars) are used to derive the following parameters for the synthetic AGB evolution model. Third dredge-up occurs for core masses above $0.58 M_{\odot}$ and the dredge-up efficiency is $\lambda = 0.75$. We consider a Reimers mass loss law (with a scaling factor η_{AGB}) and the mass loss rate law recently proposed by Bloeker & Schönberner (1993; with a scaling factor η_{BS}). We find $\eta_{\text{AGB}} = 4$ and $\eta_{\text{BS}} = 0.08$. Both models fit the observations equally well.

The model predicts that stars in the range $1.5 M_{\odot} \leq M \leq 1.6 M_{\odot}$ become carbon stars at their last thermal pulse (TP) on the AGB and live only a few 10^4 yr as carbon stars. More massive stars experience additional TPs as carbon stars (up to about 25 for a $3 M_{\odot}$ star) and live up to 10^5 yr. For $M \gtrsim 4 M_{\odot}$ hot-bottom burning prevents the formation of carbon stars. For $M \lesssim 2 M_{\odot}$, M-stars skip the S-star phase when they become carbon stars. The average lifetime of the carbon star phase is $\sim 3 \cdot 10^5$ yr.

The carbon stars for which C/O ratios have been derived in the literature (with values $\lesssim 1.5$) are predominantly optical carbon stars with a $60 \mu\text{m}$ excess. Yet, disk PNe are known with C/O ratios up to about 4. We predict that carbon stars with C/O ratios $\gtrsim 1.5$ are to be found among the infrared carbon stars. The model predicts that the probability that a carbon star has C/O $\gtrsim 1.5$ is about 30%, in reasonable agreement with the observed ratio of the surface density in the galactic plane of infrared carbon stars to all carbon stars. The infrared carbon stars are predicted to be (on average) more massive than the optical carbon stars.

The fact that carbon stars with C/O $\gtrsim 1.5$ apparently never reach the optical carbon star phase (with a detached shell) is probably due to differences in evolution. If indeed infrared

carbon stars are on average more massive (i.e. have larger core masses) than optical carbon stars, the interpulse period is shorter, and the increase in luminosity during the TP is smaller (due to the larger envelope mass). Both effects will decrease the likelihood of a detached shell to occur. We predict that two-thirds of all detached shells around optical carbon stars are oxygen-rich.

Key words: stars: carbon – stars: evolution – stars: mass loss – stars: AGB – planetary nebulae: general

1. Introduction

The study of carbon stars has gained significant momentum by studying their infrared and molecular properties. A large number of carbon stars radiate predominantly in the near- and far-infrared and there are even carbon stars (the infrared carbon stars) with no or very faint optical counterparts.

Different samples of carbon stars, selected on the basis of infrared properties, were studied by Claussen et al. (1987), Thronson et al. (1987), Willems (1988a, b), Jura et al. (1989), Jura & Kleinmann (1989) and Groenewegen et al. (1992). It was recognised that many optical carbon stars have an excess at $60 \mu\text{m}$ (Willems 1988a). This raised questions on the evolution of carbon stars in general, and that in the IRAS color-color diagram in particular.

Willems & de Jong (1988) proposed a scenario for carbon star evolution related to the occurrence of thermal pulses. In this scenario, the oxygen-to-carbon transition causes the mass loss to drop and the oxygen-rich circumstellar shell to expand and dilute. This gives rise to the characteristic excess at $60 \mu\text{m}$ observed in many optical carbon stars. Willems & de Jong (1988), Chan & Kwok (1988) and Egan & Leung (1991) modelled the evolution in the IRAS color-color diagram of a carbon star with a detached shell. They assumed the detached shell to be geometrically thick, i.e. they assumed the detached shell to correspond to the mass loss in the phase of quiescent H-burning prior to

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**Zenta Alksne, Andrei Alksnis, Uldis
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Properties of Galactic Carbon Stars Zenta Alksne, Andreĭ Alksnis, Uldis Dzervitis, 1987 **Properties of Galactic Carbon Stars** Zenta Alksne, Andreĭ Alksnis, Uldis Dzervitis, 1991 Recent advances in the study of carbon stars including the photometry variability colour and spectral characteristics of carbon stars are examined in this text Topics such as classification atmospheric modelling and the determination of chemical composition are discussed Properties of carbon stars of the galaxy Zenta Alksne, Andreĭ Alksnis, U. Dzērvītis, Radioastrofizikas observatorija (Latvijas PSR Zinātņu akadēmija), 1983 **The Stellar Populations of Galaxies** B. Barbuy, Alvio Renzini, 2012-12-06 One approach to learning about stellar populations is to study them at three different levels of resolution First in our own Galaxy secondly from nearby galaxies where stars can still be resolved and thirdly in remote galaxies in which the stellar population can only be studied in integrated light This IAU Symposium covered the entire range of galaxies in its study of their stellar populations Interspersed with theoretical papers the wealth of observational results provides an important state of the art presentation of the progress that has been made in this field **Literature 1987, Part 2** U. Esser, H. Hefele, I. Heinrich, W. Hofmann, D. Krahn, V. R. Matas, L. D. Schmadel, G. Zech, 2013-11-11 Astronomy and Astrophysics Abstracts aims to present a comprehensive documentation of the literature concerning all aspects of astronomy astrophysics and their border fields It is devoted to the recording summarizing and indexing of the relevant publications throughout the world Astronomy and Astrophysics Abstracts is prepared by a special department of the Astronomisches Rechen Institut under the auspices of the International Astronomical Union Volume 44 records literature published in 1987 and received before February 15 1988 Some older documents which we received late and which are not surveyed in earlier volumes are included too We acknowledge with thanks contributions of our colleagues all over the world We also express our gratitude to all organizations observatories and publishers which provide us with complimentary copies of their publications Dr Siegfried B hme retired from his duties as co editor of Astronomy and Astrophysics Abstracts on December 31 1987 Since 1950 he participated in the bibliographic work of the institute He served as a reviewer for the Astronomischer Jahresbericht and became one of the editors of Astronomy and Astrophysics Abstracts in 1969 After his retirement in 1975 he took care of particularly the Russian literature on a voluntary basis for 12 years It is a pleasure to thank Siegfried B hme for his valuable contributions Starting with Volume 33 all the recording correction and data processing work was done by means of computers The recording was done by our technical staff members Ms Helga Ballmann Ms Christiane Jehn Ms Monika Kohl Ms *Why Galaxies Care about AGB Stars* Franz Kerschbaum, Corinne Charbonnel, Robert F. Wing, 2007 These proceedings of an international conference held August 2006 in Vienna Austria demonstrate the relevance of Asymptotic Giant Branch stars and stellar astrophysics as a whole for our understanding of galactic structure and evolution The meeting brought together astronomers from the fields of AGB stars galactic evolution and stellar populations What do we know about the various aspects of AGB stars such as nucleosynthesis

and mass loss that will play a role in our understanding of galaxies At the same time what do galactic models need from the AGB star community and how are AGB stars included in these models What will be the role of AGB star research within the major aims of astrophysics in the coming decades These were the main questions we wanted to discuss at this conference Recent developments in instrumentation such as the Spitzer satellite and current and forthcoming ground based equipment are enabling detailed studies of individual stars and the exploration of ever more distant stellar systems AGB stars are among the first targets that can now be resolved in galaxies outside the Local Group But of equal relevance are the exciting developments that have been achieved in modeling stellar nucleosynthesis mass loss and the evolution of galaxies The book is suitable for researchers and graduate students interested in stellar and extragalactic astrophysics and in physical processes related to nucleosynthesis radiation hydrodynamics pulsation mass loss and the chemical evolution of stellar systems supplied by publisher

Physics and Chemistry of Circumstellar Dust Shells Hans-Peter Gail, Erwin Sedlmayr, 2014 This book explores why dust forms around stars and how to model stellar dust formation and dust forming environments consistently [Literature 1997, Part 1](#) Astronomisches Rechen-Institut ARI, 2013-11-11 Astronomy and Astrophysics Abstracts is devoted to the recording summarizing and indexing of astronomical publications throughout the world Two volumes are scheduled to appear per year Volume 67 records 10 903 papers covering besides the classical fields of astronomy and astrophysics such matters as space flights related to astronomy lunar and planetary probes and satellites meteorites and interplanetary matter X rays and cosmic rays quasars and pulsars The abstracts are classified under more than one hundred subject categories thus permitting quick surveying of the bulk of material published on the same topic within six months For instance this volume records 119 papers on minor planets 155 papers on supernovae and 554 papers on cosmology

Galactic and Extragalactic Infrared Spectroscopy M.F. Kessler, J.P. Phillips, 2012-12-06 The last major conference on infrared astronomy was the IAU Symposium No 96 in June 1980 Since then the discipline has continued to mature and to contribute to all branches of astrophysics One particular area of growth has been in spectroscopic capabilities at all infrared wavelengths The purpose of the Symposium in Toledo was to review the scientific questions to be addressed via infrared spectroscopy and to provide in the proceedings a useful summary of the field The sensitivity of infrared spectroscopic observations is still generally limited by detector characteristics or by thermal background radiation However in recent years improvements in detector technology together with developments in spectroscopic instrumentation have made possible both quite detailed spectroscopy of the brighter members of many classes of galactic sources and also begun to open up some infrared spectroscopy of extragalactic sources The potential of the field in the next decade or two is clear The IRAS mission has completed one of the pre requisites namely an all sky photometric survey Major space missions utilising cryogenic infrared telescopes have been approved in Europe ISO and seem likely in the USA SIRTf plans for space submillimeter telescopes are firming up On the ground large telescopes optimized for infrared observations are now in

operation at high altitude sites and specialized submillimeter facilities are under construction The particular advantages of planned very large telescopes for infrared observations are widely accepted *Physics Briefs*, 1993 **Literature 1992, Part 1** Astronomisches Recheninstitut, 2013-11-11 Astronomy and Astrophysics Abstracts appearing twice a year has become one of the fundamental publications in the fields of astronomy astrophysics and neighbouring sciences It is the most important English language abstracting journal in the mentioned branches The abstracts are classified under more than a hundred subject categories thus permitting a quick survey of the whole extended material The AAA is a valuable and important publication for all students and scientists working in the fields of astronomy and related sciences As such it represents a necessary ingredient of any astronomical library all over the world *Literature 1976, Part 2* S. Böhme, Ute Esser, Professor Dr. Walter Fricke, U. Güntzel-Lingner, I. Heinrich, D. Krahn, Dr. Lutz D. Schmadel, G. Zech, 2013-04-18 Astronomy and Astrophysics Abstracts which has appeared in semi annual volumes since 1969 is devoted to the recording summarizing and indexing of astronomical publications throughout the world It is prepared under the auspices of the International Astronomical Union according to a resolution adopted at the 14th General Assembly in 1970 Astronomy and Astrophysics Abstracts aims to present a comprehensive documentation of literature in all fields of astronomy and astrophysics Every effort will be made to ensure that the average time interval between the date of receipt of the original literature and publication of the abstracts will not exceed eight months This time interval is near to that achieved by monthly abstracting journals compared to which our system of accumulating abstracts for about six months offers the advantage of greater convenience for the user Volume 18 contains literature published in 1976 and received before March 1 1977 some older literature which was received late and which is not recorded in earlier volumes is also included Astronomical Applications of Astrometry M. A. C. Perryman, 2009 The Hipparcos satellite developed and launched by the European Space Agency ESA in 1989 was the first space mission dedicated to astrometry the accurate measurement of positions distances and proper motions of stars Amongst the key achievements of its measurements are refining the cosmic distance scale characterizing the large scale kinematic motions in the Solar neighborhood providing precise luminosities for stellar modelling and confirming Einstein's prediction of the effect of gravity on starlight This authoritative account of the Hipparcos contributions over the last decade is an outstanding reference for astronomers astrophysicists and cosmologists It reviews the applications of the data in different areas describing the subject and the state of the art before Hipparcos and summarizing all major contributions to the topic made by Hipparcos It contains a detailed overview of the Hipparcos and Tycho Catalogues their annexes and their updates Each chapter ends with comprehensive references to relevant literature **AN**

INTRODUCTION TO ASTROPHYSICS, Second Edition BASU, BAIDYANATH, CHATTOPADHYAY, TANUKA, BISWAS, SUDHINDRA NATH, 2010-01-01 This invaluable book now in its second edition covers a wide range of topics appropriate for both undergraduate and postgraduate courses in astrophysics The book conveys a deep and coherent understanding of the

stellar phenomena and basic astrophysics of stars galaxies clusters of galaxies and other heavenly bodies of interest Since the first appearance of the book in 1997 significant progress has been made in different branches of Astronomy and Astrophysics The second edition takes into account the developments of the subject which have taken place in the last decade It discusses the latest introduction of L and T dwarfs in the Hertzsprung Russel diagram or H R diagram Other developments discussed pertain to standard solar model solar neutrino puzzle cosmic microwave background radiation Drake equation dwarf galaxies ultra compact dwarf galaxies compact groups and cluster of galaxies Problems at the end of each chapter motivate the students to go deeper into the topics Suggested readings at the end of each chapter have been complemented

Meteorites, Comets, and Planets A.M. Davis, 2005-11-21 Volume 1 provides a broad overview of the chemistry of the solar system It includes chapters on the origin of the elements and solar system abundances the solar nebula and planet formation meteorite classification the major types of meteorites important processes in early solar system history geochemistry of the terrestrial planets the giant planets and their satellite comets and the formation and early differentiation of the Earth This volume is intended to be the first reference work one would consult to learn about the chemistry of the solar system

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