A&A 500, 241–242 (2009)
DOI: 10.1051/0004-6361/200912159

Astronomy & Astrophysics
Special issue

COMMENTARY ON: RENZINI A. AND VOLI M., 1981, A&A, 94, 175

Welcoming new players to the stage

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I doubt that anyone working in the field of stellar nucleosynthesis for anything but the briefest of times would not know of Renzini & Voli (1981, hereinafter RV81). It appears in this issue of A&A as a true "citation champion", with nearly 800 citations at the time of writing. It is a very valid question to ask why, nearly 30 years after its publication, it is still receiving about 30 citations per year? Re-reading the paper I was struck by a number of things, which I discuss below.

The paper consolidates what was known about asymptotic giant branch (AGB) stars at the time. It thus served as an excellent summary, for non-experts, of what these stars are about. It recognized the importance of AGB stars to the Universe's inventory of carbon and nitrogen. It was later that we recognized more fully that they are crucial to many other species, the most important of which are probably fluorine and the multitude of neutron-capture species. But in this early paper, the emphasis is on the C/O and N/O ratios, as well as the carbon isotope ratio $^{12}C/^{13}C$. The last is a good tracer of hot bottom burning. Indeed, this paper was the first to systematically investigate the effect of hot bottom burning over a range of masses and compositions. Direct integrations were performed to get the structure and the burning correct, whereas analytic approximations were made for all other aspects of the evolutionary calculations.

So what was so important about this paper? In my view it stands at the intersection of many paths. It introduces and consolidates; it synthesizes and emphasizes.

RV81 provides a summary of the past decade's research into AGB stars, distilled, dissected, and rebuilt. Thus it focuses on the importance of these stars at a time when a solid theoretical foundation had only recently been established, in no small part by Icko Iben Jr. and co-workers, as well as others. AGB stars stand at the center of the stage, as important astronomical objects with implications for many areas of astrophysics.

The heart of the paper is the calculation of the nucleosynthesis of carbon and nitrogen in AGB stars. This comes from the dual effects of third dredge-up as well as hot bottom burning. Previous detailed models had shown that many aspects of AGB star evolution followed simple relations, such as the one between the mass of the H-exhausted core M_c and the luminosity, as discovered by Paczyński (1971):

$$L/L_\odot = 59250(M_c/M_\odot - 0.522).$$

RV81 was one of the first papers to use these approximations to develop a population synthesis approach, often known as "synthetic evolution". Many of the formulae used in RV81 were taken from recent papers on AGB evolution, some famous and some unfairly overlooked. For example, the approximations for changes in composition from the first dredge-up were taken mostly from Iben & Truran (1978), whereas those for the second dredge-up were from Becker & Iben (1979), and the third dredge-up again followed the work of Iben & Truran (1978). Parameterization for mass loss and the termination of the AGB was mostly from Fusi-Pecci & Renzini (1976) and Wood & Cahn (1977). In this way, RV81 again brought together many aspects of the state-of-the-art of population synthesis on the AGB at the time, standing as a central foundation, and hence essential reading for anyone in the field. As a consequence of this, the techniques of population synthesis were also introduced to many researchers. Another new player is welcomed to center stage.

Finally, I think the emphasis on hot bottom burning, also known (albeit less memorably) as "envelope burning", was new to many reading the paper. Normally, an AGB star has a small radiative region between the bottom of the convective envelope and the H-burning shell. But it had long been recognized that, in principle, the bottom of this envelope could extend into the top of the shell, to temperatures high enough for nuclear processing to occur. There had been some pioneering work investigating the consequences of this phenomenon by Scalo et al. (1975) but possibly the first reference to it (not by name) was by Uus (1971). Nevertheless, it was not yet a phenomenon of widely appreciated importance. That was soon to change with the observation of bright, O-rich AGB stars in the Magellanic Clouds by Wood et al. (1983). These authors argued that the carbon dredged to the surface of such AGB stars had been processed by the hot bottom of the envelope through CN cycling into N, thus leaving the stars as O-rich despite the action of third dredge-up. Moreover, the discovery by Smith & Lambert (1989) that these stars were also rich in lithium further supported the existence of nucleosynthesis in the envelope. Again, RV81 was in the perfect position to welcome another player to center stage: hot bottom burning was no longer a theorist's curiosity, but now a natural phenomenon.

Apart from the main thrusts, outlined above, the paper also contains many insightful comments. I particularly liked the comments on Ba and CH stars, which planted seeds that would germinate many years later. The discussion of the simplicity of the dredge-up law, then contained on one punched card, recognized the likelihood of a sensitivity that today is known to depend on many stellar properties. It still cannot be described accurately with many lines of code, let alone one punched card. There is also discussion in RV81 about the AGB "super wind" although it was not known by that name at the time.

I asked Alvio Renzini for his memories of the paper, and he had some very interesting comments, which I pass on here. First, why did I only speak to one author? What of the second author, Marco Voli, who was to publish only two papers, RV81 and Fusi-Peci et al. (1980). *"You may wonder what did happen to Voli"*, was the reply from Alvio, *"Marco wanted to get married, hence he needed a secure salary. Soon he got a job at the local supercomputer center, happily married, and left astronomy. Too bad for astronomy! He was really very good."*

Although I know the RV81 paper quite well, I had forgotten that the title referred quite clearly to this as being paper one in a series! What of the rest? Renzini explained, *"As a result of Marco leaving the field, and me being Director of the Astronomy Department, there never was an RV Paper II. At the time my plan was to have Paper II and Paper III, respectively on the post-AGB evolution including the origin of H-poor stars via the last thermal pulse mechanism (including R CrB stars and non-DA WDs), and on the combined evolution of planetary nebulae and their central stars. Because of the lack of Marco and most of my time being absorbed in silly administration duties, there was never a Paper II in a refereed journal. To some extent it was replaced by several invited talks at conferences, and appeared piecemeal in the corresponding proceedings. But I still keep an updated dossier on H-Poor stars, hence Paper II may appear some day, perhaps to celebrate the 30th anniversary of RV81"*.

And what were Alvio's thoughts about the paper after all these years. *"Now, what about the paper itself? What was wrong with it? Well, many things, of course. The idea was to parameterize our ignorance, hopefully bracketing uncertainties in mass loss rates and convection. . . . Still, it soon became apparent that all our models were largely over-predicting the number of bright AGB stars in the Magellanic Clouds. Something had to be wrong in the models, and it took ten years to figure out what it was!"* Other authors noticed this, too, most notably Iben (1981). More on this below.

And one last and sincere comment, with which I think we can all empathize: *"Most of the effort went into producing those many tables in a publishable form."*

Looking back, what have we solved since then and where do we stand in the overall picture of what RV81 was trying to do? The luminous carbon stars were removed by increased mass loss, which was hinted at in RV81. The discovery by Blöcker & Schönberner (1991) that stars with hot bottom burning do not follow the Paczyński core-mass relation also means that the luminosities are higher, hence the mass-loss rates are higher. But, as Alvio recently said, "*How all that really works, it seems to me, still remains to be properly understood.*" Exactly!

Today, the importance of AGB stars as powerhouses of nucleosynthesis is widely recognized. The number of species they produce has steadily grown, and now includes C and primary N, as covered by RV81, as well as F, Na, Mg, and possibly Al, together with all of the s-process elements. No self-respecting study of chemical evolution can ignore them. And RV81 was one of the first to point this out.

The study of synthetic (or parameterized) evolution has grown into the industry of population synthesis, led by the principles illustrated and summarized in RV81. This is a powerful technique for exploring the effect of varying many parameters, or for "parameterizing our ignorance" as Alvio said.

And for the evolution and nucleosynthesis calculations themselves, we are so blessed with computers these days that it is now possible to do direct numerical calculations for the stars of interest, in many cases. With large clusters of computers, we can give each node one star to concentrate on, and in a couple of weeks or so, we can have the full evolution and the stellar yields. It is fast enough to be viable for many studies but not so fast that there is not still a place for the population synthesis techniques discussed in RV81.

I thought I had completed this comment with no self-citations, but there is a genuine reason for this one! I note that near the end of RV81 there is a comment about the need for some "extra" or "deep" mixing on the first giant branch, to reduce the isotopic ratio $^{12}C/^{13}C$ from the first dredge-up prediction of 20–30 down to the observed value of about 15. The paper referred to was Dearborn & Eggleton (1976). It was to be some 30 years later that the same authors (and one freeloader, see Eggleton et al. 2006) discovered what may indeed be the responsible mechanism, providing me with a very personal link to RV81.

References

Becker, S. A., & Iben, I., Jr. 1980, ApJ, 232, 831
Blöcker, T., & Schönberner, D. 1991, A&A, 244, L43
Dearborn, D. S. P., & Eggleton, P. P. 1976, QJRAS, 17, 448
Eggleton, P. P., Dearborn, D. S. P., & Lattanzio, J. C. 2006, Science, 314, 1580
Fusi-Pecci, F., & Renzini, A. 1976, A&A, 46, 447
Iben, I., Jr. 1981, ApJ, 246, 278
Iben, I., Jr., & Truran, J. W. 1978, ApJ, 220, 980
Paczyński, B. 1971, Acta Astr., 21, 417
Renzini, A., & Voli, M. 1981, A&A, 94, 175
Scalo, J. M., Despain, K. H., & Ulrich, R. K. 1975, ApJ, 196, 805
Smith, V. V., & Lambert, D. L. 1989, ApJ, 361, L69
Uus, U. 1971, Nauchnye Informatsii, 20, 60
Fusi-Peci, F., Voli, M., & Rosino, L. 1980, A&A, 85, 269
Wood, P. R., & Cahn, J. H. 1977, ApJ, 211, 499
Wood, P. R., Bessell, M. S., & Fox, M. W. 1983, ApJ, 272, 99