graph form a sparse set, and the reader can pursue the text with confidence.

EUGENE N. PARKER
University of Chicago
Chicago, Illinois

Nucleosynthesis and Chemical Evolution of Galaxies

Bernard E. J. Pagel
Cambridge U. P., New York, 1997. 378 pp. $74.95 hc ($29.95 pb)
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(0-521-55958-8 pb)

Nucleosynthesis is the process by which the chemical elements and their isotopes are formed. In the 1950s, there was great discussion as to whether the abundance pattern observed in the Solar System and in stars was the result of cosmological or of stellar nucleosynthesis. We now believe that more than 90% by mass of the solar abundance pattern is a relic of cosmological nucleosynthesis—that is, a product of the Big Bang.

While dominant from the perspective of mass of material, cosmological nucleosynthesis is not so from the perspective of variety. Big Bang nucleosynthesis made few elements: only hydrogen and some of the helium and lithium. The rest, including the elements needed for making terrestrial planets and people, is thought to be the result of thermonuclear burning in stars, and in particular the relatively rare stars that become supernovae. Thus, nucleosynthesis has become a probe, a diagnostic, of extreme stellar conditions and of the ongoing evolution of stellar systems. The increase in abundance of what astronomers term "metals" (that is, elements with $Z > 2$) has long been used to distinguish the ancient population II stars from the more recent (approximately solar) population I.

The empirical basis of the subject has changed dramatically within the past decade or so, with the detection of gamma-ray lines from freshly synthesized nuclei; pre-solar grains that solidified in supernova events and were later incorporated in meteorites; two of the brightest supernovae (SN1987A and SN1993J) since the invention of the telescope; galaxies at early times (high redshift) in the Hubble Deep Field; and a wealth of other new observations, bearing on supernovae and galactic evolution, from new-technology telescopes in space and on the ground. Our understanding has also risen with the increase in computer power. Given the rapid growth in this field, any new monograph relating to the subject is a welcome aid in organizing the thicket of ideas and data.

The strength of *Nucleosynthesis and Chemical Evolution of Galaxies* by Bernard Pagel is in its treatment of the connection between astronomical observations and phenomenological models of the evolution of galaxies. The author has been a leader in this area for many years, and the book reflects his interests. The discussion of galactic evolution begins on the two-hundredth of 378 pages, and so occupies the last half of the book. The discussion of galactic evolution uses as a paradigm the "one zone" model, which has the great advantage of simplicity but is sufficiently unlike real galaxies to give rise to the worry that its parameters are poorly connected to what is really occurring. The notions of what these parameters mean may crowd out real understanding of the underlying processes. However, in Pagel's hands, this phenomenological model brings some order to a messy subject.

What of the first half of the book? The discussion of spectral-line formation, based upon the traditional curve-of-growth method, gives an indication of the issues in abundance determinations. Model atmosphere simulations are now the methods of choice, but many of the uncertainties are shown more clearly from this historical approach. Chapter 4, on cosmological nucleosynthesis, contains an excellent critical review of the observational constraints at present and is a valuable addition to the literature. For insight into the underlying issues of physics, the reader will need to delve into the reference list (Rocky Kolb and Michael S. Turner's *The Early Universe*, Addison-Wesley 1990, is my favorite, although somewhat old by the standards of this rapidly evolving field).

Pagel includes a fairly extensive index and six appendices. Each chapter is followed by notes and problems. One appendix gives hints for solving the problems, which is a nice touch. The problems are not as intimately connected to the text as in Don Clayton's *Principles of Stellar Evolution and Nucleosynthesis* (McGraw-Hill, 1968 and U. Chicago P., 1984). The reference list is a bit lean, but probably adequate as a starting point.

From my perspective, the book does have significant flaws. The causal connection between the astronomy and the physics often leaves the reader needing more information; the discussion is simple, but could have been more complete without becoming more complex. In the discussions of the underlying physics, the emphasis is on phenomenology rather than analysis. There are only about seven pages on the evolution of massive stars, even though they

have done almost all of the nucleosynthesis since the Big Bang—that is, almost all that can be seen in the evolution of galaxies. The book gives no explanation of why the massive stars are so effective as nucleosynthesizers, or why the physics of their evolution produces the characteristic element abundance patterns, although the answers have been available for more than two decades now (neutrino cooling is the clue). The evolution of other stars is discussed in more detail, but still tersely. The r-process and s-process of neutron capture are mentioned, but with little depth.

This is a good and useful book nevertheless. The astrophysicist will find the astronomical lore enlightening, and the astronomer will find references to discussions of the underlying physics. This could be used as a text for a graduate course (it derives from a course at Copenhagen University), if the weaknesses are supplemented by lectures or other material.

DAVID ARNETT
University of Arizona
Tucson, Arizona

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