The Solar Corona

Leon Golub and Jay M. Pasachoff
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The awesome appearance of the solar corona spilling out around the Moon during a total solar eclipse is the poor man's view of one of the outstanding scientific puzzles of modern astronomy. The corona is the tenuous outer atmosphere of the Sun, heated to more than 10^6 K and extending far out into space. Where the magnetic field is sufficiently weak (10 gauss), the corona expands away into space to form the supersonic solar wind at large distance from the Sun. Where the magnetic field is strong (50 gauss), the gas is trapped and the density may build up to 10^{10} ions and electrons per cm^3, providing the x-ray emission from the Sun.

For researchers, the challenge is to work out the physics of the heat input that creates and maintains the mega-degree temperature. Both the mass loss and the x-ray emission from late main-sequence stars like the Sun are the result of the heat input, but we cannot assert why stars are obliged by the laws of physics to lose mass and emit x-rays until the riddle of the corona is solved. *The Solar Corona* by Leon Golub and Jay Pasachoff is all about the riddle. It provides a welcome update on the immense progress that has occurred over the last 20 years in describing and defining the scientific problem.

Golub is an international leader in studying the x-ray corona. He was involved in x-ray observations from the beginning of that technology, and he recently obtained the sharpest x-ray pictures ever with his Normal Incidence X-ray Telescope, a monumental achievement of high technology, lofted above the terrestrial atmosphere for a few minutes at a time on a sounding rocket. Pasachoff is well known for his expository prowess in describing astronomical phenomena, and his comprehensive textbooks on astronomy are widely used at universities throughout the country.

The Solar Corona is a pleasure to read. It is generously illustrated with graphs, diagrams and photographs at appropriate places in the text. The introduction and historical review are of interest to the scientist and nonscientist alike; they outline the long campaign over the past 80 years to understand the nature of the mysterious corona of the Sun. One reason the coronal riddle has been so difficult is that the essential action on the visible surface of the Sun is on small scales (10^2 km, well below the resolution of ground-based observations). Only in the last few years has it become possible to glimpse the essential dynamical magnetic elements. The corona itself is extremely faint, representing only about 10^{-6} of the total emission from the Sun. So the observer is pursuing a whisper in the ear-splitting roar of a jet engine. Observations from spacecraft are essential at ultraviolet and x-ray wavelengths, and ground and space observations play complementary roles.

It is looking more and more as though both the magnetically open coronal hole, which produces the fast solar wind, and the magnetically confined x-ray corona are heated by myriad small flares, each flare involving the explosive conversion of magnetic free energy into heat in the distinct environments of the coronal hole and the x-ray corona. The magnetic free energy is continually replenished by the convective shuffling of the photospheric footprints of the magnetic field. *The Solar Corona* provides a broad review of the state of things at the visible surface and in the transition region and corona above, from which the inference of small flaring is drawn, including a description of the flare phenomenon, both large and small. There are also sections on the basic ideas of radiative transfer and the interpretation of the radiation from the optically thin corona, followed by a brief presentation of the microscopic structure of the tenuous coronal plasma.

Now, no monograph, even one as excellent and interesting as *The Solar Corona*, can avoid human error. For instance, equation 3.47 is not the solution to the differential equation 3.46 as claimed. But it is no great matter, because all of the equations that follow are correct. In equation 7.60, the partial derivative with respect to time should be the Lagrangian derivative. On page 152, there is the curious statement that the volume of plasma cannot be treated as a fluid unless the plasma parameter is large compared to one. The usual derivation of the Debye radius is no longer valid, but the plasma is no less a fluid on large scales. On page 75, the opacity is defined as a measure of the ability of the radiation to pass without absorption; the authors meant to say that the opacity is a measure of the *in*ability to pass without absorption. Anyone who has struggled with writing long review articles or monographs, only to find some obvious slips remaining in the published result, will be comforted to know that every author goes through the same ordeal. The errors in the present mono-

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

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Nucleosynthesis and Chemical Evolution of Galaxies

Bernard E. J. Pagel
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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