The Loop Paradigm

Plasma Loops in the Solar Corona. R. J. Bray, L. E. Cram, C. J. Durrant, and R. E. Loughhead. Cambridge University Press, New York, 1991. xxiv, 498 pp., illus. $99.50. Cambridge Astrophysics Series.

The sun, like other stars of its type, possesses an extended outer atmosphere, or corona. Although the corona is so faint at optical wavelengths that it is visible only when the solar disk is occulted (as during an eclipse), the coronal gas is hot enough—up to several million degrees—that the corona is a copious source of x-rays.

By the late 1940s, astrophysicists including L. Biermann, E. Schatzmann, and M. Schwarzschild had pointed out that the energy required to maintain the high coronal temperature is probably derived from the mechanical energy of convective motions in the solar photosphere. These motions generate acoustic waves, and it was thought that these waves would propagate upward and eventually dissipate, thereby supplying heat to the corona.

The past 40 years of continued theory and observation have upheld some features of this early picture, but it is fair to say that changes of emphasis add up to nothing less than a true paradigm shift in the way we view the solar corona. Although it is clear from any eclipse photograph that the corona is highly structured, many early workers, motivated in part by the need to define a mathematically tractable problem, idealized the corona as a smooth, spherically symmetric atmosphere and sought to understand its average properties. Although it was equally well known that the sun has a global magnetic field, and that especially near sunspots the field is quite large, the magnetic field was generally deemed to be an inessential ingredient in understanding the coronal heating process.

Theory and observation combined to change the simple picture of a spherically symmetric corona heated by acoustic waves. On the theoretical side, detailed hydrodynamic models showed that waves would either be dissipated or reflected downward before they could reach coronal heights. On the observational side, x-ray and far-ultraviolet observations made from space showed that the corona is highly structured and that most of the radiation from coronal plasma comes from material that is confined to magnetic loops. Detailed comparison of magnetic field and x-ray measurements has suggested strongly that the heating mechanism is intrinsically electromagnetic. Thus loops are now seen as the basic unit of coronal structure, and both the thermal and the dynamical properties of loop plasma are thought to be largely controlled by magnetic fields.

Despite the apparent success of the loop paradigm as a basic framework, many basic questions about coronal loops remain unanswered. Observations of loops do not spatially resolve them, so fine structure goes undetected. The coronal magnetic field is not directly measured but must be extrapolated from Zeeman measurements in the lower atmosphere. Although it is generally accepted that the magnetic field of the loop has erupted from the solar interior and remains attached to the subsurface field, the processes that control the emergence and destruction of magnetic flux are not well understood. The mechanism (or mechanisms) that heats the loops is likewise uncertain. Finally, the events that govern the rapid release of magnetic energy in loops, causing a solar flare, are still unclear.

Plasma Loops in the Solar Corona is the first book-length exposition of the properties of coronal loops. Bray and Loughhead wrote the first four chapters, which begin with a historical introduction to the subject and go on to describe "cool" loops (those with temperatures less than about a half million degrees), "hot" loops, and loops associated with flares. Durrant wrote the fifth chapter, on the structure, dynamics, and heating of loops, and Cram wrote the sixth, which attempts to unify the loop phenomenon with the structure of the solar interior and applies the loop model to the coronas of the sun and other stars. Literature up to about 1988 is cited. The book is written for advanced graduate students and scientists working in the field.

The early chapters lay out the complexity of the loop phenomenon, with discussions of optical, ultraviolet, x-ray, and radio observations. Bray and Loughhead trace the advances in instrumentation that underlie these observations and often discuss methods of data analysis. Yet, despite the summaries of loop properties that appear at the end of each chapter, much of this material has an anecdotal flavor: we learn about studies of particular loops, but little about their appearance over space and time on the solar surface or correlation with the solar cycle. These chapters are valuable primarily as a survey of observations, and as such they provide a detailed guide to the literature, with more than 400 references cited.

The fifth chapter is a broad survey of loop models, including theories of thermal and magnetohydrodynamic stability and a discussion of heating mechanisms. This chapter attempts to be self-contained in that it provides introductory material on magnetohydrodynamics and fluid mechanics. It is made clear that there has been little integration of theories of the energy balance of the thermal plasma with theories of the magnetohydrodynamic equilibrium of the loop. The unknown heating mechanism lies at the heart of this missed conjunction. Durrant gives a balanced discussion of theories of heating by magnetohydrodynamic waves (so-called AC theories) and direct-current dissipation (DC theories), although his discussion of mode conversion and phase mixing should have included work by Y. Q. Lou, R. Rosner, P. Simillon, and R. Sudan as well as the older work cited. Likewise, the discussion of the formation of electric current singularities, originally proposed by E. N. Parker and extensively written on by him and others, deserves a fuller discussion—if only to summarize the present controversy. None of these theories is fully self-consistent, and the constraints imposed on them by observations are weak at this time.

The final chapter is an ambitious attempt to place coronal loop models in the overall context of solar and stellar physics. Cram briefly reviews theories of the generation of the solar magnetic field and its interaction with convective motions near the solar surface. This summary underlines the need for high-resolution observations of the photospheric magnetic field and its extension into the corona. The final sections discuss evidence for coronas and loop structures on other stars.

Plasma Loops in the Solar Corona summarizes a subject that appears at first sight to be extremely specialized but turns out to be vast. The observational basis for the subject rests on the spectroscopy of hot plasmas, much of which must be carried out from space, above the absorbing terrestrial atmosphere. Theoretical models of loops require magnetohydrodynamics and plasma physics as well as the thermodynamical and radiative properties of hot gases as their input physics. Challenging as the field may be, it promises to reward us with an understanding of the outer atmospheres of the sun and stars.

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Very Luminous Objects

Active Galactic Nuclei. R. D. BLANDFORD, H. NETZER, and L. WOLTJER. Springer-Verlag, New York, 1990. xii, 280 pp., illus. $49.50. Saas-Fee Course 20, Lecture Notes 1990.

The active galactic nuclei (AGNs) are the most luminous objects in the universe. Many have power outputs in excess of a trillion times that of the sun, and this energy generation occurs in a region no larger than the solar system. They are the most distant objects visible: the furthest ones emitted their light when the universe was only 10 percent of its present age. Since their discovery 30 years ago, the central questions have remained the same: How do they make their energy, and can they be used as probes of conditions and evolution in the early universe?

This work is based on a series of lectures given by the three authors. The first section, by Woltjer, nicely sets the stage for what follows. It describes the range of phenomena we hope to understand, including the various subclasses of AGN (the quasars, Seyfert galaxies), and provides a census of their population.

The second section, by Netzer, outlines the interpretation of the ultraviolet and optical spectrum. Careful analysis of the emission lines, and the underlying continuum, is the only way we can hope to be able (someday) to measure the chemical composition and luminosity of an AGN directly. Then it will be possible to determine the chemical enrichment of the earliest galaxies and the deceleration of the universe by observing quasars at high redshift. The problem is one in nonequilibrium thermodynamics, since this is the physical state of the gas making the observed spectrum. Netzer is a leader in the numerical simulation of the emitting regions of AGNs, and this section of the book is certain to become a much-quoted reference for studies of the emission-line regions.

The last section, by Blandford, tackles the most difficult problem of all, how and why the AGNs emit so much energy. Quasars were most common in the distant past, when galaxies were being formed. The release of gravitational potential energy, as matter is accreted into the center of a galaxy, is thought to play a major role in producing energy. Blandford is a leader in non-thermal processes and helped develop today's "standard model" of AGN energy generation near supermassive black holes. The theoretical discussion is nicely integrated with the observational consequences, so this section will be a useful aid for both observations and theory.

This book will become the definitive graduate text on AGNs. The attempt to understand a phenomenon such as AGNs cannot be limited to specialized subfields such as radio astronomy or numerical hydrodynamics, and it would be impossible for any one person to combine the breadth of expertise found here. The editors have done a nice job of tying the three sections together. Although there are other review articles that compare in some way to each of the three sections of this book, there is no single place where an effort has been made to bring things together in a coherent manner.

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Dark Matter

Molecular Clouds. R. A. JAMES and T. J. MILLAR, Eds. Cambridge University Press, New York, 1991. xxii, 336 pp., illus. $59.50. From a conference, Manchester, U.K., March 1990.

We tend to associate astronomy with the study of stellar objects, which are visible by their own emitted light, or, closer to home, of planetary objects, which are visible by reflected sunlight. The universe, however, has a comparable amount of "dark matter" that is of equal importance astronomically but that is, perforce, more difficult to study. Simple consideration of cosmic elemental abundances suggests that 90 percent of this matter is hydrogen. The distribution of atomic hydrogen is now reasonably well known from radiofrequency observations of its fine structure transition at a wavelength of 21 centimeters. Observation of molecular hydrogen is more difficult. Cold H_2 can be observed via ultraviolet electronic absorption lines, but only from above the atmosphere and against appropriate continuum sources. Hot H_2 can be observed via weak infrared vibrational emission lines, but these also suffer from telluric obscuration. Nonetheless, the existence of large amounts of H_2 in "dense molecular clouds" was inferred in the 1970s from radiofrequency and microwave observations of a myriad of trace molecular species, the most abundant of which is carbon monoxide. Study of this molecular interstellar gas is now an important subdiscipline in astrophysics.

Despite the current vitality of molecular radioastronomy (or perhaps indeed because it is still evolving so rapidly) there are few volumes that provide a good overview of the subject, although several reviews treating various aspects are available in the periodical literature. An attempt to provide a comprehensive collection of survey articles was reviewed recently in these pages (26 October 1990, p. 576). As in any active field there are frequent international conferences, the proceedings of which can provide a glimpse into current activity. *Molecular Clouds* contains the proceedings of such a conference held a year ago. The volume is very much a mixed bag, with nearly a dozen invited review talks and about two dozen each of short contributed papers and poster presentations. The latter two categories are essentially primary literature unlikely to interest those who do not regularly scan the *Astrophysical Journal*.

What I found most interesting about this volume is the picture that emerges of the pivotal role of carbon monoxide for tracing the invisible hydrogen gas and the problems associated with quantifying the relationship between them. There have been two large-scale surveys of CO emission, confined mainly to the Galactic plane, and one of these is discussed in some detail in the somewhat historic and chatty introductory review by Thaddeus. Blitz surveys complementary CO observations away from the Galactic plane. In fact, half the papers here discuss observations of CO. Despite a wealth of data, the appropriate method of inferring hydrogen mass from CO line intensities remains controversial, although there is general agreement that the ratio is not a universal factor but depends on a number of local parameters. A basic problem is that calibration requires an independent means of determining the hydrogen mass for at least some regions where CO is observed. The most thorough studies to date use infrared or gamma-ray surveys for this. The infrared surveys measure mostly dust particles associated with the gas, so some assumption about the gas-to-dust ratio is necessary. The gamma-ray surveys measure the product of local matter density and (the somewhat uncertain) cosmic ray flux. Differing perspectives on these and other methods are found in papers by Bloemen and by Wolfendale. Since the calibration studies have relied mainly on data from our own Galaxy, their utility for interpreting the very interesting extragalactic data is an important question, and this is discussed cogently by Booth, who also gives arguments