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The active Sun

Following the sun we left the old world – Christopher Columbus

The title of this chapter presupposes that there exists a Sun that is Non-active or Quiet. Modern research, however, is discovering more and more that there is no such thing as a perfectly placid Sun. Activity occurs on all scales at all times in the solar atmosphere. As solar instrumentation improves, the subsequent advances in our knowledge of what physics controls this continuous activity will lead to a better understanding of how stars like the Sun work. Ever since Fabricius and Galileo first confirmed that sunspots were solar phenomena, the nature of our nearest star has been a subject of scientific investigation. The culmination of this line of inquiry is the present-day field of solar physics, the goal of which is to investigate the constantly changing Sun. Solar activity in all of its myriad forms, from cyclical variations of the whole Sun to small-scale transient phenomena, is ubiquitous in solar research. Improved instruments now demonstrate that even the quiet Sun is far more dynamic than once thought. The intrinsic variability of the Sun provides a touchstone to the intricate workings of stars. In this chapter we will explore the active Sun and examine how our knowledge of this dynamic star has blossomed in this Century of Space Science.

An important early tool in the exploration of solar activity was the solar eclipse. The popular attraction of eclipses remains strong today but their scientific value has steadily declined since the invention of the coronagraph by French astronomer Bernard Lyot in 1930. The eclipse expeditions of the late nineteenth and early twentieth centuries are a testimony to the dedication of early solar astronomers. The word “expedition” itself conjures up the effort involved in observing an eclipse since, more often than not, the eclipse was best observed from a remote and inhospitable part of the planet. Despite all of the hardships, the astronomer was often rewarded with wonderful scientific data and occasionally an important discovery. Eclipse observations provided a strong foundation for the subsequent research into solar activity.

Eclipses always yielded spectacular displays in the darkened sky, but until 1836 the coronal phenomena observed were thought to originate on the Moon or even in the Earth’s atmosphere and, therefore, merited little scientific interest. The last four decades of the nineteenth century, however, were witness to many discoveries which laid the foundation for the study of solar activity in the solar corona. Eclipse data, in particular, were responsible for a number of these discoveries and significantly advanced our knowledge of the Sun and its behavior: the solar origin of prominences (1860; Pietro Secchi, Warren De La Rue), the discovery of helium (1868; Jules Janssen), the existence of a chromosphere (1870; Charles Augustus Young), the unequivocal identification of the corona as solar (1871; Jules Janssen), and the relation between sunspot cycle and corona (1878; Jules Janssen). The eclipse of 1878 was particularly interesting as it occurred during solar minimum and exhibited a corona with a marked equatorial extension (in contrast with the nearly circular corona observed in 1871). It was noted that the coronal streamers, as the extensions off each limb were called, had a strong resemblance to magnetic lines of force and it was proposed that the Sun must, in fact, be a large magnet (Frank Bigelow in 1889 and Störmer in 1911). Subsequently in 1912,
Henri Deslandres suggested that the forms and motions of prominences seen during solar eclipse appeared to be influenced by a solar magnetic field. The link between magnetic field and the emitting plasma on the Sun was beginning to take shape.

The key to understanding solar activity is the Sun’s ever-changing magnetic field. It is now virtually certain that all solar activity, and perhaps the solar atmosphere itself, is there because of solar magnetism. However, it is only in this last century that the fundamental importance of the magnetic field for solar phenomena has been realized. The epochal discovery of magnetic fields on the Sun by American astronomer George Ellery Hale in 1908 signalled the birth of modern solar physics. This realization led to fundamental progress in our understanding of many physical processes occurring on the Sun and set the foundation for most of the solar physics advances in the modern age. The discovery of solar magnetism arose out of Hale’s supposition that the distinctive alignments of penumbral filaments in sunspots bore a remarkable resemblance to the iron filing patterns formed around the poles of a bar magnet. To test his hypothesis Hale looked for the line splittings expected from the newly-discovered Zeeman effect: the first application of this in astronomy. Using the spectrograph at the recently completed solar tower telescope at Mount Wilson, Hale was immediately rewarded with a clear line-triplet indicating the presence of a strong magnetic field.

The study of the Sun’s magnetic field was limited to strong-field regions, such as those of sunspots, until the invention of the solar magnetograph in 1952 (see Figure 1). Harold Babcock and his son Horace used the first ever solar magnetograph to discover that the magnetic field existed outside of sunspots and was, in fact, distributed across the whole solar surface. The solar magnetograph, refinements of which are now used in virtually every major solar observatory in the world (there is even one currently in space), introduced an improvement of about two orders of magnitude in the sensitivity of magnetic field measurements over the contemporary visual or photographic techniques. Without these observational breakthroughs we would know very little of what turned out to be the active Sun.

Solar physics research was, literally, taken to new heights by the advent of observations from space. The age of space astronomy has its roots in the flight of a captured World War II German V2 rocket on 10 October 1946 from White Sands Missile Range in New Mexico. This rocket, carrying instruments to observe for the first time the far ultraviolet spectrum of the Sun, reached an altitude of 90 km above the Earth’s surface. However, despite the increasing sophistication of rocket-borne experiments in the following decade and a half, discoveries were hampered by the very short flight durations attainable by these sounding rockets.

In March of 1953 the National Academy of Sciences appointed a National Committee to oversee US participation

Figure 1  Two of the original magnetograms of the Sun taken with the Babcock magnetograph in July 1953. (Reproduced with permission of H.W. Babcock and the American Astronomical Society.)