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Arvind Bhatnagar
William Livingston

Fundamentals of SOLAR ASTRONOMY

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Fundamentals of SOLAR ASTRONOMY

"The point of living is to study the Sun"

Anaxagoras (499—428 BC)

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Cover page. Displaying the sun as Surya — the Sun god; ancient emblem of the dynasty of Mewar (Udaipur, Rajasthan, India) kings, along with solar Coronal Mass Ejections and prominences.

FUNDAMENTALS OF SOLAR ASTRONOMY

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Professor M. K. Vainu Bappu
(1927 – 1982)

This book is dedicated to our friend and mentor
Professor M. K. Vainu Bappu.

Arvind Bhatnagar
William Livingston

Preface

The aim of this book is to inculcate, motivate and inspire readers to take up the study and observations of our nearest star – the Sun, and enjoy its beauty and glory. Our Sun is the only star in the Universe which presents its surface details, as there is no other star near enough to show features of the order of a few hundred kilometers. Extending from deep inside the Sun to the solar surface and beyond, the Sun manifests a variety of phenomena, ranging from a few hundred kilometers to thousands of kilometers in size, temperature ranging from a few thousands to several million degrees and in temporal domain from a few seconds to several decades and dynamical events with speeds from a few tenths of km/sec to thousands of km/sec. Thus why not make use of this unique celestial laboratory to study the physical characteristics of matter and to understand other celestial bodies in the Universe.

The remarkable dynamical phenomena occurring on the Sun, such as mass ejections in the form of eruptive prominences, filaments, surges, sprays, Coronal Mass Ejections, transient events; like solar flares, ephemeral regions, sunspots, granulations etc., make the study of the Sun extremely fascinating and interesting. One can see various solar phenomena occurring *right in front of one's eyes* and follow them for hours and days. The purpose of this book is to present some of these fascinating phenomena, in their full glory to the readers through ample number of illustrations, sketches and photographs.

This book is mainly addressed to those who are starting to study the Sun and want to pursue an advance course in solar physics, but lack the basic knowledge of solar astronomy. To encourage young people, especially the budding amateur solar astronomers, we have pointed out to

the high quality early visual solar observations made in the seventeenth and eighteenth centuries, through small telescopes by Father Secchi, Langley, Captain Tupman, Professor Fenzley and many others of solar granulations, sunspots, prominences, spicules, solar corona etc. We have emphasized that keen, persistent and careful visual observation through small telescopes can not only provide extremely useful scientific data, but also gives great joy and fun, and one can always think of serendipity discovery that is just awaiting to be made about the Sun. Thus people with limited means in terms of equipment need not be discouraged, but follow the example of early observers and take up observing the Sun and contribute to its global watch.

From time immemorial Sun has occupied a central stage in all ancient cultures. It had been and still worshiped in many cultures, countries and civilizations. Our ancestors had considered the Sun as god and goddess, because it gave them light, warmth, seasons and the very existence of life on this planet. To perpetuate its glory and might, all the ancient cultures created mythological stories about the Sun, and interwoven them in their daily cultural life and rituals. To give an idea about these ancient myths, in Chapter 1 we have briefly described them, as these are not readily available in the standard texts on solar astronomy. The readers will note that actual solar observations during the year were very important activity in ancient times, to mark the solstices and equinoxes, which were part of the cultural, religious and agricultural life. For this purpose huge structures like the ***Stonehenge*** were built more than 5000 years ago.

We have tried to keep to bare minimum the use and derivation of mathematical equations, only some basic knowledge of physics and mathematics is required to understand the text. There is some amount of repetition also, which to some extent it is intentional so that various Chapters could be read independently too.

In Chapter 2, we have given a brief description of some of the operating solar optical and radio observatories, ranging from very small observatories with 10-15 cm aperture telescopes to the state-of-the art observatories, such as the New Swedish Solar Observatory, the Dutch Open telescope, the German Vacuum Solar Observatory, the THEMIS and the National Solar Observatory at Kitt Peak, USA. It has been pointed out that even small observatories have and are significantly

contributing to synoptic solar observations, in spite of available highly sophisticated solar telescopes and space missions. A brief description of some of the operating and planned space solar missions has also been given. We feel guilty of the fact that in this list of solar observatories we have not been able to include the enormous contribution being made by amateur solar astronomers.

In Chapter 3, some of the basics of solar structure, energy generation, transport, irradiance, solar rotation and the neutrino puzzle are discussed. Chapter 4 gives a description of the *Quiet Sun*, although the Sun is never quiet, it is in *active* all the time. In Chapter 5, we present the *Active* aspect of our Sun, covering activities in the photosphere, chromosphere and the corona. To appreciate and enjoy the *Sun in Action*, the readers are advised to see time lapse movies now available from Websites of several solar observatories.

In Chapter 6, we have given methods and techniques to determine basic solar parameters, such as the Solar Parallax, mass, distance, temperature, heliographic coordinates of solar features. These may be found useful for those initiated in solar astronomy from other disciplines. Chapter 7 covers in some detail, description of solar optical instruments, especially the various types of light feeds (solar telescope), spectrographs, imaging equipment, like narrow band filters and spectrohelographs. In this Chapter we have gone to great length in discussing the principle and working of birefringent filters, this is essentially because narrow band filters are the 'heart' of any solar observational investigation, and description of such filters is not readily available in standard textbooks. We hope that the discussion given on the birefringent filter will familiarize the readers enough, not to consider it as a 'black box'.

The fascinating phenomenon of the total solar eclipse is discussed in Chapter 8, emphasizing the importance of eclipse observations, and what we have learnt and what more can be learnt. Since the early days in nineteenth century, enormous scientific data and results are now available, but still some unsolved problems persist. However, we urge the newcomers to this field, that there is nothing like watching the whole event of the total solar eclipse with naked eyes (of course after taking due care), and suggest the readers of this book to witness at least once,

one of the nature's most beautiful and fantastic phenomenon.

In Chapter 9, we take the readers to the solar interior and introduce the new subject of *helioseismology*. We have not dealt the topic in great detail, but have amply discussed the basic principles of helioseismology and given the latest results obtained through this technique.

In Chapter 10, is a description of personal experience of a solar observer to share his joy of observing the Sun.

The authors feel apologetic that it was impossible to meet out all the references to the enormous wonderful work that is being carried out in solar astronomy and mentioned in this book. Actually, the scientific literature in all sciences, especially in Astronomy is inflating at an exponential rate and it has become almost impossible to keep track of all the research papers in spite of the 'information highway' and Internet access etc. In this book we have tried to mention at number of places older references on the subject, which had been often forgotten or left out or people are simply not aware of them. Lately, it has been noticed that younger people hardly refer to literature earlier than 10 years, and in this process either miss the earlier findings or '*re-discover*' the same phenomenon. We found it interesting to look in the past literature and were amused to note that how the concept about our Sun has changed. In the eighteenth century, even the great astronomer Sir William Herschel thought that the Sun could be inhabited and that sunspots are windows to the interior! Now after 300-350 years, we talk of resolving features in the order of 70-100 kilometers, know precisely the physical condition of even the solar interior and are preparing to see the Sun in 3-dimension (STEREO mission).

We strongly feel that to bring out the real beauty of our Sun and its activities, it is most essential to display it through high quality illustration and pictures, which are now available from modern ground-based solar telescopes and solar space missions such as YOHKOH, TRACE, EIT and SXI. Therefore, in this book we have tried to present as many good pictures and illustrations as possible, those would inspire and motivate the beginners to take up Solar Astronomy, as a subject for study, enjoyment and fun. We believe that one good illustration is equivalent to thousand words; hence this book contains a fairly large number of illustrations, which is the crux to manifest the beauty of our Sun. The

Publisher, World Scientific Publishing Company, Singapore (WSPC) had been generous to allow large number of high quality illustrations appearing in this book.

We wish to acknowledge several authors, publishers and individuals who have provided and permitted us to make use of photographs, illustrations for this educational book. We would like to record our gratitude to Ashok Ambastha, Nandita Srivastava, Sushant Tripathi, Kiran Jain of the Udaipur Solar Observatory for their help in preparing this manuscript. Jingxiu Wang and Li Ying sent us photographs of Chinese observatories and Sun's myth in China. Takeo Kosugi and his student K. Yaji helped to process YOHKOH images of January 14, 1992 event. Paul Gilman and Steve Padilla sent us a latest picture of the 150-foot Solar tower telescope at Mount Wilson Observatory and K. Sundararaman of Kodaikanal Observatory sent us pictures of the Observatory and spectroheliograms. Major typing and computer setting of diagrams, text etc., was done very devotedly by Ms. Anita Jain and helped by her husband, Naresh Jain, the authors feel indebted for their help. One of the authors (AB) acknowledges receipt of partial financial grant from the Indian Space Research Organization (ISRO) for this project, and wishes to thank Professor U. R. Rao, Chairman, Physical Research Laboratory's Governing Council and Dr. K. Kasturirangan, former Chairman, ISRO for their interest in this project.

We have taken great care that no mistake has crept into the text, but if any, we shall be responsible. The Publisher, WSPC has taken great care to perfectly reproduce the large number of color and black and white illustrations presented in this book.

Arvind Bhatnagar,
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William Livingston,
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Contents

Chapter 1

Ancient Solar Astronomy

1.1 Mythologies about the Sun

Among cultures of antiquity, the Sun has always occupied a central position. It caught the imagination of early man because the Sun gave him warmth, light, life, and acted as his clock. Because of this, he made the Sun his god and goddess, and worshipped it. Even today, in modern times, the Sun is worshipped in many countries and religions. Number of temples dedicated to the Sun god had been built. Many of the great cities of the ancient world were known as "The City of the Sun", such as Baalbec, Rhodes, and Heliopolis. More than just cult centers, scientists and astronomers of the day who lived in these cities studied the Sun, Moon and planets, in an effort to devise accurate calendar systems. What are the folklore and mythological stories about our Sun from these civilizations? It is of interest to note that many of these stories originated at different times in history, and in far off places, yet they still possess meaning to us.

1.1.1 *In Early Europe*

In early Europe generally the Sun was considered as a male god, but among the Indo-Europeans it was a female goddess, and the Moon was a male god. In German, and Gaelic languages the word for Sun is still female. In many other languages a common solar association is still reflected, for example: in Sanskrit, the Sun is called 'Surya' and Savitra or Savita, in Gaul 'Sulis', in Lithuanian 'Saule', and in Latin and

German 'Sol'. In addition, in Sanskrit the solar year is called 'Sama', which is similar in modern English to the word 'summer', and Celtic words such as 'Samhain' mean summer's end. Commonality is found in the names of the Sun among various cultures.

1.1.1 *Norse*

Europe has a long history with celestial deities. It was, in fact, named after the goddess Europa. Long ago a tribe known as Teutons colonized Europe or what is now called the European countries. Teuton people stemmed from an even older people known to us as Indo-Europeans. Early Teutons believed in a Sun goddess, Sol, and a Moon god Mani. Today in the German language, Sun is addressed as Die Sonne, a female noun, and the Moon as Der Mond, male. Like the dawn goddesses of the Greeks, Hindus and Egyptians, the early Germans propitiated a dawn goddess known as Ostara, or Easter. It is this goddess from which the Christians incorporated a ceremony known as Easter, and her season, lenoten in Anglo-Saxon, or literally "spring", became the Christian "Lent", leading to the Easter holiday. This reasoning leads to the medieval belief that the Sun "danced" on Easter day. Yet Easter's most dominant symbol remains the "egg", which symbolizes birth and renewal.

Celestial knowledge of the Norse is steeped in symbols and myth. For thousands of years, the most sacred and important symbol was the "Wheel of the Year", represented by a 6 or 8 spoke wheel, or by a solar cross within a wheel. Such wheels are depicted on the famed silver cauldron of Gundestrup, which shows a horned deity touching a wheel. The Norse people, who lived in what is now known as Yorkshire, often cut out a solar wheel and placed it on the tops of mounds, inserting a pole or pillar to make a solar compass or a sundial. As in many other ancient cultures, the solstices played a key role in their lives, customs, and religious traditions. Solstices refer to the most northern and southern positions of the Sun in the sky. The modern word "solstice" stems from the Latin "sol sistit", or literally meaning that the "Sun stands still", and the official modern name of the Sun, Sol also finds it's origins in Latin, where sol is a feminine noun meaning 'Sun'.

Norse people devised their calendar taking into consideration the

midsummer solstice. Among the Norse, the god Balder is the most closely associated with the solstices. In a myth that explains the actions of the midsummer and midwinter Sun, Balder, the son of the god Odin, was said to die at the hands of his evil brother who, wielded a mistletoe stake each summer solstice. He was reborn at the winter solstice, or what is still known in Germany as Mother Night (the 'mother' in question being the goddess who brings the new born Sun back into existence).

There are a large number of Norse myths about the Sun. In the epic of Sigmund, also known as Sigurd or Siefried, the Sun's magic sword is named Balmung, which means 'Sun beam'. In this tale, the hero comes across a valkyrie surrounded in a ring of fire. It is a lovely Brunhild, who symbolizes a dawn maiden. The Saxon god, Saxnot (sax-sword) also had a magic sword, and one was said to have hung in his temple in such a way as to reflect the dawn's first light. Even Odin was associated with the Sun. The tale explains that Odin, in search of wisdom, once went to the well of Mimir (memory) to think deeply and gain knowledge in the process. The guardian of the well asked one eye as a price for the act. Odin plucked the eye and threw it into the well, where it became the Sun.

Presently in Scandinavia, on the eve of the summer solstice, thousands of people flock to the hillsides to light bonfires and to watch the Sun set, following a tradition started in the dawn of time. Though originally a tribute to the Sun, the event has since been assimilated by the Christians and transferred to honor St. John. Another notable, and still living midsummer tradition is the construction of large wheels made of wood or straw which are set on fire and rolled down hills to represent the Sun's journey toward the winter.

1.1.1.2 *England/Ireland/Scotland*

Norse tribes such as the Angles, Saxons, and native people of areas such as the Celts and Picts, invaded and influenced the English-Scottish people. This explains the Irish name for the Sun goddess Grian, a female noun. It indicates a close relationship with the Celts culture and their Indo-European descendents. The Irish concept of the 'solar cross' was prevalent and the 'central mound cosmology' was considered sacred centers known as 'Tara'. They were constructed in such a way that from