Patrick Moore’s Practical Astronomy Series
Other Titles in this Series

Navigating the Night Sky
How to Identify the Stars and Constellations
Guilherme de Almeida

Observing and Measuring Visual Double Stars
Bob Argyle (Ed.)

Observing Meteors, Comets, Supernovae
Neil Bone

Human Vision and The Night Sky
How to Improve Your Observing Skills
Michael P. Borgia

How to Photograph the Moon and Planets with Your Digital Camera
Tony Buick

Practical Astrophotography
Jeffrey R. Charles

Pattern Asterisms
A New Way to Chart the Stars
John Chiravalle

Deep Sky Observing
The Astronomical Tourist
Steve R. Coe

Visual Astronomy in the Suburbs
A Guide to Spectacular Viewing
Antony Cooke

Visual Astronomy Under Dark Skies
A New Approach to Observing Deep Space
Antony Cooke

Real Astronomy with Small Telescopes
Step-by-Step Activities for Discovery
Michael K. Gainer

The Practical Astronomer’s Deep-sky Companion
Jess K. Gilmour

Observing Variable Stars
Gerry A. Good

Observer’s Guide to Stellar Evolution
The Birth, Life and Death of Stars
Mike Inglis

Field Guide to the Deep Sky Objects
Mike Inglis

Astronomy of the Milky Way
The Observer’s Guide to the Southern/Northern Sky Parts 1 and 2 hardcover set
Mike Inglis

Astronomy of the Milky Way
Mike Inglis

Astronomy of the Milky Way
Mike Inglis

Observing Comets
Nick James and Gerald North

Telescopes and Techniques
An Introduction to Practical Astronomy
Chris Kitchin

Seeing Stars
The Night Sky Through Small Telescopes
Chris Kitchin and Robert W. Forrest

Photo-guide to the Constellations
A Self-Teaching Guide to Finding Your Way Around the Heavens
Chris Kitchin

Solar Observing Techniques
Chris Kitchin

How to Observe the Sun Safely
Lee Macdonald

The Sun in Eclipse
Sir Patrick Moore and Michael Maunder

Transit
When Planets Cross the Sun
Sir Patrick Moore and Michael Maunder

Light Pollution
Responses and Remedies
Bob Mizon

Astronomical Equipment for Amateurs
Martin Mobberley

The New Amateur Astronomer
Martin Mobberley

Lunar and Planetary Webcam User’s Guide
Martin Mobberley

Choosing and Using a Schmidt-Cassegrain Telescope
A Guide to Commercial SCT’s and Maksutovs
Rod Mollise

The Urban Astronomer’s Guide
Rod Mollise

A Walking Tour of the Cosmos for City Sky Watchers
Rod Mollise

Astronomy with a Home Computer
Neale Monks

More Small Astronomical Observatories
Sir Patrick Moore (Ed.)

The Observer’s Year
366 Nights in the Universe
Sir Patrick Moore (Ed.)

Care of Astronomical Telescopes and Accessories
A Manual for the Astronomical Observer and Amateur Telescope Maker
M. Barlow Pepin

(continued after index)
Aurora

Observing and Recording Nature’s Spectacular Light Show

Neil Bone

Springer
## Contents

**Preface** ................................................................. ix

1. **Atmospheric Phenomena** ........................................... 1
   - Aurorae in History ................................................. 2
   - Aurorae in Mythology ............................................. 3
   - Other Atmospheric Phenomena ................................... 7
     - Haloes ................................................................... 7
     - Sun-Pillars and Related Phenomena .......................... 10
     - Rainbows .......................................................... 11
   - Meteors .................................................................... 12
   - Space Weather ..................................................... 16

2. **Causes of the Aurora** .............................................. 19
   - The Variable Sun ................................................... 20
   - The Sun as a Star ................................................... 24
     - Sunspots and the Solar Magnetic Field .................... 27
     - The Active Chromosphere and Corona .................... 29
     - Coronal Holes ..................................................... 31
     - Solar Flares ......................................................... 32
     - Linking the Sun and the Earth—The Solar Wind ........... 34
     - New Insights on Coronal Mass Ejections and Solar Flares ... 36
   - Interactions with the Solar Wind ............................... 37
     - Comets .................................................................. 37
     - Earth’s Magnetosphere .......................................... 40
       - Structure of the Magnetosphere .............................. 40
       - The Van Allen Belts ............................................ 43
       - Plasma Movements and Currents in the Magnetosphere;
         the Auroral Ovals ............................................... 44
     - Auroral Activity Types and Causes ............................ 49
     - Auroral Substorms ................................................ 49
     - Geomagnetic Storms .............................................. 50
     - Other Effects Associated with CMEs ....................... 51
     - Coronal Hole Aurorae .......................................... 52
     - Sector Boundary Crossings and Chromospheric Filament
       Disappearances ...................................................... 53
     - Auroral Emissions ................................................ 53
   - Other Solar Effects on the Atmosphere ....................... 57
     - The Ionosphere .................................................... 57
# Contents

1. The Heliosphere ................................................. 58

2. Effects on Terrestrial Climate ................................ 60

3. Auroral Forecasting .......................................... 63

    - Aurorae and the Sunspot Cycle .................................. 64
    - Keeping an Eye on the Possibilities for Auroral Activity—The DIY Approach! .......................... 66
    - Solar Observing ................................................... 66
    - Recent Past Activity ............................................. 70
    - Early Warnings of Ongoing Auroral Activity ................. 72
    - Magnetic Effects .................................................. 72
    - Magnetometers .................................................... 72
    - Behavior of the Magnetic Field ................................ 74
    - Indices of Geomagnetic Activity ................................. 76
        - The aa Index .................................................. 76
        - The Kp Index .................................................. 76
        - The Ap Index .................................................. 77
    - Radio Aurorae ..................................................... 77
    - Internet Resources ............................................... 79

4. Observing the Aurora ......................................... 81

    - Auroral Activity at High Latitudes ............................ 81
        - The Auroral Zones ............................................. 82
        - Location, Location, Location ................................ 83
    - Polar Cusp Aurorae ............................................. 83
    - Polar Cap Absorptions (PCA) .................................. 84
    - Theta Aurora ..................................................... 85
    - Substorm Events .................................................. 86
    - Geomagnetic storms ............................................. 88
    - Auroral Activity at Lower Latitudes ........................... 88
    - Geomagnetic Storms ............................................. 89
    - Coronal Hole Aurorae ........................................... 97
    - “Flash Aurora” .................................................... 97
    - Visual Observation ............................................... 98
    - Photography ...................................................... 102

5. Historical Aurorae and More Recent Events ............... 105

    - Aurorae in Classical Times .................................... 105
    - Auroral Records from the Dark and Middle Ages ............ 106
    - The Nineteenth Century ......................................... 108
    - Aurorae in the Twentieth Century ............................... 108
        - The Great Aurora of 13–14 March 1989 ...................... 109
        - Other Events in Cycle 22 ..................................... 111
        - The Major Aurora of 8–9 November 1991 .................... 113
        - The Strange Case of Cycle 23 ................................. 114
        - The Aurora of 6–7 April 2000 .............................. 115
        - The Bastille Day Event, 15–16 July 2000 ................... 116
        - March–April 2001—A Rash of Sunspots .................... 117
Contents

The Hallowe’en Storms of October 2003 .................................................. 119
A Sting in the Tail ......................................................................................... 126
The Next Two Cycles .................................................................................. 126

6. Aurora Elsewhere .................................................................................... 129
Jupiter ........................................................................................................... 129
Saturn ........................................................................................................... 132
Uranus and Neptune ..................................................................................... 133
Mercury .......................................................................................................... 135
Venus ............................................................................................................. 135
Mars .............................................................................................................. 136

7. Scientific Investigations .......................................................................... 137
The Eighteenth Century ............................................................................... 137
The Nineteenth Century .............................................................................. 138
The Twentieth Century ................................................................................ 139
Development of Auroral Theory to the 1950s .......................................... 140
High-Latitude Observations ...................................................................... 142
The International Geophysical Year and Beyond .................................... 142
Studying the Solar Wind and Earth’s Magnetosphere ................................ 144
Staring at the Sun ......................................................................................... 147

8. Noctilucent Clouds and Other Phenomena .......................................... 151
Noctilucent Clouds ...................................................................................... 151
Noctilucent Clouds and Solar/Auroral Activity ....................................... 155
Appearance and Behavior ......................................................................... 157
Visual Observation ......................................................................................... 159
Photographic Observation ......................................................................... 162
Nacreous Clouds ......................................................................................... 164
Airglow ......................................................................................................... 164
Rocket Launches and Releases from Satellites ........................................ 165
The Zodiacal Light ....................................................................................... 167
The Auroral Sound Controversy ............................................................... 168

Appendix: Observational Organizations .................................................. 169

Glossary ....................................................................................................... 171
Bibliography ............................................................................................... 177
Index ............................................................................................................ 179
Preface

The popular astronomical literature has, over the years, been rather unkind to phenomena of astronomical origins occurring in the Earth's atmosphere. Together with meteors, the aurora has often been presented as something rather exotic, and not really astronomical anyway, before the author passes on to the next topic. It is my hope here to redress the balance somewhat, by presenting an account of the aurora, its causes, and how to observe it, in a form accessible to the reasonably well-informed amateur astronomer.

Many years ago, back in the late 1960s, I was as a young newcomer to astronomy and avid reader of the even-then numerous general introductions to the subject. Among these, one of the most eye-catching features would often be a garishly colored “artist’s impression” of the Aurora Borealis or northern lights. These displays, one would usually be informed, could only be seen from high Arctic latitudes, and were caused by a rain of particles from the Van Allen belts. Our understanding of auroral phenomena has certainly moved on from then, and “Space Weather” has become a hot current topic, given its influence on satellite operations on which life in the early twenty-first century has become ever-more reliant. We also now have excellent photographic equipment capable of recording auroral displays in all their beauty and magnificence!

Countless amateur astronomers and others marveled at, and photographed—and even digitally imaged—the “Hallowe’en Storms” of 2003, perhaps the most intense and extensive auroral activity of modern times.

When I saw my first aurora back in 1973, I mistook it for an unusually early moonrise! Simply, the pictures in the popular texts I had immersed myself in were inadequate preparation for the real thing. Here, I have assembled a set of photographs that should give ample guidance as to how the aurora really appears, and with familiar constellations often recorded in the background, the reader should also gain some appreciation of the scale of displays.

I was fortunate enough to be born and raised in Scotland, from where I enjoyed numerous opportunities to observe the aurora (not strictly a polar phenomenon at all!) subsequent to my February 1973 misidentification. Having moved, through professional commitments, to more southerly climes in England, I find the aurora a less-frequent visitor to my skies, but even from the depths of Sussex, I have over the past couple of decades witnessed several good displays. Events visible to southern England spark a lot of interest, and I have given countless talks on the subject to local astronomical societies, particularly in times following major displays. This book brings together much of the lecture material as a theoretical background to how the aurora comes about, as well as outlining how to go about recording such events for oneself.

Many people have helped me in compiling this account of the aurora. I should especially acknowledge the long-standing contributions of Ron Livesey—for 25 years
Preface

Director of the BAA Aurora Section—and Dr. Dave Gavine. Dave, and colleagues such as Richard Pearce, Tom McEwan, and Russell Cockman have generously allowed me to use copies of their frequently stunning images to illustrate my lectures over the years, and some of their work can be seen in this volume. The late Dr. Michael Gadsden inspired many to take up the related study of noctilucent clouds, covered in the final chapter.

I should also give a special mention to my wife, Gina, to whom this book is dedicated, for her patience and understanding during the time taken compiling this work. We have been lucky enough to observe together one or two of the more spectacular aurorae of cycles 22 and 23.

As I write, cycle 23 is drawing to its close, and auroral activity at lower latitudes has died away for the time being. In another couple of years, however, we may well expect the onset of some vigorous activity as the sunspots start to appear again in large numbers; some forecasts suggest we may even be in for a particularly good solar cycle for major aurorae, peaking around 2010. Time will tell, but for the moment, it is my hope that its readers will find this book a useful introduction to the aurora and how to observe it.

Neil Bone
Chichester, 24th September 2006
A clear, early spring evening, Thursday, 6–7 April 2000 had been keenly awaited for some months by amateur astronomers across northwestern Europe and North America. On this occasion, the planets Mars, Saturn, and Jupiter would form a neat grouping in the western sky together with the waxing crescent Moon in the growing twilight. Such conjunctions, when members of the Solar System are seen relatively close together in line of sight, are not especially rare, but the apparent gathering of four objects in a small area of the western evening sky was sufficiently noteworthy and photogenic to attract a lot of attention and, visible for that one evening only, was an event to be savoured and imaged while it lasted! Clear skies across the British Isles afforded excellent viewing and were especially welcome after a spell of cloudy, unseasonably cold weather.

As the twilight deepened and the planetary–lunar grouping sank low in the northwest, observers began to notice something odd about the sky. Patches of red light appeared across the north and northwest, resolving at times into curtained and banded forms: as an unexpected bonus to an already splendid evening, the aurora had returned to low-latitude skies after some years of absence.

Triggered by violent magnetic activity on the Sun a couple of days previously, the geomagnetic storm and its associated extensive auroral display continued throughout the night, and was also enjoyed by American observers. The first of several such events in sunspot cycle 23, the major aurora of 6–7 April 2000 was visible down to the southern United States, and from locations such as Portugal in the south of Europe where the aurora is seldom seen. To the thousands who witnessed it, this spectacular natural light show certainly made this a night to remember.

Part of the thrill lay in the unexpectedness of the event; while the conjunction was long-anticipated (desktop planetarium programs can predict such alignments for centuries in the future with consummate ease), the aurora took many—even
Aurora

Figure 1.1. The strongly coloured aurora of 6–7 April 2000 was widely seen across the British Isles. The Author captured this view from his home near Chichester, West Sussex.

professional scientists—by surprise. Recent developments afford the possibility of more reliably forecasting the likely occurrence of aurorae, and an important part of what follows in this book will discuss the online resources where the reader can obtain information in real time about conditions in near-Earth space and whether auroral storm conditions are likely.

Aurorae in History

Aurorae have been observed and recorded throughout history, being a source of awe to many and an inspiration for myth and poetry. There is some debate as to where the descriptive name of aurora borealis—in Latin, “northern dawn”—originated. Some writers ascribe the first use of the term to the French astronomer Pierre Gassendi (1592–1655) following a display seen on 12 September 1621. Others give the priority to Galileo (1564–1642)—famed, of course, as the first to apply the telescope to astronomical purposes—who also witnessed the 1621 aurora. Perhaps more realistically, aurora borealis has its origins with Gregory of Tours more than a millennium before either Galileo or Gassendi. Gregory (538–594) was involved in clerical and political life, and wrote the ten-volume The History of the Franks (French). In this are clear descriptions of a number of celestial phenomena such as parhelia. Several passages can be interpreted as accounts of auroral displays:
Atmospheric Phenomena

“While we were still hanging about in Paris portents appeared in the sky. Twenty rays of light appeared in the north, starting in the east, and then moving round to the west. One of them was longer than the others and shone high above them: it reached right up into the sky and then disappeared, and the others faded away, too.” (AD 578)

“While I was staying in Carnignan, I twice during the night saw portents in the sky. These were rays of light towards the north, shining so brightly that I had never seen anything like them before: the clouds were blood-red on both sides, to the east and to the west. On a third night these rays appeared again, at about seven or eight o’clock. As I gazed in wonder at them, others like them began to shine from all four quarters of the earth, so that as I watched they filled the entire sky. A cloud gleamed bright in the middle of the heavens, and these rays were all focused on it, as if it were a pavilion the coloured stripes of which were broad at the bottom but became narrower as they rose, meeting in a hood at the top. In between the rays of light there were other clouds flashing vividly as if they were being struck by lightning. This extraordinary phenomenon filled me with foreboding, for it was clear that some disaster was about to be sent from heaven.” (AD 586)

The “pavilion” described above sounds remarkably like the coronal form adopted by the aurora in the most major storms when activity extends overhead and on toward the equatorwards side of the sky.

Among Gregory’s descriptions, one particularly stands out as a likely original for the nomenclature:

“At this time there appeared at midnight in the northern sky a multitude of rays which shone with extreme brilliance. They came together and then separated again, vanishing in all directions. The sky towards the north was so bright that you might have thought that day was about to dawn.”

Aurorae in Mythology

The aurora has, not surprisingly, often entered into the folklore of peoples living at higher latitudes. The Scottish city of Aberdeen is connected to the Northern Lights or “Heavenly Dancers” in a popular song, for example. Robert Burns, Scotland’s national bard, makes mention of the aurora in his galloping epic Tam O’Shanter:

But pleasures are like poppies spread,  
You seize the flow’r, its bloom is shed,  
Or like the snow falls in the river,  
A moment white—then melts for ever,  
Or like the borealis race,  
That flit ere you can point their place;  
Or like the rainbow’s lovely form  
Evanishing amid the storm-  
Nae man can tether time nor tide;  
The hour approaches Tam maun ride

The Edinburgh Edition, 1793
The much-traveled poet, Robert William Service (1874–1958) spent some time in the far north of Canada, during the declining years of the late nineteenth-century Klondike and Yukon gold rush. Some of his writings provide a fascinating record of frontier life. Not surprisingly, the aurora occasionally features as a backdrop:

The mighty mountains bare their fangs unto the moon;
There where the sullen sun-dogs glare in the snow-bright, bitter noon,
And the glacier-gutted streams sweep down at the clarion call of June:
There where the livid tundras keep their tryst with the tranquil snows;
There where the silences are spawned, and the light of hell-fire flows
Into the bowl of the midnight sky, violet, amber and rose
There where the rapids churn and roll, and the ice flows following run;
Where the tortured, twisted rivers of blood rush to the setting sun—
I’ve packed my kit and I’m going, boys, ere another day is run.

The Heart of the Sourdough

A longer narrative tells the tale of three miners seeking their fortune in the far north, guided by their dreams. The sole survivor—a down and out—relates their experiences and describes the aurora:

Oh, it was wild and weird and wan, and ever in camp o’ nights
We would watch and watch the silver dance of the mystic Northern Lights.
And soft they danced from the Polar sky and swept in primrose haze;
And swift they pranced with their silver feet, and pierced with a blinding blaze.
They danced a cotillion in the sky; they were rose and silver shod;
It was not good for the eyes of man—’twas a sight for the eyes of God.
It made us mad and strange and sad, and the gold whereof we dreamed
Was all forgot, and our only thought was of the lights that gleamed.
And the skies of night were alive with light, with a throbbing thrilling flame;
Atmospheric Phenomena

Amber and rose and violet, opal and gold it came.
It swept the sky like a giant scythe, it quivered back to a wedge;
Argently bright, it cleft the night with a wavy golden edge.
Pennants of silver waved and streamed, lazy banners unfurled;
Sudden splendors of sabres gleamed, lightning javelins were hurled.
There in our awe we crouched and saw with our wild, uplifted eyes
Charge and retire the hosts of fire in the battlefield of the skies.

The storyteller informs us that the aurora originates from a hollow mountain range on the polar rim. Echoing a popular belief among the frontier gold miners of the time, he finally reveals:

Some say that the Northern Lights are the glare of the Arctic ice and snow;
And some say that it’s electricity, and nobody seems to know.
But I’ll tell you now—and if I lie, may my lips be stricken dumb—
It’s a mine, a mine of the precious stuff that men call radium.

The Ballad of the Northern Lights

References to auroral displays can be found in ancient literature. Perhaps the earliest record, unearthed by Durham astronomical historian Prof. Richard Stephenson, dates back to Babylonian tablets from March 567 BC. An oblique reference to the aurora, also dated to the sixth century BC, is made in the Bible:

“And I looked, and, behold, a whirlwind came out of the north, a great cloud, and a fire infolding itself, and a brightness was about it, and out of the midst thereof as the colour of amber, out of the midst of the fire.”

Ezekiel 1:4

Over the years there has been much speculation as to the possible astronomical nature of the Star of Bethlehem. Planetary conjunctions, novae, and comets have all been proposed as the celestial events interpreted by the Biblical Magi as a sign that a new King of Israel had been born. It is quite possible that the aurora might provide a further, reasonable, alternative. Computations extrapolating the ephemerides back to the time of Christ indicate that there were no bright planetary conjunctions at the appropriate time, while searches through contemporary Oriental records give no indication of a candidate comet or nova. The rare penetration of auroral activity to the latitudes of the Middle East—a once-in-a-lifetime event, perhaps—would certainly be sufficiently unusual to be noted by such watchers of the sky as the Magi. In its coronal form, the aurora may very well assume the appearance of a stylized “star,” with rays and other forms radiating out from a central point.
Norse mythology makes frequent reference to the bridge Bifrost, a burning, trembling arch across the sky, over which the gods could travel from Heaven (Asgard) to Earth. It is not unlikely that the inspiration for the bridge was the aurora. In a parallel to Bifrost, Finnish mythology refers to a river—Rutja—which stood in fire, and marked the boundary between the realms of the living and the dead.

The vivid red sometimes seen in intense auroral displays can probably be associated with the Viking “vigrod,” or war-reddening.

In Scandinavian mythology, the Valkyries, “Choosers of the Slain,” were beautiful young women mounted upon winged horses. Their role was to visit battlefields to select the bravest of those who had fallen (the Einherjar), and escort them to Odin’s Hall (Valhalla), in preparation for the impending battle of Ragnarok. In some traditions, auroral rays were perceived as lights reflected from the Valkyries’ armor as they rode the sky.

Some Norwegian folklore describes the aurora as a harbinger of harsh weather: snow and wind are believed to follow bright displays. Another Norwegian folk-legend suggests that the aurora is a celestial dance by the souls of dead maidens. A Swedish tradition associates the aurora with light reflected from the scales of fish in large shoals—Sillblíxt, or “herring flash.”

Other Scandinavian folk tales talk of a contest among the swans to see which could fly farthest north. Some competitors became trapped in the northern ice, and as these swans flap their wings in a bid to escape, the light of the aurora results.

The Norse chronicle Kongersepeilet (The King’s Mirror) from about 1230 AD makes what is probably the first explicit reference to the Northern Lights (Nordrjós). Here, they are described as rays of sunlight reaching over Greenland, then thought to represent the edge of the flat, ocean-surrounded Earth:

“The northern lights resemble a vast flame of fire viewed from a great distance. It also looks as if sharp points were shot from this flame up into the sky, these are of uneven height and inconstant motion, now one, now another darting highest; and the light appears to blaze like a living flame.”

Eskimo peoples in the Hudson Bay area of North America, and elsewhere, are naturally very much aware of auroral phenomena. A common belief among the Eskimos is that the aurora can be attracted by whistling to it, while a handclap will cause it to recede. Other Eskimo beliefs suggest that the aurora is produced by spirits, playing a game of celestial football with the skull of a walrus. (One group, on Nanivak Island, suggested that a human skull was, instead, used by walrus spirits!). Some Eskimo groups regard the aurora as an indicator of good weather to be brought by the spirits. Alaskan Eskimos at Point Barrow saw the aurora as malevolent, and carried weapons for protection if venturing outside when it was present. It is also said by some Eskimos that:

“He who looks long upon the aurora soon goes mad!”

Some tribes of North American Indians believed the aurora to be the light of lanterns carried by spirits seeking the souls of dead hunters. Like the Point Barrow Eskimos, Fox Indians in Wisconsin feared the aurora, seeing in it the ghosts of their dead enemies. Other tribes perceived the aurora as the light of fires used by powerful northern medicine men.
Atmospheric Phenomena

The aurora has also entered the folklore of the Australian aborigines, who saw it as the dance of gods across the sky. To the Maoris of New Zealand, the aurora is Tahu-Nui-A-Rangi, the great burning of the sky. Aurorae may well have been the source of Chinese dragon legends. The twisting snake-like forms of active auroral bands are often portrayed as celestial “serpents” in ancient chronicles. European dragon legends, too, may have their origin in auroral activity, although some commentators also ascribe these to descriptions of meteoric fireballs.

In ancient Roman and Greek records, references may sometimes be found to “chasmsata” in the sky, the auroral arc structure being regarded in such instances as being the mouth of a celestial cave. The term *isochasms* is used nowadays to relate two geographical points that share an identical frequency of auroral occurrence.

Even in quite modern times, misconceptions regarding the cause of the aurora have persisted among the general public. Writing in *National Geographic* in 1947, for example, American auroral scientist Charles W. Gartlein relates how, in his youth, people in mid-west America widely believed the aurora to be the reflection of sunlight from the polar ice, disregarding the perpetual darkness of the winter months at Arctic latitudes! Another romantic notion, long-since safely dismissed, was that auroral light results from icebergs crashing together in the polar seas.

Modern scientific understanding of the processes underlying the aurora is now sufficiently advanced that good working models to describe the causes of the polar lights are available. This understanding, however, does not detract from the majestic spectacle that a major auroral display can present and—rather as is the case with total solar eclipses, thunderstorms, and other displays of Nature at its grandest—an active, colorful display of the Northern (or Southern) Lights can still trigger, even in an informed observer, primitive emotions of wonder.

Other Atmospheric Phenomena

The aurora is the most awe-inspiring of a range of phenomena occurring in the atmosphere, many of which become familiar to regular watchers of the skies. Amateur astronomers who carry out (or at least attempt to carry out) regular observations are all too familiar with the various cloud forms in the lower atmosphere’s “weather layer”—the troposphere. Clouds all too often disrupt a night’s plans, or obscure that once-in-a-lifetime event like a total solar eclipse or meteor storm. In a maritime temperate climate like that of the British Isles, the weather is often quite dynamic, bringing frontal systems and their attendant cloud at intervals of a few days.

Haloes

While the arrival of high, thin cirrus clouds (at altitudes of around 10 kilometers) ahead of a frontal system can signal the loss of planned astronomical observations, the optical phenomena produced by refraction of sunlight in the ice crystals of which this cloud is comprised can be of interest in their own right. The tiny ice crystals in
cirrus have a hexagonal geometry, and under the right conditions each can act as a minute prism through which sunlight (or moonlight) can be refracted. A consequence of this is the occurrence of the family of halo phenomena, which can sometimes be seen—usually when the Sun is low in the evening or morning sky—on occasions when the cirrus sheet is extensive.

Most commonly seen are the often colorful brightenings known as parhelia—mock Suns or Sun-dogs. The laws of refraction dictate that these appear at an angular distance on the sky of 23 degrees from the Sun, and at more-or-less the same altitude (elevation) above the horizon as the Sun. Sometimes there may be only a single parhelion, either to the Sun’s east or west. On other occasions, both are present. Appearing like little patches of outside-in rainbow (with the red closest to the Sun, blue farthest), parhelia are usually brightest when the Sun is low in the sky; they are probably most often noticed in the evening sky as the Sun is setting, and would-be observers make a check to see whether conditions might be clear later on.

Given the right conditions, with an extensive, fairly even cirrus sheet covering much of the sky, the parhelia can be seen as brightenings just outside the circumference of a halo surrounding the Sun at a distance of 23° (radius 23°, diameter 46°). Directly above the Sun, another brightening—the upper tangent arc—may also be apparent on the halo’s circumference.

Other components of the halo family of refraction phenomena include a parhelic arc, extending through the parhelia, parallel to the horizon at the same altitude as the
Atmospheric Phenomena

Figure 1.3. Under favourable conditions, the complete 23° halo may be seen around the Sun when cirrus cloud is present. Image: Neil Bone.

Sun. When present, this is usually seen only as a partial streak at temperate-latitude locations; from the Antarctic, where cirrus fields can be much more extensive and stable, the parhelic arc’s complete 360° extent has been seen and photographed.

The halo family does not stop here! A further pattern of light refraction within ice crystals in the high atmosphere results in a second, outer set of halo phenomena at an angular distance of 46° from the Sun under the right conditions. The 46° radius halo is color-reversed relative to that at 23°, with blue on the sunward side, red on the outside. A bright, often strongly colored circumzenithal arc—tangential to the upper part of the 46° halo—can sometimes be seen, and parhelic brightenings may also be evident, level in altitude with the Sun and just outside the 46° halo. The circumzenithal arc is prominent only when the Sun is low, and its appearance requires a solar elevation of less than 32° above the horizon; at midsummer when solar elevations in excess of 58° may be attained, a circumhorizontal arc can sometimes be seen 46° below the Sun.

All these halo phenomena can be imaged, sometimes making spectacular, colorful pictures. With the camera being aimed toward the dazzling Sun, care has, of course, to be taken. As with any other piece of optical equipment, the observer should avoid direct viewing of the Sun through the camera viewfinder. One way to ensure this—and enhance the resulting image—is to hide the Sun behind a suitable local obstruction—a tree, the corner of a building or whatever; amateur astronomers afflicted by light pollution will enjoy the irony of using streetlights for this purpose!

For imaging of halo phenomena in a brightly sunlit sky, slow film (ISO less than 100), or a slow setting on a digital camera, is preferred; there is usually more than
Aurora

Figure 1.4. Circumzenithal arcs are often highly coloured (inexperienced observers sometimes describe them as 'partial rainbows'), and can be bright especially in the evening when the Sun is low. Image: Neil Bone.

enough light. A narrow lens aperture will be sufficient. If using the camera’s internal meter to set the exposure, a good rule of thumb is to underexpose by one or two f-stops. This will darken the background sky somewhat, better showing the halo or Sun-dog.

Closer examination of the resulting image can be interesting, revealing, for example, that the sky inside the $23^\circ$ halo is markedly less bright than that outside—a result of preferential refraction of sunlight away from this region.

While most obvious when produced by a low Sun, equivalent halo phenomena can also be produced by the Moon in the night-time sky. However, as moonlight is much less intense, the parselene (mock Moons) and halo are fainter: only the $23^\circ$ radius family members are likely to be seen, and then only when the Moon is at its brightest, within about five days of Full. Again, these can be attractive targets for imaging, if less colorful than their solar equivalents.

Sun-Pillars and Related Phenomena

Sometimes, on cold winter afternoons, the setting Sun will be seen to have extending upward from it perpendicular to the horizon a faint streak of light, perhaps slightly