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Cambridge Scholars Publishing

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This book first published 2019

Cambridge Scholars Publishing

Lady Stephenson Library, Newcastle upon Tyne, NE6 2PA, UK

British Library Cataloguing in Publication Data
A catalogue record for this book is available from the British Library



ISBN (10): 1-5275-2075-7
ISBN (13): 978-1-5275-2075-2

For Eileen

*Fascination is the magic of the extraordinary*
*—Ralph Anstoetz*

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# About the Author

The author is a physicist, but not an archaeologist. He has an MSc in astrophysics from Queen Mary College and a PhD in space plasma physics from Lancaster University. His thesis entitled: "ULF oscillations in the terrestrial magnetosphere" was a study of Poynting flux impulses in Polar satellite data and their connection with the beautiful natural phenomena of the northern lights. His work at Marconi was in the field of signal processing algorithms and he also taught physics. The astro-photographs in this book are amongst the many that he has taken and exhibited. An interest in traditional wooden boats led to the building of a Hvalsoe 13 from Siberian larch which he enjoys sailing on the Norfolk Broads. And he likes to try and solve mysteries!

# PREFACE

Many years ago, we were fortunate enough to have lived in Northumberland for a while. It is a beautiful part of the country that has been called “the land of many weathers” because of its open skies, with constantly changing cloud formations, rainbows and winds. At night the skies were often dark and clear, although sometimes cold, and the stars shone brightly. It was that darkness on a clear night, when the moon was out of the way, that made looking at the stars in Northumberland really enjoyable. Indeed, a region of Northumberland in the west has now been designated as an International Dark Sky Park.

Across the sky on a clear dark night is a ribbon of light known as the Milky Way: a hundred, thousand, million stars too far away for our eyes to resolve individually, together with glowing nebulosity and dark dust clouds. It is really amazing that we can see these things at all, and it is only possible because the space between the stars is so transparent. And, fortunately for us, in the final stages of its long journey to earth, the starlight from far away encounters the atmosphere of earth that is transparent to certain wavelengths.

And although we know that they are distant, the stars are part of our natural world in the same way that rocks, plants and little creatures are. Human beings are curious by nature and cannot help wondering about what they are seeing around them. One way of understanding these observations is to make notes or records that can be perused later, something that has to be done with attention to detail. This then leads to classification and to the finding of patterns and associations which develop into the discoveries that provide a few answers to the many questions. Is this activity something new? Perhaps not. The folk who lived in Northumberland in the Neolithic era might not have been that different to us, except in some respects: they were probably closer to the natural world, and of course they didn’t have our kind of technology. Nevertheless, the thesis of this book is that they made a record of their night sky in the form of a set of petroglyphs, literally rock graphics. These petroglyphs were made with great perception, and also very accurately, given the available technology. They were made in a way that has allowed some of the original record to withstand the test of time, and what is really important is that some of what remains can still be read and analysed today.

There were two reasons for writing this book. The first was to try to prove beyond reasonable doubt that the Northumberland petroglyphs preserved a record of the stars in the Neolithic era, and the second was to pass on the way in which a few of these petroglyphs were interpreted by the author. It is interesting to do this and there are almost certainly new discoveries to be made. If nothing else, the fieldwork required is another way to enjoy being out in the beautiful Northumberland countryside. However, the story that is told here is not definitive, just a record of understanding so far, and every time a petroglyph site was examined it was found that there was always something new or different to discover about it.

At the beginning of the book there are some notes on stars, but if the reader appreciates the general idea that the night sky was somewhat different in the Neolithic era then that is enough to make a good start at analysing a petroglyph. This introduction is followed by a discussion of each of the nine petroglyph sites that were studied: they all provided further clues as to how petroglyphs might be interpreted. Reading through these interpretations will give some background to the list of criteria that was found to be useful for interpreting cup and ring petroglyphs in general. But if the reader would prefer a simple guide, then the last chapter of the book provides a summary of all these findings.

It may be thought that even if the petroglyphs were completely deciphered that still would not explain what their purpose was. But maybe there actually was no purpose other than to make a record. It is not always appreciated that much of science is just doing this. To give an example, there is currently being constructed, in the Atacama Desert of Chile at an altitude of 3,046m, a telescope called the ELT [Extremely Large Telescope]. The main mirror is 39.3m across and consists of 798 hexagonal segments that are positioned with incredible accuracy by precision actuators which correct for the constantly changing distortion introduced by the thin air above the telescope. The angular resolution achieved will be an incredible 0.005 second of arc, and the instruments on the telescope will generate petabytes of data that will be available over the successor to the internet, the grid. The cost will be around a billion euros, yet the telescope has just one purpose, to make an accurate record that allows us to understand the stars: nothing more than that. It is just our curiosity at work, so maybe the Neolithic era folk of Northumberland would have understood perfectly.

# Chapter One

# Setting the Scene

This chapter gives a little background to the cup and ring petroglyphs in Northumberland.

## 1.1 Northumberland in the Neolithic era

After the end of the Ice Ages, when the climate began to become warmer, the period of prehistory which is known as the Mesolithic began. The way of life for the people who lived in Northumberland at that time is often referred to as that of hunter-gatherers. This era was characterised by the beginnings of agriculture and a gradual transition to the Neolithic era. The formidable Neolithic polished stone axe, together with fire, would have allowed trees to be felled to create places to grow crops. The farming way of life and the keeping of animals, such as sheep and goats, made for more stable settlements. This era of prehistory lasted until around 2,400 BCE when it was replaced by a culture that made use of metalworking. Initially there may have been a transitional age of copper working which then gave way to the Bronze Age, as bronze is copper modified by the addition of tin. But the details of the transition from the Neolithic era to the Bronze Age are obscured by the mists of time, and what happened to these earlier peoples is not known, although the analysis of DNA is beginning to provide some answers.

By comparison with the climatic upheavals of the ice ages and their aftermath, the climate in the Neolithic era seems to have been more settled and possibly slightly warmer than today [Burroughs 2005]. It is possible that the petroglyphs of Northumberland date from this relatively stable period of prehistory. The folk that lived in Northumberland in the Neolithic were certainly resourceful. There would have been many more wild animals around than there are now, including perhaps, reindeer, elk, bears, wild boars, wolves and lynx. They would have had leather and furs for clothing and ways to keep warm passed down from the colder and unstable climatic period before 8,000 BCE. As well as stone with different degrees of hardness they would have had antlers, tusks and horn with which to make implements, including those which would have been needed to engrave the petroglyphs, many of which are on relatively soft sandstone. But there is no trace of a written language and so, sadly, we do not know what names they gave to the stars.

Northumberland has a coastline which is a day's walk from many of the petroglyph sites, and today you can walk to Holy Island along St. Cuthbert's Way. Sea coal is found on the beaches and the grey Atlantic seals that swim around the Farne Islands may have provided oil for simple lamps which would have been useful for drawing at night. The sea might also have supplied salt for preserving food in the winter and feathers and eggs from sea birds, all factors that would have contributed to a period of relative stability.

This era of prehistory is also associated with stone circles, but whether these were connected to the stars is uncertain, although stone circles have been associated with the moon [Thom 1967] and the remains of stone circles were sometimes seen near to the petroglyph sites.

There is some evidence that the climate began to change from around 2,400 BCE onwards, and the broad picture is one of a tendency towards lower temperatures. Ice rafted debris in ocean sediments from the coasts of Iceland and Greenland suggest that there was a cooling in the North Atlantic region, and ice cores from Greenland show a layer of tephra from a major volcanic eruption of Hekla in Iceland around 2354 BCE. This event may have contributed to a cooling of the climate as a result of the large amounts of dust released into the stratosphere. But much more dramatic around this time were events far afield in the Middle East where there was a sharp decline in rainfall. In particular the Akkadian civilisation in what is now Syria suffered badly around 2,200 BCE and there was a great famine in Egypt around 2,150 BCE. Agricultural disasters and prolonged droughts led to changes that may well have driven migration, causing metallurgy technology to spread westwards. The details of these events though are still being uncovered.

The folk that lived in Northumberland in the Neolithic era however did not disappear entirely without trace, as they left behind their intriguing petroglyphs for us to enjoy today. It is the interpretation of these that this book is about.

## 1.2 Cup and ring petroglyphs

Although drawings on rock may seem primitive, they have the really valuable attribute that they can stand the test of time. The cave paintings at Lascaux date from perhaps 17,000 thousand years ago, and yet they can be read by eye today. Not so for modern digital media which degrade over time as a result of cosmic rays and become obsolete as new innovations come along, so that even if the record itself survives the means to read it may disappear. Paper might last a few hundred years and papyrus a few thousand. Wood, leather and animal skins decompose, although some of the clay tablets from the ancient Near East have survived in dry conditions. But for a really lasting record in wet conditions outdoors, stone is an excellent choice. Of course, it may just have been the only medium around, but maybe, and enticingly, it was chosen because the record made on it was actually intended to last. This would mean that the Northumberland petroglyphs may have been created for future generations to read.

Maps of the sky have been made over a long period of time in different ways. Well known is the set of thirteen Chinese star-maps from Dunhuang in Gansu Province that were painted in three colours on paper, and which depicted over 1,350 stars. These are thought to date from around 700 CE in the time of Emperor Zhongzong of Tang [Walker 1996]. They are now in the British Museum and they depict the stars as small circles or dots without reference to their brightness. What is also interesting about these star-maps is that just small numbers of stars were joined by straight lines between them. These small groupings are mostly completely different to our present-day constellations. Small groupings of stars are also apparent in the earlier work of the three Chinese astronomers She Shan, Gan de and Wu Xian between 370 BCE and 270 BCE. They grouped 1,464 stars into 284 constellations, giving an average of only about five stars in a constellation. This shows that different cultures looked at the patterns of stars in the sky differently, as would be expected. And it does seem, from the studies described here, that some of the Northumberland petroglyphs also just depicted relatively small numbers of stars.

Petroglyphs are found all over the world with a vast array of designs that include large animals and other extinct creatures, people, hands, spirals, waves, grids and rays. Many have not been deciphered. This book is about deciphering a particular class of petroglyphs known as cup and ring petroglyphs, although as well as the cup and ring motifs there are often many other kinds of markings included on these petroglyphs too. They have been found in England in Northumberland, Cumbria and Cornwall, in Scotland at Ballochmyle in Ayrshire, Drumtroddan in Dumfries and Galloway and in Cairnbaan and Ormaig in Argyllshire amongst many other places. They have also been found in Ireland, Brittany, North West Spain and Portugal and further afield in Italy, Greece, Mexico and India.

The cup is an indentation in the rock face a few centimetres across and that may be all that there is, or there may be one or more concentric circular rings engraved around the cup. These rings are not always complete, but this may well have been intentional. Rings may merge, weave, or even become spirals, and these variations in design almost certainly contain information. The cups may have originally held something such as water or a spherical stone, and the cup and ring motifs may have been coloured by pigments, although no trace of anything seems to have survived. Modern techniques of analysis on pristine petroglyph cup and ring motifs could make new discoveries here. The cup and ring sites in Northumberland are often on high ground with panoramic views to the distant horizon in some, although not necessarily all, directions. Cairns, tumuli, hill forts, stone circles and other features of antiquity are often nearby, although many of these will have dated from other times. However, some may be connected with the petroglyphs, notably the cairns and possibly the stone circles.

Petroglyphs are fascinating, partly because the artwork is somehow beautiful and partly because they are a little mysterious. Either way, they always make an impression on the observer, which is not altogether surprising as most rocks do not have any particularly remarkable features. They tell us that someone was here before us with something interesting to record. At some sites, such as at Old Bewick and West Horton, the petroglyphs almost have a lifelike quality and it would have been wonderful to have met the folk that created them.

Not surprisingly the cup and ring motifs have often weathered and been eroded to the point that they are almost invisible, although they stand out better when the sun is low in the sky. At night time the engravings on the rock face might also be visible by moonlight and, like braille to a blind person, they have a tactile aspect, so could even be read in complete darkness.

An enormous amount of fieldwork was carried out by Stan Beckensall in Northumberland and beyond and the reader is encouraged to read about his ideas which are detailed and open minded. A good reference is his book

"Prehistoric Rock Art in Northumberland" [Beckensall 2001]. This would make a good accompanying reference for fieldwork as it contains tracings and photographs of the rock faces, as well as many other interesting observations. His records were archived by Newcastle University where there was a project that laser scanned the petroglyphs. But the description of the Northumberland petroglyphs as rock art, a phrase that Stan Beckensall made much use of, is not used in this book as the thesis here is that, although the petroglyphs are, without doubt, works of art in the landscape, they are much more than that, and specifically depict an accurate scientific record of the night sky in the Neolithic era. However, the artistic element is well summarised in Stan Beckensall's wonderful description of the Ketley Stone [Beckensall 2001].

In this study I came to greatly appreciate Stan Beckensall's wonderful achievement in documenting what he found in the Northumberland landscape. Since he made his tracings of the petroglyphs at the end of the last century many of the cup and ring motifs have become so faint as to be unreadable, even in low angle light, and his records provide all that there is of the number of rings and other features that were faint, even when he recorded them. In relating the petroglyphs to star fields these earlier tracings were found invaluable and data on some of the faint and hidden cup and ring motifs was sometimes inferred from them. In the fieldwork they showed what to look for, although some of the cup and ring motifs that he documented are now under grass and heather. The author did not feel that these should be disturbed, so they are not shown here, but they are in Stan Beckensall's book.

## 1.3 Thesis

One of the aims of this book was to show that the Northumberland cup and ring petroglyphs could be interpreted as depicting regions of the night sky. This is not an original idea, but it is probably true to say that it is very far from being an accepted explanation. But if it is true then we now have a record made in antiquity of the heavens that may include some features of interest to astronomers in the same way that ancient Chinese manuscripts are examined for historical evidence of comets, eclipses, supernovae, aurorae and other phenomena. This would make this class of petroglyph a potentially useful resource of transient astronomical information.

It is thought that the Northumberland cup and ring marked petroglyphs date from the Neolithic era which lasted into the third millennium BCE. The four or five thousand years that have elapsed since then are a very tiny interval of time in the life of a star so it is statistically unlikely that the brightness of many stars will have changed much since the late Neolithic era. But what is possible is that, if an ancient record depicting many stars is compared to modern records it might reveal significant events for a few of the stars. This is particularly true for unstable and variable stars, such as the red giants, which undergo rapid changes in the later stages of their evolution.

Deciphering petroglyphs requires clues, and some of these gradually emerged from the fieldwork. An important clue is provided by the number of rings around a cup motif. These rings may have denoted the brightness of the star whose position in the Neolithic star field was shown by the position of the cup motif on the petroglyph. Thus, given this interpretation, a cup and ring petroglyph would be a representation of a star field with stars of different brightness and relative positions. It is further suggested that other petroglyph motifs depicted star clusters, nebulae and nebulosity, as seen long ago. These additional features can often confirm an interpretation that was inferred from the brightness of the stars alone. A summary of the criteria used to decode these petroglyphs is given at the end of the book.

# CHAPTER TWO

# STARS AND THE MILKY WAY

This chapter describes several aspects of stars. The main reason for discussing these is to show that stars evolve over time so that a Neolithic star-map may reveal some differences when it is compared to a modern day one, changes which may be of great interest. The reader might find some of this material rather astrophysical in nature and it is only really necessary to appreciate that change is everywhere, even for stars.

There has long been a debate as to whether an understanding of physics loses the sense of awe and wonder of phenomena in the natural world. The view of the author is that it is really the opposite. After six years spent studying the physics of the northern lights the beauty of this natural phenomenon was never lost, and moreover that particular scientific study led to living in the far north of the wonderful country of Finland. It is the same with studying petroglyphs: it can lead you to interesting places.

## 2.1 The life of stars

Stars have a life: they are born and they grow old. The very first stars were made from the material created at the beginning of time as we know it. This raw material was mainly particles of the element hydrogen with some helium and lithium. During the lifetime of these early stars many more elements were synthesized including carbon, nitrogen and oxygen. These new elements were scattered far and wide when the stars exploded at the end of their lives and succeeding generations of stars, the planets around them, and finally life itself were formed from this more complex material.

The force that brings the particles of raw material together to create stars is that of gravity, a force that becomes stronger as the particles are drawn ever closer together. But there is also another principle at work in star formation known as the principle of conservation of angular momentum. Angular momentum is something that all particles have if they are moving around a point in space. It is the product of the mass of the particle, the speed of the particle and the distance of the particle from the point. The conservation of angular momentum means that as the particles are drawn closer together by gravity they gain additional speed. The swirling primeval dust cloud rotates ever faster as it collapses under gravity to form a spinning star, just as dancers on ice skates spin faster as they lower their arms.

As the particle cloud collapses it warms up and begins to glow in the infrared region of the spectrum. At this stage it is not yet a star. But as the heating continues there comes a point when electrons break free from their nuclei and the material of the proto-star changes from being a hot gas to being a hot plasma. Plasma is a state of matter in which positive and negative particles are separated: it is highly electrically conducting and all stars are made of plasma. Further heating of the plasma results in the hydrogen nuclei travelling so fast that they sometimes collide and fuse together to make the nuclei of helium. This process releases energy because the helium nuclei are fractionally less massive than the original hydrogen nuclei and the lost mass appeared in the form of energy, as predicted by Einstein's theory of special relativity. The point in star formation when spinning dust clouds start to shine with starlight as a result of nuclear fusion is called ignition.

There are many regions in space where stars are being created. The newly ignited stars shine brightly and illuminate the dust and particle clouds around them with ultraviolet light. The surrounding material may then become excited and fluoresce with a range of wavelengths, including the deep red hydrogen alpha light. A good example of this is in the sword belt of Orion, the nearest region of star formation to earth and a region of glowing nebulosity that is easily visible to the unaided eye. It may even have been depicted by a motif on the Weetwood Moor petroglyph that is described in Section 6.3.

How fast nuclear fusion proceeds is dependent upon how much material there is in the star. A massive star burns so brightly that, despite having more material to fuel it, it has a shorter life than a small star. Small stars can live for billions of years, but a very large star may only last a few million. But eventually the material that fuels the nuclear fusion process runs out and then, at the end of its life, a star may collapse further under gravity and become a white dwarf, a neutron star or even a black hole. These objects can spin really fast, such as the neutron star pulsar at the heart of the Crab Nebula in the constellation of Taurus that spins at 30.3 times a second.

The gravitational collapsing of a star is often accompanied by very bright explosions which scatter the outer layers of the star. The largest examples of these are known as supernovae, and in the case of the formation of the Crab Nebula the light from the explosion was recorded by the Chinese in 1054 CE as being visible in daylight before it faded away. The ultraviolet light from the hot remains of the original star may subsequently cause the surrounding ejected material to fluoresce for thousands of years, and a few of these glowing supernovae remnants may just be discernible to the unaided eye at a very dark sky site. It is possible that the beautiful Veil Nebula supernova remnant in the constellation of Cygnus, that came from an event nearer in time to the Neolithic era than the present, was depicted on the petroglyph on Chattonpark Hill that is described in Section 6.4.

Returning to the star formation stage, the initial particle cloud may actually collapse to form more than one star if it subdivides into several smaller clouds. These then collapse individually to create a cluster of stars. Examples include the Pleiades star cluster in the constellation of Taurus that is described in Section 6.2 and the star cluster that is known as Melotte 111 which is referred to in Section 6.9. The number of stars in a cluster can vary from just a few stars to many hundreds of stars, and they are a common feature of the night sky. However, the stars in a cluster are all of different sizes and brightnesses so it may not be possible to see all the stars within a cluster with the unaided eye, although it is often possible to discern a few. The fieldwork at Old Bewick and at Buttony described in Sections 6.1 and 6.6 suggested that there were specific petroglyph motifs that depicted the brightness and the shape of star clusters, together with the number of stars that were observed in them.

## 2.2 The Milky Way

There is something wonderful about the stars and the experience of seeing them on a clear night in winter when they twinkle in a dark sky is very memorable. All the stars that we see with our unaided eyes are part of our own galaxy of a hundred, thousand, million stars that we call the Milky Way. But most of the stars of the Milky Way are so far away that we cannot make them out individually, and we only resolve the ones that are relatively near to the earth. The distant stars merge to form a ribbon of starlight like spilt milk across the sky. At a really dark sky site, such as is found today at remote places away from artificial lighting, or at high altitudes above the clouds, the Milky Way is the dominant feature in the night sky, and it is a wonderful sight. There are also dust clouds between the stars where new stars are being born and there are the remains of stars that have exploded. This material between the stars can give rise to dark regions where it obscures the light from the more distant stars, and also to bright regions where ultraviolet starlight causes it to fluoresce.

Figure 1 shows an astro-photograph of part of the Milky Way in the constellation of Cygnus, and the dark band of dust known as the Cygnus Rift can be seen running down it. This dark nebulosity may have been depicted on the large petroglyph on Chattonpark Hill that is described in Section 6.4. The Aztec and Australian Aboriginal cultures gave names such as the Emu to these dark features in the Milky Way [Norris 2009], and the Northumberland petroglyphs often seem to include depictions of Milky Way nebulosity in the form of grooves on the rock.

We do not see the stars as they are at the present time because of the long time that it has taken for their light to reach us. The speed of starlight is high, but the distances are so unimaginably great. It takes thousands of years for the light to reach us from the distant regions of the Milky Way and from beyond our Milky Way it takes over 2 million years for the light to reach us from the Andromeda Galaxy, which can just be seen on a dark night as a faint smudge of light. The image of this galaxy, which is shown in Figure 2, was taken with a 120mm refracting telescope, and it shows the disc of stars that is tilted towards us. It is just possible to make out two spiral arms in this disc which are separated by a dark dust lane. The Andromeda Galaxy is one of the many objects that may have been depicted on the Northumberland petroglyphs, in this case on the petroglyph at Tod Crag, as described in Section 6.8.

The stars show us that we are part of something beyond our earthly existence. Our world is an infinitesimal part of the Milky Way, which is just one galaxy in an immense, perhaps infinite, Universe of galaxies. There is something like a hundred, thousand, million galaxies in the observable Universe so if we multiply the typical number of stars in a galaxy by the number of galaxies in the observable Universe we find that we receive the starlight from ten thousand, million, trillion stars. We are far from being alone.

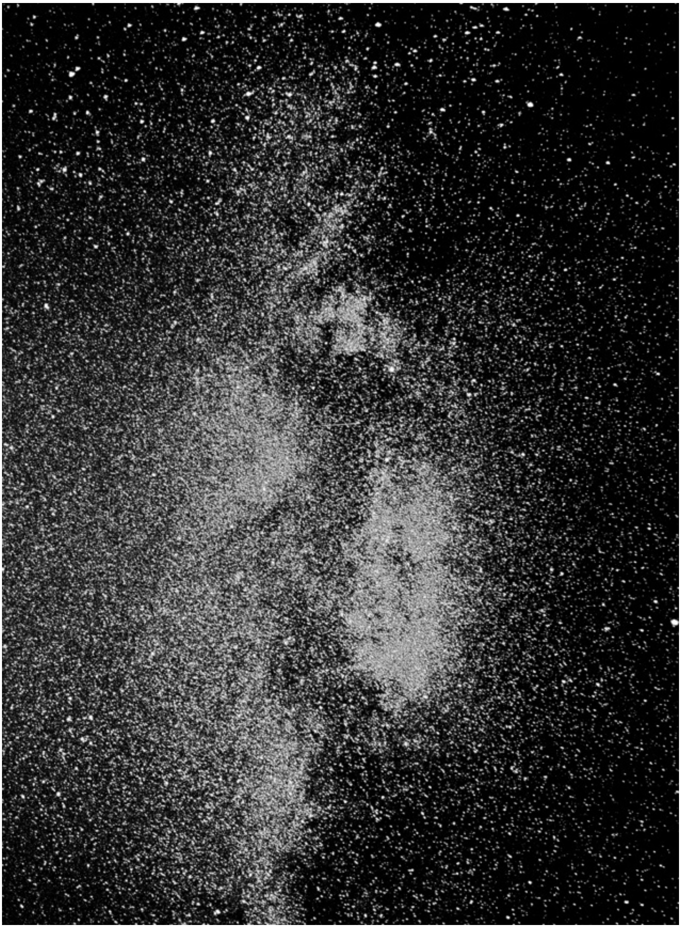

Figure 1 Astro-photograph of the Milky Way in the constellation of Cygnus. Under a dark sky the Milky Way can be so bright that it outshines the nearby stars in it. The dark band of dust is known as the Cygnus Rift and it may have been depicted by the long groove on the Chattonpark Hill petroglyph that is described in Section 6.4. The bright star Deneb is just visible to the right of the upper dark nebulosity. Fujifilm X-M1 with 18mm lens: 20s exposure at f/2: ISO 1600.

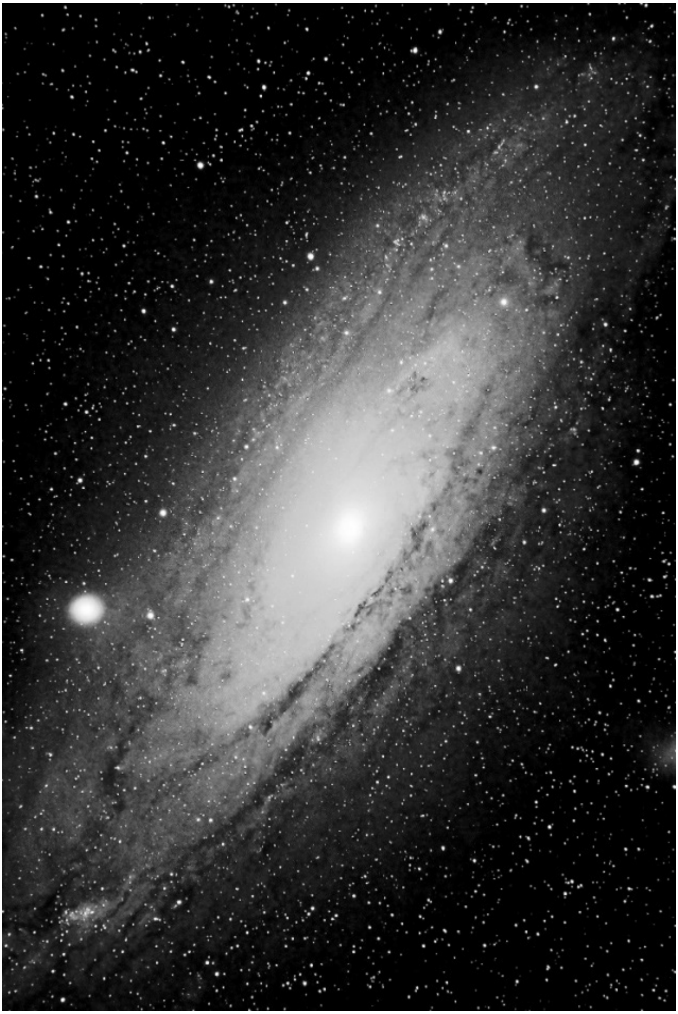

Figure 2 Astro-photograph of the Andromeda Galaxy M31. This beautiful spiral galaxy of stars may have been depicted in the petroglyph on Tod Crag.
Fujifilm X-E3 on a 120mm f/7.5 refractor: 480s exposure: ISO 800.

# Chapter Three

# Star Magnitudes

Although again a little astrophysical, the idea of a star's magnitude is a rather important concept for the deciphering of petroglyphs, so this chapter is perhaps worth persevering with.

## 3.1 Seeing stars

In this book the brightness of stars means how they appear visually in the night sky, rather than how they appear in photographs. This depends upon the light from the star, the sensitivity of the human eye and the observing conditions. Genetic differences can result in creatures with more sensitive eyes, such as owls and giant squid, so it is always possible that there were some slight differences in the eyesight of the people who drew these pictographs long ago, compared to our eyesight today. It may also be that their diet and plants had an effect upon their ability to see in the dark in the same way that carrots were anecdotally given to RAF pilots in WW II. And in a landscape with some dangerous creatures around the ability to see well in the dark would have had real survival value.

It became clear from the analysis that nearly all the petroglyphs studied had grooves that may have depicted nebulosity between the stars. Depending upon the elements that fluoresce this nebulosity can emit light of many wavelengths, but the most common wavelength is the 656nm wavelength of hydrogen alpha light. This light is nearly always very faint, and at the deep red end of the visible spectrum where the sensitivity of the eye falls rapidly away. The apparent ability of the Neolithic people to depict it with grooves in the rock face suggests that their eyesight may have been good at these longer wavelengths. And the possible depiction of the blue reflection nebulosity of the Pleiades that is described in Section 6.2 suggests that their eyesight may also have been very good at the shorter wavelength blue end of the visible spectrum.

A very significant feature that aids seeing in the dark is known as dark adaptation, whereby the sensitivity of the eye increases as the time spent in the dark increases. Another technique called averted vision also makes it possible to see faint objects by looking at them out of the corner of the eye, rather than by looking straight at them. This is because the cells in the eye that are most sensitive to light are arranged around the edges of the retina and catch the light that enters the eye obliquely. Someone whose eyes are dark adapted and who makes use of averted vision would be able to detect much fainter stars and nebulosity.

Good eyesight is not enough though if the atmosphere is not clear and dark, so weather and climate are significant factors that determine how visible stars and other features of the night sky are. Dust and moisture in the night air scatters starlight, and a disturbed atmosphere makes the stars twinkle. It is a matter of experience that the Milky Way is much brighter on some nights than others, and of course in our polluted atmosphere it is often not visible at all. On some nights there are fleeting moments of what is called “good seeing”, when momentarily it is possible to perceive fainter objects and more detail. These atmospheric effects are particularly noticeable when trying to discern details on planets.

The sky gets progressively darker after sunset and a distinction is made between civil twilight, with sometimes a beautiful milky twilight, nautical twilight as it gets darker and astronomical twilight, which is the darkest twilight of all. Around midnight in winter on a moonless night is the best time to observe the faint stars of the winter constellations. And it seems that these were often depicted on the petroglyphs, although some of the petroglyph interpretations suggested that some stars of the summer constellations were also depicted.

The distance that starlight has to travel through the earth’s atmosphere is greatest when the star is low in the sky. The absorption of starlight by the atmosphere through which it passes gives rise to a phenomenon called the atmospheric extinction of starlight. Because of this absorption only the very brightest stars can be seen when they first rise above the horizon, and the other stars only come into view when they are at a higher elevation above the horizon. The angle in degrees above the horizon at which a star becomes visible is very approximately equal to the magnitude of the star, a topic which is discussed next. Thus, a bright star of the first magnitude such as Aldebaran might become visible when it rose to about 1° above the horizon and a less bright star of the second magnitude like Mirach would not become visible until it rose about 2° above the horizon. All this is assuming that the sky is dark. In the dusk or dawn twilight of course the sky is brighter, making all the stars much less visible.

The atmosphere also refracts the starlight so that when a star is near the horizon it appears higher in the sky than it actually is. One consequence of this is that when we watch our nearest star, the sun, disappear over the horizon at sunset, it has actually already set and we are seeing it over the horizon. This bending of starlight is called astronomical refraction. There is yet another effect caused by temperature gradients in the atmosphere near the ground which is called terrestrial refraction. It also acts to modify the position of the stars in the sky. An extreme example of this is a mirage, when even distant camels in the desert can appear to be high in the sky!

These atmospheric effects near to the horizon become very significant if an alignment were to be established with a petroglyph site and used to derive an accurate date for it, as discussed later.

## 3.2 The brightness of stars

The brightness of the stars that may have been depicted is an important key to decoding the petroglyphs, so it is useful to understand the way in which the brightness of stars is described. The word that denotes the brightness of astronomical objects is magnitude. However, as many stars vary in brightness over timescales that vary from seconds to many years, a star can actually have a range of magnitudes. Many stars emit radiation in the radio, infrared, ultraviolet and X-ray regions of the spectrum, so there are different magnitudes for these wavebands. But throughout this book the only magnitude used is the apparent visual magnitude.

The eye has a sensitivity to light that is approximately, but not exactly, logarithmic. This allows it to detect light over a wide range of brightness from very faint starlight to bright sunlight, an amazing dynamic range of over a trillion. The non-linear sensitivity of the eye to light means that a star that gives off ten times as much light as another star might be perceived to be brighter by a certain amount, but it would take another star with a hundred times the brightness to be perceived as having about the same increase in brightness and a third star with a thousand times the brightness to be perceived as being about as bright again. Modern astronomy uses a precise logarithmic magnitude scale of brightness. It is defined so that there is a difference of five units of magnitude between one star and another star that is a hundred times as bright. Because of the logarithmic nature of the magnitude scale each unit of magnitude is defined as a multiplication, rather than an addition, by a factor of 2.51 in brightness. This can be understood by multiplying together the factor of 2.51 for one unit of magnitude five times to give the required factor of 100 for five units of magnitude: 2.51 x 2.51 x 2.51 x 2.51 x 2.51 = 100.

In practice this factor of 2.51 for one increment in brightness works well because it corresponds to a small, but nevertheless noticeable, change in perceived brightness. With some care it is actually possible for the eye to perceive differences in brightness between two stars of less than a magnitude, but a change in brightness by one unit of magnitude could be said to correspond to a naturally perceived difference in brightness. What is very counterintuitive though is that in the modern system of magnitude the brighter the star the smaller the numerical magnitude. It is rather like the results of a race in which the faster runner, the brightest star, gets the first prize. The brighter stars in the sky have magnitudes of 1 or 0, and sometimes even negative magnitudes. Sirius, the brightest star in the night sky, has a visual magnitude of -1.4 and the sun, the brightest star of all, has a visual magnitude of -26.7. It is possible that supernovae explosions could be brighter than Sirius for a time, and therefore have an even more negative magnitude number. Venus and Jupiter also have negative magnitudes.

To understand cup and ring petroglyphs it is necessary to know the approximate magnitude of the faintest stars that can be observed with the unaided eye, and this of course depends upon all the factors mentioned in the preceding section. A magnitude of 6.5 is often cited as the limit of visual observation, although for many nights under our cloudy and polluted skies the limit is probably nearer to magnitude 5. There is a scale of sky brightness called the Bortle scale that is used to decide whether an observing site merits a particular category of dark sky status. On this scale the naked eye limiting magnitude for a truly dark sky site is in the range 7.1 to 7.5. This is Bortle Class 2. The naked eye limiting magnitude for a Bortle Class 1 dark sky site is a very faint, and very rare, 7.6 - 8.0. There is some evidence from this study that the Neolithic era folk in Northumberland were able to see down to magnitude 7.5 as some of the small cup markings on the petroglyph at Chattonpark Hill which are shown in Figure 17 correspond to the location of star asterisms of this magnitude. Thus, at a truly dark sky site, the range of magnitudes that might be seen runs from magnitude -1.4 for Sirius through zero to magnitude 7.5 for the very faintest stars that can be visible with the unaided eye under the most favourable conditions. This gives the following set of nine numbers that together spans the unaided eye magnitude range of stars: [-1, 0, 1, 2, 3, 4, 5, 6, 7].

The modern, but counterintuitive, system of star magnitude has its roots in the astronomy of ancient Greece, and perhaps in even earlier observations of the stars. The Greek genius who acquired much of the earlier Mesopotamian knowledge, and added his own, was Hipparchus of Nicaea who worked in Rhodes. His knowledge was then passed on to another Greek called Ptolemy who worked in Alexandria. Around 150 CE in ancient Greece, a point in time nearly halfway back between the present-day and the end of the Neolithic era in Northumberland, Ptolemy wrote a long treatise on astronomy called the Almagest [Toomer 1998]. It was divided into 13 books of which Books 7 and 8 give a catalogue of 1,022 stars divided into 48 constellations. Ptolemy gave the position of these stars in their constellations, their longitudes, latitudes and their magnitudes. The brightest star in the Almagest catalogue is the red giant star Betelgeuse which has a present-day magnitude of 0.5. Ptolemy recorded it as magnitude 1 whilst the faintest stars were given a magnitude of: “greater than 6”. The set of seven numbers that span the range of magnitudes in the ancient Greek system was thus: [1, 2, 3, 4, 5, 6, >6]. However, had Sirius, which is nearly two magnitudes brighter than Betelgeuse, been included this span would have been increased to the set of nine numbers: [- 1, 0, 1, 2, 3, 4, 5, 6, >6]. This system might therefore be compared to the present-day span of nine numbers that is described above.

The interesting thing about these spans of nine magnitudes is that they are also the same numerically as the span of nine in the number of rings that were encountered in the cup and ring petroglyphs in Northumberland: [8 rings, 7 rings, 6 rings, 5 rings, 4 rings, 3 rings, 2 rings, 1 ring and zero rings].

The inference from this is that the number of rings may be connected to the visual magnitude in some way. There are relatively few very bright stars in the sky and there are also very few petroglyphs with cup and ring motifs that have a large number of rings, so the connection seems to be that the brighter stars were depicted with more rings. This is entirely logical, but it is the reverse of both Ptolemy’s, and of our modern magnitude system. However, it is easy to approximately relate the two systems, and an empirical formula that was found useful for fieldwork, and for an analysis of a petroglyph, is that the number of rings around a cup motif N is related to the magnitude M of the star as: $N = 7 - M$. The rearranged version of this empirical formula: M = 7 – N gives an estimate of the magnitude of a star depicted by a petroglyph cup and ring motif.

This would mean that Sirius, with a magnitude of -1.4, might be depicted as a cup and ring motif with 8.4 rings and a faint star with a present-day magnitude of 7 would be depicted as just a cup motif with no rings. Any star or object fainter than a visual magnitude of 7 would also have no rings since of course it is impossible to have less rings than no rings! However, it is perfectly possible to have incomplete rings that might denote fractional magnitudes, and many examples of incomplete rings were encountered in the fieldwork. It was found that this empirical formula was correct for about half the cup and motifs that were encountered. Any interpretations of cup and ring motifs where the number of rings departed by more than one ring from that predicted by the formula needed closer examination. However, it perhaps needs to be borne in mind that this formula takes no account of the possible changes in a variable star's brightness since the Neolithic era. And to anticipate the interpretation of the Tod Crag petroglyph that is described in Section 6.8 the number of rings that were actually engraved may have been reduced for all of the cup and ring motifs on a petroglyph to save space on the rock face, and no doubt a lot of work in engraving!

In Appendix II the data derived from all of the interpretations was used to attempt to refine the above empirical formula. But the refined formula came out the same as the empirical formula which is perhaps not too surprising as this had been used to interpret the motifs! However, it does need to be borne in mind that the response of the human eye to brightness is not perfectly logarithmic so that what was depicted was what would have actually been seen, and not what was measured on a modern, precise logarithmic scale.

In practice, and without instruments to measure brightness, the magnitude of a star may be estimated by comparing it to nearby stars of known magnitude. If these stars are about one magnitude different then fractions of a magnitude can be estimated, and this is sometimes done by amateurs when studying variable stars that change their magnitude over time. As any scale needs reference points certain special stars would perhaps have been ascribed certain magnitudes, which could then be compared to the star in question.