*Skoll the wolf who shall scare the Moon*
*Till he flies to the Wood-of-Woe:*
*Hati the wolf. Hridvitnir's kin,*
*Who shall pursue the Sun.*

--The Grimnismal, of the Eldar Edda

## Introduction: A Day with Two Dawns and Midnight at Noon

I am an astronomer; I have spent my whole life watching the sky. I've been to observatories all over the world and used every kind of telescope to image distant star clusters and massive galaxies. Every clear night is an opportunity for me to see something beautiful and discover something amazing. I have seen comets that hung motionless amongst the stars for months and a Milky Way so bright that the lights of its billion stars cast shadows on the ground. But in all my life I have never seen anything as awe inspiring, as *awesome* - in the original definition of the word - as a total eclipse of the Sun. It is the only astronomical wonder that requires no telescope or fancy equipment to see and looks more spectacular to the eye than through the lens of any camera.

For an event that has at some point touched almost every place on Earth, remarkably few people have ever seen a total solar eclipse. The fact that *anyone* is able to see one is due to the coincidence that our Moon is exactly the right size and distance from the Earth to completely cover the Sun. At that moment we are in the Moon's shadow and a solar eclipse occurs. Where the Moon fails to cover the Sun completely, the eclipse is only partial.

But at the very center of the shadow, where the alignment of Earth, Moon and Sun is absolutely perfect, a *total* eclipse occurs.[*] This spot of totality is small - maybe no more than a few dozen miles wide - yet the Moon's motion draws the shadow eastward across our planet in a path thousands of miles long. For anyone on the ground, the experience can be either awe-inspiring or merely interesting, depending entirely on whether one is inside or outside that path of totality. As those who have been to the shadow's center can attest: it is literally the difference between night and day. Ninety-nine percent totality is *definitely* not ninety-nine percent of the spectacle.

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It's exactly 11:28 in the morning when a tiny nick in the side of the Sun first appears. Were it not for the shouts from the crowds around me on this August morning I never would have noticed it. The Sun is so bright during this initial, partial, phase of the eclipse that without the cardboard safety glasses protecting my eyes I never would have noticed it. But don't let these cheap glasses fool you, they're only necessary during the partial phase when the Sun's rays are still as strong as on any normal day. Once totality occurs the spectacle will be perfectly visible to all and I can easily toss the pair aside.

Watching the notch turn into a bite, it is no coincidence that cultures from all over the world witnessed this sight with some degree of dismay. The Greek origin of the word *eclipse* is *ekleipsis* meaning "omission" or "abandonment." Ancient Chinese eclipse accounts contain the characters for "ugly" and "abnormal." For the Aztec, the eclipsed Sun "faltered" and became "restless" and "troubled."[1] These reactions make perfect sense when you consider that the Sun

[*] If the Moon, in its elliptical orbit around the Earth is too far away to completely cover the Sun, then the eclipse is annular, and it appears as a "ring of fire" with a tiny strip of Sun completely encircling the dark side of the Moon.

is the giver of heat and life. When the Sun goes away, it leaves behind the creeping fear that it might not come back.

It takes forty minutes for the bite to grow so big that the Sun is now a crescent. Beneath me that same shape is visible by the thousands within the shadow of the tree under which I've taken refugee from the heat. Every tiny gap in the leaves overhead acts as a "pinhole camera" projecting a bright fingernail of light on the ground. Nearby children have spotted them too and begin to yell and giggle as they point and play amongst the tiny crescents. Had I not known what was happening before, this oddity would certainly have revealed the eclipse in progress above.

An hour has passed since this all began: only twenty minutes left until totality. Even without glasses, a quick glance out of the corner of my eye now reveals an arc across the Sun that divides the blinding from the merely brilliant. The life-giving nature of the Sun is no longer an abstract concept: the sky is growing darker and colors are strangely wrong. The landscape is sapped of saturation. The worlds are aligning.

With ten minutes left, the conditions are changing fast. The world has turned to twilight. The shadows of trees and me are sharp as if lit by a single spotlight. All illumination now comes, not from a yellow Sun set amid a bright blue sky, but from only a narrow white crescent in a sky no longer bright.

The crescent shrinks. The crowd rises. Conversations hush and I can hear that all birdsong has ceased; birds have returned to their nests to sleep in the unexpected night. The eclipse is now a multisensory experience of sight, sound, and touch as an unseasonably cool wind gently blows across my arms. So little of the Sun is left that surely totality should begin at

any second, but I can't tear my eyes away to look at my watch. Even the passage of time seems affected now, as a minute becomes an hour and seconds like minutes.

Suddenly, the thin sickle breaks apart into an array of brilliant specks that dance and shimmer along the jet-black rim. They are called Baily's Beads and they are the last rays of the vanishing Sun streaming through actual mountain valleys along the curved lunar rim. I finally remove my protective glasses to see them quickly wink away until there is only a single glistening star set in a band of white fire encircling the Moon: the glorious diamond ring.

And then the spot collapses upon itself and is gone.

Totality.

Where before there was light and heat, now there is only a cold, black hole in the sky surrounded by a ghostly crown. The corona, a ring of pearly tendrils, envelopes the darkness and stretches off into the sky in all directions. It is unimaginably beautiful, only ever visible during these few precious minutes of totality, and all around it are the brighter stars and planets invisible until now. It is a day that has become night at noon with Sun, Moon, planets, and stars overhead.

While I know the mechanics of this celestial alignment, it is in this moment of totality that I understand the difference between knowledge and feeling. The hair is raised on the back of my neck and my mind screams at the wrongness of what I am seeing. It is clear to me now why people throughout time did what they did to scare away the demons, chase away the jaguars, and slay the monsters they imagined devouring the Sun. The French astronomer and historian Jean-Pierre Verdet, has found this fear-fueled call to action was universal.[2]

But there has always been a purpose to this pandemonium. In Paraguay and Argentina, the roar of the crowds and barking dogs frightened the celestial jaguar that ate the Sun. Norsemen yelled to frighten away Loki's demon dogs sent to hunt and feed upon the Sun and Moon. The Ojibwe of North America sought to help the beleaguered Sun by firing flaming arrows to help him regain his light. In India the people banged pots and pans to frighten Rahu, an immortal head who chased and ate both Sun and Moon.[3] If they were loud enough then Rahu would be startled, and drop the Sun from his jaws: totality would be averted and the eclipse would be only partial. For the Aztec, however, matters were more serious, where, "the common folk raised a cry, lifting their voices, making a great din, calling out, shrieking… People of light complexion were slain [as sacrifices]; captives were killed."[4]

Fortunately for any fair-skinned Aztecs, total solar eclipses for any one location are rare. Though eclipses happen roughly twice each year, each follows a different path across the planet. Every 18 years these patterns repeat in shape, but one third way around the planet and a little farther north or south than the one before. As seen from a location high above the globe these paths slowly spiral around the planet from pole to pole until eventually any spot on Earth can expect to see totality every 300 years on average. Though three centuries is long in human terms, the different paths do cross, and a single person in a fixed location may periodically see two eclipses in as little as a dozen years or less. For cultures that looked to the sky for omens, where every new star, comet, or eclipse could be the sign of the end-times, imagine what seeing three total eclipses in one lifetime would have meant?

A thousand years ago, in what would become the American southwest, Chaco Canyon was the ceremonial center of the Ancient Puebloan people (who used to be called the Anasazi).

There, on the side of a massive boulder is a pictrograph unlike any other; one that may be a record of the total solar eclipse of July 11, 1097 that was one of three solar eclipses visible there over 58 years at the height of their culture.[5] It features a large circle pecked into the yellow sandstone surrounded by strange looping tendrils similar to the appearance of the solar corona, including an eruption of hot gas (called a coronal mass ejection) and Venus just where it would have been visible in the sky to the upper left.[6]

Imagine the effect such an apparition would have had for a sun-watching people at the heart of their ceremonial society during a decade of extreme drought when the climate was changing for the worse. For a people in the midst of extreme cultural and environmental crises, might such an eclipse have been yet another contributing factor in what made the Chacoans eventually wall up their monumental "Great Houses," set them aflame, and ultimately abandon the canyon a thousand years ago?[7]

Even today, eclipses play on our fears. The American anthropologist, Ward Keeler, describes the event of June 11, 1983, when a total solar eclipse swept across Indonesia, and:

> [T]he air became very still and Java's lush vegetation glowed in the eerie light characteristic of sunset in the tropics. As at sunset, too, the horizon turned red, but it did so not only in the west but in all directions, and in the half-light distant volcanoes usually obscured by the glare of the Sun became visible. For the four minutes of total eclipse, the Sun, almost directly overhead, looked like a black ball surrounded by a brilliant white light. Most eerily of all, in one of the most densely populated rural areas in the world, there was no traffic on the roads, no movement in towns or villages, and no one watching the eclipse.[8]

For weeks prior to the event, newspapers, radios, and TVs had gone to great length to warn people about the event for fear that people would damage their eyes. Posters were prominently displayed in villages across the country bearing the message that watching the eclipse would cause you to go blind and were so effective that:

> [N]o one dared even to look outside, let alone look at the sky, for a period of about three hours before and after as well as during the eclipse. People stayed inside their houses, some watching the eclipse on television, others lying in bed, all thoroughly intimidated by what had come to be known as the Sun's "sharp rays."[9]

I know that fear first hand. The last total solar eclipse to touch the continental United States did so in Portland, Oregon on February 26, 1979. I was a boy, only nine years old then. In my fourth grade class we made clay medallions of the upcoming eclipse. While others painted black circles with yellow crescents in representation of the partial phase, I had found library books showing the corona and so carefully painted the billowing white ring around the central black hole. Yet on the morning of the eclipse, rather than go out and see the sight for myself I hid indoors with the curtains drawn. My local TV and radio stations had been inundated with the exact same messages of fear that would later be broadcast all over Indonesia. I hid indoors from the very same mysterious rays with the power to make me go blind if I so much as got a glimpse of the eclipsed Sun.

Today I know that there are no special rays, sharp or otherwise. Only during the partial phase is the Sun so bright that staring at it for even a couple seconds can cause permanent

damage to the retina (just as it will do on any other day). For this reason, it is only for curious onlookers during the partial phase that eclipse glasses are even necessary; when totality comes its light is as safe as it is awesome. Yet, in our zeal to be "safe" we flood the airwaves with our fears, never with our hopes. That is why, to this day, my first eclipse memory is of watching the events unfold on my RCA color TV (snapping photos off the screen with my plastic drugstore camera). My only direct experience of the event itself was noticing how dark the house became as totality passed unseen overhead. It would be thirty-eight years before a total solar eclipse would touch this country again and I have spent every one of those years wishing I'd turned around, gone to the window, parted the curtains, and simply looked up.

My career as an astronomer has taken me around the world since then, partly in pursuit of exactly that which I so narrowly missed when I was nine. Yet though I have seen multiple solar eclipses since, I will never be able to see the one that I missed that day. Every eclipse is different. The corona that is such a startling phenomenon of totality is different every time depending upon the conditions on the Sun at just that moment, and its exact shape is unknown until the instant of totality.

Astrological records of ancient eclipses in China claimed that while solar eclipses were a reflection of the quality of the king, the corona's appearance revealed the political plots at work behind the throne:

> (If the king) does not share his fortune with his subjects, the condition is called unstable. Then there will be a total eclipse with Sun being black and its light shooting outward…. If there are two ear-rings beside the Sun during eclipse

while in the east, west, south, and north corners there are white clouds shooting outward, then the whole country will be in war.[10]

The search for meaning in celestial events is the purview of astrology. A comet appears in the sky? The king will be overthrown. A supernova (a new star) appears in Leo? A new king will be born. The Sun is eclipsed? The king is wicked. When even I, a steely-eyed science-type, am moved to awe by such a rare and beautiful phenomenon, it makes sense to want to associate it with something of great importance.

It therefore follows naturally that if eclipses record momentous events, then a momentous event must require an eclipse. Both Ragnarok and the Rapture (as well as the Crucifixion in the gospels) are accompanied by the Sun turning black, often interpreted as a total eclipse. Only slightly less momentous, to anyone not from Boston, is the fact that the Red Sox only broke their 85-year long World Series curse during the final moments of the total lunar eclipse of October 2004.

If eclipses were harbingers of end-times (at least for Yankees fans), then to call on one was a sign of one's power with the gods. This is the thinking that drove Columbus to take advantage of the Jamaican's fear. The moral question of his actions aside, the fact that he could possesses a book that predicted an eclipse years in advance from the other side of the globe is startling. The fact that those predictions can be tested, is what makes science so powerful. Wish to see a solar eclipse? Astronomers can calculate the location and time of any future eclipse down to the mile and the second. The proof of whether or not we are correct will be waiting for you when you get there: either you see the corona or you don't. If you don't, then we learn we

didn't understand the world as well as we thought and we seek to correct what we failed to get right. This process is the tool for learning everything we know about the physical Universe in which we live.

Astrology also makes predictions. Based on the motions of the heavenly bodies it identifies all manner of auspicious dates and compatible mates. The one thing it does not do, however, is include the same self-testing, self-correcting mechanism that is the defining characteristic of science. Yet in a 2014 National Science Foundation survey, nearly half of all Americans (45%) responded that they believed there was some scientific basis to astrology. Imagine my disquiet when during my most recent trip to the doctor the nurse drawing my blood looks at my paperwork and says with a smile, "Oh hey, you're a Scorpio too!"

The primal appeal of pseudo-sciences like astrology is understandable. Life is full of dangers and misfortune that plague us at random. Astrology gives us hope that there is a cosmic reason, a connection with the Sun, Moon, and stars, which gives order to the apparent chaos we encounter. Yet the science of astronomy reveals a far more direct way in which the heavens guide our lives on a daily basis.

The Sun gives us light and heat. What organisms don't feed directly on sunlight, feed on other organisms that do. Our everyday concepts of position, direction, and time intimately depend upon astronomy. What is a "day" but the rotation of our planet? A "year" measures its orbital motion about the Sun. Even the orbit of the Moon is marked in the period of time we call a "month." Imagine every task, chore, rite, or celebration that happens on an annual basis and you will find a need for some astronomer in our past. Could civilization have arisen without

astronomy? Might we all be the descendents of astronomers? Is there any evidence? Where did astronomy begin?

Let's imagine a family tree of our distant ancestors. Four million years ago, our small *Australopithecus* ancestor first stood erect out on the African savanna. As the American astronomer Neil deGrasse Tyson has said, "Once we were standing upright, our eyes were no longer fixated on the ground." Out, away from the cover of trees, the night sky was more vivid than almost any sky current humans can see. We are not the only beings on this planet who have noticed the stars and Milky Way. Sea turtles, birds, and dung beetles all make use of the stars and Milky Way for navigating. But use alone isn't science.

By 2.5 million years ago, our *Homo habilis* ancestors were following animal herds in their annual migrations. Evidence exists for seasonal camps during their travels. Did they plan them by noting the passing of the seasons with the changing sun and stars in the sky, or did they merely set up new camps as the kept close to the animals upon which they depended? Lions follow herds, but they aren't scientists.

A million years later our *Homo erectus* forebears mastered fire which for the first time, extended the day's work into darkness. Perhaps the first constellations, were made during those nights? If so, we have no record of them.

Only 60,000 - 100,000 years ago, the first *Homo sapiens* fed on shell fish from tide pools on the south coast of Africa. But the tides are tied to the Moon and change each day, both in time and size as the Moon goes through phases. There'd be a benefit to understanding these patterns: those that did, got to feed themselves and their families; those that didn't got washed out to sea. Maybe this is where astronomy began?

But consider for a moment what is required to make these mental connections. The ocean tide is a direct physical effect; it gets you wet and reveals its food when it goes out. The Moon, by contrast, is so far away you can't touch it, hear it, or smell it. There's no reason these should be connected and what connection there is can only be revealed through observations over a long period of time, requiring memory, abstract pattern recognition, and a belief in an underlying order or connection.

The archaeologist, Steven Mithen refers to these skills as "cognitive fluidity": the ability to synthesize different forms of intelligence (the ability to build fires, tools, and weapons, along with the ability to interact in a group and structured society) and to combine these in ways that incorporate abstract ideas, myths, and long term observations.[11] Evidence for this fluidity appears about this time in the first examples of representational art and bone-artifacts where a physical thing has been created as a representation of something else.[12] If this is the earliest time when science could arise, then it is not surprising that the first, most unambiguous evidence of human astronomical knowledge is more recent still.

Less than a mile from the Nile, in what once was ancient Nubia, is a complex of graves in which 58 bodies were found all buried on their left-side, head to the East, facing the rising Sun.[13] The simple fact that they face the East means that between 10,000 and 12,000 years ago someone knew how to identify one of the four cardinal directions. These directions are defined by the sky. The East is where the Sun rises, West is where it sets. The line joining north to south is where the Sun is at its highest during the day and at night (at least in the northern hemisphere) the North is the direction around which all the stars turn. Here in the Nubian

Desert is finally evidence of an astronomical knowledge and of its association with some abstract, intangible meaning.

When one first asks the question, “Why does the Sun rise in the East?” there are two paths to follow for an answer. One path leads to science, the other leads to religion. For most of human history these paths ran side by side and were often indistinguishable; the answer, “Because the gods make it so,” covers a lot of phenomena and is difficult to refute. This is what we see in the stories of eclipses. Demons and deities eat the Sun and Moon and do so for reasons only known to them.

This is a tricky path to follow because any phenomenon we don’t understand can always be blamed on the gods or God. Why does the Sun rise in the East and not fall from the sky? It’s the work of the god Apollo and his gleaming chariot. Why do the Sun, Moon and stars all circle overhead? Because God has placed the Earth at the center of the Universe around which all things move. In recent years this reasoning has been extended to biological evolution by those who believe the process is too complex to have occurred without an Intelligent Designer.

This explanation is called the “God of the Gaps,” a term first coined by Henry Drummond, a nineteenth-century Scottish evangelist. Over time, as we discover more about our world, the gaps in our knowledge grow smaller as does our need for miraculous intervention to explain what is seen. This is neither fair to science nor religion. For the religious-minded individual who looks for physical proof that God is at work in the cosmos, the duties of His job grow less consequential with every year. God gets demoted from being the Prime Mover of the heavenly firmament to merely twiddling the knobs on the values of a few physical parameters. It’s unfair to science because once a miracle is invoked (in essence to say what is

unknown is unknowable), all further investigation stops. After the “Miracle Card” is played there is no reason to keep testing hypotheses.

So while the question “why” can be fraught with metaphysical traps, science also asks “how;” a question that has answers open to direct experimentation. How long is a day? How can I learn this from the changing position of the Sun in the sky? How do the locations of the Sun and the stars at night define direction and the passage of seasons?

For careful observers, the sky becomes a calendar easily used to predict the changing seasons upon which individual and complex society’s survival (and ultimately civilization) depend. It is, perhaps, no coincidence that the first signs of agriculture are found at the roughly the same period in time as the Nubian graves.

This transition from a chaotic world of seemingly random changes to a predictable world of returning stars, rain and food, is embodied in the story of eclipses. Like the ancient Chinese astrologers who courted palace intrigue, or even Christopher Columbus saving his own skin, whoever could understand the motion of the heavens and thus predict an eclipse had the power to declare why they occurred and impart order on chaos. In a modern world where twice as many Americans believe there is some science to astrology than there are that accept evolution, we are still in thrall to the cycles and patterns of the sky.

…

My attention returns to the black Sun overhead. A single needle of light bursts forth into a second diamond ring even more beautiful than the first. The light has returned too quickly and the Sun is once more too bright to behold. It is over and my first thought is, “When can I see another?”

That I chase eclipses where my ancestors feared them is not to say that they were foolish to fear the sky. Thanks to science, while we no longer blame demons and believe in omens, we do understand that ancient terrors like comet impacts and nearby supernova explosions could kill most life on Earth (and in some instances already have). But, thankfully, we now know that eclipses are utterly without harm, and thus it is the one astronomical phenomenon that has made the transition from terrifying omen, to scientific tool, to benign tourist attraction.

As with Columbus and others, eclipses have already altered our history and shaped our world view. We will look at how this has happened; from the very first shamans and astrologers who over long years divined the true pattern of eclipses and learned to predict them, to the philosophers and scientists who discovered their true cause and used them to measure the world and explore the universe beyond. Today we've witnessed eclipses of other worlds that reveal we are just one planet in an ever-growing family of planets throughout this galaxy in an ever-expanding universe. This is the story of science, the path down which totality leads.

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