Astronomy and Ethics

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Astronomy, from the Greek *astron*, star, plus *nomos*, law, thus the laws or regular patterns of exhibited by the stars, is now defined as the science of objects beyond the Earth's atmosphere, including their physical and chemical properties. This science of what is beyond the Earth paradoxically served as the model for the early modern effort to create a science of terrestrial phenomena. Because of their apparently more simple and necessary order, astral phenomena were the first to be subject to explanations in the form of ‘laws’, the methods of which were then extended in modern physics to explain the dynamics of falling bodies at or near the Earth. Yet just as modern physics emerged to give human beings greater powers over material affairs than ever before, and thus as a challenge to ethics, so subsequent developments in astronomy deprived humans of an order that could be perceived as a transcendent and normative guide for human conduct. Immanuel Kant (1724-1804) could still wonder at the correspondence between the "starry heavens above and the moral law within" (*Critique of Practical Reason,* 288); but the achievements of modern astronomy have left the moral law within to fend for itself.

Pre-Modern Astronomy

Astronomy has been called the world’s second oldest profession. Notations found on artifacts scattered over Africa, Asia, and Europe, dating from 30,000 b.c.e., appear to be rudimentary calendars based on the phases of the Moon (Hartmann and Impey 1994). The transition from hunter-gatherers to life in stable villages, occurring around 10,000 b.c.e. with the rise of agriculture, required a refined estimation of the timing of seasonal changes. The sky, although no doubt deeply mysterious to these ancient cultures, was also reassuringly deterministic. By 4000 b.c.e. for instance, Egyptian astronomers knew that the first appearance of the brightest star in the dawn sky, Sirius, marked the beginning of the Nile’s annual flooding. Many, probably most, cultures, timed their agricultural activities based on similar annual celestial events.

The stars of course were also used for navigation. The Minoans of the island of Crete employed the stars to navigate the Mediterranean and to forge relationships with the Greeks as long ago as 2600 b.c.e. In developing this technology, they grouped the stars into pictures that gave rise to some of the constellations that we still know today (Hartmann and Impey 1994). The navigational prowess of the Polynesians is legend. The courage and faith these seafarers had in the heavens’ ability to guide their way is astonishing. Crossing vast expanses of the Pacific, Polynesians discovered that if they sailed north until the Southern Cross dropped to a hand's length above the horizon, they would be at the latitude of Hawaii. To return, they would point their outriggers south until two stars, Sirius and Pollux, set together.

The megalithic monument, Stonehenge, on the Salisbury Plain in Great Britain, had a utilitarian as well as spiritual design (Fig. 1). On the longest day of summer, at solstice, the sun rose over a huge, notched boulder, the 'Heel Stone', as seen from the center of concentric rings of massive boulders, some 30-50 tons (Hawkins 1965). The accompanying midsummer ritual, 4000 years ago would have been an annual part of the cultural weaving of astronomy, beliefs and values for the participants. Enormously demanding achievements such as the construction of Stonehenge and of the Egyptian pyramids are testament to the power the heavens exerted on the societies that built them.

Possibly the most extraordinary early example of institutional astronomy was that of the Mayans. The priest-astronomers that observed the heavens and performed the calculations to produce their calendars were publicly supported for at least 200 years around 400 c.e. The Mayan calendar did not only chart the seasons for agriculture. It also predicted eclipses, experienced by the Mayans as traumatic and darkly mysterious. Mayan astronomers computed the complex motions of Venus, believing it to be one god in the evening, and another when it reappeared in the morning. Venus' quasi-periodic disappearance and reemergence on the other side of the world was seen as a journey and transformation in the Underworld (Aveni and Hotaling 1994). It appears that in all early cultures, astronomy and religion were deeply interconnected. Astronomy, by giving an accurate description of the motions of heavenly bodies, was at the same time a very powerful tool for sustaining civilization and exploring the world.

However it goes about it, religion seeks to provide guidance for living in harmony with the Earth, with other people, and with the Universe. But peace, it could be argued, is only possible for human beings if they have in some way accepted what their lives mean. Religion addressed the human question of meaning, by defining our relationship with the cosmos. So astronomical questions, such as what brought forth the Universe, how old it is, and what our place in it is, were religious questions. It has been suggested that the starkly hierarchical Medieval (Aristotelian) cosmology with the Universe consisting of ten concentric spheres around the Earth (the outermost being Heaven) was reflected in the rigidly hierarchical society that oppressed the vast majority of people (Abrams and Primack 2001).

Galileo's astronomical observations, using the new technology of the telescope, began the fracture of science and religion that is today a deep chasm. As is well known, Galileo kept his head because he recanted his conclusions that the Sun was at the center of the solar system and that the celestial bodies were not flawless. With improving technologies and the bold modern project begun by Descartes, Bacon and Locke, however, science and religion diverged under the auspices of an uneasy truce. As the quest for truth in the Universe became a scientific endeavor, it was no longer part of the institution that spoke directly to meaning in human lives, to guidance for living in harmony, and for rules that guide human behavior.

Modern Astronomy and the Rise of Scientific Cosmology

Modern astronomy can be described in terms of its institutional structures, its intellectual debates, and its scientific discoveries.

National, Private, and University Observatories

Astronomy may have grown from a fundamental desire to understand the Universe, but the use of heavenly motions as a powerful *technology* for navigation grew with it. Systematic observations of the heavens for centuries allowed us to chart the limits of our world, and to navigate confidently within it.

By the end of the 19th century, large national observatories existed in England, France, the United States, and Russia. Although originally designed to survey the heavens for applications in geodetics and navigation, these institutions also began to branch out and address more fundamental questions (Struve and Zebergs 1962). Especially as instrumentation improved, astronomers were increasingly making observations in attempts to understand the structure, history, and origin of the Universe. Larger and larger telescopes would enable astronomers to see further into the Universe and with ever greater sharpness. The excitement of this quest was felt keenly by a number of American philanthropists, and the late 19th century saw the rise of large, privately funded observatories such as Lick (1888), Lowell (1894), and Yerkes (1897). Following these, construction of the last of the giant, privately funded observatories was completed with the McDonald Observatory in 1939 and the Palomar Observatory in 1947. The flagship of Palomar is the 200”-diameter Hale telescope, which reigned supreme as the largest and most capable telescope in the world until the launch of the Hubble Space Telescope into Earth orbit in 1990.

Hubble was born of the dreams of Lyman Spitzer, who, in the heady days of the post-war technology boom, first advocated a telescope in space to explore the Universe with unprecedented clarity. Above the veil of obscuring atmosphere and luminous clamor of the Earth, a moderate telescope in space would see the Universe 100 times clearer than the behemoths on Earth. This meant that it could see 100 times further away and 100 times further back in time. This it has done, and the images of the Universe that it has returned have astonished us and enriched out lives.

Light is the only form of electromagnetic energy that is directly perceived by human beings. Electromagnetic waves are produced by a vast array of physical phenomena in the Universe, which include stars, planets, galaxies, supernovae remnants, black holes, and almost everything in between. Many of these emissions have wavelengths that are much longer than those of light; these are radio waves. Because they are absorbed by dust and gas less readily than is light, radio waves traveling through space allow a glimpse of parts of the Milky Way that cannot be seen by optical telescopes. In addition, radio waves are produced by different processes than those that create light, giving scientists insights into the physical processes and compositions of many objects in space.

Primitive radio receivers were first pointed at the sky in the early 1930s. It became clear soon thereafter that radio waves can be detected from all parts of the sky, but most especially from the center of the Milky Way. The rapid advances in electronics due to the technological efforts in waging World War II paved the way for vast improvements in radio telescope sensitivity. Serious construction of large astronomical radio telescopes began in 1947. Some are steerable, such as the 250 ft wire-mesh dish at Jodrell Bank in Great Britain. The largest is Aricebo, the immovable 1000 foot dish carved into a limestone sinkhole in Puerto Rico. Today, enormous arrays of radio dishes are icons of modern astronomy, probing the Universe's mysteries and listening for signs of alien minds.

The Island Universe Debate

On a clear night away from city lights, a ghostly swath cuts through the sky. It is thickest in the constellations of Sagittarius and Scorpio, but thins as its path is traced northeast through Cassiopeia or southwest through the summer constellations of Cygnus and Aquila. One of the great conceptual leaps of mankind was the realization that this apparition was our view of a great island universe, a galaxy, *from the inside*. The peculiar smudgy swirls seen in early telescopes, such as Galileo's, were vast communities of stars, comparable to ours but unimaginably far away. The close ones, such as Andromeda, can be seen to be in the shape of a pinwheel with a bright central bulge. As we look to Sagittarius, we look into the core of our galaxy from the inside of the disk. On the other side of the sky where the Milky Way is more diffuse, we can see dark lanes of dust obscuring stars, and the outline of spiral arms. Our Sun is one dot in the multitudes that blend together with such promiscuity that they form the milk of the Milky Way.

By the end of the 19th century astronomers knew that the Milky Way was a vast field of stars in which the Sun and Solar System were embedded. Systematic star counts led to estimates of the size and shape of our galaxy, but also to the erroneous conclusion that the Sun was at the center of it. In spite of the Copernican revolution, subtle assumptions on the centrality and primacy of humans in the Universe remained, skewing scientific interpretations of the observational data.

Our view of the Milky Way galaxy from within was sharpened considerably by the observations of Harlow Shapley. Shapley noticed that globular clusters - beautiful, tightly packed spherical aggregates of stars (Fig. 2), tended to form a vast spherical halo around the nucleus of the Milky Way. His observations successfully set the stage for the 20th century view – that the Sun exists in an enormous, flattened disk of stars, about two-thirds of the way from the center to edge. This final dethroning of the role of humans in the cosmos played out during the 1910s and 1920s and was one of the great classic scientific debates of the century. The new picture did little at first to illuminate what the Universe was, or its extent. Was our disk, 100,000 light years wide and 10,000 light years thick, with a central bulge and 100 billion stars THE Universe? What was outside of it, and how did it come to be? These questions could only be answered with improvements in telescope and photographic technology, which followed rapidly.

Immanuel Kant proposed, in the 18th century, that the Milky Way we are inside of was a disk-shaped spiral, similar to the far-away spiral nebulae seen in telescopes at the time. He called these spirals ‘island universes’. Kant’s famous intuition turned out to be largely correct, although the scientific path to this conclusion did not end until the middle 1920s. During that decade, the shape of our galaxy’s spiral arms came into focus, and the correspondence to the shapes of the far-off spiral nebulae became scientifically accepted. Until then, it was generally thought that the Milky Way was all that there was, and the large variety of spiral nebulae were smaller aggregates of stars within or just outside of it. As telescopic and photographic technology progressed in the 20th century, and ever more detailed images of the deep heavens were acquired, this view began to change.

It was Edwin Hubble who eventually solved the mystery of the celestial spirals. It had long been known that a special class of variable stars, known as Cepheid variables, exhibited a well-determined relationship between periodicity and intrinsic brightness. Distance determinations to celestial objects were bootstrapped to ever more distant objects by noting the parallax shifts of nearby stars (including Cepheids) due to the Earth’s orbit around the Sun. This technique was used to calibrate Cepheid variables at far more distant locales. Using the 100” telescope at Mt. Wilson observatory above Pasadena, then the largest instrument in existence, Hubble was able to resolve individual Cepheid variables in the Andromeda galaxy. Extrapolating from the period-luminosity relation for these variables in our own galaxy, in 1923 Hubble conclusively showed that the Andromeda galaxy was far, far away, about 10 times further than the diameter of our own galaxy. So spiral galaxies are indeed island universes, vast collections of stars very much like our Milky Way, many with 100 billion stars or more. The press for larger, more powerful instruments in the early part of the 20th century was on, driven almost entirely by a thirst for understanding the depth and breadth of all existence. This thirst was very much felt by society in general, and was part of the great scientific excitement of the time, which included the development of quantum mechanics and the deeper understanding of space and time worked out by Einstein.

We now know that the Andromeda galaxy is only one of more than 100 billion such whirlpools of stars, making the observable Universe an inconceivably large place, containing 100 billion times 100 billion stars, and perhaps almost as many solar systems. On a cloudless night in autumn, the Andromeda galaxy is clearly visible to the unaided eye. It is the farthest thing we humans can perceive directly. Light reaching us today left the galaxy 2.2 million years ago, traveling 10,000,000,000,000,000,000 miles before leaving its impression on our retinas and minds.

In his famous book, *The Realm of the Nebula*, Hubble classified the vast diversity of extragalactic forms into a more-or-less coherent taxonomy (Hubble 1926). The realization that spiral nebulae (Fig. 3) and their brethren, giant elliptical galaxies, were island universes, coequal with our own vast Milky Way, paved the way for one of the most extraordinary scientific discoveries of all time and gave birth to modern cosmology. In 1929 Hubble announced his discovery that the recessional velocities of galaxies were proportional to how far away they were. The furthest galaxies were receding the fastest, as measured by the

Doppler shifts of their emitted light. The constant of proportionality became known as the Hubble constant. The implications of this relationship are profound. The simplest way to explain it is that at some time in the very distant past, all the galaxies were packed together. If we reverse the movie of the Universe, all the galaxies speed in toward each other until – what? Georges Lemaitre hypothesized that the movie takes us back to the primeval egg, a cosmology that poetically phrased the juxtaposition of myth and science. But how far one can extend the movie and continue to rely on the laws of physics as we know them is at the heart of modern cosmology. At the beginning of time and space, the galaxies or their precursors were propelled somehow from the egg. In this picture, the reciprocal of the Hubble constant is the age of the Universe, and its extent is approximately the distance that light travels in this time. This theory became known as the Big Bang. Science has thus looked directly at *the* question: What is the origin of everything? We cannot go back: The countless and varied myths, societies' identification with the infinite, have been supplanted by the power of scientific truth.

The Morality of Supernovae

One of the great natural wonders of the Universe is the supernova. In school children, descriptions of the great power of these exploding stars excites a keen intellectual wonder in the natural world. Stars are a great balance between gravity trying to squeeze them small, and nuclear-generated heat trying to pull them apart. The story of the supernova is awesome and kinetic, its wonders easily readable in the faces of children who listen to it. A single, supergiant star approaches the end of its life. As its final generation of fuel is exhausted, the giant radiation engine that supports the star shuts down. Massive collapse ensues, on a scale that is well beyond human comprehension. The implosion rebounds ferociously, spewing the alchemy of the old star into the cosmos. The transmuted elements are made no where else but here, the hellish belly of the most powerful beast of the Universe. And these elements – they disperse through the cosmos – and become us.

Supernovae are so rare that one occurs in our Galaxy, with 100 billion stars, only about once a century. For about a month, though, the maelstrom from that single, dying star is brighter than all of its 100 billion siblings combined. Overall, in the 100 billion galaxies that we can see from our vantage point, that means we have seen and measured and analyzed many hundreds of supernovae.

It isn't hard to see how a driving scientific curiosity could be drawn to trying to understand this thing. Indeed, supercomputer models of unimaginable explosions are quite refined, and scientific models of how stars explode have been highly successful. What is curious is that they are aided by a rather keen interest in an entirely different field: The nature and yield of human-made nuclear explosions. As declassification of the fundamental nuclear science of the 1940s and 1950s has proceeded in the last twenty years, there has been a highly successful synergy between the study of the most fantastic, wondrous, violent explosions in our Universe and the efficiency and effectiveness of nuclear weapons.

Conclusion

For 200,000 years, human beings have had an intense, powerful relationship with the skies above them. We all evolved within societies for which the sky was a pervasive source of magic, awe, religion, and art. For *every* human being, for 99.9% of the history of mankind, there was a personal relationship with the sky. For 10,000 generations, the sky had personal meaning to people, figuring in much of what they did and how they behaved, how they moralized and how they loved. We were born with humanity's relationship to the sky in our genes. The scientific study of astronomy doesn't change this, although it has changed the feelings we have about our place in the Universe. As humanity explores and understands the natural world, the ever-growing power it wields over Nature demands clarity and wisdom. Shortly before his death in 1695, the eminent Danish astronomer Christiaan Huygens wrote in *Kosmotheoros*, for his time and ours:

> "This shows us how vast those Orbs must be, and how inconsiderable the Earth, the Theatre upon which all our mighty Designs, all our Navigations, and all our Wars are transacted, is when compared to them. A very fit Consideration, and matter of Reflection, for those Kings and Princes who sacrifice the Lives of so many People, only to flatter their Ambition in being Masters of some pitiful corner of this small Spot."

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Figure Captions

Figure 1. Stonehenge is a megalithic monument on the Salisbury Plain, 85 miles southwest of London. It had a utilitarian as well as spiritual design. The monument consists of a ditch and bank surrounding huge stones arranged in circle and horseshoe patterns. On the longest day of summer, at solstice, the sun rose over a huge, notched boulder, the 'Heel Stone', as seen from the center of the concentric rings of massive boulders.
(Photograph courtesy of English Heritage Photo Library.)

Figure 2. This photograph of the globular cluster M80 (the 80th cataloged item in Messier's catalog) was taken with the Hubble Space Telescope. It contains hundreds of thousands of stars, all held together by their mutual gravitational attraction. Globular clusters tell us much about stellar evolution and provide a means of measuring the ages of stars. All the stars in a globular cluster like this one were formed at the same time and so are of the same age. They are among the oldest stars in our galaxy. The more massive stars in the cluster burn their nuclear fuel more quickly and evolve into red giants and ultimately white dwarfs. The less massive stars have longer lives and many are still burning their original hydrogen fuel in their central cores, much like our own Sun does. The Hubble Space Telescope's accurate measurements, coupled with recent improvements in the measurement of the clusters' distances, has led to revised estimates of the ages of the oldest stars in our galaxy -- about 13-14 billion years.
(courtesy Space Telescope Science Institute)

Figure 3. A detailed view of the Whirlpool galaxy's spiral arms and dust clouds, which are the birth sites of massive and luminous stars. This galaxy, also called M51, is having a close encounter with a nearby companion galaxy, NGC 5195, just off the upper edge of this image. The companion's gravitational influence is triggering star formation in the Whirlpool, as seen by the numerous clusters of bright, young stars [highlighted in red]. Image courtesy NASA's Hubble Heritage Team.

Figure 1.

Figure 2

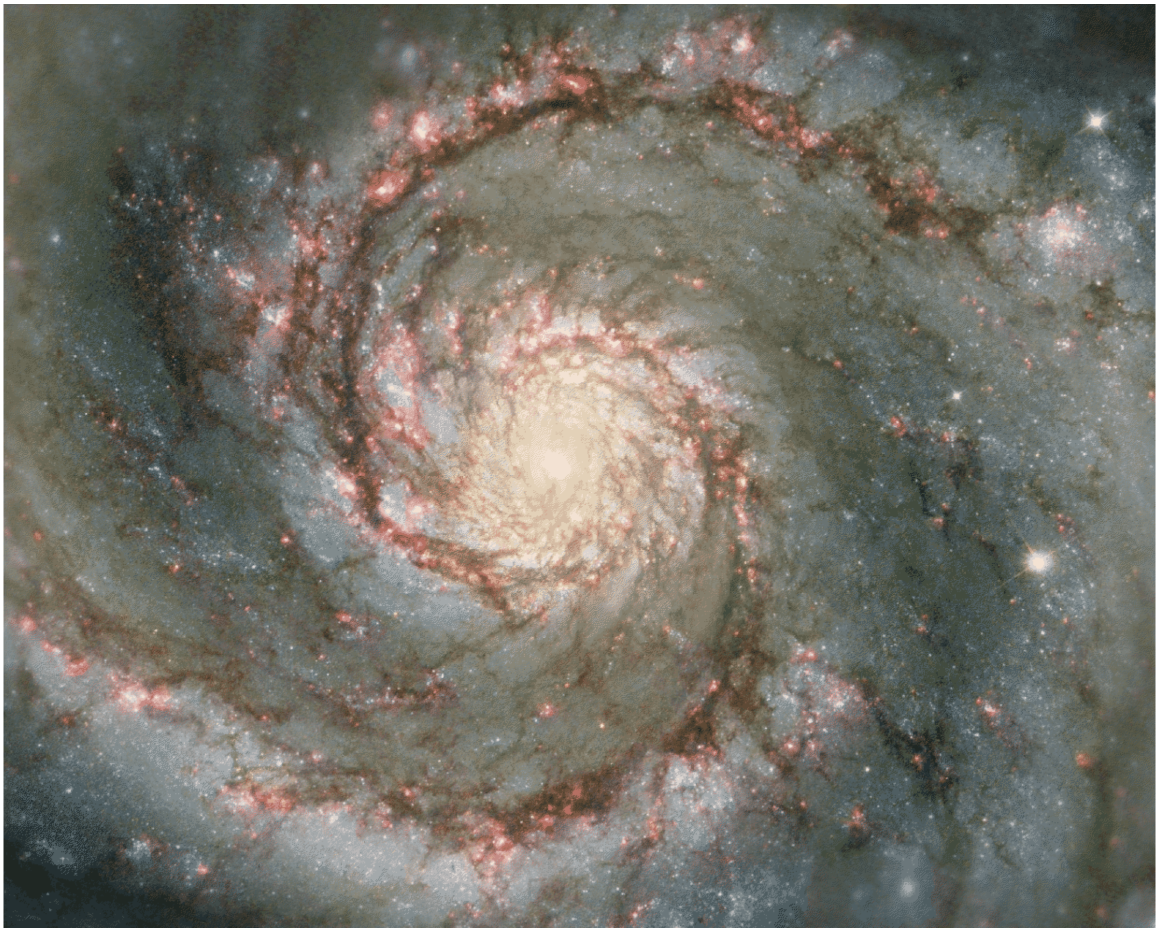

Figure 3