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# A FRAC SPECIAL EDITION

# ON THE SHOULDERS OF GIANTS

## Astronomy from Prehistory Through 2000 a.d.

## by Bill Warren

***Pablo Picasso** was once asked, "How do you know when a painting is finished?"*

*"You don't finish a painting," he replied, "you abandon it."*

*I know what he meant. I decided to examine astronomy's roots and see how we got from there to here. But every time I thought I was finished, I'd remember something else I'd forgotten to include. One of the last things I added was the 1966 publication of the greatest astronomy book ever written. The author was a high school graduate and self-taught astronomer whose only previous claim to fame was discovering a comet.*

*That's an example of how I approached writing this report. I wanted to flesh out the bare bones of astronomy history to make it more than just a collection of dates and names.*

*By the year 2000, the basics of astronomy were already well established so I stopped there. Astronomy hasn't stopped, but its theories have moved far beyond what you and I need to know in order to enjoy it. Things like* string theory *and* multiple universes *may be important to professional astronomers, but not to us.*

*So I chose to ignore them.*

*–Bill*

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If I have seen farther than most, it is because I have stood on the shoulders of giants.

-**Sir Isaac Newton** (1642-1726)

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**Introduction.** Mankind's storehouse of astronomical knowledge has grown from humble beginnings in the sense that **Sir Isaac** was referring to -- men studying and adding to the wisdom of others who preceded them. But it also has arisen through sudden, massive leaps of logic, intuition and insight by highly gifted and talented individuals. For example, 2,250 years ago the Greek mathematician/astronomer/geographer **Eratosthenes of Cyrene** devised a method for accurately measuring the circumference of the Earth when most people thought the Earth was flat, and most of the planet was unknown and unexplored. Eratosthenes's were two of the broad shoulders that Newton stood on – but they were not the only two.

And they were not the first.

## Chapter One: From the Darkness of Prehistory to Astronomy's Dark Ages

**Prehistoric Stargazers.** Humans have always looked up at the sky with wonder and awe.

Long before civilizations arose, men sat around their campfires at night discussing in rudimentary language forms the topics that were important to their lives. Undoubtedly, they talked about those strange lights in the sky: the Sun, whose brightness hurt their eyes but whose presence they associated with carrying out their daily activities; and the Moon and those tiny points of light in the night sky. They didn't know what they were – and they certainly didn't call them the "Sun," "Moon" and "stars" – but they recognized the importance of those objects in their lives.

**The Dawn of Civilization.** Civilizations arose in the Middle East, Europe, Asia and elsewhere when primitive hunter-gatherers added farming to their survival skills, recognized the benefits of living together in large groups, and settled down in permanent dwellings that eventually became villages, towns and cities. They developed formal languages, both oral and written, to enable large-group communication and to express and record their thoughts and information regarding the world around them.

Early in mankind's recorded history, men named bright stars and star patterns after animals, gods, people and objects, creating myths to explain their presence in the night sky. The development of languages produced (among other things) mankind's first astronomers. Originally known as *astrologers,* they were men who studied the sky and gave names to those familiar stars and the patterns they formed.

The first to do so were the Akkadians in 3900 b.c. (At about the same time, the Mesopotamians built the first astronomical observatories, cone-shaped spiral towers called *ziggurats,* which probably were also used for religious purposes.) The Chinese began naming the familiar stars as early as 1400 b.c. (They also predicted eclipses as early as 2300 b.c., and they recorded 1,500 solar and lunar eclipses between 1300 b.c and 1300 a.d.) And in 1200 b.c., the Babylonians followed suit with their own names for their stars and star patterns.

Three other early developments paved the way for astronomy's future growth:

*Ancient astronomers recognized early on that, besides moving across the sky every night, those bright stars and star patterns also followed a highly predictable schedule of rising in the east, staying "up" for long periods, and vanishing in the west for equally long periods before reappearing in the east to begin another cycle. The length of time between the beginning of one cycle and the next was a *year*.

That realization, combined with study of lunar phases and the Sun's location among the bright star patterns, led to the development of solar-lunar calendars by ancient Egyptians and Mesopotamians around 2000 b.c., and in 45 b.c. to the Julian calendar, a solar-based calendar devised by the early Romans.

American Indians used a lunar-based system to measure time, with a "moon" being the time between one Full Moon and the next. They gave names to each of the "moons," and because the lunar cycle is only 29 days, there were more than twelve moons in a year. As a result, although the moons' names remained constant, they changed seasons periodically.

*Speaking of which…The concept of *seasons* arose around 1200 b.c., when Babylonian astrologers divided the sky into four zones in which the Sun spent three months in each zone. By studying the sky, they could tell when crops should be planted to take advantage of the spring rainy season, when animal herds would begin their annual migrations, when to begin preparing for winter, etc.

It wasn't until around 350 a.d. that the ancient Romans began referring to the familiar star patterns as *constellations,* which meant "set with stars" and referred to the immediate area around those stars. Also around that time, the concept of a belt of *zodiac* constellations arose, based on the Sun's path through thirteen -- not twelve – constellations in the course of a year. (Ophiuchus the Serpent Bearer was eventually dropped from the zodiac.)

Even today, many of the world's farmers "plant by the signs," using zodiac constellations as a guide to when they should plant their crops.

*Finally, ancient skywatchers had long noted that, among the thousands of objects visible in the night sky, a few of them were different from all the others. There was the Moon, of course – but there were also a handful of stars that behaved differently. They moved across the sky faster than the other stars, and the two brightest among them were sometimes seen as a “morning star” in the east before sunrise, and at other times as an “evening star” in the west before sunset. Eventually, it “dawned” on some ancient astronomer – probably **Pythagoras of Samos** in the 5th century b.c. – that those two stars were in fact the same star (Venus) seen at different times.

So now there were five fast-moving stars that didn’t act like stars. The ancient Greeks used the word *planos* to describe these “wanderers.” (We know them, of course, as *planets.)* Astronomers began to study the Moon and planets (including planet Earth) as a related family of celestial objects. Throw in the Sun for good measure, and you had a solar system, waiting to be understood.

**Early Greek Contributions to Astronomy.** The ancient Greeks were by far the most scientific-minded culture among Earth’s early civilizations. They developed the first written language in Europe, probably around 1450 b.c., and they quickly put it to good use. They kept detailed records of their achievements in mathematics, astronomy, physics, the natural sciences and practically everything else. Around 300 b.c. they created the first and largest library in the world. Located in Alexandria, the 900,000 sq. ft. building eventually burned down in a series of fires, destroying between 100,000 and 1 million papyrus scrolls and documents. But the seed had been planted, and other libraries soon arose. Libraries permitted mankind’s history and progress to be preserved in written form, and not just passed on from one generation to another by word of mouth.

Important advances in astronomy by the early Greeks included:

*After observing a lunar eclipse around 350 b.c., **Aristotle** used Earth’s shadow cast on the Moon to suggest that the Earth is a sphere. But he also developed a model of the solar system that had the Earth, not the Sun, at its center.

*Around 280 b.c., **Aristarchus of Samos** suggested that the Earth revolves around the Sun. That started a controversy that lasted for more than 19 centuries. (Aristarchus also made the first estimates of the distance from Earth to the Sun. He was wrong by a large margin, but at least it was a start in applying scientific and mathematic principles to astronomy.)

*Around 240 b.c., the brilliant and diversely talented astronomer and mathematician **Eratosthenes:** (a) measured the Earth’s circumference -- his figures may have been wrong by as little as 250 miles, depending on which of two units of measurement he used; (b) he accurately calculated both the tilt of Earth’s axis of rotation and the distance from Earth to the Sun; (c) he devised a system of latitude and longitude and produced the first map of the known world; and, as if that were not enough, (d) he devised a calendar that defined a year as 365 days, with an extra day added every four years.

*Around 130 b.c., the Turkish astronomer **Hipparchus,** living in Greece, developed the first accurate star atlas and catalog. It contained 1,080 of the brightest stars. Much of its contents were based on earlier works, most notably that of another Greek astronomer, **Timocharis of Alexandria,** in 300 b.c. (Hipparchus also created the first stellar brightness scale: the brightest naked-eye stars were magnitude 1, the next-brightest magnitude 2, etc., down to the faintest, magnitude 6. Each magnitude was twice as bright as the one before it. We don’t use the same scale today, but Hipparchus paved the way for it.

*Around 150 a.d., **Claudius Ptolemaeus** (a.k.a. **Ptolemy**) produced *The Almagest,* a 13-volume work of mathematical and astronomical formulas. For more than a thousand years thereafter it was the most influential astronomy book in existence. In it, Ptolemy devised an Aristotle-like geocentric model of the solar system. For our purposes, though, his book is noteworthy for his listing of the names and locations of Hipparchus’s stars and 48 constellations, 46 of which are still in use today. (The two that are no longer constellations are *Argo Navis* and the *Pleiades.*)

After **Ptolemy** wrote the *Almagest* in 150 a.d., it was as if the light of learning suddenly turned off. Astronomy progressed little over the next 1,400 years.

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## Chapter Two: From Darkness to the Light of Sir Isaac Newton

The Roman Empire rose and fell over a thousand-year period called the *Pax Romana* (“Roman Peace”). But the Romans were primarily warriors, not scientists or thinkers: they were peaceful *after* they conquered new territories. And they were borrowers, not innovators or seekers of knowledge as the Greeks had been. For example, after conquering Greece in 146 b.c. the Romans adopted their religion, giving Roman names to the Greek gods (and the planets as well). And when, in the early 300s a.d., the emperor **Constantine** converted to Christianity, he declared it to be the official religion of the Roman Empire, which included most of Europe.

When Rome eventually fell into decline, Europe plunged into the Dark Ages, a period lasting hundreds of years in which advances in science and astronomy were virtually nonexistent. The invaders who hastened the Roman Empire's downfall were warlike barbarian illiterates, and as they assimilated into Europe they did nothing to promote learning. Neither did the early Roman Catholic Church, whose leaders considered the purpose of education to be understanding the *Bible.* Books were in short supply and unavailable to the masses, so there was no great demand for reading skills except among the clergy. Not until the Renaissance in the 14th-16th centuries did a revival of interest in learning occur in Europe.

One of the earliest hints of that revival came around 1265 a.d., when the English philosopher and Franciscan friar **Roger Bacon** described the *scientific method:* observation, hypothesis, experimentation and independent verification.

Unquestionably the greatest single impetus toward learning in Europe during the Renaissance came in 1450 a.d. with **Johannes Gutenberg's** invention of the movable-type printing press. His invention – along with the development of paper around 1400 a.d. to replace the less durable papyrus, parchment and cloth that had been used previously -- made it possible to mass produce the *Bible* and other books quickly and inexpensively, making them available to everyone, not just royalty or Church officials. Gutenberg's printing press could print 3,600 pages a day.

**Out of the Shadows.** Astronomy officially re-emerged from its long hibernation when, in the year 1543 a.d., Poland's **Nicolas Copernicus** published *De Revolutionibus,* which placed the Sun, not the Earth, at the center of the solar system. The Greek **Aristarchus** had said the same thing 1,800 years earlier – but Copernicus's book had a greater impact on astronomy because it sold 100,000 copies.

Copernicus was first of all a priest and only a part-time astronomer -- an "armchair astronomer" who learned about the sky and how it operates, not from his own observations, but by analyzing the works of earlier astronomers such as Aristarchus and **Ptolemy.**

Thus, the question arises: Since the Inquisition (that had been established by the Roman Catholic Church in 1231 a.d. to punish heretics who challenged or defied the Church's beliefs) was still going strong, *why wasn't Copernicus burned at the stake for his heretical Sun-centered theory?* There were two reasons.

First, although the pope – and by extension, the Inquisition – knew of Copernicus's theory before *De Revolutionibus* was published, they considered it harmless, since he offered no proof or visual evidence to support it. Copernicus's revolutionary theory received more "heat" (criticism) from the Protestant reformer M**artin Luther** than from the Inquisition. The situation would be radically different 67 years later, when another well-known astronomer used telescopic evidence to support Copernicus's theory.

Second -- and more importantly -- Copernicus died in 1543 before his book was published that same year.

After Copernicus, developments in astronomy came quickly and often. They have seldom slowed down since then.

*In 1572 a.d., the Danish astronomer **Tycho Brahe** observed a supernova in Cassiopeia. Tycho's observations of the night sky – especially the planets -- are generally regarded as the most accurate ever made without the benefit of a telescope. That's why the brightest rayed crater on the Moon – Tycho -- was named after him.

*In 1603 a.d., the German **Johannes Bayer** introduced the Bayer classification of stars, assigning them Greek letters in each constellation based on their brightnesses. He made mistakes, of course – for example, he designated Betelgeuse as Alpha Orionis and Rigel as Beta Orionis, when in fact Rigel is the brighter of the two. Nevertheless, the unchanged Bayer classification of naked-eye stars is still in use today.

*In 1608 a.d., the Dutch eyeglass manufacturer **Hans Lippershey** – not **Galileo --** invented the telescope.

*A year later, the Italian **Galileo Galilei** became the first person ever to use a telescope for astronomical purposes. In late Dec., 1609 a.d. Galileo observed the Moon in his 1-1/4" 'scope, and saw that it contained mountains and other Earth-like features. He called the dark areas *maria* ("seas") because they appeared to be large ocean-like bodies of water.

In the following months Galileo found that Venus undergoes Moon-like phases, and he discovered four moons (Callisto, Io, Ganymede and Europa) orbiting Jupiter**.** Those observations convinced him that Copernicus was right: the Sun is the hub of the solar system, and everything else revolves around it. Galileo unwisely chose to include his heliocentric theory in his book, *The Dialogue*, published in 1632.

When **Pope Paul V** – who observed the Moon through Galileo's telescope and became his close friend and admirer -- read Galileo's book, things changed between them. Galileo's telescope offered visual evidence to support the Copernican theory of a Sun-centered solar system. The immensely popular astronomer was brought before the Inquisition, and although he recanted his theory he was found guilty of heresy and sentenced to house arrest for the rest of his life. (Official Church doctrine, which was based largely on **Aristotle's** and **Ptolemy's** geocentric models, held that everything in the solar system revolved around the Earth; any other belief was heresy.) It was not until 360 years later, in 1992, that **Pope John Paul II** officially apologized for the Church's having wrongly convicted Galileo.

*Also in 1609 a.d., Germany's **Johannes Kepler** announced his First and Second Laws of Planetary Motion; a decade later he added a Third Law. Kepler used his laws and Tycho's detailed observations of the planets to plot their orbits and relate their orbital speed to their distance from the Sun.

*In 1656 a.d., the Dutch astronomer **Christiaan Huygens** discovered Saturn's rings. That alone ensured his lasting fame and popularity, but he also discovered Saturn's moon Titan, Orion Nebula and surface markings on Mars. (And oh, by the way, Huygens was the first person to contend that light travels in waves.)

*****In 1666 a.d., Italian **Giovanni Cassini** discovered Jupiter's Great Red Spot. A year later, he discovered the polar ice caps on Mars, and nine years after that he discovered a dark gap -- the *Cassini Division* -- in Saturn's rings.

*Astronomy took a giant leap forward in 1668 a.d. when England's **Sir Isaac Newton** invented the reflecting telescope. Immediately, men began building telescopes that were larger than the little refractors they had been using until then. Larger telescopes permitted men to peer farther into space and see objects and features that previously had eluded them.

*In 1669 a.d., Italian **Geminiano Montanari** discovered that Algol (Beta Persei) varies in brightness over a short span, thus introducing the concept of *variable stars.* But three millennia earlier, Middle Eastern astronomers had named the star Algol, which meant "demon star." Doubtless, they recognized its variations in brightness; why else would they choose such a name for one otherwise ordinary star among the 6,000 naked-eye stars in the night sky?

*In 1675 a.d., Denmark's **Ole Romer** attempted to measure the speed of light. Romer's calculations were wrong, but the brilliant method and formulas he employed eventually led to an accurate measurement.

*In 1687 a.d., **Sir Isaac Newton** published his epic work, *Philosophiae Naturalis Principia Mathematica* (commonly referred to as *Principia*), in which he formulated his law of universal gravitation.

It is unknown whether an apple falling on Newton's head actually led to his formulating the law of gravity. What *is* known, however, is that another eminent scientist of the day, **Robert Hooke,** accused Newton of stealing his idea. No one took him seriously, though, or else we would be talking about "Hooke's Law of Gravity."

At any rate, the publication of *Principia* is regarded by most astronomers as the beginning of modern astronomy. (As you'll see at the beginning of Chapter Three, there was another reason why modern astronomy dates from Newton.)

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## Chapter Three: Astronomy Grows Up

*Before moving ahead, I should interrupt myself here to explain a situation that was mentioned briefly in Chapter One:* astronomers as astrologists.

*The term* astrology *predates astronomy. By the year 1200 b.c. in Babylonia, people who studied the sky were known as* astrologers. *Later -- probably around 300 b.c. -- the Greeks began to study Babylonian astrology. They expanded on it and gradually developed their own version, which was far more advanced than the Babylonians had been. They began to refer to their new form of astrology as* astronomy, *although for a very long time the two* *terms were used interchangeably and there was no clear-cut distinction between them.*

*Why? Because there was no "science" as we know it back then. Although the Greeks used logic, reason, math and physics to develop theories about the Earth, the planets and the solar system, with few exceptions they did not use proven scientific methods to test the validity of their theories. The technology simply did not exist for them to do so.*

*Although both astrologers and astronomers studied the sky, a distinction eventually arose regarding what they were used for. Astronomers studied the universe in order to understand it and comprehend man's place in it; astrologers studied it in order to cast* horoscopes*, or predictions of future human events based on the position of the Sun, Moon and planets among the zodiac constellations.*

*The rift between astrology and astronomy widened with inventions such as: spring-powered and mechanical clocks and watches in the 1400s and 1600s, respectively, which afforded precise measurements of time; and the telescope in 1608 a.d. Such developments and others dramatically expanded men's ability to study, measure and apply scientific principles to the universe around them. Still, it took public declarations in the mid- to late 1600s by two of history's greatest astronomers,* ***Christiaan Huygens*** *and* ***Sir Isaac Newton****, to turn the tide against astrology. Both men formally rejected astrology as a superstition-based pseudo-science that was unworthy of the attention of serious astronomers. Their fame, and their opposition to astrology, were so compelling that, by the 1800s, every serious student of the skies had followed suit in rejecting the title of* astrologer.

*Unfortunately, astrology is still alive and well today. In the U. S., millions of people read their horoscopes every day as a guide to how they should conduct their daily affairs. But there are also people who believe that the Earth is flat, men never walked on the Moon, and* ***Elvis*** *is still alive. (I think I saw him in WalMart the other day.) How are any of those people different from people in medieval Europe who believed in sorcery, witchcraft, alchemy, black magic and fortune-telling?*

To return to our history of astronomy:

After **Isaac Newton** identified gravity's role in the scheme of things in 1687 a.d., things started falling into place:

*Having noted orbital similarities in comets that had appeared in 1456, 1531, 1607 and 1682 a.d., English astronomer **Edmund Halley** concluded that they were all the same comet. In 1705 a.d., he predicted that the comet would return in 1758 or 1759. He died 17 years before it returned in 1758 as he predicted. Ever since, the comet has been known as Halley's Comet. (Halley was also the first person to catalog the stars in the southern hemisphere, and in 1677 he discovered Omega Centauri, the largest and brightest globular cluster in the night sky.)

*The year 1781 a.d. was a milestone in astronomy in two respects. First, the German-English astronomer **Sir William Herschel** discovered Uranus, the first planet to be added to the list of six naked-eye planets that had been known since antiquity. His discovery was accidental in the sense that he wasn't looking for it.

Second, the French comet hunter **Charles Messier** published the third and final installment of his list of 103 galaxies – they were thought to be "spiral nebulae" – and other nebulae and star clusters that might be mistaken for comets. It was the first list of deep-sky objects ever compiled.

Searching for the 110 "Messier objects" is a popular pastime among modern amateur astronomers. (Seven additional objects that appeared in Messier's observing notes but not his list were added in the late 1940s by the American **Helen Sawyer Hogg.**) The Messier list contains many of the most beautiful objects within reach of backyard telescopes.

*Messier used telescopes that were effectively no larger than 4-1/2 in.; **William Herschel,** on the other hand, working with his sister **Caroline,** used his 47-in. telescope to discover 2,500 "nebulas and star clusters." His catalog was published in 1786, five years after Messier's. (In 1864, **Sir John Herschel,** son of Sir William, added 2,579 objects to his father's list.)

*In 1790 a.d., France's **Pierre Simon LaPlace** suggested that extremely compact stars could produce gravitational effects so powerful that not even light could escape their inward pull, thereby introducing the concept of *black holes.* (And we thought that black holes are a recent concept.)

*(Note: Since at this point eighteen centuries have passed since b.c. became a.d. and things aren't going to change in the rest of the article, I'll skip the "a.d." references from here on.)*

*In 1801, Italian **Giuseppi Piazzi** discovered the first asteroid, Ceres.

***In 1803, a heavy meteorite fall in the French village of L'Aigle led to public and scientific acceptance of the fact that sometimes rocks fall from the sky.

In 1840, a Frenchman, **Louis Daguerre** (who developed the first photographic process, *daguerreotype*) attempted to photograph the Moon, but his photo was blurry and indistinct. Later that year, American **John William Draper** succeeded in producing a clear photo of the Moon. It was the first successful astrophotograph.

*In 1845, Ireland's **William Parsons, the 3rd Earl of Rosse,** built a 72-in. telescope that weighed 12 tons. It was known as "the Leviathan of Parsontown." Its mirror was 5 in. thick, weighed three tons and, because it was made of speculum, a metal that tarnishes quickly, it had to be re-polished every year. Lord Rosse solved the problem by having two mirrors built. He used one while the other was being polished. For 72 years, the Leviathan was the largest telescope in the world.

*In 1846, German **Johann Galle** discovered an eighth planet, Neptune, based on earlier mathematical computations that suggested its existence and probable location due to irregularities in the orbital path of Uranus.

***In 1862, England's **Sir William Huggins** discovered that, by examining the spectra of stars through a prism, he could determine their chemical compositions by comparing their wavelengths with those of terrestrial elements of similar wavelengths.

A decade later, American **Henry Draper** photographed the stellar spectrum of Vega.

*In 1877, American **Asaph Hall** used the U. S. Naval Observatory's 26-in. refractor to discover the Martian moons Deimos and Phobos. Astonishingly enough, the existence of the tiny moons -- they measure 8 and 14 mi. in diameter, respectively -- was predicted 150 years earlier by **Jonathan Swift,** the author of *Gulliver's Travels.* Seeing objects that small from 140 million miles away is like standing in Griffin and seeing a quarter that is being held aloft by someone standing in Jonesboro.

*In 1888, the Danish-Irish astronomer **Louis Dreyer** was asked to update **William Herschel's** catalog of deep-sky objects. The result was Dreyer's *New General Catalog* containing 7,840 "NGC objects," most of them Herschel's. Dreyer later produced the *Index Catalog* that added 5,836 more "IC objects" for a grand total of 13,676 deep-sky objects. Both catalogs are still in use today.

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## Chapter Four: Small Steps and Giant Leaps in the 20th Century

*In 1908, Denmark's **Ejnar Hertzsprung** identified giant and dwarf stars. Six years later, he and American **Henry Russell** created the *Hertzsprung-Russell diagram*, which grouped stars according to their brightness/spectral type/surface temperature. The H-R diagram greatly improved astronomers' understanding of the evolution of stars.

*In 1912, American **Henrietta Swan Leavitt** discovered Cepheid variable stars – giant stars that pulse in highly regular periods according to their luminosity, or apparent brightness. Her discovery provided the means for American **Edwin Hubble** to show conclusively in 1923 that "spiral nebulae" are in fact distant spiral galaxies beyond the Milky Way. (Until Hubble, everything in the sky was thought to be part of the Milky Way galaxy.)

*In 1916, the German-born physicist **Albert Einstein** published his general theory of relativity, which basically stated that matter curves space, causing objects to move in response to gravity. Einstein's revolutionary space-time theories fundamentally transformed the study of astronomy and led to the discovery of such things as neutron stars, quasars, gravitational lensing and black holes.

*In 1917, Mt. Wilson observatory in California was completed. Its 100-in. Hooker telescope was the largest optical telescope in the world for the next 31 years.

*In 1920, England's **Sir Arthur Eddington** suggested that the Sun derives its energy from nuclear fusion of hydrogen atoms into helium at its core.

In 1927, the Belgian Jesuit priest, astronomer and physicist **Georges Lemaitre** proposed what would later become known as the *Big Bang theory* of the origin of the universe. (He referred to it, not as the "Big Bang," but as "the Cosmic Egg." So the next time someone asks you, *Which came first, the chicken or the egg?*, you'll know what to say.)

*In 1929, Dutch astronomer **Jan Oort** showed that the center of the Milky Way lies in Sagittarius. More importantly in terms of 20th century astronomy, he produced the first map of the Milky

Way, showing it to be a spiral galaxy with long, sweeping arms; in 1932, Oort found evidence suggesting the presence of some kind of invisible "dark matter" in the Milky Way; and in 1950, Oort put the icing on his stellar career in astronomy by predicting the existence of a vast *Oort cloud* of comets-in-waiting surrounding the solar system, far beyond the most distant planets.

Also in 1929, **Edwin Hubble** used Cepheid variable stars to show that the universe is expanding, and that the farther away galaxies are, the faster they are moving away from us. While most proponents of the Big Bang theory expected that at some point in space-time the universe's initial Big Bang expansion would slow down, Hubble showed that it is actually speeding up.

*In 1930, American **Clyde Tombaugh** discovered Pluto; for the next 76 years it was the ninth planet in the solar system. Now known to be a part of the *Kuiper Belt*, Pluto was downgraded to *dwarf planet* status by the International Astronomical Union (IAU) in 2006.

Also in 1930, the IAU adopted official boundaries for the 88 constellations. Those boundaries encompass the entire celestial sphere, not just the stars that form the constellations' identifiable patterns.

*In 1931, American **Karl Jansky** made the first radio astronomy observations. Six years later, American **Grote Weber** built the first radio telescope designed specifically for astronomy.

*In 1948, the 200-in. Hale telescope on Mt. Palomar in California opened for business. For the next 41 years it was the largest optical telescope in the world. (In 1975, the Russians built a 238-in. telescope, but it performed poorly and was never used for research purposes.)

*Sometime during the 1950s, American **John Dobson** invented the *Dobsonian mount*, an inexpensive, lazy-Susan type of mount that has permitted telescope manufacturers to build and sell large-aperture telescopes for extremely low prices. Dobson's concepts and choice of materials for the telescopes he built revolutionized and expanded amateur astronomy to a greater extent than anything else in the 20$^{th}$ century.

Also sometime during the 1950s, American **Fred Whipple** developed the *dirty snowball hypothesis,* describing comets as "dirty snowballs" composed of ice, gases and dust.

*In 1957, the Russian satellite *Sputnik 1* became the first man-made object to orbit the Earth.

*In 1958, American **James Van Allen** discovered the *Van Allen belt*, a radiation zone of trapped ions and electrons above Earth's atmosphere. The importance of his discovery lay in the fact that future Russian cosmonauts and American astronauts would have to pass through that radiation belt in order to reach the Moon or anywhere else beyond it.

*In 1959, the Russian spacecraft *Luna 2* crash-landed on the Moon, becoming the first man-made object to land on another celestial object. That same year, *Luna 3* took the first photos of the dark side of the Moon, but did not orbit it.

*On April 12, 1961 Russian cosmonaut **Yuri Gagarin** became the first human to orbit the Earth, aboard *Vostok I*.

A month later, **President John F. Kennedy** announced his intention that an American should land on the Moon before the end of the decade. His announcement spurred public interest in, and support for, the fledgling U. S. space program, which quickly developed powerful rockets and technology capable of accomplishing that task. In the brief span of eight years they succeeded via a two-phase program, *Gemini* and *Apollo.*

*In 1964, Americans **Arno Penzias** and **Robert Wilson** accidentally discovered the *cosmic microwave background*, which consists of radiation left over from the universe's formation.

*In 1966, a self-taught astronomer with a high school education wrote and self-published the most incredible astronomy book ever written. The author was American **Robert Burnham,** and his 3-volume book was *Burnham's Celestial Handbook* (subtitled *An Observer's Guide to the Universe Beyond the Solar System*). Its 2,138 pages include hundreds of photographic plates – he worked at Lowell Observatory in Flagstaff, AZ and wrote the book in his spare time – and contain tables, charts, diagrams, scientific and observing information, star lore, and even poetry relating to the stars and constellations. Thousands of stars and deep-sky objects visible in small telescopes are covered in minute detail. It was a massive undertaking, especially considering that Burnham typed the manuscript himself, prepared the tables, charts and diagrams and compiled his data without benefit of computers or the Internet. His book was so popular that, in 1978, Dover Publications reissued the *Handbook.* It became an astronomy best-seller,

Unfortunately, Burnham knew nothing about contracts, and he received very little money from book royalties.  He died a penniless pauper in Phoenix in 1993.  But his book lives on, and if I were stranded alone on a deserted isle with but one astronomy book for companionship, I'd want it to be the *Celestial Handbook.*  The star lore and poetry alone – not Burnham's poetry, but collected from history's greatest poets, I can't imagine how he did it – would ensure that, although I was alone, I would not be lonely.

Also in 1966, the Russian spacecraft *Luna 10* orbited the Moon.  Two years later, Americans **Frank Borman, James Lovell** and **William Anders** aboard *Apollo 8* became the first humans to orbit the Moon.  They did not land, but completed ten orbits before returning safely to Earth.

*On July 20, 1969, one out of every five humans on planet Earth was watching via live tv transmission as American astronauts **Neil Armstrong** and **Edwin "Buzz" Aldrin** became the first humans to walk on the Moon.  The event was significant in many ways, one of which was that, until the *Eagle* landed and Armstrong stepped out onto the Moon's surface, no one knew for sure whether the lunar soil was substantial enough to support their weight.  For all anyone knew, they might sink like someone dropping into quicksand.

Armstrong, Aldrin and ten other American astronauts in the Apollo Moon Landing program brought back hundreds of pounds of Moon rocks and soil samples before the Apollo program shut down in 1972.

A persistent rumor exists to this day that, in a last-ditch effort to upstage the U. S., a manned spacecraft was launched by the Russians on July 7, 1969 with the intention of landing on the Moon before the Americans, but failed.  The Russians, who were extremely secretive about failures in their space program, have always denied that such a launch took place.  So it might have been dismissed as nothing more than just another urban legend – except that on that date, a rocket was known to have been launched in Russia, and a few transmissions between Russia's ground control and a cosmonaut were intercepted but never explained.  (It's difficult to explain something you claim never happened.)

*In 1970, Russia's *Venera 7* spacecraft landed on Venus, but its parachute failed to open properly and the lander tipped over onto its side at impact.  It continued to weakly transmit data for 23 minutes before expiring.

*In 1974, the American *Mariner 10* satellite transmitted the first close-up photos of Mars while on its way to Mercury.

*In 1976, the American *Viking 1 and 2* landers touched down on Mars.

*In 1977, Americans **James Eliot, Edward Dunham** and **Douglas Mink** discovered that Uranus has a very faint Saturn-like ring system.  (In 1789, England's **William Herschel** claimed to have seen rings around Uranus in his 47-in. telescope, which he named "Forty Foot" after the length of its optical tube.)

Also in 1977, the U. S. launched the *Voyager 1* and *Voyager 2* space probes.  Their mission was to explore the outer planets and interstellar space.  Both spacecrafts have been transmitting data continuously ever since.

In 1979, while passing Jupiter *Voyager 1* detected that planet's faint ring system, making Jupiter the third known planet besides Saturn and Uranus to have rings.  And in 2012, having already visited Jupiter and Saturn, *Voyager 1* became the first known man-made object to leave the solar system.  (Remember the rumored 1969 Russian lunar attempt that failed if in fact it occurred?)

*Voyager 2,* launched 16 days after *Voyager 1*, passed Uranus in 1986 and Neptune in 1989, and trails *Voyager 1* by 1.9 billion miles.  The two spacecrafts have enough electrical power and fuel to last until 2020, at which time *Voyager 1* will be 12.4 billion miles from the Sun.

*In 1978, Americans **James Christy** and **Robert Harrington** discovered Charon, a moon of Pluto.  Since then, four additional smaller moons have been discovered.  That's not bad as accomplishments go, considering that Pluto itself is only 1/6$^{th}$ as large as the Earth and lies about 3.67 billion miles from us.

*In 1980, **Carl Sagan's** 13-part epic astronomy documentary *Cosmos:  A Personal Voyage* was first broadcast on tv by PBS.  It was broadcast in 60 countries, and 500 million people watched it.

A remake entitled *Cosmos:  A Spacetime Odyssey* appeared in 2014.

Elsewhere in 1980, American physicist **Alan Guth** proposed a pre-Big Bang *inflation period* to explain how the Big Bang might have come about.

*In 1981, the Very Large Array of twenty-seven 82-ft. radio telescopes linked together to produce radio images became operational in New Mexico.

*In 1986, to celebrate the return of Halley's Comet that year, five space probes flew past the comet, some of them coming as close as 360 miles.

Their photos showed a very dark nucleus that was larger than anyone suspected.

*In 1988, **Bruce Campbell, G. A. H. Walker** and **Stephenson Yang** -- three university professors in Canada -- discovered the first verifiable *exoplanet*, i.e., a planet orbiting a star other than our Sun. The exoplanet was circling Gamma Cephei. Since then, so many exoplanets have been detected – as of Sept. 2014 the total had risen to 1,821 confirmed discoveries – that the present challenge lies in finding Earth-sized (as opposed to Jupiter-sized) exoplanets. Many (if not most) exoplanets have been discovered by amateur astronomers.

*In 1990, the Hubble Space Telescope was placed in orbit from the space shuttle *Discovery*. Shortly thereafter, scientists discovered that its main mirror had been ground improperly, producing blurred images. But after the problem was corrected via a series of spacewalks in 1993, the 95-in. HST began sending back some of the most awe-inspiring photos of the cosmos ever taken: they took us vastly farther into space than any Earth-bound telescope had ever seen.

Also in 1990, the first of two giant Keck telescopes atop 13,600-ft. Mauna Kea in Hawaii was completed. Unlike previous large telescopes, the 33-ft. mirrors of the Keck telescopes consist of hexagonal segments fitted together to work as a single unit. Each of the 36 segments in each telescope is computer-controlled and can be fine-tuned to an accuracy of 4 billionths of a meter. The two telescopes can be used separately or combined to function as a single telescope.

*In 1991, the Jupiter-bound American space probe *Galileo* was diverted slightly from its route to pass within 960 miles of asteroid 951 Gaspra. Later, *Galileo* visited the asteroid 243 Ida and found that it had a tiny moon of its own, Dactyl, orbiting it. Finally, in 1995, having reached Jupiter a detachable probe from *Galileo* was parachuted into the Jovian atmosphere. That probe sent back data for about an hour before the planet's awesome pressure and heat destroyed it.

*In 1992, the Dutch-born American astronomer **Gerard Kuiper** suggested the existence of an area beyond Neptune and Pluto where comets, minor planets and other, smaller space debris form a belt around the solar system. The *Kuiper belt* now includes Pluto (but not Neptune), and objects within the Kuiper belt are referred to as *trans-Neptunian objects*.

Aside from Pluto, Kuiper was wrong in one other respect: comets come from the *Oort cloud*, which is a thousand times farther from the Sun than the Kuiper belt is. The Kuiper belt is thought to contain about 200 times as many objects as the *asteroid belt* between Mars and Jupiter.

*In 1997, the American lander *Pathfinder* set down on Mars. Its attached *Sojourner* rover vehicle immediately began exploring the Martian surface.

*In 1998, work was begun on the International Space Station (ISS), an orbiting laboratory with living quarters for astronauts conducting space-related research. Continuously occupied since its first module was completed in 2000, the ISS has been added to like a giant Lego structure ever since. It is the most expensive man-made object ever built.

*In 1999, the *Chandra X-Ray Observatory* began orbiting the Earth.

*In 2000 a.d., the space shuttle *Endeavor* made a detailed global map of the Earth. Also that year, the American NEAR spacecraft reached the asteroid Eros, and elsewhere evidence was found that Mars once contained water.

**Conclusion.** *And there you have it: 30,000 years of astronomy history condensed into ten pages.*

*In writing this article (and re-reading it at least a hundred times for editing purposes), I constantly found myself amazed at the brilliance of the giants who preceded us. It would be unfair – and grossly false – to imply, as I have done throughout, that some developments were more important than others. Some of them (e.g., Newton's law of universal gravity, Einstein's theories, the invention of the telescope, deployment of the Hubble Space Telescope, development of spacecraft capable of traveling to the Moon and beyond, etc.) have had broader applications for astronomy than other, more specific accomplishments. But that fact in no way diminishes the importance of any of the other advances I've listed.*

*Astronomy has come a long way, baby, since its infancy. Sometimes its progress has been agonizingly slow; but at other times it has grown literally at the speed of light, and always on the shoulders of giants.*

*I hope you enjoyed the ride.*

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