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HEAVENS ABOVE:
STARS, CONSTELLATIONS, AND THE SKY

COURSE GUIDE

Professor James B. Kaler
UNIVERSITY OF ILLINOIS
AT URBANA-CHAMPAIGN

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Stars, Constellations, and the Sky

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Photo courtesy of James B. Kaler

About Your Professor

James B. Kaler

James B. (Jim) Kaler is Professor Emeritus of Astronomy at the University of Illinois at Urbana-Champaign. He received his AB in astronomy from the University of Michigan in 1960 and his Ph.D. from the University of California, Los Angeles, in 1964. He has been at Illinois ever since. His research area, in which he has published over 120 papers, involves dying stars, specifically the graceful shells and rings of gas ejected in stellar death called “planetary nebulae.” He has held both Fulbright and Guggenheim Fellowships and has been awarded medals for his work from the University of Liège, in Belgium, and from the University of Mexico. He is currently president of the board of directors of the Astronomical Society of the Pacific.

Long interested in science popularization, Professor Kaler has written for a variety of magazines that include *Astronomy*, *Sky and Telescope*, *Stardate*, *Scientific American*, the Italian magazine *l’Astronomia*, and the Dutch magazine *Zenit*. He was also a consultant for Time-Life Books on their Voyage Through the Universe series and appears frequently on various radio and television programs. Professor Kaler has written several books that include four for Cambridge University Press, two for Copernicus Books, a pair of textbooks, and another pair for the prestigious Scientific American Library series. *Stars and Their Spectra* (Cambridge) was selected by *Sky and Telescope* as one of the astronomy books to bring to a desert island; *Choice* called *Stars* (Scientific American Library) “an elegantly written book . . . recommended for general readers”; the *Observatory* referred to *The Ever-Changing Sky* as “a notable success . . . a fine book which fills a notable gap in the literature”; *Extreme Stars* was the American Association of Publishers choice for “Outstanding and Scholarly Title in Physics and Astronomy” for 2001.

Professor Kaler has been cited several times in the University of Illinois’s list of excellent teachers and has won three teaching awards from student groups. Outreach activities include extensive lecturing to the public and to planetarium groups, and a suite of popular and award-winning websites that include “Skylights” (featuring a weekly column on what’s up in the sky at www.astro.uiuc.edu/~kaler/skylights.html) and “Stars” (which highlights a star of the week, complete with labeled photographs, at www.astro.uiuc.edu/~kaler/sow/sow.html).

A planetarium show based on his life and work (*The StarGazer*) has played in small planetaria around the world. Professor Kaler’s outreach activities were honored by the University of Illinois with the “Campus Award for Excellence in Public Engagement” for 2003.

Professor Kaler is married with four children and is blessed with six granddaughters. He likes to cook, run, photograph the beauty of the world, and play the guitar and trumpet. He is also past president of the board of directors of the Champaign-Urbana Symphony.

The Prague Astronomical Clock (or Prague Orloj), is a medieval astronomical clock located in Prague, the capital of the Czech Republic. The Orloj has three main components: the astronomical dial, representing the position of the Sun and Moon in the sky and displaying various astronomical details, "The Walk of the Apostles," a clockwork hourly show of figures of the Apostles and other moving sculptures, and a calendar dial with medallions representing the months.

Introduction

Have you ever gone outside at night to admire the stars? And wonder what they all are, and what stories they have to tell? Have you ever thought you'd like to know and understand the constellations or know the names of the stars? Here you can learn to find your way across the celestial landscape and begin to understand these patterns of the ages. Learn why the Big Dipper, not a true "constellation," might be seen all night, or why the Southern Cross is invisible from New York. Find out the meanings of the celestial figures, where they came from, and why we still use them today thousands of years after the first ones were invented.

This audio course is designed to guide the listener through the sights of the naked eye sky, wherein we directly witness the effects of the turning and revolving of the Earth, the artistry painted by the human mind using the sky and stars, and how the view changes with time and with our place on the planet.

Lecture 1:
Sky and Stars

The Suggested Reading for this lecture is James B. Kaler's *Stars.*

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We stand in a field with a blue sky over our heads. It looks as if we are in a huge inverted bowl, an imaginary "celestial sphere" that wraps all the way around the Earth. The Earth gets in the way, however, cutting it in half at the horizon. Above the horizon we see the Sun and stars, below it the beautiful Earth, the sky half our world. Everything we see in the sky, Sun, Moon, stars, their constellation patterns, seems to lie on the celestial sphere, which is not really there, but an illusion. In this lecture, however, we look not at the constellations themselves, but at the background: watching the Sun set, we explore something of the true natures of the heavens and of the stars.

Blue Skies

Our knowledge about the sky rides on a spectrum of light waves that range from red at longer wavelengths through orange, yellow, green, blue, and violet at shorter. Sunlight is a mixture of all these colors. Light is a flow of alternating electric and magnetic fields that moves at the speed limit of the Universe, 186,300 miles per second. Longer than red lies the invisible infrared and then radio, while shorter than violet is the domain of ultraviolet, X-rays, and gamma rays. At the same time, light acts as a collection of particles called "photons" that carries the waves along with them. The shorter a photon's wavelength, the more energy it carries. "Light" stimulates our eyes. Longer-wave infrared and radio are mostly benign, while shorter-wave photons become increasingly dangerous, even deadly.

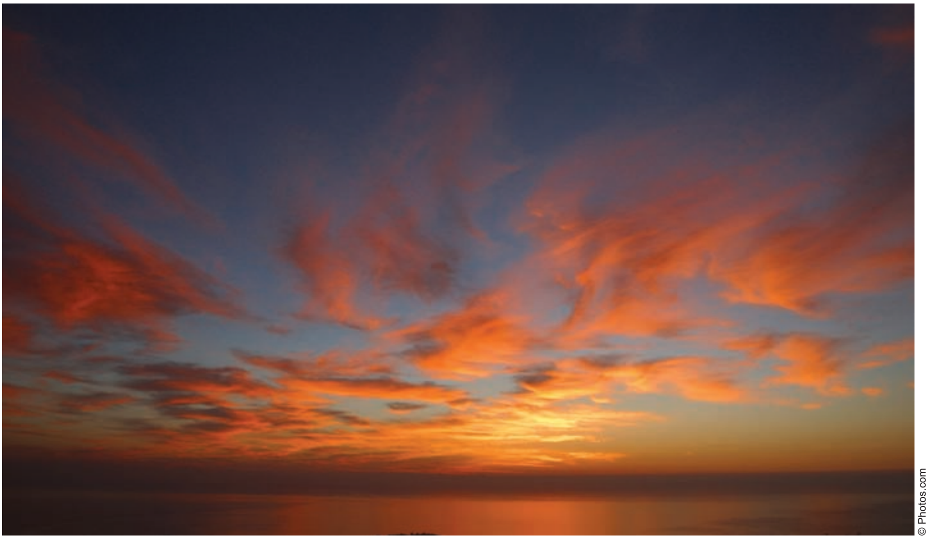
The illusion of the celestial sphere is created by the blue sky, which is the product of our encompassing atmosphere. Some of the photons from sunlight bounce off air molecules. The shorter the wave, the more likely it is to scatter. The red component of sunlight gets through nicely, while blue and violet are bounced around and can come at you from any direction. There isn't much violet in sunlight, nor is the eye very sensitive to it, so the sky turns blue. The Sun is so bright that the stars, which are there in daylight, are overwhelmed. Only the Sun, the Moon, and occasionally Venus are bright enough to be seen in full daylight.

Sunset, Night, and Dark Skies

The Earth turns. The movement is so smooth that we are unaware of it. It seems thus that it is the Sun that is moving, rising over the eastern horizon, gliding across the sky, and finally moving toward the western horizon. As it drops below the land, the sky darkens. Watch as a gray band—the shadow of the Earth—climbs in the east to bring the approaching night. While the Earth is really a sphere, within your horizon, it appears more or less flat. Locally, the atmosphere therefore acts as a flat blanket over your head. As the Sun descends, its light must pass through more and more air. Ever more blue is scattered out and absorbed, so the Sun turns redder. At the horizon it can shine with a reddish light that reflects from clouds to give us glorious sunsets.

When the Sun drops below the horizon, it does not get immediately dark. Instead, we enter a period of twilight, caused by sunlight scattering from high in the air. You can continue to play ball, at least for a while. For a brief time, sunset colors can intensify. But gradually the sky darkens and the first stars appear.

When the Sun reaches 18 degrees below the horizon, all the light is gone, and full night is upon us. If the Moon is out, it can light the air just as the Sun does, except nowhere nearly as brightly. The more full the Moon, the fewer stars you see. A full Moon (the Moon opposite the Sun on its monthly round of Earth) will wash out all the faint ones, and actually turn the sky a very dark blue.



When the Stars Come Out

In a fully dark sky, stars seem everywhere; they seem countless. A few are quite bright, while fainter ones are more populous, until at the limit, vast numbers fade into the darkness. The count of naked-eye stars depends on location (altitude, humidity, eye-sensitivity), but at the limit, some 6,000 to 8,000 can be seen without aid. The number seen on any given night depends on what part of the sky you are looking at. Some of it is sparse, while near the Milky Way—a band of light that runs across the sky—there are crowds of them. On any night, one can see perhaps 2,000, less than half the total because absorption by the Earth's atmospheric blanket dims the ones near the horizon, rendering the fainter ones invisible. They fall into random, charming patterns that we name and call "constellations."

We can't talk about stars and constellations until we have a handle on gauging the stars' apparent brightnesses. The usual scheme, which goes back to Hipparchus of the second century BCE, is to divide the stars into six basic brightness groups called "magnitudes," first magnitude the brightest, sixth the faintest you can see without aid. The modern decimalized version places magnitudes on a precision basis whereby five magnitude divisions corresponds to a factor in radiated brightness of 100, one division thus corresponding to a factor of 2.512 (the fifth root of 100). The original scaling of magnitude 2.00 to the North Star sends the brightest into magnitude zero, even –1. With telescopes we can see to roughly magnitude 30, a trillion times fainter than magnitude zero.

While most stars at first appear white, many are subtly colored, the colors depending on temperature. At the cool end, half the temperature of the Sun (5,800 degrees Celsius), stars take on a washed out orange-red hue. As temperatures increase, they go through yellow-orange to white, to blue-white at the hot end (which can go to 50,000 degrees C).

Real Natures of the Stars

Though they look like points, all stars are in some way similar to our rather average Sun. The Sun is a giant ball of gas just over 100 Earth-diameters across, carrying over 300,000 times the mass of Earth, and 1,000 times the mass of the largest planet, Jupiter. The Sun is heated by gravitational compression to a central temperature over 15 million degrees Celsius and a density a dozen times that of lead. Conditions within the inner half of the solar mass sustain "thermonuclear fusion," whereby abundant hydrogen is converted to helium with the generation of solar heat and light. Like the rest of the Solar System, the Sun is 4.5 billion years old.

Stars are born from the dusty gasses of interstellar space, and are initially made of 90 percent hydrogen, 10 percent helium, and a smattering of everything else. Their luminosities and temperatures depend almost entirely on mass and age. Masses range from a few percent that of the Sun to 100 times solar. True luminosities range from a few percent that of the Sun to more than a million solar at the upper end of the mass scale. Diameters of normal stars range from under that of the Earth to near the orbit of Saturn, 1,000 times that of the Sun. Their apparent magnitudes (seen by eye on Earth) depend on both luminosity and distance, the latter ranging from a few light years (the light year the distance light travels in a year, six trillion miles) to thousands.

As long as stars have any hydrogen left in their cores, they are quite stable and change very little, and are said to be on the “main sequence,” in which luminosity climbs quickly with increasing mass. Main sequence lifetimes run from a few million years for high-mass stars to greater than the 14-billion-year lifetime of the Universe. When the internal hydrogen is gone, they begin to die. At first they swell into “giants,” even “supergiants” of much greater size and luminosity that at some point fuse their helium into carbon and oxygen and even beyond, at the high-mass end running their central compositions to iron. The Sun will live another 5 billion years before succumbing and becoming thousands of times brighter and expanding to near the orbit of the Earth.

As stars swell to large sizes and luminosities, they lose mass through powerful winds. Stars more or less like the Sun (those with masses under about 10 times solar), whittle themselves down to their old, dead cores, which shrink under gravity to become “white dwarfs” whose only fate is to cool forever. Stars with masses above about 10 solar do much the same for a while, but they are so massive that the iron cores they develop become unstable, collapse, and explode as rare “supernovae.” Those visible to the naked eye come along every 200 years or so.

Stars are born into giant systems called galaxies that come in a variety of sizes and shapes. Our own contains more than 200 billion stars in a volume of space about 100,000 light years across. Most of the stars are arranged in a flat disk. Since the Sun is within the disk, you see the combined light of the Galaxy as a disk around you called the Milky Way. Even a small telescope shows it to be made of myriads of stars. The naked-eye stars that make the constellations are nearly all local, only a few to a few hundred light years away. Four other galaxies are visible to the naked eye. With the telescope, the number approaches a trillion, all of it expanding away from us at ever-increasing speeds as if from some gigantic explosion, a “Big Bang.” Our galaxy is one of the many, but a most important one, as we are in it and can look outward through our ancient constellations into the cosmos so as to begin to understand it.

Barred spiral galaxy NGC 1300 photographed by the Hubble space telescope in September 2004.

FOR GREATER UNDERSTANDING

Questions

1. What factors influence the count of naked-eye stars that a person can see on any given night?
2. What do the luminosity and temperature of a star depend on?

Suggested Reading

Kaler, James B. *Stars*. New York: Scientific American Library, W.H. Freeman, 1998.

Other Books of Interest

Kaler, James B. *Extreme Stars*. Cambridge: Cambridge University Press, 2001.

———. *The Little Book of Stars*. New York: Copernicus Books, 2001.

Lecture 2:
Constellations

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

With the exception of true physical groupings that are part of the stellar birth process, and the concentration of stars toward the Milky Way, stars are arranged across the sky more or less at random. Randomness, however, does not equate to uniformity, but instead can produce the prominent (and many not-so-prominent) patterns called constellations, which over the millennia have been given names. Since no one knew anything about the stars' true natures, the most ancient constellations were woven into the fabric of peoples' sacred world and into their storytelling. All societies have their own astronomies, their own celestial lores, and their own constellations, which can all differ mightily from the ones next door.

Appearance

If you've ever found any constellations, your first reaction might have been that they don't look like what their names suggest. That's really no surprise, since no master painter had a hand in them; they are inventions of the human mind from random—and sometimes not so random—stellar scatterings. A few, Orion the Hunter, for example, really do rather resemble their namesakes, but most don't. Trying to see a goat in Capricornus—a "water goat" no less—is a frustrating exercise. Constellations are meant to represent things, not portray them. But still, with a relaxed imagination, rather like looking at cloud shapes, they remarkably begin to come alive, speaking to you over the ages from our cultural forebears.

The Ancient and the Modern

There are four different, overlapping ways of dividing the constellations. Historically, they split into the "ancient" and the "modern." Though the origins of the oldest patterns are lost to history, they probably go back to 2000 BCE or before and to the ancient lands of Mesopotamia, to Babylonia and its surroundings. Our first glimmerings come down from what we now call ancient Greece of 800 BCE, and the writings of Homer. Over the generations, the Greeks wove their own mythologies into the patterns that for the most part were already there. Their names and descriptions were written down, codified, through classical Greek times by various astronomers and poets, and finally set in cement in the second century CE by the last of the great Greek astronomers, Ptolemy, whose textbook ruled the subject for the next thirteen centuries, until Copernicus started us on the long road to astronomical truth. The result is a set of forty-eight ancient constellations that in the eighteenth century became fifty with the division of Argo (the ship of the Argonauts) into three parts.

For the most part, the ancients named only the most obvious of the figures. Among them lay faint, fallow stellar soil that seemed not to organize itself into much of anything. The Greeks called these voids the "*amorphotoi*," the "unformed." (Be a hero and maybe the gods will place you in the sky.) With the post-Copernican blossoming of science, the new astronomers had a need to fill in the blanks so that all the sky was covered, if for no other reason than to name the stars. They also seem to have had a need to make themselves famous as creators of immortal constellations. And then there was the deep southern part of the sky that could not be seen from ancient Greece and related lands. So during the 200-year period from roughly 1600 to 1800, astronomers went mad creating new figures in the *amorphotoi*, in the far south, and by tearing ancient constellations apart and rebuilding them. Most people have heard of Orion (the Hunter) or Taurus (the Bull). Few have heard of Lynx (so-named because one would have to be "lynx-eyed" to see it unaided), Monoceros (the Unicorn), or Apus (the Bird of Paradise). Fewer still can find them.

The Living and the Dead

The inventors left the sky a bit of a mess, with various astronomers having different views of constellation patterns with differing boundaries between them. During the 1920s, the international professional astronomical community took the matter in hand by adopting Ptolemy's ancient forty-eight (cum fifty) and thirty-eight of the moderns, giving us a total of eighty-eight. They also drew in rectangular boundaries so that all stars resided in a unique constellation, then added three-letter abbreviations ("Ori" for Orion, for example).

The rest of the moderns were thankfully dumped. Otherwise the sky would have an office machine, an additional fly (one is enough), and more royalty than you care to know (maybe if I put the king in the sky, he'll give me money). The defunct are still there, though, if you want to find them.

The Sacred and the Profane

The most profound division separates the constellations into those that had sacred meanings and those used for fun and storytelling (the separation not complete). The figures with the deepest meanings are the twelve of the Zodiac (Aries, Taurus, Cancer . . .), those through which the Sun, Moon, and five planets seem to pass over the course of the year. These dozen seemed to be the homes to gods, so they must have some sort of mystical meanings.

As to the rest, the other thirty-six? After a long day of herding the goats, you and your family and friends relax around the campfire with whatever potable your tribe has come up with. Among the most honored of your group is the storyteller, whose tales may have been handed down through the generations, or maybe made up on the spot. Overhead, in a sparkling sky, is a fabulous storyboard. "Look, there is the Great Bear, let me tell you how he got his tail . . ." And do we not do this yet today? Who are the most famed? Our storytellers. We still sit around the campfire. We call it "television."

The Formal and the Informal

The most beloved figure in the North American sky is the Big Dipper, which really looks like its name. It's not a constellation. Well, it is, but not an *official* one with boundaries and an abbreviation. Instead it's one of the many *in*formal constellations that dot the sky and are called *asterisms*. The best ones add another couple dozen charming pictures to the sky.

And if you don't like these, make your own! It's free. When I was just beginning to learn them, I saw a pattern that looked like something familiar, then gave it a name. It's mine. Nobody else knows it or has seen it, but it's with me still, and that is what I first see instead of the formal constellation to which it is attached. Behold the power of imagination.

Seasons in the Sky

Among the joys of constellations is seeing them change as the Earth goes around the Sun, in watching them marching in tune with the seasons. Here comes Orion: northern winter must be approaching; there is Leo bringing spring, Cygnus announcing summer, Pegasus fall. They bring memories of our own seasons of life, of when we find them. Andromeda might evoke your youth when you first saw the graceful curve of stars, the Southern Cross your years at sea. We do not just learn the constellations, we fall in love with them as companions for life.

© James B. Kaler

The Big Dipper, the famous and prominent part of Ursa Major, the Greater Bear, is seen through the open shutter of the 90-inch telescope of the University of Arizona atop Kitt Peak. Just down and to the right of Mizar is its companion Alcor, the two easily separable with the naked eye. The central five stars of the Dipper, plus Alcor and several other stars, constitute a physical group, the Ursa Major Cluster.

Reality

Constellations are the novels of the sky. They are not real, but made up, which, like actual novels, hardly reduces their meaning and their power over the imagination, or their ability to entertain and instruct. They are, however, made of stars that lie at all different distances from us. From another nearby star, the sky would look different, distorted. And there would be our Sun, shining as a star in some alien sky, perhaps an important part of someone's pantheon of gods. Go farther away, and the distortion becomes so severe that all our own constellations are lost, to be replaced by new ones. Every star has its own sky. Wouldn't it be fun to see one?

And they won't last either. All stars orbit the Galaxy on somewhat different paths. They are all thus moving relative to each other. The movement is achingly slow from a human point of view, but nevertheless real. While we see essentially the same skies and constellations that our Greek or Babylonian or Chinese ancestors did, those that founded our species a couple hundred thousand years ago saw a very different sky, the Dipper not even recognizable as such. And our descendants of a million years hence will observe few of the stars that enchant us now. Like life itself, all is changing, so enjoy what we have today.

Other Points of View

We speak of "our" constellations as if they are the only ones. But other cultures had them too. They ranged from those of ancient Arabia to the Navaho to those who walk the Andes and sail the southern Pacific seas. Britain knows the Big Dipper as the Plow, while to the Arabs it was a funeral bier. The Arabic Zodiac has not twelve but twenty-eight constellations, one for each day of the month. Chinese, Korean, Indian, Mayan, all are different. No one culture has license. But we can't cover them all, so we concentrate here on the "Western" figures, even though they were born in the "Middle East," the "globalization" nothing new.

Questions

1. What are the four ways of dividing the constellations?
2. How are constellations like novels?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Kaler, James B. Chapter 1. *The Cambridge Encyclopedia of Stars*. Cambridge: Cambridge University Press, 2006.

Rey, H.A. *The Stars: A New Way to See Them*. New York: Houghton-Mifflin, 1980.

Williamson, R.A. *Living the Sky*. Boston: Houghton-Mifflin, 1984.

Lecture 3:
Circles of Earth

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

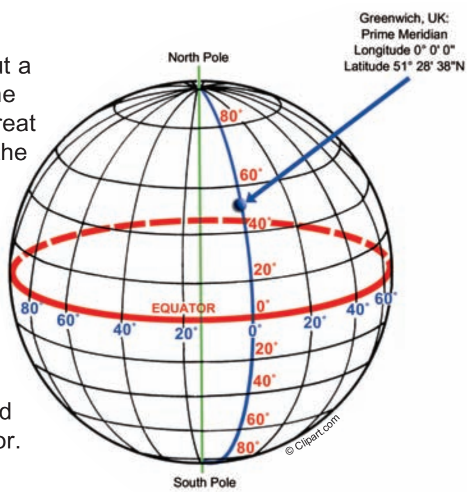
Two classic student questions: "Why do we have to know this stuff?" "Is it going to be on the test?" No tests here, so we are left with the first query. We have to know this stuff, the circles of the Earth and sky, because they form the basic road map to learning the constellations, why they are visible from some places and not from others, and why they can be seen at some times and not at others. We start here to lay out a grid on which the constellations are set so that we can find them and follow them throughout our travels and our lives.

Angles and Circles

Draw two lines on a sheet of paper so that they intersect, forming an angle between them. Angles are measured in degrees, 360 of them all the way around. Place a compass at the intersection and draw a circle around the lines. The lines cut off an arc of the circle. The length of the arc in degrees is the same as the central angle in degrees. Why 360? There are 365-plus days in the year, a fact known even to ancient societies, and 360 is the closest easily divisible number. The Earth (as we know now) thus moves about a degree per day in orbit.

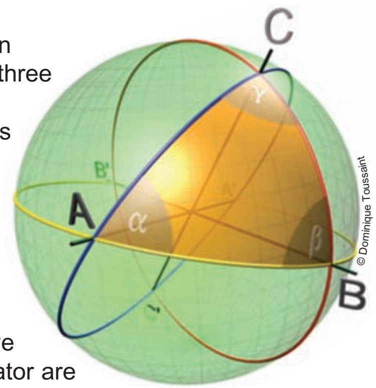
Now draw three lines on your paper so that each intersects the others. They cut off a triangle, the sum of whose angles always equals 180 degrees. The study of triangles—trigonometry—is a foundation stone of science and engineering, and of knowing the sky and where things are.

Circles on a Sphere



The sky is not a sheet of paper, but a sphere, the celestial sphere. Imagine drawing circles on the sphere. A "great circle" is centered on the center of the sphere; it is the largest circle that you can make and cuts the sphere in half. Anything else is a "small circle." A great circle through any two points on the sphere shows the shortest arc between them. For long hauls in the shortest time with the least fuel, airliners fly great circles between cities. The most famed of great circles is the Earth's equator. Many more flock the Earth and sky.

Three great circles intersect to form a "spherical triangle." A triangle on a sheet of paper has three sides measured in inches or centimeters and three angles measured in degrees. A spherical triangle has the same three angles, but its sides are arcs that are also measured in degrees. Because the sphere is curved, the angles always add up to *more* than 180 degrees.



An example of a spherical triangle is displayed on this three-dimensional sphere.

Run a line through the center of the sphere perpendicular to your favorite great circle, and it pierces the sphere at two opposing "poles" that are everywhere 90 degrees from the circle. All great circles have pairs of poles. The poles of the Earth's equator are the north and south rotation poles that lie in the Arctic Ocean and in Antarctica.

The Real World

We've known the Earth to be a sphere since ancient Greek times. The evidence is all around us. You see the horizon in the distance, but you cannot travel to it: it recedes in front of you. As you walk north, the stars seem to move to the south in accordance with walking on a curved surface. In the third century BCE, Eratosthenes of Cyrene accurately measured the Earth's circumference by noting the angle through which the Sun shifted when viewed from two places that lay a known distance apart. We now know the Earth to be 12,700 km (7,900 miles) in diameter.

The Earth rotates every twenty-four hours around an axis through its center in the counterclockwise direction (to the east) as viewed from above the north rotation pole. The Sun thus seems to move across the sky clockwise (to the west), which is why clock hands move in the direction they do. The north and south poles are the points of zero rotation speed and define a great circle that splits the difference between them (90 degrees away), the equator, at which the rotation speed is greatest (1,660 km/hr, 1,030 mph).

Rotation makes the Earth into an "oblate spheroid" whose equatorial diameter is 41 km (25 miles) bigger than the diameter taken through the poles. This bulge, we will see, has a powerful effect on the visibility of the constellations. To keep things simple, for now assume Earth to be a sphere.

Proofs

While the visible evidence leads us to believe the Earth is a sphere, "proving" it is something else again and goes to the heart of science. A theory is a model (in physical sciences, a mathematical one) that satisfies all the observations and can predict new ones to be made. The sphericity of the Earth is just such a theory. Scientific theories can never be "proven," only "disproven." If you can't disprove a theory with contradicting evidence, then the theory is accepted as some sort of "truth." No one has found counter-evidence that the Earth is not "round," so we accept it as fact. Anything not contradictable has no place in science.

Evidence for rotation is more difficult. We see the heavens going around us. Watch a star and it moves slowly westward. Is it the Earth that is turning, or is it, as was so long believed, the celestial sphere that rotates around *us*? To find out, go to the north pole and swing a pendulum on a long wire. The direction of swing will not stay constant, but will rotate clockwise through a full circle over a period of 24 hours. The simplest explanation (which is usually taken to be the correct one) is that the pendulum's direction is really constant, but that the Earth is rotating beneath it. The first such experiment was not done until 1851, in Paris by Léon Foucault. It caused a sensation. You can find Foucault pendulums in museums around the world.

Further evidence comes from the "coriolis effect." From a location in the northern hemisphere, imagine firing an artillery shell due north. Instead of going straight, however, it drifts steadily to the east of the target. The effect is easily explained by rotation, as the firing point is moving faster around the terrestrial axis than is the target, and thus the Earth provides a relative kick to the east. The effect must be taken into account in rocketry and warfare. It is also in part the source of weather patterns in temperate latitudes.

Coordinates

Speaking of latitudes, we now find our way by the use of latitude and longitude. Between the rotation poles, you can run an infinite number of great circles called "meridians" that are all perpendicular to the equator. Pick one to be a "prime meridian." Because of Britain's historic sea power, the world agreed to use the meridian that passes through the observatory at Greenwich, a suburb of London. The prime meridian intersects the equator in the Atlantic Ocean off the west coast of Africa.

Now draw a meridian through your home town and note where it intersects the equator. The arc measured *on the equator* between the prime meridian and your local meridian is your longitude. It's traditionally measured to the east or west of Greenwich up to 180 degrees.

Now note the arc on your local meridian between the equator and your town. That arc is your latitude and is measured north or south of the equator. The coordinates of Phoenix, Arizona, are 112°W, 33°N, of Sydney, Australia, 151°E, 34°S. One degree of latitude spans about 111 km (69 miles). Going along a meridian of longitude takes you north or south. Except for the equator, lines of constant latitude are small circles, and are called parallels, along which you move east or west. Since all the meridians converge at the poles, these points have no longitudes, only latitudes 90 degrees north and south.

We can be very precise. A degree is subdivided into 60 parts called "minutes" (not to be confused with time units), and each minute into 60 further parts called "seconds" (giving 3,600 seconds per degree). The nautical mile (1,852 km, 1,151 ordinary miles) is about one minute of arc in length at the equator. A second of arc conveniently spans about 100 feet. The Global Positioning System can determine your coordinates to within a foot or so, allowing you to navigate your car through the streets of New York or to lead you to your favorite fishing hole.

Geographical coordinates can be generalized to fit any need. Just pick a great circle analogous to the equator and a prime secondary circle that runs through the fundamental's poles. The sky has several such systems that interlock to help us find our way both across the heavens and the Earth.

FOR GREATER UNDERSTANDING

Questions

1. How do circles and angles help us to understand constellations?
2. Why is evidence of the Earth's rotation more difficult to prove than proving that the Earth is a sphere?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

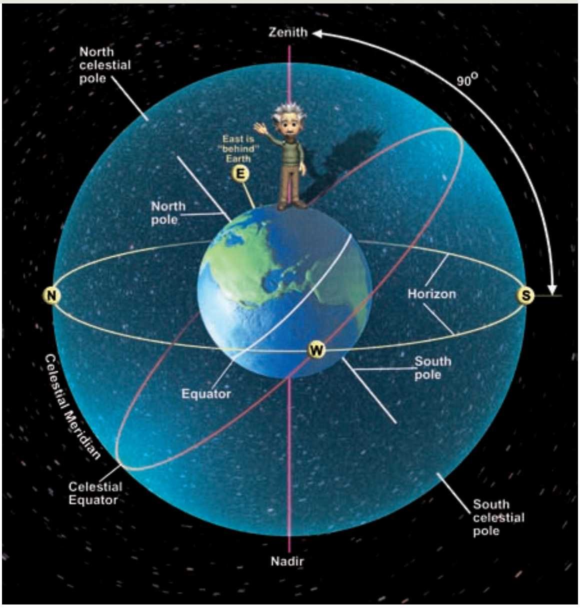
Kaler, James B. Chapter 2. *The Cambridge Encyclopedia of Stars*. Cambridge: Cambridge University Press, 2006.

Nassau, Jason John. *Textbook of Practical Astronomy*. New York: McGraw-Hill, 1948.

Lecture 4: Celestial Circles

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

Using the Earth as a springboard, we launch ourselves into the sky and to more circles within circles so as to begin to make some sense out of what we see. Such knowledge is crucial, not just for learning the constellations, but for using them: for professional observation with telescopes, for timekeeping, for navigating our cars, ships, and planes, and for sending spaceships across the Solar System.



The Earth lies at the center of a fictitious "celestial sphere." The terrestrial poles and equator then define celestial poles and equator. Everything above the horizon is visible; all below it is invisible. As the celestial sphere rotates, stars rise and set over it.

Up, Down, and Around

Look upward. Stars plaster the heavens. But before we can address their patterns in detail, we need to bring order to the sky, as we did for Earth. Two special points immediately draw attention. Look directly upward to your *zenith*, the point overhead. It can be located precisely with a carpenter's plumb bob. Hanging downward along the Earth's gravitational field to the Earth's center, the weighted string also points upward at the zenith. Because the Earth is curved, even across the room where you are sitting, your friend's plumb line will point upward in a somewhat different direction, and his or her zenith will be different from yours. You have your own personal zenith. It's yours alone. As you walk, it follows you. In the opposite direction, 180 degrees away, downward along the plumb bob, but on the invisible part of the celestial sphere, is your *nadir*. You will sadly never see your nadir: the Earth always gets in the way.

Stand on a flat floor. Extend the floor outward in all directions, and it eventually cuts the celestial sphere in half to create the great circle of the *horizon*. Stars and constellations that lie above the horizon are visible, while those below it are not, at least not to you.

The sky has rotation poles and an equator just like the Earth. Because gravity presses you downward toward the Earth's center, you always appear to be on "top" of the Earth. Everyone else does too. For argument's sake, stand halfway between the equator and the north pole, at a latitude of 45 degrees north. The rotation axis of the Earth must then make a 45 degree angle with the plane of the horizon. Extend this axis outward, and it eventually pierces the celestial sphere at the *celestial poles*. They can be found by extending your arms to the north and south but at a 45 degree angle to the horizon. The Earth, rotating counterclockwise around its terrestrial poles (to the east), makes the sky seem to rotate in the opposite direction, clockwise (to the west), about *its* celestial poles. You can see the north celestial pole above the northern horizon, while the southern pole is below the southern horizon and invisible to you. Splitting the difference between the poles is the *celestial equator*, which everywhere lies above and parallel to the Earth's equator. As on Earth, the celestial equator divides the sky into its northern and southern hemispheres.

The great circle that runs through the north celestial pole, the zenith, the south celestial pole, and the nadir is the *celestial meridian*, which divides the sky into its eastern and western hemispheres.

Directions

The cardinal directions, the "compass points" (north, south, east, and west), are formally defined by the circles in the sky. The intersection of the meridian and the horizon directly below the north celestial pole is called "north," that between the meridian and the horizon in the direction of the south celestial pole is "south." East and west are similarly defined by the intersections of the celestial equator and the horizon, and each are 90 degrees from north and south. (Face north and east is on your exact right.) Note that these directions are *points on the celestial sphere and on the horizon*. If you walk toward them, they proceed in front of you. You cannot ever arrive at them. At the north pole, however, you can go no farther north, so all directions are south.

The direction between north and east is called "northeast," that between east and south "southeast," and so on. That between north and northeast is "north by northeast," and so on.

Magnetic Earth

Circulation in the Earth's liquid nickel-iron core generates a magnetic field that, in its simplest form, acts like a bar magnet plunged through the center of the Earth. The bar emerges from Earth at the north and south magnetic poles. A magnetic compass will align itself along the field and point toward the north magnetic pole.

The magnetic field, however, is not aligned along the rotation axis, but because of vagaries in the core's circulation and rotation, it is tilted at a 10 degree angle. The north magnetic pole thus lies 10 degrees from the north rotation pole and falls in the Canadian arctic archipelago. Use of a magnetic compass requires corrections that depend on latitude and longitude. Moreover, the pole moves up to 40 kilometers (25 miles) per year, so the corrections keep changing. The "compass points" are thus a bit of a misnomer, as they are actually defined entirely by celestial circles.

Measuring the Sky

We find our way on Earth with coordinates: with latitude and longitude. Though we may not use them directly, those who make our maps ultimately have to. Similarly, we find our way in the sky by establishing coordinate grids against which we can find and locate the constellations and understand their positions and apparent movements.

We first need a basic great circle on which to build a coordinate grid. The most obvious is the one we can actually see, the horizon. We use “north” as a starting point. Pick your favorite star. Drop a vertical line (or circle) from the star until it intersects the horizon. The angle between this intersection and the north point (measured clockwise from north, through east) is the *azimuth*. In navigation circles, it is sometimes called the “heading.” The east point of the horizon is at right angles with north, so its azimuth is 90 degrees; that of south is 180 degrees, that of west 270. Northeast is at 45 degrees azimuth, and so on.

Then measure how high in angle the star is above the horizon in degrees, that is, its *altitude*. The altitude of the zenith is 90 degrees, that of the horizon 0 degrees. Anything below the horizon has a negative altitude that descends to the nadir at –90 degrees. All stars, anything in the sky, have altitudes and azimuths (except the zenith and nadir, which have no azimuths, just altitudes). We now have a precise means of location and of directing the observer eye.

Finding Our Way

At our sample location, a latitude of 45 degrees north of the equator, the north celestial pole is 45 degrees above the horizon, that is, its altitude is 45 degrees. Go to the north pole, latitude 90 degrees north. Relative to you, the rotation axis of the Earth is vertical, that is, perpendicular to the horizon, and comes up right through you. Follow the axis upward and it must hit the celestial sphere at the zenith. The north celestial pole thus has an altitude of 90 degrees as well. Step one degree south of the pole (all directions are south), and the north celestial pole drops by one degree to 89 degrees, and so on. Go to the Earth’s equator, latitude 0 degrees. Now the rotation axis is parallel to the horizon, the celestial equator passes overhead, and the north celestial pole is coincident with “north”; its altitude is therefore 0 degrees. The two, the altitude of the north celestial pole, and the latitude, are the same! Follow the standard rule: “the altitude of the north celestial pole equals the observer’s latitude,” and you begin to navigate the Earth. Step across the Earth’s equator. The north celestial pole now drops below the horizon and you can see the south celestial pole above the southern horizon. Since the north pole now has a negative altitude, so does your latitude.

By chance, northerners have a marvelous guide with which to find their way. The North Star—Polaris, at the end of the handle of the Little Dipper—sits just three-quarters of a degree off the north celestial pole. We now take our first foray into finding stars and their constellations. From a map, read off your latitude. At night, look upward to the north by an angle equal to your latitude, and there’s the star, bright, but not overwhelmingly so. At mid-second magnitude, it ranks forty-ninth in apparent brightness. If the sky is really dark, perhaps you can see the faint stars of the Little Dipper (the major asterism of

Ursa Minor, the Smaller Bear) curving away from it. Once you know Polaris and its constellation, you will always be able to find approximate latitude. Various almanacs give nightly/hourly corrections from Polaris to the exact pole, allowing latitude to be determined with great precision. In the early days of exploration, the old mariners could easily find their way to their destinations in the new world by keeping Polaris at a constant altitude. Pirates, of course, knew that too. Though the south celestial pole (in modern Octans, the Octant) has no significant pole star, latitude can still be estimated from knowing the point of zero rotation among the southern constellations. Crux, the Southern Cross, points at it and thus provides a pretty good guide.

Proper navigation also requires that we find longitude, which is much tougher. The distortion found on antique maps is almost always in the east-west direction, not to the north or south.

Altitude and azimuth have a major problem as well. As the Earth rotates, and the stars move across the sky, altitude and azimuth continuously change. Specific values are correct but for the instant. To find the constellations—and longitude—we need more, a system that is fixed with the stars, not with the Earth.

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A time-lapse exposure of the sky around Polaris, the North Star, which lies near the north celestial pole. The image was taken using a star filter, which gives Polaris a spiky appearance. The stars appear to orbit the true pole and leave tracks during the exposure.

Questions

1. Why can you never see your nadir?
2. How does the North Star's location help northerners to navigate?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Kaler, James B. Chapter 2. *The Cambridge Encyclopedia of Stars*. Cambridge: Cambridge University Press, 2006.

———. *Stars*. New York: Scientific American Library, W.H. Freeman, 1998.

Nassau, Jason John. *Textbook of Practical Astronomy*. New York: McGraw-Hill, 1948.

Websites to Visit

1. Measuring the Sky: A Quick Guide to the Celestial Sphere — http://www.astro.uiuc.edu/~kaler/celsph.html
2. Celestial sphere — http://csep10.phys.utk.edu/astr161/lect/celestial/celestial.html
3. Animated celestial sphere — http://brahms.phy.vanderbilt.edu/~rknop/astromovies/celsphere1.html

Lecture 5: Rising and Setting

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

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Star trails wheel over the horizon in this time lapse image taken in the Netherlands in 2006. Stars close enough to the pole are perpetually visible.

Except for a few references to rotation, we've looked at the sky from a stationary point of view. It's time now to put the Earth into motion, which we will do over the next two lectures. In this one, we will examine the Earth's spin and the effects it has on the sky, on the rising and setting of stars and constellations, and how they are affected by location both on Earth and on the celestial sphere. What you see up there depends critically on your latitude and the time of day (or night). Here's why.

Location

Altitude and azimuth cannot give us permanent positions, because they change continuously as the Earth rotates. We need something akin to latitude and longitude. The celestial analogue to latitude on Earth is *declination*, which gives the angular separation between the star and the celestial equator. The declination of the equator is zero degrees, that of the north celestial pole 90 degrees north, of the south celestial pole 90 degrees south.

If you are at the north pole, latitude 90 degrees north, the north celestial pole (90 degrees north declination) is at your zenith. At the Earth's equator (latitude zero degrees), the celestial equator runs overhead, so the declination of the zenith is zero degrees. The numbers are the same. So latitude is not just the altitude of the north celestial pole, it is also the declination of the zenith, giving us another means to find our way.

There are two analogues to longitude, one fixed to the observer, the other fixed to the stars. The first of these is the star's *hour angle*, which gives the angle the star makes with the celestial meridian as measured to the west along the celestial equator. The hour angle of the meridian is zero degrees, that of the west point of the horizon 90 degrees, of the east point 270 degrees. (The second system will be taken up in the next lecture.)

Hour angle and declination are actually defined the same way as latitude and longitude. The celestial analogue to a meridian of longitude is the *hour circle*, which is the semicircle passed from the north celestial pole through the star to the south celestial pole. The celestial meridian is an hour circle that hits the celestial equator at the *equator point*. The hour angle is the arc on the celestial equator between the equator point and where the star's hour circle hits the equator, measured to the west. The declination is the arc measured along the hour circle to the north or south to the star.

Hour angle is traditionally measured in time units at the Earth's turn rate of 15 degrees per hour (360/24). An angle of 90 degrees is also an angle of 6 hours. The hour angle of the meridian is 0 hours. The west point of the horizon, 90 degrees around the sky from the equator point, has an hour angle of 6 hours, the east point of 18 hours.

Time as told by the Sun (with a sundial) is the hour angle of the Sun plus 12 hours. If the Sun is on the equator (which happens twice a year), at sunset the solar hour angle is 6 hours, so the time is 6 + 12 (or 18) hours (on a 24-hour system), or 6 PM.

Daily Paths and Circumpolar Stars

As the Earth turns counterclockwise, to the east, the stars and everything else in the sky seem to move in the other direction, clockwise, to the west. Because the stars are fixed in declination, any star will appear to trace a path across the sky, a *daily path*, around the visible celestial pole parallel to the equator, which it repeats over and over.

The daily path of a star that lies on the equator, one with a declination of 0 degrees, will simply track the equator, so it will set exactly west and rise exactly east. Since all daily paths are parallel to the equator, a star to the north of the equator will set in the northwest and rise in the northeast, whereas one south of the equator will rise and set in the southwest and southeast.

If a star is so far north of the celestial equator that it is closer to the north celestial pole than the pole is to the horizon, the star cannot set at all, and remains perpetually (ignoring daytime) visible; that is, it is *circumpolar*. Because the pole is up by an angle equal to the latitude, to be circumpolar, a star must have a declination greater than 90 degrees minus the latitude. If you are at 40 degrees north latitude, the pole's altitude is 40 degrees, and all stars north of 50 degrees declination are circumpolar.

From anywhere in the Earth's northern hemisphere, the south celestial pole must be down (negative altitude) by the same angle that the north celestial pole is up. If a star is closer to the south celestial pole than the pole is below the horizon, it can never rise, and is perpetually invisible. That will happen if the declination is less (more negative) than 90 minus the latitude. If you are at 40 degrees north, no star with a declination under 50 degrees south can be seen.

From sufficiently far northern latitudes, Polaris and the Little Dipper, the Big Dipper, and Cassiopeia (the Queen) are circumpolar, whereas the Southern Cross and most of Centaurus (the Centaur) can't be seen.

Travel

If you are at the Earth's equator, 0 degrees latitude, the celestial poles are on the horizon and there are no circumpolar stars. Barring sunlight, you could see the whole sky, all the stars and constellations, over the course of the day. It would be a fine place for an observatory except that the equator is not a very hospitable place. Daily paths are all perpendicular to the horizon. The Sun sets straight down, resulting in very short twilights.

As you go north from the equator and the north celestial pole climbs higher in the sky, you see more and more circumpolar stars, and more of the sky is hidden below the southern horizon. Daily paths become more and more tilted relative to the horizon and twilights become longer.

At the Earth's north pole, the north celestial pole is at the zenith and the celestial equator lies on the horizon. Daily paths are now parallel to the horizon, and stars and their constellations neither rise nor set. You can see only the northern celestial hemisphere, whereas none of the southern is seen at all. Only the upper half of Orion, which straddles the celestial equator, can be seen.

As you enter the southern hemisphere from the equator, the northern hemisphere begins to disappear below the northern horizon, and now the deep southern constellations become circumpolar. From mid-southern latitudes, the Southern Cross and most, if not all, of Centaurus are perpetually visible.

At the south pole, in central Antarctica, only the southern celestial hemisphere is observed, and it is the northern that is invisible. In spite of that restriction, central Antarctica is a fine place to observe because of the dryness and the height above sea level.

Finding and Keeping

You can find a constellation by using one that you know to guide you to another, or you can look at a specified hour angle and declination. A star map will give a constellation's declination, and from your latitude you can at least tell if you can see it, whether it rises or sets, or whether it is circumpolar.

While the rotation of the Earth seems small to the eye, it is magnified by the telescope. If you view anything through a fixed telescope, it will immediately move out of the field of view. Telescopes are therefore designed to follow a star across the sky to compensate for the Earth's spin. They are traditionally placed on "equatorial mounts" that have one axis of rotation pointed at the visible celestial pole. The telescope, set on one axis to a specific declination, will then move on the other axis along a daily path. You can link a clock to the axis so that the telescope will follow the star's motion automatically.

Hour angle and declination can be converted back and forth to and from altitude and azimuth. For mechanical reasons, very large telescopes are mounted so as to point in altitude and azimuth, wherein the conversions are instantaneously calculated so as to follow the stars. Such conversions are also necessary for celestial navigation.

However, to find and keep the stars, to find and keep our way, requires yet another step, one that involves the Sun, which now gets thrown into the mix.

FOR GREATER UNDERSTANDING

Questions

1. What are “hour angle” and “declination”?
2. How can a star be perpetually invisible to someone in the northern hemisphere?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

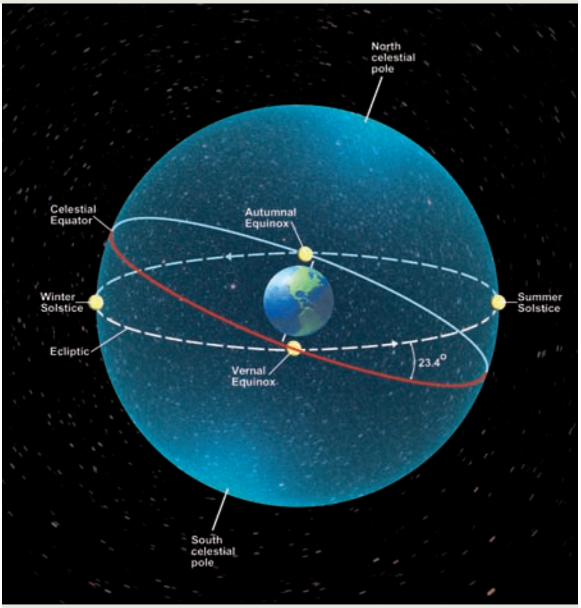
Anderson, Geoff. *The Telescope: Its History, Technology, and Future*. Princeton: Princeton University Press, 2006.

Kaler, James B. *Stars*. New York: Scientific American Library, W.H. Freeman, 1998.

Nassau, Jason John. *Textbook of Practical Astronomy*. New York: McGraw-Hill, 1948.

Lecture 6:
That Old Sun

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*



The Northern Hemisphere Seasons

Vernal Equinox	March 20	Spring Begins
Summer Solstice	June 21	Summer Begins
Autumnal Equinox	September 23	Autumn Begins
Winter Solstice	December 22	Winter Begins

If we are going to learn about constellations, why is there a whole lecture on the Sun? If the Sun is up, you can't see the stars! That's the point. The position of the Sun controls what you can and can't see. Moreover, the stars are there in the daytime whether you can see them or not, so the Sun is set against their background, against the constellations of the zodiac, which without discussing the Sun and its family of planets would make no sense. The orbit of the Earth and the apparent movement of the Sun also control the seasons, and thus give seasonal spice to the stars we get to see, creating the "constellations of autumn," of summer, and so on. The Sun is also the source of the last of our celestial grids, and provides the basis for timekeeping, which in turn allows us to tell what is up and what isn't.

The Orbit of the Earth

The Earth orbits the Sun in a nearly circular path in the counterclockwise direction (as viewed from above the north pole) every 365.2422 . . . days at an average distance of 150 million kilometers (93 million miles). Since we do not feel the motion, the Sun instead appears to go around us also in the counterclockwise direction (to the east) in a circular path, on a great circle called the *ecliptic* against the background of the constellations of the zodiac, which are there even if you can't see them. Since there are 360 degrees in a circle, the Sun moves relative to the stars at a rate of just under one degree per day. This solar motion is divorced from the movement along the daily path caused by the Earth's rotation. Because the Sun is moving slowly counter to its daily motion, the stars move across the sky slightly faster than does the Sun—with profound implications.

The stars and constellations that you see are the ones that are more or less opposite the Sun and away from the solar glare. Because the Sun is moving against the stars by one degree per day to the east, the constellations you see at night at a specific time shift slowly to the west at the same rate. Note the direction of a star tonight at 9 PM, and tomorrow at 9 PM it will be a degree farther west. Over the course of the year, the sky appears to rotate against the Sun, letting you see all that your latitude will allow.

Ecliptic and Seasons

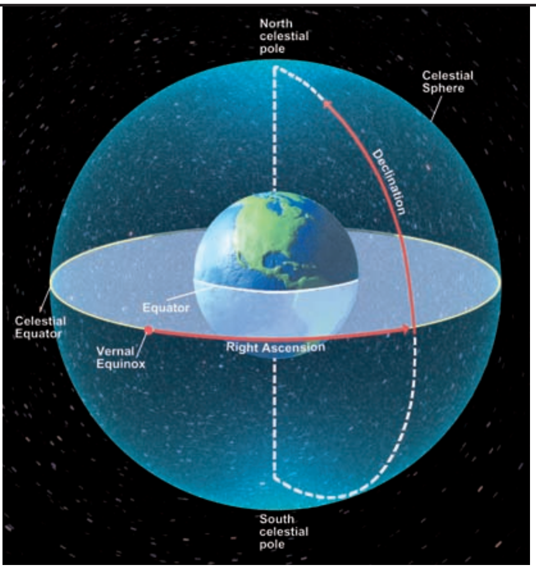
Common wisdom is that Earth's seasons are caused by the Sun's changing distance. The variation from the average, however, is just 1.7 percent. Moreover, the Earth is closest to the Sun (*perihelion*) during the northern chill of January 2, farthest around July 4 (*aphelion*). Distance has nothing to do with seasons.

The root of the seasons is the 23.4 degree tilt of the Earth's rotation axis relative to the orbital, called the *obliquity of the ecliptic*. If the rotational and orbital axes are tilted against one another, so are the planes of Earth's rotation and orbit. The ecliptic is thus tilted on the sky relative to the celestial equator by the same 23.4 degrees.

As the Sun traverses the ecliptic to the east, it must also move to the north or south of the celestial equator and must cross the equator twice. When the Sun is on the equator, it rises due east, sets due west, is up for 12 hours and down for 12 hours. Days and nights are equal, hence the two points are called the *equinoxes*. On March 20, the northbound Sun hits the *vernal equinox*, which lies in the direction of the Pisces (the Fishes), while on September 23, now southbound, it drifts across the *autumnal equinox* in Virgo (the Maiden). These two dates mark the beginning of northern hemisphere spring and fall. In between, on June 21 at the *summer solstice* in Gemini (the Twins), the Sun reaches its maximum northerly declination, 23.4 degrees north, while on December 22, the Sun crosses the *winter solstice* in Sagittarius (the Archer), the two passages marking the beginning of astronomical northern summer and winter (and the reverse in the southern hemisphere).

From mid-northern latitudes, when the Sun is in the northern hemisphere in spring and summer, it rises in the northeast, sets in the northwest, and is up for longer than it is down. On the first day of summer, it also crosses the celestial meridian as high as possible. Since the Sun's rays beat down at their most perpendicular, they most efficiently heat the ground, and the Earth below warms. When the Sun is south of the equator, it rises in the southeast, sets in the southwest, is down more than it is up, and crosses the meridian low in the sky, causing the heating rate to drop, so the ground chills. There are your seasons.

Many are the ancient monuments to sunrise. The most impressive is Stonehenge in southern England, where massive stones ring a structure that points to the rising Sun on the first day of summer.



An illustration showing right ascension and declination, which are based on the celestial equator and the vernal equinox.

Even mid-points are important. On Groundhog Day, February 2, the Sun is midway between the winter solstice and the vernal equinox. It's an astronomical holiday. So are May Day Eve (the Sun halfway between the vernal equinox and the summer solstice) and Halloween (the Sun halfway between the autumnal equinox and the winter solstice).

Special Places

At 40 degrees north latitude, the declination of the zenith is 40 degrees, so that the highest arch of the Sun's daily path on the first day of spring is 40 degrees down from zenith. On the first day of summer, the Sun can reach 23.4 degrees higher, but that's it: it cannot be overhead. A zenith Sun can occur only between latitudes 23.4 degrees north, at the tropic of Cancer, and 23.4 degrees south, at the tropic of Capricorn (named after the constellations that once held the solstices). Because the Sun is most nearly overhead, the land between the tropics is Earth's hottest place, and since sunlight is not blocked by much air thickness, you can get the worst sunburns.

The closest the Sun can get to the north celestial pole is 90 minus 23.4 degrees, or 66.6 degrees. At a latitude of 66.6 degrees north, at the arctic circle, the north celestial pole has an altitude of 66.6 degrees, so that on the first day of summer, the Sun becomes circumpolar. As you proceed north, you see more and more days of the midnight Sun. When you reach the pole, the Sun is up so long as it is in the northern hemisphere, from March 20 until September 23. You then have six months of daylight (and no visible stars), followed by six months of twilight and night. You would see the reverse at the antarctic circle at 66.6 degrees south. Even though the poles get six months of sunlight, it never gets very warm because the Sun can reach a maximum altitude of only 23.4 degrees.

Star Maps

The vernal equinox provides the key to knowing the sky. The hour circle passed from the north celestial pole to the south celestial pole through the equinox represents the sky's real "prime meridian." The arc measured to the east between the intersections of this prime hour circle and the hour circle through a star gives the star's *right ascension*. The right ascension is fixed to the rotating celestial sphere and tells how far in angle the star is to the east of the equinox. Like hour angle, "RA" is also measured in hours. If the equinox crosses the meridian at a certain time, the star crosses RA hours later. The RA of the vernal equinox is 0 hours, of the summer solstice 6 hours, of the autumnal equinox and winter solstice 12 and 18 hours.

Maps of the sky are made against the grid of right ascension and declination, coordinates that do not change (except for a matter to be discussed later).

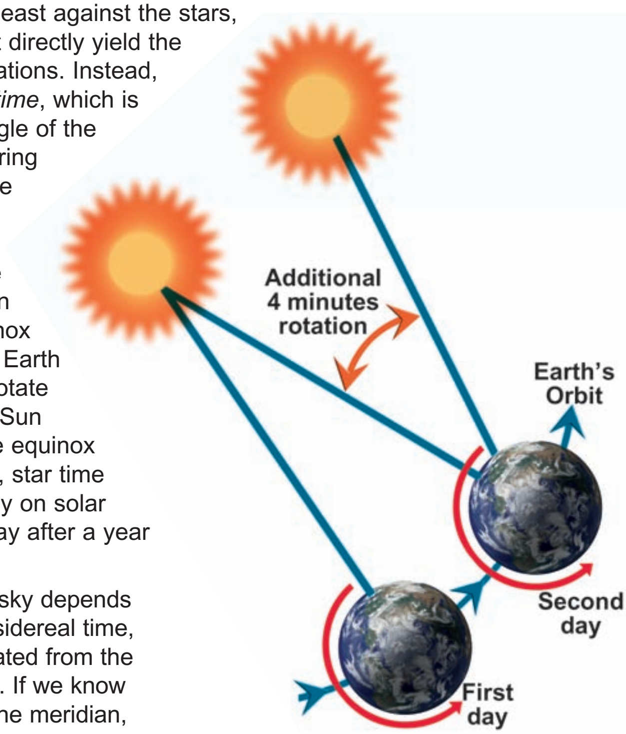
Time

The appearance of different stars and constellations depends on the time of day, which was defined as the hour angle of the Sun plus 12 hours. But as the Earth changes its distance from the Sun, it also changes its orbital speed, causing the Sun to move at a variable rate on the ecliptic, to which is added a time variation caused by the tilt. So we average the vagaries of the real Sun to make a "mean sun" that smooths things out. Our clock time starts with the hour angle of this fictional mean Sun plus 12 hours.

If you move east, hour angles increase, and vice versa. As a result, mean solar time is longitude-dependent. We compensate by using "standard times," wherein everyone agrees to use the mean time at a local meridian of longitude (75 degrees west for Eastern Standard, 90 for Central, and so on).

Since the Sun moves east against the stars, standard time does not directly yield the visibility of the constellations. Instead, we use *sidereal (star) time*, which is defined as the hour angle of the vernal equinox. Measuring backwards, it is also the right ascension of the celestial meridian. Star time and solar time are the same when the Sun hits the autumnal equinox on September 23. The Earth takes four minutes to rotate one degree. Since the Sun moves east against the equinox by one degree per day, star time gains 4 minutes per day on solar until it gains a whole day after a year has passed.

The orientation of the sky depends on the latitude and on sidereal time, the latter readily calculated from the solar time and the date. If we know the right ascension of the meridian, we can orient our star maps and know what parts of the sky, and what constellations, can be seen.



Sidereal Time and Solar Time

Careful observation of the sky will show that any specific star will cross the meridian about four minutes earlier every day. In other words, the day according to the stars (the sidereal day) is about four minutes shorter than the day according to the sun (the solar day). The effect is exaggerated in the picture.

FOR GREATER UNDERSTANDING

Questions

1. Why does the Sun appear to go around us in a counterclockwise direction?
2. Why do you get the worst sunburns in the tropics?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

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Lecture 7:
Star Names

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

In the coming lectures we will tour the sky, making stops at various constellations to examine them and to see something of the sights they have to offer. Among them are many glorious stars that we need to distinguish from each other, which we do by naming them. There is a huge variety of such appellations that range from ancient proper names to technical catalogue numbers. The brighter, more important stars can have as many as fifty designations. We look here at a few of the most important, the ones that are critical for knowing the sky. Star names also give us a short history of the Western world.

Proper Names

We know the bright stars best by their familiar proper names—Sirius, Vega, Regulus, Betelgeuse—which come to us from a variety of cultures and languages. Most are in some way descriptive of the star or of the star's location within its constellation. Most would also now be incomprehensible to their originators.

Some of the earliest star names are, not surprisingly, from Greek. "Sirius," in Canis Major (the Larger Dog), at magnitude –1.5 the brightest star of the sky, refers to "searing," or "scorching." From its reddish color, "Antares" in Scorpius (the Scorpion) means "like Mars." "Naos" in Argo (the Ship), means just that. However, even though the constellations are woven with Greek myths, Greek names are in a distinct minority.

Greek culture was greatly admired by the Romans, who adopted much of the Greek pantheon of gods (Zeus becoming Jupiter and so on) as well as their constellation lore. And they and later astronomers added some Latin names: Virgo's "Spica" (sheaf of wheat) and "Vindemiatrix" (woman grape gatherer), both of which refer to harvest time when the Sun is in or near the constellation, and "Polaris," which obviously refers to the pole. Latin names are in the minority too.

The vast majority of proper star names are Arabic. The great Arabic civilizations that flowered after the passing of Rome's glory adopted and translated much of Greek astronomy, while also melding it with their own. They named a large number of stars according to their positions within both the Greek and their own constellations. The names, filtering back to Europe, were later condensed and corrupted such that their meanings were sometimes hopelessly mangled, giving us what we have today. The bright reddish star in Orion (the Hunter), originally "yad al jauza"—the hand of the mysterious "al jauza"—became "Betelgeuse," which is commonly misrepresented as the "armpit of the Hunter." In many cases, the names were even ascribed to the wrong stars. You can often tell an Arabic name by the first syllable, “al” or “el,” Arabic for the article “the”; “Altair,” for example, originally meant “the flying eagle,” while “Algol” refers to “the demon.”

Hundreds of stars carry proper names, most of which are at best obscure. They can also be devilishly difficult to remember. Nevertheless, they are in common use for the first magnitude stars and for several others of special importance (like the Big Dipper’s “Mizar”) or charm, everyone’s favorite being Libra’s “Zubenelgenubi,” which actually refers to the southern claw of Scorpio, the Scorpion.

Bayer and His Greek Letters

To bring better order to the sky, in 1603 the German astronomer Johannes Bayer (1572–1625) used the star positions of Tycho Brahe (1546–1601), the greatest of the naked-eye astronomers, as well as new information from the southern hemisphere, to construct a magnificent star atlas, the *Uranometria*. He hired a woodblock artist to overlay his maps with beautiful figures that show the constellations’ positions, and named the stars within each by using Greek letters.

The general rule was to alphabetize stars in order of brightness, though he commonly used position as well as schemes that were known only to him. Betelgeuse then became “Alpha of Orion,” which, using the Latin possessive case ending, becomes Alpha Orionis; with the constellation’s abbreviation, the name then becomes Alpha Ori (α Ori). Sirius is Alpha Canis Majoris (α CMa). Canis Major’s second brightest star, Adhara, near the constellation’s southern end, got the fifth letter, Epsilon (ε).

There are some overlaps. Elnath, Beta Tauri (one of the horns in Taurus, the Bull), is also part of classical Auriga (the Charioteer), and is thus also Gamma Aurigae. But the modern boundaries put the star formally in Taurus, so Gamma Aur is never used. Alpheratz, Alpha Andromedae, is also Gamma Pegasi (Pegasus, the Flying Horse), which also goes unused.

Others added to the naming of the stars in modern constellations, especially those in the southern hemisphere. The tattered history of the subject left some constellations with gaps in the run of Greek letters. Two, Norma (the Square) and Leo Minor (the Smaller Lion), lack alpha stars.

With only twenty-four Greek letters, Bayer’s scheme is limited. He followed the Greek letters with lower- and then upper-case Roman letters, but few of these are ever used. The system is usefully extended, however, by adding numbers for stars that lie near one another. Usually the numbers go from west to east in order of increasing right ascension, as in Alpha-1 Librae (in Libra, the Scales) and Alpha-2 Lib (which is the brighter of the pair), though the rule can be broken: the stars in northwestern Orion that represents an upraised animal skin are called Pi-1 through Pi-6 from north to south. No star-naming system seems sacred.

The Greek Alphabet							
Alpha	(α)	Beta	(β)	Gamma	(γ)	Delta	(δ)
Epsilon	(ε)	Zeta	(ζ)	Eta	(η)	Theta	(θ)
Iota	(ι)	Kappa	(κ)	Lambda	(λ)	Mu	(μ)
Nu	(ϖ)	Xi	(ξ)	Omicron	(ο)	Pi	(π)
Rho	(ρ)	Sigma	(σ)	Tau	(τ)	Upsilon	(υ)
Phi	(φ)	Chi	(χ)	Psi	(ψ)	Omega	(ω)

Flamsteed and "His" Numbers

Even with numbers, Greek letters are nowhere nearly sufficient to name all the naked-eye stars visible in a constellation. A big step was taken by the English astronomer John Flamsteed (1646–1719), the first Astronomer Royal, who used a telescope to measure accurate positions of some 3,000 mostly brighter stars. His stars were posthumously mapped onto the *Atlas Coelestis* of 1729.

Flamsteed was so slow in producing his observations that Edmund Halley, probably in league with Isaac Newton, published them out from under him, and numbered his stars from west to east within each constellation in order of increasing right ascension. Flamsteed bought up nearly all the illicit copies and burned them. Few survive, but the *Flamsteed numbers* endured. The rules of use are the same as for the Bayer Greek letters. Vega, Alpha Lyrae (in Lyra, the Harp), is also 3 Lyrae, Betelgeuse 58 Orionis. The numbers are commonly used when Greek letters are not available.

Other astronomers tried adding numbers in the southern hemisphere inaccessible from England, but the southern sky had so many constellations that were later dropped that the numbers never caught on. As a result, there are no Flamsteed numbers below about 35 degrees south declination. Shifting boundaries left some Flamsteed-numbered stars orphaned in the wrong constellations: 1, 2, 3, 6, and 9 Aquilae (or Aquila, the Eagle) are in Scutum (the Shield).

The Bright Star Catalogue

There remained huge numbers of naked-eye stars without designation. The bible of the non-telescopic realm, roughly to magnitude 6.5, is the Yale *Bright Star Catalogue*. It does away with constellations and simply serially numbers stars around the sky from zero hours right ascension. The BSC was derived from an earlier Harvard publication, so the stars are prefixed by "HR" for "Harvard Revised." The numbers go from HR 1 in Andromeda to HR 9110 in Cassiopeia. Vega is HR 7001, Betelgeuse HR 2061. HR numbers are commonly used when Greek letters are not available, even when Flamsteed numbers were assigned.

More Catalogues

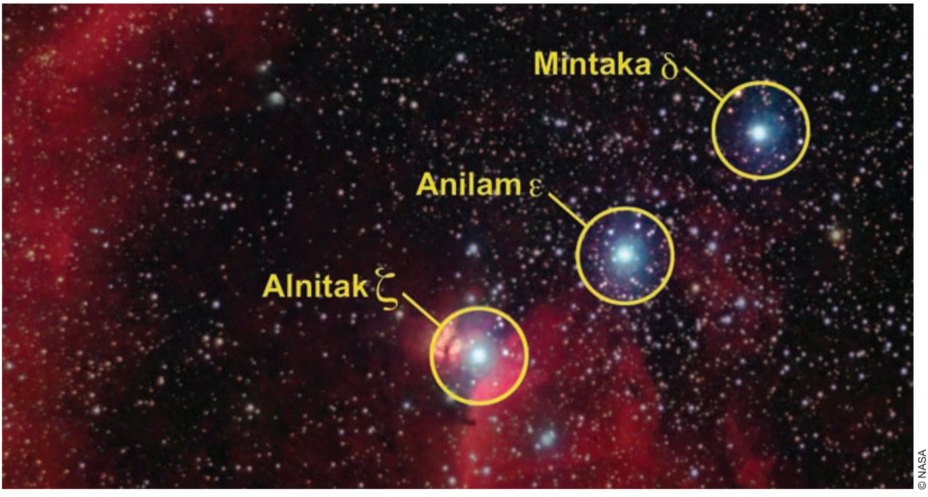
Then there are the thousands, millions, of telescopic stars. The problem was first dealt with at the Bonn, Germany, Observatory, where stars to about the ninth or tenth magnitude were numbered serially from 0 hours right ascension in one-degree-wide declination strips in the *Bonner Durchmusterung* ("Bonn Survey"), or *BD*. Vega is also BD+38 3238. The catalogue and resulting atlas were extended to the southern hemisphere as the *Cordoba Durchmusterung*, or *CD*.

Stars in the famed *Henry Draper* spectroscopic catalogue (in which stars are classed by the appearance of their spectra) carry "HD numbers" that, like those of the Bright Star Catalogue, run serially around the sky. The HD and a later extension contain more than 350,000 stars. Vega is HD 172167.

Many more catalogues are highly specialized, many of the "names" simply coordinate numbers. The Hubble "Guide Star Catalogue" contains 19 million stars. And we are far from done with our stellar surveys.

Can I Name a Star?

Sure. But nobody else will use it, even if you pay for it. Stick to tradition.



© NASA

The three stars of Orion's belt: Alnitak ζ (zeta), Anilam ε (epsilon), and Mintaka Δ (delta).

FOR GREATER UNDERSTANDING

Questions

1. What sources did Johannes Bayer use to construct his star atlas?
2. Why are there no Flamsteed numbers below about 35 degrees south declination?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Allen, Richard H. *Star Names: Their Lore and Meaning*. Rev. ed. New York: Dover Publications, 1963.

Kunitzsch, Paul, and Tim Smart. *A Dictionary of Modern Star Names: A Short Guide to 254 Star Names and Their Derivations*. 2nd rev. ed. Cambridge, MA: Sky Publishing, 2007.

Websites to Visit

1. Star Names — http://www.astro.uiuc.edu/~kaler/sow/starname.html
2. Star Names — http://www.naic.edu/~gibson/starnames/starnames.html

Lecture 8:
The Sacred Zodiac

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

We looked earlier at the general natures of the constellations. Now, with the past few lectures as background, we can reach out to examine the constellations as individuals. We start with the most important set, those of the zodiac, which historically hold the bodies of the Solar System that in the early days took the forms of gods. The story will be told from the point of view of a northern hemisphere observer. From the southern hemisphere, all appears reversed.

The Zodiac

The zodiac is the set of twelve constellations through which the Sun travels over the course of the year, the patterns that are beaded on the string of the ecliptic. With one exception, they are all animalistic, the very name "zodiac" from Greek meaning "circle of animals." From them came the mystical zodiacal "signs," from which it was long believed (and sadly still is) one could find one's fate or path to fortune. Here, however, we visit the actual astronomical constellations.

The Moon, a natural satellite a quarter the size of Earth, orbits in a plane tilted by only five degrees relative to Earth's orbit. The Moon must therefore always appear within five degrees of the ecliptic, and consequently also resides in the zodiac (although it can stray across modern boundaries into neighboring constellations). Reflecting sunlight, its orbit takes it through phases as a result of our seeing different portions of lunar day and night. The phase cycle of 29.5 days is the origin of the month. To an approximation, every time the Moon goes through a specific phase, the Sun has gone another twelfth of the way around its path and is in a different constellation, hence the zodiacal dozen.

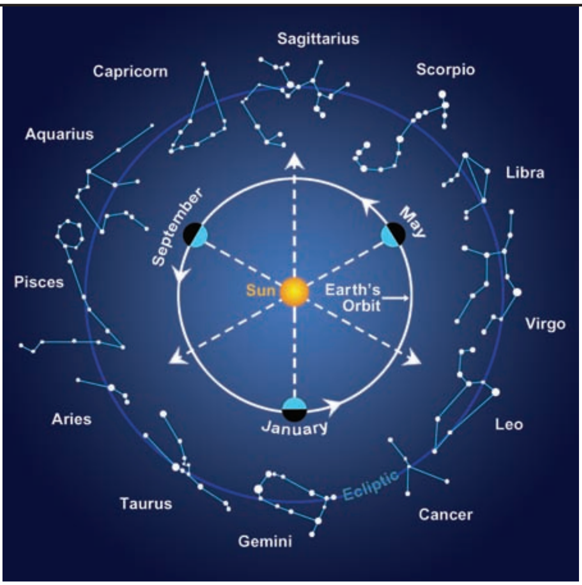
The five naked-eye planets (in order outward from the Sun: Mercury, Venus, Mars, Jupiter, and Saturn), plus Uranus and Neptune, also orbit close to the ecliptic plane, their small tilts generally keeping them within only a few degrees of the zodiac's center-line. The twelve constellations are therefore home to the once-mysterious seven bright moving bodies of the sky, and to ancients seemed to be the homes of the gods, including the sun-god.

At night you see the constellations more or less opposite the Sun. When the Sun is at the winter solstice in December, you have your best view of the constellation that contains the *summer* solstice, and so on.

Taking the Tour

While most lists begin with Aries (which tops the astrological zodiac) or Pisces (the astronomical), we instead start here with the summer solstice, and thus with *Gemini*, whose modern boundaries contain the Sun from June

21 to July 20. (The dates, and those below, are those for the astronomical constellations, not the astrological "signs," the difference to be explained in the next two lectures.) Gemini depicts the warrior "twins" of the ancient Greeks, which are directly represented by two bright stars, second magnitude Castor (he a god) and first magnitude Pollux (mortal). The remainder of the constellation is in the form of a long rectangle stretching to the southwest, the western foot of which closely marks the solstice. Passing high in northern winter skies, the figure quite looks like its name, the two stars staring down at us as if they are celestial eyes.



The basic stars of the twelve common constellations of the zodiac and their relative position to the Earth during the year.

From the brilliant to the obscure, descend to the southeast along the ecliptic to dim *Cancer* (July 21–August 10), the Crab, which Juno elevated to the sky as a reward for harassing Hercules. The most significant part is a small box of stars at the center. At the center of the box lies a faint but lovely cluster, the Praesepe (Latin for "manger," one of the few Christian allusions among the constellations) or Beehive, all its stars born together hundreds of millions of years ago.

We next confront *Leo* (August 11–September 16), the bright celestial Lion, whose evening apparition tells of spring. Leo represents the Nemean Lion that was slain by Hercules in his first labor. Bisect the handle of the Big Dipper to the south to find it. The front (western) end, Leo's head, looks like an old-fashioned sickle, or backward question mark, with first magnitude Regulus at its end. The back end of the Lion is marked by bright second magnitude Denebola (Beta Leonis), Arabic for "tail."

Then flash southeastward across the autumnal equinox, which lies in *Virgo* (September 17–October 30), the Maiden. While the constellation sprawls with no outstanding pattern, it does contain first magnitude Spica, the "Sheaf of Wheat," the star and the Maiden providing powerful harvest and fertility symbols. Well away from the dusty obscuring power of the Milky Way, Virgo is filled with a huge, nearby (50 million light years away) cluster of thousands of galaxies. The fall equinox lies smack between Leo's Regulus and Spica.

Dropping farther down we pass rather faint *Libra* (November 1–23), the Scales, the only nonliving thing to be found in the solar path. The Scales represent the balance of days, as the figure once held the autumnal equinox.

However, the two brighter stars of the distorted box that makes the constellation (Zubenelgenubi and Zubeneschamali) refer to the southern and northern claws of neighboring Scorpius. All the zodiacal constellations are thus related to animals.

Scorpius (November 24–29), a brilliant sign of summer made of a graceful curving string of stars, looks quite like its namesake and is really hard to miss. At the Scorpion's heart beats great first magnitude Antares, a red supergiant destined to explode. Though we have not yet bottomed out at the winter solstice, Scorpius's classical figure is the most southerly of any of the zodiac. The constellation is filled with star clusters, two of which are easily visible in binoculars. If you do not find Scorpius scary, ask Orion when we get there.

As a half-man, half-horse Centaur holding a drawn bow, *Sagittarius* (December 18–January 19), the Archer, looks equally dangerous. Summer's Sagittarius is sometimes identified with the teacher and physician Chiron. He is quickly recognized by a bright five-star "Dipper" that is spilling its load into the Milky Way. To the west of the asterism, find the Lagoon Nebula, a fuzzy cloud of interstellar gas and dust and the seat of recent star formation. Just to the northeast of it is the winter solstice. Sagittarius's arrow points rather well at the center of the Galaxy, which is believed to contain a massive black hole (a body so compact that light cannot escape) that contains more than two million Suns of matter.

Following our southerly ride, we now—like the Sun—climb back to the north, next encountering one of the weirder (if you ignore Sagittarius) zodiacal inhabitants, *Capricornus* (January 20–February 16), the "water goat." Difficult to find, the constellation looks like an upside-down cocked hat. It seems that Bacchus fell into a river. His bottom became a fish, the top a goat. Watch where you step.

Capricornus is the first of three zodiacal constellations that with a couple others belong to the sky's "wet quarter," which celebrates an ancient rainy season. *Aquarius* (February 17–March 11), the Water Bearer, just to the northeast, is the next. Though his main figure, nicely visible in northern autumn, is a bit hard to find, his "water jar" is marked by a prominent "Y" of stars. He's depicted as pouring water in the mouth of Piscis Austrinus, the Southern Fish, which we will catch in a later chapter.

Farther to the north, we again cross the celestial equator at the vernal equinox in northern autumn's *Pisces* (March 12–April 18), the still-wet Fishes, seen as two fish tied at their tails by a ribbon. The most noticeable part is the "Circlet," which lies just east of the Water Jar and just northwest of the equinox. The rest of the constellation looks like a big "vee" sprawling to the east.

Drying out, we encounter *Aries* (April 19–May 14), the Ram, whose position at the head of the astrological zodiac gives it a fame all out of proportion to its appearance. The most prominent part is a flat triangle that lies a fair bit to the north of the actual ecliptic. That it once held the vernal equinox made it of prime astrological importance.

We end our ecliptic tour with one of the grandest and most powerful of all the zodiacal fertility figures, northern autumn and winter's *Taurus* (May

15–June 20), the Bull. A distinctive “vee,” the Hyades star cluster, makes his obvious head. Gleaming reddish first magnitude Aldebaran, which lies in front of the cluster, is his glaring eye. To the northwest is one of the most charming gifts of the sky, the Pleiades star cluster, its Seven Sisters the daughters of Atlas and Pleione. After admiring them, we then return to Gemini, where we started.

The Thirteenth Man

Ophiuchus, the Serpent Bearer, is often depicted as standing on or below the ecliptic, making him the “thirteenth constellation” of the zodiac. Though the Sun is within his modern boundaries between November 30 and December 17, longer than it is in Scorpius, Ophiuchus is *not* a part of the classical twelve. We’ll encounter him again, along with his Serpent, three chapters hence.

Questions

1. Why must the moon always appear within five degrees of the ecliptic?
2. What is believed to lie at the center of the Galaxy?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

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Mitton, Jacqueline. *Zodiac: Celestial Circle of the Sun*. Illus. Christina Balit. London: Frances Lincoln, 2005.

Rey, H.A. *The Stars: A New Way to See Them*. New York: Houghton-Mifflin, 1980.

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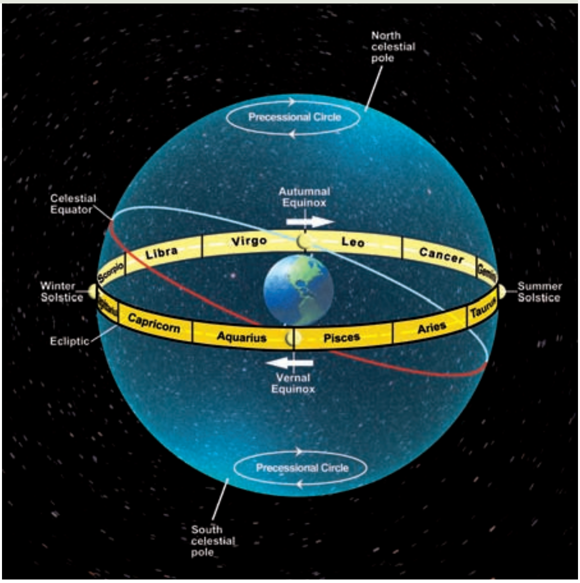
2. Constellations of the zodiac — http://www.astro.uiuc.edu/~kaler/celsph.html

Lecture 9:
Wobbles

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*



A celestial sphere illustrating the general precessional rotations (wobble) of the Earth relative to the constellations.

That the tropics are named after Cancer and Capricornus while the solstices are in Gemini and Sagittarius, that Libra's name reflects the balance of days while Virgo hosts the autumnal equinox, that Aries heads the astrological zodiac instead of Pisces, tells that something odd is going on. We've known what it is for over 2,000 years. The effects are slow, but quite remarkable, as well as remarkably observable.

The Wobbling Earth

Spin a top, and the axis wobbles around the perpendicular. The same thing happens with Earth, indeed with all rotating bodies, the effect called *precession*. Earth's precession has been known since 150 BCE, when the Greek astronomer Hipparchos discovered it by comparing star positions made 150 years apart.

Precession is caused by the gravity of the Moon and Sun, which are in the ecliptic plane, acting on the Earth's equatorial rotational bulge, which is tilted to the ecliptic plane by 23.4 degrees. The seemingly logical result would be to reduce the tilt so as to bring the Earth's rotational axis perpendicular to its orbit, thus effectively ending the seasons. Rotation, however, imparts great stability. The actual effect is therefore to make the Earth's rotational axis wobble around the orbital axis while maintaining the obliquity. Precession, the third motion of the Earth, is very slow, one full wobble taking 25,800 years to complete. The effects are profound.

The Shifting Sky

The perpendicular to the Earth's orbit points to the *ecliptic poles* in northern Draco (the Dragon) and southern Dorado (the Swordfish). Each of the ecliptic poles is 23.4 degrees away from its respective celestial pole. The declinations of the ecliptic poles are thus 66.6 degrees north and south. The ecliptic plane and poles are among the most stable of all features of the Earth. Over the 26,000-year precessional period, the north and south celestial poles gyrate in a small circle of 23.4 degrees radius around their respective ecliptic poles, the north celestial pole seeming to move in the counterclockwise direction as seen from Earth (reversed in the southern hemisphere).

Precession does not affect latitude, so at any given location, the celestial poles remain at a constant altitude. Since we ride along on the precessing Earth, it looks as if it is the sky that is moving, that the stars are sliding slowly past the celestial poles, in the north in the opposite clockwise direction. The north celestial pole is now pointing close to Polaris. The star will appear to approach the pole until 2105, when the two will be only about a quarter of a degree apart, after which they will separate. The southern pole star, dim fifth magnitude Sigma Octantis (in Octans, the Octant), has already passed its closest approach to the south celestial pole. In 1100 BCE, the north pole passed within seven degrees of Kochab (the front bowl star of the Little Dipper), while in ancient Egyptian times, 2700 BCE, Draco's Thuban was excellent. In 12,000 years, zero-magnitude Vega, which now passes overhead in mid-northern latitudes, will lie less than five degrees off the pole.

If the Earth's axis wobbles around the direction to the ecliptic poles, then the celestial equator must wobble as well, which causes the intersections between the ecliptic and equator—the equinoxes—to move to the west. Over 26,000 years, these four points will go all the way around the ecliptic and the zodiac. From the moving Earth, it looks as if the zodiacal constellations are on a belt that moves easterly along the ecliptic. With twelve constellations in the zodiac, on average the equinoxes spend 25,800/12 or 2150 years in each one. The actual rate of 50 seconds of arc per year (from 360 degrees over 25,800 years) corresponds to about a degree in a human lifetime, a quite-noticeable amount.

The vernal equinox is now in Pisces, but in ancient times, 1000 BCE or so, it was one constellation to the east, in Aries, which is why Aries tops horoscope listings. (More about that in the next lecture.) Reflecting the past, the astronomical symbol for the vernal equinox is a stylized ram's horn. In 3000 BCE, the equinox was in Taurus; both constellations are powerful fertility symbols for spring. About the year 2700, the westerly moving equinox will enter Aquarius (rather Aquarius will start to shift across the equinox). The autumnal equinox *was* in Libra, the Balance (or Scales), but is now in Virgo.

The solstices, halfway between the equinoxes, must move westerly against the constellations at the same pace. In ancient times, the summer solstice was in Cancer, one constellation to the east of its present position in Gemini. The Sun was then in Cancer when it was overhead at 23.4 degrees north latitude, hence the "tropic of Cancer" rather than the "tropic of Gemini." Similarly, the winter solstice was in Capricornus, giving us the "tropic of Capricorn."

Precession does not affect the dates of the seasons, because they are fixed to when the Sun crosses the vernal equinox. It instead affects the constellations that we see *during* particular seasons. In 13,000 years, half the precessional period, residents of the northern hemisphere will see Sagittarius high in winter, Gemini low in summer (the opposite of now), while Leo will announce fall rather than spring, Taurus spring rather than fall and winter.

Over the past century, the summer solstice crossed the artificial modern border into Taurus, and technically belongs to the Bull, but since it's still closer to the classical figure of Gemini than it is to that of Taurus, we'll let the warrior twins continue to guard it.

As the sky appears to shift relative to the poles, it must also move relative to the horizon, which powerfully affects the southern stars that can be seen from any northern location and vice versa. In 13,000 years, Canis Major, the Larger Dog, will be not be seen from New York, and Orion will be gone from the arctic, while deep southern constellations now not visible will grace Chicago's skies. A few thousand years ago, mid-latitude Native Americans could admire the Southern Cross.

Indeed, the entire grid of right ascension and declination, which is connected to the celestial equator and vernal equinox, rotates around the sky. Because the vernal equinox is moving westward and right ascensions are measured eastward from it, the right ascensions of stars cycle in a complex way, generally increasing, through a full 360 degrees, while declinations all flop back and forth through 47 degrees (double the obliquity). Star positions are thus always tagged with a date, the "epoch," for which they are correct. To find a star, we must then calculate the current coordinates from the rules and formulas of precession. We currently use the beginning of the year 2000 (2000.0) as standard; 2050.0 coordinates are coming soon.

Looking Closer

The obliquity, a near sacred number in astronomy, is rather surprisingly not fixed. Instead, it wobbles between 22 and 24.4 degrees and back over a period of 41,000 years. As a result, the circle of precession is not quite closed. When Polaris returns as the pole star in 26,000 years, it won't be quite as good a marker. So enjoy it now.

The obliquity is currently decreasing at a rate of 0.47 seconds of arc per year. This angle, however, defines the latitudes of the tropics and of the arctic and antarctic circles. The tropics are sliding toward the equator at a rate of 14 meters per year (four centimeters per day), for an annual loss of 1,000 square kilometers of tropical land, while the arctic circle is moving north, the antarctic circle south. A monument to the tropic of Cancer in Taiwan built in 1908 is now 1.5 kilometers north of it.

Precession coupled with changes in variations in the obliquity and in the eccentricity of the Earth's orbit may combine to cause climate changes that have led to past ice ages.

There's More

The precessional "circle" (such as it is) contains huge numbers of additional tiny wobbles with different periods, the most prominent of which is 18.6 years caused by the precession of the Moon's orbit.

Even the Earth's orbit, one of the most stable things we know of, is not constant, but slowly precesses as a result of the gravitational pulls of the planets.

The effect ever-so-slightly offsets the ordinary precession caused by the Moon and Sun on the equatorial bulge.

Moreover, the Earth is not close to being a perfect rotator. The axis actually shifts a bit, causing the north and south poles to drift, while ocean tides raised by the Moon and Sun cause the rotation to slow down, which requires continuous corrections to our clocks. All these small closer-look effects must be taken into account to navigate both on Earth and in the sky. Interesting as they are, however, they are not needed to enjoy the quiet beauty of the evening's stars.

FOR GREATER UNDERSTANDING

Questions

1. How did Hipparchos discover precession?
2. Why is the obliquity a near sacred number in astronomy?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

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Nassau, Jason John. *Textbook of Practical Astronomy*. New York: McGraw-Hill, 1948.

Lecture 10:
Astronomy, Astrology, and UFOs

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

What could astrology and the pursuit of UFOs (unidentified flying objects) have in common? At some point in their lives, all astronomers, whether amateur or professional, will encounter both, and need to be prepared to discuss them. They are in a sense the "dark side" of astronomy. One is a system of magic and fortunetelling that has come down across the ages in some parallel with astronomy, while the other is a modern belief in the existence and power of alien beings, none of which have ever been objectively detected. Yet both are important and significant. In pre-Copernican times, before anyone knew much about the cosmos, astrology drove much of the pursuit for astronomical knowledge, while the consideration of UFOs may at least bring people out to look at the sky and then learn of the real glory of the celestial sphere. If we do not understand the two belief systems, we cannot confront them.

Signs of the Zodiac

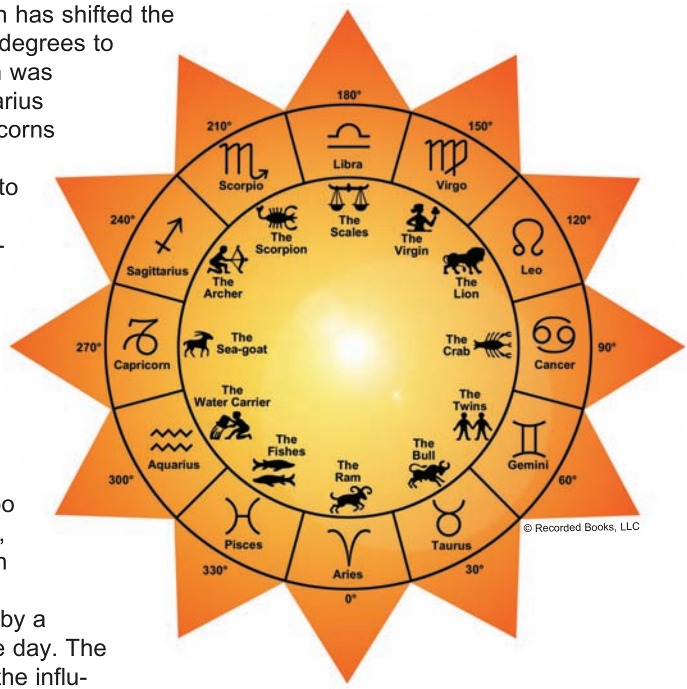
The signs of the zodiac are not constellations, but magical symbols that at one time overlaid the real constellations and that took their various and different powers from the constellations' characters. In ancient days, the two sets were indistinguishable from each other, but are now separated both by modern boundaries, precession, and above all, knowledge.

While the zodiacal constellations are of all different angular sizes, the astrological signs are uniform, 30 degrees (one twelfth the circle) across. The large majority of astrologers adopt a system whereby the sign of Aries is always tied to the vernal equinox. Indeed, the ram's-horn symbol for Aries is not only used for the vernal equinox, but the equinox is also known as the "first point of Aries," even though over the past couple millennia precession has shifted the equinoxes and solstices into the next astronomical constellations to the west.

Sun-Sign Astrology

The simplest form of astrology, that seen in the newspapers, magazines, and countless other media, is based on the sign that held the Sun when one was born. The signs begin with the Sun entering Aries on March 21. Each sun-sign then spans about a month, with some shifts tied to the solstices and autumnal equinox (the Sun in Cancer begins June 22, in Libra September 23). Your personality and fate were determined by the character of the sign that had long ago been taken from its cognate constellation. Those born with the Sun in Capricorn, for example, are practical and ambitious (or goat-stubborn and cheap), while Libra people might be romantic, easy-going, and easily-fooled. Not all astrologers agree about various characteristics.

Since precession has shifted the signs roughly 30 degrees to the west, the Sun was actually in Sagittarius when most Capricorns were born, while Libras must look to Virgo for their astronomical constellation, Leos to Cancer, and so on.



An illustrated astrology chart showing the symbols used for each of the twelve astrological signs under which a person is born (or dies) or when some event might occur.

"Real" Astrology

Most astrologers dismiss the Sun-sign version as too simplistic. Clearly, not everyone born under the sign of Aquarius gets hit by a truck on the same day. The "real thing" adds the influences of the Moon and planets to that of the Sun. Each planet has characteristics associated with it that relate to the ancient god after which it was named. Jupiter is generous, Mars warlike, Mercury quick and intelligent, and so on. The effect and influence of each planet on the individual depends on the characteristics of the sign that holds it. The placements of the planets relative to one another is critical. Jupiter seen opposite in the sky from Mars has a different magical effect than when the two are together in the same sign. Conjunction with the Sun can destroy a planet's influence. Each planet rules a different sign in which it has the greatest effect.

Horoscopes, charts that show the locations of the planets, Moon, and Sun within the signs, may be cast for the moment of your birth to reveal your personality and general fate, or may be cast as of the moment for you to see what will happen today or tomorrow.

The influences must somehow get to the person on the ground, which is done through a set of a dozen "houses," segments of the sky that are fixed to the observer. The equal-sized houses may be projected onto the sky from the north point of the horizon, or by hour circles from the north celestial pole, or in other ways. The set begins with the first house at the east point and then wraps around the sky in the counterclockwise direction. Each controls a different aspect of personality and life: love, sorrows, money, pets. A complete "natal" horoscope has not only the positions of the planets within the signs, but also within the houses at the time and place of birth. Jupiter in Virgo in the seventh house has a different effect than if in the sixth house. And then Jupiter's effect is influenced by where the other planets, Moon, and Sun happen to be. There is much more, the whole thing becoming extraordinarily complex, with different astrologers interpreting different meanings.

Like constellation lore, different cultures have different systems. Chinese astrology is quite different.

But Does It Work?

After all that, it does not work. How can it? The constellations from which the signs took their properties are not real, but made of stars at all different distances, the stars "suns" of all different kinds. There is nothing magical about them.

While the planets and Moon do indeed have influences, they affect our planet as a whole, not individuals. A believer points out that the Moon affects the Earth's waters through tides, and since humans are largely water, it must influence us too. But tides are global phenomena. We are far too small. Then, the planets radiate and may influence us that way. Jupiter is one of the strongest radio sources in the sky. But it's overwhelmed by local sources of radiation, from light bulbs to radio stations. And there are no "cosmic vibes" we know of. Even blind tests of personality vs. horoscope have come up null. There is nothing there.

Unidentified Flying Objects

For decades, people have seen what to them are mysterious lights or objects in the sky. Oddly, those who make professions or avocations out of astronomy rarely see such things, telling us that most are natural (or man-made) and are simply ordinary things that are misunderstood. Without that understanding, the imagination roams wild, such that many sightings have been associated with "space aliens," for which there is no credible evidence whatsoever.

Venus is everyone's favorite UFO. This brightest of planets (the "evening" or "morning star") can be seen through light clouds, and even as a pinpoint of light in full daylight. As you drive along a country road, it follows you, until it sets and disappears or dawn takes over. Common meteors, pieces of comet fluff or small asteroids that hit the Earth's atmosphere and burn up, are favorites as well. A big one can leave a glowing celestial path that approximates a rocket ship and may even make booming sounds. Odd clouds also can appear as UFOs.

Orbiting satellites are good too. You can see one or more almost any night reflecting sunlight long after the land has fully darkened. Even though they are moving in straight lines, the eye may make them seem to shift back and forth. Then they hit the Earth's shadow and disappear. Some can catch sunlight so brightly that they cast shadows on the ground. In pre-satellite days, we were similarly fooled by high-altitude weather balloons blowing in the winds. Airplane landing lights can be startling and mysterious when seen through clouds.

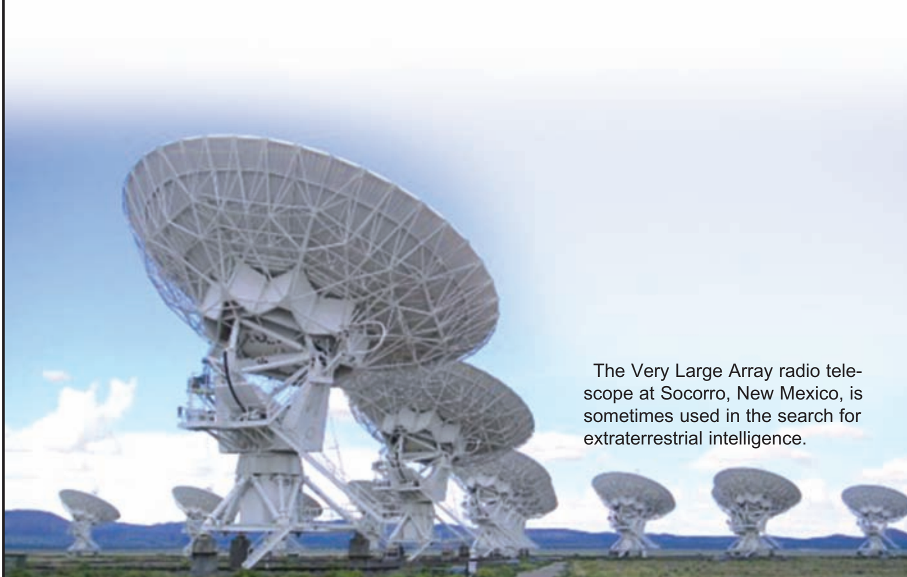
Then there are the hoaxes: candles flown on balloons, photos of flying garbage can covers, added to which are outright delusions.

There are also unexpected natural phenomena. We are far from knowing everything about the Universe. Unidentified flying objects are just that, *un*identified. It's a giant leap to identify one as an alien spacecraft with no further data.

Neither astrology or ufology are "sciences." Science deals with replication of data and with new data being able to falsify theories. Neither qualifies.

Real "Aliens"

UFOs must be divorced from the real search for extraterrestrial intelligence (SETI). Various SETI programs are designed to look for radio or other rational signals from civilizations that have evolved on planets belonging to other stars. The planets are there, more than two hundred found so far (though none yet like Earth). We don't expect to see their residents here. But maybe they are admiring their own constellations in their own darkened skies and wondering if there is anyone else out there thinking the same thing.



The Very Large Array radio telescope at Socorro, New Mexico, is sometimes used in the search for extraterrestrial intelligence.

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FOR GREATER UNDERSTANDING

Questions

1. In the modern age, why might astrology continue to appeal to so many despite its lack of scientific support?
2. What are some of the many objects that have been mistaken for UFOs over the years?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Culver, Roger B., and Philip A. Ianna. *Astrology: True or False?: A Scientific Evaluation*. Amherst: Prometheus Books, 1988.

Frazier, Kendrick, Barry Karr, and Joe Nickell, eds. *The UFO Invasion: The Roswell Incident, Alien Abductions, and Government Coverups*. Amherst: Prometheus Books, 1997.

Jerome, L. *Astrology Disproved*. Amherst: Prometheus Books, 1977.

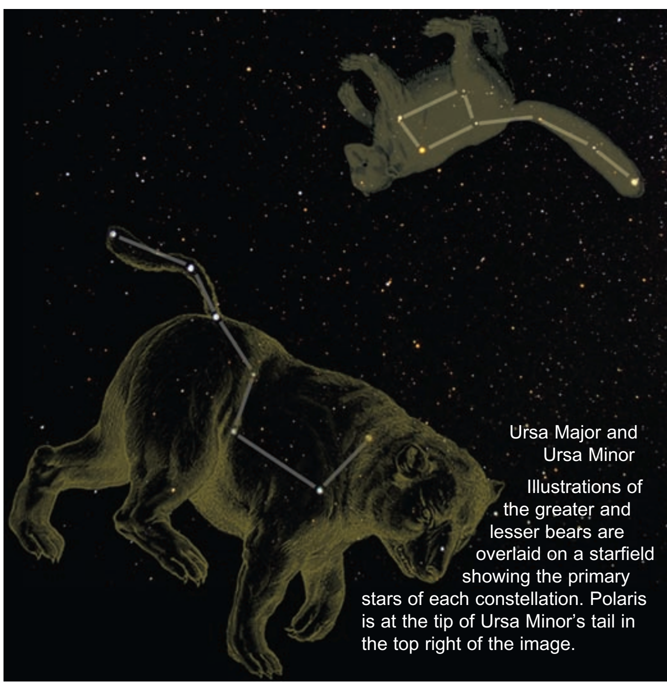
Lecture 11:
Mythical Magic

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

While astrology may be a system of magical beliefs, it should not have a hold on the word "magic," which in the context of the constellations uses a different meaning of the word, one that evokes not wizardry, but beauty and wonder. Though the patterns are not real, we are nevertheless enchanted by them, by the pictures they presented to the ancients and still do for us today. In a previous lecture we looked at the sacred constellations of zodiac. In this one we admire those figures that gang together into mythological storytelling groups. None of the tales is sacrosanct; there are numerous variations and crossovers.

Ursa Major

Ursa Major, the Great Bear, running across the zenith sky in mid-northern spring and summer, is perhaps the most beloved constellation in the sky, mostly as a result of its famed asterism, the seven-star Big Dipper (all but one star second magnitude). In one story, the Bear is the nymph Callisto transformed by Juno. Relax the imagination and you might see its snout, long tail, and three legs. But bears have short tails. Not after you've grabbed it to hurl the bear upward into the sky. Look at the second star in from the Dipper's handle, Mizar (Zeta UMa, "the groin"). Next to it is Alcor (80 UMa), the two making a close pair the Arabs called "the Horse and Rider."



Ursa Major and Ursa Minor

Illustrations of the greater and lesser bears are overlaid on a starfield showing the primary stars of each constellation. Polaris is at the tip of Ursa Minor's tail in the top right of the image.

The front two stars of the Dipper's bowl point nicely at Polaris, the Alpha star of *Ursa Minor*, the

Smaller Bear (Callisto's son), which consists mostly of the *Little* Dipper, whose dim handle curves in the other direction from that of the Big Dipper. Circumpolar from populated northern areas, the lesser bear is on display all year.

Following behind and to the south of Ursa Major is *Boötes*, the Herdsman, who in the sky drives not his oxen, but the bear. The kite-shaped figure is anchored by zero-magnitude Arcturus, "the bear driver," the luminary of all the stars of the northern sky. Rising on its side, Boötes signals the coming of spring.

Orion

With Ursa Major, *Orion* (the Hunter) is among the most recognizable of constellations. Straddling the celestial equator, the sparkling seven-star figure practically defines northern winter. His stories, which end badly, are complex. In one, he was mistakenly shot by Diana, sister to angry Apollo, while in another, he was killed by a scorpion, Scorpius, who was then put in the sky opposite the Hunter so that each would not see the other. Orion hosts two bright stars, zero-magnitude Rigel ("foot of al-jauza") and Betelgeuse, plus a brilliant three-star "belt" that the Arabs called the "string of pearls." In the center of his dangling sword is the famed Orion Nebula, a seat of star formation.

Down and to the left of Orion find *Canis Major*, the larger of Orion's two hunting dogs. Unmistakably marked by Sirius (the "Dog Star," the brightest star of the sky), the pattern really does look like a dog standing on its hind legs. Immediately to the left of Betelgeuse is *Canis Minor*, the Smaller Dog, which is made of just two stars, one of which is first magnitude Procyon (from Greek, "before the dog," its rising announcing that of Sirius). Procyon, Sirius, and Betelgeuse are linked by the prominent "Winter Triangle."

Just south of Orion is the distorted but pretty rectangle of stars that makes *Lepus*, the Hare, the Hunter's Prey.

Perseus and Andromeda

These two are the central figures in the sky's grandest myth. *Cassiopeia* (the Queen, her "W" across the pole from the Big Dipper), wife of *Cepheus* (the King, a dim pentagon northwest of Cassiopeia), bragged that her daughter *Andromeda* was lovelier than Juno and the sea nymphs. In a rage, Neptune ordered Andromeda chained to a rock at the coast to be devoured by ravaging *Cetus* (the Whale or Sea Monster). *Perseus*, coming back from slaying the Medusa on *Pegasus* (the Flying Horse) and seeing Andromeda's plight, descended to Earth and showed Cetus the Medusa's head, which turned the monster to stone, saving the young lady.

The "Great Square of Pegasus" rises as a large diamond. To the left it attaches to a lovely stream of Andromeda's stars that in turn runs into Perseus (southeast of Cassiopeia), which is noted for its own star-streams. Cetus, harder to find, straddles the equator south of Perseus, with Aries in between.

Andromeda is best known for the Andromeda Nebula, a nearby galaxy similar to ours. Two million light years away, it is the most distant thing a person can see with the naked eye. Perseus is famous for Algol ("the Demon"), which varies between second and dim-third magnitude over a period of 2.9 days as a result of two closely orbiting stars that eclipse each other. Cetus has equally well-known Mira ("the wonderful"), an unstable giant star that intrinsically varies in brightness from second or third magnitude to naked-eye invisibility.

The Ship

Over a vast amount of sky southeast of Orion and Canis Major floats *Argo*, the great sailing ship of the Argonauts, which Jason used to search for the golden fleece (Aries). While most of current Argo was visible to the ancients (and seen "floating" on the horizon), it has been slowly sinking out of sight as a result of precession. Bayer's view of it, in part from descriptions of southern hemisphere travellers, is highly distorted.

Argo is so monstrously large that in the eighteenth century, the Abbé Nicolas de Lacaille broke it into three parts: *Puppis* (the Poop), *Vela* (the Sails), and *Carina* (the Keel).

Puppis, the high stern, is rather easily seen wrapping around to the south and east of Canis Major. Vela, lower down to the southwest of Puppis, is more difficult, and requires a latitude below about 30 degrees north for full appreciation. At the bottom, stretching to 70 degrees south declination, lies Carina, most of the modern portion far out of sight for the ancients.

Greek letters were assigned to Argo as a whole. When the Ship was broken up, the letters were kept within the parts. Alpha and Beta are in Carina, whereas Gamma is in Vela.

Carina contains the second brightest star of the sky, minus-first magnitude Canopus (Alpha Carinae). Almost immediately south of Sirius, the star is visible only from far southern U.S. latitudes and lower. Eta Carinae (60 degrees south declination) may be the most massive star in the Galaxy. Now just barely visible to the naked eye, in 1846 it underwent a giant eruption to become the second brightest star, with Sirius, Canopus, and Eta all in a fine row.

Centaurus

Centaurus (the Centaur) and two of his group are also only partly seen from northern climes. The constellation, which consists of bright stars in no obvious pattern, lies directly south of Virgo's Spica. Centaurus is more readily identified with wise Chiron than is that other centaur, Sagittarius, and is variously said to have mentored Jason, Hercules, and Achilles, and even to have invented the constellations.

Between Centaurus and Scorpius lies the prominent long stellar loop of *Lupus*, the Wolf, far enough south to be underappreciated. *Ara* (the Altar), below the curve of Scorpius's tail, and the most southerly of all ancient constellations, is well out of sight for most northerners. Centaurus is sometimes depicted as sacrificing Lupus upon Ara.

Centaurus is famed for the closest star to the Earth, Rigil Kentaurus (the "foot of the Centaur"), better known as Alpha Centauri. The third brightest star in the sky, Alpha Cen lies a mere four light years away. It, first magnitude Beta Cen, and Crux (the Southern Cross) make an unforgettable sight as they glide across southern skies. Centaurus is also home to the greatest cluster in the Galaxy, which is bright enough to have received a Greek letter, Omega.

Ophiuchus

Directly north of Scorpius lies the dim, huge pentagon that makes *Ophiuchus*, the Serpent Bearer. And where there is a bearer, there must be a *Serpens*. Ophiuchus comes down to us from Asclepius, the physician of the Trojan wars, his snake-wrapped body still seen in medicine's symbol, the Caduceus.

Serpens divides in two parts, Serpens Caput (the Head) and Cauda (the tail), that are separated by Ophiuchus. The Greek lettering takes it as one constellation.

Ophiuchus crosses the ecliptic and appears to be part of the zodiac, but isn't. With the dozen of the zodiac and the above twenty-one, we are left with seventeen more or less "single" ancient constellations, some of which are among the most exquisite figures of the nighttime sky.

FOR GREATER UNDERSTANDING

Questions

1. Why is Ursa Major one of the most beloved constellations?
2. What myth of Perseus and Andromeda is played out in the night sky?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Allen, Richard H. *Star Names: Their Lore and Meaning*. Rev. ed. New York: Dover Publications, 1963.

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Raymo, Chet. *Three Hundred Sixty-Five Starry Nights: An Introduction to Astronomy for Every Night of the Year*. New York: Fireside, 1990.

Rey, H.A. *The Stars: A New Way to See Them*. New York: Houghton-Mifflin, 1980.

Websites to Visit

1. Constellation photos — http://www.astro.uiuc.edu/~kaler/sow/sowlist.html
2. Constellation lists and star maps — http://www.astro.uiuc.edu/~kaler/sow/const.html

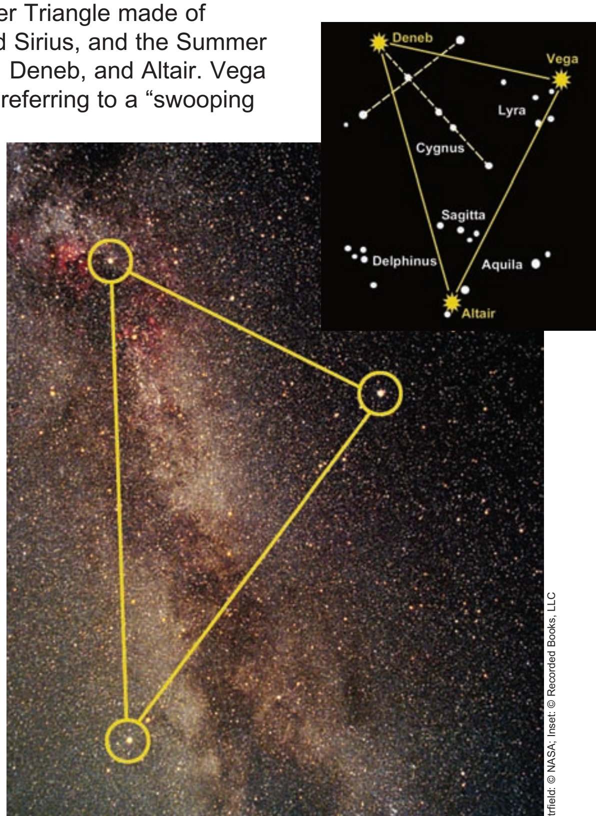
Lecture 12: Singular Sights

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

While many ancient constellations are arranged in storytelling groups, a good fraction are also single, that is, can stand alone. Yet even these have relationships with others such that they can be grouped in a variety of ways that include proximity, size, similarity, and mythology. Added to them are numerous popular asterisms that show how the stars can be seen differently by different eyes.

The Summer Triangle

Two of the sky's four triangles are formal constellations, while two more are giant asterisms: the Winter Triangle made of Betelgeuse, Procyon, and Sirius, and the Summer Triangle formed by Vega, Deneb, and Altair. Vega (descended from Arabic, referring to a "swooping eagle"), second brightest star of the northern hemisphere, lies at the northwestern corner of the Summer Triangle, and is the luminary of *Lyra*, Orpheus's Lyre or Harp, whose main body is an exquisite small parallelogram of fairly faint stars. Passing nearly overhead in mid-latitude summers, Lyra leads much larger *Cygnus* (the Swan) across the sky, its tail marked by first magnitude Deneb (Arabic for "tail"), which lies at the Triangle's northeastern apex. Turn Cygnus upside down and you get the Northern Cross, an asterism with Deneb now at its head.



A view of the Summer Triangle as it appears from North America and an inset showing Cygnus and other stars in the area.

The Summer Triangle's southern anchor is first magnitude Altair in *Aquila* (the Eagle). The star's name is another descendent of the Arabic phrase for a "swooping eagle," showing how badly corrupted such appellations can get when translated. Aquila is instantly recognizable by a pair of stars (Beta and Gamma Aquilae) flanking Altair that look like the great bird's outstretched wings.

Just to the northeast of Vega lies Epsilon Lyrae, which sharp eyes can see as double. A telescope shows each one to be double as well, making it the well-known "double-double star." Cygnus's head (the Northern Cross's foot) is marked by Albireo (a name of no meaning), a beautiful orange and blue telescopic double star. Deneb, one of the more luminous stars in the Galaxy, is one hundred times more distant than nearby Vega, which is only twenty-five light years away. The light you see from Deneb today left the star during the time of ancient Greece when our ancient constellations were first being written down.

The Crowns

The sky holds one King (Cepheus), one Queen (Cassiopeia), and two crowns that belong to neither of them. In the northern hemisphere immediately to the east of Boötes is a graceful semicircle of stars, *Corona Borealis*, the Northern Crown, the Crown of Ariadne (of "Theseus and the Minotaur" fame). Symmetrically in the southern hemisphere below Sagittarius is another, the more distorted half circle of *Corona Australis*, the Southern Crown that seems to belong to Sagittarius.

Two More Guys

Six giant strongmen stomp the sky: Orion, Ophiuchus, Perseus, Boötes, *Auriga* (the Charioteer), and the greatest hero of all, *Hercules*. (We might also add the warrior twins of Gemini.) Auriga lies north of Orion and Taurus's extended horns; indeed, it shares a star with the Bull. This lovely large pentagon holds Capella, the most northerly first magnitude star and third brightest in the northern hemisphere. Capella is a "she-goat," and Auriga is depicted as carrying her and her "kids" (a pretty triangle southwest of Capella), a neat trick for somebody driving a chariot. There is no relation to Capricornus.

Hercules, the hero of the twelve labors, falls north of Ophiuchus, right between Corona Borealis and Lyra. While none of his stars is very bright, the main part, which looks like two adjoining squares, is distinctive, the northern one called the "Keystone." Hercules is famed for its huge star cluster, which is just barely visible to the naked eye. Depicted upside down, the constellation descends from an earlier mysterious ancient figure called "the Kneeler." His brightest star, third magnitude Rasalhague ("the Kneeler's Head"), lies immediately northwest of the star that marks the Serpent Bearer's head, second magnitude Rasalgethi, the two giants seeming to share a confidence.

The Long

The human eye loves to discover patterns, and none jumps out more than strings of things, including those of stars, giving us a Dragon (Draco), a huge water-snake (Hydra), and a river (Eridanus).

Draco winds its way around the Little Dipper to the north of Boötes, its squarish head winding up just north of Hercules. Its alpha star Thuban (look between the end of the Big Dipper's handle and Polaris) was the pole star of ancient Egypt. Equally dangerous Hydra, the longest and largest constellation in the sky, begins just south of Cancer with a distinctive ring-like head, then winds way down past the celestial equator, ending just southeast of Spica. The fearful beast of Hercules' second labor, it's tough to see all in one piece.

More benign is the River Eridanus, which wends its wintery way from Rigel (Beta Eri, part of "Orion's Footstool") far to the west. It then drops to the most southerly first magnitude star, Achernar ("the end of the River"). Eridanus has been linked to a variety of streams as well as to the "River Ocean" that was believed to flow around the Earth. The part visible from classical lands ended at Theta Eridani, which was "Achernar" until southern explorers extended the river downward to the bright star that now occupies that exalted position.

And the Little

A collection of seven wonderful small constellations completes our tour of the ancient patterns. Even the largest of them ranks but thirty-ninth in size. They divide into animals and artifacts. Among the former are two more of the "wet quarter." Piscis Austrinus, the Southern Fish, into which Aquarius pours his water, is a sure sign of northern fall as first magnitude Fomalhaut (the "fish's mouth") crosses low above the southern horizon. Back in the northern hemisphere, Delphinus, the Dolphin, is tucked under Cygnus's eastern wing. It looks more like a tiny hand with a southwesterly pointing finger.

Just to the southeast of the Dolphin is the smallest of the ancient constellations, Equuleus, the Little Horse (or foal), which is quite dominated by its very large brother Pegasus to the northeast of it. Only the modern Southern Cross is smaller. Just barely bigger than Equuleus flies nearby Sagitta, the Arrow. Immediately northwest of Delphinus (it, Sagitta, and Equuleus all in a row), its name is no surprise. It even has feathers. It's been related to arrows shot by Apollo, Cupid, Hercules, and Sagittarius. If either of the latter two, they weren't very good shots.

Joining the other birds, Cygnus and Aquila, is spring's *Corvus*, the Crow or Raven, which is sacred to Apollo. It's made of a prominent box of stars that rides on Hydra's tail. As the front bowl stars of the Big Dipper point to Polaris, the top stars of Corvus point leftward to Spica in Virgo. Also on Hydra's back, just to the west of Corvus, is the dimmest of all the ancient forty-eight, Crater, the Cup, its brightest star but fourth magnitude. It does, however, really look like the ancient vessel after which it was named. It's been claimed by many, earliest perhaps by Apollo.

Finally, if it looks like a small isosceles triangle, it's probably the imaginatively named Triangulum. Viewed in northern autumn evening skies, it occupies a very nice but tiny space between triangular Aries and the lower curve of stars that makes Andromeda. It houses a nearby galaxy, the eponymous "Triangulum Spiral" that is barely visible to excellent eyes.

More Asterisms

Among the most charming patterns of the celestial sphere are the many asterisms that for a variety of reasons never became formal constellations. Many have already been mentioned: Ursa Minor's Little Dipper, Ursa Major's Big Dipper and Pointers, Cassiopeia's "W," Auriga's three Kids, Pegasus's Great Square, Leo's Sickle, Orion's Belt and Sword, Cygnus's Northern Cross, Sagittarius's Little Milk Dipper, Hercules' Keystone, and several others.

Like Orion, several constellations boast more than one asterism. Cassiopeia has her prominent "Chair," which, as further punishment by Neptune, rides her upside down over the pole. Sagittarius has his "Teapot," of which the Little Milk Dipper is the eastern part. Scorpius ends with a two-star "Stinger," while the stars that flank the Scorpion's heart, Antares, are "the Arteries."

The ancient Arabs gave us a number of indigenous asterisms, among them the feet of Ursa Major, which they called "the leaps of the gazelle," and the prominent triangle in Canis Major below Sirius known as "the virgins."

Among the grandest asterisms are those that are not parts of constellations, but cross over them, the best-known the Summer and Winter Triangles. Even larger is the "Great Diamond," made of Arcturus, Spica, Denebola (Beta Leonis, at Leo's tail), and Cor Caroli (in modern Canes Venatici, the Hunting Dogs). Through the Diamond, with a telescope we see into the great Virgo cluster of galaxies, these stars and their constellations thus giving us an entryway into the vastness of the Universe.

FOR GREATER UNDERSTANDING

Questions

1. For what is the Hercules constellation famed?
2. What constellation is a sure sign of northern fall?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

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Websites to Visit

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2. Constellation lists and star maps — http://www.astro.uiuc.edu/~kaler/sow/const.html

Lecture 13: Modern Design

The Suggested Reading for this lecture is James B. Kaler's *The Ever-Changing Sky.*

The Greeks and their predecessors left a lot of space on the celestial vault. A prime example is a huge blank area between Gemini-Auriga and the north pole; there are no classical constellations, and seemingly little to make one from. These and various other empty regions were the Greek's "unformed," their "*amorphotoi*," which were rather like blank canvases on which the gods could paint new pictures. The *amorphotoi* sometimes "belonged" to a neighboring constellation, sometimes not. Then there were the vast fields of the deep southern hemisphere that could not be seen from 35 degrees north, the latitude that bordered the ancient constellation-making cultures. The astronomical revolution fathered by Copernicus, new scientific curiosity, and exploration into the southern hemisphere asked that the sky be filled, that new constellations be created, especially if doing so could bring fame to the inventors. So for two centuries, between about 1600 and 1800 CE, fifteen hundred years after Ptolemy sealed the ancient constellations in the stone of his "Almagest," the new astronomers vied to create the "modern constellations." Some made it permanently to the sky; others are now either obscure asterisms or totally forgotten. By 1801, Johannes Bode had 110 constellations in his magnificent atlas (the *Uranographia*) of seventeen thousand stars. In 1922, the International Astronomical Union cut the list to the ancient fifty (including the separation of Argo) plus thirty-eight moderns. Rectangular boundaries were finally drawn for all eighty-eight in 1930. The role of the constellations today is to parcel out the sky rather like provinces of a country. They break the sky into smaller, recognizable areas, which gives us a convenient way of naming stars and other celestial objects such that everything has a home.

Signs of the Times

Constellations reflect the times, the mores, and the beliefs of those who created them. Ancient constellations honor heros, sacred and worldly myths, fertility symbols: Orion, Virgo, Taurus, Andromeda. The modern constellations reflect their inventors' own interests. They started with familiar animals in the early years (a crane, a swordfish) and ended in the artifacts of the beginnings of the industrial revolution (an air pump, a microscope). Were we to invent more today—and there is nothing to stop us but tradition—we might have celestial computers, running shoes, and cell phones, all to the amusement of future astronomers.

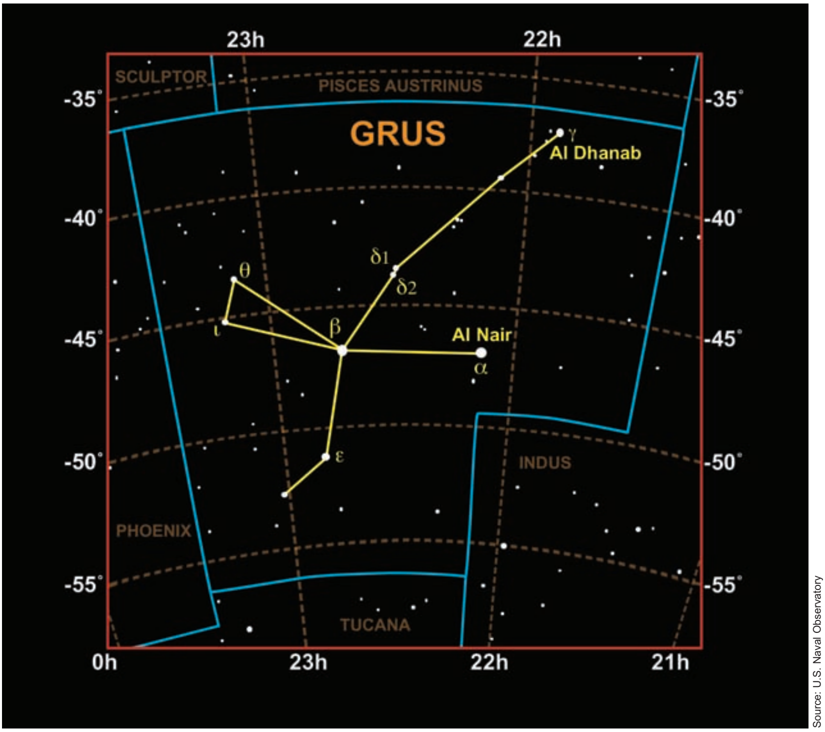
From the Past

Two of the "modern" constellations, *Coma Berenices* and *Crux* (the Southern Cross), descend to us from the ancient past. Coma Berenices is a beautiful, large, lacy star cluster that rides the northern sky south of the Big Dipper's handle, and in myth is the hair of the Egyptian Queen Berenice, who offered it in trust that her husband would return from battle. Ptolemy had it as part of Leo; it was not given singular status until 1551.

Though the stars of Crux were visible in the southern lands of ancient Greece, they were considered to be part of Centaurus. Precession has since sunk them from sight. But the allusion to Christianity was so powerful to the early explorers that it was finally made its own constellation.

The Big Empty

We can pretty closely divide the moderns into those of the north and those of the south. Oddly, the south came first, probably because there was so much there to be named. Of course, the native peoples of the southern hemisphere had already done some of that, but typically were ignored by the visitors from above the equator.



A chart showing the modern constellation Grus, surrounded by three other modern constellations. The star "Al Nair" refers to "the bright one" in Arabic, while "Al Dhanab" is "the tail."

The heroes of the south were a pair of Dutch explorers, Pieter Keyser and Frederick de Houtman, who sailed the southern hemisphere in 1595–96. Keyser skimmed the cream by cataloguing stars within twelve new bright, obvious constellations of his own invention. In 1598, the Dutch astronomer Petrus Plancius (1552–1622) inscribed them on his celestial globe, while inclusion in Bayer's great atlas of 1603 (the *Uranometria*) rendered them permanent.

The bright dozen surrounds the south celestial pole below 40 degrees south declination (within 50 degrees of the pole). Nine are common creatures, one is human, one is fanciful, and one inanimate. Imagine that you stand at 40 degrees south latitude on a late September midnight looking at the south celestial pole with the vernal equinox (in Pisces) at your back. High in the sky are two that can be seen from mid-northern latitudes, *Phoenix* (the mythical firebird) and *Grus* the Crane (which looks amazingly like its namesake).

From your position, the rest are circumpolar, or nearly so. Higher than the pole clockwise from east to west (left to right) are *Dorado* (the Swordfish), *Hydrus* (the Water Snake, south of Achernar), *Tucana* (the Toucan); over a bit to the west is *Indus* (the American Indian), then *Pavo* (the Peacock). Swinging below the pole now from right to left are *Apus* (the Bird of Paradise, very close to the pole), *Triangulum Australe* (the Southern Triangle, much larger than its northern counterpart, Triangulum), *Musca* (the Fly), *Chamaeleon* (obvious), and *Volans* (the Flying Fish). Of course all change position as the Earth turns.

That work left mostly fainter stars, what in the north would have been the Greek's "amorphotoi." They were addressed much later by the French astronomer Abbé Nicolas de Lacaille (1713–1762), who spent four years in South Africa charting southern skies. He had less to work with, but came up with another fourteen modern patterns that lie within and north of Keyser and de Houtman's. All but one are things that reflect the times.

Stand as above. Enclosing the south celestial pole is, appropriately, *Octans* (the Octant, an old navigational instrument). To the left of the pole is *Mensa* (the Table, referring to Table Mountain), farther left *Pictor* (the Easel, which lies just above bright Canopus). Higher up and to the left is *Caelum* (the Engraving Tool), while closer to the pole lies *Reticulum* (the Net). Higher still ticks *Horologium* (the Clock). A bit to the north of the zenith, and again overlapping what can be seen from the mid-northern hemisphere, are (from east to west) *Fornax* (the Furnace), *Sculptor* (the Sculptor's Studio, east of Fomalhaut in Piscis Austrinus), and *Microscopium* (the Microscope). Swinging under the pole to the right is circumpolar *Circinus* (the Compasses, south of Alpha Centauri), while farther to the right and not quite circumpolar are *Telescopium* and *Norma* (the draftsman's Square, just south of Scorpius). Not circumpolar from your location but soon to rise in the southeast are *Pyxis* (the Compass) and the ever-popular *Antlia* (the Air Pump). Pyxis is usually linked with the classical Argo trio of Puppis, Vela, and Carina.

The Unfilled North

The modern architect of the north was Johann Hevel (1611–1687), or Hevelius, whose seven eventually adopted constellations took on several of the Greek *amorphotoi*.

Four animals tread the fairly far north. Just south of Cepheus is a squiggle of stars named *Lacerta* (the Lizard). In the winter sky stretches long, nearly invisible *Lynx*, while riding the back of Leo is the Lion's smaller counterpart, *Leo Minor*. The best known of Hevelius's inventions is found just south of the Big Dipper's handle between it and Coma Berenices, *Canes Venatici*, the two-star Hunting Dogs that are sometimes linked to Boötes. A bit farther down, right under the head of Cygnus, Hevelius placed *Vulpecula*, the Fox.

Hevelius then extended his work to just below the celestial equator to create *Sextans* (the Sextant, just south of Regulus in Leo), and well-known *Scutum*, the Shield. A memorial to John Sobieski, King of Poland from 1674 to 1696, Scutum guards the sky within the Milky Way between Aquila and Sagittarius.

The Rest

Only three remain. Plantius himself came up with *Columba* (the Dove), a pretty triangle south of Lepus (which is south of Orion). At the very end of the tale, *Camelopardalis* (the Giraffe, between Perseus-Auriga and the pole) and *Monoceros* (the Unicorn, mostly within the Winter Triangle) are usually attributed to Jakob Bartsch (Bartchius), son-in-law to Johannes Kepler.

The Gratefully Dead

Many the invented, many the inventors, many the rejected, some thankfully. The best-known "goner" is probably *Antinoüs*, companion to the emperor Hadrian. Coming to us from the year 132 CE, he lies with the southern part of current Aquila. Though popular, the figure was not included in the final listing.

Hevelius, who successfully added constellations to the north, also came up with Triangulum Minor just south of classical Triangulum as well as a couple others that did not make it.

Attempts by other astronomers failed completely. The French astronomer Joseph Lalande (1732–1807) tried manfully, with Globus Aerostaticus (the Balloon) and of all things Felis, the Cat. His singular contribution is defunct Quadrans, the Quadrant, which completes the set of navigational instruments and still lives near the Big Dipper as the heart of January's Quadrantid meteor shower. Celestial monuments to Frederick the Great, Louis XIV, Stanislaw Poniatowsky (the last King of Poland), and Charles II (by none other than Edmund Halley) didn't do so well either.

In 1627, Julius Schiller dumped them all and put the Apostles into the Zodiac, New Testament figures in the northern hemisphere, and Old Testament in the southern, none of which survive. In the eighteenth century, the physician John Hill produced Bufo the Toad near Libra, as well as a plethora of others. Perhaps you can find your Uncle Frank or your classic car. Nobody else will use them, but you'll have fun trying, as almost certainly did the astronomers of long ago.

FOR GREATER UNDERSTANDING

Questions

1. What themes were embodied in the ancient and modern constellations?
2. What is the best known of Hevelius's inventions?

Suggested Reading

Kaler, James B. *The Ever-Changing Sky*. Cambridge: Cambridge University Press, 2002.

Other Books of Interest

Allen, Richard H. *Star Names: Their Lore and Meaning*. Rev. ed. New York: Dover Publications, 1963.

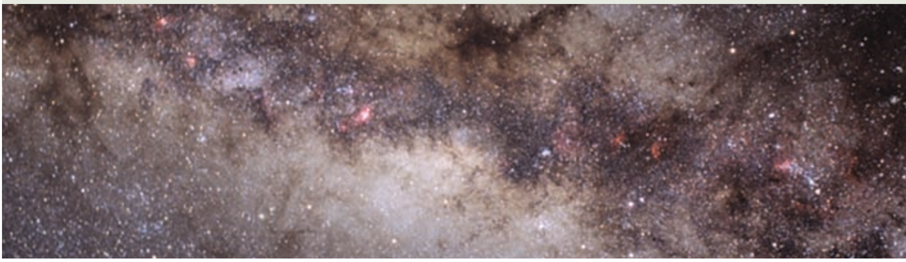
National Audubon Society Field Guide to the Night Sky. New York: Knopf, 1991.

Websites to Visit

1. Constellation photos — http://www.astro.uiuc.edu/~kaler/sow/sowlist.html
2. Constellation lists and star maps — http://www.astro.uiuc.edu/~kaler/sow/const.html

Lecture 14:
The Milky Way

The Suggested Reading for this lecture is James B. Kaler's *Stars.*



The Milky Way, a wide chaotic band of milky light some 20 degrees across, runs across the sky in a great circle, slicing the heavens in two. Not a constellation, it instead helps define the constellations, as to whether they are in it, near it, away from it, in the faint parts, the bright parts, the southern or northern parts. One of the great sights of nature, few now admire it because of city, even village, lights. But from a dark, moonless countryside, it brings a sense of profound wonder, its cascades, streams, tributaries of starry light flowing across the night sky making us feel at one with the beauty of the cosmos. On a northern fall or summer evening, one does not have to look for the Milky Way, it is simply THERE; like a forest or an ocean, there is no mistaking it. From the southern hemisphere, with the brightest part over our heads, it creates a silent natural celestial cathedral in which we might contemplate the very reason for existence.

Mythology

Is there a culture anywhere that does not have stories of the meaning of the Milky Circle? It has served the imagination and the soul as a river of life, the street of the gods, the pathway to heaven. Milton wrote of it, as did Longfellow and countless other poets who were moved by its near-mystical beauty.

Reality

In 1609, Galileo turned his telescope to the Milky Way and discovered its real nature, that it was made of stars, countless distant stars, bringing the seemingly eternal myths to an end. The more telescopic power you bring to bear, the more stars there are. Even the naked-eye stars flock strongly to the silver stream, showing that they too are part of the Milky Way.

Our Galaxy is a flat disk roughly 100,000 light years across. Since we are in the disk, we see its combined light around us as the Milky Way. Indeed, the very word "galaxy" is related to the Greek and Latin words for "milk." We are set off to one side, some 30,000 light years from the center. The Milky Way therefore varies considerably in brightness. When we look toward the Galaxy's center in Sagittarius, the Milky Way is broad and bright, whereas when we look in the other direction, toward the anticenter in Taurus-Auriga, we peer through the thinnest part of the disk, and the shining path is dimmer, even hard to follow.

The Milky Way's visibility is also affected by nearby clouds of interstellar gas and dust, the stars' birthplaces, which can block much, if not all, the background light, giving great structure to the celestial river. Some of the dark clouds, appearing as near-black splotches against the distant Galactic disk, are so obvious that the Incas made "dark constellations" out of them.

Orientation

The center line of the Milky Way, a great circle called the Galactic equator, divides the sky into northern and southern Galactic hemispheres. The perpendicular to the Galactic equator defines the Galactic poles, the northern pole in Coma Berenices, the southern one in the modern constellation Sculptor.

The spinning Earth and its orbit are not influenced by the Galaxy at large. As a result, the Galactic equator bears no physical relation to either the celestial equator or to the ecliptic. By chance, the Milky Way is tilted to the celestial equator through an angle of 63 degrees. As a result, the Galactic equator's most northerly reach lies at 63 degrees north declination, where it sits on Cassiopeia's Chair, while the most southerly, at 63 degrees south declination, lies almost within the Southern Cross.

There is, however, an odd coincidental relation in that the center of the Galaxy currently lies very close to the winter solstice, which makes the anticenter of the Galaxy close to the summer solstice. The Milky Way therefore runs nicely between the two points. The alignment is simply a result of our current moment within the precession cycle. The relation looked quite different three thousand years ago.

Floating the Stream

Cruise the Milky Way. Begin at the far north, our hostess Cassiopeia. Since the Milky Way is a complete circle, we can go in either direction, southwest toward Orion or southeast toward Cygnus and Sagittarius. The first heads off toward the anticenter and is a more peaceful stream, whereas the second looks more like a whitewater adventure. We'll take that one and save the more restful part of the river for later.

At first, we drift quietly through southern Cepheus, where there is less to see, compliments of the King's considerable interstellar dust. We pick up speed and sights as we drop through Cygnus, first running past great Deneb and the large North America Nebula (barely visible to the naked eye) right into the heart of the Swan itself, the great bird flying southward along with us. Here the stream breaks into two parts that are separated by a long dark island called "The Great Rift."

Taking the western branch, we float rather gently into northern Ophiuchus, where it rather abruptly stops. Working back upstream and around the point of the rift takes us to the main eastern channel down past Albireo then through Aquila, the Eagle, and into Scutum, where the Milky Way brightens to look much like the Shield of the constellation's name. Now the starry circle widens immensely into Sagittarius and Scorpius, where we cruise past the brightest and most beautiful parts, with clusters and bright and dark clouds seemingly everywhere, the shining path a full 30 degrees wide.

At this point we sail out of the sight of mid-northerners. Southern hemisphere residents have told us, though, of the glories yet to come. Here we follow the path down through Corona Australis, Ara, Norma, and Circinus. The stream then begins to flatten out as we enter Centaurus and head for the Southern Cross into one of the finer parts of the journey. To the southeast of Crux is a dramatic island, one of the few dark clouds with a common name, “The Coalsack,” which the Incas called “Yutu,” a partridge-like bird. Next to it lies the sparkling Jewel Box cluster.

Turning the bend, we head back north. Hailing Argo and the Argonauts, we pass through the star clouds of Carina and Vela—and pause to admire the bright Carina Nebula, a huge dusty gas cloud that surrounds what may be the most massive star in the Galaxy, Eta Carinae (and which in 1846 was the sky’s second brightest star).

Passing north through Puppis, the river calms some. We then quietly glide through Canis Major, where our way is lit by Sirius, the Milky Way next running faintly north to the east of Orion. The soft passage through southern Gemini and into the quiet waters of Taurus and Auriga follow, where the glowing river is faint and hard to see because of both the sparseness of the Galaxy’s disk and nearby star-forming dark clouds.

Almost done, the Milky Way picks up beautifully through the rapids and star streams of Perseus, after which we return to Cassiopeia, where the Queen welcomes us back home.

The Clouds of Magellan

In the deep southern hemisphere, far from the main path of the Milky Way, lie two fuzzy clouds named after the southern explorer Ferdinand Magellan and which look rather like pieces of the Milky Way that broke off and drifted away. The Magellanic Clouds, one large, the other small, lie respectively within Dorado and Tucana. The bigger is around 10 degrees across, the smaller about half that size. They bear a strong relation to the Milky Way in that they are nearby galaxies whose starlight blends into balls of light much as the Milky Way itself is the combined light of distant stars. The closest galaxies of any decent size, each with roughly one percent the number of stars in our own Galaxy, the Clouds lie about 170,000 light years away. These plus the Andromeda and Triangulum galaxies are the only ones that can be seen without the telescope.

Full Circle

As the Milky Way completes its full circle, so do we. Having started with the Galaxy and the Universe, we have returned to them through the magic of the constellations that the ancients set in the sky for us so long ago. They are our link to the past as well as to the future. When astronomers thousands of years from now, with vastly greater knowledge than we have, look out at the sky and see the same patterns that we love and cherish today, they might think of us, and then back to those who came before us, the past, present, and future all tied together through the paintings of the stars.

FOR GREATER UNDERSTANDING

Questions

1. Why has the Milky Way held such poetic interest?
2. What causes the Milky Way?

Suggested Reading

Kaler, James B. *Stars*. New York: Scientific American Library, W.H. Freeman, 1998.

Other Books of Interest

Allen, Richard H. *Star Names: Their Lore and Meaning*. Rev. ed. New York: Dover Publications, 1963.

Bok, Bart J., and Priscilla F. Bok. *The Milky Way*. 5th ed. Cambridge, MA: Harvard University Press, 1981.

National Audubon Society Field Guide to the Night Sky. New York: Knopf, 1991.

Websites to Visit

Starmatt Astrophotography by Matt BenDaniel — http://starmatt.com

THE TOP 22 BRIGHTEST STARS

LEGEND
- Rank
- Proper Name
- Greek Letter Name
- Distance (DIST) in light years
- Apparent Visual Magnitude (APP MAG) (combined for close double stars and binaries)
- Absolute Visual Magnitude (ABS MAG) (what the apparent visual magnitude would be at a distance of 32.6 light years), corrected for dimming by interstellar dust if necessary
- Meaning

RANK	PROPER NAME	GREEK LETTER NAME	DIST (Light Years)	APP MAG	ABS MAG	MEANING (In Arabic, if not otherwise noted)
1	Sirius	Alpha CMa	8.6	–1.46	1.43	Scorching (Greek)
2	Canopus	Alpha Car	313	–0.72	–5.63	Proper name (Greek)
3*	Rigil Kentaurus A	Alpha Cen A	4.36	–0.01	4.34	Centaur's foot
3*	Rigil Kentaurus B	Alpha Cen B	4.36	1.33	5.68	Centaur's foot
4	Arcturus	Alpha Boo	37	–0.04	–0.30	Bear Watcher (Greek)
5	Vega	Alpha Lyr	25	0.03	0.58	Swooping Eagle
6	Capella	Alpha Aur	42	0.08	–0.48	She goat (Latin)
7	Rigel	Beta Ori	775	0.12	–6.8	Foot of al-jauza
8	Procyon	Alpha CMi	11.4	0.34	2.62	Before the dog (Greek)
9	Achernar	Alpha Eri	144	0.46	–2.76	River's end
10	Hadar	Beta Cen	335	0.61	–4.44	Proper name
11	Betelgeuse	Alpha Ori	425	0.7	–4.9	Hand of al-jauza
12*	Acrux A	Alpha Cru A	320	1.33	–3.6	Alpha Cru (modern)
12*	Acrux B	Alpha Cru B	320	1.73	–3.2	Alpha Cru (modern)
13	Altair	Alpha Aql	16.8	0.77	2.21	Flying Eagle
14	Aldebaran	Alpha Tau	65	0.85	–0.65	The Follower
15	Antares	Alpha Sco	600	0.96	–5.9	Like Ares (Greek)
16	Spica	Alpha Vir	260	1.04	–3.49	Sheaf of Wheat (Latin)
17	Pollux	Beta Gem	34	1.14	1.07	Proper name (Latin)
18	Fomalhaut	Alpha PsA	25	1.16	1.73	Mouth of Southern Fish
19	Deneb	Alpha Cyg	2600	1.25	–8.0	Tail
20	Mimosa	Beta Cru	350	1.25	–3.9	Unknown meaning (Latin)
21	Regulus	Alpha Leo	78	1.35	–0.53	Little King (Latin)
22	Adhara	Epsilon CMa	430	1.50	–4.2	The Virgins

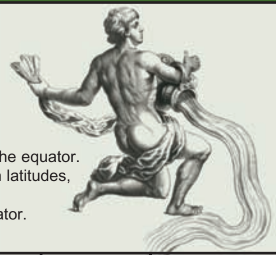
*Double stars. Alpha Cen combined magnitude –0.29; Alpha Cru combined magnitude 0.76.

TABLE OF CONSTELLATIONS

LEGEND

- The constellation name.
- The constellation's meaning (what it represents).
- The Latin possessive form.
- The three-letter abbreviation.
- The location (linked to its Constellation Map) as follows:

E: Equatorial–lying on the celestial equator.
EN: Equatorial North–lying between the celestial equator and 45 degrees north of the equator.
NP: North Polar–north of 45˚ north of the celestial equator; circumpolar for northern latitudes, not rising for far southern latitudes.
ES: Equatorial South–lying between the celestial equator and 45˚ south of the equator.



NAME	MEANING	POSSESSIVE	ABR	LOC
Andromeda	Chained Lady	Andromedae	And	EN-NP
Antlia	Air Pump	Antliae	Ant	ES
Apus	Bird of Paradise	Apodis	Aps	SP
Aquarius	Water Bearer	Aquarii	Aqr	ES
Aquila	Eagle	Aquilae	Aql	E
Ara	Altar	Arae	Ara	SP
Aries	Ram	Arietis	Ari	EN
Auriga	Charioteer	Aurigae	Aur	EN-NP
Bootes	Herdsman	Bootis	Boo	EN
Caelum	Engraving Tool	Caeli	Cae	ES*
Camelopardalis	Giraffe	Camelopardalis	Cam	NP
Cancer	Crab	Cancri	Cnc	EN
Canes Venatici	Hunting Dogs Dogs	Canum Venaticorum	CVn	EN-NP
Canis Major	Larger Dog	Canis Majoris	CMa	ES
Canis Minor	Smaller Dog	Canis Minoris	CMi	EN
Capricornus	Water Goat	Capricorni	Cap	ES
Carina	Keel	Carinae	Car	SP
Cassiopeia	Queen	Cassiopeiae	Cas	NP
Centaurus	Centaur	Centauri	Cen	ES-SP
Cepheus	King	Cephei	Cep	NP
Cetus	Whale/Sea Monster	Ceti	Cet	E
Chamaeleon	Chameleon	Chamaeleontis	Cha	SP
Circinus	Compasses	Circini	Cir	SP
Columba	Dove	Columbae	Col	ES
Coma Berenices	Berenices Hair	Comae Berenices	Com	EN
Corona Australis	Southern Crown	Coronae Australis	CrA	ES-SP
Corona Borealis	Northern Crown	Coronae Borealis	CrB	EN
Corvus	Crow, Raven	Corvi	Crv	ES
Crater	Cup	Crateris	Crt	ES
Crux	Southern Cross	Crucis	Cru	SP
Cygnus	Swan	Cygni	Cyg	EN-NP
Delphinus	Dolphin	Delphini	Del	EN
Dorado	Swordfish	Doradus	Dor	SP
Draco	Dragon	Draconis	Dra	NP
Equuleus	Little Horse	Equulei	Eql	EN
Eridanus	River	Eridani	Eri	ES-SP
Fornax	Furnace	Fornacis	For	ES

TABLE OF CONSTELLATIONS

LEGEND (continued)

SP: South Polar–south of 45˚ south of the celestial equator; circumpolar for southern latitudes, not rising for far northern latitudes.

Intermediate positions are indicated by combining location codes, a constellation lying across the circle 45˚ north of the celestial equator called EN-NP and so on.

Constellations not on the Constellation Maps are indicated by an asterisk (*); their positions are described in the text of the appropriate map.

- The Luminary, or brightest star by both proper and Greek letter name (or number). Many luminaries, especially those of southern constellations, have no proper name.
- Remarks. These include whether the constellation is modern, references to mythology, some asterisms, and what poles (celestial, ecliptic, galactic) the constellation may contain.

LUMINARY	REMARKS
Alpheratz=Alpha, Mirach=Beta	Perseus myth; Daughter of Cassiopeia and Cepheus; galaxy M 31
Alpha	Modern
Alpha	Modern
Sadalsuud=Beta	Zodiac; Water Jar; wet quarter
Altair=Alpha	Summer Triangle
Beta	Most southerly ancient
Hamal=Alpha	Zodiac
Capella=Alpha	Three “Kids”
Arcturus=Alpha	Brightest northern hemisphere star
Alpha	Modern
Beta	Modern
Al Tarf=Beta	Zodiac; Beehive Cluster
Cor Caroli=Alpha-2	Modern
Sirius=Alpha	Winter Triangle
Procyon=Alpha	Winter Triangle
Deneb Algedi=Delta	Zodiac; wet quarter
Canopus=Alpha	Argo
Shedar=Alpha	Perseus myth; Andromeda's mother
Rigil Kentaurus=Alpha	Hadar=Beta first mag.
Alderamin=Alpha	Perseus myth; Andromeda’s father
Deneb Kaitos=Beta	Perseus myth
Alpha	Modern
Alpha	Modern
Phact=Alpha	Modern
Beta	“Modern” but old; Coma Berenices Cluster; North Galactic Pole
Alfecca Meridiana=Alpha; Beta	Sagittarius’s Crown
Alphecca=Alpha	Ariadne's Crown
Gienah=Gamma	“Pointers” to Spica
Delta	Very faint
Acrux=Alpha	Modern; icon of southern hemisphere
Deneb=Alpha	Northern Cross, Summer Triangle
Rotanev=Beta	Wet quarter
Alpha	Modern; South Ecliptic Pole
Eltanin=Gamma	North Ecliptic Pole
Kitalpha=Alpha	Smallest ancient const.
Achernar=Alpha	Second longest
Alpha	Modern

TABLE OF CONSTELLATIONS

NAME	MEANING	POSSESSIVE	ABR	LOC
Gemini	Twins	Geminorum	Gem	EN
Grus	Crane	Gruis	Gru	ES-SP
Hercules	Hero; Hercules	Herculis	Her	EN
Horologium	Clock	Horologii	Hor	ES-SP*
Hydra	Water Serpent	Hydrae	Hya	E-ES
Hydrus	Water Snake	Hydri	Hyi	SP
Indus	Indian	Indi	Ind	SP
Lacerta	Lizard	Lacertae	Lac	EN-NP*
Leo	Lion	Leonis	Leo	EN
Leo Minor	Smaller Lion	Leonis Minoris	LMi	EN
Lepus	Hare	Leporis	Lep	ES
Libra	Scales	Librae	Lib	ES
Lupus	Wolf	Lupi	Lup	ES-SP
Lynx	Lynx	Lyncis	Lyn	EN-NP*
Lyra	Lyre	Lyrae	Lyr	EN
Mensa	Table	Mensae	Men	SP*
Microscopium	Microscope	Microscopii	Mic	ES*
Monoceros	Unicorn	Monocerotis	Mon	E*
Musca	Fly	Muscae	Mus	SP
Norma	Square	Normae	Nor	ES-SP*
Octans	Octant	Octantis	Oct	SP*
Ophiuchus	Serpent Bearer	Ophiuchi	Oph	E
Orion	Hunter; Orion	Orionis	Ori	E
Pavo	Peacock	Pavonis	Pav	SP
Pegasus	Winged Horse	Pegasi	Peg	EN
Perseus	Hero; Perseus	Persei	Per	EN-NP
Phoenix	Phoenix	Phoenicis	Phe	ES-SP
Pictor	Easel	Pictoris	Pic	SP
Pisces	Fishes	Piscium	Psc	E-EN
Piscis Austrinus	Southern Fish	Piscis Austrini	PsA	ES
Puppis	Stern	Puppis	Pup	ES-SP
Pyxis	Compass	Pyxidis	Pyx	ES
Reticulum	Net	Reticulii	Ret	SP
Sagitta	Arrow	Sagittae	Sge	NE
Sagittarius	Archer	Sagittarii	Sgr	ES
Scorpius	Scorpion	Scorpii	Sco	ES
Sculptor	Sculptor's Studio	Sculptoris	Scl	ES
Scutum	Shield	Scuti	Sct	ES
Serpens	Serpent	Serpentis	Ser	E
Sextans	Sextant	Sextantis	Sex	E
Taurus	Bull	Tauri	Tau	EN
Telescopium	Telescope	Telescopii	Tel	ES-SP
Triangulum	Triangle	Trianguli	Tri	EN
Triangulum Australe	Southern Triangle	Trianguli Australis	TrA	SP
Tucana	Toucan	Tucanae	Tuc	SP
Ursa Major	Greater Bear	Ursae Majoris	UMa	NP
Ursa Minor	Smaller Bear	Ursae Minoris	UMi	NP
Vela	Sails	Velorum	Vel	ES-SP
Virgo	Maiden	Virginis	Vir	E
Volans	Flying Fish	Volantis	Vol	SP*
Vulpecula	Fox	Vulpeculae	Vul	EN*

TABLE OF CONSTELLATIONS

LUMINARY	REMARKS
Pollux=Beta	Zodiac; Summer Solstice; cluster M 35
Al Nair=Alpha	Modern
Kornephoros=Beta	“The Kneeler”; cluster M 13
Alpha	Modern
Alphard=Alpha	Longest constellation
Beta	Modern
The Persian=Alpha	Modern
Alpha	Modern
Regulus=Alpha	Zodiac
Praecipua=46	Modern
Arneb=Alpha	Orion’s prey
Zubeneschamali=Beta	Zodiac
Alpha	Classic odd star Chi Lup
Alpha	Modern
Vega=Alpha	Summer Triangle
Alpha	Modern
Gamma	Modern
Beta	Modern
Alpha	Modern
Gamma-2	Modern
Nu	Modern; South Celestial Pole
Rasalhague=Alpha	With Serpens; on ecliptic; cluster M 10
Rigel=Beta	Winter Triangle
Peacock=Alpha	Modern
Enif=Epsilon	Perseus myth, Great Square; cluster M 15
Mirfak=Alpha	Perseus myth; rescuer of Andromeda; Double Cluster; Alpha Per Cluster
Ankaa=Alpha	Modern
Alpha	Modern
Kullat Nunu=Eta	Zodiac; Vernal Equinox; Circlet; wet quarter
Fomalhaut=Alpha	Wet quarter
Naos=Zeta	Argo
Alpha	Modern
Alpha	Modern
Gamma	Arrow of Hercules; of Cupid
Kaus Australis=Epsilon	Zodiac; Winter Solstice; Little Milk Dipper; Teapot; Galactic center
Antares=Alpha	Zodiac
Alpha	Modern; South Galactic Pole
Alpha	Modern
Unukalhai=Alpha	Two parts; with Ophiuchus
Alpha	Modern
Aldebaran= Alpha	Zodiac; Hyades; Pleiades; Galactic anticenter
Alpha	Modern
Beta	Galaxy M 33
Atria	Modern
Alpha	Modern
Alioth=Epsilon	Big Dipper/Plough; Ursa Major Cluster
Polaris=Alpha	Little Dipper; North Celestial Pole
Regor=Gamma	Argo
Spica=Alpha	Zodiac; Autumnal Equinox
Gamma	Modern
Anser=Alpha	Modern; Coathanger non-cluster

Suggested Readings:

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