Starlight Theatre - Astronomy Slide Set
- Descriptive Booklet -

What is the Celestial Sphere?

The stars are so far away that we can not perceive their distance. Therefore, they appear fixed to a dome representing the night sky. This is the Celestial Sphere. It seems to rotate above our head from the east to the west. The stars appear to be fixed to it and carried across the sky as it moves.

The Celestial Equator on the Celestial Sphere
Stars may be found on the celestial sphere using co-ordinates similar to those of longitude and latitude on the Earth. The Earth's north and south poles are projected upward making the north and south celestial poles. The Earth's equator is projected onto the celestial sphere to produce the celestial equator. Therefore, this is called the "equatorial co-ordinate system".

The Ecliptic on the Celestial Sphere
The Earth's north-south axis is tilted 23.5 degrees with respect to the Earth's orbital plane about the Sun. This plane is called the "ecliptic plane". Projecting this plane onto the celestial sphere produces a circular path called the "ecliptic". Since the Sun and most of the planets are close to the ecliptic plane, they are always found close to the ecliptic. As the Earth orbits the Sun, the Sun appears to move slowly eastward along the ecliptic.

The Celestial Sphere Co-ordinates
The co-ordinates for the equatorial co-ordinate system are called "right ascension" (R.A.) and "declination". Declination is measured north and south of the celestial equator. Right ascension is marked off from a starting point in the constellation Pisces and increases eastward (to the left) around the sky. However, instead of using degrees, right ascension uses "hours:minutes:seconds". For example, the co-ordinates of a star are written as R.A. 4 hours:00 minutes:0 seconds, Decl.+30 degrees.

What does the night sky look like?

The celestial sphere can be mapped in the same way as the Earth. The constellations are like "countries", the stars are like "cities" and remote deep sky objects are like "tourist sites". Carrying the analogy further, the planets are like trains that run on tracks across the sky. Each one travelling at its own speed. The "track" is the ecliptic.

Only half the sky can be seen at any one time. However as the Earth rotates, the stars appear to drift across our sky from the east to the west. Thus, over the year we can see most of the entire sky.

Star Map (No Annotation)
This slide shows the celestial sphere flattened into a map. The brightest stars are printed with large disks. The solid red line is the apparent yearly path of the Sun around the sky (the ecliptic). It is also the plane of the Earth's orbit if it was projected up onto the celestial sphere. The curved hazy band is the plane of the Milky Way (the plane of our galaxy).

The principal asterisms or star patterns for each season are highlighted with white lines.

Star Map (Names and Lines)
This map is based on the previous one. The faint horizontal lines are the lines of constant declination. The vertical ones are lines of right ascension (R.A.). The point where the ecliptic crosses the celestial equator from the south into the northern half of the sky (centre) is defined as R.A. 0 hours. This point is also called the "First Point of Aries". The wobbling of the Earth's rotational axis (a period of 25,600 years) is moving this point westward. It is now in the constellation Pisces. In about 500 years, it will move into Aquarius, hence the term "the coming Age of Aquarius".

The major constellations can be identified with this map. The set of constellations that lie along the ecliptic are called the zodiac.

Star Map (Visibility Bands)
The annotations above and below this map are used to determine what stars are visible at any time. The top band is used at midnight daylight saving time and is used typically for summer observing. The stars directly below the month, date of the observation are located on the observer's "meridian" at midnight. The meridian is the imaginary line drawn from the northern horizon over head to the southern horizon.
The lower band is used in the same way. However, it is set for use at 8 p.m. standard time. It is used in the autumn, winter and spring when the sky darkens earlier in the evening than in the summer.

North-western Sky in Spring
In late evening on March 1, the western sky has many bright stars. With the aid of a star map and guide books, we can learn the constellations and our way around the sky.

With these resources, can you find the constellations of Cassiopeia, Perseus and Auriga? The small star cluster called the Pleiades is in the lower left corner.

Western Horizon in Autumn (Annotated)
Looking towards the western horizon in autumn we see the stars of summer setting. This is how the sky looks at about 22:00 on November 1 from a dark rural sky. The main asterism of the summer sky is the Summer Triangle. The three stars of the Triangle are the brightest stars in the three constellations: Cygnus, Lyra and Aquila. A few other constellations are highlighted: Delphinus, Sagitta and Draco.

Western Horizon in Spring (Not Annotated)
In the early April evenings, the "stars of winter" are setting in the west. Bright stars are characteristic of the winter sky. Some of these stars are relatively near to us and others are very far away but extremely luminous.

The most recognisable constellation is Orion, the Hunter. He is lead across the sky by Taurus the Bull (the "V" formation of stars to the right). Following Orion are the Big and Little Dog (Canis Major and Canis Minor) marked by the bright stars to the left (Sirius) and to the upper left (Procyon) respectively. The void between them is the faint constellation of Monoceros (the Unicorn).

The Milky Way is not easily seen in the winter sky. It passes east (left) of Orion from the top centre of the slide, past Sirius to the lower left. In this direction, we are looking towards the faint outer rim of our galaxy.

The ruddy coloured star of Betelgeuse in the right shoulder of Orion is an enormous super red giant 425 light years away. The bright "white" star Sirius is a "blue" giant, only 8.5 light years away.
Orion's Sword

Faint treasures can be found in the sky. The three bright stars above the centre are the belt stars of Orion. Below his belt and in the scabbard in which he carries his sword is a faint glowing cloud of gas. This is the Great Orion Nebula. Nebulae are the birthplaces of stars. The gas is excited to glow by hot recently formed stars embedded in the nebula. Light from this object has taken 1,500 years to reach us! Another nebula is around the left most belt star.

South in Summer (Not Annotated)
The warm nights of summer have more than bugs to greet us as we star gaze from a dark location. Looking south during the late evenings, we see the centre of the Milky Way rising like steam across the sky from the south into the northeast.

The brightest star-like object is not part of the celestial sphere; it is Jupiter. As it orbits the Sun it moves eastward across the celestial sphere taking almost 12 years for one circuit.

South in Summer (Annotated)
Low in the south in summer, our view is dominated by the constellations Sagittarius and Scorpius. The brightest star in Scorpius is Antares.

Sagittarius is more easily distinguished by the asterism of the "tea pot" or kettle. The Milky Way appears as steam rising from its spout.

Magnitude Scale
Astronomers refer to the brightness of stars and planets by a term called "magnitude". The magnitude "scale" is logarithmic. A change in brightness of 100X corresponds to a difference of 5 magnitudes. In other words, a one-magnitude difference corresponds to a brightness difference of 1001/5 or 2.512.
This slide shows the magnitudes of a number of important celestial objects. The scale was conceived by the ancient Greek astronomer Hipparchus. In his catalogue of stars, he grouped stars into five ranks of brightness. The brightest stars were of the "first rank" and the faintest had a "rank of five". So, faint stars had a high "numerical magnitude".

In the 1800's astronomers recognised that five magnitudes equalled a factor of about 100X in brightness. So, they quantified the scale based on the star Polaris (the North Star) as magnitude 2. They calculated the magnitudes of the other stars based on this logarithmic scale.

Why does the sky change?

Only occasionally do most people look at the sky. Their lasting impression is a star-filled sky without form. Only after studying the sky and identifying its asterisms and constellations does it become familiar. Regular observations show that the celestial sphere slowly shifts towards the west. After a month, this motion becomes obvious. We will better appreciate our planet and our place in the solar system by observing and understanding this motion.

Culmination of Celestial Objects
As the Earth rotates, the celestial sphere appears to rotate above us. This carries the stars each night from the east to the west. Since the celestial sphere is a curved surface, the stars follow an arc as they are drawn across our sky. They reach their highest point above the horizon when they cross the "local meridian". This is an imaginary line between the northern horizon, through a point directly overhead called the zenith and down to the southern horizon.

Superimposed on this daily or "diurnal" rotation is a general annual motion caused by the Earth's orbit about the Sun.

Daily Motion of the Sun
The daily path of the Sun across the sky is not always the same. In the winter, it is low in the south. The path above the horizon is also relatively short resulting in short days and hence the winter nights are long. In the summer, the Sun at midday is high in the sky. It follows a long path from the north-east almost overhead and down to the north-west. The long path results in the long summer days and short nights. The high elevation of the Sun causes warm summers as the Sun shines more directly to the ground in summer than in winter.

In spring and autumn and specifically on the equinoxes (date of equal day and night), the Sun rises due east and sets due west and it crosses our meridian between the winter and summer extremes.
Source of the Seasons

The seasons are caused by the tilt of the Earth's axis of rotation. As the Earth orbits the Sun, its axis does not rotate with the orbit. It continues to point in the same direction. In summer, the axis is tilted toward the Sun so it appears high in our sky. In winter, the axis tilts away from the Sun so it then appears low in our sky. In spring and autumn, the noon time Sun shines down on our equator and appears halfway up our sky.

Each season is determined by where the Sun appears to be on the celestial sphere. When it is highest in the sky, summer is said to "begin" in the northern hemisphere. Autumn begins when the Sun crosses the celestial equator from the north into the southern hemisphere. Winter starts when the Sun is lowest in the sky.

In the southern hemisphere (Australia), our winter corresponds to their summer because the Sun then appears high in THEIR sky.

Finally, spring in the northern hemisphere begins as the Sun appears to cross the celestial equator on its northern journey around the ecliptic.

The Earth's orbital path is an ellipse with the Sun at one "foci". The second foci of the ellipse is said to be empty. This elliptical path carries the Earth close to the Sun called "perihelion" and far from the Sun called "aphelion"

Because of the Earth's elliptical orbit, each season has a different length. Summer in the northern hemisphere is the longest season and winter is the shortest. This is caused by the varying speed of the Earth in its orbit around the Sun.

During summer in the northern hemisphere, the Earth is farthest from the Sun so, the force of gravity from the Sun pulls less on the Earth. This causes the Earth to move more slowing around the Sun and extends the length of the season. During winter in the northern hemisphere, the Earth is closest to the Sun and the Sun's gravitational pull is stronger, so winter is the shortest season.

Stars of the Seasons
We often hear about the "summer sky" and the "winter sky". Stars are associated with seasons because of their location in the sky at different times of the year. These constellations are better placed for observation in the evening sky of a particular season.

Diurnal Motion of the Earth
Although the celestial sphere appears to rotate above us, it is the Earth that moves. If viewed from above the north pole of the Sun, the Earth would appear to rotate counter clockwise. This is the definition of a "north pole". When viewed from above the north pole, a planet, a star or a galaxy appears to rotate counter clockwise.

Therefore as the Earth rotates, the Sun will appear to rise in the east, cross the sky from east to west then set below the western horizon. As the Earth continues to rotate, the stars seem follow the Sun across the sky.

A "tropical year" is 365.24 days long. Every day, the Earth moves one part in 365.24 of a circle counter clockwise around the Sun. Therefore, every night the Earth is about 1 degree further around the Sun. This causes the stars to appear about one degree further west at the same time each night. In other words, the stars will appear to rise about four minutes earlier than the previous night.

What are Other Consequences of Planetary Motions?

Motions of the Earth and Moon result in several interesting phenomena. These have made astronomy a major science from antiquity to the present.

Source of the Phases of the Moon
The Moon goes through a progression of "phases" over a four week period. The phases are caused by the changing illumination of Moon. This is caused by the near-monthly change in the angle between the Moon-Earth-Sun.

The Moon's phases begin as a thin crescent in the west after sunset and then grows or "waxes" into full moon and from full moon it shrinks or "wanes" to thin crescent visible in the east before sunrise.
The Moon orbits the Earth in 27.3 days. This is called the sidereal period of the Moon (period with respect to the stars). However, it is not the time between successive full moons! As the Earth orbits the Sun, it carries the Moon along with it. During one orbit of the Moon, the Earth will carry it about 1/12 of a circle around the Sun. Therefore, the time between full Moons is longer than the sidereal period by about 2.2 days. This is the "synodic period" or synodic month. The synodic month is longer than the sidereal month (29.5 days) because the Moon has to "catch up" to align with the Sun and Earth.

The moon's orbit is independent of the Earth's orbit and slightly inclined by 5.15 degrees to the plane of the Earth's orbit (the ecliptic). Since the Moon can be found over five degrees on either side of the ecliptic, at times it can be seen very low in the south during summer or high overhead in winter.

Thin Crescent Phase
A few days after the Moon passes between the Earth and Sun, it appears above our western horizon as a thin crescent. Through binoculars we can easily see some of the surface features and following them helps us understand the phenomena of the Moon's phases.

Approaching First Quarter
The Sun shines from the right. The increase in illumination helps us see large scale features on the Moon's surface especially when viewed with binoculars.

First Quarter
The Moon is in the first quarter phase when it is due south as Sun sets. It is also called a "half Moon". Surface relief is seen along the sunrise line or "terminator" because the light shines at a low angle to the surface and the shadows exaggerate vertical relief.

Approaching Full Moon
When the Moon is almost opposite the Sun in the sky we see most of the full face illuminated. In this slide, it appears that the Sun is shining over our right shoulder.
Few shadows are visible. The markings we see on the Moon's surface are caused by the varying reflectivity of the lunar surface.

After Full Moon
Here the Sun appears to shine from over our left shoulder. The larger features will be labelled on slide #58 in this set.

Fourth Quarter.
Here the Moon is illuminated by the Sun from the left side. The "last" or "fourth quarter" Moon rises at approximately midnight and crosses the local meridian at sunrise.

Waning Crescent
The waning crescent is visible low in the east before sunrise. Only a small portion of the surface is illuminated so features are difficult to identify. Also, the large region called Oceanus Procellarum dominates this portion of the Moon. Some impact craters are visible and their bright rays of ejected material extend across the surrounding plane.

The Phases of the Moon
The progression of the lunar phases gives us a changing view of our closest celestial neighbour.

Elongation of the Terrestrial Planets
The orbital speed of all the planets depends on their distance from the Sun. The Sun's gravity is felt more strongly by the closer planets making them move faster in their orbit. This produces a constantly changing pattern of bright planets in our sky.

The planets inside the Earth's orbit (Mercury and Venus) are called "inferior planets" and can never be seen far from the Sun. The angle between the Sun-Earth-planet is called the elongation angle.
Mercury is closest to the Sun and has the smallest elongation angle. Its orbital path is also quite elliptical so its angle of maximum elongation can vary between 18 and 28 degrees. Although Mercury is very bright, it is difficult to see in the twilight after sunset and before sunrise because it orbits so close to the Sun.

Venus is further from the Sun with a more circular orbit so its maximum elongation is always about 47 degrees. It is also very bright and easily visible above the horizon in the twilight sky.

Mars is a "superior planet" orbiting beyond the Earth. Unlike the inferior planets, it may be seen at midnight, as can all the planets in the outer part of the solar system.

Constellations of the Zodiac
Projecting the plane of the Earth's orbit out onto the celestial sphere produces a line around the sky where they intersect. This is called the ecliptic and the constellations that lie on the ecliptic are called the zodiac. We must wait for the Earth to orbit about the Sun to see all the stars near the ecliptic.

Error in Lunar Calendar
Some cultures use the phases of the Moon as a basis for a calendar. It was convenient because the Moon is an easily observed celestial object that is visible over a wide area. However, such calendars require constant revision because the time the Moon takes to orbit the Earth does not divide evenly into the time the Earth takes to orbit the Sun. Every three years, a lunar calendar must be corrected by one month to stay synchronized with the "tropical year".

A tropical year, the time the earth orbits the Sun, is important to all agrarian cultures.

Graph of Equation of Time
The Sun has been used since antiquity to measure the passage of time. However, we find that a sun-based timepiece (a sundial) is not precise enough for our society. The correction to the time displayed by a sundial is called the "equation of time".

The operation of a sundial is based on two assumptions: The time between noon on one day to the next is constant throughout the year and the motion of the Sun around the celestial sphere is constant. They are not.

The path of the Sun around our sky mirrors the orbit of our Earth around the Sun. The orbit of the Earth is elliptical, thus its speed around the Sun varies from perihelion (fast) to aphelion (slow). Also, the apparent daily motion of the Sun around the celestial sphere varies because the ecliptic plane is tilted with respect to the Earth's equatorial plane. (See the wavy ecliptic line on slides #4 to #6).

In summer and winter, the Sun moves eastward about 1 degree per day. In autumn and spring, the motion is at an angle to the equator. Thus, the daily eastward motion of the Sun around the sky is slower in spring and autumn than in summer and winter. These are all predictable and modern sundials are designed to correct for these variations.

The Analemma
The equation of time can be plotted in a figure resembling a slightly distorted "figure 8". This figure is usually printed on globes of the Earth in the area of the Pacific Ocean because there are few landmasses to be obscured.

This figure is called the "analemma". Knowing the date, it gives the correction to convert "sundial time" to local time.

Aberration of Star Light
Does the Earth really move? In the 18th century, the British astronomer James Bradley measured a periodic shift in the position of stars. It is a very small shift (one part in about 63,000)! He correctly attributed it to the Earth's orbital motion.

This effect is similar to that of driving a car during a snowfall. The motion of the car makes the falling snow appear to come from the direction of the car's motion. In the case of the star light, the shift is very slight because the speed of light (300,000 km/sec) is much greater than the speed of the Earth about the Sun (30 km/sec).

Definition of Parallax
The distance to the closest stars can be determined by measuring their apparent displacement with respect to more distant stars as the Earth orbits the Sun. This is parallax and the amount of displacement is the parallax angle.

We determine the distance to nearby terrestrial objects subconsciously in a similar way. However, the great distance of celestial objects results in a very small parallax angle. Astronomical parallax uses a baseline of the radius of the Earth's orbit (about 150 million km)! Even with this large distance, the closest stars have a parallax of less than 1 arc second or 1/3,600 of a degree! This is the diameter of a "loonie" at 5.4 km.

When the parallax of an object is equal to one arc second, the distance is defined as a "parallax-second" or "parsec". Astronomers prefer to state the distance of an object in terms of parsecs because; the parsec is the most basic measure of interstellar distance.

What causes Eclipses?

The most astounding phenomena in the sky are a solar eclipse and its lesser spectacle: a lunar eclipse. These relatively rare though predictable events have affected our history and attract amateur astronomers from around the world to remote observing sites.

If the Moon orbits precisely between the Sun and the Earth, it progressively covers the Sun's disk. These are called the "partial phases". Since the Sun's surface is still visible, viewing the partial phases will cause permanent blindness unless proper solar filters are used.

It is fortuitous that the ratio of the Earth-Sun distance to the Sun's diameter and the ratio of the Earth-Moon distance to the Moon's diameter are the same (about 400). Thus, both bodies appear to be about 1/2 degree across in the sky. The Moon can just cover the brilliant surface of the Sun. The short period of time when the Moon obscures the Sun it is called "totality". The "length" of an eclipse is the duration of "totality". It is never longer than about 7 minutes. However, many observers will still travel half way around the world to view a totality of less than one minute!

The orbits of the Moon and Earth are ellipses. When the Earth is farthest from the Sun (aphelion) and the Moon is closest to the Earth (perigee) the Moon will appear about 10% larger than the Sun in the sky. This produces a long eclipse (about 7 minutes). When the Earth is at perihelion and the Moon is at apogee, the moon will appear too small to cover the Sun and we will see the Sun as a brilliant ring. This is an "annular eclipse".

The duration of "totality" also depends on the time of day when the eclipse occurs. At mid-day, the rotation of the Earth helps the observer "keep up" with the Moon's shadow as it sweeps eastward across the Earth. Early morning or late evening eclipses tend to be shorter.

Earth and Moon shadows
During its orbit around the Earth, the tilt of the Moon's orbit carries it above and below the ecliptic plane. Only on relatively rare occasions will the Sun, Earth and Moon be precisely aligned. When this happens either the Moon will orbit through the Earth's shadow or it will pass in front of the Sun. At these rare times an eclipse occurs.

Solar and Lunar Eclipses
A solar eclipse is caused by the relatively rare circumstance when the Moon crosses the ecliptic as it passes between the Sun and Earth such that its shadow is cast on the Earth. Because the Moon is between the Earth and the Sun, a solar eclipse can only occur during the day of a "new moon".

When the shadow of the Moon is cast onto the Earth, it travels along a very narrow path across the Earth. So, observers must travel to the path to be under the shadow at the right time.

The narrow path of a total solar eclipse is a curve across the Earth. The curve is produced by the combined motions of the diurnal rotation of the Earth, the orbit of the Moon and the orbit of the Earth around the Sun.

About two weeks before and after a solar eclipse, the Moon may pass through the Earth's shadow resulting in a lunar eclipse. A lunar eclipse is visible from anywhere the Moon can be seen during the eclipse. It occurs at night because the Moon is opposite the Sun in the Earth's sky.

Diamond Ring
In a solar eclipse, during the last moments before the Sun's photosphere is completely covered or the "total phase" begins, the Sun shines through low areas on the Moon's limb producing a "diamond ring".
As the Moon drifts off the Sun's disk, a second diamond ring occurs. Between diamond rings (during totality), the eclipse is safe to observe without filters. However, viewing must end before the second diamond ring or eye damage will result.

Total Solar Eclipse - Outer Corona
During "totality", the disk of the Moon covers the blinding light of the Sun's surface. This reveals the very tenuous atmosphere of the Sun called the "corona". Although the temperature of the corona can be over 2

million degrees, the total light is equivalent to only a full Moon and is safe to look at even with unfiltered binoculars!

The streamers radiating from the Sun are caused by gases escaping from its surface and are directed by its magnetic field. Every eclipse looks different because the magnetic field is always changing.

Total Solar Eclipse - Inner Corona
Most of the light from a totally eclipsed Sun comes from the inner corona. The Sun's atmosphere is most dense near the surface so it appears brighter than the outer corona.

There may be as many as 5 solar eclipses somewhere on the Earth in any one year. However, it is very rare for the "moon's shadow" to touch one place in the Earth more than once every thousand years. So, they seem rare unless you can travel to the eclipse path.

Lunar Eclipse
There are fewer lunar eclipses in a year than solar eclipses. Some years there are none, other years there may be three. However, there are more opportunities to view a lunar eclipse. Since they must occur when the Moon is full phase and opposite the Sun in the sky (at night) anyone on the night-time hemisphere of the Earth who can see the Moon will be able to view the lunar eclipse. Therefore, we can see lunar eclipses more often than the solar variety.

The Earth is about four times larger than the Moon (12,756 km compared to 3,476 km). Projecting out to the Moon, the Earth's shadow tapers down with an angle of 1/2 degree to about 9,500 km at the distance of the Moon. Therefore, the Earth's shadow appears to be about three times the diameter of the Moon's disk.

An interesting project is to photograph a lunar eclipse. Make a print of the picture then cut a disk of paper to match the curvature of the edge of the Earth's shadow. By comparing this with the diameter of the Moon, the diameter of the Earth can be inferred.

Total lunar eclipses last several hours. There are two phases in a lunar eclipse: a penumbra phase and an umbra phase. The "penumbra phase" is similar to the partial phase of a solar eclipse. During this period, an observer on the Moon would see the Sun partially covered by the Earth. Therefore, the Moon's surface will still be illuminated by the uncovered portion of the Sun. During a penumbra eclipse, the Moon appears only slightly fainter than a full moon.

During the "umbra phase", an observer on the Moon would see the Earth completely covering the Sun. However, some sunlight will refract and scatter through the Earth's atmosphere. This light will bathe the lunar surface in a reddish colour. The absence of blue light is a result of the shorter wavelength light being absorbed by the Earth's atmosphere.

On the right of the slide, the penumbra is illuminating the Moon. The umbra is progressively dark to the left and towards the centre of the Earth's shadow.

How do telescopes work?

Astronomers need tools to gather much more light than our eyes and to feed this light into sensitive instruments. The principal tool is the telescope. Understanding how they work draws on our understanding of reflective and refractive optics. But first we will start with our eye.

Structure of the Human Eye
The way we view the stars is determined by the structure of our eye and how it works. Our eyes adapt to the darkness in two ways and this allows us to see better in the dark.

First, our iris opens letting in more light. Second, the amount of "photo-chemical" that detects the light in our detector cells increases at low light levels. After shielding our eyes from light, the build up of this chemical in the cells of the retina takes 10 to 30 minutes to occur.

There are two types of "photo-detectors" in the retina: cones and rods. The cones work in daylight and can distinguish colours. They are also located in the centre of our vision and give us our visual acuity. The rods are in the periphery, and are very sensitive to light. So in the dark when the cones cannot detect light, the rods allow us to see. However, they cannot distinguish colour and they produce a rather "grainy" image.

Astronomers use red lights to see at night. This is because although the cones detect the red illumination, rods are blind to it. So, we can see obstacles with our cones if they are illuminated by the red light but we will retain our dark adaptation of our rods. When the light is turned off, we are still dark-adapted.

How a Simple Lens Works
A simple lens is a single piece of glass. Its two sides have been ground and polished into convex curves. As light passes through the lens, its path is bent and focused to a point. Blue light bends or "refracts" more than red light.

The two faces of the glass are not parallel and this causes the light to be separated into its colours, preventing all the colours from focusing at the same point. This is called "chromatic aberration".

An Achromatic Lens
An achromatic lens has two elements made from different types of glass. Each element causes colour distortions but of the opposite sense. Thus, the total colour aberrations are minimised.
These lenses are found in all binoculars and most inexpensive refracting telescopes.

Telescopes
There are two basic types of telescope: the refracting and the reflecting telescopes. The light path for both these instruments are shown.

Both require an "eyepiece" to change the diverging cone of light into a bundle of parallel rays. This allows our eye to more easily focus the light onto our retina.

Schmidt-Cassigrain Telescope
One of the most popular designs of amateur telescopes combines a thin lens and a mirror. The result is a very short telescope with an effective focal length that is about 4-times the length of the telescope's tube. The primary mirror has a spherical curve in its front surface. The corrector plate bends the incoming light slightly to ensure all the light converges at a point after reflecting off the large primary and smaller secondary mirrors without any colour distortions. This design produces relatively high magnification with very little distortion in a short portable telescope.

What can we learn from star light?
We have only journeyed to the Moon. And we only have samples of rock from the Moon and Mars. How have we learned so much about the Universe without visiting or touching or handling its pieces?
Most of what we know about the planets, stars and galaxies has been carefully culled out of the faint light that reaches us from far away places. Encoded in this light is information about what emitted it, how it was emitted, the characteristics of the emitter and the medium through which it has travelled.

The study of starlight has been one of the most important fields of science within astronomy.

Visible Spectrum
Light is composed of waves of electric and magnetic fields that are coupled together. They are characterized by their wavelength. The brightness of the light is a measure of the number of electro-magnetic waves reflected or emitted by a surface.

Different wavelengths correspond to different colours. Therefore, if we can separate the light into its component wavelengths we will see a band ranging in colour from blue (short wavelengths) to red (long wavelengths). This is called a "spectrum".

Blue light has a wavelength of about 0.35 microns (millionths of a meter) and red light is about 0.7 microns. Green light is about 0.5 microns.

Thermal Emission of a Surface
Light is emitted by the acceleration of charged particles. The more energetic the acceleration, the higher the energy carried by the light and the shorter its wavelength.

One way of accelerating charged particles is to heat a surface. As the atoms on the surface vibrate they emit light. The hotter the surface, the more energetic the light they emit. Therefore, we can determine the temperature of the surface by the energy or wavelength of the light. The shorter the wavelength of light, the more rapidly the atoms vibrate and the hotter the surface.

Colour versus Temperature of Source
The brightness and colour of the glowing surface is determined by its temperature. As a body is heated, the atoms and molecules on the surface vibrate more vigorously and in doing so, they emit shorter electromagnetic waves. If it is heated to a high enough temperature, this emission will cause the surface to glow more brightly and its colour will shift from red to white. This should not be confused with a coloured surface that is reflecting ambient light. The colour a surface is painted has little effect on its emitted light. The shift in colour is caused by the shift in peak wavelength from red to blue (Wien's Law on slide #47). A very hot surface does not look "blue" because the emitted light is composed of all colours from red to blue which at high temperatures approximates white.

Electromagnetic Window
Light carries information about how it was produced. High energy processes produce short wavelength radiation and low temperature processes emit long wavelength radiation. Therefore, to study a range of processes requires astronomers to observe a range of wavelengths. Unfortunately, our atmosphere is not transparent to all wavelengths.

The most prominent range is the "visual wavelength". This is the range in which our Sun emits most of its radiation. Long radio waves also pass relatively unimpeded through our atmosphere. However, most other wavelengths are filtered to some extent by the atoms and molecules in our atmosphere. To view these has required the development of satellites to observe from space.

The Earth's Atmosphere
The Earth's atmosphere protects us from the hazards of interplanetary space. The density of our atmosphere increases close to the surface. At an altitude of about 100 km, the density is high enough to stop most meteoroids and charged particles. This elevation is also the lower limit for aurora.
The ozone layer absorbs ultraviolet light from our Sun. By absorbing this energy, it heats the atmosphere at this altitude creating the "thermopause".

What is the Solar System?

Astronomy has been an important part of human history. Astronomical data have been found dating back to the beginning of recorded history and has affected all cultures around the world. However, much of astronomy after the creation of useful star maps involved following the planets around the sky. Their positions were referenced to the stars. Only in this century has our attention been re-focused on the stars.

History of Astronomy
Against the background of stars on the celestial sphere, astronomers followed the planets referencing their positions to the stars. Therefore, astronomy up to the invention of the telescope around 1600 AD was centred on the planets.

Advances in astronomy accelerated at the beginning of 1600 with the development of the telescope. With these new instruments, the planets were found to be disks with surface detail. As telescopes grew in size, attention was drawn from the planets to the stars and non-stellar objects of the night sky (nebulae and galaxies).

Our Sun - The Photosphere
The sole source of heat and light in our solar system is the Sun. As the most massive object in the solar system (333,000 times the Earth), its gravity rules the motions of the planets, meteoroids and comets. It is

also the largest object in the solar system with a diameter of 1,392,000 km (109 times the diameter of the Earth). The Earth orbits about 150 million km away so it appears about 1/2 degree across in our sky. It is too bright to view directly. However with proper filters or by projecting its image onto a screen, sometimes we can see markings on its apparent disk. These are sunspots and they usually appear in groups. Even the smaller spots can be larger than the Earth!

The Sun's yellow colour comes from the light emitted by the "photosphere". It glows at 5800 Kelvin. This corresponds to a wavelength of about 0.5 microns in the green part of the spectrum. It appears yellow because of the contributions from the red, orange and yellow light.

The Sun's Surface

The photosphere is not really a surface but a transition region with a temperature and density that allows light to escape the Sun. Below the photosphere, light is scattered. Above it, light escapes with minimal scattering.

Sunspots are relatively cool areas in the Sun's photosphere. The Sun's magnetic field grows progressively more complex over a period of about eleven years. Where it erupts through the photosphere, it inhibits the convection of heat from below. The surface cools, radiates less light and appears darker.

Prominences

The magnetic fields can raise glowing hydrogen gas above the surface. These form "prominences" beyond the Sun's limb and are seen silhouetted against the sky when viewed with special telescopes.

Structure of the Earth

The structure of the Earth reflects a period of violent formation. The surface was once molten allowing only minerals and metals that could survive at very high temperatures. The dense material settled to the centre forming a metallic core. The lower density material floated to the surface forming a silicate crust. The planet is slowly cooling. Eventually, when the radioactive elements in our planetary crust and core have decayed, the Earth will solidify. Plate tectonics will cease and the geological processes that support the composition of our atmosphere will stop.

History of the Earth

The record of the Earth's surface has not been retained like that of the Moon. The Earth's surface is constantly rejuvenated by the dynamic plate tectonics.

However, life has dramatically changed the nature of our atmosphere. Originally, it was composed of carbon dioxide, nitrogen and other gases. Under these conditions life established itself in the oceans. The respiration of living creatures broke down the CO_2 into oxygen and created carbonate rocks. This major transformation was completed about 250 million years ago leaving CO_2 only a trace compound in our atmosphere.

Once the oceans became saturated with oxygen, it entered the atmosphere. At an altitude of about 30 kilometres the oxygen combined to create ozone. This shielded the surface from the Sun's ultraviolet radiation and allowed life to survive its migration from the water onto land.

Comparison of Terrestrial Cores

The relative diameters of each core and crust of the terrestrial planets are compared. The further from the Sun, the smaller the relative diameter of the metallic planetary core.

Exceptions indicate catastrophic events. The relatively small core for our Moon supports our present belief that it did not form with our Earth. Rather, it formed from debris shot into space from our Earth's crust by a large impacting proto-planet.

The Moon's Near Side

There are large scale features on the Moon's surface that are easily seen from Earth. The prominent dark markings are called "mare" or seas because to observers in the 1600's, they appeared to be flat oceans. They are actually vast lava flows that solidified over 3.5 billion years ago. These flooded countless impact craters leaving areas relatively smooth, featureless and darker than the more rugged areas. Only more recent and less violent impact scars are recorded on the mare.

Some areas of the Moon have a brighter, heavily crater-scared surface and are called the "highlands". Craters are caused by the explosive impacts of interplanetary bodies called "meteoroids". Most are very small grains of rock but some are many hundreds of kilometres across called "asteroids". Although they tend to look very deep, these depressions rarely have a depth of more than a few kilometres. There are also bright rays that originate from relatively fresh caters. The violence of the impact sprayed lighter coloured subsurface material across the surface.

Small craters (less than a few kilometres across) have a simple bowl shape. Larger craters have more complex wall and floor structures.

There are many features on the Moon that can be identified with binoculars. The largest is Mare Imbrium (about 1,300 km across). The largest crater (Clavius near the southern limb) is about 200 km across. The one in centre of the Moon's disk (the "nose" of the Man in the Moon) is Copernicus. It is a good example of the relatively "fresh" crater only 3.5 billion years old.

Crater Plato
The crater Plato is just above the "right eye" of the Man in the Moon. It is 101 km in diameter on the northern limit of Mare Imbrium. Its floor was flooded with lava leaving a smooth plane.

The mountains to the lower right are called Montes Tenerife, about 110 km long and 2.4 km high.

Crater Archimedes
Archimedes is south of Plato in Mare Imbrium and north of the "nose" of the Man in the Moon. It is a complex area with the Montes [Mountains of] Archimedes to the south. The mountain range to the lower right is Montes Apennines. Some of its peaks are 5 km high.

Crater Hyginus
This area is near the centre of the Moon's disk. The area near the crater Hyginus has a linear depression called a "Rill". These are typically found near the edges of the mare. They result from the run-off of lava during the first billion years of the Moon's history.

Apollo 11 Landing Site
Although the mare are relatively smooth, viewing the surface when the Sun is low in the lunar sky exaggerates surface relief. The "wrinkles" seen in the Mare Tranquillitatis (Sea of Tranquillity) are caused by successive lava flows.

The highland region to the left is the western edge of the Sea of Tranquillity. The field of view is about 250 km square.

History of the Moon
The Moon's history is dominated by the first billion years of its existence. The Moon's small size ensured that its core quickly solidified after formation. Without plate tectonics to modify the surface from within, the surface has retained the evidence of violent bombardments that created the planets.

From the crater record and dating of the rock samples returned to the Earth by the American Apollo and Soviet Luna projects, we have learned that the period of planet formation was quite short (about 1/2 billion years). By the end of one billion years, most of the interplanetary debris had been accumulated into the existing planets.

The appearance of the Moon has changed little in the last 3.7 billion years. One of the most recent features is on the nose of the "Man in the Moon": Crater Copernicus is 0.9 billion years old!

Mars - Xanti Terra
This image of Mars is from the "Mars Digital Image Map". It is a thirteen CD-ROM set showing the surface of Mars down to 1/4 km resolution and is available from:

http://nssdc.gsfc.nasa.gov/cd-rom/cd-rom.html

Mars is only about half the diameter of Earth (6,794 km) and is just over 50% farther from the Sun. It is interesting that its surface area is the same as the area of the dry land on Earth. Remember that 70% of the Earth is covered by oceans.

The surface of Mars shown here is reminiscent of our Moon with its craters. However, other features distinguish it: large features suggesting the flow of fluids.

Farther from the Sun, craters still abound. Indeed, every object in our solar system has been pounded by collisions. However at over 5 times the distance to the Sun than the Earth, the main structural material is not rock but water ice! This results in different features and crater details from those closer to the Sun. Ganymede is the largest satellite in our solar system with a diameter of 5,260 km (our Moon is only 3,475 km).

Ganymede, Satellite of Jupiter
This image was created from the Voyager Project CD-ROM set available from:

http://nssdc.gsfc.nasa.gov/cd-rom/cd-rom.html

Temperature of the Planets
The temperature of the planets in our solar system decrease with distance from our Sun. The amount of heat illuminating the surface is a function of the size of the Sun in the sky of each planet.

On Mercury, the Sun covers an area 6 1/4 times larger than in our sky. Therefore, the amount of heat incident on Mercury's surface is 6 1/4 times greater than on Earth. Similarly, the more distant planets are colder.

Differences from this pattern are caused by the amount of heat that is reflected away from the planet by its clouds and by the amount of heat that is retained by an atmosphere through the "green house effect".

The green house effect is caused by the different transparency of an atmosphere to short and long wavelength radiation. Relatively short wavelength radiation from the Sun enters the atmosphere and is absorbed by the ground. The ground heats up and emits long wavelength radiation (Wien's Law) to which the atmosphere is opaque. Thus, the heat is trapped. The temperature of the atmosphere increases until the top layers can emit as much heat as the planet absorbs.

This is most evident between Mercury and Venus. Venus is farther from the Sun than Mercury but the average surface temperature of Venus is much hotter.

Comet West
Occasionally, a new member of our solar system makes itself visible. Although over a dozen comets may cross our sky every year, most of these are too faint to be seen without a telescope.

Comets have a bright gaseous head with a faint tail extending from the head away from the Sun. Inside the head is the nucleus, which is too small to be seen even with a telescope. The head is composed of gases and dust from the nucleus. These are ionized or charged by the ultraviolet (UV) light from our Sun and are then swept away by the solar wind. The solar wind is the tenuous upper atmosphere of the Sun that is continually emanating from the Sun and blows by the planets of the inner and outer solar system. Therefore, the comet with its tail always "points" towards the Sun.

Structure of a Comet
A comet has a nucleus of ice crystals and dust a few tens of kilometres across. As it nears the inner part of the solar system, the surface heats up and the ice sublimates (vaporises). The escaping gases carry away dust.

Over time and numerous passes through the inner solar system, the surface darkens with exposure to the ultraviolet (UV) light from the Sun. This produces a dark crust of organic (carbon based) molecules.
On entering the inner solar system, heat is conducted into the comet. Internal ices vaporise and the gas pressure cracks the crust resulting in jets of gas.

Most of the ice is composed of water. The escaping gas forms a cloud of water vapour, which is dissociated by the Sun's UV light into hydrogen and oxygen atoms. This forms a hydrogen cloud over a hundred thousand kilometres across.

The electrically charged gases are pushed away from the Sun producing the ion or gas tail. The pressure of sunlight and the force of gravity push the dust into a slightly different path. This results in two tails: one of gas (glowing blue) and one of dust (reflecting the Sun's yellow colour).

Shower and Non-shower Meteors
The Earth is subject to bombardments of interplanetary debris. These result in an occasional meteor streaking across our sky every few minutes. The high speed of collision (30 to 60 km/sec) causes the meteoroid to vaporize high in our atmosphere. The process excites the gases in our atmosphere to glow creating the streak of light (a meteor).

Rich meteor displays are seen at predictable times every year when dozens and even hundreds of meteors per hour can be seen. This happens when the Earth passes through the debris tail left by a comet as it passed through the inner solar system. The cometary debris is fluffy, fragile dust and ice left behind by the comet. These vaporise harmlessly in our atmosphere over 100 kilometres above the ground.

Unlike the cometary debris, the meteoroids that produce the non-shower or sporadic meteors are made of solid rock and stony material. If they are large enough, they will pierce our atmosphere and impact the ground. The fragments that hit the ground are called meteorites.

Leonid Meteors
Shower meteors seem to radiate from a particular point. The name of a meteor shower comes from the constellation from which they radiate. This point is called the "radiant". The slide shows two "Leonid" meteors radiating from the head of Leo the Lion.

Minor Planets to Meteoroids
The particles that produce meteors do not all come from comets. They are also produced by the continuous collision between small bodies in our solar system. During the collisions, they are sent on random orbits through our solar system.

Although the cometary debris is very "fluffy", the particles from these collisions are usually much tougher stuff. The meteoroids are composed of different materials. Some are fragments of a metallic core and others are from a stony crust. This range of properties provides clues in our understanding of the formation and structure of planets.

Over four billion years ago, the proto-planets accumulated and there were frequent collisions. The energy of impact melted the bodies allowing the dense metal to settle into the central core. Low speed impacts allowed the bodies to stick together. However, high-speed impacts could result in the break-up of one or both bodies. Eventually, a few large bodies survived (the planets we study today).

Some of the debris from this process is still in orbit about the Sun providing fragments of a metallic core and a shattered crust for our study.

Three Stages of Planetary Studies
Our study of the Earth progressed through history from local areas to include larger regions as humans travelled farther from home. Only in the last 40 years have we gained a full planetary perspective with satellites. This has been a very inefficient process.

Unlike the way we learned about our planet Earth, our study of the other planets has started on a global scale. These methods of studying the planets have been driven by need to lower costs.

First, telescopic observations give us information on a planet of a general nature (distance, size, temperature, global climate and weather information). Then, spacecraft are sent to fly-by the planet recording information with greater precision and measuring characteristics that can not be sensed from Earth (magnetic field, variation in surface density). Unfortunately, these missions give us only a snapshot of the planet. We see them only during the brief hours or minutes of the close encounter.

Therefore, these are followed by spacecraft dispatched to orbit the planet. They provide long-term observations and result in very high precision measurements increasing our understanding of weather systems, surface features and mineralogy and the structure of the planet.

The next stage of planetary exploration is to land a robot on the surface and make ground measurements. This too is limited because the small size and mass of the lander restricts the number of instruments carried on any one mission.

The final stage is a sample return where material from the planet is returned to the Earth for analysis in well-equipped laboratories.

How has the Universe Changed?

One of the most remarkable feats of astronomy has been the development in our understanding of the evolution of our Universe! This study is called cosmology.

Study of Cosmology
Cosmology is one of the most profound fields of study by humankind. We attempt to understand the formation, evolution and fate of the Universe. Contributing to this study are all aspects of science: classical physics (relativity) and quantum physics (dealing with sub atomic particles), high energy and theoretical physics. All these are ultimately tested and confirmed or rejected by observations of the Universe made by astronomers.

Evolution of the Universe
The goal of cosmology is to understand the formation and evolution of the Universe. The closest we can study to the beginning is 10^{-43} seconds AFTER the Big Bang. The physics before this time is "unknowable".

The subsequent expansion and evolution has been a balance between the density of energy and matter. The basic structure of the Universe was permanently cast only a millionth of a second after the Big Bang. All that followed was the playing out of the physical laws. Only some of the "details" such as the formation of life and other things escaped the deterministic evolution of space and were ruled by chaotic processes.

Gravitational Well
In the Theory of Relativity, Albert Einstein proposed that mass and energy were related. Thus, light being an electro-magnetic wave and hence a form of energy has an equivalent mass corresponding to the equation E=mc2. Therefore, a gravitational field can bend the path of a beam of light.

This was confirmed during a solar eclipse in 1919. Stars near the Sun's limb appeared to be "repelled" away from the Sun's disk. The amount of shift for our Sun is very slight (1.75 arc seconds). However, for very massive bodies a gravitational field can act as a lens to focus light from a more distant object. Several of these gravitational lenses have been discovered.

In the most extreme cases, a massive body may have such a strong gravitational field that a "black hole" is created. The energy of all light emitted by its surface is expended as it tries to climb out of the intense gravitational field. So, light can not escape from a black hole.

4-Dimensional Space-time
The expansion of the Universe has been approximated as an expanding balloon. Since a surface has only two dimensions, our third dimension is collapsed into the thickness of the balloon's skin and ignored. The galaxies of our Universe are fixed to the balloon's surface and are carried in a general motion away from each other as the balloon is inflated.

"Where is the centre of the Universe from which the expansion started"?

As the balloon inflates over time, its radius increases. The surface area of the balloon grows larger carrying the galaxies farther apart. Each point on the balloon moves away from every other point on the surface.

Looking back in "time", the balloon and its radius were smaller. Therefore, the balloon's radius is a measure of time. So, the "centre of the expansion" is not a position ON the balloon, but rather in "the centre of the balloon" where the radius is 0 and hence time is 0!

Can we tell time by the night sky?

The stars of the northern sky can be used to tell time. However, we have to know the approximate date to get any meaningful results.

The following four slides show the northern sky during the four seasons. Similar orientations of the Big Dipper and Little Dipper can be seen earlier in the year but at later times during the night.
The line between Polaris and the pointer stars of the Big Dipper can be seen as an hour hand. However, since the Earth rotates once in 24 hours, we use the Polaris-pointer as the hour hand on a "24 hour clock". At midnight on March 15, the line points as the hour hand does at midnight. Each hour, this line moves counter clockwise 15 degrees (1/24 of a circle). Each following month, this midnight "hour" rotates counter clockwise another 15 degrees.

Spring North
This is the orientation of the Polaris-pointer line corresponding to midnight on March 15. It is also the orientation at the end of evening twilight on May 8.

Summer North
This is the orientation of the Polaris-pointer line corresponding to midnight on June 15. It is also the orientation at the end of evening twilight on August 1.

Autumn North
This is the orientation of the Polaris-pointer line corresponding to midnight on September 15. It is also the orientation at the end of evening twilight on December 25.

Winter North
This is the orientation of the Polaris-pointer line corresponding to midnight on January 15. It is also the orientation at the end of evening twilight on March 8.

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