THE MOON

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Within this case you discover the geometry of the orbit of the Moon and the nature of its phases. As special case of the circumstances of Moon's orbit, the use case introduces the eclipses, both of Moon and Sun.

If used in the classroom by the teacher this use case can be very simple and allow the teacher a good explanation of the content to young pupils (who can afterwards experiment on their own). Using the full content of the use case rises its level to intermediate.

1 Introduction

The Moon is, after the Sun, the brightest celestial object in the sky and the easiest to observe.

The Moon behaves in a little strange way: some days it is visible during the night, others during the day, some times it is full and others only partially illuminated.

This use case helps us, using Stellarium, to understand the orbit of the Moon and the main phenomena related to it.

2 The orbit of the Moon

The Moon moves around the Earth on a elliptical orbit: the semi-major axis measures 384000 km. A complete revolution of the Moon around the Earth (*sidereal month*) takes 27.3 days.

The orbit of the Moon is tilted at an angle of about 5° with respect to the ecliptic (the plane of the orbit of the Earth around the Sun). As a consequence the altitude of the Moon above the horizon, as seen form a certain location, is at maximum 5° lower or higher than the altitude of the Sun.

Fig. 1: Full Moon.

Like all celestial objects, the Moon appears to move on the celestial sphere because of the rotation of the Earth and we see it rise eastward and set westward. Moreover, since the Moon orbits around the Earth, it also moves eastward along the zodiac constellations. A complete tour of the zodiac takes a sidereal month (27.3 days): the Moon moves at 0.5° per hour with respect to the stars.

Another interesting characteristic of the Moon is that we see different phases but always the same side. This occurs because the time it takes the Moon to perform a rotation around its axis is the same it takes to complete an orbit around the Earth. This type of motion is called synchronous rotation (rotation and revolution periods are equal).

3 The phases of the Moon

The illuminated surface of the Moon and the time of rise and set change every day. Lunar phases depend on the mutual positions of Sun, Moon and Earth.

Half of the surface of the Moon is always illuminated by the Sun. Phases are due to the fact that we see part of the illuminated surface and part of the dark side, in ratios that change day by day.

A phase is defined by shape, size and orientation of the illuminated surface of the Moon that is visible to us.

From Earth we see the Moon with the same phase after a synodic month (29.5 days). The reason because the synodic month is longer than the sidereal month is the following: during a sidereal month the Earth covers nearly one twelfth of its orbit around the Sun. In order to have the same Sun-Moon-Earth configuration, and thus the same phase of the Moon, the Moon has to cover one more twelfth of its orbit around the Earth. This additional motion takes slightly longer than 2 days and hence lunar phases repeat every sidereal month + 2 days = 29.5 days.

The main lunar phases are: new moon, first quarter, full moon and last quarter.

New moon: the Moon is located between the Sun and the Earth and the illuminated side is not visible from Earth. We can not see the Moon in the sky.

First quarter: the Moon is at 90° with respect to the Sun-Earth direction. From the Earth we see exactly half illuminated surface and half dark surface.

Full moon: Moon, Earth and Sun are aligned, as in the case of new moon, but now the Moon is located at the opposite side of the Earth with respect to the Sun. We see the entire Moon disk illuminated.

Third (last) quarter: as the first quarter phase, the Moon is at 90° with respect to the Sun-Earth direction, but now on the opposite side. From the Earth we see exactly half illuminated surface and half dark surface.

The Moon not only displays a change of phases, but also rises, reaches the maximum height above the horizon (culminates) and sets at different times.

For example, since the Moon is full when it is opposite to the Sun, in this phase it rises at sunset, culminates at midnight and sets at dawn. At the first quarter the Moon is 90° eastward of the Sun: it rises at noon, culminates at sunset and sets at midnight.
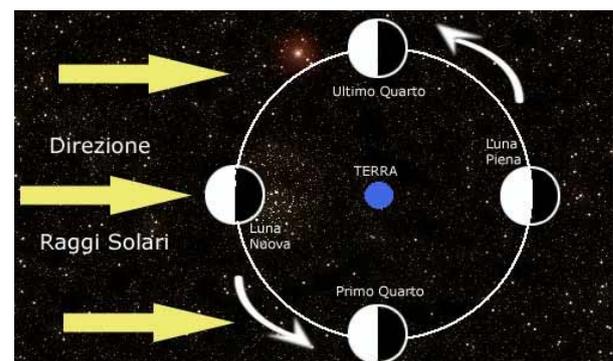

Fig. 2: Scheme of the lunar phases: the Earth is at the centre and the Sun is on the left, outside the picture. (http://astroimperia.altervista.org).

4 Solar and lunar eclipses

Sometimes when Moon, Earth and Sun are exactly aligned they give rise to a spectacular phenomenon: the eclipse.
Eclipses can be classified into solar and lunar eclipses.
A *solar eclipse* (fig. 3) occurs when the Moon is located between the Earth and the Sun and casts its shadow on the Earth. People who live in regions covered by the shadow of the Moon will see the Sun being obscured.
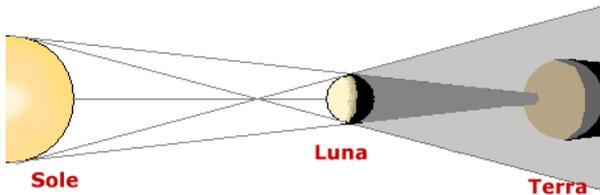We call totality of an eclipse the moment when the disk of the Sun is completely obscured by the Moon.

Fig. 3: Scheme of a solar eclipse (www.pd.astro.it).

During totality we can observe the solar corona (fig. 4). The solar corona is the outermost part of the solar atmosphere, characterized by a very low density. It is much less luminous than the disk of the Sun at optical wavelengths and therefore usually invisible. The total brightness of the corona is about one millionth of the total brightness of the Sun.
When a total eclipse occurs while the Moon is at its longest distance from the the Earth (apogee), the disk of the Moon can be slightly smaller than the disk of the Sun. In this case a thin annulus of the Sun remains visible and the eclipse is called annular.
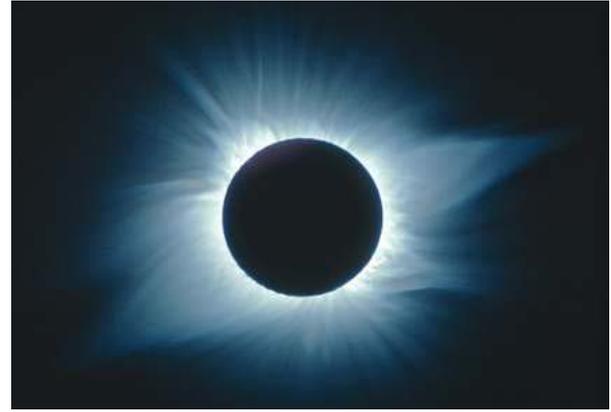

Fig. 4: Total solar eclipse of March 29th, 2006.

A *lunar eclipse* (fig. 5) occurs when the Earth is located between the Sun and the Moon with the Earth casting its shadow on the Moon.
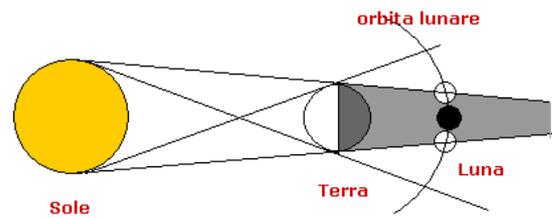

Fig. 5: Scheme of a lunar eclipse (www.pd.astro.it).

During the totality of a lunar eclipse, the Moon does not disappear completely , but it glows with a faint reddish (fig. 6).
The red colour is caused by light from the Sun that passes through the Earth's atmosphere where green-blue rays are absorbed.
The Moon passes between the Sun and the Earth every 29.5 days at full Moon. So why are eclipses rarer phenomena? In order to have an eclipse a very accurate alignment is required. The orbit of the Moon is tilted at an angle of 5° with respect to the ecliptic. We have an exact alignment only when the Moon is in one of the two points where its orbit intersect the ecliptic (nodes).
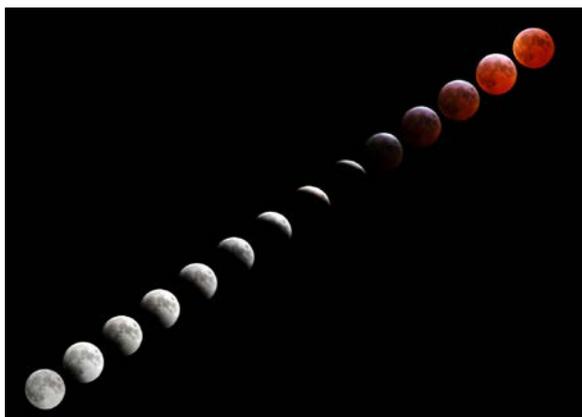
Fig. 6: Sequence of the lunar eclipse of March 3rd, 2007. Note the red color during the totality.

Fig. 7: Scheme of the lunar orbit and the ecliptic. Note the 5° inclination between the two planes and the position of the nodes (http://www.astronomia.com).

It is interesting to note that we can see total solar eclipses from the Earth by sheer coincidence: the Sun and the Moon as seen from the Earth appear to have the same angular diameter even if they have different sizes.

5 Stellarium

Stellarium is a free software that transforms a home computer in a planetarium. It calculates the positions of Sun and Moon, planets and stars, and draws the sky how it would be seen from an observer anywhere on the Earth and at any epoch. Stellarium can also draw the constellations and simulate astronomical phenomena such as meteor showers and solar or lunar eclipses.

Stellarium may be used as an educational tool for kids of all ages, as an observational aid for amateur astronomers wishing to plan an observing night, or simply to explore the sky (it is fun!). Stellarium shows a realistic sky, very close to what you see with naked eye, binoculars or telescope. Stellarium gives astronomical data (coordinates, magnitude, distance, etc.) of most of the celestial objects visualized on the screen. You can freely download Stellarium from our site http://vo-for-education.oats.inaf.it or from http://www.stellarium.org.

6 Observing the Moon in Stellarium

Observing the Moon and the related phenomena in Stellarium is very easy. In the left menu we can set location (location window -) and time (date/time window -), and then see if the Moon is visible in the sky. Use the mouse wheel in order to increase or decrease the field of view and pan the field of view in order to watch a different part of the sky.
If the Moon is visible in the sky we can select it: in the upper left corner its astronomical data will appear.
Zoom on the Moon in order to observe the lunar phases.
If the Moon is not in the sky, it could be not yet risen or already set.
Stellarium lets us move forward and backward in time, using the arrows () at the right of the bottom menu. By clicking (more then one time) on the button with the left or right double arrow, the time is accelerated so we can have a quick view of phenomena lasting many hours. The button "play - " brings back the flow of time to its standard rate.
After the selection of the Moon we can follow it in order to have the Moon always in the centre of the screen: push the space bar on the keyboard or the button

"centre the selected object" - ⬚ in the bottom menu.

The same thing can be done for any astronomical object, including the Sun.

In order to see (and follow) the Moon also when it is below the horizon or during the day, we can turn off the effects of atmosphere (button "atmosphere" - ⬚) and the visualization of the ground ("ground" - ⬚). Eventually, for a better visualization, turn off the cardinal points (button "cardinal points" - ⬚). In some cases it could be useful to visualize the ecliptic (push comma on the keyboard), constellations (button "constellation lines" - ⬚) or other reference lines on the celestial sphere. Such options, and many others, can be turned on from the left menu "sky and view options - ⬚".

Stellarium has a plugin that allows to compute angular distances. Activate it from *configuration window -> plugins -> angle measure*. Select "load at start-up": at the next start up of Stellarium the button (⬚) will appear in the bottom menu.

Try to measure the diameter of Moon and Sun and the shift of the Moon in one hour with respect to the stars.
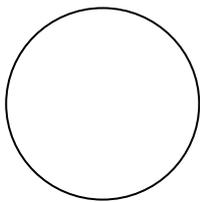
EXERCISES

Exercise 1

Observe the Moon motion in Stellarium and compute the duration of the sidereal and synodic lunar months.
Hint: turn off atmosphere, cardinal points and ground, put the Moon fixed at the centre of the screen and turn on ecliptic and constellation lines.
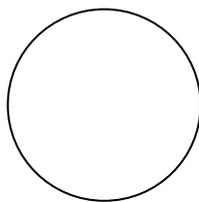Switch from azimuthal mount to equatorial mount in order to have the ecliptic fixed at the centre of the screen. In order to compute the sidereal month, move the moon (going forward and backward in time) in the nearing of a easily recognizable constellation and observe after how many days the Moon returns in the same position. In order to compute the synodic month, observe the time interval that goes between two equal phases of the Moon, e.g. between a new moon and the next one.
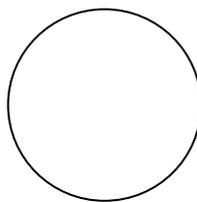
Exercise 2

Paint the following circles in order to show how the Moon appears during different phases.
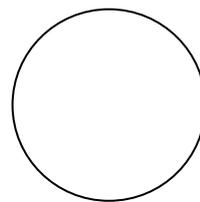
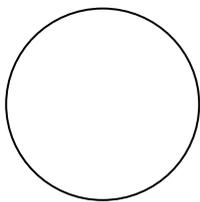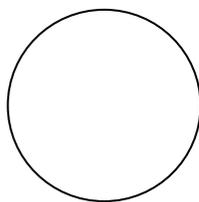   new moon   first quarter   full moon   last quarter

Exercise 3

How do people who live in the southern hemisphere see the Moon?
Observe, from Europe, the Moon at first quarter and draw both the phase and the position of some craters. Then move to the southern hemisphere, e.g. in South Africa, and draw the Moon as you see it from there. What do you notice?

    Europe   South Africa

Exercise 4

Fill the following table observing the Moon in Stellarium in the given day and location,
Pay attention: one of the eclipses is particular, can you tell which one and why?

Table columns:
Type: solar or lunar eclipse; start, max, end: time of start, maximum and end of the eclipse; tot. durat.: how long does the totality last; lunar phase: full moon, new moon, first quarter, etc; visib. Italy: is the total eclipse visible from Italy?

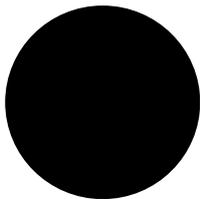| Date	Observer latitude	Observer longitude	Type	Time start	Time max	Time end	Tot durat.	Lunar phase	Visib. Italy
11/08/1999	45°04'48" N	24°17'18" E							
21/02/2008	10°00'00" N	50°00'00" W							
01/08/2008	65°38'48" N	72°16'24" E							
15/01/2010	01°16'00" S	36°49'00" E							
15/06/2011	18°55'00" S	47°31'00" E							
03/11/2013	03°30'06" N	11°41'30" W							
28/09/2015	00°00'00" N	40°00'00" W							

SOLUTIONS

Exercise 1

Observe the Moon motion in Stellarium and compute the duration of the sidereal and synodic lunar months. *Sidereal month: 27.3 days, synodic month 29.5 days.*
Hint: turn off atmosphere, cardinal points and ground, put the Moon fixed at the centre of the screen and turn on ecliptic and constellation lines.
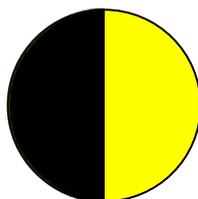
Switch from azimuthal mount to equatorial mount (⚡) in order to have the ecliptic fixed at the centre of the screen. In order to compute the sidereal month, move the moon (going forward and backward in time) in the nearing of a easily recognizable constellation and observe after how many days the Moon returns in the same position. In order to compute the synodic month, observe the time interval that goes between two equal phases of the Moon, e.g. between a new moon and the next one.
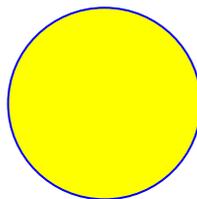
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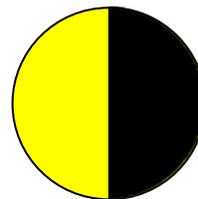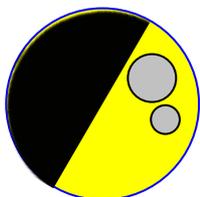

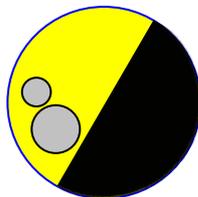| new moon | first quarter | full moon | last quarter |

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| Europe | South Africa |

Exercise 4

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Pay attention: one of the eclipses is particular, can you tell which one and why?

Date	Observer latitude	Observer longitude	Type	Time start	Time max	Time end	Tot. Durat.	Lunar phase	Visib. Italy
11/08/1999	45°04'48" N	24°17'18" E	sun	09:30	11:03	12:35	2m 22s	New	no
21/02/2008	10°00'00" N	50°00'00" W	moon	01:43	03:26	05:08	49m	Full	Yes
01/08/2008	65°38'48" N	72°16'24" E	sun	09:24	10:21	11:18	2m 27s	New	no
15/01/2010	01°16'00" S	36°49'00" E	anul.	04:06	05:30	07:15	6m 53s	New	no
15/06/2011	18°55'00" S	47°31'00" E	moon	18:22	20:12	22:02	100m	Full	yes
03/11/2013	03°30'06" N	11°41'30" W	sun	11:05	12:46	14:27	1m 39s	New	no
28/09/2015	00°00'00" N	40°00'00" W	moon	01:07	02:47	04:27	77m	Full	yes

Note: table times are UT.
The peculiar eclipse is the one on January 15, 2010 because it is an anular solar eclipse.