Grazing Occultations of Stars by the Moon

A field of professional astronomy between science and beauty

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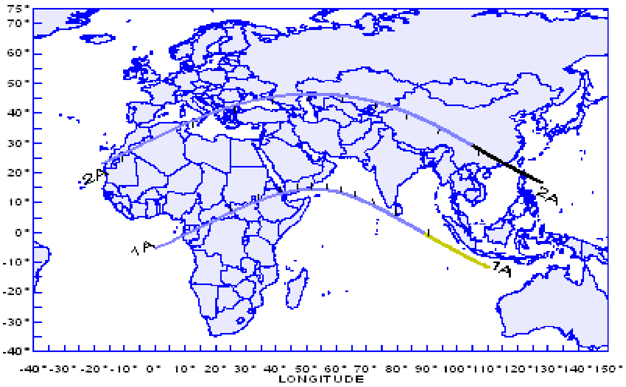
Among all occultation phenomena in the sky grazing occultations of stars by the moon have a very unique character. The observation of these spectacular events does not require any large and expensive telescope, but rather a small and transportable instrument like many amateur astronomers own one. As the moon circles the earth monthly it occults stars that lie in the lunar path. At that instant the star casts an invisible shadow of the moon on the earth's surface. Anyone standing at the edges of this shadow can see the lunar surface scratch along the star, covering it behind higher terrain features often several times at each graze and revealing it in between in depressed areas.



Being in the right location at a specified time the glance through the telescope's eyepiece easily lets you find the star to be occulted next to the moon. As the moon gets closer to the star the lunar brightness sometimes makes it more difficult to clearly see the star depending on the lunar phase and thus of the sunlit percentage of the moon's surface. When the distance between the lunar structures and the star is really small a fascinating phenomenon occurs which cannot be seen in any other astronomical observation: the motion of the moon around the earth becomes directly visible: The lunar landscape slowly but noticeably crawls along the star. Since the moon has no atmosphere the disappearances and reappearances of the star in the terrain structures happen so unexpectedly that even trained visual observers often don't react for a few tenths of a second. The beauty of these events is famous.

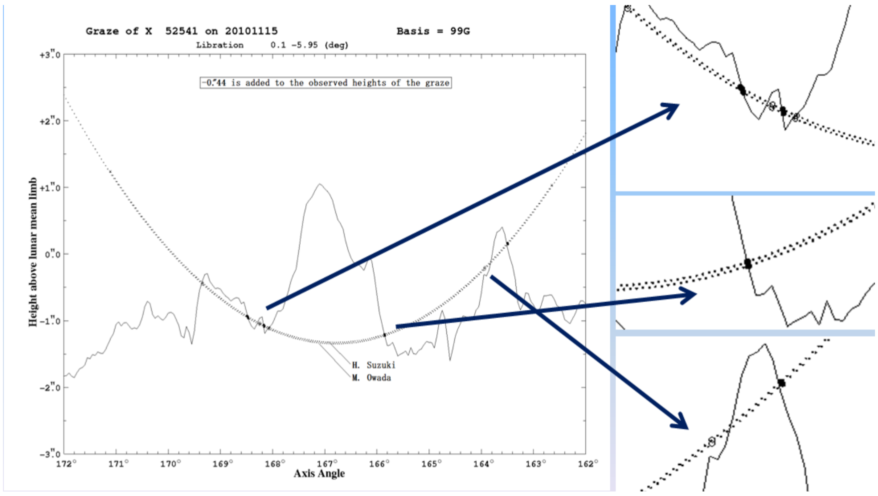
The Scientific Purpose

Through the observation and timing of grazing occultations especially amateur astronomers can contribute to science. The scientific value itself changed over the decades. First systematic observations reach back to the end of the 1950s and allowed both the measuring of lunar limb terrain features as well as the detection of erroneous stellar positions. Back then even many zodiacal stars did not have well measured positions or proper motions. The lunar limb itself during a grazing occultation is best captured by a group of observers standing on a line more or less perpendicular to the graze path and thus in different depths referred to the limb structures. As the lunar shadow sweeps over the earth the limb profile can be assembled through the different lengths of timings of dis- and reappearances of the star. Due to lacking precision in the past concerning the lunar limb heights missed observations were not rare in cases a depressed terrain left the star fully unocculted.

A photographic catalog by C. B. Watts, USA, published in 1963 gave lunar profile height values in all libration ranges and helped in improving the prediction precision. It was not very precise though and also left blank a big limb area that never is hit by sunlight (Cassini-region).

In the beginning of the 1990s the Hipparcos catalog improved the precision of stellar positions and proper motions considerably allowing to set out grazing occultation observations more on improving the knowledge of the lunar limb details. That way the photographic Watts data could be corrected more and more and the empty Cassini-regions became known event by event. Latest spacecraft laser ranging as by the Japanese Kaguya-mission launched in 2007 and the NASA Lunar Reconnaissance Orbiter mission (LRO) in 2009 resulted in lunar surface structures with a precision of 200 meters down to 5 meters.

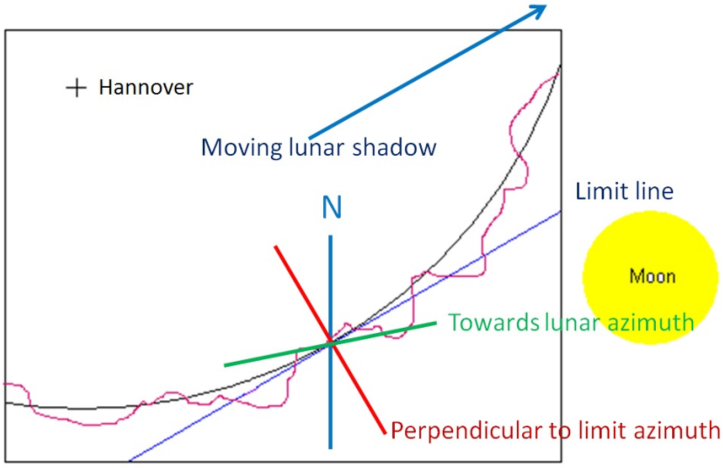
But until today the reductions of earthbound observations of grazing occultations contribute to further precision improvement of both lunar terrain features and knowledge of the occulted stars. The technical demands for earthbound measurements have increased though to yield the needed precision concerning both positioning and timing necessities for the observer (see further down: Needed Equipment). Since the predictions are very precise nowadays it is possible to reveal many more profile details by a narrow positioning of the observing stations. Still yet unknown double and multiple star systems are discovered and/or can be investigated closely through their occultations by the moon. If timing is possible with high resolution there is a high professional interest to learn more about these systems and to measure stellar diameters.



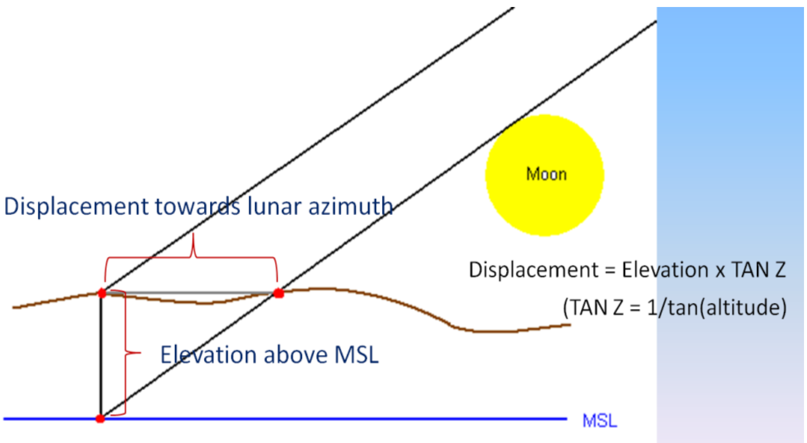
Reductions of grazing occultations also still reveal errors in the stellar proper motions as published in the Hipparcos catalog. Reductions so far even suggest an overall rotational error of the Hipparcos reference frame. These errors are expected to be solved through the upcoming Gaia mission of the European Space Agency when 1 billion stars will be newly measured with a precision down to 1 micro second of arc.

A detailed knowledge of the structures of the lunar limb allows the precise measurement of the diameter of the sun during total or annular solar eclipses. For these events observing positions at the northern as well as the southern edge of the moon’s umbra must be selected by several observers to see the moon ‘graze’ the solar limb. At closest contact the beautiful Baily’s Beads phenomenon shows those parts of the solar photosphere glaring through the smallest valleys at the lunar limb. These allow to find the mean lunar limb and thus the baseline between the northern and the southern mean limb as the precise diameter of the lunar shadow. The solar radius deducted from this so far showed variations within a range of some 400 km. More research is needed here to achieve more evidence that the sun is really pulsating to a small extent.

Moon’s Invisible Shadow Projected on Earth



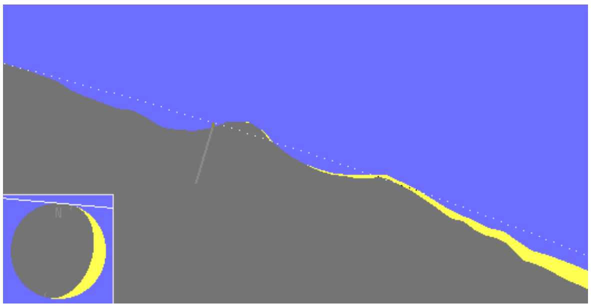
The picture to the right shows the shape of the moon as it is invisibly projected on the earth’s surface during an occultation of a star. The lunar terrain features are considerably increased in scale. The shadow can move over the earth in different angles but always from west to east according to the motion of the moon. The path of the mean lunar limb on mean sea level (MSL) is the one that is always calculated and shown in the predictions. The planning of the location of observing stations needs to take into account the positive and negative extent of the projected lunar limb structures over the mean limb as well as the altitude on Earth.

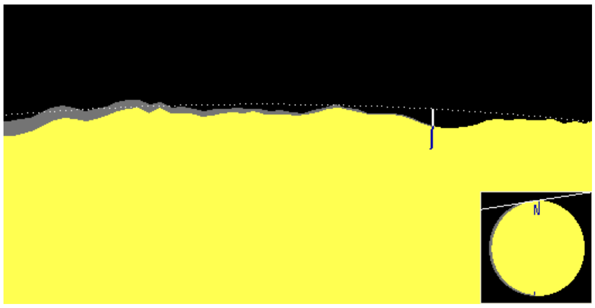


Due to the lunar parallax the line of view to the moon and thus the distance of the lunar surface to the star to be occulted changes with the altitude of the observer. Therefore the observing position must be adjusted accordingly by a displacement in the direction of the lunar azimuth (see picture on the left).

Circumstances at the Lunar Limb

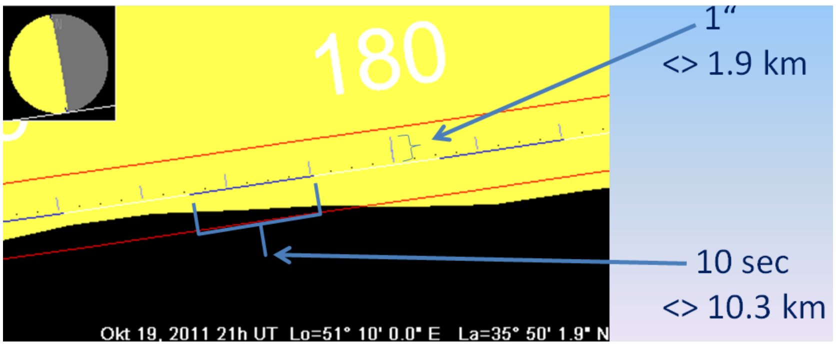
Each grazing occultation has its unique character. Depending on the phase of the moon, the magnitude of the star, its altitude above the horizon and the sky brightness due to the sun's altitude circumstances always differ. It is needless to explain that a bright star event on the unlit limb part of a crescent moon even with a brighter sky background (left) is much easier to





observe than a grazing occultation of a faint star on the bright lunar limb close to full moon (right). Even for events on the dark lunar limb at gibbous phases the glare of the bright moon causes seeing problems through irradiation for visual as well as video observations. Grazing occultations on the sunlit lunar limb are limited to stars of magnitude 3.5 or brighter. Each observer has to judge the observability of an occultation, also depending on his or her equipment.

The picture below shows a part of the southern sunlit lunar limb in true scale covering about



1 degree of position angle. The dotted line marks the mean lunar limb which is overtopped by the true lunar terrain in this area. The right curly bracket includes an angle of 1 second of arc which equals 1.9 km on the moon at mean lunar distance from earth. The line dashed blue and white is the apparent stellar path, where each equally colored leg shows the lunar motion within 10 seconds of time (see bracket below). At mean lunar distance in 10 seconds about 10.3 km of lunar terrain move alongside the star.

Observing Precision Requirements

Since the moon moves approximately 1 km in one second a timing precision of 0.1 seconds results in a horizontal terrain resolution of 100 meters. Since most visual timings do exceed the precision of 0.3 seconds the resolution of approximately 300 meters is not competitive to the least quality measurements of the Kaguya and the LRO spacecrafts. Timings by video means show a better time resolution usually referred to 0.03 seconds yielding a very competitive 30 m of horizontal resolution. To achieve measurements that allow reduction to this precision also the coordinates and the altitude of the observing site must be precise. Only an offset of some 15 meters is allowed, which can be easily be reached with any GPS device or by using Google Earth.

But also visual observations have still their value! Especially at the edges of a grazing occultation event (in the highest or deepest lunar terrain structures) it is always good to add visual timings or even missed reports to the video data. If there is a dis- and reappearance at one location and none could be seen visually at station at just a little distance to the video station then even the visual observation contributes to a high precision.

Observing Techniques - Needed Equipment

As the magnitudes of the occulted stars are usually far below 10 observations of grazing occultations do not require large telescopes. Even a 6 cm refractor or an 11 cm reflector do this job for most graze events. A stable telescope mount and a good tracking device are much more important than large apertures. A good instrument for stellar occultations by the moon must be transportable and easy to set up someplace in the countryside.

The biggest technical challenge is the recording of the event. For visual observations the use of a simple stop watch is not sufficient since that way only the first of probably several dis- and reappearances can be recorded. Special stop watches with a memory device allow the recording of maybe up to 10 time stamps. Any kind of voice recorder nowadays availably in almost every mobile telephone can meet this purpose as well when a time signal is recorded simultaneously. The most simple way to record a sufficient time signal is by some beep or knock that is being recorded every 10 seconds by an assistant observer always watching a clock that was set to UTC shortly before the event. Also a calibration of the recording device through an acoustic time stamp at the beginning and one at the end of the recording would be sufficient if no assistant is available. The voice recording also allows spoken comments while the event is going on. These comments can be immediate time corrections due to a longer reaction time of the observer at the eyepiece or remarks about possible uncertainties of noticed dis- or reappearances, for example resulting from bad seeing or partial disappearances of a double star system.

Video recordings allow a much higher timing precision but also require much more and rather expensive electronic equipment. A sensitive video device must be connected at the telescope's focal plane increasing the necessity for a stable telescope mount and good tracking. A recording device is necessary, either the classical analog or digital tape recording or by use of an A/D-converter-software when feeding the analog video signal via a USB-port directly to a laptop next to the telescope. The latter technique must be fast enough to guarantee that not a single one of the recorded video frames is lost. Also the hard disc must be fast and empty enough to cope with the high amount of video data to be saved.

Timing along with the video recording presents the next problem to be solved. Video time inserters are electronic devices that feed the time signal directly into the video frame. In those countries where a radio time signal is distributed an appropriate receiver is included in the time inserter. Recently video time inserters have become popular that also connect to a GPS-antenna thus receiving the precise and universally available GPS-time and displaying it along with the measured geographical coordinates. These devices are especially well suited in countries with no radio time signal. In Iran Aria Sabouri has developed a system to feed the laptop's system time into the video recording.

No matter which technical effort is chosen to approach observations of grazing occultations anyone curious in these phenomena will not be disappointed. IOTA will offer any help to support this work. Predictions of the best events are published regularly in the different IOTA newsletters for different regions in the world. Anyone interested to find out still more about upcoming events in his area can obtain IOTA's GRAZPREP software (via the IOTA/ES homepage) that assists on any step towards a successful observation. IOTA also explains the forwarding of occultation reports in order to have all data collected and reduced to utilize and evaluate successful timings. The author can also be addressed for any questions that arise.

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