Submitted to Sky&Telescope magazine where it was edited and published in the January 2011 issue:

The Magnitudes of the Planets

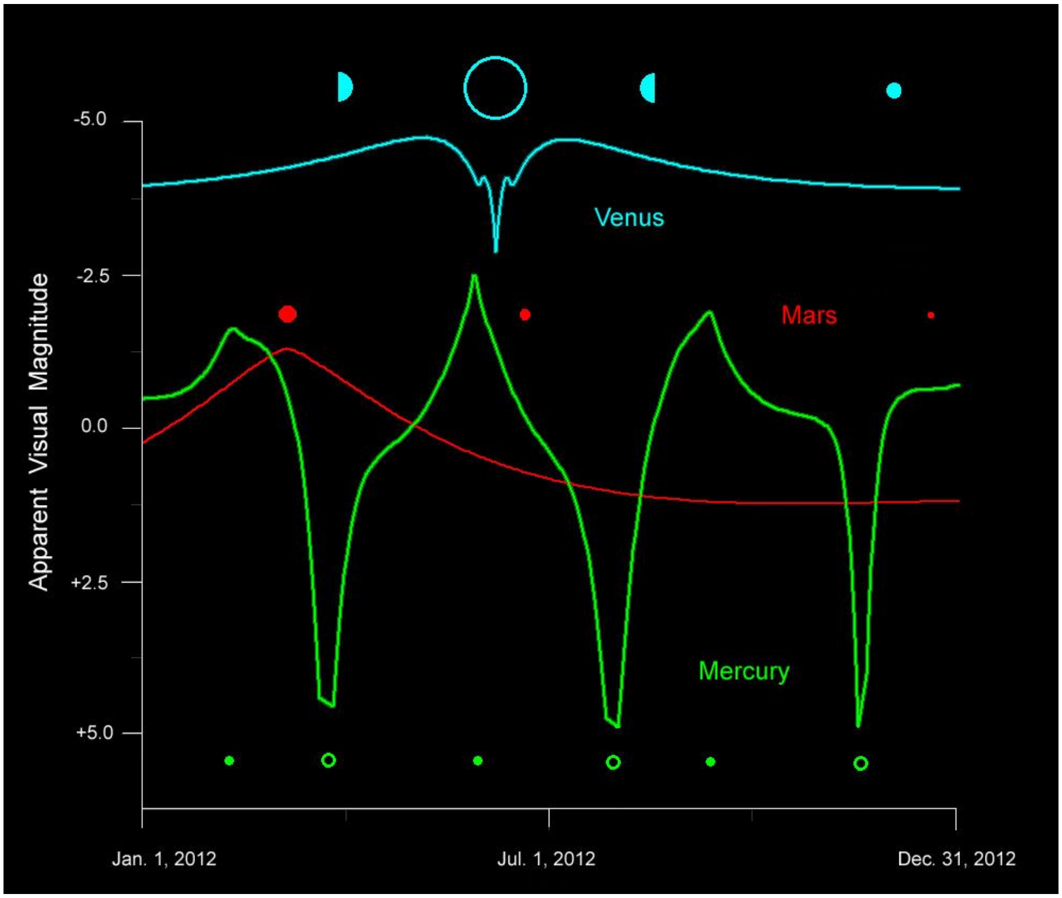
Anthony Mallama

2010 September 30

"How bright is that planet?" Thousands of amateur sky watchers ask this question every year and many look to S&T's Celestial Calendar for the answer. This article tells how the magnitudes of our solar system neighbors are predicted and explains what we can learn about planets based on their luminosities.

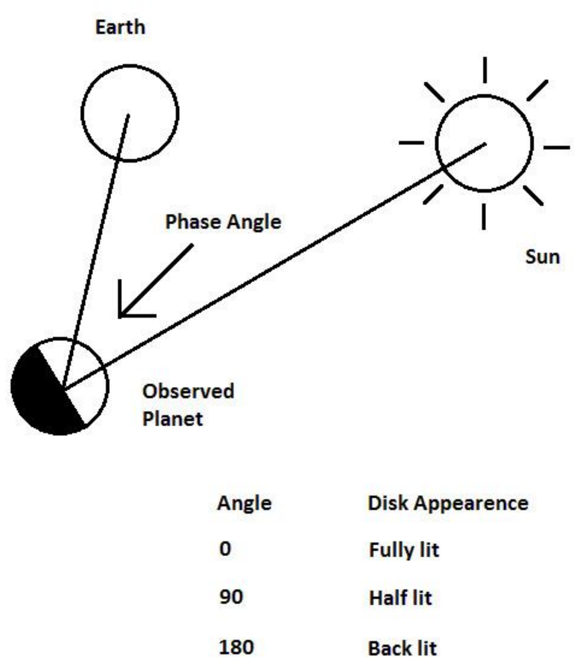
The distance from the planet to the observer and that from the planet to the Sun both affect its brightness. The 'inverse square law' of distance means that a planet twice as far away appears one-fourth as bright. The phase angle corresponding to the planet's crescent, quarter, gibbous or full shape also contributes to its magnitude. A disk seen fully illuminated by the Sun is at phase angle 0 degrees while the thinnest crescent approaches phase angle 180. Distance and phase are geometrical effects.

Two physical factors that influence brightness are the planet's size and its reflectivity. Luminosity depends directly on the surface area of the body. Twice the area produces twice the brightness. Reflectivity indicates how a planetary ground or cloud layer redirects the sunlight that it receives. This is the most enlightening aspect of planetary photometry (the study of luminosities) because characteristics of the planets themselves are revealed. Clouds reflect a large fraction of the incoming light and they distribute it over a wide angle. Meanwhile solid surfaces reflect less light and return it more strongly in the direction from which it came. If the brightness of a planet is observed over an appreciable span of phase angles, then something can be learned about its physical composition even if the disk is not resolved. Photometric characterization has contributed to our understanding of Mercury and Venus as explained later.

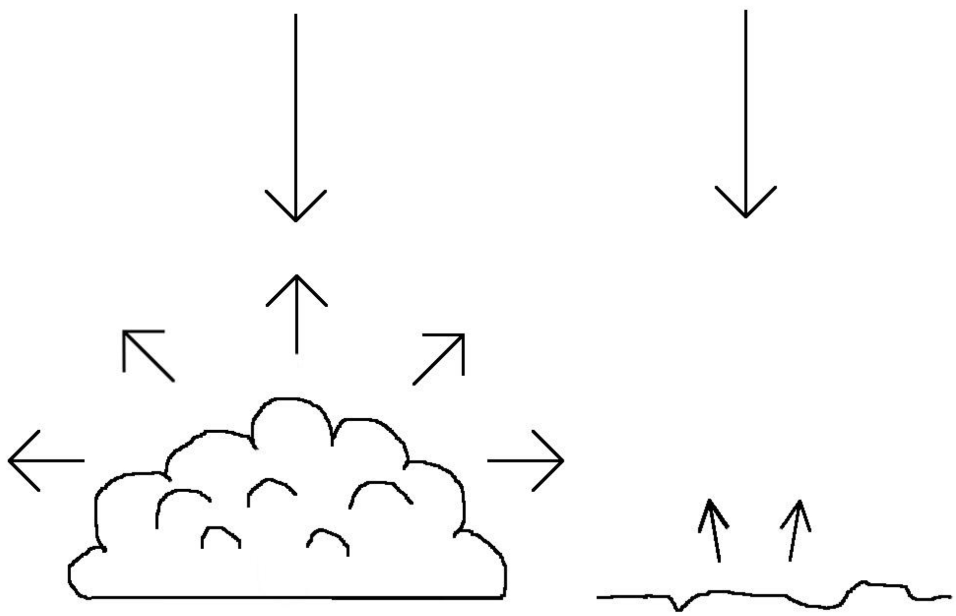


The varying magnitudes of Mercury, Venus and Mars are shown along with their phases and relative diameters. Open circles indicate inferior conjunctions when a planet is between the Sun and Earth. Mercury's asymmetric luminosity changes are due to its eccentric orbit. Venus brightens and fades four times in the vicinity of inferior conjunction. Mars will be at opposition next year on March 3rd.

When I began studying the brightness of the terrestrial planets Mercury, Venus, Earth and Mars about 12 years ago, many of the magnitudes in use dated back to the 1800's and were not very precise. Thanks to a novel spacecraft instrument and the availability of CCDs for earth-based observation, though, it was prime time for an update. The Large Angle Spectrometric Coronograph (LASCO) onboard the NASA/ESA Solar and Heliospheric Observatory (SOHO) was designed to photograph the solar corona. However, it is also an ideal instrument for observing Mercury because the planet's small elongation from the Sun often places it in the same field of view. LASCO principal investigator Russell Howard at the Naval Research Laboratory approved a program to observe Mercury from 1999 to 2000, and LASCO scientist Dennis Wang obtained images when Mercury was in the field of view but outside of the solar occulting disk.

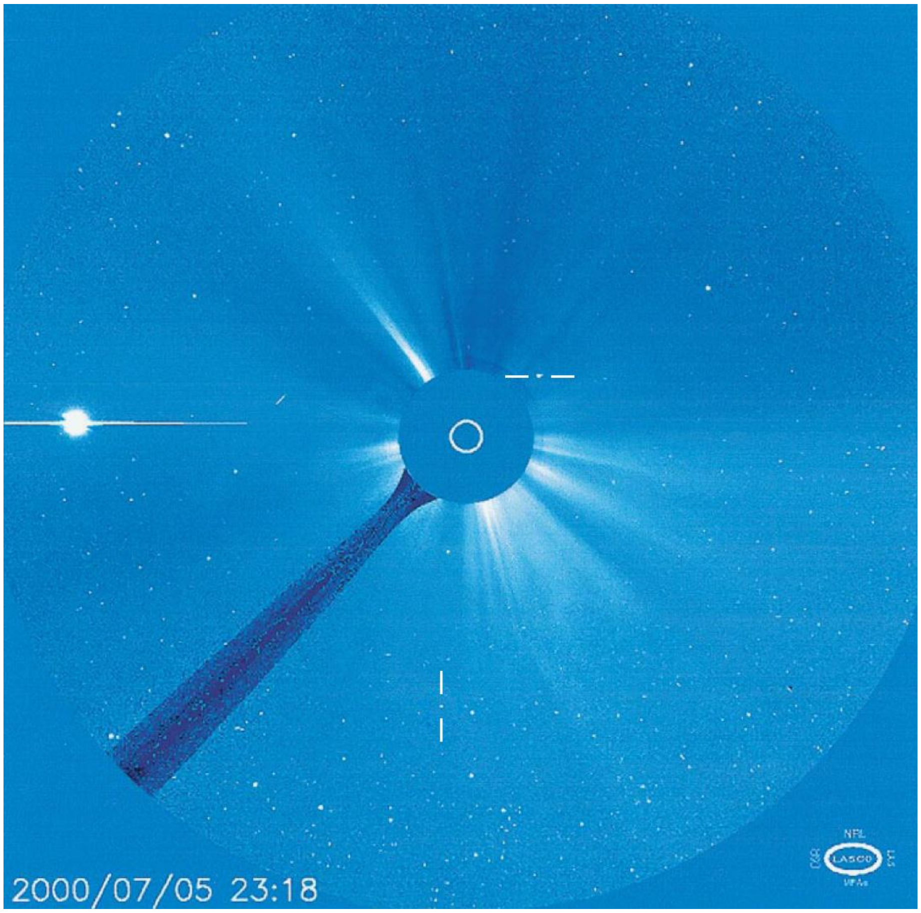


Phase angle is the arc between the Sun and the Earth as seen from a planet.



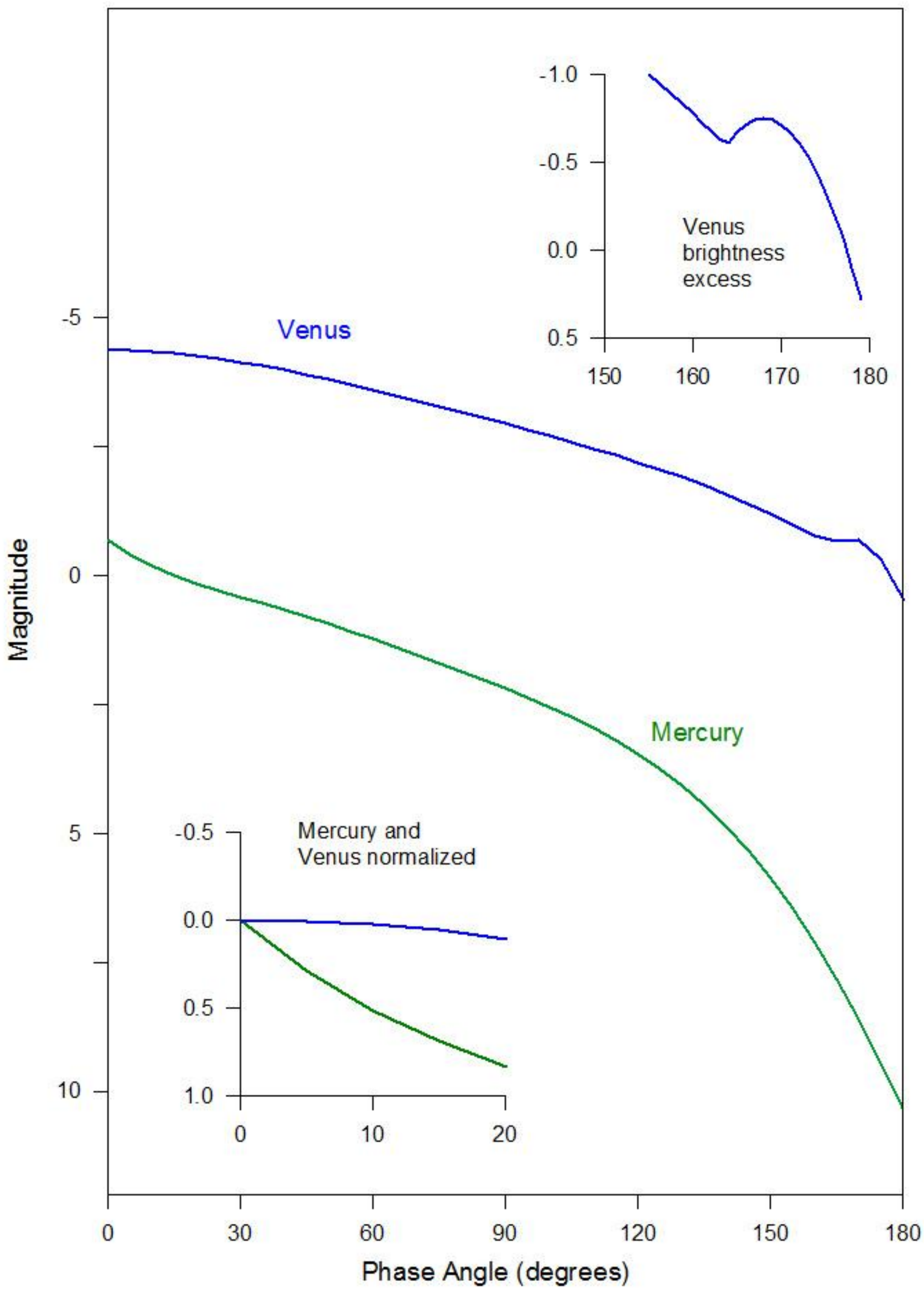
Clouds reflect brightly and disperse the incoming light broadly while solid surfaces are usually darker and their reflected light is confined to a narrow angle.

Photometric analysis of LASCO imagery provided luminosity data at large phase angles where the planet had not been observed from the ground due to the solar glare. LASCO revealed that the magnitude of Mercury near inferior conjunction is about +5 while at superior conjunction it can be a thousand times brighter at magnitude -2.6. Ground-based CCD observations by the author during the same years covered phase angles closer to 90 degrees when Mercury was near greatest elongation from the Sun and outside of the LASCO field of view.



The Sun is behind the occulting disk at the center of this LASCO image and brilliant Venus is to its left. Fainter Mercury and Mars are marked below and to the upper right, respectively. Also visible are the solar corona and background stars.

The shape and the slope of a phase curve (magnitude corrected for distance and plotted against phase angle) contain clues about the mean roughness of the planetary surface. Generally, the steeper the curve the rougher the surface. Our analysis indicates that the average slope on the surface of Mercury is 16 degrees which makes it somewhat smoother than the Moon. The phase curve also indicated that Mercury's regolith or soil is compacted about as much as the Moon's and that the distribution of particle sizes is similar too. These findings will be compared to results from the MESSENGER spacecraft obtained from orbit around Mercury.



Phase curves of Mercury and Venus are characteristic of a barren planet and a cloudy planet. The magnitudes are corrected to a distance of one astronomical unit from the Sun and observer.

A similar LASCO program for Venus in 2003 and 2004 shows a distinctly different phase curve than Mercury's. At small phase angles the brightness maximum is rounded for cloudy Venus where it is steep for barren Mercury. The difference is due principally to the wide angle reflectivity of clouds and the narrow angle response of a solid surface.

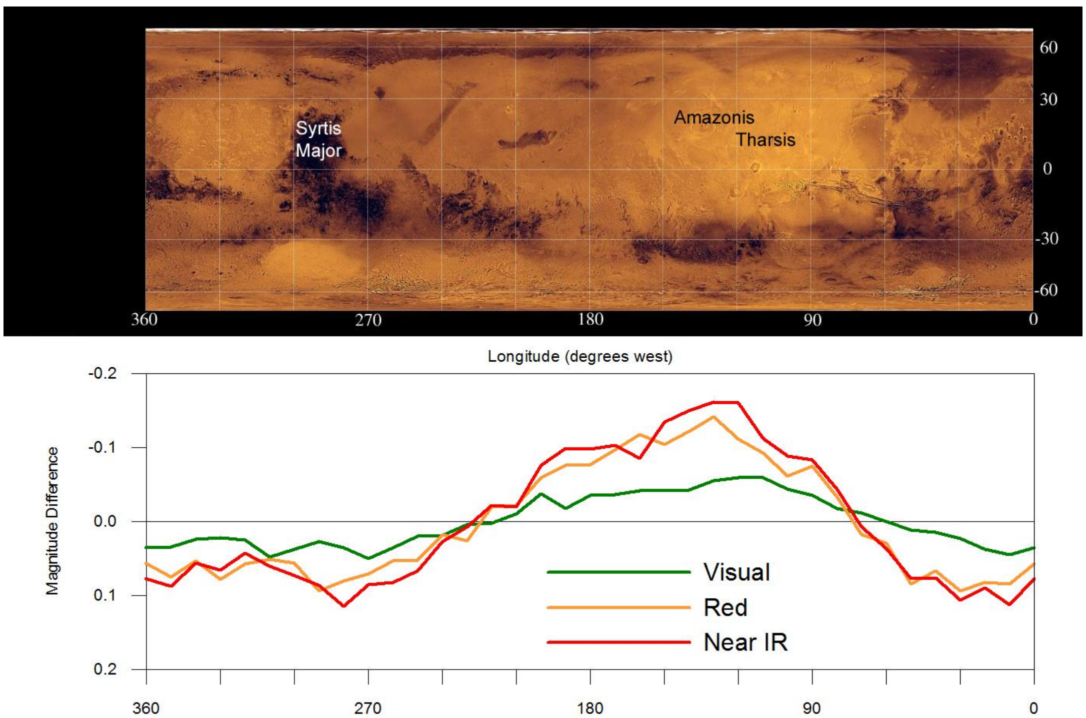
There is a surprising reversal in the phase curve of Venus near 170 degrees where the planet actually gets brighter as its crescent becomes thinner! We attribute the excess brightness to droplets of sulfuric acid based on the phase angle where the reversal occurs and on the planet's atmospheric composition. The acid droplets appear to be suspended high in the atmosphere of Venus above its opaque cloud tops. We estimated the liquid's abundance from the amount of excess brightness. Haloes sometimes seen around the Sun and Moon are an analogous phenomenon caused by water droplets in the Earth's atmosphere.

Brightness variations of Venus are far less than those of Mercury. The range is only from magnitude -3.0 around inferior conjunction to -4.8 when crescent Venus is near phase angle 125 degrees. The luminosity changes by a mere factor of 5 which is less than 1% that of Mercury. The widely scattering cloud layer that enshrouds Venus accounts for its small brightness variation.

The new LASCO and ground-based photometry for Mercury and Venus were also analyzed by James Hilton of the U.S. Naval Observatory. The formulas he derived for predicting magnitudes in the Astronomical Almanac depend exclusively on the new observations for Mercury and rely heavily on those for Venus.

Mars has an eccentric orbit so its magnitude varies significantly even from one opposition to another. At the very close approach that occurred in August 2003, Mars shone at magnitude -3.0. At a distant opposition, like that of March 2012, it will be much fainter at -1.4 . When Mars is on the far side of the Sun it can be as dim as magnitude +1.6.

The prominent surface marking on Mars and its dynamic atmosphere add dimensionality to the study of its luminosity. Fortunately abundant magnitudes are available to distinguish between these effects including a 15 year run of measurements obtained by Richard Schmude of the Association of Lunar and Planetary Observers, SOHO data and new ground-based observations by the author. The ensemble of magnitudes indicate that Mars is 10 to 15 percent brighter than previously thought.



Bright and dark features produce luminosity changes as Mars rotates on its axis. The amplitude of those variations are greater in red and near infrared light. The map is based on Viking data processed by Paul Geissler and Alfred McEwen.

The magnitude of Mars changes every few hours as bright and dark albedo features cross its central meridian. The visual luminosity is elevated by about 10 percent at west longitude 100 degrees when the bright Amazonis - Tharsis region is in view compared with longitudes near 300 degrees where the dark

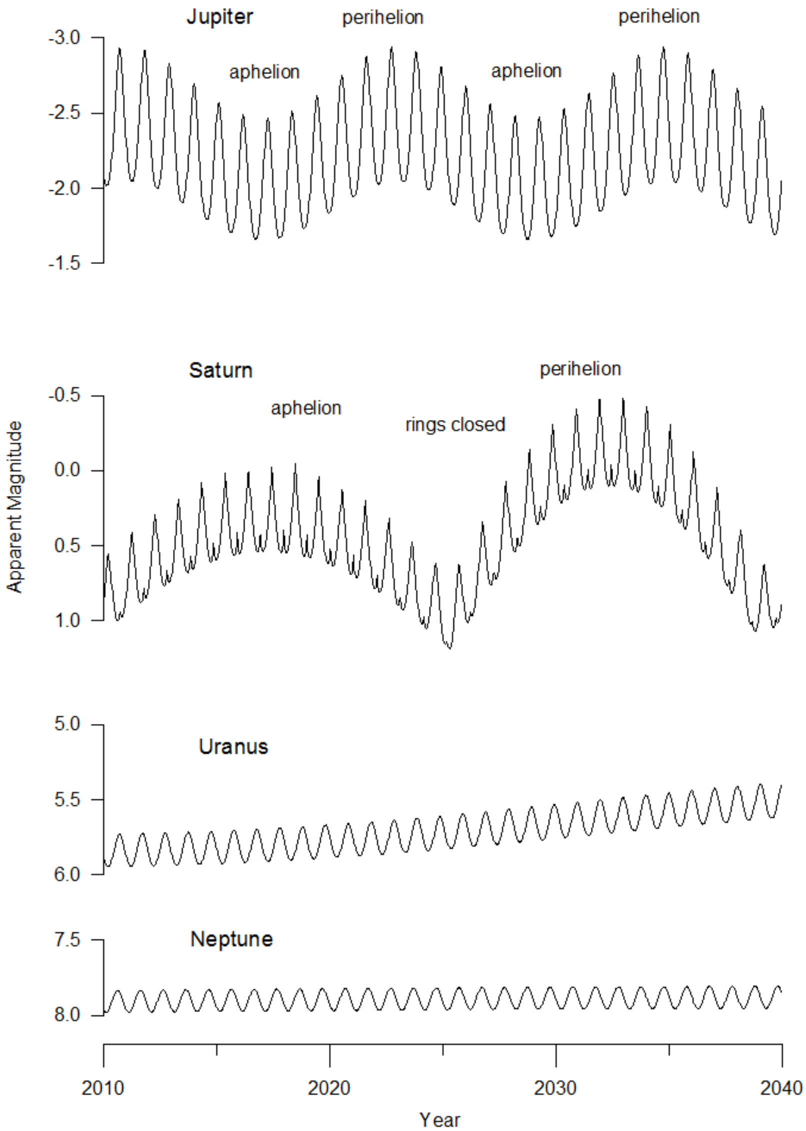
Syrtis Major feature is visible. The effect is even more pronounced at red and near-infrared wavelengths.

The presence of dust storms can affect the luminosity of Mars more strongly than its albedo markings. During the global dust storms of 2001 and 2003 the brightness surged by about a quarter of a magnitude. Photometric data suggest that the first of those storms came on suddenly and lasted at least several months while the second storm began more gradually and ended more quickly.

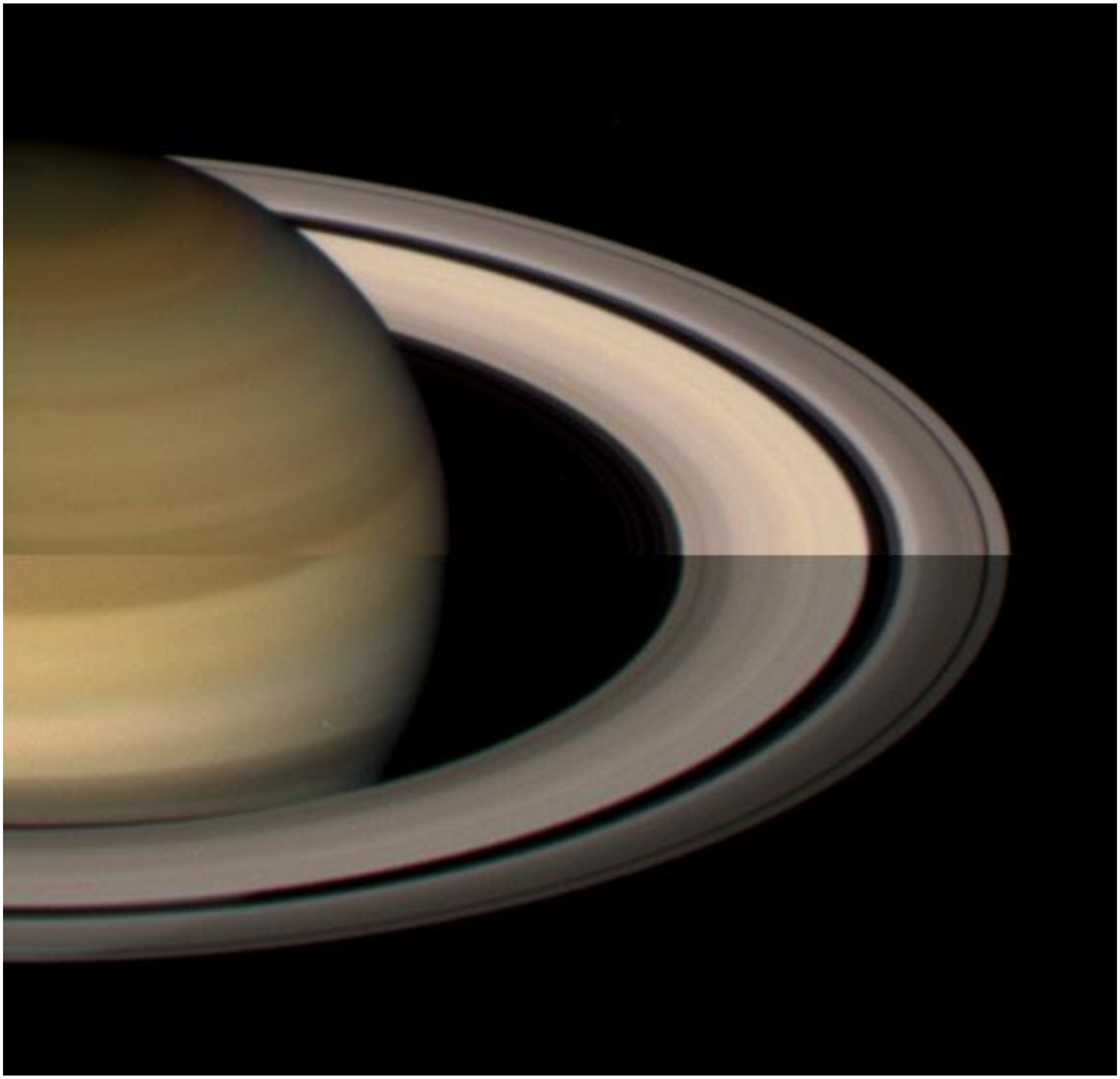
Mercury, Venus, Earth and Mars span the full range of terrestrial planet characteristics. From a photometric perspective Venus is a bright cloud orbiting the Sun while Mercury is a dimmer sphere of regolith. The Earth and Mars are intermediate between those extremes.

The gas giants, Jupiter, Saturn, Uranus and Neptune, orbit at much greater distances from the inner solar system. So, their phase angles are restricted and their disks are almost fully illuminated. The magnitudes of these planets oscillate over the course of a year as they cycle between oppositions. Jupiter typically attains magnitude -2.7 at opposition and then fades by a magnitude at superior conjunction. However, Jupiter can be as bright as -2.9 when opposition occurs near perihelion, the closest point in its orbit to the Sun.

Saturn's disk is magnitude +0.7 at an average opposition and does not change as much as Jupiter. However the ring system adds a magnitude of luminosity when displayed at the maximum inclination of 27 degrees. Moreover, images from the Hubble Space Telescope and the Cassini spacecraft demonstrate that the rings produce an extra brightness surge near opposition giving scientists insight into the size of the ring particles. Saturn will be unusually brilliant at magnitude -0.5 during the opposition of December 2032 when perihelion coincides with a wide ring opening and a phase angle of just 0.01 degree.



The luminosity of Jupiter oscillates on a yearly timescale between oppositions and on a decadal timescale between successive perihelion passages. The magnitude of Saturn is modulated by the opening angle and the opposition surge of its ring system as modeled by Richard Schmude.



Hubble Space Telescope images of Saturn taken at phase angles 0 degrees (top half) and 6 (bottom half) are spliced to highlight the opposition surge of the rings.

Uranus is twice as distant as Saturn from the Sun and Earth, and it is less than half Saturn's diameter.

Ranging between magnitudes 5 and 6 the planet is just bright enough to be seen with the unaided eye.

Uranus is becoming a little easier to see each year as it approaches perihelion.

Neptune is so remote that the intensity of sunlight is barely a thousandth of that received on Earth, and its clouds reflect less incoming light than any other giant planet. Glowing weakly at magnitude 8, Neptune was the faintest planet until the discovery of Pluto and it regained that distinction when Pluto was reclassified as a trans-Neptunian object.

The magnitudes of the planets are constantly changing as they course along their orbits. Furthermore each planet reveals something of its itself by the variations that repeat as it cycles through its phases. Add a planet’s reflectivity and size to the mix, and factor in any weather and surface markings. Then you can answer the question “How bright is that planet?”