SkyWAAtch

Iris Nebula

Gary Miller braved the sub-freezing weather at Ward Pound Ridge on November 11th to capture this image of the Iris Nebula (NGC 7203) in Cepheus. Gary used an Explore Scientific 127mm ED refractor on a Losmandy GM811G Mount. The camera was a Canon T7i dslr (50 - 60 second subs, 21 dark frames, 21 flats; stacked in Deep Sky Stacker and processed in Photoshop).

The Iris Nebula is located about 1300 light years distant and spans about six light years. The nebula is classified as a reflection nebula; it glows from the reflected light emanating from the star cluster embedded in NCC 7203. Infrared analysis of the nebula indicates the presence of polycyclic aromatic hydrocarbons (PAHs), a complex organic compound.

Events for December

WAA December Lecture

“Bright Lights from Gravitational Wave Sources”
Friday December 7th, 7:30pm
Lienhard Hall, 3rd floor
Pace University, Pleasantville, NY

Our December speaker will be Dr. Andrew MacFayden from NYU, who will discuss gravity waves. Gravitational waves are subtle ripples in space and time flowing through the universe. Albert Einstein predicted their existence in his famous theory of general relativity published in 1916, but it took a hundred years of strenuous effort for humans to detect them. In 2015, the LIGO interferometer detected gravitational waves from the inspiral and merger of two blacks hole leading to the 2017 Nobel prize in physics to LIGO's leaders. On August 17, 2017, an even more exciting event for astronomers occurred: the merging of two neutron stars accompanied by a gamma-ray burst and a "kilonova" along with long lived afterglow radiation which is still being detected. Prof. MacFayden will discuss recent research on black hole mergers, including supermassive black holes, along with predictions for ongoing astronomical observations of the merging neutron star event.

Dr. MacFayden is an Associate Professor of Physics at New York University, specializing in computational astrophysics. He obtained his degrees in astrophysics from Columbia (BA) and UC Santa Cruz (PhD) and was a postdoctoral fellow at Caltech and the Institute for Advanced Study in Princeton before coming to NYU. Directions and Map.

Note: We will hold the brief but official WAA Annual Meeting at the beginning of the meeting.

Upcoming Lectures

Leinhard Lecture Hall
Pace University, Pleasantville, NY

Our January 11th speaker will be Joe Rao. He will present on celestial highlights 2019-2022.

Call: 1-877-456-5778 (toll free) for announcements, weather cancellations, or questions. Also, don’t forget to visit the WAA website.

Starway to Heaven

Ward Pound Ridge Reservation, Cross River, NY

There are no scheduled Starway to Heaven observing events for December, January or February. Our monthly star parties will resume at Ward Pound Ridge in March 2019.

New Members. . .

David Lobato - Yonkers
Richard Segal - Yorktown Heights

Renewing Members. . .

William Meurer - Greenwich
Satchi Anderson - Tuckahoe
Edgar S Edelmann - Tarrytown
Daniel Cummings - Croton-On-Hudson
James Steck - Mahopac
Scott Nammacher - White Plains
Hans Minnich - Mahopac
Eileen Fanfarillo - Irvington
Oliver E. Wayne and Elizabeth Scott - Cliffside Park

Also In This Issue . . .

Westchester Amateur Astronomers

ALMANAC
For December 2018 by Bob Kelly


Dec 7


Dec 15


Dec 22


Dec 29

We start this month's discussion with leftovers—comets and meteors—left over from the formation of the solar system and from fragments of those leftovers, respectively.

Comet 46P Wirtanen should be visible as a fuzzy glow from dark locations as it passes the Pleiades and Hyades clusters around the 15th. 46P will scoot by Earth only 7.1 million miles away on the 16th. Since its orbit stays beyond the Earth's during its closest approach to the Sun, 46P will be in a dark sky at perihelion and easier to find than most comets when they approach the Sun. Be wary of statements about the comet 'as bright as a third magnitude star'! The comet's nucleus is tiny, so we'll be seeing its coma, the material ejected from the comet, spread out and making the comet look like a small cloudy patch. It might not show a tail. Binoculars may give the best view. It will move quite a bit from night to night. For a few days around the 15th, short, steady time exposures of the comet and the clusters might make memorable moments worth framing.

The Geminid meteor shower will peak on the morning of the 14th. The count of meteors will rise with the Gemini twins after 8pm, so quite a few Geminids may be seen on the 13th before midnight. Just keep the evening's first quarter moon out of your eyes. Early morning risers with a clear sky could see more than 60 meteors an hour. These leftovers are from 3200 Phaethon, which is spewing rocky bits out into its orbit. Scientists are debating if Phaethon is a rocky comet or an asteroid giving up pieces of its crust to space after being cooked by close passes to the Sun.

Mars is the remaining planetary beacon in the evening sky, staying up late by seeming to outrun the Sun as it climbs the ecliptic. It is tiny and lopsided in a telescope at 9 arc seconds wide and decreasing and 87 percent lit. Use it like a laser pointer to find Neptune in the same telescope view on the 6th and 7th. Neptune will be fainter than a couple of stars from Aquarius in the area. Catch the Mars/Neptune pair on a couple of nights so you can see how quickly Mars is moving against the background sky.

Uranus will be higher and brighter than Neptune, but among the faint sparkles of Aries and Pisces, it doesn't have its own pointer-outer star or planet.

Saturn lies low in the southwest and goes to bed soon after sunset.

Venus, low in the southeast, dominates the morning sky. The Morning Star seems to linger, not gaining altitude into the celestial dome. It's as if Venus is waiting for her friends Jupiter and Mercury to join her. Far to the lower left of Venus, Mercury and Jupiter do their impression of two fellows trying to get through a door at the same time. Mercury zips up in the first week of December with the Moon dropping down nearby on the 5th. The following week, Mercury gains altitude, and attitude, as it brightens past zero magnitude. On the 15th, Mercury seems to run out of gas and peaks at 11 degrees above the horizon a half hour before sunrise. Jupiter comes up to greet him in the week of the 17th. On the 22nd, they are side-by-side, about a degree apart. At magnitude minus 1.8, Jupiter is brighter than Mercury's minus 0.4, but when you look at them in a telescope, Jupiter looks larger, as expected, but ghostly. Jupiter spreads out its brightness over a larger area than Mercury; so Jupiter has a dimmer surface brightness. (Another example this month of how total magnitude and surface brightness are different. This difference will make getting a good photo of both through a telescope more challenging.) Jupiter and Venus will meet up in late January. Compare photos of the Mars/Neptune, Jupiter/Mercury and Jupiter/Venus pairings.

Celebrate the old and new years outdoors and inside! Start with WAA'er Scott Levine's spread in Sky and Telescope on watching the stars roll by on New Years' Eve/New Years' morning. Then, pull up a chair and watch the early returns from New Horizons' reconnaissance of Kuiper Belt object Ultima Thule. The NH team has scheduled some inbound photos to return to Earth on the afternoon of the 31st and some photos from the midnight close approach should arrive by the evening of New Years' Day.

What we northern hemisphereians call the 'Winter' Solstice occurs at 5:23pm ET on the 21st. Earliest sunsets occur in the first half of December. Latest sunrises happen in early January.

December's lunar perigee occurs 40 hours after the December 22nd full moon. Next month, perigee is only several hours from the total lunar eclipse.

Preview of 2019 Events and a Guide to Guides

Bob Kelly

The Moon and Inner Planets:

There are five eclipses in 2019; six, if you count the transit of Mercury partially eclipsing the Sun. The transit, plus one total lunar eclipse, are visible from the USA.

- Jan 1: New Horizons spacecraft flies by Kuiper Belt object Ultima Thule.
- Jan: Good morning appearance of Venus.
- Late Feb: Mercury has its best appearance in the evening sky
- Jan 20/21: A Supermoon Midnight Total Lunar Eclipse. Lunar perigee is only 15 hours later.
- Feb 19: Largest full moon in 2019
- Early Jun: A good appearance of Mercury in the evening sky
- Aug 30, Sep 27: Invisible supermoon: perigee at new moon. Beware of larger than normal tides with all new and full moons near perigee.
- Mon Nov 11: Transit of Mercury 7:36am to 1:04pm EST. Next Mercury transit 2032. Next Venus transit 2117.
- Late Nov: Best appearance of Mercury in the morning sky through early December.
- Late Dec: Venus' appearance into the evening sky improves into early 2020.

The Outer Planets:

- Mars in the evening sky January through May. Higher and more noticeable, even though dimmer and tiny. In November, Mars pops into the morning sky, even tinier than earlier this year on its way to a 2020 opposition.
- Jupiter starts in the morning sky, reaches opposition in June. Visible in the evening sky though November.
- Saturn rises in the morning sky in February, reaches opposition in July. In evening sky through November. Rings not as wide as 2018, but still very wide open.
- Neptune reaches opposition in September, Uranus in October.

Meteor showers:

- The Quadrantids peak on January 3-4, but the center of the storm is at 3pm and the peak only lasts for ¼ of a day. The source rises around 10pm our time. No moonlight to interfere this year, so it's worth a look to see occasional fireballs.
- Our favorite strong showers, the Perseids of August and the Geminids of December occur during nearly full moons.
- We may need to look to the weaker Aquirids of early May and late July for excitement. The daytime Taurids may have a rare dense stream of larger meteors spill over into nighttime in late June.

Our Quiet Sun:

Like the footballer who breaks through the stout defense to score, coronal holes can develop even during the present minimum in solar activity and produce strong aurorae that might be viewed even this far south. With only 136 days with any sunspots so far in 2018, white light solar viewers like me have been sorely lacking for targets. This situation is likely to continue for the next few years.

A Guide to Guides About What's Happening in the Heavens in 2019

The Astronomical Almanac (2019 – 2023) by Richard J. Bartlett: Divided into sets of 10 days, with daily information about lunar and planetary location, brightness, phase, size and visibility. List of significant events. Illustrations show the apparent size of the planets each 10 days. Glossary not only explains all the entries, it often has helpful descriptions of how to use the data.

2019 Guide to the Night Sky by Dunlop and Tirion: Be sure to get the North American edition. Light and wonderfully handy. Whoever decided "we should turn the pages to be viewed in the landscape (sideways) direction" should get a prize. Includes sky charts, descriptions of objects and how to find them and diagrams of significant sights for each month. Strangely, no entry for the transit of Mercury in November 2019.

Observer's Handbook 2019 – Royal Astronomical Society of Canada: Second year where the Canadians have translated their almanac into a United States language and location edition. Lots of data. Each month has a two-page listing of events and summary of planetary locations and visibility. Well-written sections on astronomical topics. Like a textbook, but with without the heft or the high sticker price. Great section on observing the Sea of Tranquility this 50th year after the first moon landing.

<u>Sky Watch 2019</u> from Sky and Telescope:* This is a classic. A lightweight magazine with monthly star maps, planet visibility and highlights. Articles with observing and equipment tips. Great for beginners, but not just. Buy two and give one away to a budding astronomer.

<u>Skygazer's Almanac 2019</u> from Sky and Telescope:* A graphical almanac, this two page graph of rise and set times is a great way to see how our universe moves on a giant timeline of the night sky. Worth getting January's issue of S&T just to get the chart. Also available for purchase as a wall poster. The digital version, the printed mag will be out in a week or so.

<u>Astronomical Almanac for the Year 2019:</u> From the US Department of the Navy and UK Nautical Almanac Office More than most of us need on exact planetary positions.

The <u>Astronomical Phenomena for the Year 2019:</u> Pamphlet includes the most useful information for observers, excerpted from the Astronomical Almanac. Strangely, it is backordered at the US Gov't Bookstore. It used to be available as a free PDF from the US Naval Observatory website two years in advance, but the last copy is for 2018 and I can't find out why.

*Not published as of press time.

Astrophotos

Flame Nebula and Horsehead

Mauri Rosenthal captured this image of the bright Flame and dark Horsehead Nebulae which flank Alnitak, the first star in Orion's belt. He used a Borg 71FL lens with a 2X Powermate to provide an 800mm focal length scope mounted on a portable iOptron CubePro 8200. Forty minutes of 8 second exposures were shot with a ZWO 1600MC cooled astrocam through an IDAS LPS-V4 filter which has become Mauri's favorite for dealing with light pollution. This was shot from his Scarsdale yard during the brilliant "Beaver" full moon just before Thanksgiving.

Japanese Nightscape

The Japanese city of Takamatsu, population 418,000, lights up the underside of the clouds over Kagawa Prefecture on the Japanese island of Shikoku. Mars shines overhead and 1.2 magnitude Alpha Piscinus Australis, better known as Fomalhaut, is visible through a gap on the left center of the image. The photo was taken by Larry Faltz from the south coast of Naoshima Island, 7 miles north of Takamatsu across Japan's Inland Sea, on October 28, 2018.

Phobos: Doomed Moon of Mars

This moon is doomed. Mars has two tiny moons. The larger moon, at 25-kilometers across, is Phobos, and is seen to be a cratered, asteroid-like object in this false-colored image mosaic taken by the robotic Viking 1 mission in 1978. Phobos orbits so close to Mars - about 5,800 kilometers above the surface compared to 400,000 kilometers for our Moon - that gravitational tidal forces are dragging it down. The ultimate result will be for Phobos to break up in orbit and then crash down onto the Martian surface in about 50 million years.

Credit APOD.

Image Credit: Viking Project, JPL, NASA; *Mosaic Processing:* Edwin V. Bell II (NSSDC/Raytheon ITSS)

Weighing the Earth: Measuring the Gravitational Constant

Larry Faltz

Science continues to describe the world with ever-increasing accuracy. In particular, the values of the physical constants of nature keep getting more and more precise. The fine structure constant α, describing the coupling of charged particles to the electric field (among other uses), is known accurately to 11 decimal places. Its currently accepted value is 0.0072973525664(17) (a useful approximation is $^1/_{137}$). The charge of the electron is known to eight decimal places, $1.6021766208(98)\times10^{-19}$ Coulombs. The magnetic moment (μ_e) of a single electron is $-928.4764620(57)\times10^{-26}$ J T^{-1}. The difference between the mass of a proton and that of a neutron is $2.30557377(85)\times10^{-30}$ kg. Boltzmann's constant, critical in thermodynamics and the physics of gases, is $1.38064852(79)\times10^{-23}$ J K^{-1}. Avogadro's number, the number of atoms in a "mole" of an element (its atomic weight in grams), is $6.022140857(74)\times10^{23}$ mol^{-1}. The Compton wavelength of an electron is $2.4263102367(11)\times10^{-12}$ m. The Rydberg constant, important in spectroscopy, is 10973731.568508(65) m^{-1}.The hyperfine transition of hydrogen, so important for radio astronomy, emits a photon with a frequency of 1420405751.7667(09) Mhz. The numbers in parentheses express the variation in the last two digits of the value. You can find a list of currently accepted values for a large number of physical constants on the web site of the National Institute of Science and Technology.[1] The official values are vetted by the Committee on Data of the International Council for Science, also known as CODATA.

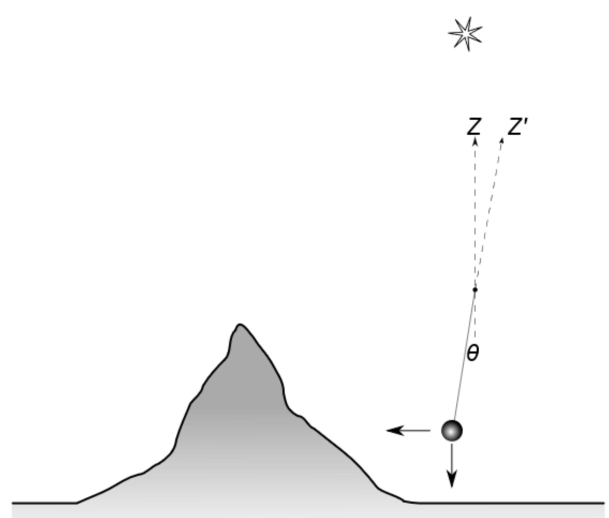
Amazingly, one of the first constants of nature to be proposed, Newton's gravitational constant *G* (*a.k.a.* "Big *G*" to distinguish it from *g*, the force of gravitation at the Earth's surface) is only known accurately to only three significant digits. The value given by NIST is $6.67408(31)\times10^{-11}$ m^3 kg^{-1} s^{-2}. This level of imprecision, compared to other fundamental constants, was described in 2014 as "irritating" by Terry Quinn, former director of the International Bureau of Weights and Measures (BIPM) in Paris.

Gravity is very weak. Just think of how easily a tiny magnet holds up a paper clip against the force exerted by the entire Earth. Gravity is about 10^{-38} as strong as electromagnetism. As a result, it is hard to measure it with instruments of laboratory-scale mass.

The gravitational constant is familiar to us in the Newtonian formulation of the gravitational force that we learned in high school:

$$F = G\frac{m_1 m_2}{r^2}$$

This equation was actually not used by Newton, but was cast into this form in the late 19th century. Newton's understanding of gravity is developed in the *Philosophiæ Naturalis Principia Mathematica*, undoubtedly the most important single work in the history of science. The first edition dates from 1687. In Book III, Proposition VII states "That there is a power of gravity tending to all bodies, proportional to the several quantities of matter which they contain." Proposition VIII states "In two spheres mutually gravitating, each towards the other, if the matter in planes on all sides round about and equidistant from the centers is similar, the weight of either sphere towards the other will be reciprocally as the square of the distance between their centers."



A large mountain causes a deflection of a plumb line from the vertical, found by projecting it onto the celestial sphere.

Newton considered how to measure the proportionality factor but did not calculate it himself. He suggested that a large mountain could disturb the position of a nearby plumb-line from the vertical because it exerted a gravitational force at right angles to that of the Earth. To

[1] https://physics.nist.gov/cuu/Constants/index.html

measure the deflection, one has to measure the change in the position of the plumb line projected onto the fixed stars. Newton thought that the effect would be too small to detect. Some others didn't.

The first attempt to measure the strength of gravitation by this method was made in December 1738 by two French astronomers, Pierre Bouguer and Charles Marie de La Condamine. They had been sent to measure the length of one degree of arc at the equator, but realized that the massive, symmetrical stratovolcano Chimborazo in Ecuador (20,564 ft.) might provide sufficient mass to deflect a plumb line. They were able to measure a deviation of 8 seconds of arc and published their results in 1749. The quantity they calculated was actually not *G* but the density of the Earth. By extension, since its diameter was known, the Earth's mass could be determined. The density value was high enough to prove that the Earth was not hollow, as was believed by many people, Edmund Halley among them. Bouguer and La Condamine could not accurately measure the volume of the mountain, so they recognized their value was approximate, and they recommended that the measurements be made in Europe with better equipment.

Chimborazo (1864) by Hudson River School artist Frederic Edwin Church. Huntington Library, San Marino, California.

The band of brilliant and curious gentlemen in the Royal Society took up the challenge. In 1772, Astronomer Royal Neville Maskelyne proposed several sites in Great Britain for the experiment, and a "Committee of Attraction" (sounds like a dating service, doesn't it?) was appointed, its members including Maskelyne, Joseph Banks and Benjamin Franklin. Charles Mason, the surveyor of the Mason-Dixon Line and an astronomer himself, was sent to find a suitable peak. To ensure that its volume could be reasonably estimated, the mountain should be relatively conical, like Chimborazo. Mason reported that Schiehallion, a 3,553-foot massif in the southern Scottish Highlands, had favorable characteristics.

Maskelyne undertook the experiment. Observatories were constructed on either the side of the mountain. Very high quality instruments were laid in, including a quadrant that had been used on Captain Cook's 1769 Transit of Venus expedition to Tahiti, on which Banks had been the botanist. Banks was later President of the Royal Society for 40 years and a big supporter of William Herschel.

Measurements were made during the rare clear nights, this being Scotland after all. Maskelyne had to compensate for the Earth's curvature and other factors, but was finally able to come up with a preliminary value for the deviation of 11.6 seconds of arc. Maskelyne made calculations that suggested that if the densities of the Earth and the mountain were the same, the deflection should have been twice that value; thus, the Earth was at least twice as dense as the mountain, and therefore couldn't simply be made of rock. More exact computations would be made after Charles Hutton surveyed the area in order to better estimate the mountain's actual volume.

When Hutton finished his survey in 1776, it took him two years to reduce the data. In 1778 he presented a paper to the Royal Society in which he calculated the mean density of the Earth to be 4,500 $kg{\cdot}m^{-3}$. He suggested that the center of the Earth was metallic, with a density of 10,000 $kg{\cdot}m^{-3}$ occupying 65% of the planet's volume. The current value for the Earth's density is 5,515 $kg{\cdot}m^{-3}$, a difference of 20%. This isn't a bad result for so complex a measurement.

The importance of this value for astronomy was enormous. It allowed Hutton to calculate the densities of the planets, utilizing mass data derived from their by then well-defined orbits. His results were reasonably in the ball-park except for Mercury, which was overestimated by 69%. He found that the Sun, Jupiter and Saturn had much lower densities than the inner planets.

Needing to measure the volume of a mountain isn't an optimal way to do experimental science. It was just 20 years later that another Royal Society member, the prolific Henry Cavendish, performed an experiment that became the prototype for subsequent measurements of the gravitational constant.

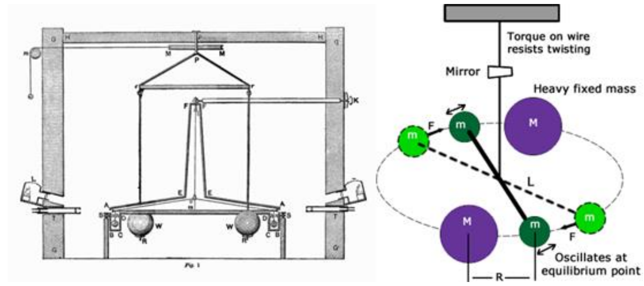
Cavendish was primarily a chemist. He gets the credit for identifying hydrogen and determining that the ratio of hydrogen to oxygen in water is 2:1, although he delayed publication of his results and James Watt beat him to literature priority. He also found that the ratio of nitrogen to oxygen in air was 4:1. He correctly identified heat as the motion of matter and not a material substance, as was previously thought.

John Michell, the astronomer who first envisioned the possibility of black holes, invented the torsion balance, a device that could measure the strength of gravitation. He built one, but died in 1793 before he could use it. Cavendish obtained it and set up the apparatus on his property at Clapham Common, a mile south of the Thames in London. The Common is now a park surrounded by a densely populated section of the city, but in the 1790's it was still very suburban.

Cavendish called his experiment "weighing the Earth." The Michell/Cavendish torsion balance allowed measurement of the gravitational attraction between small lead balls at either end of a wooden rod suspended on a wire and a pair of larger, stationary lead balls. The smaller balls were 2 inches in diameter and weighed 1.61 pounds each. The larger ones were 12 inches in diameter and weighed 348 pounds each. The balls were separated by a distance of 9 inches. Gravitational attraction of the masses deflected the balls and caused them to twist on the wire. The oscillation of the device depended on the torque on the wire at a given angle. Earth's gravity is not a direct factor in the experiment because it is at right angles to the masses and therefore is nulled out. Since the gravitational attraction of the Earth to the small balls can be found simply by weighing them, the ratio of the attraction of the balls to each other and then to the gravitation of the Earth could be determined. From that the mass of the Earth and then its density (since its volume was known) could be calculated. Cavendish's apparatus took pains to minimize temperature changes and air currents, and he observed the displacement of the balance using a telescope so that he wouldn't disturb its motion. The deflection was only 0.16 inches, but his observations were so accurate that he was able to calculate the Earth's density as 5.448 ± 0.033 kg·m^{-3}. This translates into a value for G of 6.74×10^{-11} m^3 kg^{-1} s^{-2}, just 1% from the current CODATA value. Like the French, Cavendish didn't measure G itself, but it can be done using the formula

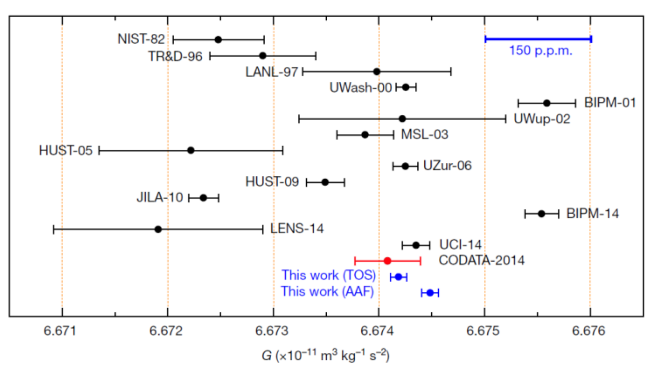
$$G = g\frac{R_{\text{Earth}}^2}{M_{\text{Earth}}} = \frac{3g}{4\pi R_{\text{Earth}}\,\rho_{\text{Earth}}}$$

where g is the gravitational acceleration at the Earth's surface (32 feet sec^{-2} or 9.8 meters sec^{-2}). The values for R, M and g were already known to reasonable accuracy, so by determining the Earth's density (ρ) out pops Big G.



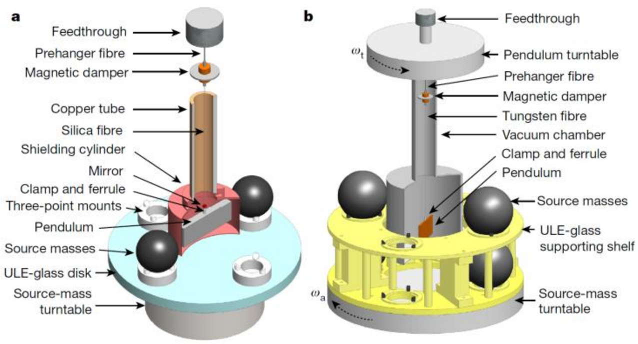
Cavendish's apparatus and a schematic of how it works.

Over the next 200 years the torsion balance was technically, but not conceptually, refined, as we would expect from the march of science and technology. Since Cavendish, over 200 experiments have been performed with it to determine G. Better isolation from vibrations, temperature control to a few thousandths of a degree Kelvin, more accurate component masses, sophisticated measuring techniques and other improvements got results within a spread of 0.05% by the end of the 20$^{\text{th}}$ century, but that only added two decimal places to the absolute value, results that Terry Quinn calls "extraordinarily imprecise." In 2000, a substantial improvement in the apparatus was made by substituting a thin plate in place of the two smaller balls, called a "plate pendulum." The uncertainty within each experiment was reduced to 21 parts per million by 2010, but the absolute value obtained by different experiments still varied over a span of 750 parts per million. Since CODATA has to report *some* value as the standard for the world to use, the value of $G = 6.67408(31)$ was chosen. This may still not be correct, since many well-performed experiments gave results outside of the range of variance. Were the experiments or the apparatus not fully understood by their creators, resulting in hidden systematic errors in each case? Is there some unknown fundamental physics at play?



Results of measurements of G over the past 40 years. The red point and error bars are the official CODATA value. Error bars are 1σ. Fig 3 from Qing *et. al*.

In the August 30, 2018 issue of *Nature*, a large group of experimenters led by Jun Luo from the Huazong University of Science in China reported on measurements of *G* using two variations of the plate pendulum.[2] By using different, exquisitely crafted instruments and taking data from multiple runs, the experimenters hoped to cancel out unknown systematic errors. The apparatuses were constructed to use different detection methods. The "time of swing" (TOS) method measures the change in the oscillation frequency of the pendulum when the test masses are in different positions. The "angular-acceleration-feedback" (AAF) method uses two turntables that interact to cancel out the twist angle of the fiber on which the pendulum is suspended, providing a direct readout of the gravitational acceleration of the test masses.



The TOS device (a) and the AAF device (b). The stainless steel spheres in (a) are 57.2 mm in diameter and weigh 778 grams. The fiber is 900 mm long. In (b) the fiber is 870 mm long, the stainless steel spheres 127 mm in diameter and weigh 8,541 grams.

The paper in *Nature* describes the two devices and addresses the technology and possible systematic error sources in incredible detail. Supplemental material posted on line, a common practice in research papers these days, includes a data table with 36,000 entries! After meticulously performing experiments over a three-year period, the group obtained a value of *G* by the TOS method of 6.674186(78) with a relative uncertainty of 11.64 parts per million and by the AAF method of 6.674484(78) with a relative uncertainty of 11.61 parts per million. The two values do not overlap at 1σ, as seen in the diagram on the previous page (these values are at the bottom of the figure in blue). The authors state "The *G* values obtained with the two independent methods have the smallest uncertainty reported until now and both agree with the CODATA-2014 value within a 2σ range, indicating the substantial contribution of this work to the determination of the true value of *G*." But they admit "we currently have no definite explanation for the inconsistency between the two results. This illustrates that determining the true value of *G* is very difficult." Indeed, we may be a bit closer to the truth, but we're still quite far away from the precision of other fundamental constants.

Why is measurement of *G* important for astronomy? Our current understanding of gravitation, using the accepted value of *G*, seems adequate for routine use. The planets are always where we expect them to be. New Horizons was within 60 miles of its target window after a journey of more than 4.67 billion miles. However, making progress in some of the most important cosmological problems depends on an accurate value of *G*. Solutions of General Relativity relating to the expansion of the universe will vary subtly for different values of *G*. Determining the quantity and behavior of dark matter needs a precise *G*. Sophisticated supercomputer simulations of galaxy formation in the epoch after recombination (the formation of the cosmic microwave background at 380,000 years after the Big Bang) also depend on *G*. As these simulations undergo multiple iterations, deviations from the true value of *G* will mislead the results with increasing inaccuracy. Predicting the magnitude of accelerated expansion by dark energy is another important use for an accurate value of *G*.

There has been an explosion of interest in understanding and modeling the high gravitation regimes of neutron stars and black holes. Calculations of the behavior of matter in such situations require an accurate value of *G*. Simulations of black hole and neutron star mergers, needed to determine the likely masses of the precursor objects and the amount of energy released, also need *G* to be accurate, since they too depend on iterative modeling.

We would expect precise physical experiments measuring fundamental constants to place results within the (larger) error bars of prior results. That's how science ought to progress. That this is not quite the case for recent determinations of *G* is both frustrating and intriguing. It's rare for a sophisticated research group to show their work in such detail and yet admit that they don't have an explanation for failing to nail down the answer. Future attempts must address whether there is something fundamental about physics that prevents *G* from being accurately determined. ■

[2] Qing Li, Chao Xue, Jian-Ping Liu, *et. al.*, Measurements of the gravitational constant using two independent methods, *Nature* 2018; 560: 582-588

NASA Night Sky Notes: Observe Apollo 8's Lunar Milestones

David Prosper

December marks the 50th anniversary of NASA's Apollo 8 mission, when humans first orbited the Moon in a triumph of human engineering. The mission may be most famous for "Earthrise," the iconic photograph of Earth suspended over the rugged lunar surface. "Earthrise" inspired the imaginations of people around the world and remains one of the most famous photos ever taken. This month also brings a great potential display of the Geminids and a close approach by Comet 46P/Wirtanen

You can take note of Apollo 8's mission milestones while observing the Moon this month. Watch the nearly full Moon rise just before sunset on December 21, exactly 50 years after Apollo 8 launched; it will be near the bright orange star Aldebaran in Taurus. The following evenings watch it pass over the top of Orion and on through Gemini; on those days five decades earlier, astronauts Frank Borman, Jim Lovell, and Bill Anders sped towards the Moon in their fully crewed command module. Notice how the Moon rises later each evening, and how its phase wanes from full on Dec 22 to gibbous through the rest of the week. Can you imagine what phase Earth would appear as if you were standing on the Moon, looking back? The three brave astronauts spent 20 sleepless hours in orbit around the Moon, starting on Dec 24, 1968. During those ten orbits they became the first humans to see with their own eyes both the far side of the Moon and an Earthrise! The crew telecast a holiday message on December 25 to a record number of Earthbound viewers as they orbited over the lifeless lunar terrain; "Good night, good luck, a merry Christmas and God bless all of you - all of you on the good Earth." 50 years later, spot the Moon on these holiday evenings as it travels through Cancer and Leo. Just two days later the astronauts splashed down into the Pacific Ocean after achieving all the mission's test objectives, paving the way for another giant leap in space exploration the following year.

The Geminids, an excellent annual meteor shower, peaks the evening of December 13 through the morning of the 14th. They get their chance to truly shine after a waxing crescent Moon sets around 10:30 pm on the 13th. Expert Geminid observers can spot around 100 meteors per hour under ideal conditions. You'll spot quite a few meteors by avoiding bad weather and light pollution if you can, and of course make sure to bundle up and take frequent warming breaks. The Geminids have an unusual origin compared to most meteor showers, which generally spring from icy comets. The tiny particles Earth passes through these evenings come from a strange "rock comet" named asteroid 3200 Phaethon. This dusty asteroid experiences faint outbursts of fine particles of rock instead of ice.

You can also look for comet 46P/Wirtanen while you're out meteor watching. Its closest approach to Earth brings it within 7.1 million miles of us on December 16. That's 30 times the average Earth-Moon distance! While passing near enough to rank as the 10th closest cometary approach in modern times, there is no danger of this object striking our planet. Cometary brightness is hard to predict, and while there is a chance comet 46P/Wirtanen may flare up to naked eye visibility, it will likely remain visible only via binoculars or telescopes. You'll be able to see for yourself how much 46P/Wirtanen actually brightens. Some of the best nights to hunt for it will be December 15 and 16 as it passes between two prominent star clusters in Taurus: the Pleiades and the V-shaped Hyades. Happy hunting!

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Earthrise, 1968. Note the phase of Earth as seen from the Moon. Nearside lunar observers see Earth go through a complete set of phases. However, only orbiting astronauts witness Earthrises; for stationary lunar observers, Earth barely moves at all. Why is that?
Credit: Bill Anders/NASA

Member & Club Equipment for Sale

December 2018

Item	Description	Asking price	Name/Email
Celestron 8" SCT on Advanced VX mount	Purchased in 2016. Equatorial mount, portable power supply, polar scope, AC adaptor, manual, new condition.	$1450	Santian Vataj spvataj@hotmail.com
Celestron CPC800 8" SCT (alt-az mount)	Like new condition, perfect optics. Starizona Hyperstar-ready secondary (allows interchangeable conversion to 8" f/2 astrograph if you get a Hyperstar and wedge). Additional accessories: see August newsletter for details. Donated to WAA.	$1100	WAA ads@westchesterastronomers.org
Celestron StarSense autoalign	New condition. Accurate auto-alignment. Works with all recent Celestron telescopes (fork mount or GEM). See info on Celestron web site. Complete with hand control, cable, 2 mounts, original packaging, documentation. List $359. Donated to WAA.	$225	WAA ads@westchesterastronomers.org
Meade 395 90 mm achromatic refractor	Long-tube refractor, f/11 (focal length 1000 mm). Straight-through finder. Rings but no dovetail. 1.25" rack-and-pinion focuser. No eyepiece. Excellent condition. A "planet killer." Donated to WAA.	$100	WAA ads@westchesterastronomers.org
Televue 55mm 2-inch Plossl.	Very lightly used. Excellent condition. Original box.	$175	Eugene Lewis genelew1@gmail.com

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