Air and Space this Week

Item of the Week

THE THINGS ASTRONOMERS LEARN WHEN THEY STUDY WHEN THINGS GO IN FRONT OF OTHER THINGS

Originally appeared March 4, 2024

KEY WORDS: Eclipse Transit Einstein Helium Eddington Mariner 4 Rings Exoplanets Lensing

The upcoming total solar eclipse is a wonderful education/outreach astronomical event. While two past solar eclipses played a very important role in the advancement of Scientific Knowledge, today the biggest value of a total solar eclipse is that it engages the educational process for learners of all ages and backgrounds. It's also an opportunity for me to make an Item inspired by a rather overly-silly Monty Python sketch (YouTube) about a meeting of the non-existent Royal Society for the Putting of Things on Top of Other Things.

In this case, astronomers DO learn a lot of things "when things go in front of other things!"

ASTRONMERS LEARN FROM A TOTAL SOLAR ECLIPSE

A total solar eclipse occurs when the Moon passes **directly in front of** the Sun. Two total solar eclipses in history allowed astronomers to make two important physical science contributions: the discovery of a new element, previously unknown, in the Sun, and the confirmation of Einstein's Theory of Special Relativity.

THE DISCOVERY OF HELIUM

Isaac Newton showed that sunlight was actually a blend of all of the colors in the rainbow, by passing sunlight through a prism. Subsequent astronomers developed the branch of astronomical science we now know as "spectroscopy" when they found that the light of the Sun was missing certain wavelengths (colors), each set unique to a specific element. Those particular wavelengths would be absorbed by the gases in the lower solar "atmosphere" and then be re-emitted in all directions. If you were looking at the Sun, the spectrum of the sunlight would be dark in those specific wavelengths (an "absorption spectrum"); if you were looking at the gas alone from the side, you'd see *only* those specific wavelengths of light (an "emission" spectrum.

Astronomer Pierre Janssen, observing the edge of the Sun during the total solar eclipse of 1868, obtained an emission spectrum of the lower solar atmosphere that showed the emission wavelengths of a number of known gases, including hydrogen and sodium. It also showed a bright orange wavelength that did not correspond to any known element. Astronomer Joseph Normal Lockyer found a way very soon after the eclipse to obtain a spectrum from the Sun without needing an eclipse, and he saw the same thing Janssen did. The new element, which wasn't found on Earth until several years later, was named "helium," after the Greek God of the Sun, Helios.

EINSTEIN CONFIRMED

One of the predictions derived from Einstein's Theory of Special Relativity was that a gravitational field could affect the passage of light through it. A beam of light passing by a massive object would be deflected by the object's gravity a very slight, but measurable, amount. The problem was, how could such a deflection be measured given how bright the Sun is? Astronomers knew that if they could compare the positions of stars very close to a totally-eclipsed Sun and the positions of those same stars when the Sun was nowhere near them, they could confirm or reject Einstein's theory.

The total solar eclipse of 1919 would be the first satisfactory eclipse to observe since Einstein presented his theory. Two expeditions were mounted, and the one led by Arthur Eddington claimed success. Some have since questioned whether Eddington's observations were definitive, but he got the headlines and the credit, and a knighthood to boot. Subsequent observations have proved Einstein to be correct, and today, recreating Eddington's observations are a popular exercise for advanced astronomy students (*e.g.* here).

See also the *Smithsonian Magazine* article here: https://www.smithsonianmag.com/science-nature/total-solar-eclipse-100-years-ago-proved-einsteins-general-relativity-180972278 and

Nordgren, Tyler, 2016, *Sun Moon Earth: The History of Solar Eclipses from Omens of Doom to Einstein and Exoplanets*, New York: Basic Books, ISBN 978-0465060924.

ECLISPING BINARIES

The night sky provides information for the astronomers, of course, but it also informs the research of archaeologists attempting to understand earlier civilizations, many of which were surprisingly sophisticated in their understanding of observational astronomy. The names we use today for many of the constellations come to use from the Greeks of more than two millennia ago, who came up with them by borrowing from even earlier civilizations; we use the Greek names because they were recorded for posterity more effectively. Yet most star names are Arabic, derived from the Dark Ages time after the burning of the Library of Alexandria when the seat of astronomical learning moved solidly into the Arab world.

The prevailing view of the sky in both Greek and Arab thinking was that there were seven objects in the sky that moved relative to a background of stars that kept their same position and brightness, rising and setting at the same points on the horizon and following the same path across the sky, as though they were "fixed" to an overhead sphere. The Sun and the Moon, and the five known planets (the very word "planet" comes from the Greek word for "wanderer") moved over the starry background in a predictable way.

But the Arabs knew that one star was different (and some earlier civilizations knew it, too). Anything unusual or different on the land or in the sky was almost always regarded as being evil or dangerous in some way, and this particular star was no different. It varied in brightness in a very predictable, but undeniable, way.

The Arabs called this star “Rā’s al Ghūl” the “Head of the Demon.” We know it today as “Algol.” The Greeks had it marking the head of the Gorgon, Medusa, the gal with snakes for hair and a look that could turn anyone into stone, slain be Perseus. The Greeks and Arabs weren’t the first to notice this star’s variations in brightness; Algol also figured similarly in astronomical depictions from other early civilizations.

Undeterred by possible statue-dom, astronomers found that Algol was actually a pair of stars orbiting their common center of gravity, with the Earth happening to lie in the plane of the orbit, so we see them **pass in front of each other**. That’s what makes the brightness drop off; one of the two otherwise visible stars is blocking the light of the other. Astronomers know that Algol is not the only member of the “Eclipsing Binary” types of star systems, and they have worked out a lot of information about the stars comprising eclipsing pairs by analyzing in detail how the system’s total brightness varies over their rotational period. [For an example, see: https://britastro.org/vss/Handbook15b.pdf.]

TRANSITS AND THE SIZE OF THE SOLAR SYSTEM

Simple trigonometry is in many cases all that is needed to measure sizes on an astronomical scale. For example, observing the Venus-Sun-Earth angle when half the illuminated side of Venus is visible allows for a reasonably-accurate measurement of the size of the Solar System, but not in absolute units (miles, kilometer, etc.), but rather in terms of the Earth-Sun distance. This much was known by 1750 CE. But how large is the Earth-Sun distance?

Scottish mathematician James Gregory came up with the idea that if simultaneous measurements of a transit of Venus, those rare events when Venus passes **directly in front of** the Sun at its inferior conjunction and is seen against the Sun’s face in silhouette, could be made, then the actual distance to Venus could be worked out, which would then yield the actual distance to the Sun to be worked out trigonometrically. Edmund Halley, of comet fame, amplified and promoted Gregory’s idea in the Royal Society in 1716. But the technique needed simultaneous observations from a number of locations spread out across the side of the Earth facing Venus during the transit.

The island of Tahiti had been reached by the Polynesian diaspora around 500 BCE. There is no consensus as to the first arrival of Europeans. Spanish explorer Juan Fernandez was in the general area in 1576-1577 and Portuguese navigator Pedro Frenandes de Queiros was, too, in 1606, but neither have a definitive claim to actually visiting Tahiti.

The English and French had just the Seven Years’ War, a European-wide conflict that spilled over to North America as well as many other places. Even though the outright fighting was over, there was a very strong sense of competition between England and France, especially when it came to claiming new lands in the pursuit of empire.

The first European to for sure visit Tahiti was Britain's Samuel Wallis, circumnavigating the globe in *HMS Dolphin*. He arrived at Tahiti on June 18, 1767. French explorer Louis-Antoine de Bougainville followed on April 2, 1768. Both visits were cordial, and much less violent than some European-Islander clashes of the day. Word got back to England and France of Tahiti and the other "Society Islands" quickly.

Astronomers knew that there would be transits of Venus in 1761 and 1769. A number of expeditions were mounted in 1761, but the War, the weather, and insufficient preparation prevented the necessary observations from being made with adequate precision. Clear, too, was the necessity for countries to cooperate on the observing program for 1769 in the new post-War era. Making the observations necessary was important to all vying for a great role in world affairs, both scientifically and reputation-wise. The second opportunity would be on June 3, and newly-discovered Tahiti was in the proper geographic position to one of the observing sites used for the next transit measuring attempt.

The English were able to fit out an astronomical mission to Tahiti in amazingly short time, and were fortunate enough to have a captain as intelligent and capable as James Cook to lead it. Cook's team was a capable as he, and the Admiralty gave him a good ship, the *HMS Endeavour*.

Cook arrived at Matavai Bay on Tahiti on April 12, 1769. He established friendly relations with the local leaders, and selected observing sites on the northeast end of Matavai (primary) with other sites on the east end of Tahiti and on nearby Moorea. The primary site was at a place that to this day is called Point Venus. Transit Day came, and Cook's astronomy team made their measurements successfully. Upon return, the necessary observations were analyzed by Thomas Hornsby and published in the *Philosophical Transactions of the Royal Society*, volume 61, pp. 575-579, in 1771. The results were remarkably-close to the modern accepted value; for details, see: https://maa.org/sites/default/files/pdf/pubs/mm_dec03-Venus.pdf !

Cook would go on after the transit and make a "secret" attempt to find a southern continent. He did have time to observe a transit at still-named Mercury Bay on New Zealand's North Island. He was the best explorer and navigator of his time. The made three great voyages of discovery, but only completed two. He was killed at Kealakekua Bay in Hawai'i on February 14, 1779.

MARINER 4

The United States and the USSR were starting to explore the Solar System at the start of the Space Race of the 1960s. The U.S. had a success with *Mariner 2*, the first successful fly-by of Venus, in 1962. We tried again with a pair of Mariners in 1964. *Mariner 3* was a failure, but *Mariner 4* successfully flew by Mars and returned a few images of its surface. The area covered by the photos were of part of Mars that is old and heavily cratered and led planetologists to think Mars was old and dead, just like the Moon. Just how geologically-interesting Mars really is was not discovered until *Mariner 9* orbited Mars in 1971.

Mariner 4 carried a few instruments along with its cameras. Life on Mars and martian canals were still on the minds of the public, and everyone had hoped the images and other data it would return would indicate that Mars was more Earth-like than it turned out to be. Hopes were further dashed by a clever experiment thought up *after the spacecraft had been launched*.

Data from *Mariner 4* was being sent to Earth's Deep Space Network by radio. Earth and Mars orbit the Sun in nearly the same plane, and it takes a lot of extra energy (fuel) to send a spacecraft out of Earth's orbital plane, so NASA didn't do that, which meant that, as seen from the Earth, *Mariner 4* would seem to pass behind Mars as it went by. In other words, Mars would be **seen to be directly in front of** *Mariner 4*. Engineers knew that Mars would temporarily block *Mariner 4*'s radio signals during this blocking period, and they also realized that, as *Mariner 4* seemed to approach the edge of Mars, any atmosphere Mars had would begin to attenuate the signal prior to Mars itself actually getting in the way. The level of that attenuation, if monitored, could provide key information about the density and structure of the martian atmosphere! As only NASA can!

The necessary attenuation measurements were made and it became quite clear that Mars' atmosphere was not Earth-like at all, but was only about 1% as thick as Earth's, and predominantly carbon dioxide. That, and the pictures showing Moon-like ancient terrain, put a real damper on the John Carter model of Mars.

For more on the wonderful Mariner Mars missions mentioned, see here for *Mariner 4* and here for *Mariner 9*. For the roster on all Mars mission and mission elements, and their (partial) success or failure, see here.

RINGS!

Saturn's amazing ring system is one of the showpieces of the Solar System. *Voyager 1* detected the much-fainter-but-yet-similar rings around Jupiter during its fly-by some 45 years ago. Could Uranus and Neptune also be home to faint ring systems, too?

On rare occasions, a planet will occult, or **pass directly in front of**, a star. Astronomers look for such things with the *Mariner 4* example in mind – how starlight dims down at the start of an occultation, and how it brightens back up again as the occultation ends, can provide evidence as to the thickness and structure of that planet. One such occultation was coming, and Jame Elliot and his colleagues were going to observe Uranus occult a star, using the telescope aboard the *Kuiper Airborne Observatory*, NASA's first flying observatory, back in 1977. The recording equipment then was a strip chart, primitive by today's standard, but it produced a real-time written record of the brightness of the star as it was occulted by Uranus. The results were more than Elliot's wildest dreams; not only did they see evidence of a thick uranian atmosphere, they also saw five small dips in brightness just before the main occultation, and a matching five dips just after it.

Elliot and his team almost burst with excitement, because the instantly knew that the small dips absolutely had to be due to a little occultation by five different rings. Elliot grabbed a standard Federal quad-ruled pad and began working out a draft of the discovery telegram he would send out announcing the discovery as soon as they landed. He was so excited his handwriting is barely legible; see here for yourself because that note and the strip chart are in NASM's collection.

A similar **occultation observation** involving Neptune in 1989 revealed that it, too, like Uranus, had a ring system. Asteroid 10199 Chariklo and possibly asteroid 2060 Chiron also have rings, found in occultation measurements in 2013, remarkable because nobody thought such small objects could have a ring. Another similar observation of the KBO Haumea in 2017 shows that it, too, is in the "I Have a Ring" club. And this tactic of discovery of rings is so powerful that astronomers have even found a **planet with rings orbiting another star**, too! Exoplanet J1407, a super-Saturn, was discovered in 2012 and later found to have rings because they got directly in front of the light from the exoplanet's star. Wow!

How ***could*** a small object have a ring of fragmented rock and ice? A clue comes from the recent Double Asteroid Redirection Test (DART) mission, in which a heavy mass was deliberately crashed into a small asteroid, Didymos, that orbited another, Dimophos, to see if the former's trajectory could be altered, as a means of deflecting an asteroid on a collision course with Earth. The experiment worked, and yielded a second benefit. The *DART* spacecraft was able to image the pre-impact surface of Didymos at high resolution, showing it to be one of the "rubble pile" asteroids we've seen so far. Such bodies are just of pile of fragments and ice held together by their weak mutual gravity. Data from the impact show that a lot of already-fragmented material was ejected from the surface; the impact was enough to actually alter the overall shape of Didymos! The ejected debris left at fairly low speed, so much of it will eventually come back together, but in the meantime, it's possible that gravitational forces will move the fragments into a flat ring. For more on *DART* and its aftermath, see: https://edition.cnn.com/2024/02/27/world/nasa-dart-dimorphos-impact-scn/index.html and: https://skyandtelescope.org/astronomy-news/nasas-dart-impact-reshaped-the-asteroid-dimorphos.

ASTEROID SHAPES

Asteroids are too small to have enough gravity to cause their shape to be spherical (if they were, like Ceres, large enough to be spherical they'd be called a "dwarf planet!"). Determining their shape would be an interesting thing to do, but asteroids are so small and so far away that they'd never reveal their shape to direct observation. But there is a way, because even small asteroids are occasionally seen to **pass directly in front of** a star. The key is to have a number of observing stations along the track the shadow of the asteroid makes across the Earth, with each station having the same exact time as the others. Plotting the starlight seen by each station as a function of time can reveal the general cross-sectional shape of the asteroid; you can see an example of the results here. This tactic makes for a wonderful and valuable group citizen science project!

DETECTION OF EXOPLANETS

Eclipsing double stars appear dimmer when one of the stars **passes directly in front of** the other. A similar, but smaller dimming results when an exoplanet, otherwise dark, passes directly in front of ("transits") its star (see: https://exoplanets.nasa.gov). Thousands of exoplanets have been discovered that way, mostly by two Space telescopes built largely for exoplanet detection. First was the *Kepler Space Telescope*, launched in 2008. It had a tiny field of view, but it was able to observe it continually, looking for transit-caused dimmings in over 530,000 stars. By the time its maneuvering fuel ran out in 2018, it had returned data that led to the discovery of 2,662 confirmed exoplanets! For more on the Kepler mission, see: https://exoplanets.nasa.gov/keplerscience.

The *Transiting Exoplanet Survey Satellite* was *Kepler*'s successor, launched in 2018 and still in full operation. *TESS* acquires data from much of the sky, one 0.25% of the total sky segment at a time. Thousands of additional exoplanets have been found by *TESS* to date.

The Simonyi Survey Telescope at the Vera Rubin Observatory, presently under construction, will be able to monitor the entire sky visible from its location continuously, covering that vast area on a weekly basis. Such broad and frequent coverage will no doubt lead to the discover of thousands of additional exoplanets, as well as Trans-Neptunian Objects and a variety of transient phenomena.

One limitation requires consideration in the analysis of exoplanet transit data. The volume of Space from which an exoplanet transit can be observed depends strongly on the exoplanet's size and even more strongly on how close it is to its star. Transits of large exoplanets close to their star can be seen from a relatively-large volume of Space; transits of small planets millions of miles from their star can be seen only if the observer lies (almost) in the plane of the exoplanet's orbit, a much smaller volume of Space. Consider this: Earth very rarely sees either Mercury or Venus transits the Sun, and we are right on top of them in an astronomical-distance sense; *TESS* at interstellar distances would have almost zero chance of seeing any of old Sol's planets! The detection problem would be compounded drastically by the fact that those transit-caused dimmings occur once in a multi-year period. That's why so many exoplanets discovered to date are very close to small, dim stars, so close that their "year" is a matter of tens of hours or so.

The search for exoplanets has many opportunities for citizen scientists to make meaningful contributions. If you are interested in the search, or know someone that might be, check out: https://exoplanets.nasa.gov/citizen-science!

EINSTEIN CROSSES

Einstein showed, and Eddington confirmed, that light can be bent slightly by passing close to a gravitational field. But the Sun isn't the biggest deflector of light out there! Astronomers now have the tools to detect objects directly in front of other objects because the object in front deflects the light around it, even on intergalactic scales. For example, a quasar is one of the brightest objects in the Universe, and if there is a galaxy with a large black hole in it **directly in front of** the quasar, the black hole's gravity will deflect the energy from the quasar around itself, making a ring or cross shape of multiple images of the quasar behind; the black hole bends light like a lens does, hence, such a situation is referred to as "gravitational lensing." The first such discovered was in Pegasus in 1985, where the light from a quasar 8 billion light-years away is bent around a black hole in a galaxy 400 million light-years away.

Closer to home, research has been underway for some time to assess the possibility of using the Sun as a gravitational lens to allow the study of exoplanets in detail not otherwise available and to even assist the search for extraterrestrial intelligence. Some are now hypothesizing that using the Sun as a lens could facilitate the construction of an interstellar communications network, which has implications on our search for techno-signatures. Even more interestingly, the prospect that other civilizations could use lenses as a way to send power from one stellar system to another. For more on this intriguing idea, see here: https://phys.org/news/2023-11-civilizations-gravitational-lenses-transmit-power.html.

Dark matter is thought to be more common in the Universe that the stuff we're used to. We can't see it, but dark matter does have gravity, and we can see the bending effect that its gravity has when the gas is **directly in front of** the light source behind it! Intrigued? Find out more about finding dark matter this way at:
https://science.nasa.gov/mission/hubble/science/science-highlights/shining-a-light-on-dark-matter.

TELL THEM WHAT YOU TOLD THEM

Astronomers DO learn a lot of things "when things go in front of other things!"

Last Edited on March 3, 2024