SkyWAAtch

The Newsletter of Westchester Amateur Astronomers

June 2021

Bode and Cigar by Gary Miller

The well-known pair of galaxies Messier 81 and 82 are half a degree apart in Ursa Major. Gary made this image in December 2020. He created a gray-scale image and applied StarNet to remove the stars. Then he cloned the StarNet image. Using the clone stamp tool he eliminated one galaxy in one image and the other in the other image. Each was applied separately as masks to the original image, allowing custom processing of each galaxy. The Color Saturation Process worked well to bring out color in M81. HDR produced a lot of detail in M82, and then he changed the color saturation to bring out the orange-red starburst zone. ExploreScientific 127ED triplet, Losmandy GM811G mount, ZWO ASI2600MC Pro camera, total exposure time: 6 hours, 10 minutes.

WAA June Meeting

Friday, June 11 at 7:30 pm

Via Zoom

Citizen Science

Rick Bria
Astronomical Society of Greenwich & WAA Member

Astronomy started out as an avocation, and some of its most important discoveries were made by amateurs. Before the late 17th century there were no professional astronomers! Still, even today, amateurs make important contribution to the science of astronomy.

Rick will review how amateurs, using modest equipment, can contribute to our understanding of celestial phenomena. He'll present his own efforts in three areas of "citizen science:" asteroid occultations, transiting exoplanets and variable stars. Rick notes: "Amateur astronomers come from all walks of life with many skill sets. When they come together for a common goal, the results can be remarkable. I have found that my contributions, however small, are extremely satisfying to me personally. I want to express that to WAA."

The link is on the opening page of the WAA web site www.westchesterastronomers.org

Pre-lecture socializing with fellow WAA members and guests begins at 7:00 pm!

WAA Members: Contribute to the Newsletter!
Send articles, photos, or observations to waa-newsletter@westchesterastronomers.org

SkyWAAtch © Westchester Amateur Astronomers, Inc.

Editor: Larry Faltz
Assistant Editor: Scott Levine
Almanac Editor: Bob Kelly
Editor Emeritus: Tom Boustead

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

WAA September Meeting

Friday, September 10 at 7:30 pm

Venue to be announced

Members' Night

Presentations by WAA members

Starway to Heaven

Meadow Picnic Parking Area
Ward Pound Ridge Reservation,
Cross River, NY

6/5/2021 (rain/cloud date 6/12/2021)

Pandemic restrictions for outdoor events may be lifted, but masking and social distancing may still be an effective risk-reduction strategy.

New Members

Marcy Cohen	Croton on Hudson
Kenneth Creary	White Plains
Michael Sheridan	Mt. Kisco

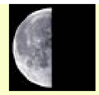
Renewing Members

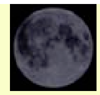
Arun Agarwal	Chappaqua
Donna Cincotta	Yonkers
Nicole Heselton	White Plains
Arthur Linker	Scarsdale
Arumugam Manoharan	Yonkers
Lydia Maria Petrosino	Bronxville
Daniel Rosenthal	New York
Dante Torrese	Ardsley
Michael & Angela Virsinger	Seaford
Jordan Webber	Rye Brook

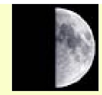
Also In This Issue

ALMANAC For June 2021

Bob Kelly, WAA VP for Field Events


3Q
6/2


New
6/10


1Q
6/17


Full
6/24

The Big Event

The sunrise of Thursday, June 10 brings a horned Sun rising in the east-northeast. Find a clear horizon at an azimuth of 58 degrees from north to view this event. With sunrise at 5:23 a.m., it will be an early start to the day, but it'll be worth it if the clouds allow. It's probably a good idea to do some location scouting in the days before so you're not searching before dawn on the big day.

Maximum eclipse, with 75 percent of the Sun covered, is at 5:33 a.m., with the Sun only one degree above the horizon. See the chart on page 4. It's all over by 6:31 a.m., with the Sun only 10 degrees high. You can see this event and still make the first-of-the-morning Zoom call for work. Get out early to see if the morning twilight looks weird, since the eclipse begins 46 minutes before sunrise. Atmospheric refraction could produce some fantastic mirage images at sunrise. This is all we get to see of the annular eclipse that courses over northeastern Canada, Greenland and the Arctic Ocean.

Lovely Evening Views

Mars is a faint, pale version of the typically vibrant red planet we love. It'll still be around for a couple of months, looking like an aircraft with a red tracking beacon gliding in the western sky on approach to a runway.

On the 23rd, Mars tries to hide in M44, the Beehive. Can you catch both in a photo of Mars' magnitude +1.8 tiny disk in the midst of minute flecks of sixth magnitude stars? Earlier, the 12-percent illuminated Moon photobombs Mars' scene on the 13th. We're in the time of year when the Moon passes M44 but doesn't overwhelm it.

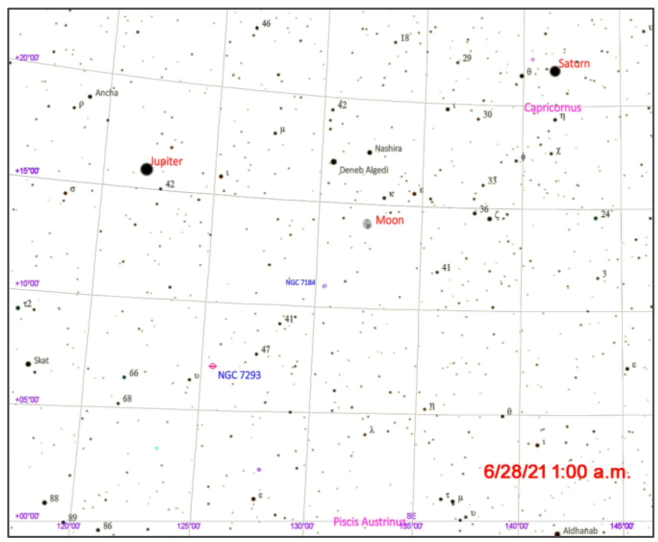
Can you see Castor and Pollux to the right of Mars around the 11th and to the right of Venus by month's end?

Venus, like one of our liquid-fueled rockets, is struggling to gain altitude in the west northwest. It's spectacular at magnitude -3.9, its disk 85 percent lit. It's going to be around after sunset through the end of the year.

Outer Planet Lament

It's mid-June, and Jupiter rises at… midnight! It's going to take until August for the gas giants to rise by sunset. In the meantime, the best time for viewing Jupiter and Saturn will be after midnight, with Saturn leading the way. Saturn rises by 10:30 p.m. near the end of June. If you want to get up early the day after Memorial Day, the Moon will be hanging below Jupiter on the 1st.

On the 27th and 28th, the Moon glides well below Saturn and Jupiter.



Inner Planet Ascent

Mercury hides in the solar glare, visible in the Solar & Heliospheric Observatory's C3 viewer from the 5th through the 16th. The innermost planet may be visible at magnitude +1.0 by the end of the month low in the morning dawn part of the sky, rising by 4:30 a.m.

Does This Make Me a Supermoon?

The Moon reaches perigee 33 hours before June 24th's full Moon. It continues the trend for the lunar monthly perigee moving farther from the time of full Moon. The lunar apogee on the 7th is a reason for the annular, rather than total, eclipse on the 10th.

Satellites

We have the shortest dark nights of the year, but because the Sun doesn't get too far below the horizon, satellites can be visible most any time of the night. The International Space Station (ISS) is in the evening sky only though the 4th. Can you catch it when it rises near Venus? The ISS is much fainter when it's that low in the sky than it would be if higher up. The long-running human outpost in space will be visible in the morning sky starting on 25th.

Pieces of Ice and Rock

The brightest comet (so far) for June is 2020 T2/Palomar, which might brighten a bit from magnitude +10.5. It's between Boötes and Virgo. Prospects for 2021 A1/Leonard are dimming a bit. There are hopes this will become a magnitude +4 comet in the morning sky by the end of the year. The British Astronomical Association's Comet Section says electronic observations are showing a fainter than expected comet. But, with a present magnitude of +17.5, it's still early.

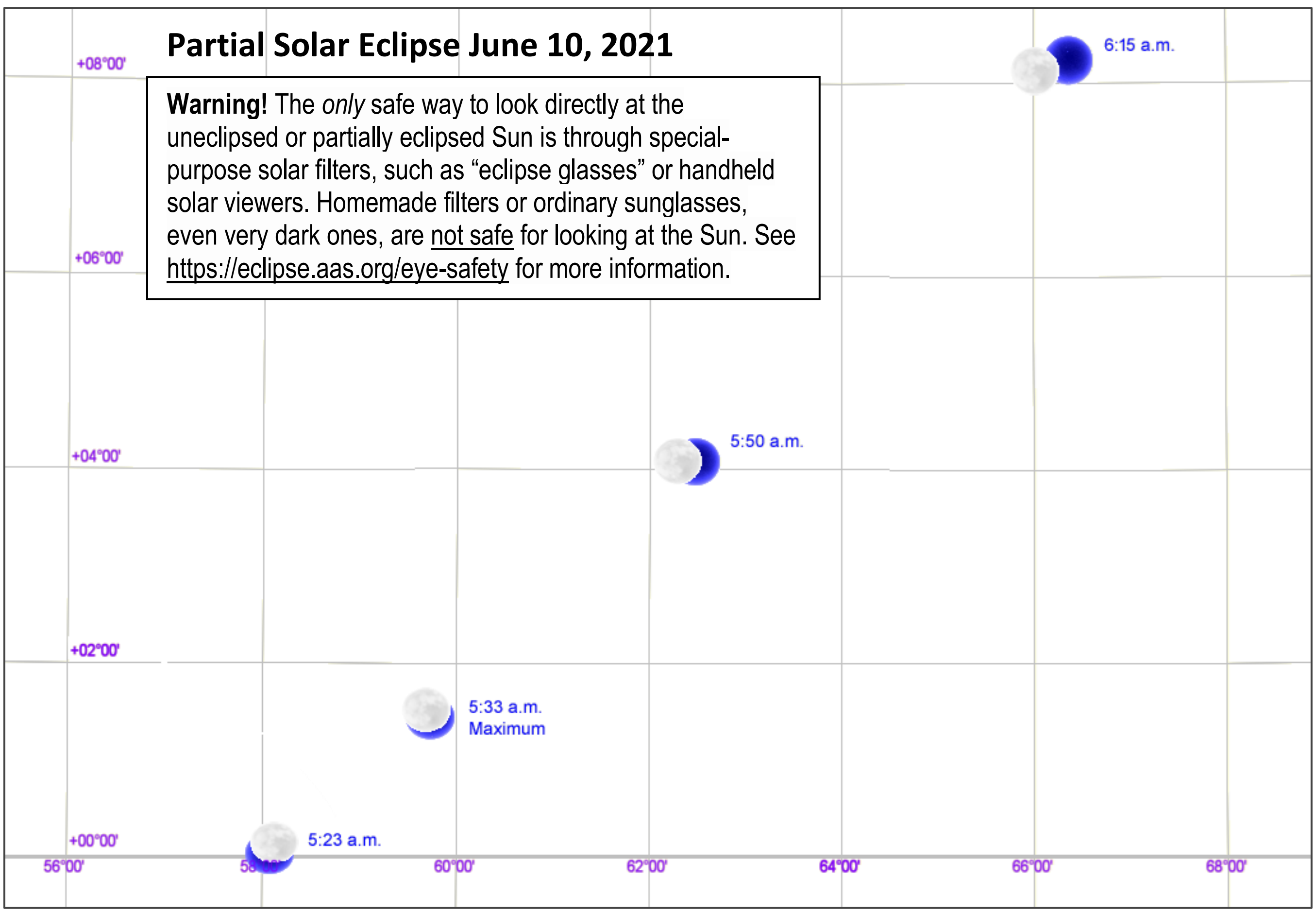
June is a quiet month for meteors, with no major showers. Maybe because of the lack of darkness, no one has noticed.

Views of Our Galaxy

Scorpius rising in the southeast heralds the return of the Milky Way once astronomical twilight ends just after 10 p.m. The inexorable increase in light pollution makes seeing our galaxy from Westchester very difficult, from the more remote parts of the county it will still be evident on a clear night once you get dark-adapted.

Summer!

The summer solstice, when the Sun is at its highest declination north, occurs at 11:32 p.m. EDT on the 20th. The latest sunset at our latitude is on the 27th, when the Sun will set at 8:31 p.m. at a compass point of 302 degrees, in the northwest.



Partial Solar Eclipse June 10, 2021

Warning! The *only* safe way to look directly at the uneclipsed or partially eclipsed Sun is through special-purpose solar filters, such as "eclipse glasses" or handheld solar viewers. Homemade filters or ordinary sunglasses, even very dark ones, are <u>not safe</u> for looking at the Sun. See <u>https://eclipse.aas.org/eye-safety</u> for more information.

Member Profile: Melissa Toole

Home town: NYC

Family: husband Chris, sons Mikey (16) and Brendan (14)

How did you get interested in astronomy? I joined the club for my son Brendan, who took a class in Astronomy in 6th grade and fell in love with it.

Do you recall the first time you looked through a telescope? What did you see? I looked through a telescope when I was 18, on the roof of our hotel in Hawaii. The sky was bright and filled with stars. I was not sure what I was seeing.

What's your favorite object(s) to view? I would love to see anything. We learning how to correctly operate our telescope!

What kind of equipment do you have? We have a Celestron Power Seeker 127 EQ

What kind of equipment would you like to get that you don't have? If we could work this telescope properly, we'd be good!

Are there areas of current astronomical research that particularly interest you? My son Brendan is particularly interested in Mars. Also, asteroids.

Do you have any favorite personal astronomical experiences you'd like to relate? When my son was taking his class, I took him to the Hayden Planetarium for a show about dark matter. He was riveted.

What do you do in "real life"? I am a preschool teacher. We just finished our section on the solar system. I'm still singing the songs in my head.

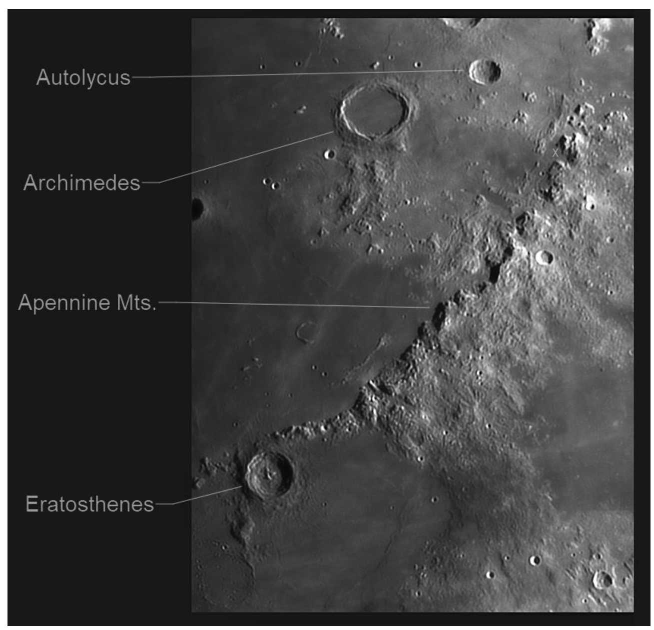
How did you get involved in WAA? My son wanted to learn more about astronomy, but I knew nothing. The club seemed like a great way to learn.

What WAA activities do you participate in? We were very excited to go to Ward Pound Ridge and have some help operating our telescope, but we joined and then the Covid Quarantine happened.

Besides your interest in astronomy, what other avocations do you have? Our family loves history. We like to visit historical sights. I am hoping to get to Normandy soon.

Provide any other information you think would be interesting to your fellow club members, and don't be bashful! I come from a Soap Opera family. My dad was Dr. Seneca Beaulac on *Ryan's Hope*, and my mom was Edna Thorton on *All My Children*. I was a host on an MTV show called *Oddville MTV*, and my sister Andrea Gabriel was Nadia on *Lost*, among other things.

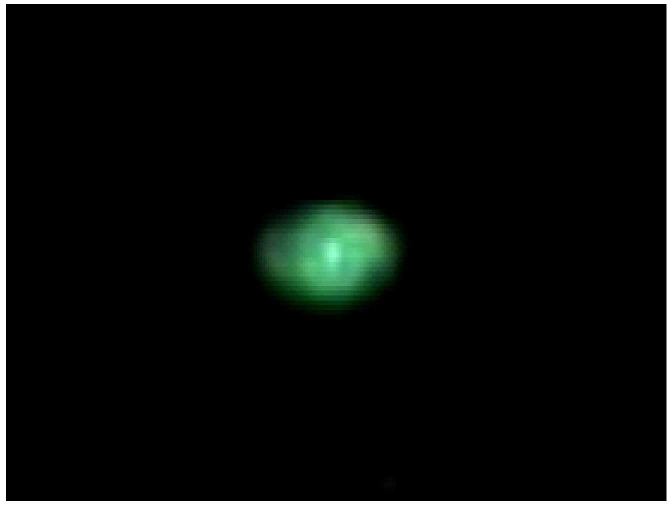
The Apennine Mountains Rick Bria



The Apennines form the southeastern edge of the Mare Imbrium (Sea of Rains), a gigantic impact crater filled in by lava. The tallest of the Apennines is 17,700 feet above the lunar surface.

Deep Sky Object of the Month: Cat’s Eye Nebula NGC 6543

NGC 6543	
Constellation	Draco
Object type	Planetary Nebula
Right Ascension J2000	17h 58m 36.0s
Declination J2000	+66° 38’ 00”
Magnitude	8.3
Size	22 x 16 arcseconds
Distance	3,300 LY
Other designations	Caldwell 6
Discovery	W. Herschel, 1786

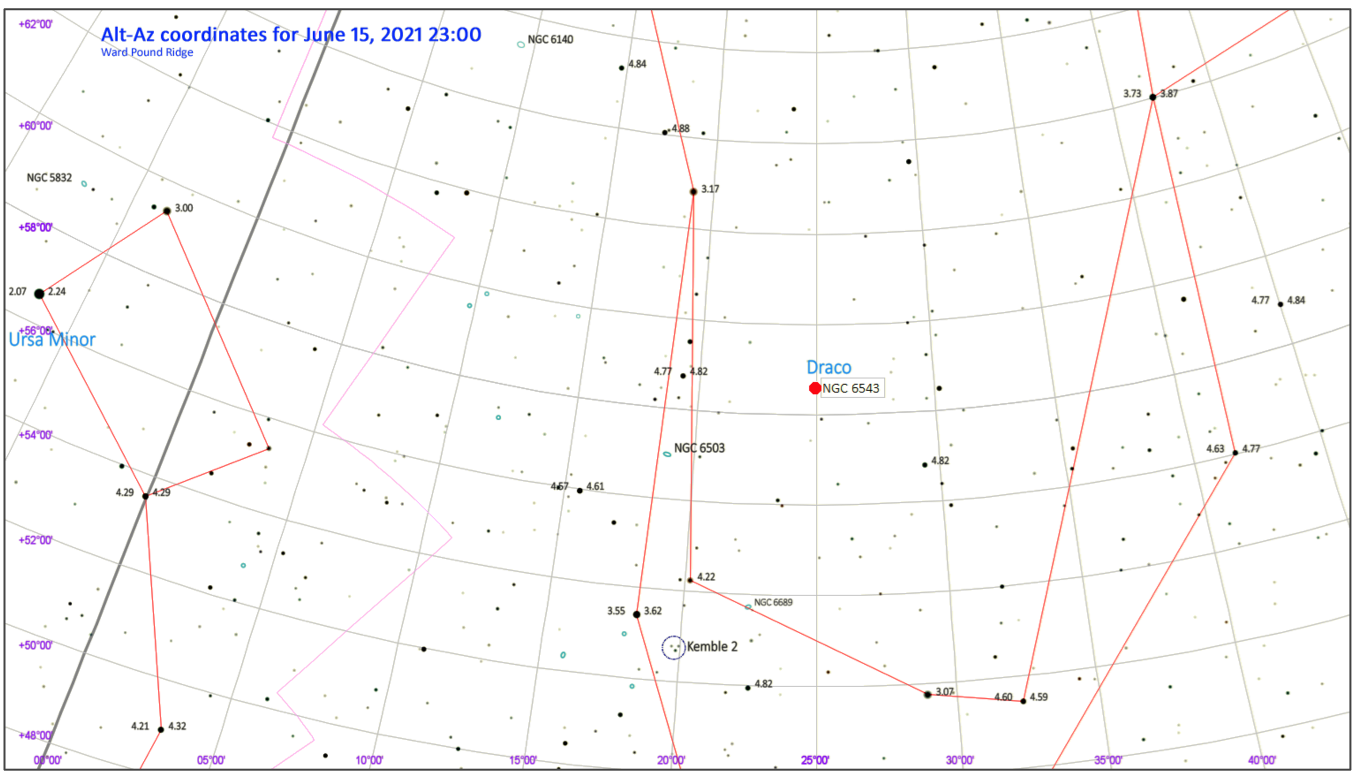


Visibility for NGC 6543			
11:00 pm EDT	6/1/21	6/15/21	6/30/21
Altitude	65° 34’	72° 30’	69° 6’
Azimuth	140° 2’	176° 47’	217° 30’
In June, astronomical twilight doesn’t end until 22:17 on 6/1 and 22:47 on 6/30, so the coordinates are given for 23:00. You have to be willing to stay out late in June and July!			

I couldn’t find an on-line image of the Cat’s Eye that reproduces the view in an amateur telescope. A high-quality scope at high power might mimic this Mallicam image I made in 2011. Deep astrophotographs show its faint outer shells, and the familiar Hubble images show all sorts of internal structure, beyond the reach of our amateur instruments. It’s a fairly homogenous, slightly ovoid blob in telescopes but its greenish-blue color is impressive. The central star is magnitude 11 and is easy to see. Use your highest powers for the best view.

Most of the gas we see is thought to be only 1,000 years old.

WAA imagers might try for a high-power view of the Cat’s Eye this summer.



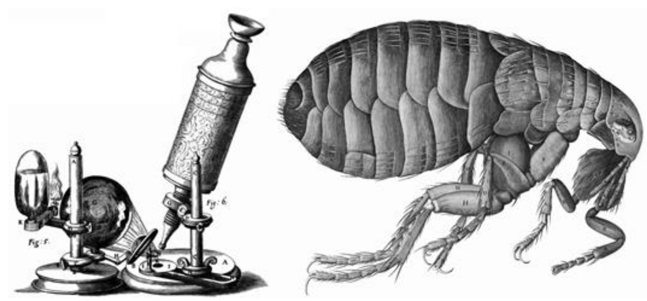
Notes from the Junkyard Astronomer

Robert Hooke & the Telescope that Never Was (But is Now) John Paladini

Back in the year 1668, in the era of the long focal length singlet-lens telescopes, the noted English polymath Sir Robert Hooke (1635-1703) proposed a method using mirrors to shorten those long, unwieldy instruments and make them more manageable. His idea was to fold a 60-foot-long telescope and cut it down to a 20 foot length (still long to me!). Unfortunately he failed at his attempt and the idea became a footnote to astronomy history.

Being who I am, I was not going to let Sir Hooke off the hook so easily! So 342 years after Hooke's failure I successfully built a folded long focal length singlet refractor.

What is a folded refractor? In modern times it's simply taking a long-length achromat (usually f/15 to f/20) and bouncing the light inside the telescope tube with mirrors (usually two) in order to fold the light path and shorten the length of the tube. This is usually done with 6-inch f/15 refractors. These scopes would ordinarily be 7½ feet long, but with folding you can cut them down to 2½ feet. Folded telescopes were popular for a while with ATMers and on occasion you can see them at telescope conventions like Stellafane. There are not too many commercial examples with the exception of the rare and highly sought-after 3 and 4 inch Unitron models.[1] With the advent of modern apochromatic objectives the need to fold has pretty much gone away, since highly corrected refractors can be made with much shorter focal lengths.



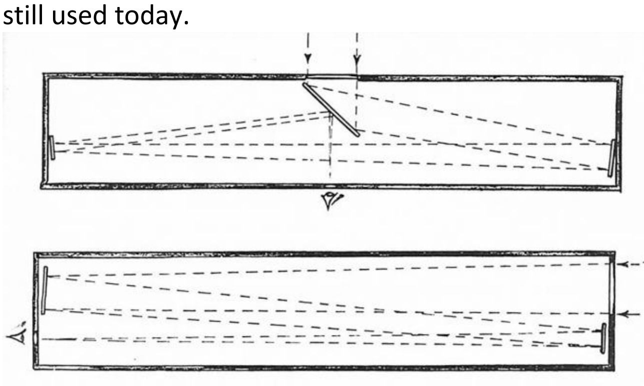
Hooke's microscope and his drawing of a flea

So who is Sir Robert Hooke? He was a noted scientist in his day, best known in modern times for his book *Micrographia*. The book is mostly about observations with a microscope of his own invention. It has a famous illustration of a flea. Born on the Isle of Wight to a poor family, he was educated at Oxford. Hooke found fortune and fame by supervising the architectural surveys required after the Great Fire of London in 1666. He became member of the Royal Society and in 1662, just one year after its founding, and because of his protean interests and skills he was made its Curator of Experiments, eventually being considered "England's Leonardo."

Hooke had access to a number of long-focus telescopes. They ranged in focal length from six to 60 feet. Lens grinding in the 17th century was still a crude process. Hooke found that telescopes with apertures of just two and 2½ inches had best defining power. Having ground my own singlets using old methods I agree with this assessment. With modern

[1] R.E. Brandt made a small number of 6, 8, 10 and 12-inch folded refractors in the 1970s and early 80s. [Ed.]

glass and grinding methods you can push sizes up to about four inches (excluding modern narrow band solar singlets). It was common to use an aperture mask to stop down the diameter of the lens because the central part of the lens was closer to an accurate figure than the edge. His favorite lens had a 36-foot focal length. With this he carried out observations of the Moon and planets. His illustration of the crater Hipparchus is quite detailed and proves those old scopes did put up a good image despite optical shortcomings. He also observed comets and in 1678 published *Cometa*, which introduced comet terminology still used today.



Two of Hooke's plans for folded telescopes

In this period there was a philosophical belief that all the planets were inhabited by some sort of beings, the idea being that God wouldn't make all these worlds but leave them barren. Hooke and other astronomers of the period, including Christiaan Huygens and Adrien Auzout, believed if you made a telescope long enough you could see the inhabitants of the Moon. Hooke proposed telescopes of 1,000- and 10,000-foot focal lengths with a 21-inch aperture. Auzout wrote a letter to the Royal Society accusing Hooke of having a pipe dream. Auzout proposed that 600 feet was more reasonable. Today we understand resolution is not dependent on focal length but on the diameter (and quality) of the lens plus seeing conditions, not to mention the simple mechanics of using a very long telescope. I have a 4-inch, 80-foot focal length singlet. Trying to line up an eyepiece for a proper image is no easy task. I cannot imagine trying to look thru a 21-inch lens from nearly two miles away!

There are no true portraits of Robert Hooke. He and Isaac Newton did not get along. Newton once referred to Hooke as "that ugly little dwarf." So much for great men being perfect gentlemen! Newton allegedly destroyed or at least failed to preserve the only known portrait of Hooke. To add insult to injury a stained glass likeness of Hooke was destroyed in the 1993 IRA bombing of St Helen's Bishopsgate, one of the few London churches to survive both the fire of 1666 and the Blitz.

So why did Hooke fail on his attempt to fold those long length refractors? To put it simply, he could not make a good flat mirror, known in optics simply as a "flat." Strange as it may seem, it is easier to make a good glass sphere, parabola or ellipse then a good smooth flat surface. Alan Witzgall, who has given some talks at our WAA Friday meetings, told me that when you grind a lens, nature likes curves, not flat surfaces. To know that you have made a good flat, you have to test it with another good optical flat. Today you can buy these on Ebay. Hooke had no such opportunity. Reasonably good flats did not appear until the second half of the 18th century, although Newton managed to make a small one for the secondary of his famous reflector. Another problem is that mirrors in those days were made from speculum metal, which has at best 66% reflectivity.

I obviously have access to modern flats that are truly flat. You also don't have to learn how to grind and polish your own singlets. The lens I used is a commercial 50-mm, 4 meter focal length singlet, f/80. This lens is similar to a lens that Christiaan Huygens made in 1684 through which he observed Saturn, now in the Rijksmuseum Boerhaave in Leiden. This lens is 67 mm in diameter with a focal length of 408.9 cm, f/61, The lens Huygens used for his most famous observations of Saturn in 1655 is now at the University of Utrecht Museum. It is 57 mm in diameter and has a focal length of 336.7 cm, f/59. These lenses were always stopped down because of severe aberrations in the outer zones, making them slower than f/60. Telescopes of this size and length were as common in that time as 80-mm Apo's are today.

I purchased two 2-inch flats. My scope is made in a box of wood eight inches high, 51.5 inches long and four inches wide. The lens is mounted in a section of PVC pipe two inches in diameter. The mirrors are mounted on flat pieces of wood, each with three screws and springs behind them to collimate the light path. The back end has a focuser, also mounted on PVC pipe. Alignment of lens and mirrors is actually quite easy. I use a modern finder scope, but in Hooke's time it would have been a simple narrow tube or sight like you may find on an old rifle.

How does it work? Delightful! Star images show nice Airy disks with some spherical and chromatic aberration, as to be expected from a singlet even of that long focal length, but not as much as one might expect, since running at f/80 the errors are nicely controlled. Many on-line forums say bad things about these telescopes but if you read carefully many of the lenses used are f/10 or f/20. That's simply not good enough! You need to get up to f/40 or better with a singlet. You also need to use a long focal length eyepiece, 40-mm or 50-mm. A 40-mm eyepiece gives you 100X or about 50X per inch which is about maximum you can do.

Missing from Hooke's plan is the need for baffles. Without baffles you get a lot of stray light bouncing around the inside of the tube. I found that adding short segments of black tubing inside the scope around the optical elements got rid of the problem. These scopes make a good tool to check your eyepieces for dirt. Since light coming out at end of scope is nearly parallel, dirt in the eyepiece creates a shadow. Just point scope at moon and put in eyepiece and you will see any dirt on the eyepiece lenses. ■

(L) Dirty eyepiece, (R) Clean eyepiece

Telescopes in *The Simpsons*

Apropos of our April movie quiz, here are some telescopes in *The Simpsons*. I'm a big fan and I think the show is television's intellectual and comic zenith! (LF)

Temporarily Duff Man, Homer observes from the Duff Blimp.

The Simpsons version of Hitchcock's *Rear Window.*

Principal Skinner is an amateur astronomer. Bart discovers an Earth-bound comet.

Lisa with Neil DeGrasse Tyson.

How Stars Produce Energy

Larry Faltz

Last month we left off with Cecelia Payne-Gaposchkin's discovery of the vast amount of hydrogen and helium in stars, with the implication, initially disdained by Henry Norris Russell, that a star is fundamentally a big ball of hydrogen gas. We have to drop back a few years to see how our conception of the atom led to the realization that hydrogen fusion powered the stars.

Leucippus, a 5th century BCE Greek philosopher, is credited with originating the theory that all matter is made from tiny, indivisible atoms. His pupil Democritus often gets the credit, because the later philosopher Epicurus claimed that there was no actual person named Leucippus. Later writers restored Leucippus to actual historical existence. Either way, the theory was intellectually attractive but didn't have an impact on science until the late 18th century, when experiments on gases suggested that their behavior could be best be understood if they were composed of individual particles. At the beginning of the 19th century, experiments by John Dalton led to the "law of multiple proportions," based on observations that common chemicals seemed to be made up of individual elements in simple numerical ratios. This was best explained by conceiving of the elements as being made of distinct atoms. Brownian motion was discovered in 1827 when Robert Brown observed dust particles moving in water. In 1905 Einstein proposed that this motion was due to the impact of water molecules, made of atoms. This was experimentally proven by Jean Perrin, who measured the mass and dimension of the molecules.

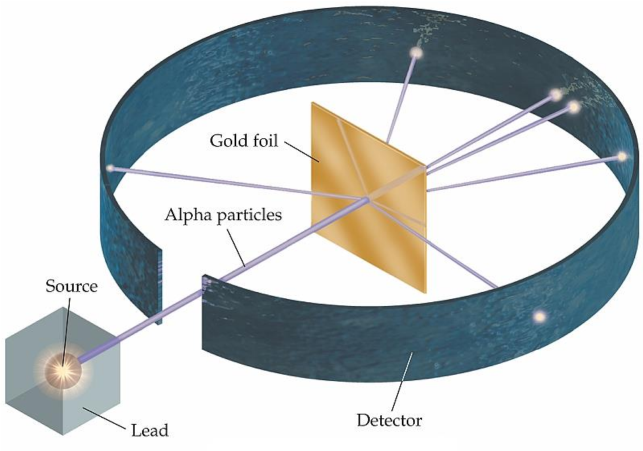
X-rays were discovered in 1895 by Roentgen and radioactivity in 1896 by Becquerel, both rather serendipitous findings that unleashed a revolution in physics. In 1897, J.J. Thomson at Cambridge discovered the electron by looking at how gases conducted electric currents. One of his research fellows was New Zealander Ernest Rutherford.

Thomson recommended Rutherford for a position at McGill. There, in 1899, he discovered alpha and beta radiation, noting the different penetrating power of the two types of emissions. In 1900, Paul Villard encountered a third kind of emission from certain radioactive substances. It had much greater penetrating power than either alpha or beta rays and was named the gamma ray by Rutherford. In 1903, Rutherford showed that alpha particles were positively charged, being deflected in a magnetic field in the opposite direction from the more easily perturbed beta rays, which Becquerel had identified in 1900 as electrons by measuring their mass to charge ratio. Rutherford discovered the gas radon (from a sample of radium given to him by Marie Curie) and he developed the concept of radioactive half-life. In 1907, now back in England as Chair of Physics at Victoria University in Manchester, he determined that the alpha particle had two "units" of charge. He later detected a build-up of helium in his apparatus and correctly concluded that the alpha particle was a helium nucleus. For his many discoveries, Rutherford was awarded the 1908 Nobel Prize in physics and is rightly deemed the "Father of Nuclear Physics." But his most important contribution to the understanding of the atom came the following year.

In 1909, Rutherford supervised the famous gold foil experiment, which was actually performed by Hans Geiger and undergraduate student Ernest Marsden. A thin gold foil was bombarded with a stream of alpha particles,[2] which made a brief flash when they impacted a glass screen coated with a phosphor. The detector was the human eye, and the experimenters had to sit the dark for many hours to count the flashes of light made by the impact of the alpha particles. While most of them went straight through the foil, a few were deflected at mildly oblique angles, and a very small number were reflected back at highly acute angles. From this experiment, Rutherford concluded that Thomson's model of the atom, a "plum pudding" with positively and negatively charged particles intermingled, was not correct. The positively charged particles were concentrated in a tiny nucleus that contained most of the atom's mass, and the negatively charged particles were outside the nucleus, presumably orbiting it. Rutherford later went on

[2] An alpha particle emitted from a ^{238}U atom has a velocity of $1.4*10^7$ meters per second (4.6% of the speed of light). It only travels a few centimeters in air before interacting, and can only penetrate skin a few cells deep. It's only biologically dangerous if the parent element is inhaled or ingested.

to show that when a nitrogen atom was bombarded by an alpha particle, it ejected a positively charged particle of unit mass, which he dubbed the proton.



The gold foil experiment.

In 1900, Max Planck had theorized that the spectrum of thermal radiation from a "black body," a perfect absorber or emitter of radiation, was "quantized," that is, the energy levels were not continuous but could take on only certain discrete values. Einstein's analysis of the photoelectric effect, published in his *annus mirabilis* year of 1905, provided an explanation. Einstein's Nobel Prize was for this work, not for relativity, although he deserved one or even two for that achievement. Incorporating Planck's quanta into Rutherford's model, Niels Bohr in 1913 proposed that the positively charged nucleus is surrounded by electrons in discrete orbits with quantized energy levels.

While this is a useful model and is how atomic structure is first broached to students, it can't be right. Electrons moving on a curved path would give off radiation (synchrotron radiation) and lose energy, falling into the nucleus. Bohr's model also failed to give precise explanations for newly-discovered spectral subtleties of the hydrogen atom. Another baffling aspect of the model was how the positively charged particles of the nucleus could stay together, given the strong electrostatic repulsion between like charges at such short distances. Surprisingly, the idea that there was a distinct force within the nucleus that was stronger than electromagnetism (now known, appropriately enough, as the strong force), wasn't explicitly proposed until 1932, by Eugene Wigner.

In early 1920, Francis William Aston, inventor of the mass spectrograph, showed that the mass of a helium atom was 0.8% less than the sum four hydrogens (since the neutron had not yet been discovered, the elements were characterized by their mass and not their atomic number).

Eddington, his stature having enormous influence on posterity, usually gets the credit for proposing later in 1920 that this mass difference could power stars by somehow being converted to energy, $E=mc^2$. However, he was not the first to think of this mechanism. In 1915, physicist William Draper Harkins, then at the University of Chicago, was studying the structure of nuclei. He proposed that fusion of hydrogen into helium as the source of solar energy.[3] Jean Perrin also suggested this process in 1919, but no one knew of a mechanism to overcome the electrostatic repulsion when positively charged nuclei were brought together. Even at the enormous heat inside the Sun, which we will shortly calculate, it didn't seem possible. When it was remarked to Eddington that even the interior of the Sun wasn't hot enough, he replied, "go and find a hotter place."

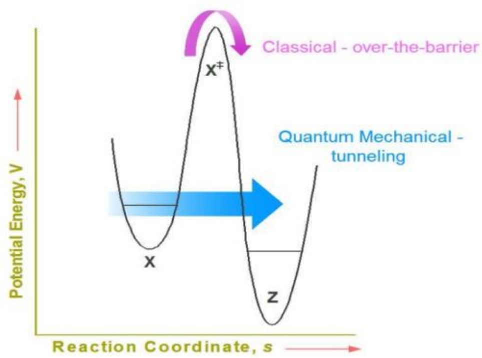
While Payne-Gaposchkin was studying stars, Werner Heisenberg and Erwin Schrödinger were puzzling out the behavior of subatomic particles, particularly electrons and photons. Heisenberg's formulation of their behavior was published in 1925. It was based on discrete matrices of complex functions (those involving *i*, the square root of -1) while Schrödinger's 1926 theory described the evolution of each particle with a single equation known as the "wave function." Shortly thereafter, the two approaches were found to give identical results when applied to real-world problems. A major consequence of quantum theory is Heisenberg's "uncertainty principle:" we cannot specify everything we want to know about a particle to absolute precision. We can get off on an enormous tangent describing the philosophy of quantum mechanics: whether we can actually know reality or only describe it through mathematics, or how something can be a wave and a particle seemingly at the same time, but suffice it to say that it works.[4] In addition, the model of the atom described by quantum mechanics posits that the electrons are not in discrete

[3] Biographical memoir of Harkins by his student Robert Mullikan is at https://is.gd/wdharkins.

[4] See "The Universe as a Dream: Quantum Mechanics" in the April 2014 SkyWAAtch, p. 5.

orbits at all, but in "orbitals" that describe only the probability of finding them in a particular place.

In 1928, using quantum principles, George Gamow solved the problem of radioactive decay by alpha emission. He was able to show that alpha particles can escape the deep energy potential well that confined them in the nucleus by "quantum tunneling," a consequence of the indeterminacy of quantum states. Without additional energy being applied to the system, at random a particle simply appears on the other side of the energy barrier holding it in place, as long as its final energy level is lower than where it started. Gamow showed that there was a relationship between the half-life of an alpha-decay event and the energy of the emitted particle.



With his exquisitely sensitive mass spectrometer, Alston found elements with "isotopes" of different masses, although what made them vary in units of the mass of a proton was unknown. In 1931, Harold Urey discovered deuterium, naturally occurring hydrogen of mass 2. It was present in water at a concentration of 0.0156% (one deuterium for every 6400 protons). In 1932, James Chadwick discovered the neutron by bombarding beryllium with alpha particles from polonium. A beam of uncharged particles was detected by its irradiation of a block of paraffin (with a high content of hydrocarbons and thus hydrogen atoms), releasing protons. Chadwick was able to show that what was emitted from the beryllium was not gamma radiation, but a neutral particle with mass similar to the proton. This explained deuterium: a nucleus with one proton and one neutron, called a deuteron, but with one electron it still had the chemistry of hydrogen. And it explained beta decay, a neutron splitting into a proton and an energetic electron.

Now all the pieces were in place for understanding the power of the Sun. Quantum tunneling could overcome the unfavorable energy barrier between colliding nuclei even though temperatures were not hot enough to overcome electrostatic repulsion.

In 1937, Gamow and Carl Friedrich von Weizsäcker proposed that two protons could merge to form a deuterium nucleus, but they couldn't account for other atomic species found in the Sun. The critical calculations were done by Hans Bethe.

George Gamow tells a charming story in his 1940 popular science book *The Birth and Death of the Sun* about how Bethe figured out fusion.

> "But it should not be so difficult after all to find the reaction which would just fit our old Sun," thought Dr. Hans Bethe, returning home by train to Cornell from the Washington Conference on Theoretical Physics of 1938,[5] at which he first learned about the importance of nuclear reactions for the production of solar energy: "I must surely be able to figure it out before dinner!" And taking out a piece of paper, he began to cover it with rows of formulas and numerals, no doubt to the great surprise of his fellow passengers. One nuclear reaction after another he discarded from the list of possible candidates for the solar life supply; and as the Sun, all unaware of the trouble it was causing, began to sink slowly under the horizon, the problem was still unsolved. But Hans Bethe is not the man to miss a good meal simply because of some difficulties with the Sun and, redoubling his efforts, he had the correct answer at the very moment when the passing dining car steward announced the first call for dinner.

In 1938, Bethe and Charles Critchfield published "The Formation of Deuterons by Proton Combination."[6] This described the first step in the proton-proton chain of fusion. This was followed by Bethe (writing alone) with "Energy Production in Stars" in 1939,[7] describing a second reaction series called the CNO cycle. Bethe's calculations suggested that the CNO cycle was dominant in the Sun because he didn't think there was enough energy coming from the di-

[5] The conference, organized by the Carnegie Institution and George Washington University, had 34 invitees, among them Gamow,. Bengt Strömgren, John von Neumann, Donald Menzel and Subrahmanyan Chandrasekhar. The topic was stellar energy generation. Bethe was not really interested in the topic, but was persuaded to go by his friend and fellow exile Edward Teller.

[6] *Phys Rev* 54: 248-254 (1938) https://is.gd/betheh38

[7] *Phys Rev*, 55: 434-456 (1939) https://is.gd/betheh39

rect proton reaction at the expected temperatures, even with tunneling.

Gamow doesn't tell us which of the two cycles Bethe calculated that afternoon on the train, but In *The Birth and Death of the Sun* he only describes the CNO cycle, leaving out the proton-proton chain altogether. By the 1950s the CNO cycle was demoted to being a lesser component of energy production in our Sun, but it is the major pathway in stars larger and hotter than the Sun. See the graph on page 15.

We can work through some of the aspects of the fusion process, but first we should show how the temperature at the center of any star can be calculated. Certainly we can't measure it directly: the rest of the star is in the way! The calculation is based on these principles:

- The entire star, regardless of the temperature, pressure and density at any point, behaves as a gas, which allows us to use the well-characterized gas laws.
- The temperature in the interior is hot enough for atoms to ionize, freeing their nuclei and electrons; that is, it is a plasma, the so-called "fourth state" of matter.
- Protons are 1836 times more massive than electrons, so we can ignore the electron's contribution to gravitation.
- There are more than ten times as many protons as helium nuclei, so for the initial calculation we can ignore the helium.
- Each proton at the center of the star has enough kinetic energy by virtue of its temperature to resist the gravitational compression of all the other matter in the star. This is true because stars are at hydrostatic equilibrium, with essentially constant mass and dimensions (until they use up their fuel).

The thermal energy of a particle in a gas is given by the equation

$$E = \frac{3}{2}kT$$

where k is Boltzmann's constant, 1.381×10^{-23} J K^{-1} and the temperature *T* is in Kelvins.

The gravitational energy is the good old Newton equation, so at equilibrium thermal energy equals gravitational energy. The equation becomes

$$\frac{3}{2}kT_c = G\frac{m_p M_s}{R_s}$$

T_c is the temperature at the center of the star. For the Sun, its mass M_s is 1.98×10^{30} kg (which we figured out last month) and its radius R_s is 6.955×10^8 m, which was determined by observation once the astronomical unit was measured in the 18th century. The mass of the proton, m_p, is 1.6726×10^{-27} kg. Solving for T_c we get

$$T_c = \frac{2Gm_p M_s}{3kR_s} = 1.56 \times 10^7 K$$

which is 15.6 million Kelvin. Now, to take into account the contribution of helium, we note that in terms of particles, 91.2% are hydrogen and 8.7% are helium (0.1% other nuclei) so we can make a correction for the m_p term. By my calculation it yields 1.93×10^7 K, 19.3 million Kelvin. You will see the temperature at the center of the Sun variously given between 15 million and 20 million Kelvin. The temperature decreases as you move towards the surface, and the reaction rate of the first critical step of hydrogen fusion will be proportional to the temperature, until it drops below a point at which the hydrogen is not moving fast enough and there are an insufficient number of collisions in the requisite time.

In the center of the Sun, protons are flitting about with a mean velocity of 6.26×10^5 meters per second.[8] Each proton collides with another about 20 million times a second. But mostly, nothing happens. The protons may interact, but there's no tunneling, the strong force does not take over and what could be a nucleus of helium-2, called a "diproton," is simply never created.[9] Each proton has to make on the average about 10^{25} collisions before an impact is accompanied by a quantum tunneling event, allowing it to overcome the energy barrier. A diproton is formed, but it has a fleeting lifetime of less than 10^{-18} seconds and decays into a deuteron, one of the protons be-

[8] An exercise: The thermal energy $^3/_2$kT equals kinetic energy ½mv^2. *m*, *k* and *T* are in the text. Solve for v. It's just algebra. It's been a long time since high school, but it's still in your brain somewhere! YOU CAN DO IT!

[9] If the strong force was just 2% greater than it is in our universe, diprotons would be more stable. The reaction rate would be greater, and stars would use up their fuel much, much faster, probably too fast for life to evolve.

coming a neutron in a process known as β+ decay[10] by emitting a positron (maintaining charge neutrality) and an electron neutrino with an energy of 0.42 MeV.

$$ {}^1_1H + {}^1_1H \rightarrow {}^2_2He \rightarrow {}^2_1H + e^+ + \upsilon_e $$

This is the rate-limiting step. All subsequent reactions occur much more efficiently.

The positron, an antimatter electron, immediately collides with a free electron to annihilate into two gamma rays, each with 0.511 MeV of energy.

Unlike the proton-proton collision, a proton-deuteron collision is energetically favorable, and very quickly a proton and deuteron combine to form "light" helium. An energetic gamma ray is emitted.

$$ {}^1_1H + {}^2_1H \rightarrow {}^3_2He + \gamma \ (5.49\ MeV) $$

The helium-3 nucleus can undergo one of three reactions. Eighty-six percent of the time, in the so-called p-p I chain, two helium-3 nuclei combine to form a helium-4, releasing two protons back to the atomic soup.

$$ {}^3_2He + {}^3_2He \rightarrow {}^4_2He + {}^1_1H + {}^1_1H $$

We need two helium-3s to form a helium-4, so that ultimately means that a total of six protons go in, but two come out. The net of these reactions is

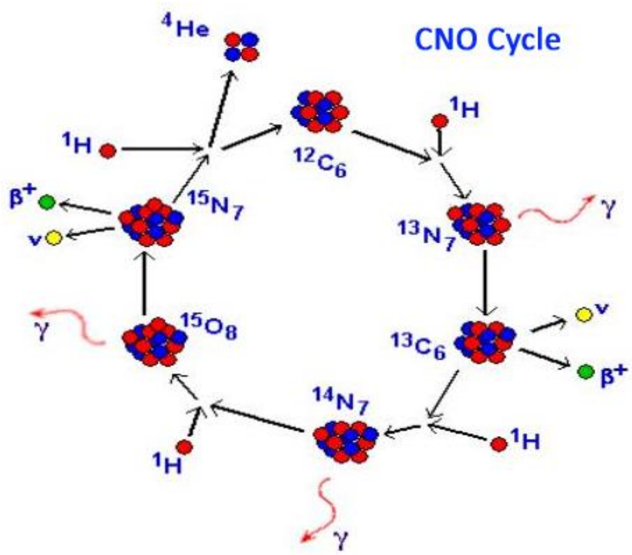
$$ 4{}^1_1H \rightarrow {}^4_2He + 2e^+ + 2\upsilon_e + 2\gamma $$

with four more gamma rays coming from the annihilation of the positrons. Of the 26.7 MeV of energy released, neutrinos carry off about 2%. The rest comes from the gamma rays.

The two other pathways, p-p II (14%) and p-p III (0.02%) start with helium-3 but involve the production of lithium and beryllium intermediates. Another distinct mechanism is the proton-electron-proton (PEP) reaction, in which two protons combine with an electron to produce deuterium and an energetic neutrino. This reaction occurs at a much lower rate, about once for every 400 p-p reactions. There's also a p-p IV chain in which a helium-3 captures a proton and emits a positron and an energetic neutrino. It's calculated to account for just 3 of every 10 million fusion reactions.

The CNO cycle is favored at higher temperatures, where the added kinetic energy can overcome Coulombic repulsion more effectively.

In the CNO cycle, reaction, carbon acts as a catalyst to convert hydrogen to helium in the same product ratio as the proton-proton cycle. A carbon-12 nucleus combines with a proton to form nitrogen-13, which undergoes β+ decay to carbon-13. This absorbs another proton to form nitrogen-14, which in turn absorbs another proton to form oxygen-15. This too undergoes β+ decay to form nitrogen-15, which absorbs another proton and releases a helium nucleus, regenerating the carbon-12 nucleus. There are several minor branches of this process, but the net result is the same as the proton-proton cycle: four hydrogens creating one helium, two positrons, two neutrinos (although with different energies than those from the proton chain) and radiation energy.



We can calculate the energy released by one fusion cycle from the mass difference between the protons and the helium-4 nucleus.[11]

$$ \Delta E = \Delta mc^2 = (4m_p - m_{He})c^2 $$

This comes to 4.2 x 10^{-12} joules for each complete proton-proton cycle. Every second, 10^{38} helium nuclei are created in the Sun from the consumption of 6.69 x 10^{11} kg (737 million tons) of protons. Since the mass of the Sun is 1.98 x 10^{30} kg, if consumption of

[10] This is governed by the weak force. We now know that the proton becomes a neutron because a down quark is converted to an up quark, but we can stick with the proton/neutron description for the purposes of this article.

[11] Proton=1.6726 x 10^{-27} kg, helium-4=6.644 x 10^{-27} kg.

hydrogen were complete the Sun could live for about 10^{19} seconds, which is 3 x 10^{11} (300 billion) years. In reality, not all the hydrogen will be consumed, and the Sun's lifespan is estimated to be about 10 billion years. We're about halfway through it.

There is one more notable cycle that occurs in stars, the "triple alpha" process. A route through ^{8}Be was predicted by Fred Hoyle, who was the first to suggest that all chemical elements are ultimately formed from hydrogen. When hydrogen is used up deep in the stellar core, helium accumulates. The energy output drops, the star contracts, and the core reheats to a higher temperature. The star becomes a red giant, with a core temperature of 100 million K and a density of 10^5 gm/cc. In this environment, helium nuclei can fuse to make carbon, through a beryllium intermediate. The first step is

$$^{4}_{2}He + ^{4}_{2}He \rightarrow ^{8}_{4}Be + \gamma$$

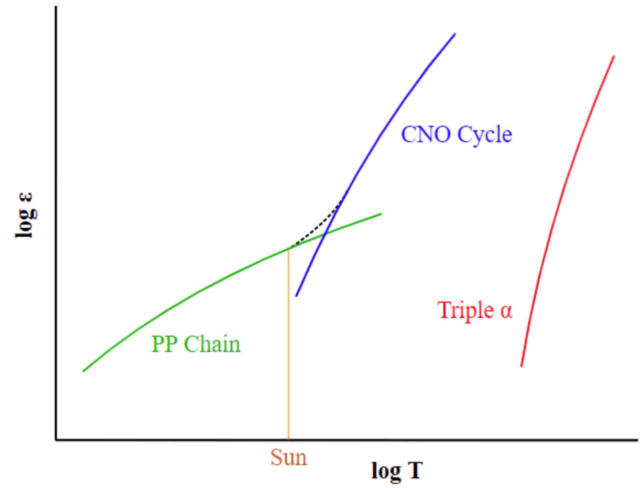
The half-life of beryllium-8 is just 8 x 10^{-17} seconds, but that's enough time for another helium nucleus to react with it in the super-hot, super-dense red giant core.

$$^{8}_{4}Be + ^{4}_{2}He \rightarrow ^{12}_{6}C + \gamma$$

The reaction occurs only once every 2421.3 He-Be collisions but it's enough to keep things burning in big, elderly stars. This is the source of almost all the carbon in the universe. The short half-life of ^{8}Be prevented the synthesis of heavier elements during Big Bang nucleosynthesis (BBN). The CNO cycle couldn't operate in Population III stars, the first generation of stars formed after the Big Bang, since they contained only hydrogen and helium (and a few parts per trillion of deuterium and lithium). They synthesized carbon through the triple-alpha process when they got old and hot enough, and then it was incorporated into the next stellar generation after the Population III stars went supernova. The Sun is far too cool to be utilizing the triple-alpha process.

Energy Output of the Fusion Chains		
Cycle	Temperature Dependence	Density Dependence
PP	4th power	2nd power
CNO	17th power	Linear
Triple-α	40th power	Linear

The reaction rates, and therefore the energy output, of each of the pathways scales with temperature and density, explaining the dominance of the CNO and triple-α pathways in hotter stars.



Temperature dependence of the three fusion pathways in stars.

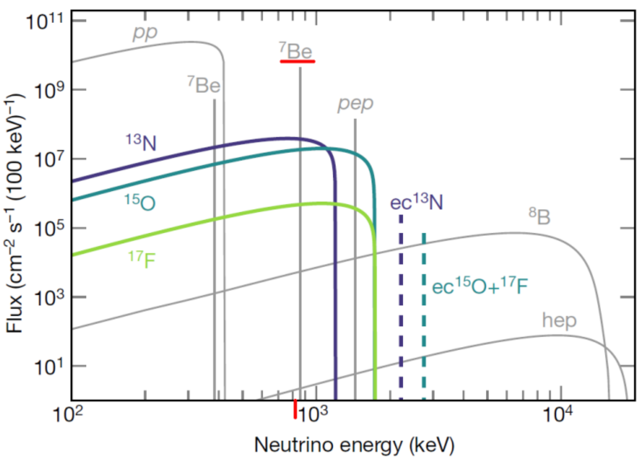
But how do we <u>really</u> know what's happening inside the Sun? We can measure its energy output and make lots of calculations about nuclear reactions, but is that proof of the mechanism? Photons emitted during fusion interact with protons and electrons, and it takes 100,000 years for those photons to finally reach the surface, in the process cooling and moving to longer wavelengths, including those that we see and feel on a warm day. Neutrinos ignore the plasma and come out at the speed of light. Characterizing the energy of solar neutrinos offers a way of checking that the expected events actually occur.

Neutrinos are hard to detect. A single energetic neutrino with an energy of 1 MeV will pass through 35 light-years of water before interacting. But there are so many neutrinos coming out of the Sun (or a nuclear reactor, or the rest of the universe) that interactions do occur and can be detected. A neutrino's energy is characteristic of its source, and detectors can be tuned to measure the energy.

The neutrino detector a mile underground in the Homestake gold mine in South Dakota started detecting neutrinos in the 1960s using 100,000 gallons of perchlorethylene. A high-energy solar neutrino can convert a stable chlorine-37 nucleus into a radioactive argon-37 nucleus with a half-life of 35 days.[12] The

[12] A neutron is converted to a proton and an electron through the "charged current interaction" (exchange of a charged W boson of the weak force). The neutrino energy has to be at least 0.814 MeV for this to occur.

system is purged with helium, which carries the argon with it. The argon-37 is separated by cooling and measured. This detector is most sensitive to the neutrinos produced by beryllium-7 in the p-p II and p-p III branches of the proton-proton chain and the PEP reaction. Calculations by John Bahcall predicted the detection rate, but only a third of the neutrinos were found. This was the famous “solar neutrino problem” that could only be explained if neutrinos have mass. They were thought massless when Pauli proposed them in 1930. Experiments at the Sudbury detector in Ontario, a heavy-water instrument that operated from 1999-2006, detected all three kinds of neutrinos, making it clear that they transformed into each other during their 8-minute trip from the Sun. The electron’s rest mass is 9.1093837015 x 10^{-31} kg or, equivalently 0.5109989461 MeV, whereas the rest mass of the three neutrinos are each somewhere between 0.1 and 0.5 eV, at least a million times lighter. The result from Sudbury was proof that the proton-proton chain was operational in the Sun.



Energy spectrum of solar neutrinos. The energy of the neutrino emitted by ^{7}Be in the p-p II chain is just above the threshold for detection by the Homestake detector (red line on the abscissa). The colored curves represent the neutrinos coming from the CNO cycle that were detected by Borexino. The neutrinos emitted by the conversion of protons to deuterons in the first step of the p-p are lower energy, as are the neutrinos from ^{7}Be in the p-p III cycle. (Graph from the Borexino Collaboration)

Detection of neutrinos emitted during the formation of deuterium, the first step in the p-p I cycle, was achieved by the Borexino detector 2014. The Borexino experiment is buried under Gran Sasso in Val Gardena (a beautiful valley in northern Italy, where all the signs are in Italian, German and the ancient Ladin language). Borexino was specifically designed to detect relatively low-energy neutrinos. It contains 280 tons of pseudocumene (1,2,4-trimethylbenzene) with a small amount of a fluorescent material mixed in. The neutrino impacts an elementary particle and creates a brief flash of light that is detected in the photodetectors surrounding the liquid.[13]

Subsequently, Borexino was able to measure neutrinos from all of the steps in the various branches of the proton-proton chain.

What about the CNO cycle? Similar to the proton-proton chain, the only direct evidence that the CNO cycle actually operated would be the detection of the neutrinos from that cycle.

In November 2020, the Borexino experiment reported detection of solar neutrinos from the CNO cycle.[14] This was an extremely complex experiment. Detecting and separating the true signal from noise and background sources was arduous. The CNO solar neutrinos produce only a few counts above background. Not only did the detector fluid and surrounding water jacket have to be purged of as much naturally occurring radioactivity as possible, even the slightest temperature variations in the chamber would interfere with the accuracy of the experiment, so strict thermal control equipment had to be installed. The experiment was also limited by the senescence of the photomultiplier tubes in the apparatus: of the original 2,212 tubes in place, only 1,238 could be used for data gathering, which took four years. The authors’ conclude, “The absence of a CNO solar neutrino signal is excluded with a significance of 5.0σ. We therefore present a direct detection of CNO solar neutrinos.” In other words, “We didn’t not see them.” A peculiar way to phrase it, but the data is there.

Neutrinos prove that the Sun shines by the fusion of hydrogen. The insights and theoretical reasoning of Harkins, Perrin and Eddington and the calculations Gamow and Bethe were finally confirmed. ■

[13] This is the “neutral current interaction” of the weak force. The neutrino remains a neutrino, as do the other particles, but energy and momentum are transferred from the neutrino to a nucleon by exchange of a Z^0 boson.

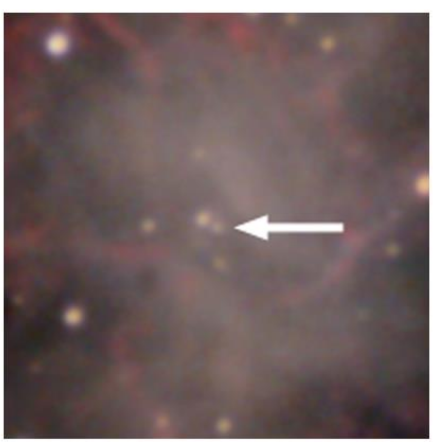
[14] The Borexino Collaboration, Experimental evidence of neutrinos produced in the CNO fusion cycle in the Sun, *Nature* https://doi.org/10.1038/s41586-020-2934-0, published on line November 25, 2020.

Images by Members

Portrait of a Pulsar by Robin Stuart

This image of the Crab Nebula, M1, in Taurus is a stack of 203 60-second subs acquired over four nights in March 2021 from Valhalla, NY, through a Televue NP127 refractor equipped with a 2X Televue Powermate. The camera was a Canon 60Da DSLR at ISO 1600. Processing was done with ImagesPlus, now available for free at http://www.mlunsold.com/ILOrdering.html.

The Crab Nebula is the remnant of a supernova explosion observed in the year 1054 and is home to the first pulsar to be discovered, in 1967. Unlike some types of planetary nebulas in which the progenitor star often sits isolated and obvious (see WAA News-letter December 2020, p.20), the central region of the Crab appears rather crowded with stars and contains several possible candidates. In order to be sure of its identification the image was uploaded to Astrometry.net (http://nova.astrometry.net/) which will identify and label the brightest stars and provide calibration data for an image. This consists of the right ascension and declination of the point at the center, the image scale in arcseconds per pixel and the orientation of the "up" direction in degrees from north. This information allows a precise map to be constructed between pixel positions and celestial co-ordinates. From the pulsar's published position, its location in the image could be unambiguously identified and is shown arrowed on the detail on the left.

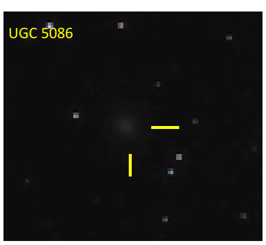


It is staggering to contemplate what this magnitude 16.5 star represents. It is an object just 20 km (12 miles) in diameter yet we see it from across 6,500 light years of space. Into its tiny shell it packs 1.4 solar masses of neutron matter and spins on its axis 30 times a second. Its mass and volume equate to an average density of 0.7 billion tons per cubic centimeter and a surface gravity 200 billion times that of the Earth!

Robin Stuart

NGC 2903 by Steve Bellavia

This fairly large (11.6’ x 5.7’) magnitude 9 galaxy is just west of the sickle of Leo. It’s a mixed spiral galaxy with a prominent central bar and active star formation in its arms. NGC 2903 was discovered by William Herschel in 1784. He thought it was actually a binary object. About 70 years later, Lord Rosse, using the 72-inch “Leviathan of Parsonstown,” saw that it was a single spiral. The second object perceived by Herschel and others was just a knot of bright gas and stars in the galaxy’s northeastern arm, but distinct enough to confuse Herschel, who made two entries in his first catalog (I 56 and I 57). This carried through to his son’s General Catalog (1861 and 1863) and then to the NGC as 2903 and 2905. NGC 2903 is a “field” galaxy, meaning that it isn’t a member of a tightly defined galactic group. It is 23 million light-years distant, inclined 60 degrees to our line of sight.



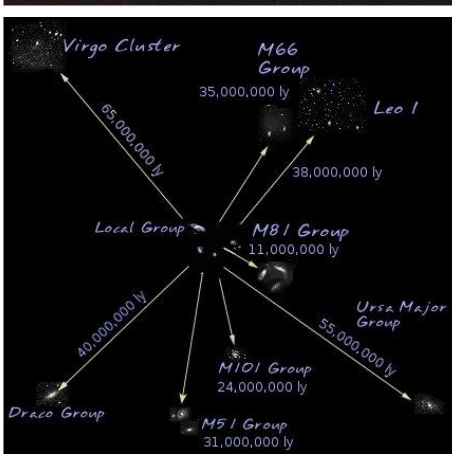
If you enlarge the image a bit and look closely, you will see, below NGC 2903 two-thirds of the way to the lower edge, the very low-surface-brightness galaxy UGC 5086, a satellite of NGC 2903. The NASA/IPAC Extragalactic Database gives this object magnitude as 15.73 but it seems much fainter. About one galaxy-diameter to the right of NGC 2903 is star-like galaxy 2MASX J09320403+2122238, red shift 0.03429, distance 467 million light years. Visual magnitude is not given in the 2MASX catalog, but it can be estimated to be around 16.0, since the star just below and to its right is UCAC4-557-047166, magnitude 15.917. The image on the right is from the Dark Energy Survey camera on the 4-meter Victor Blanco telescope at Cerro Tololo in Chile, showing it’s a spiral galaxy.

Steve made this image in March 2021. Technical details are at https://www.astrobin.com/dvae96/.

Messier 51, the "Whirlpool Galaxy," by **Tony Bonaviso**. The main galaxy is NGC 5194; the companion is NGC 5195. See "The Wonderful Whirlpool" in the June 2016 SkyWAAtch.

35 light frames x 180 seconds @ -10° C; 25 dark frames; 50 bias frames. Astro-Tech AT92 triplet refractor. ZWO ASI294 MC Pro cooled camera Software: captured with Astrophotography Tool; guided with PhD2 multi-star guiding; processed with Pixinsight and Photoshop.

Olivier Prache made this image of 9.3-magnitude **Messier 63**, the "Sunflower Galaxy," from his observatory in Pleasantville during the first week of April. He captured about nine hours of signal over three nights with a 12.5-inch Hyperion f/8 telescope. At the upper right edge of the image is UGC 8313, a 14.5-magnitude galaxy.



Located in the constellation Canes Venatici, M51 and M63 are the largest and brightest members of the so-called M51 group of galaxies, which also includes NGC 5023, NGC 5229 and UGC 8331. The M51 group lies at an average distance of about 31 million light-years, and may be part of a loose, extended structure with the M101 and NGC 5866 galaxy groups. All of these groups are part of the larger Virgo Supercluster.

Diagram: NASA

The Moon and Venus on May 12

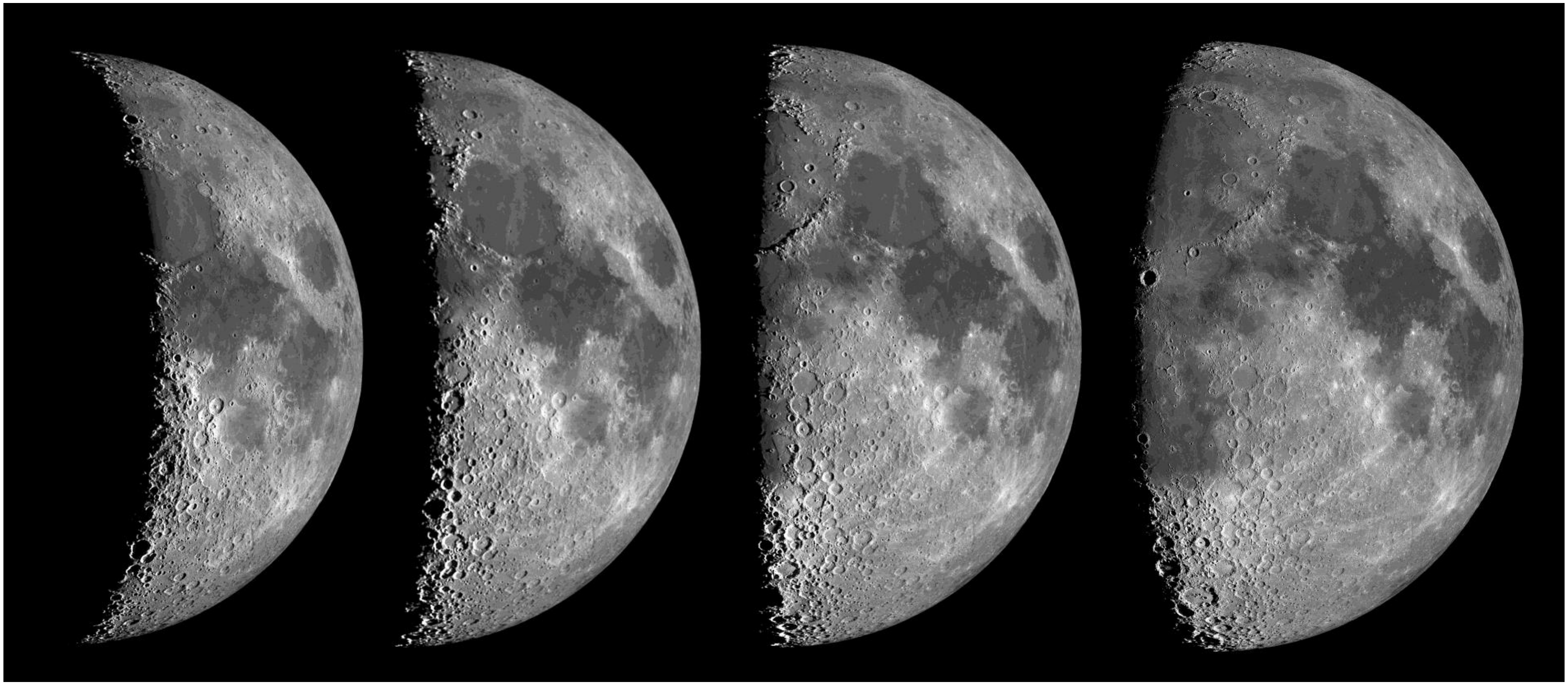
The edge of the 29-hour old, 1.2% illuminated Moon was just 49 arc-minutes from 97.7% illuminated Venus on May 12. **Alex Mold** captured the top image from Tarrytown, while **Steve Bellavia** made the bottom image from eastern Long Island. The Sun was about 12½° away, having set about 35 minutes earlier.

The youngest Moon ever seen with the naked eye was 15½ hours, reported by Stephen James O'Meara in 1990. Mohsen G. Miraseed in Iran used large binoculars to see the 11-hour 42-minute Moon on September 7, 2002. The first sighting of the lunar crescent inaugurates a new month on the Islamic calendar. The history of the sighting of the lunar crescent is the subject of an interesting Ph.D. thesis by Louay J. Fatoohi, University of Durham, from 1998. *First visibility of the lunar crescent and other problems in historical astronomy*, https://is.gd/FatoohiLunar.

The lunar crescent is thought not be visible if the Moon is closer than 7° from the Sun, the "Danjon limit." Nevertheless, using infrared filters and advanced processing techniques, Thierry Legault managed to image a lunar crescent on a new Moon (age exactly zero) separated from the Sun by 4.6°.

The Waxing Moon

Robin Stuart



March 19 to 22 afforded a rare interval of four consecutive clear evenings with relatively good seeing and the waxing Moon sailing high in the sky.

The full face of the Moon is a tempting target for imaging but can present a challenge when it comes to displaying the output in a way that reflects its visual appearance. With their linear response over a wide dynamic range, raw images from digital sensors show the Moon's surface gradually fading into darkness as the terminator is approached. At the eyepiece however we observe detail across the entire disk with the terminator seen as a ragged but distinct boundary.

The stacked images on this page were taken through a Televue NP127 with a Meade LPI-G monochrome camera and processed using the method described in SkyWAAtch April 2021 p. 14. Subtly wrinkled ridges in the maria surfaces appear and vanish from one day to the next. In third image the Straight Wall (Rupes Recta) has just crossed the terminator and the crater Birt to its west casts a long shadow. In the image at right, sunlight illuminates the rims of the prominent craters Copernicus and Bullialdus but is yet to penetrate their inky depths.

The Moon's diameter increased by 3.2% over the four-day period as its elliptical orbit took it 12,500 km closer to Earth.

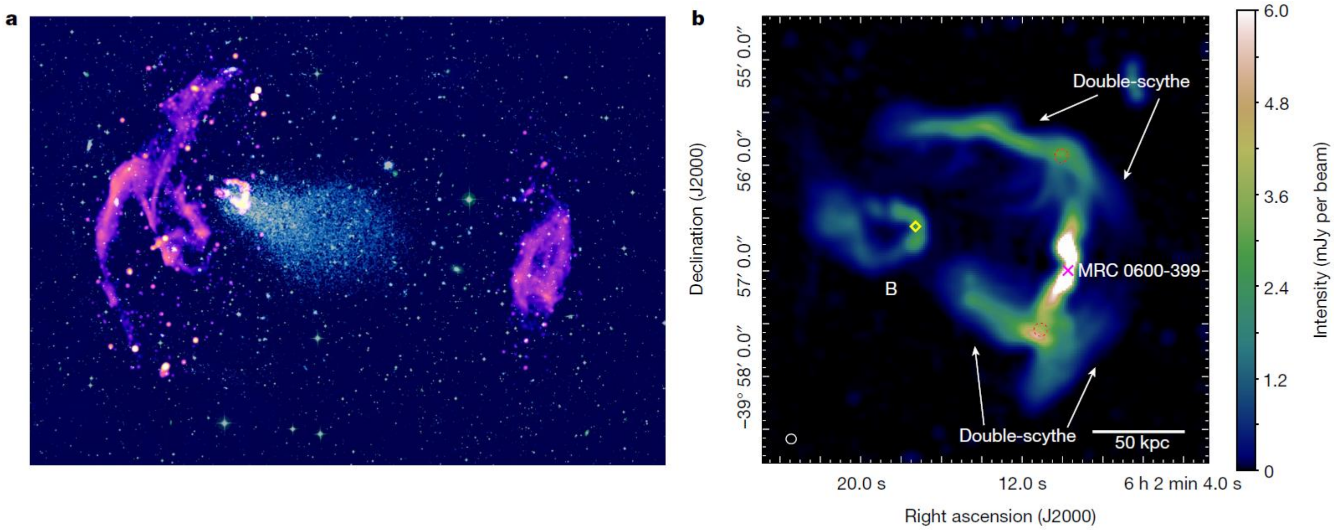
Research Highlight of the Month

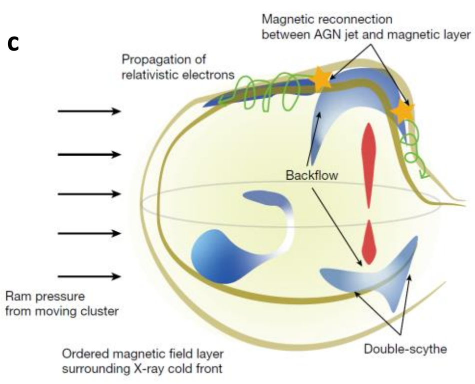
Chibueze, J., Sakimi, H, Ohmura, T, et. al., Jets from MRC 0600-399 bent by magnetic fields in the cluster Abell 3376, *Nature* 2021; 593: 47-50 (May 5, 2021)

Spinning massive and supermassive black holes at the cores of galaxies can emit beams of particles at near light speed, forming radio jets as the particles spiral around magnetic field lines. The process is known as synchrotron radiation. The most famous example is the radio jet in Messier 87. These jets can extend hundreds of thousands of light years until they dissipate by interacting with the intergalactic medium. They can be sensitive probes of the environment near their host galaxies.

Using the MeerKAT radio telescope in South Africa, a group of astronomers from South Africa and Japan observed galaxy MRC 0600-399 in the galaxy cluster Abell 3376, in the southern hemisphere constellation of Columba. The radio jets coming from MRC 0600-399 are bent sharply, which can be explained if the rapidly moving jets interact with a curved magnetic field. The field is generated by shock waves from the in-fall of cold matter into the cluster, which collides with hot, X-ray-emitting gas ejected from the center of the cluster. The pressure from this interaction causes the magnetic layers to drape around the outside of the hot gas, taking the charged particles from the black hole jet, and their radio emissions, with it, with a “double scythe” appearance.

The magnetic field strength may be as high as tens of microgauss, an order of magnitude greater than in galaxy clusters less disrupted by inflowing cold matter. The field strengths were calculated from simulations. For comparison, the magnetic field strength at the surface of the Earth is ~0.5 gauss. Considering the minute mass density of intergalactic space, tens of microgauss is surprisingly strong, and clearly has an effect on the black hole jets.





(a) Composite image of A3376 (reddish color, MeerKAT 1.28 GHz; light blue: X-rays; background: optical from Sloan Digitized Sky Survey). The "bullet-like" appearance of the X-ray data is due to the interaction of hot gas with material flowing into the galaxy cluster from the right side. The giant radio arcs on the left side may be caused by shock waves generated by this merger.
(b) High resolution image of radio emissions. The diamond on the left is another galaxy in the cluster.
(c) The authors’ proposed model of the interaction of radio jets from MRC 0600-399 with the surrounding magnetic fields.

Member & Club Equipment for Sale

Item	Description	Asking price	Name/Email
Bausch & Lomb 5-inch f/8 objective lens **NEW LISTING**	Large-format/aerial camera lens in cell. Cleaned and reconditioned by John Paladini. Diaphragm removed. Weight 10 lbs. Mounted on a wooden board, can be removed. See images at https://is.gd/WAABL. Use in a telescope or camera project. Donated to WAA.	$25	WAA ads@westchesterastronomers.org
ExploreScientific 127-mm refractor	Air-spaced ED APO f/7.5 triplet OTA with tube rings, 2” diagonal, Orion focus extender. Like new condition; rarely used. See https://is.gd/es127gb for more information.	$1000	Greg Borrelly gregborrelly@gmail.com
Ritchey-Chrétien 6 inch astrograph	Astro-Tech f/9 imaging instrument. Barely used, with original shipping box. These scopes list at $399. See https://is.gd/RCf9scope.	$200	John Paladini jpaladin01@verizon.net
Denkmeier 60-mm Spectrum 60 upgrade (OTA) for PST	Unscrew the 40-mm PST tube and screw in the upgrade, and now your PST is a 60-mm solar scope. It does work with newer PST's. Original price $599.	$240	John Paladini jpaladin01@verizon.net
ADM R100 Tube Rings	Pair of 100 mm adjustable rings with large Delrin-tipped thumb screws. Fits tubes 70-90 mm. You supply the dovetail. Like new condition, no scratches. See them on the ADS site at https://tinyurl.com/ADM-R100. List $80.	$50	Larry Faltz lfaltzmd@gmail.com
ExploreScientific 40-mm eyepiece	68° field of view. Argon-purged, waterproof, 2" eyepiece. New in original packaging, only used once. Lists for $389.	$340	Greg Borrelly gregborrelly@gmail.com
Atco 60-mm f/15.1 refractor	A classic Japanese refractor from the early 1970s. Obtained from the original owner about five years ago. It had been used only a few times, then stored for 40+ years. Current owner used it maybe seven times. Very good condition. Comes with three eyepieces and a 1.25" eyepiece adaptor star diagonal. Straight-through finder. Equatorial mount with slow-motion adjustment knobs (screws). Wooden tripod, metal tube. Everything is original.	$150	Robert Lewis lewis@bway.net

Want to list something for sale in the next issue of the WAA newsletter? Send the description and asking price to ads@westchesterastronomers.org. Member submissions only. Please offer only serious and useful astronomy equipment. WAA reserves the right not to list items we think are not of value to members.

Buying or selling items is at your own risk. WAA is not responsible for the satisfaction of the buyer or seller. Commercial listings are not accepted. Items must be the property of the member or WAA. WAA takes no responsibility for the condition or value of the item, or for the accuracy of any description. We expect, but cannot guarantee, that descriptions are accurate. Items are subject to prior sale. WAA is not a party to any sale unless the equipment belongs to WAA (and will be so identified). Sales of WAA equipment are final. *Caveat emptor!*