SkyWAAtch

The Newsletter of Westchester Amateur Astronomers

May 2021

NGC 5707 by Gary Miller

This galaxy in Draco is often called the "Splinter Galaxy" for obvious reasons. Fifty million light years distant, It shines at magnitude +11. It is 12.7 x 1.4 arcminutes in size. It is peculiar in that it is apparently composed only of dwarf stars. Studies with the Hubble Space Telescope should have resolved at least some giant stars, but failed to do so. Its disc is actually slightly warped, and very deep images show large, looping tidal streams of stars surrounding it, suggesting prior gravitational interactions other galaxies of the NGC 5866 group, of which it is a member.

WAA May Meeting

Friday, May 13 at 7:30 pm

The Night of the Shooting Stars

Joe Rao

Associate and Guest Lecturer at the Hayden Planetarium, Contributing Editor for *Sky & Telescope*

In 1995 Comet 73P/Schwassmann-Wachmann 3 broke apart in dramatic fashion. Now a number of meteor dynamicists have confirmed what Joe Rao predicted last year: a stream of particles ejected during the comet's disruption may yield a dramatic meteor outburst at the end of May 2022. The predictions are uncertain because no one knows for sure how fast the concentrated dust swarm left 73P's disintegrating nucleus. But there is *a chance* that we could see meteors briefly fall at rates numbering in the scores or maybe even in the hundreds per hour! In this presentation, Joe will explain the reasons why late on the night of May 30th, you may see more shooting stars than you've seen in your entire life!

For 21 years, Joe Rao was the Chief Meteorologist and Science Editor at News 12 Westchester. He was nominated for 8 Emmy Awards and in 2015 was voted first among weathercasters in New York State by the Associated Press. Since 1986 he has served as an associate and guest lecturer at the Hayden Planetarium. He is a contributing editor for *Sky & Telescope* and writes a syndicated weekly column for the online news service *space.com.* He also pens a monthly astronomy column for *Natural History* magazine and provides annual astronomical data for The *Farmers' Almanac*. Joe is a long-time friend of WAA.

Club meetings are in-person at Willcox Hall, Pace University and on-line via Zoom (link on the WAA web site)

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

WAA June Meeting

Friday, June 10 at 7:30 pm

Astrophotography in Urban Skies

Mauri Rosenthal

Westchester Amateur Astronomers and Amateur Astronomy Association (NYC)

Starway to Heaven

Ward Pound Ridge Reservation, Cross River, NY

Saturday, May 21 (make-up date May 28)

New Members

Jill Abel	Ardsley

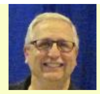
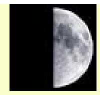
Renewing Members

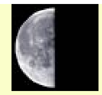
Arun Agarwal	Chappaqua
Erik & Eva Andersen	Croton-on-Hudson
Rob & Melissa Baker	West Harrison
Lawrence C Bassett	Thornwood
Richard Bronstein	Bedford
Marcy Cohen	Croton on Hudson
Kenneth Creary	White Plains
Everett Dickson	Dobbs Ferry
Ingrid & Tracy Ehrensbeck Edwards	Binghamton
Robbins Gottlock	Sleepy Hollow
Arthur Linker	Scarsdale
Anthony Mancini	Pleasantville
Gary Miller	Pleasantville
David Parmet	Mt. Kisco
Lydia Maria Petrosino	Bronxville
Anthony Sarro	Brooklyn
Jude Stenson	New Rochelle
Dante Torrese	Ardsley
Joseph Trerotola	Woodbridge
Jordan Webber	Rye Brook
Alan Young	Tarrytown

Also In This Issue

ALMANAC For May 2022

Bob Kelly, WAA VP for Field Events


Bob Kelly

1Q 5/8

Full 5/16

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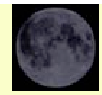

New 5/30

Mark your Calendars!

There are some events WE have to write on our calendar this month! We can look forward to a **total lunar eclipse** on May 15/16, and, a **possible meteor storm** on May 30/31. But that's not all!

A Burst of Meteors?

We'll see the Tau Herculid meteors late in the month. Bits of **Comet 73P/Schwassmann-Wachmann 3** might give us a meteor storm overnight May 30/31, with the possible peak around 1 a.m. The meteors appear to be radiating from the constellation Hercules.

Of the more regular meteor showers, the pre-dawn hours of May 6 have the **Eta-Aquariids** visible with no interference from the Moon. You might see 20 or more fast, bright meteors an hour.

Pre-sunrise Planet Pile-up

Jupiter is crawling along low in the eastern sky in the morning. The king of the planets moves from aligning with **Venus** to hanging around with **Mars** in the morning sky. Jupiter is closest to Mars in our sky on the 28th. It's worth comparing them in a telescope. Pay attention to their size and brightness, and test your ability to see details on their faces.

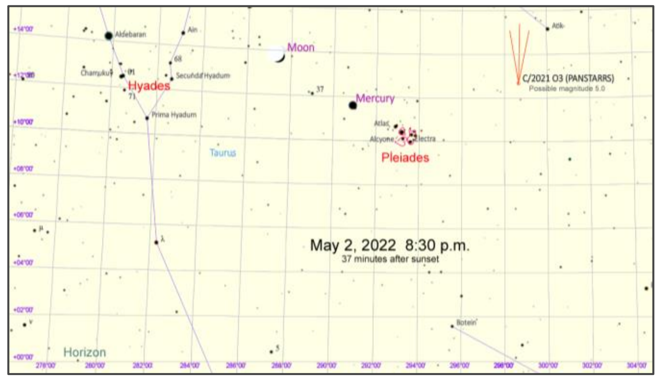
Mars surpasses **Saturn** in brightness this month at magnitude +0.8, but the Red Planet is only one-third the apparent size of Saturn.

Ordinary Moon Stuff

The **Moon** joins the morning planet parade, visiting Saturn on the 22nd, passing Jupiter and Mars on the 25th, and is near Venus on the 27th. Lunar perigee is on the 17th. Only the full Moons of June, July and August will be larger in apparent diameter.

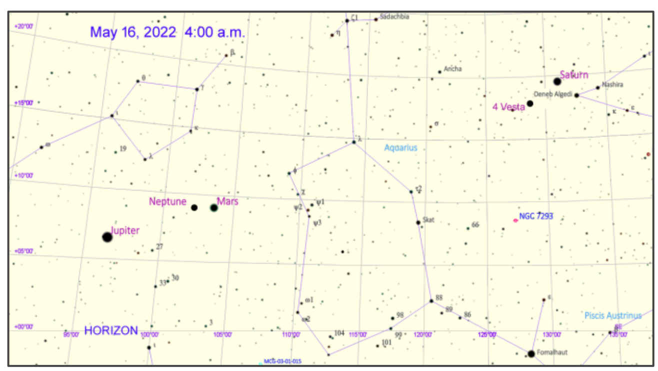
Mercury Pop-up

Mercury continues its fine evening performance. We get a lovely array of the very thin crescent Moon, Mercury and the **Pleiades**, with the **Hyades** nearby, on the 2nd. They are only ten degrees above the west-northwestern horizon about 8:30 p.m. EDT, but worth finding. Did nearby **C/2021 O3 PANSTARRS** pan out as an object findable in binoculars? Mercury drops out of sight by mid-month, dimming from magnitude +0.9 to +3. It faintly crosses the C3 field of the Solar and Heliospheric Observatory[1] from May 16th to 27th. Mercury continues to be the planet closest to Earth until we start to close in on Mars in July, well ahead of our closest approach to the red planet in December.



Further Out

Uranus is in conjunction with the Sun on the 5th, on its way to the morning sky. It may also be visible in the C3 view. Neptune is already out in the morning. It passes Mars on the 17th.

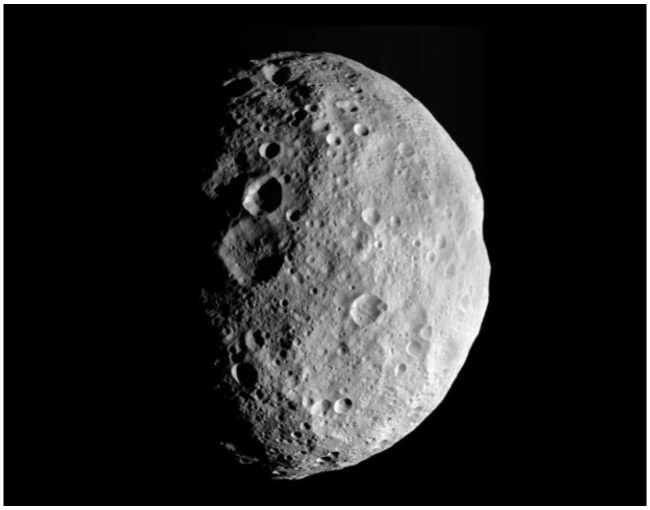


A Bright Asteroid

Asteroid **4 Vesta** is brightening through magnitude +7½ in May. It's brighter than any of the other asteroids for 2022. It's even brighter this year than minor planet Ceres. 4 Vesta's brightness will peak at +5.9 in August. Vesta spends the first half of May within a

[1] https://www.swpc.noaa.gov/products/lasco-coronagraph

few degrees of Saturn, motoring away to the left of Saturn later in the month.



Asteroid 4 Vesta from Dawn spacecraft (NASA)

International Astronomy Day is May 7th.

The winter constellations are gone, with **Gemini** waving goodbye after the sky gets dark. **Boötes** is peaking in the evening sky, with **Cygnus** rising opposite the Sun. The **Milky Way** is low in the western evening sky. There may be quite a few live and on-line events. Check the NASA/JPL Night Sky Network calendar for more information. https://nightsky.jpl.nasa.gov/.

Many ISS Overflights

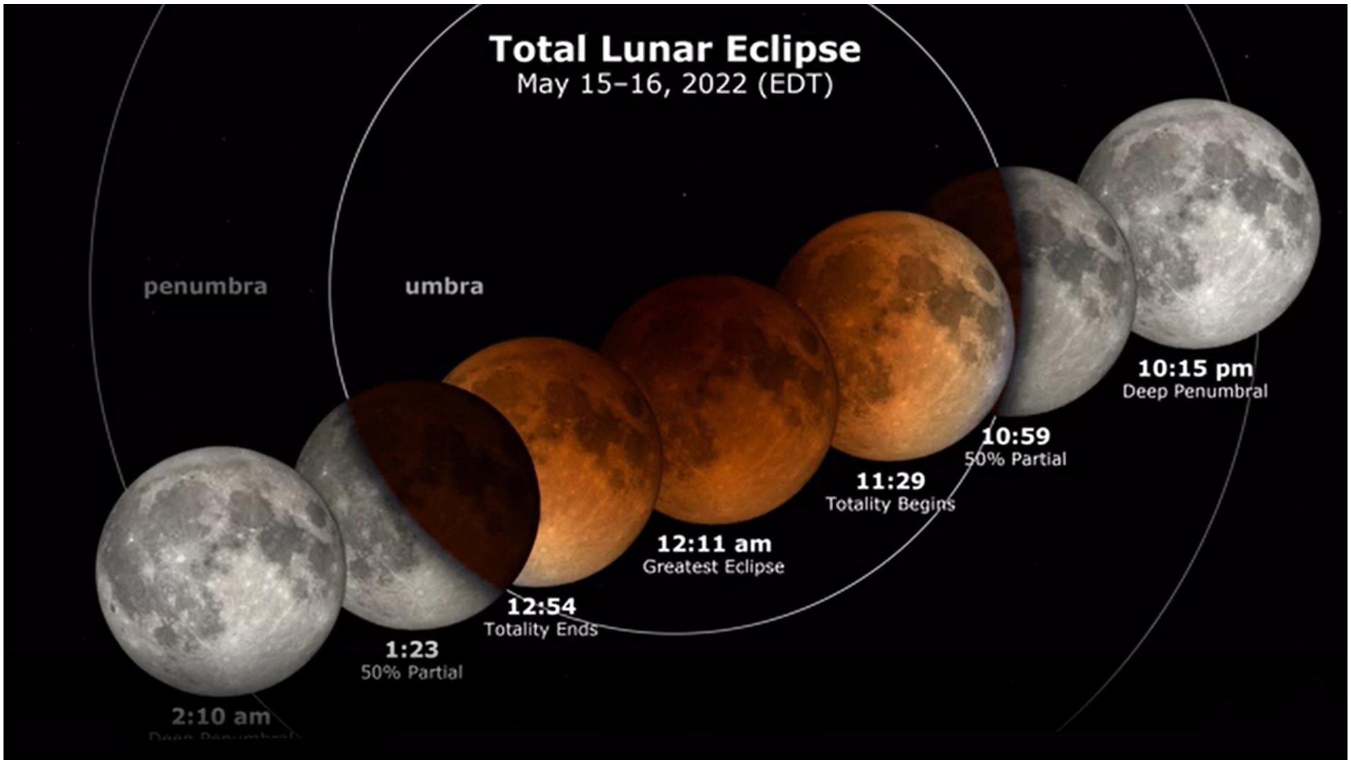
The **International Space Station** is a busy hotel in April and May, with the first all-commercial crew having arrived in April, increasing the population to ten souls.

This longest permanently crewed spaceship is visible in the morning twilight in early May. Around the middle of the month, the ISS pulls some all-nighters, with as many as six overflights visible on at least one night. The second half of May has evening visits to our skies.

The Total Lunar Eclipse of May 15/16

The **Moon** will be entirely in the Earth's shadow for a nice, long hour and twenty-five minutes, from 11:29 p.m. EDT through 12:54 a.m. The partial phase starts at 10:27 p.m. and ends at 1:56 a.m.

The lunar north pole will pass through the center of the Earth's shadow, making this a pretty dark eclipse. The Moon's highest altitude will be just under 30 degrees above our southern horizon, so check in advance if you have a clear view to the south. As always, send your photos to us for publication in Sky*WAA*tch! ■



From the Editor: The Shape of Einstein's Universe

Within a couple of hours of my posting the April issue of Sky*WAA*tch, WAA member Arthur Linker wrote to me to point out an error in my article "Webb, the Early Universe and Infinity." Arthur, who obtained a graduate degree in physics prior to his law degree, noted that my statement "Einstein deemed space to be infinite and eternal, and threw in the cosmological constant to keep it that way" is not quite correct.

To educate me, Arthur sent two papers. The first was an English translation of Albert Einstein's actual paper on the subject, "Kosmologische Betrachtungen zur allgemeinen Relativitätstheorie" (Cosmological Considerations in the General Theory of Relativity).[1] It was in this paper that Einstein introduced what later was named the "cosmological constant." The other paper was "Einstein's 1917 Static Model of the Universe: A Centennial Review."[2] It provides important background and thorough analysis. The authors make use of Einstein's prolific correspondence with other physicists, particularly Willem de Sitter, to show how he developed his ideas about the physical nature of cosmic space. The authors write:

> There is little doubt that Einstein's 1917 paper… constituted a key milestone in 20th century physics. As the first relativistic model of the universe, the paper, later known as "Einstein's Static Universe" or the "Einstein World," set the foundations of modern theoretical cosmology.

Einstein first presented General Relativity in a lecture at Berlin's Archenhold Observatory on June 2, 1915 (a plaque there commemorates the event), followed by four papers submitted to the Prussian Academy of Sciences in November 1915. Continuing to explore the mathematical implications of General Relativity (GR) Einstein became puzzled by the "boundary condition." This is value of the gravitational field at infinite distance, if the universe was static and infinite as was commonly assumed. Einstein needed to understand the distribution of matter to account for a reference frame that provides local inertia according to "Mach's principle."

In his 1917 paper, Einstein examined the boundary implications of the field equations of GR and came to the conclusion that GR requires a "continuum, which is finite (closed) with respect to its spatial dimensions." He proposed a constant, λ (he used the small letter in the paper, but now the capital Λ is used). It "defines both the mean density of distribution ρ [of matter] which can remain in equilibrium and also the radius R and the volume $2\pi^2R^3$ of spherical space." Although the value of λ would be extremely small, it was enough to make the boundary disappear.

Einstein concludes

> Thus, the theoretical view of the actual universe, if it is in correspondence with our reasoning, is the following: The curvature of space is variable in time and place, according to the distribution of matter, but we may roughly approximate to it by means of a spherical space…. In order to arrive at this consistent view, we admittedly had to introduce an extension of the field equations of gravitation which is not justified by our actual knowledge of gravitation. It is to be emphasized, however, that a positive curvature of space is given by our results…

This is not the universe as ball, but as a three-dimensional sphere in four-dimensional Euclidean space, something that is not easily pictured.

This was ultimately newsworthy enough to be covered in a *NY Times* report of a lecture Einstein gave at Princeton in 1921. Entitled "Einstein Cannot Measure Universe," it is reproduced on the next page. The implications of Einstein's argument were explained by "Professor [Edwin] Adams of the department of physics." There is still an allusion of infinity, but not infinity itself. On a sphere, if you keep heading in one direction, you may eventually come back to where you started, but you will never come to a boundary. Unlimited, yet not infinite.

Einstein abandoned λ in 1931 in the face of Hubble's finding that the universe was not static. We now think of λ (Λ) as having to do with dark energy and the expansion of the universe, but Einstein originally invoked it to account for mass density and inertia in a static universe described by the newly formulated laws of General Relativity. A mass density (ρ) of 5.5 hydrogen atoms per cubic meter (3×10^{-28} kg/m^3) now seems generally accepted, but observations have yet to determine whether space has a curvature.   LF ■

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[1] https://einsteinpapers.press.princeton.edu/vol6-trans/433

[2] O'Raifeartaigh, C, O'Keeffe, M, Nahmb W, Mittonc, S, Einstein's 1917 Static Model of the Universe: A Centennial Review, *European Physical Journal H*, Volume 42, 431-474 (2017), Preprint version https://arxiv.org/abs/1701.07261.

EINSTEIN CANNOT MEASURE UNIVERSE

With Mean Density of Matter Unknown the Problem Is Impossible.

FINAL PRINCETON LECTURE

Universe Called Finite and Yet Infinite Because of Its Curved Nature.

Special to The New York Times.

PRINCETON, N. J., May 13.—Professor Einstein explained his conception of a finite and yet unlimited universe in the last lecture of the series he has been giving this week at Princeton before scientists who have been working on his theory in this country since it was first announced. Just what the size of the universe is he said could not be determined at present, because it is first necessary to know the mean density of matter in it, and this at present is a quantity of which there is no knowledge.

Professor Einstein's idea of the finite universe is that of a spherical universe of finite extent, but infinite because of its curved nature, as was explained some months ago in THE TIMES by Professor L. P. Eisenhart. He conceives the universe as being bent back upon itself much as the mythical snake which swallows its tail, although, of course, there is no way of making a graph of what is a mathematical abstraction. In a summary of Professor Einstein's lecture today Professor Adams of the department of physics said:

"It is a remarkable fact that the general theory of relativity, built up as it is from physical considerations resulting from experiments on the earth, should have anything to say concerning the problems of the universe as a whole. It has generally been thought that the universe is infinite in extent. Telescopes of increasing power have brought more and more distant stars to our vision. If we imagine a sphere of radius very large compared to the mean distance between the stars, our first view is that as we increase the radius of the sphere more and more a definite density of matter in the universe is approached. The astronomer Seeliger first showed that such a view is definitely opposed to the Newtonian law of gravitation, for this view immediately leads to the result that the gravitational field would also increase beyond all limits as we go out toward infinity, and this would mean that the stellar velocities would necessarily increase beyond all limits.

Conflicts With Gravitation.

"Thus on the basis of Newton's theory we should have to conclude that the mean density of matter in the universe is zero. This could only be attained by assuming that the universe is an island floating in infinite space free from matter. But this view is wholly unsatisfactory, and Seeliger attempted to reconcile an infinite universe with finite density by assuming that matter of negative density is present in the universe. This assumption involves a departure from Newton's law of gravitation, but no other argument leads to a similar conclusion, and so this is not a satisfactory solution.

"By making slight modifications in his general theory of relativity which do not change any of the other conclusions drawn from it, Professor Einstein shows that a uniform distribution of water in the universe is possible only in space of constant curvature. In order to be able to form a conception of what is meant by space of constant curvature, we can imagine beings of two dimensions living on a surface so that their space is this surface. If viewed from three dimensions this surface is a plane surface, then the laws of Euclidian geometry would hold. If, however, the surface is a curved surface, for example, the surface of a sphere, and our imaginary beings were unable to go away from the surface, then their space would have a definite curvature at each point and would be non-Euclidian. Such a space for them would be finite, although unbounded. By making measurements on a large enough scale in their space, our imaginary beings would be able to find out whether or not their space was Euclidian.

Misprint. "matter", not "water"

"And thus in the three dimensional case we can form a conception of how it is that sufficiently large scale measurements will enable us to show that the space we live in has properties different from those of Euclidian space. In order to determine the size of the universe it is necessary to know the mean density of matter in it. But this is a quantity of which we have no knowledge.

The Origin of Matter.

"Another remarkable bearing of the general theory of relativity on the physical properties of matter comes from the results of recent researches which indicate that all matter as we know it has an electrical origin. There has, however, always been a very serious difficulty involved in this view. For if we regard a portion of electricity which must be supposed to have a finite although it may be very small volume, the repulsion between elements of that volume requires some unknown force in order that it may hold together. In order to get round this difficulty, Poincaré assumed the existence of a kind of pressure in the universe of sufficient magnitude to balance the electrostatic repulsion between the elements of electricity. Professor Einstein showed that this assumption of pressure throughout the universe is wholly consistent with the general theory of relativity, although it does not follow as a consequence of the theory."

NY Times, May 14, 1921, page 10, single column. From www.timesmachine.nytimes.com

The Astronomer at the Museum Larry Faltz

A Roman Coin with Urania, the Muse of Astronomy

Elyse and I are great fans of the Yale Art Gallery, a richly endowed museum with a great collection, kind of a mini-Met, with free admission. It's an easy drive from Westchester to New Haven via the Merritt Parkway or I-95. The museum holds a substantial range of objects from ancient Egyptian, Asian and pre-Columbian cultures to European and American art, contemporary art and decorative objects. Special exhibitions are always interesting and of international quality.

We were there in early March and chanced upon this small Roman silver coin. About the size of a penny, it was minted in 66 BC by the Magistrate Quintus Pomponius Musa. It shows Apollo with a star behind his head on one side and Urania, the muse of astronomy, on the other, along with the magistrate's name. The value of this 3.94-gram coin was one denarius, a standard denomination. It is one of a set of 10 coins, nine showing one of the muses and one of Hercules. Moneyers were appointed by the Roman state to mint currency. They chose designs to boast of their real or imagined ancestors or to make wordplays on their names ("musa" and "muse" in this case). One of the moneyers in 54 BC was Marcus Junius Brutus, who minted coins celebrating his alleged ancestor L. Junius Brutus, who had supposedly overthrown the last of the Roman kings in 509 BC to establish the Republic. Marcus Junius Brutus was the principal assassin of Julius Caesar on the Ides of March, 44 BC.

Urania is pointing with a wand to a celestial globe, her traditional pose, also seen in frescoes from Pompeii and in mosaics. This suggests that celestial globes were made in Greek and Roman times, although the only surviving ones from antiquity are the giant marble celestial globe on the Farnese Atlas and two very small brass globes of less certain origin (see "Celestial Globes" in the March 2020 SkyWAAtch).

Urania was the daughter of Zeus and Mnemosyne, the goddess of memory and mother of the nine muses. Urania was the great granddaughter of Uranus, father of the Titans. Ουρανός (uranós) is Greek for "sky." ■

Member Profile: Bob Kelly

Name: It took a decade or two to call myself "Bob" in public. My relatives called me "Bobby". My Catholic School friends called me "Robert". I didn't know my friends Christopher and William could be Chris and Bill.

Home town: When I got married, my wedding announcement in the Staten Island Advance called me an "ex-Islander." I was born there, but moved to New Jersey the year of the first Moon landing. Now Ardsley is my hometown.

Family: One of six Irish-Polish kids. My wife is Italian-Irish. Carol and I met in Durham, North Carolina. She's from Milford, Mass. We have three kids and seven grandkids age seven and under. Five of the grandkids can find the Moon on their own, even in the daytime.

How did you get interested in astronomy? I just always loved looking at anything in the sky.

Do you recall the first time you looked through a telescope? What did you see? I saw a big fuzzy dot. I deduced stars were round. I didn't know the telescope was out of focus. The Moon and Jupiter were wonderful and fortunately how to focus with the slide-tube on my 60-mm cardboard tube refractor was obvious for the Moon and Planets. I didn't have someone to show me the right way to do it.

What's your favorite object(s) to view? I love bright objects. I admire people who can go deep in the sky and show faint things. But I love lots of photons. So, the Moon, bright planets, bright clusters, the Andromeda Galaxy. I love finding things in the bright sky. I've seen Venus, Mercury and Jupiter in daytime. I love racing to see who can find the first objects (often planets) after sunset (or before!)

What kind of equipment do you have? I have an 8-inch (200-mm) reflecting telescope on a Dobsonian mount. I put it down, align the primary mirror in a few minutes and point it where I want to go. Forty-three pounds is all I can carry. It has a good finder, plus I use a red-dot finder to get me in the ballpark of where I want to tour the sky. I have an older but nice 60-mm refractor. The finder is useless, with a view dimmer than the unaided eye. I bought the Dob after I won a set of eyepieces at NEAF. The three two-inch wide eyepieces didn't fit in my 60-mm refractor, so, of course, I had to buy a new scope!

What kind of equipment would you like to get that you don't have? If they ever come back in stock, a (motorized) go-to Dobsionian. I toy with the idea of hydrogen-alpha solar telescopes, but it would require *soooo* much more time to spend looking at things.

Have you taken any trips or vacations dedicated to astronomy? Tell us about them. I've rarely taken trips just for astronomy. Medomak Camp in Maine was a wonderful week of astronomy in 2016, a present from my wife. I went overnight to Clemson University in South Carolina to see the 2017 total solar eclipse. The only total solar eclipse I've seen so far.

Are there areas of current astronomical research that particularly interest you? I love to read about what we think we know about anything in our solar system. Any area of astronomy or cosmology is interesting to me.

Do you have any favorite personal astronomical experiences you'd like to relate? A cold fall night in the mountains of North Carolina where Carol and I could see the Andromeda Galaxy with direct vision and we were lost in the stars. There were so many stars we couldn't see the constellation patterns.

The total solar eclipse at Clemson, including hoping that one cloud wouldn't move over and cover the Sun during totality. Reminding people around me that sacrificing a meteorologist to the cloud gods has not been shown to be effective at clearing skies. The total solar eclipse was the greatest astronomical event I have ever seen. But I won't chase around the world to see them. Looking forward to 2024 in western New York to show the grandkids!

I love to see the amazed and excited expressions on the faces of people seeing Saturn's rings or Jupiter's moons for the first time, even on a night of bad seeing or down near the horizon. How about the night we had 120 Boy Scouts at our star party and it clouded over? I found Jupiter and keep nudging the scope to show it to them, even when at times we couldn't see Jupiter with the unaided eye through the clouds. The 8-inch gathers so much light and makes what people want to see distinct and bright.

What do you do (or did you do, if retired) in "real life"? I am an air pollution meteorologist, retired after 37 years at the US Environmental Protection Agency in NYC. I have Bachelor's and Masters' degrees from Rutgers, the State University of New Jersey. As a college student, I worked at the National Meteorological Center's World Weather Building for two semesters. I am active as a lay minister in my Catholic parish.

Have you read any books about astronomy that you'd like to recommend? I tend toward non-fiction I can use every day, so the RASC's annual almanac is my go-to book. Bob King from Duluth has two great books on what you can see in the sky. *Astrophysics for Busy People* keeps the best parts of Neil DeGrasse Tyson's description of cosmology, without the off-key distracting comments. I have a shelf of books about showing people what they can see in the sky. I've had enough of over-processed photos that aren't representative what we really can see. I grew up in the beginning of the human exploration of space. I love talking about the missions to the Moon and I'm sad there is no Space Camp in space.

How did you get involved in WAA? I had read about the WAA, but Carol and I were busy raising three kids, so I couldn't commit. I was a Lieutenant in the Air Force's Civil Air Patrol with my son for a decade. Getting to talk about aerospace education every week was a fun trip. Eventually I joined.

What WAA activities do you participate in? I help with events, like the star parties. I was doing a Heads UP! blog already (CapsLock got stuck one day on 'up' and I kept it), so it was a smooth transition to write a column on what's up in the sky for the WAA in addition to my wordpress.bkellysky2.com blog. Did I mention I love to do public events?

If you have or have had a position in WAA, what is it, what are/were your responsibilities and what do you want the club to accomplish? VP for Events! My main focus is on scheduling the dates for star parties. As much as I love the Moon, we set star parties for moonless nights so people can go deep. I get lots of help with people in the club working with our partners on community events.

Besides your interest in astronomy, what other avocations do you have? As a meteorologist, I predict the weather for our star parties. We are rarely rained out, but we seem to have a lot of nights where it's uncertain if it's going to be clear or partly cloudy. That's the curse of having a meteorologist as a star party planner. I love discussions of climate and day-to-day weather prediction.

I am a big fan of the history of space exploration, especially the Moon landings. So glad I had the opportunity to celebrate 50 years since the moon landings doing talks and exhibits, before COVID-19 shut us down. ■

The Moon is surrounded by jetliner contrails in this cell phone photo by WAA President Karen Seiter.

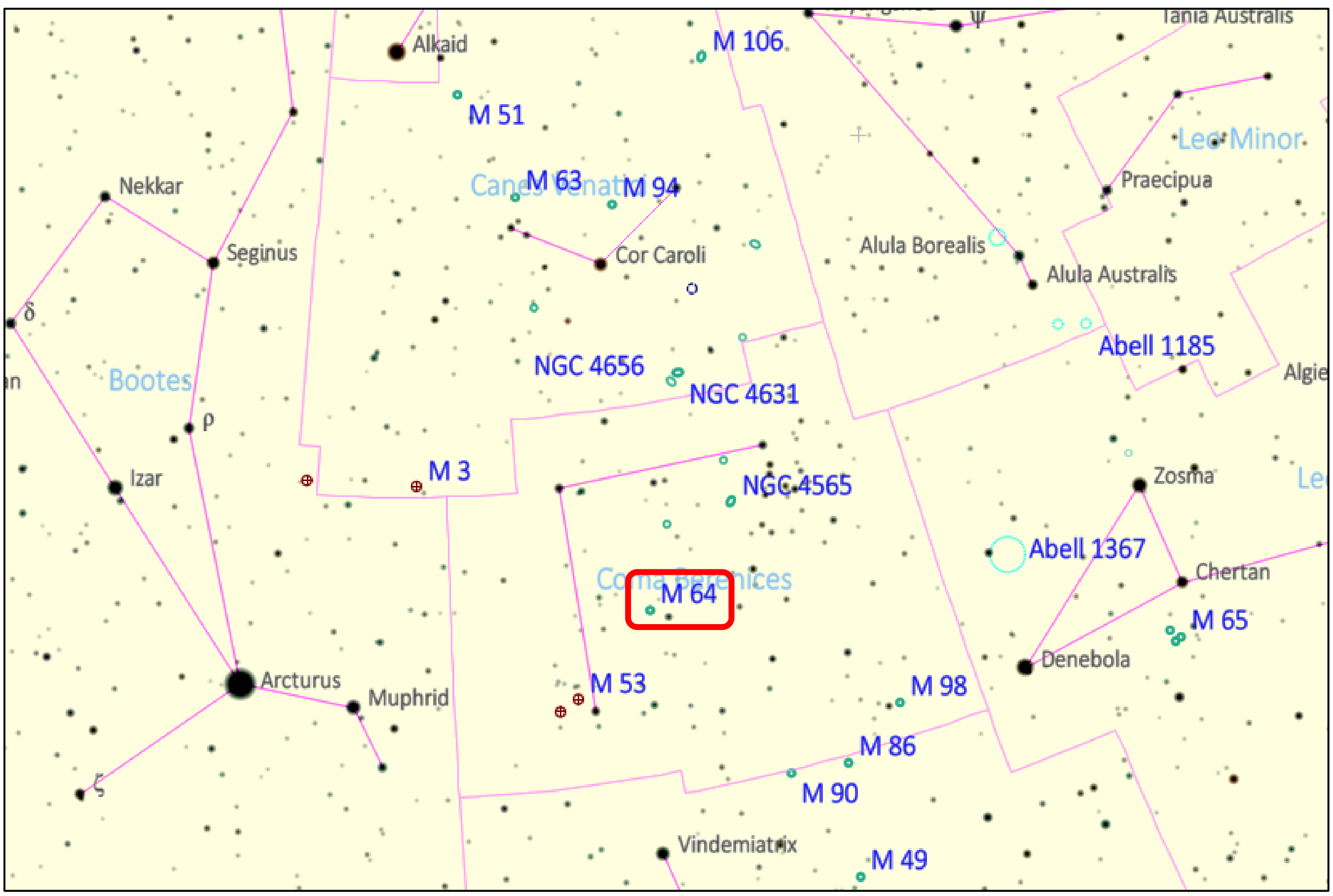
Deep Sky Object of the Month: Messier 64

Messier 64	
Constellation	Coma Berenices
Object type	Galaxy
Right Ascension J2000	12h 56m 20.0s
Declination J2000	+21° 41′ 00″
Magnitude	8.5
Size	10.3 x 5.0 arcminutes
Distance	17.3 Million LY
NGC designation	4826
Other names	Black-Eye Galaxy
Discovery	Edward Pigott, 1779

With a fairly high surface brightness and a distinct dust lane, the "Black Eye" Galaxy is just south of the more distant Coma cluster of galaxies and northwest of Markarian's Chain. M64 is a type II Seyfert galaxy. It has a LINER (low-ionization nuclear emission-line region) nucleus. The galaxy is tilted 60 degrees to our line of sight, exposing the band of dust that's distinct in moderate-sized telescopes.

Visibility for Messier 64			
10:00 pm EST	5/1/22	5/15/22	5/31/22
Altitude	65° 06′	69° 50′	68° 42′
Azimuth	131° 45′	168° 19′	209° 42′

May is a perfect time to scan the entire galaxy-rich region between Alkaid at the end of the Big Dipper's handle, Arcturus, Vendemiatrix and Denebola.



Another Movie Telescope

We get a quick glimpse of a brass refractor in a scene from Federico Fellini's *Amarcord* (1973). The telescope is operated by two schoolteachers, typically oddball Fellini characters in a movie filled with many wonderful oddball characters.

The gigantic ocean liner *Rex*, the grand technical achievement of Mussolini's Fascist Italian government (which is skewered in the film in both comical and serious ways), is going to pass offshore. All the townspeople want to see it. Most of them go out in small boats to greet it. The ship does not arrive until midnight. It sweeps past the cheering crowd without acknowledgement, capsizing many of the boats, but no one is hurt.

The exchange between the two observers is brief: Black coat: "How far will we see?" White shirt: "Four miles. But thanks to Galileo, it will seem like 400 feet to us." Black coat: "Marvelous, it will seem like it's coming straight at us." The telescope scene, only these three camera angles, lasts just 18.5 seconds.

In the opinion of your editor, *Amarcord* is one of the supreme achievements of cinema. It won the Oscar for Best Foreign Language film in 1974. "Absolutely breathtaking filmmaking." (Roger Ebert)

White Dwarfs Larry Faltz

This is the way the world ends
This is the way the world ends
This is the way the world ends
Not with a bang but a whimper.[1]

We like to think that stars end their lives in spectacular fashion, entertaining us with supernova explosions, but for more than 95% of them the end is far more prosaic. They don't really die, but like the "old soldier" General Sherman, they just fade away. They do put on a little show before settling down to retirement, blowing off their outer layers to make pretty planetary nebulas, a flourish visible for the merest fraction of their existence. Then they just sit and radiate heat, until essentially nothing is left but a dark, inert crystalline core, waiting for the heat death of the universe, or perhaps the Big Rip.

The thermonuclear reactions that power stars for the bulk of their lives produce energy that counteracts the force of gravity.[2] All stars, no matter their birth weight, start their lives by fusing hydrogen to helium. As fusion proceeds, the core inevitably becomes helium-rich, the rate of energy production drops and the star contracts. How the star ages, and its ultimate fate, depends on its birth size.

Cool red class K and M stars weighing less than half a solar mass (0.5 $M_\odot$) are the most common stars in the universe. They never get hot enough to fuse helium into carbon by the triple-alpha process. After their hydrogen is depleted and fusion ceases, they contract and become "helium white dwarfs." Small stars have very long life spans, so long that there are probably no helium dwarfs in the universe yet. Far into the cosmological future, there will be many.

For a star the mass of the Sun, hydrogen burning in the core via the proton-proton chain lasts about ten billion years. As fuel is consumed, the energy output drops and the star contracts. The gravitational contraction heats the gas. The outer layer of the core continues to fuse hydrogen for a time, the higher temperature allowing the more thermally-efficient CNO cycle to raise the energy output. Energy is radiated outward, so the star begins to swell. The outer layers cool and a red giant is formed. For a star of 1.0 $M_\odot$ (our Sun, for example), the red giant phase lasts about one billion years. The core temperature rises to 200 million Kelvin, igniting the helium by the triple-alpha process, in which three ^{4}He nuclei are converted into carbon, ^{12}C. This reaction is highly temperature dependent. As the core heats up the reaction accelerates, resulting in a "helium flash."

This helium-burning phase lasts for perhaps 100 million years. Some of the carbon nuclei capture another helium nucleus (alpha particle) to form oxygen, ^{16}O. The core contracts more but never gets hot enough for carbon fusion. The gravitational energy of contraction raises the temperature of the shells of helium and hydrogen outside the core, generating radiation that further swells the star. At this point, the outer layers of the star can escape the star's gravity, creating a planetary nebula. When we show the Ring or Dumbbell nebulas to people at outreach events we tend to describe them as "exploded stars," but the creation of a planetary nebula is a comparatively sedate process (at least compared to a supernova). Secondary ejections and stellar winds release more gas that flows at higher velocity into the matter had been released earlier, creating the complex shapes that are so fascinating and beautiful in Hubble Space Telescope images. Planetary nebulas have life spans of perhaps 50,000 years.

In the center of the planetary nebula, the star's core is exposed. We see the "central star" or "planetary nebula nucleus" (PNN). In a short amount of time (astronomically-speaking), the core contracts to the size of the Earth, but the rising temperature from gravitational contraction is still insufficient to fuse carbon and oxygen, and eventually any helium left in the core is consumed. Fusion stops. Gravitational contraction is no longer resisted by fusion energy production but by a property of matter known as "electron degeneracy pressure." The carbon and oxygen atoms are so tightly packed that their electrons get in each other's way. It's not just that they resist each other by virtue of their electromagnetic charge (because like charges repel). When the atoms are compressed, their positions can be considered "well known." By the Heisenberg Uncertainty Principle, their momenta can be very large, and so a pressure is

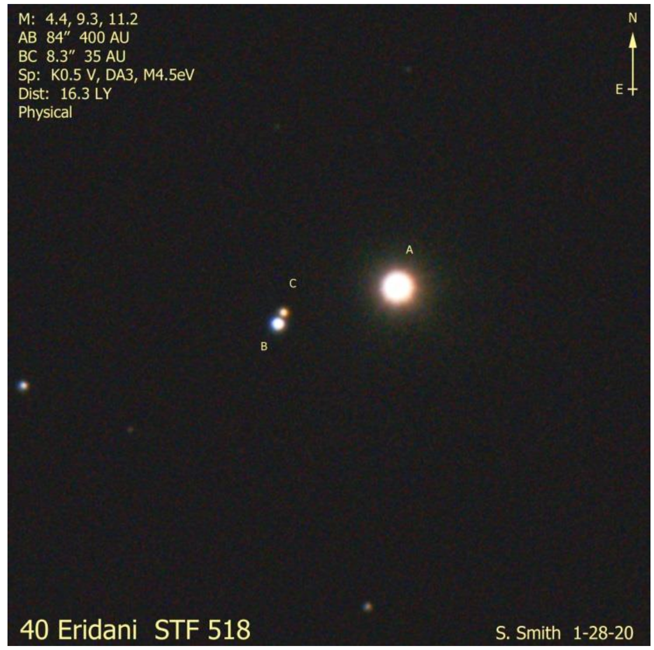
[1] From TS Eliot's *The Hollow Men*
[2] See the June 2021 SkyWAAtch, p. 10.

created that is temperature-independent.[3] The electrons are forced into their lowest quantum energy states. The Pauli Exclusion Principle says that two electrons with the same spin and energy can't occupy the same location. The particles find places to go that they wouldn't under normal circumstances: recall that atoms are mostly empty space, so some of that space can be occupied. Gravitational compression can increase the density of atoms in matter, but there is a limit to how tightly they can be packed.

A white dwarf has an enormous mass for its size, meaning it has a very high density, on the order of 10^9 kg/m^3. One cubic centimeter, about the size of a sugar cube, would weigh well over a ton. But it has all the energy of that last phase of the star's life packed into a sphere with a radius of about 6.4 x 10^3 km.

The interior of a white dwarf has a temperature of about 10^7 K. Because the electrons have to maintain themselves at a minimum energy level, there is very little, if any, heat transfer within the dwarf. A thin shell of residual normal matter on the dwarf's surface will radiate thermally, slowly reducing the white dwarf's temperature. The radiation loss is very slow because surface area is small. Over eons, the white dwarf cools and reddens. Towards the end of this process, the center of the white dwarf can crystallize, forming a body-centered cubic lattice of carbon (like a diamond, but not quite). Crystallization is a source of thermal energy that further delays cooling, but nevertheless it continues. When the heat is finally exhausted, some trillions of years will have passed. The result is a "black dwarf," a body composed of carbon and oxygen atoms in a crystal lattice that comes to thermal equilibrium with the cosmic microwave background, which will have a temperature far lower than today's 2.7 K. There are no black dwarfs in our universe yet. A universe in thermal equilibrium is a very boring place. There is no heat transfer, so no work can be done. There are just quantum jitters near absolute zero.

The first white dwarf was discovered in 1783 by William Herschel. He observed that 40 Eridani (sometimes called o^2 Eridani) was a triple system. The white dwarf is the B component and is seen as distinctly white (as compared to the cooler, redder A and C components) in this image by Colorado amateur astronomer and double-star aficionado Steve Smith.



Used with permission. See Steve Smith's web site at https://doublestar.home.blog/.

However, it wasn't until the spectral studies done at Harvard at the turn of 20th century that the significance of 40 Eridani B was understood. Princeton astronomer Henry Norris Russell, who we last encountered hassling Cecelia Payne-Gaposchkin about her discovery of the composition of stars,[4] had been looking at stars with low absolute magnitudes whose parallax showed they were nearby. These had all been spectral class G (like the Sun) or cooler. 40 Eridani is only 16.3 light years from Earth, the closest of the stars he was studying. Curious about component B's faintness, in 1910 Russell asked Harvard Observatory director Edward Pickering to determine its spectral class. Pickering telephoned Williamina Fleming. Fleming was a Scottish immigrant, a single mother who worked as a maid in Pickering's home until he invited her to do administrative work at the Harvard Observatory and then to become one of the inaugural "computers," analyzing spectra on photographic

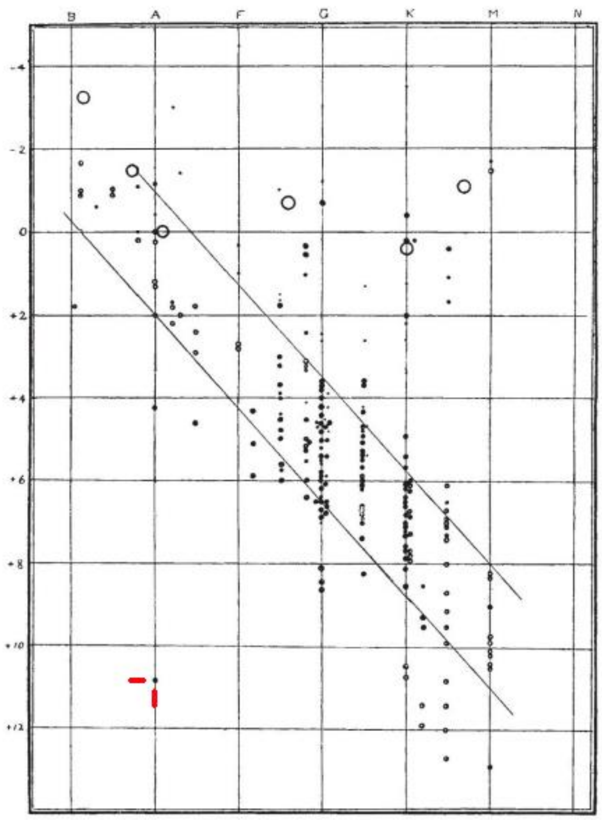
[3] For those of you who like to see the math, the equation for electron degeneracy pressure is algebraic (although its derivation involves calculus). It is

$$P = \frac{\pi^2\hbar^2}{5 m_e m_H{}^{5/3}} \left(\frac{3}{\pi}\right)^{2/3} \left(\frac{\rho}{\mu_e}\right)^{5/3}$$

where ħ is the reduced Planck's constant (h/2π), m_e and m_H are the masses of the electron and proton, ρ is the density and μ_e is the ratio of electrons to protons (N_e/N_H).

[4] See footnote 2.

plates financed by the Draper bequest.[5] Fleming found "within an hour" that the star was class A, much hotter than expected. A hot, nearby star with low absolute magnitude made no sense given the understanding of stars at the time. Russell created a plot of stellar luminosity (derived from absolute magnitudes) versus temperature, which he presented at a lecture at Princeton on June 13, 1913. In the lecture he credits Pickering and the Harvard computer Annie Jump Cannon for the spectra.[6] A similar plot had been independently discovered by Einar Hertzsprung in 1911. The plot, much refined over the years, is now called the Hertzsprung-Russell (HR) diagram.



Henry Norris Russell's plot of temperature (as spectral class, hottest to coolest, top) versus luminosity (as absolute magnitude, left), 40 Eridani B is indicated by the red markers.[7]

Russell's diagram shows a single star in the lower left quadrant, with high temperature (spectral class A) but low luminosity. Of this star, he says

> There is a certain limit of brightness for each spectral class, below which stars of this class are very rare, if they occur at all. Our diagram shows that this limit varied by rather more than two magnitudes from class to class. The single apparent exception is the faint double companion to o^2 Eridani, concerning whose parallax and brightness there can be no doubt, but whose spectrum, though apparently of Class A, is rendered very difficult of observation by the proximity of its far brighter primary.

Mt. Wilson's Walter Adams had less concern that the spectrum might not be correctly interpreted.[8]

An A-Type Star of Very Low Luminosity.

It has been suggested by Hertzsprung that there is no such range in absolute brightness among the A-type stars as among those of types F to M, and, in fact, it is doubtful whether hitherto any certain case of a very faint A-type star has been found. A recent observation of the ninth-magnitude companion of *o Eridani* shows, however, that this star must be considered as such. The companion is at a distance of 83″ from the principal star and shares in its immense proper-motion of 4″.08 annually. Its parallax, therefore, may be assumed to be that of the bright star which is 0″.17. This would make the absolute magnitude of the companion 10.3, the Sun being taken as 5.5. The spectrum of the star is A0.

Walter S. Adams.

In 1922, Dutch astronomer Willem Luyten, who was interested in stars with large proper motion, started using the term "white dwarf," "white" because of the color and "dwarf" because low luminosity suggested a small star. In a paper in 1923, he referred to "three well-known white dwarfs, (o^2 *Eridani* B, Comp. to *Sirius*, and Van Maanen's F star)." In 1917, Adriaan Van Maanen had found a 12th magnitude star in Pisces while looking for stars with high proper motion, which, like having large parallax, would suggest they are nearby. A companion of Sirius was predicted by Friedrich Wilhelm Bessel based on variations in Sirius' proper motion. The star itself was first seen by telescope maker Alvan Clark in 1862 while testing the optics of a new 18½-inch refractor for the Dearborn Observatory in Chicago.[9]

[5] Read Dava Sobel's *The Glass Universe: How the Ladies of the Harvard Observatory Took the Measure of the Stars,* (Viking, 2016)

[6] Russell, H.N., Giant and dwarf stars, *The Observatory*, 36: 324-329 (1913)

[7] Russell, H.N., Relations Between the Spectra and Other Characteristics of the Stars. II. Brightness and Spectral Class, *Nature* 93:252-258 (1914)

[8] *Publications of the Astronomical Society of the Pacific*, 26: 198 (1914)

[9] In 1911, the objective of this telescope was installed in a new tube and is still in use. The old tube is on display in the Adler Planetarium in Chicago. See the October 2018 SkyWAAtch, page 9.

Steve Smith's image of Sirius A and B.

That white dwarfs are extremely dense objects was first determined by Walter Adams when he measured the gravitational redshift of the hydrogen lines in Sirius B, following a suggestion by none other than Arthur Eddington, who proposed a relationship between a star's absolute magnitude and its mass by modeling the behavior of stellar matter as a perfect gas.[10] Perfect gases are systems in which intermolecular forces are neglected."[11] Eddington noted that "the white dwarfs Sirius *(comes[12])* and o^2 Eridani (bright component)… have long presented a difficult problem." Eddington applied atomic theory to the question and remarked that "If the density [of Sirius B] is really 53,000 [which he calculated earlier, relative to the Sun], entirely new considerations enter into the calculation of *k* [the coefficient of absorption of radiation by the medium], since the electrons are in the capture zone of two or more nuclei simultaneously." A density that high, which would be accompanied by intense gravity at the surface, could be determined "by measuring the Einstein shift of the spectrum, which should amount to about 20 km per sec if the high density is correct." He later noted that the explanation that matter in dense stars deviates from a perfect gas might "require inter-atomic forces which have not yet appeared in experimental or theoretical physics."

Adams made the measurements using a spectroscope at the Cassegrain focus of the 100-inch Hooker telescope at Mt. Wilson. Because Sirius and its companion are close (their separation varies from 3 to 11 arcseconds in a 50-year orbital cycle) and differ by ten magnitudes, the spectra were difficult to tease apart, but he succeeded (actually a Miss Ware, "who has had extensive experience with photometric curves" did the grunt work). He confirmed the small radius and very high density of the companion.[13] The value that Adams found for the gravitational red shift was within 5% of Eddington's calculation.

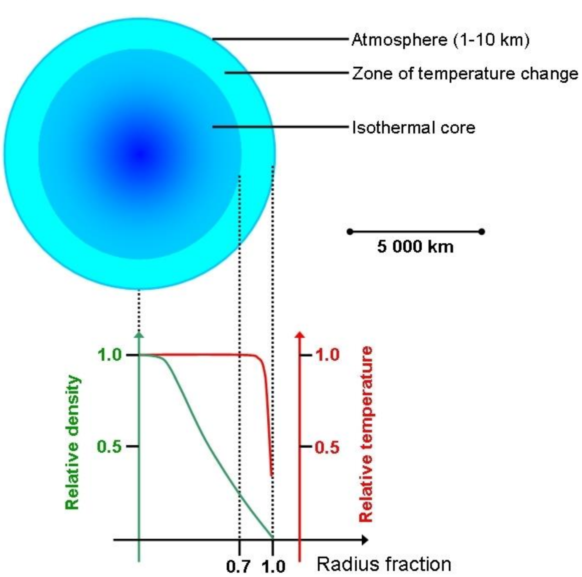
Within a year, R.H. Fowler proposed a mechanism[14] for the enormous density, invoking thermodynamics and new concepts from quantum mechanics. Astrophysics was evolving in the midst of the quantum mechanics revolution of the 1920s. Wolfgang Pauli's Exclusion Principle (to which Fowler explicitly appeals) was published in 1925, while the Heisenberg Uncertainty Principle emerged in 1927.

The final mass of a white dwarf cannot be higher than 1.4 $M_{\odot}$, although the progenitor star can be as massive as 8 $M_{\odot}$ before it ejects gas in the form of planetary nebulas and stellar winds. This limit was calculated in 1930 by the 20-year old Indian astrophysicist Subrahmanyan Chandrasekhar during his long sea voyage from India to Cambridge, where he was invited by Fowler to pursue a PhD supported by a scholarship from the Indian government (meaning, in 1930, the British government). By the time he reached Trinity College, Cambridge, Chandrasekhar had applied statistical mechanics and relativity to Fowler's original analysis[15] and discovered that a white dwarf must have a maximum mass. Above that mass, electron degeneracy pressure would be insufficient to maintain the star. Chandrasekhar and Fowler were

[10] Eddington, A, On the Relation between the Masses and Luminosities of the Stars, *Monthly Notices of the Royal Astronomical Society*, 84: 308-332 (1924)
[11] A perfect gas would follow the ideal gas law, pV=nRT. P=pressure, V=volume, T=temperature, n=number of molecules, and R=ideal gas constant, 8.3144621 J/mol·K.
[12] Latin for "companion."
[13] Walter Adams, The Relativity Displacement of the Spectral Lines in the Companion of Sirius, *The Observatory*, 98: 337-342 (1925)
[14] R.H. Fowler, On Dense Matter, *Monthly Notices of the Royal Astronomical Society*, 87: 114-122 (1926)
[15] Although the matter is degenerate, electrons within it are moving at relativistic velocities.

awarded the 1983 Nobel Prize for their work on stellar evolution. A brilliant researcher and journal editor, Chandrasekhar spent his professional life at the University of Chicago. In 1946 he was offered Henry Norris Russell's professorship at Princeton at double his Chicago salary (Russell, then 66, was retiring), but Chicago matched the offer and he remained there until his death in 1995.

For stars starting their lives with masses greater than 8 $M_{\odot}$, gravitational contraction after hydrogen and helium are consumed will provide enough heat energy to raise the temperature to 500 billion K, high enough for carbon fusion. Stars between 8 and 12 $M_{\odot}$ will blow off their outer layers with a "carbon flash," leaving a 1.1 $M_{\odot}$ white dwarf made of oxygen, neon, sodium and magnesium. More massive stars go on to burn elements all the way up to iron, a nucleus that cannot be fused. Gravitational collapse forces the merger of electrons and protons into neutrons, resulting in a supernova and forming a neutron star or, for the most massive stars, a black hole.



White dwarfs are surrounded by a thin atmosphere of ordinary matter, which provides the spectral lines and temperature by which they are classified. In more than 80% of the dwarfs, the atmosphere is composed of hydrogen; in 16% it is helium. Rarely, carbon atmospheres can be detected. Below the atmosphere is a denser envelope of heavier atoms, and beneath that the electron-degenerate nucleus. When we look at a white dwarf, we are seeing only its atmosphere. The classification scheme for white dwarfs is based on spectral characteristics, magnetic properties and temperature. For example, Sirius B is classified as DA2, D for white dwarf, the A indicating the presence of hydrogen lines and the 2 indicating a temperature of about 100,000 K (the numerical value is the star's temperature divided by 50,400, chosen for arcane reasons).

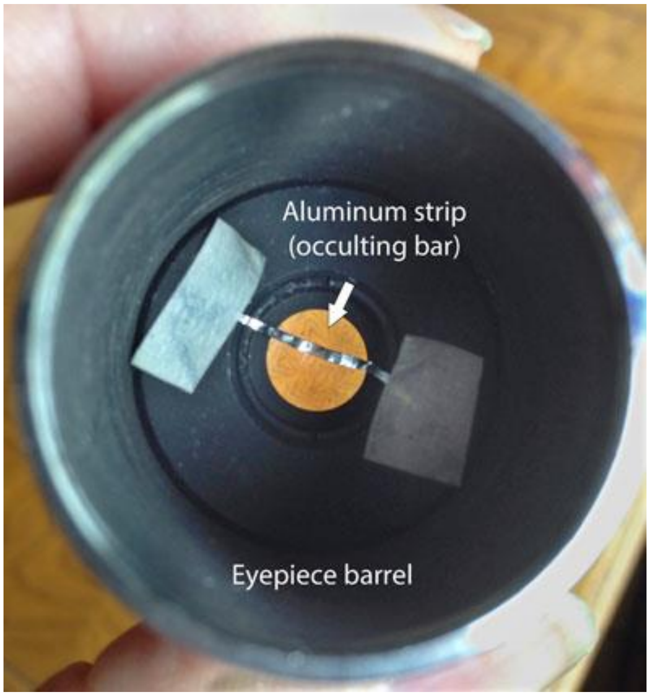
A white dwarf at the Chandrasekhar limit can't tolerate the addition of mass, which might occur if it is in a close binary system with a larger, cooler star. The intense gravity of the dwarf will pull matter from the outer layers of its companion. When the mass reaches 1.4 $M_{\odot}$, electron degeneracy pressure can no longer resist gravity, the star collapses and a Type Ia supernova results. Because the white dwarf has a discrete mass and its composition is known, the behavior of these supernovas is stereotypical and they can be used as "standard candles" for the study of the expansion of the universe.

There are ten white dwarfs brighter than magnitude 14, nine of them in the northern hemisphere. This puts them in the range of 8- to 10- inch telescopes.

The Brightest White Dwarfs

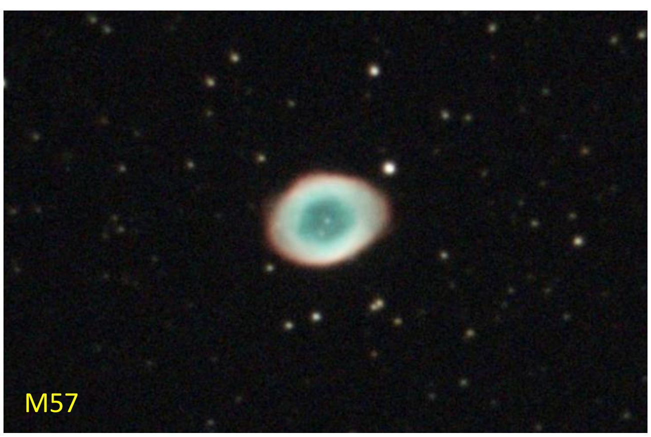
Star	Magnitude	Constellation
Sirius B	8.44	Canis Major
40 Eridani B	9.5	Eridanus
Procyon B	10.7	Canis Minor
LP 145-141	11.5	Musca
BD-07 3632	11.9	Virgo
HZ 43	12	Coma Berenices
Stein 2051 B	12.4	Camelopardalis
Van Maanen 2	12.4	Pisces
WD 1337+705	12.8	Ursa Minor
G 185-32	13.0	Vulpecula

Sirius B is difficult to see because of its proximity to the brightest star in the sky and the ten-magnitude difference between them. But many amateurs have managed to see it. You need high magnification with a clean, very well collimated telescope at ambient temperature in steady skies. The sharper the eyepiece the better, so perhaps you want to dig down in your kit and find a short focal length Orthoscopic from the old days. A useful trick is to place an occulting bar on your eyepiece. This is a thin strip of aluminum foil placed over the field stop (so it is in focus). Use it to obscure bright Sirius A enough to bring out the dim companion.

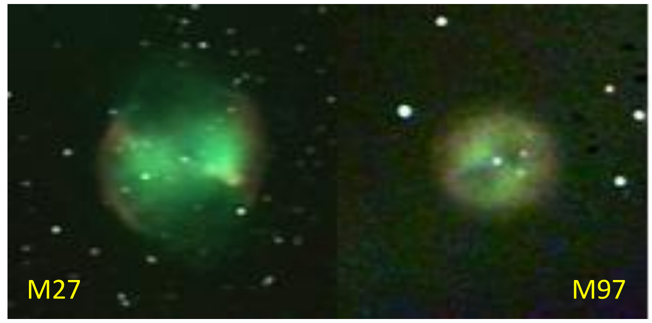


An occulting bar at the field stop of an Orthoscopic eyepiece, from an article by Bob King of *Sky & Telescope*. See https://is.gd/kingoccbar for the description of this device, and King's article on Sirius B at https://is.gd/KingSirB.

Although too faint for all but the largest telescopes at our star parties, the central star (or PNN) of several planetary nebulas can be seen with astronomy cameras in real time. Not all of them are white dwarfs yet, but almost all will be, eventually. Charlie Gibson and I made this image of the Ring Nebula, M57, with his ZWO ASI183 camera on my Celestron CPC800 in September 2021 at Ward Pound Ridge.

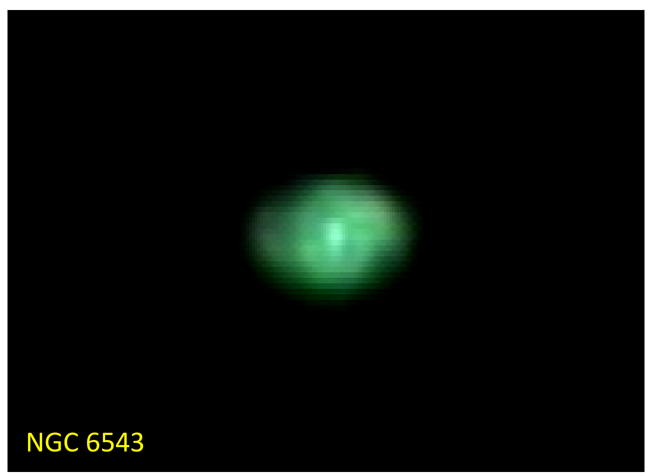


The central star of M57, WD1851+329, is composed of carbon and oxygen with a thin atmosphere. It has a surface temperature of 125,000 K, a mass of 0.61 $M_{\odot}$, 200 times more luminous than the Sun but only magnitude 15.75. Off-center in the nebula, but not associated with it, is the 15th magnitude star UCAC4 616-065948.



G-185-32, the 13.0-magnitude central star of the Dumbbell Nebula, M27, is the tenth brightest white dwarf, about 1300 light-years distant. It might be readily visible in a large Dobsonian this summer at a WAA star party at Ward Pound Ridge. The 15th magnitude central star of the Owl Nebula (M97) in Ursa Major might be visible if we set up the club's 20-inch Obsession on a very clear star party night. It's not difficult to capture in a camera. The images above are short exposures (14 and 28-seconds, respectively) with a Mallincam video camera on the CPC800 with a focal reducer operating the scope around f/3.5. This is not fancy astrophotography, just "electronically assisted astronomy."

Some years ago I was even able to catch the central star of the tiny Cat's Eye Nebula, NGC 6543, using a Mallincam with its 2X magnification feature enabled and the scope's native f/10. The image is crude, pixelated and suffers from some tracking error, but the star is there.



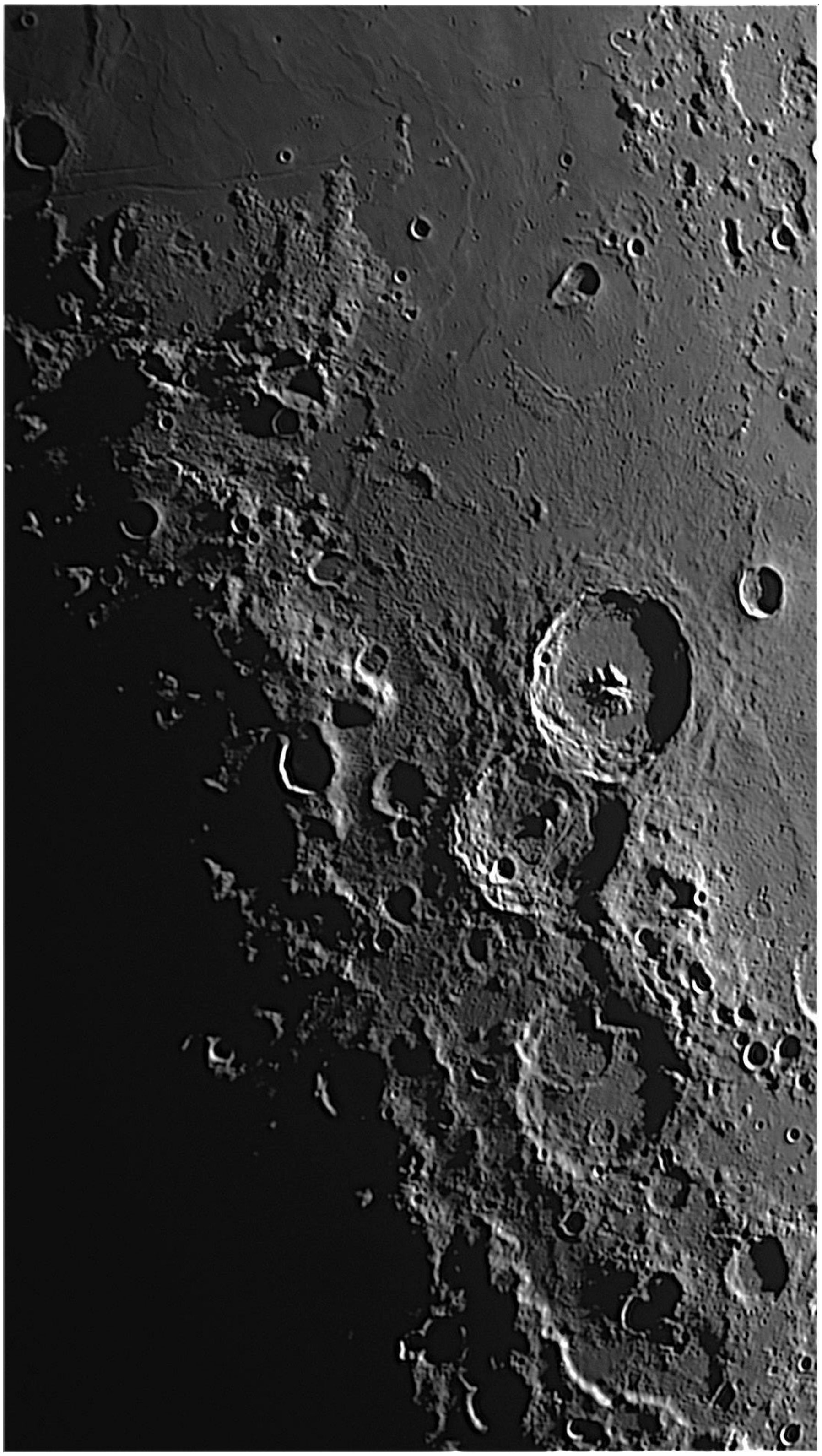
You don't need advanced astrophotography techniques to at least get a glimpse of some white dwarfs. Give it a try with eye or camera. ■

Images by Members

Hubble's Variable Nebula by Steve Bellavia

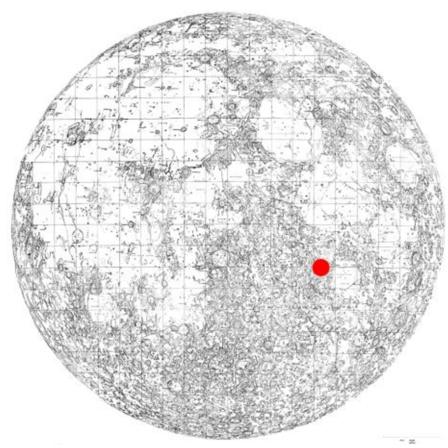
NGC 2261 (also catalogued as Caldwell 46) in Monoceros is a reflection nebula illuminated by the variable star R Monocerotis. Variability in the appearance of the nebula was first reported by the unknown 27-year old Edwin Hubble in 1916. When the famous 60-year old Hubble was given the honor of first light with the 200-inch Hale telescope at Mt. Palomar on January 26, 1949, he chose this object. Variability of up to two magnitudes is thought to be due to movement of thick dust clouds surrounding R Monocerotis. TSO 115-mm refractor, ASI 533 camera.

Theophilus, Cyrillus and Catharina on Edge of the Mare Nectaris by John Paladini



John used his venerable Criterion RV-6 6" f/8 reflector for this image along the terminator of a 6-day Moon. North (up) of the well-defined crater Theophilus, with its large and complex central peak, is the Sinus Asperitatus, which separates the Mare Tranquillitatis above from the Mare Nectaris, which is off to the lower right. In the Sinus Asperitatus, the distinct keyhole-shaped crater Toricelli sits inside of what appears to be an old unnamed crater remnant that has been almost completely obliterated by lava. To its right is the smaller crater Torricelli A. The distinct small crater to the right of Theophilus is Mädler.

Theophilus is 101 km across. Below it are the older craters Cyrillus and Catharina. At the edge of the terminator in the center of the image is the 39-km wide crater Kant, with dawn breaking on its western wall.



John used an ASI290MM camera and stacked 200 images.

Markarian's Chain by Olivier Prache

Olivier apologized for the framing, noting "Unfortunately, the pointing was a little off and I was asleep when the equipment went forward. Still, reasonable result after 225 minutes with the RASA8."

We'll forgive Olivier for bisecting Messier 87 at the bottom of the image (although M87 is not formally a member of the chain). In any case, there are at least 40 galaxies that can be seen in this image if you enlarge the page just a bit. The galaxies of the Chain itself are all present in the frame.

Charles Messier catalogued the two brightest galaxies in the chain, M84 and M86, seen in the center of the image. The rest of the brighter galaxies were discovered by William Herschel and given NGC numbers in J.E.L. Dryer's catalog of 1888. In the 1960s, Benjamin Markarian, working at the Burkaran Observatory in Armenia (then part of the USSR), found that some of the galaxies in the Virgo Cluster formed a real physical system. He based his conclusion on the galaxies' masses and their radial velocities. Markarian wrote "I arrived at the conclusion that the chain of galaxies in the Virgo cluster is not a chance grouping but a real physical system. If this is true, in which there will hardly be any doubt, then this system must be a linear system. If this conclusion corresponds to reality, then the chain must be an exceptionally young system. The reason is that, in spite of considerable dispersion of radial velocities of particular members, the observed deviations from the linear structure are exceedingly small." (Markarian, B.E., Physical Chain of Galaxies in the Virgo Cluster and Its Dynamic Instability, *Astrophysical Journal*, 66:555-557 (1961) https://articles.adsabs.harvard.edu/pdf/1961AJ.....66..555M).

Virgo Cluster itself is a collection of between 1,300 and 2,000 galaxies located at an average distance from us of 58 million light years. The Local Group is actually moving towards the center of the Virgo Cluster, the so-called Virgocentric Flow, at a rate of between 100 and 400 km/sec.

High Dynamic Range image of the Orion Nebula by Rick Bria

By the time you read this, the great Orion Nebula, the gem of northern winter skies, will be disappearing below the horizon just after sunset, lost in the twilight and not suitable for nighttime observing until the end of the year.

Rick writes:

Although it is the brightest nebula in the sky, the Orion Nebula presents a photographic challenge. Parts of the nebula are very bright and other parts extremely dim. The large range in brightness makes imaging it rather difficult. If exposure times are short, the dim areas are not recorded. If exposure times are long, the bright areas are saturated.

This Orion Nebula picture is a High Dynamic Range image. Short exposures have been blended with longer exposures in software. Stacks of images with exposure times of 20, 45, 60, 90, 120, 180, and 240 seconds were combined in PixInsight software to display both dim and bright details of the Orion Nebula.

The image was obtained at the Mary Aloysia Hardey Observatory at Sacred Heart School in Greenwich with the PlaneWave 14 CDK telescope and STX 16803 camera. The image was taken through Ha-RGB filters. The green channel was synthesized by subtracting red and blue data from the luminance data. The hydrogen alpha data was used as the luminance channel. The channels were processed in PixInsight software to create a color image. Total exposure time = 3.6 hours.

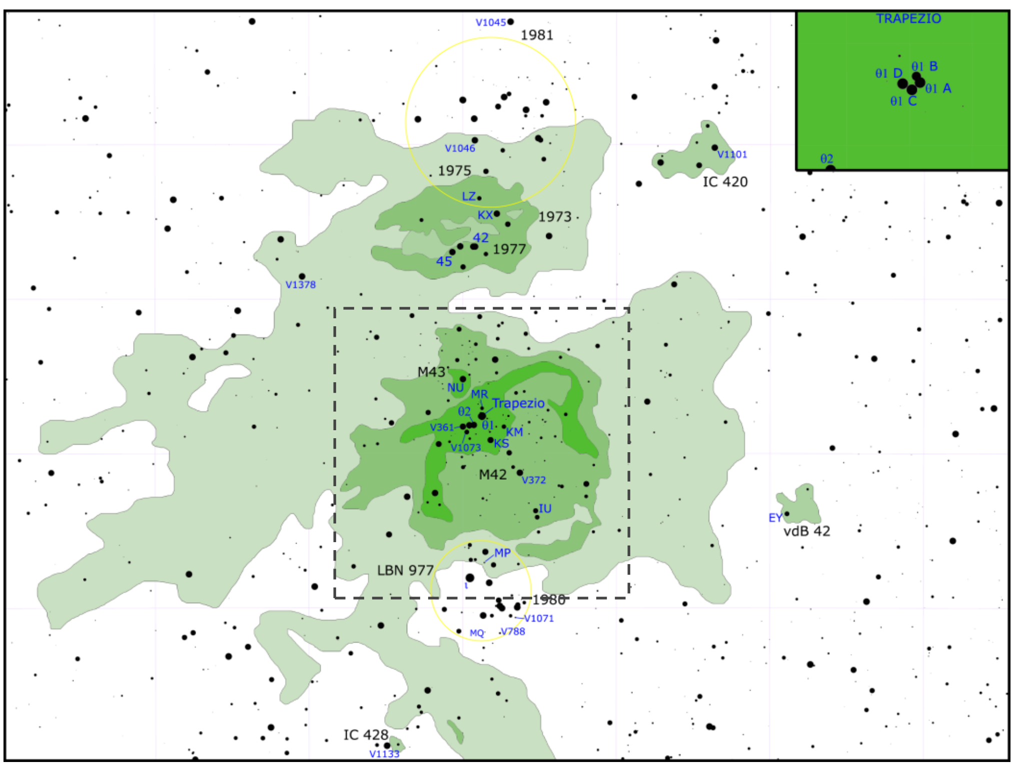
The Orion Nebula is mostly hydrogen and helium. It also contains some heavy molecular elements. Massive stars have exploded in the distant past within the nebula. Intense heat and pressure from those supernova explosions created the nebula and seeded it with all of the known heavy elements. When the nebula eventually collapses into a giant star cluster, all those elements will be incorporated into the stars and the planets that orbit them. It is recycling on a cosmic scale!

Red areas glow from bright hot stars in the center of the nebula, bombarding hydrogen gas with strong ultraviolet rays. Blue areas are from star light scattering and reflecting off gas within the nebula. The Orion Nebula is 1,400 light years distant and about 30 light years in diameter. In 1789, William Herschel wrote a perfect description of the Orion Nebula: "An unformed fiery mist, the chaotic material of future suns." I can only add that the Orion Nebula is both beautiful and intellectually intriguing.

The editor writes:

The bright and massive O stars of the famous Trapezium are almost impossible to show if the fainter gases of the nebula are visible. They end up in most images as a bright blob. With this HDR technique, Rick has managed to separate these stars and they are clearly visible in the heart of the nebula.

For an extensive discussion of the great nebula, see "Orion and His Nebula" in the February 2016 SkyWAAtch.



This map of the entire nebula complex, including the "Running Man" nebula NGC 1977, was made by Italian amateur astronomer and author Roberto Mura. The inset shows the four stars of the Trapezium. Accessed on Wikipedia.

The box shows the area in Rick Bria's image.

Research Highlight of the Month

Samsing, J, Bartos, I, D'Orazio, DJ, AGN as potential factories for eccentric black hole mergers, *Nature* 603: 237-240 (10 March 2022)

Gravitational wave detection GW190521 appears to be the merger of black holes of 85 and 66 solar masses ($M_\odot$) merging into an object of 142 $M_\odot$, releasing 9 $M_\odot$ of energy. Gravitational collapse of individual stars shouldn't result in a black hole of more than 60 solar masses. The implication is that the black holes of the GW190521 binary were themselves the result of prior mergers. An unusual month-long flare of the quasar J124942.3+344929 (which was in the approximate area of GW190521) was detected 34 days after the event. If the flare and the GW event are connected, the data suggests that the merger took place as the black hole pair traveled through the accretion disk surrounding the supermassive black hole at the center of the AGN. The pair encountered another BH which tilted the pairs' orbit relative to the plane of the accretion disk. Combining these ideas, Samsing *et. al.* modeled the mergers of black hole binaries with single black holes at various angles to the orbital plane of an AGN accretion disk. Their calculations showed that "the gas that brings the interacting black holes close to the plane of the AGN disk before interaction will also spin them up through accretion, which will drive their spin vectors towards being perpendicular to the AGN disk…This provides a possible explanation for the non-zero eccentricity and noticeable spin-orbit tilt of GW190521 if it formed in an AGN disk."

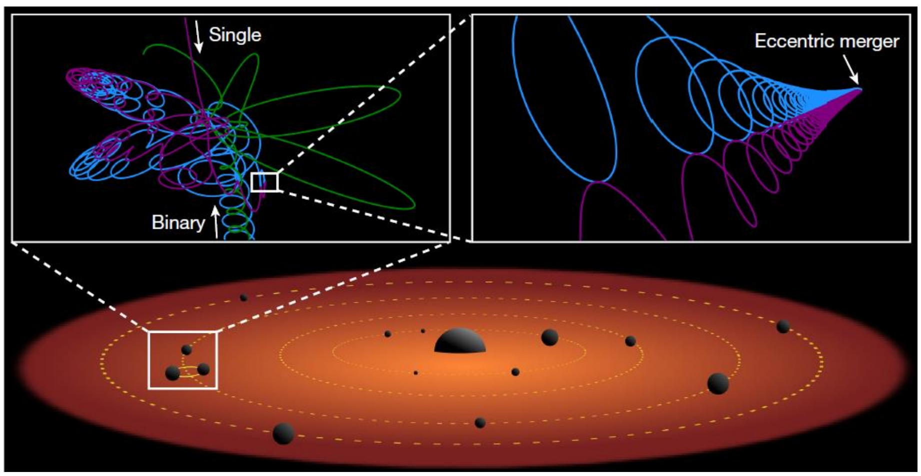
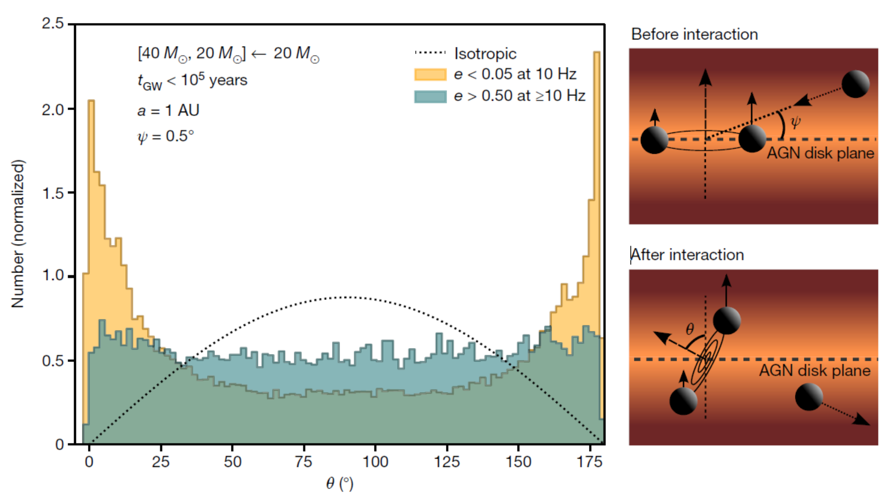


Fig. 1 Modeled outcome of a [50 $M_\odot$, 80 $M_\odot$] binary black hole interacting with an incoming [70 $M_\odot$] black hole, which results in a [80 $M_\odot$, 70 $M_\odot$] binary black hole merger during the interaction, with an eccentricity of about 0.5 in LIGO-Virgo.

Fig. 4 Distribution of orbital plane orientations. Results from 2.5-PN scatterings between an incoming 20 $M_\odot$ black hole and a [40 $M_\odot$, 20 $M_\odot$] binary black hole with a = 1 AU. The initial orbital inclination (depicted in top right panel) is set to ψ = 0.5°. The histograms, each normalized, show the inclination angle between the orbital angular momentum vector of the final merging binary black hole and the initial one, θ (depicted in lower right panel), where yellow and blue refer to the populations of merging binaries with eccentricity e < 0.05 at 10 Hz and e > 0.5 at ≥10 Hz, respectively. The dotted line shows for comparison an isotropic distribution expected in the 3D cluster-like case.



Professor Zoltan Haiman of the Columbia University Department of Astronomy was a coauthor of this paper.

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