SkyWAAtch

The Newsletter of Westchester Amateur Astronomers

April 2019

Barnard's Loop by Mauri Rosenthal

City and suburb dwellers learn to spot Orion by the three bright stars forming his belt. M42 in the sword is a popular target for small telescopes. But we never see the other vivid nebular areas that are revealed by long exposures. It's easy to overlook these really large structures when learning astrophotography. Once I had my camera lens configured with my astrocam, I wanted to try this shot of the wide semicircular emission nebula around the belt and sword. Once again, the IDAS LPS-V4 filter brings out not only the nebular regions but also a surprising star field from my "red zone" suburban yard. Tech stuff: Canon 17-55mm f2.8 zoom lens/ZWO ASI1600MC cam/IDAS LPS-V4 filter/iOptron CubePro 8200 mount unguided/70 minutes total exposure time using 8 second exposures captured with SharpCap Pro, processed with PixInsight and GIMP. SQM-L reading 18.9. From my yard 10 miles north of New York City, January 6, 2019.—Mauri Rosenthal

WAA April 2019 Lecture

Friday, April 5th, 7:30 pm
Lienhard Hall, 3rd floor
Pace University, Pleasantville, NY

Astronomy and the Ancients: A Classical Journey through the Stars

Matthew McGowan

This lecture offers a historical survey of astronomy and astronomical texts from the classical period through the renaissance including Homer, Plato, Aratus, and Copernicus. It considers the science of astronomy in light of its relation to literature and philosophy, in particular to Stoicism.

Matthew McGowan is a classical philologist with research interests in Latin literature and ancient scholarship. He has published broadly on a variety of Greek and Latin topics and his books include *Ovid in Exile* (Brill, 2009) and *Classical New York: Greece and Rome in Gotham* (Fordham University Press, 2018). He teaches a wide range of courses, from classical myth to Latin prose composition, and regularly leads tours where Latin can be found: Rome, Paris, the NY Botanical Garden, and the Bronx Zoo. He was President of the New York Classical Club (2009-2015) and is now Vice-President for Communications and Outreach for the Society for Classical Studies (2016-2020).

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

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

SkyWAAtch © Westchester Amateur Astronomers, Inc.

Editor: Larry Faltz
Assistant Editor: Scott Levine
Editor Emeritus: Tom Boustead

WAA May 2019 Lecture

Friday, May 3rd, 7:30 pm
Lienhard Hall, 3rd floor
Pace University, Pleasantville, NY

Investigating asteroid impacts using three-dimensional petrography of ordinary chondrites.

John Friedrich, Fordham University

SAVE THE DATE: WAA Club Picnic

Saturday, June 8th Rain or Shine!

Danish Home, Croton

Starway to Heaven

Ward Pound Ridge Reservation
Cross River, NY

Weather permitting

Saturday, March 30th. Sunset is at 7:17 pm.
[Saturday, April 6th is the makeup date]
Saturday, April 27th. Sunset is at 7:47 pm.
[Saturday, May 4th is the makeup date]

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

New Members

Kevin Bynum	Irvington
Robert Rusinko	Tarrytown
Matthew Winch	New Rochelle

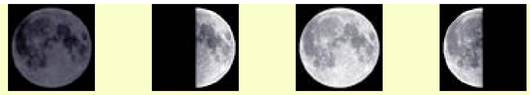
Renewing Members

Rick Bria	Greenwich
Emily Dean	Pelham
Frank Jones	New Rochelle
Barbara Matthews-Hancock	Greenwich
William Sawicki	Bronx
Dor Zaidenberg	White Plains

Also In This Issue

ALMANAC For April 2019

Bob Kelly, WAA VP for Field Events



April 5 April 12 April 19 April 26

Mars has almost completed its long climb to the top of the ecliptic, standing high in the evening sky even as its elongation from the Sun decreases by 10 degrees this month. Compare the steadier light of Mars, just 18 light minutes away, at magnitude +1.5with the brighter flickering red giants of Aldebaran and Betelgeuse at magnitudes +0.5 and +0.9, 65 and 428 light years away respectively.

The Teapot is really cooking for the next several months, with Saturn on the left side of Sagittarius and Jupiter to the right. Pop out with the telescope in the early morning and find a clear view out to the south to sight these planets. Even in twilight, Jupiter can be a beautiful sight in any telescope, as the King of the Planets can be overwhelmingly bright in a dark sky. We'll have to wait until summer to see these gas giants in the evening sky.

Saturn is getting sideways with us, at quadrature, just like Jupiter last month. Now Saturn's shadow on the rings peeks out from behind the pale globe, giving depth to the view in a telescope. The jaunty tilt of Saturn's rings is very noticeable, even if it does decrease a degree or two over the next few months. Saturn serves as a laser-like pointer to really faint Pluto about three degrees to its left and to the New Horizons spacecraft about the same distance to Saturn's upper right.

Unlike New Horizons, Saturn's largest moon, Titan, is visible in most telescopes if you can divert yourself from gazing at the rings. Iapetus is fainter, but this month its bright side faces us on the west of Saturn around mid-month. Star HD 182578 appears like an extra Saturnine moon starting around the 8th. On the 13th, it's near Iapetus. Titan appears halfway between Saturn and Iapetus around the 22nd.

Hey, Jupiter! How are those belts doing? Find some clear mornings and sketch the dark belts on Jupiter. I don't draw well (if I had only known I might have gotten away with stick figures like the talented guy who does XKCD!), but keeping a record of the dark jet streams on Jupiter is a good way to get started doing astronomical sketching. The belts may have significantly changed this year.

April Fools' Day starts off with Venus standing only 5 degrees above the horizon at 6 am Daylight Savings Time, even though Venus has 35 degrees of elongation from our Sun. The 8-percent illuminated Moon is just to Venus' right, smiling as if she is in on the joke. Two of Jupiter's moons cast their shadows on the giant planet that morning. WAA might have a policy of not providing misinformation, but if you want to show people two "black holes" on Jupiter between 8 and 9am EDT on April Fools' Day, that's your business.

Mercury reverses everything in April, compared to our view in February and March. Mercury will be in the morning sky, with an elongation from the Sun 50 percent farther than last month, but it'll only be half the separation from Sun in our skies. The southern hemisphere gets the best view of Mercury in all of 2019 this month. Mercury hangs out to the lower left of Venus, closing to within four degrees of Venus around mid-month, but no closer.

Asteroid 2 Pallas (more properly called a minor planet) keeps company near Arcturus at magnitude +8 this month, as it closes to within 150 million miles of Earth. Look for it to pass near Eta Bootis (magnitude +2.7) around the 11th. Larger and rounder dwarf planet 1 Ceres spends April as bright as Pallas in between Ophiuchus and Scorpius. At Ceres's closest approach to Earth in late May it will be magnitude +7, 163 million miles away.

April's Lyrid meteors peak on the 22nd and 23rd. There will be up to 20 hard-to-see meteors in a moonlit sky.

The Dragon spacecraft, launched from the Kennedy Space Center, visited the International Space Station in March. The SpaceX product, with room for four astronauts and their luggage, was tested without passengers ahead of a crewed flight in July. There are only three astronauts on board the ISS now. The Chinese station Tinagong 2 no longer has taikonauts[1] on board. Both the ISS and Tinagong 2 are forecast to make evening passes over us during the first third of the month. It may be possible to get sightings of the two close to the same time on late March evenings. ■

[1] Term used in non-Chinese media from Chinese *taikong* (space) and the Greek *naut* (sailor)

Member Profile: David Butler

Home town: Mohegan Lake

Family: Helen

How did you get interested in astronomy? My sons bought me an ETX 90 telescope. It had descriptions of many objects and I enjoyed reading about them before weather was clear enough to view.

Do you recall the first time you looked through a telescope? What did you see? I went through the "Tonight's Best" tour on the Meade hand control. Other tours that were enjoyable for a newcomer are "How Far is Far" and "A Star's Life.

What is/are your favorite object(s) to view? The Orion Nebula with the BIPH (a binocular image intensifier device) and hydrogen alpha filter. Open Cluster M39 on my LX90. A Dobsonian telescope viewing any object where you looking into the Milky Way and thus seeing thousands of faint background stars. The Veil Nebula on WAA's 20-inch Obsession. Saturn on school outreach events. Mars in pre-dawn twilight with the EXT90 at 312x when I could see a thin shadow that wasn't lit by the sun.

What kind of equipment do you have? I have an 8 inch Meade Schmidt-Cassegrain with right angle view finder. The eyepieces I used most often are 32mm, 8-24mm zoom, 2-inch 36mm and the BIPH.

What kind of equipment would you like to get that you don't have? Well this is a long list that has pluses and minus. One of our club members has a Dobsonian with encoders and an iPad that shows a map of what the telescope is focused on, with all the information on it and surrounding objects. As he moves the scope, the star map on the iPad follows. How cool is that!

Have you taken any trips or vacations dedicated to astronomy? We had one trip to Cherry Springs and it is requirement to go there if you have never been to a truly dark site. You see an annoying cloud that crosses the sky when it's still blue, and as it gets darker you realize that this is the Milk Way. It's the way the sky should be, without light pollution.

Are there areas of current astronomical research that particularly interest you? I really enjoyed Larry Faltz's technical astronomy articles. I am amazed by Larry's ability to present the story in a clear manner but not make it too simple. The science of astronomy is exploding both in theory and the acquisition and processing of a vast amount of data ("big data"). That's very exciting.

Do you have any favorite personal astronomical experiences you'd like to relate? Comet Holmes lasted form months in 2007. I started to view it after seeing an article on a Japanese site the day of its sudden outburst. I measured it diameter over time until it could no longer fit in the eyepiece: 1.25 degrees. Even after it was too big for the eyepiece it stood out clearly as a naked eye object for a long time.

What do you do in "real life"? I am part of the IRI Worldwide innovation team, which includes Hendry Market Structure and Hendry Simulator. These are marketing consulting, analytics and software entities.

How did you get involved in WAA? I found the club on line and wrote a letter to Bob Davison. I gave a list of objects I had viewed with my ETX 90. He actually advised me not to join the club until January, feeling that maybe viewing in late October, November and December would have a negative effect on my enthusiasm. Anyway when he saw how much I enjoyed outreach events I became WAA's VP for Field Events and did it for a long time before handing it over to Bob Kelly. Bob brought me to an outreach at Camp Ramah, a Jewish camp in Dutchess county. He brought the club's 20 inch Obsession and I brought my 90mm ETX. I enjoyed it so much it's an outreach that I do annually.

What WAA activities do you participate in? I read every article in the Newsletter. I attend all outreach events and star parties that I can. I enjoy the annual club picnic. I enjoy the lectures and I try not to miss too many.

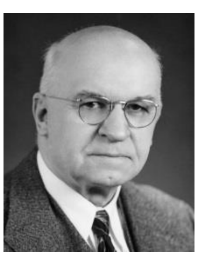
If you have a position in WAA, what is it, what are your responsibilities and what do you want the club to accomplish? As I mentioned, I was Vice President for Field Events. The viewing events are the key activity of amateur astronomy. There's no hobby without them! ■

Active Galactic Nuclei and Quasars

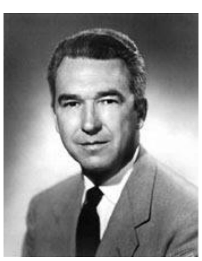
Larry Faltz

The question of whether "spiral nebulas" were located within the Milky Way or external to it was one of the most important unresolved astronomical questions of the early 20th century, as I discussed in the November 2018 SkyWAAtch. That the spirals were far outside our own galaxy, that they were receding from us and that the universe began as a hot, dense fireball weren't the only important discoveries that stemmed from work on this problem.

Until the early 20th century, it wasn't known whether the spirals were made of gas or individual stars. Astronomers using the largest telescopes available disagreed about what they saw. The development of photographic spectroscopy in the late 19th century provided an opportunity to solve the problem. If spiral nebulas were collections of stars, they should show the continuous spectra of starlight, rather than the specific emission line spectra of gaseous bodies (such as planetary nebulas). Astronomer Edward Fath built a spectrograph and attached it to the 36-inch Crossley reflector at Lick Observatory. He captured spectra of the brighter spiral galaxies on photographic plates, manually guiding the telescope through the night as was necessary in those days. The plates recorded continuous spectra with stellar absorption lines as expected from an aggregation of stars, with one exception. NGC 1068 (we know it better as Messier 77, a galaxy in Cetus) showed both absorption and emission lines, suggesting both stars and gas. Fath published his work in 1909 and should be credited with being the first person to provide real evidence that spiral nebulas were made of stars. But NGC 1068 was perplexing.



Edward Fath

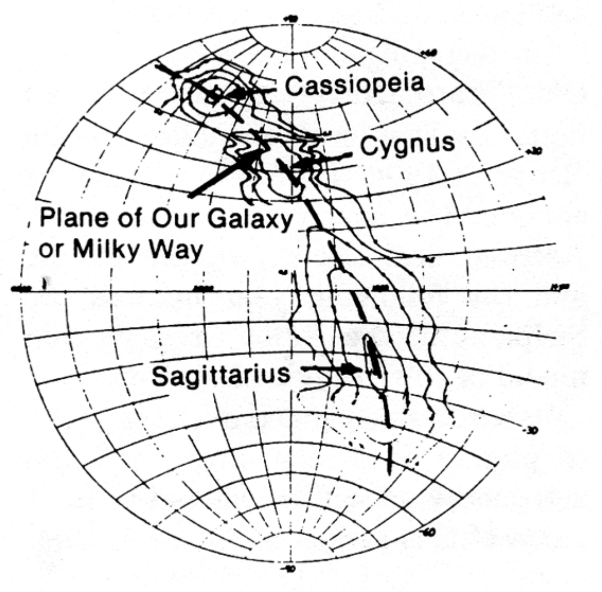


Karl Seyfert

Karl Jansky

In 1917, Vesto Slipher, the discoverer of galactic red shift, confirmed the anomalous spectrum of NGC 1068 using the Lowell Observatory's famous 24-inch Clark refractor. The narrower slit on his instrument projected the emission lines onto the photographic plate as small disks. This was interpreted as evidence that the emission was spread over a substantial range of wavelengths rather than being very sharp. Edwin Hubble noted in 1926 that NGC 4051 and NGC 4151, spirals with star-like nuclei, also showed similarly broadened emission lines in their spectra.

Karl Seyfert whose Ph.D. adviser at Harvard was Harlow Shapley, observed 6 galaxies with stellar-appearing nuclei that had broad emission lines superimposed on typically stellar spectra. He attributed the unusual width of the emission lines to a Doppler shift. This was the correct interpretation of Slipher's observation. In addition, Seyfert noted that some of the the emission lines were those of "forbidden" transitions, which occur only when certain elements exist in a very low-density gas. An example familiar to amateur astronomers is OIII, the doubly ionized (O^{++}) oxygen ion found in planetary nebulas that shine in the blue at 495.9 and 500.7 nanometers. Visible galaxies with these spectral characteristics are called "Seyfert galaxies" in his honor. Sadly, Seyfert was killed in an automobile accident in 1950 and didn't get to see how the structure and physics of these objects were revealed to astronomers.

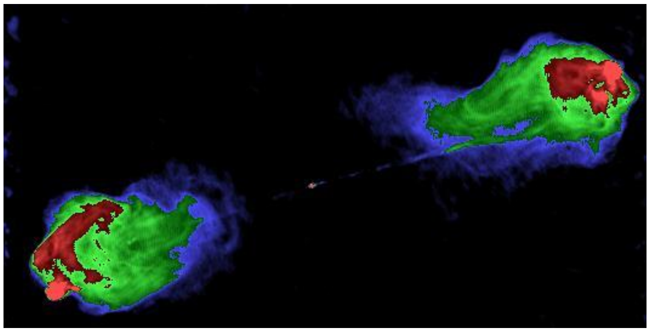


Reber's radio map at 1.9 meter wavelength

In the 1930's, a new window on the cosmos opened. Radio waves from space were first detected serendipitously by Karl Jansky in 1932. Just 6 years later, amateur astronomer and radio enthusiast Grote Reber built a 9-meter dish in his backyard in Wheaton, Illinois.

The resolution of this instrument was low and it didn't have sidereal tracking. Nevertheless he was able to draw a radio map of the northern sky, detecting bright radio sources in Cygnus, Cassiopeia and Sagittarius.

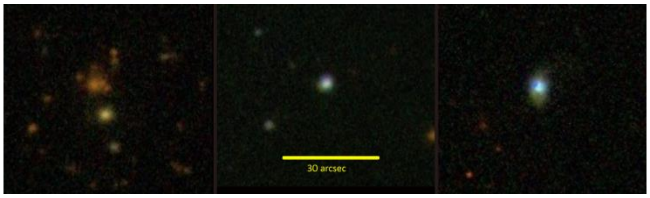
For nearly a decade, until the end of World War II, Reber was the world's only radio astronomer. Advances in radio technology during the war, particularly radar, paved the way for the development of radio astronomy as a discipline. Large radio telescopes were built around the world, and new information came quickly. In 1946, a radio telescope in Australia set an upper limit of 2 degrees on the angular diameter of the Cygnus source and also found that the signal strength fluctuated over fairly short time frames. By 1948 the angular diameter had been reduced to just 8 arc minutes. The amount of energy coming from the object was suggested as being too large for it to be thermonuclear in origin, so it couldn't arise from stars. A catalogue of 6 "radio stars" published in 1948 used the nomenclature "Cygnus A", "Cassiopeia A" "Taurus A," etc., which we still use for historic reasons for some of these objects. By 1949, Taurus A had been identified with the Crab Nebula (M1), Virgo A with the elliptical galaxy M87, and Centaurus A with NGC 5128, a galaxy with a prominent dust lane. Sagittarius A pointed to the center of the Milky Way. The 3 other objects looked like stars.



Cygnus A (3C 405) at 5 GHz (VLA)

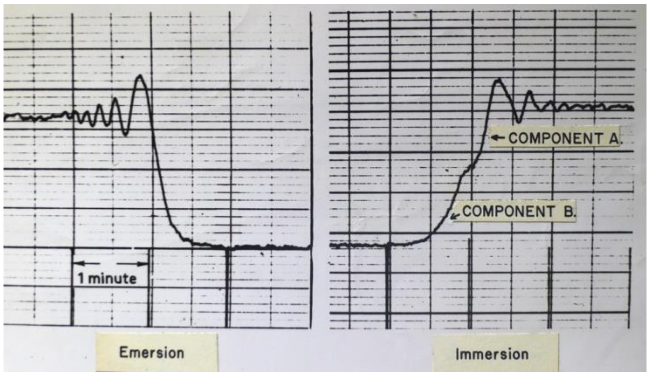
By 1952, Cygnus A was seen as a distorted object possibly representing two galaxies in collision. More impressive than its redshift (z=0.056, a remarkable redshift in 1952 but unimpressive now!) was its very high luminosity. Higher resolution radio images showed two lobes separated by 1.5 arcminutes. This 2-lobed appearance was found in a number of other intense radio sources. Optically, Cygnus A was star-like but deeper views showed a small amount of surrounding nebulosity.

The Third Cambridge survey (3C) was a comprehensive and accurate survey of radio sources published 1959 and in a revised form in 1962. It provided a wealth of interesting information and enough precision for many sources to be identified optically, which then allowed their spectra to be captured. The spectrum of 3C 295, an object in Boötes, showed a red shift of 0.46, making it the most distant object known at that time. This object is a cluster of galaxies.



Sloane Digital Sky Survey optical imges of 3C 295, 3C 196 and 3C 48 at same magnification. The bar is 30 arcsec. (from Aladin Sky Atlas, https://aladin.u-strasbg.fr/aladin.gml)

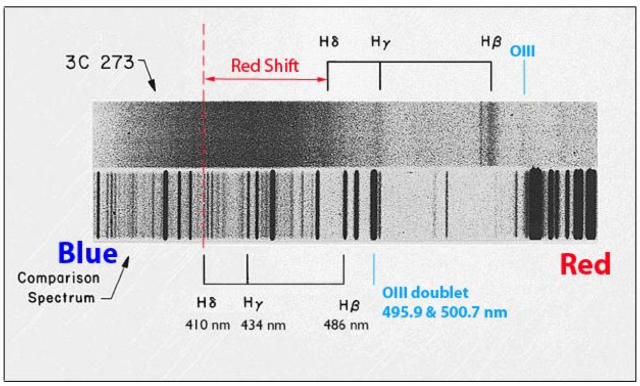
In 1960, Allan Sandage studied 3C 48, in Triangulum, with a radio interferometer at the Owens Valley Observatory in California. Optically, 3C 48 appeared to be a 16th magnitude star with a very faint nebulosity. The spectrum showed broad emission lines and photometry showed it to be variable over short time frames, similar to Cygnus A. Other star-like objects with similar spectra, rapid variability and high radio luminosities were found, and were dubbed "quasi-stellar radio sources," quickly shortened to "quasars." Sandage noted that "there was a remote possibility that [3C 48] may be a distant galaxy of stars," but "general agreement" held it to be "a relatively nearby star with most peculiar properties." It just made no sense, in the thinking of the time, for something that bright to be very far away. There were no established cosmic processes that could supply the necessary energy.



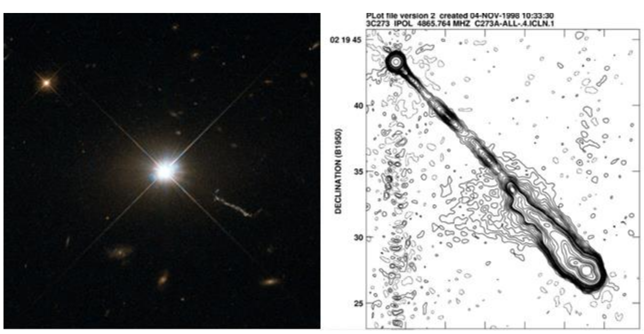
410 MHz plots of the lunar occultation of 3C 273, 8/2/1962.

In 1962, astronomers using the 210-foot Parkes antenna in Australia observed a lunar occultation of 3C 273, another star-like object with a spectrum showing broad emission lines. From the occultation they determined its exact position. It appeared to have two components. Component B was found to be a 13th magnitude star-like object and component A was a very faint streak pointing away from the star.

Maarten Schmidt obtained spectra of 3C 273 at the 200-inch Hale telescope and found emission peaks of the Balmer series of hydrogen with a red shift z=0.16. In addition, he found an ultraviolet line of MgII at 279.8 nm, similarly red-shifted. Strong ultraviolet emissions, shifted towards the visible band, were a characteristic of these objects.



3C 273 spectrum by Schmidt. 200" Hale telescope



(L) 3C 273, Hubble Space Telescope image, (R) Radio image at 5 MHz, Jansky Very Large Array

Schmidt and his colleagues published several papers in *Nature* in 1963 discussing the implications of the red shift of this star-like object. One possibility was that it was a very dense, relatively local star of an unknown type, with the red shift having a gravitational basis. If the source was dense enough, electromagnetic radiation would have to fight its way out of a deep gravitational well and would get red-shifted in the process. This theory could not, however, explain the presence of broad emission lines and forbidden lines (for example, the OIII lines in the spectrum shown above). A more daring interpretation was that these were extragalactic objects, but if so their optical luminosities were truly enormous, 10-30 times brighter than the brightest giant elliptical galaxies. The radio flux was similarly colossal. The distance to 3C 273 was estimated to be 500 megaparsecs based on the value of the Hubble constant at that time. Further, the energy would have to emanate from a source less than 1 kiloparsec in diameter because of the variability in visible and radio wavelengths. If the source was larger, the variations would have been smeared out and no longer detected.

Sandage had published a paper in 1963 before the red shift of 3C 273 was determined, identifying 3C 48, 3C 196 and 3C 286 with stellar objects. He noted variations in the light output of 3C 48 of 0.4 magnitude and claimed that these objects were stars located about 100 parsecs from the Sun. The paper was amended after Schmidt's discovery and Sandage then pointed out that the light variations, enormous distance and immense luminosity at multiple wavelengths meant the objects had to be less than 0.15 parsecs in diameter, hardly believable from the science then known. Whether he did this in repentance or to try to stick a pin in Schmidt's belief that the quasars were extragalactic isn't clear, but he eventually came around and made enormous contributions to quasar astronomy. A continuing flood of observations in the late 1960's and 1970's dispelled the notion that quasars were objects in our own galaxy, with just a few holdouts until the 1980's.

Schmidt determined red shifts for more quasars: 3C 47 at z=0.425, 3C 147 at z=0.545, 3C 254 at z=0.734, 3C 245 at z=1.029, and finally 3C 9 at z=2.012. The red shift of 3C 9 was so great that the Lyman alpha line at 121.5 nm moved into the visible band. Gunn and Peterson used the intensity and magnitude of the red-shifted Lyα line in different quasars to estimate the amount of neutral hydrogen in intergalactic space. They calculated that it was insufficient to retard the expansion of the universe. The remarkable energies and distances took the astronomical world by storm. In the mid-1960's understanding them seemed to be the dominant astrophysical problem under investigation and Schmidt even made the cover of Time Magazine on March 11, 1966.

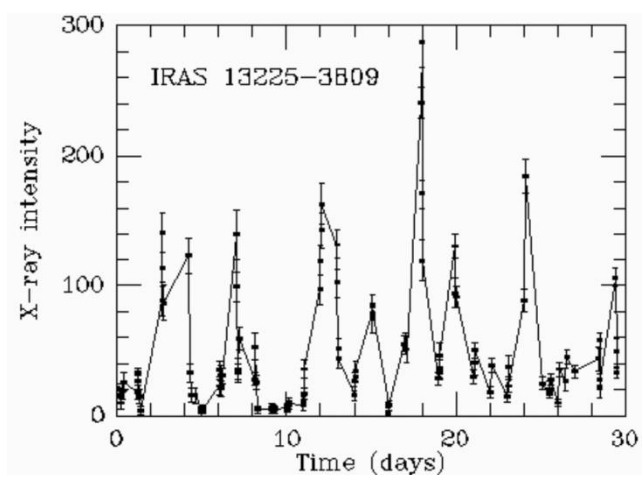
The coexistence of broad and narrow emission lines, with narrow lines showing forbidden transitions, was modeled by proposing that the central source of energy was surrounded by dense, fast moving clouds of matter (the "Broad Line Region," or BLR), outside of which were slower moving, less dense clouds (the "Narrow Line Region," or NLR). Models based on spectroscopic abundances suggested that the clouds were heated by X-rays coming from an interior region that had a small volume, high temperature and high density. The X-rays would be accompanied by a "continuum" of blue and ultraviolet emission.

If the objects were indeed at galactic distances, what could provide the required energy and yet be so compact? We of course already know the answer, but one has to recall the scientific environment of the day. Einstein had recognized that black holes were a mathematical product of general relativity, but he claimed that nature would find a way not to allow them to exist. Einstein abhorred the possibility of a singularity where mass becomes infinite. (There's a saying ascribed to him, "Black holes are where God divided by zero" but apparently he never actually said it and certainly couldn't have used the term "black hole" because it was coined by John Archibald Wheeler in 1967, 12 years after Einstein's death.) One possibility, a chain reaction of supernova explosions, was quickly dismissed. Other fanciful explanations included a collection of antimatter or a white hole at the terminus of a wormhole. Greenstein and Schmidt proposed for 3C 273 a central engine on the order of 10^9 solar masses. This mass would have a Schwarzschild radius of just 10^{-4} parsecs, or just 20.6 astronomical units by my calculation, about the size of the orbit of Uranus! They wrote "It would be important to know whether continued energy and mass input from such a 'collapsed' region are possible." They also proposed that there could be galaxies surrounding the quasars that are hidden by their glare. These objects appeared starlike in the telescopes of the time and even with today's large instruments and sensitive cameras many of them cannot be resolved as galaxies.

That 3C 273 was an enormous black hole surrounded by an accretion disc of hot, dense matter was formally proposed in 1964 by Salpeter and independently by Zeldovich. Five years later, Donald Lyndon-Bell concluded that "with different values [of the black hole mass and accretion rate] these disks are capable of providing an explanation for a large fraction of the incredible phenomena of high energy astrophysics, including galactic nuclei, Seyfert galaxies, quasars and cosmic rays." One mechanism for producing so much energy is inverse Compton scattering, a process where photons gain energy from their interaction with charged particles. The dense accretion disk surrounding a black hole is believed to produce a thermal spectrum because of friction, rich in ultraviolet and visible photons. The photons produced from this spectrum are scattered to higher energies by relativistic electrons in the surrounding plasma, amplifying the energy output and producing X-rays.

Further progress in understanding quasars depended on another window opening. X-rays cannot penetrate the Earth's atmosphere, so X-ray detectors have to be in space. The first astronomical X-ray detector was aboard an Aerobee suborbital rocket in 1962. It detected abundant X-rays in some areas of the sky but had very limited resolution. Later rocket-borne detectors found X-ray sources in the Crab nebula and M87, as well as sources coincident with 3C 273 and Centaurus A (NGC 5128). For 3C 273, the X-ray luminosity was consistent with the optical luminosity. Calculations with more recent data show that the total luminosity of 3C 273 is about 2.2 x 10^{47} erg/sec, which is 2.2 x 10^{40} watts, equivalent of about 10^{14} Suns. If 3C 273 was 10 parsecs away, the distance of Pollux, it would shine as bright as the Sun, -26.7 magnitude.

With the launch of the Uhuru X-ray satellite in 1970 and follow-up instruments in the next decade, many new X-ray sources were identified and their fluxes measured, solidifying evidence for a dense central engine surrounded by heated matter. Some of them correlated well with radio sources, but there were others that had little radio emission. It became clear that there was not a single species of high-energy objects at cosmological distances.



Variation in X-ray output of quasar IRAS 13225-3809

By the early 1980's a new technique for elucidating the internal structure of quasars called "echo mapping" or "reverberation mapping" was developed. This technique relies on time delays between the continuum radiation and emission line variations caused by light travel time across the BLR as the energy varies over fairly short time scales typical of these bodies. It helped that many large research telescopes came on line beginning in the 1970's.

The hot, dense accretion disk surrounding the supermassive black hole at the center of an AGN extends to tens of the hole's gravitational radii (R_g=GM/c^2 where M is the mass of the black hole, c the speed of light and G is the gravitational constant [see the December newsletter for more information on G]. Outside of the accretion disk is the BLR zone of diffuse gas, up to several thousand gravitational radii. The atoms in the BLR absorb the ionizing radiation from the disk and re-radiate it as specific emission lines. Because the gas is still in the gravitational well of the black hole, these lines are Doppler broadened. This area is too small to be effectively resolved by current telescopes. Astronomers can, however, use the variability of the continuum radiation emitted by the accretion disk to extrapolate information about the inner structure of the AGN. The broad emission lines respond to the flux of the continuum radiation, but there's a delay due to the light travel time across the BLR. The emission lines appear to "reverberate," thus the name. From the time delays, the size of the BLR can be estimated, and even the black hole's mass can be deduced from these measurements.

Reverberation mapping, to date performed on about 60 quasars, shows that the BLR is smaller and denser than early models suggested, and gives estimates of the mass of the central black hole in each quasar, confirming the range of multimillions to billions of solar masses.

We can increase angular resolution dramatically if we apply the technique of optical interferometry. There are only a few telescopes in the world that can do this effectively. The GRAVITY Collaboration is a team of astronomers from a number of European institutions who use an instrument that combines images from the four 8.2-meter telescopes of the ESO's Very Large Telescope observatory on Cerro Paranal in Chile, effectively creating a telescope 130 meters in diameter. The GRAVITY instrument is a cryogenically-cooled fiberoptic beam combiner, spectrometer and phase imager that also utilizes adaptive optics. With this instrument, the team observed 3C 273 for 8 nights in 2017 and 2018. They measured the offset in phase between the direct emission of light from the quasar and the light from the BLR, allowing them to spatially resolve the motion of the gas. They could resolve velocity gradients on the order of 10 *micro*arcseconds, the equivalent of seeing a coin on the Moon from Earth. The motion of the gas is perpendicular to the quasar's jet, and the data suggest that the gas forms a thick ring with a radius of 0.12 parsecs. The data was also used to calculate the mass of the black hole as 3×10^8 solar masses. These results are similar to those obtained by reverberation mapping, but apparently with smaller error bars. GRAVITY provides an independent verification of the validity of reverberation mapping. Unfortunately, the method can be used on perhaps only the 10 closest and brightest quasars.

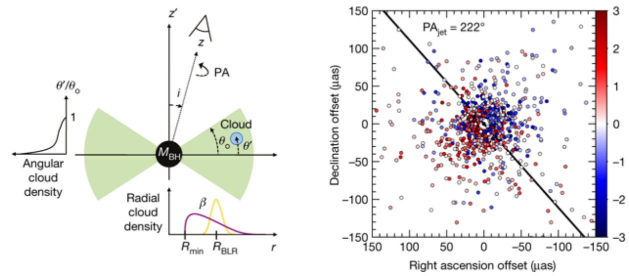


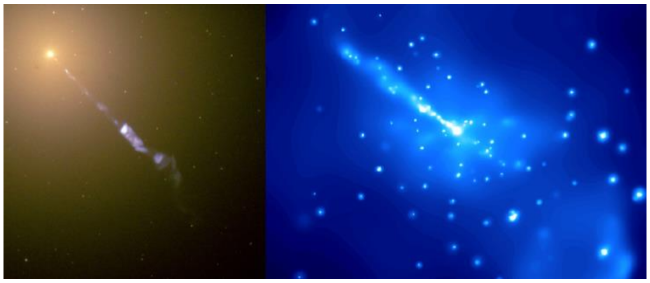
Fig 1 panels (c) and (d) from the GRAVITY Collaboration paper,[2] showing the model of the quasar and the resolved clouds of the BLR at microarcsecond sensitivity

Another feature of galaxies with strong radio emission is a jet. The jet in the giant elliptical galaxy M87 was discovered by Heber Curtis in 1918. While many energetic astrophysical objects can have jets, those associated with active galactic nuclei (AGN, the best catch-all term for these objects) are the most powerful. The rapidly rotating accretion disc creates intense magnetic fields which are projected in the axis of rotation. They pull charged particles into the field and accelerate them to relativistic speeds and may even create particles from energetic photons by "pair production" (photon → electron + positron, as long as the photon energy is > 1.022 MeV). Roger Penrose has proposed an alternate (most likely coexisting) mechanism, frame dragging due to general relativity, where the space close to the black hole is rotationally distorted and gravitational energy can accelerate the particles. Frame dragging is certain to be a major factor of any physical process in the environment of a supermassive black hole.

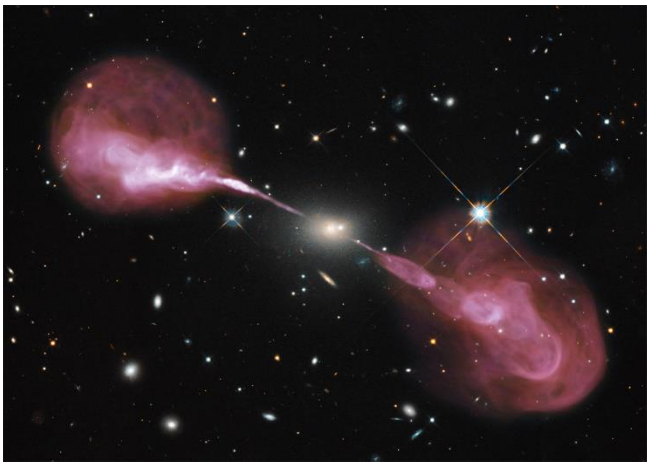
Charged particles twisting in a magnetic field give off synchrotron radiation in radio wavelengths. In addition, the particles give off radio waves when they are

[2] Spatially resolved rotation of the broad-line region of a quasar at sub-parsec scale, Nature 2018 (29 November) 563: 657-660

slowed by their interaction with the intergalactic medium, thus accounting for the appearance of radio "lobes" on either side of the object.

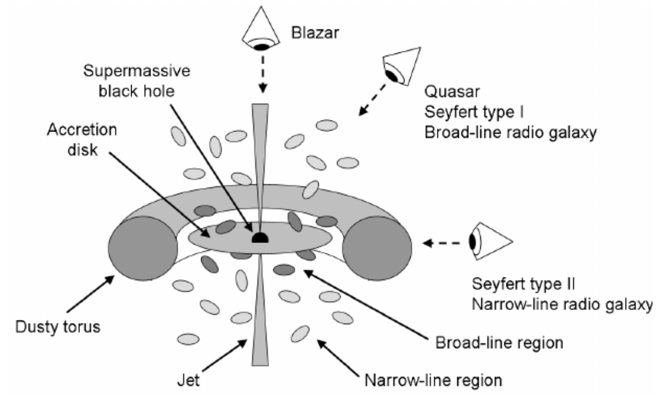


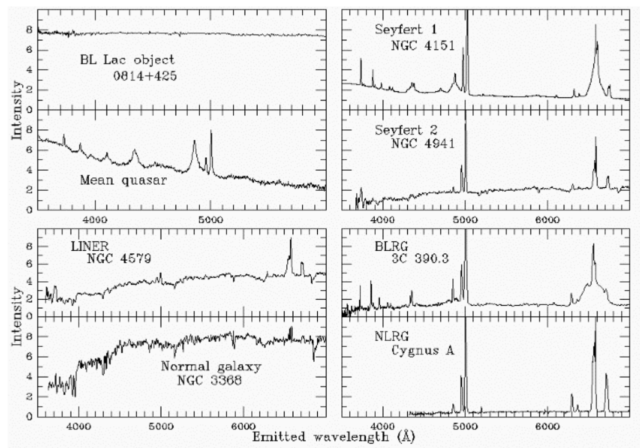
AGN jets: (L) HST image of M87 in visible light. (R) Chandra X-ray image of Centaurus A (NGC 5128)



Combined Hubble (visible) and VLA (radio) image of Hercules A (3C 348) showing the star-like nucleus, the elliptical galaxy, jets and radio lobes.

With the enhanced capabilities of modern ground and space-based telescopes, active galactic nuclei and quasars have been classified into some major groups, although there are objects that still remain to be understood. The classification of AGNs can get complicated and definitions overlap. One of the major reasons for this is that these objects are evolving. Galaxies have life spans and probably don't all evolve the same way. Astronomers are fairly certain that galaxies in the early universe were different from those that formed later. The smaller early universe may have had higher concentrations of gas and more dust from the first generation of massive stars that went supernova, and there is good evidence that star formation was much greater in these early galaxies than recently. There may have been many more galaxy mergers. Also, accretion disks can be at least partially consumed by their black holes; local stars can fall into the hole, powerful winds of charged particles and radiation pressure can prevent more matter from falling in, and with enough time the black hole can become quiescent, as Sagittarius A* seems to be. The accretion disks are becalmed.





Representative spectra of AGNs and quasars

The general model of an AGN is a supermassive black hole at the center of a galaxy, with a superheated accretion disk that emits electromagnetic radiation from optical through X-ray wavelengths. The disk is surrounded by zones of high (BLR) and lower velocity (NLR) gas. A dusty torus surrounds these zones in the plane of the accretion disc. A relativistic jet can extend from the supermassive black hole. As more details about AGNs are discovered, it is likely that different structural schemas will be developed. For the time being, the most important and common objects are blazars, Seyfert galaxies, BL Lac objects and quasars. The term *quasar* usually refers to distant, bright star-like AGNs whose radiation outshines the rest of the stars in the galaxy, making the outer parts of the galaxy invisible in the quasar's glare, or nearly so. Quasars can even be relatively radio poor, detected only by their spectra and calculated luminosity relative to their distances. Nearby *radio galaxies* don't have the luminosity of quasars or Seyferts. They seem to be the result of recent mergers, as M87 may be, or are galaxies actively merging now.

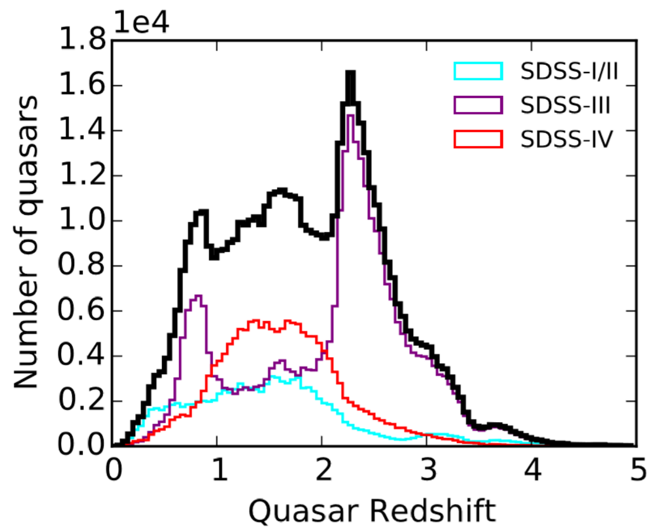
The brightest AGNs are *blazars*, in which the jet is pointed directly at Earth. These are intense gamma ray sources. They are variable over short time frames and have polarized emission.

Seyfert galaxies have strong nuclear emission although they are less luminous than the distant quasars and are found at lower red shift. Seyfert type I galaxies are tilted to our line of sight so that we can see both broad and narrow lines. Seyfert type II galaxies are tilted so the BLR is obscured by the dusty torus and we see only narrow lines. Seyfert I galaxies can be further classified as Broad Line Region Type I (BLRG) or Narrow Line Region Type I (NLRG), the latter probably having smaller black holes.

BL Lac objects are named after a prototype object that was thought to be a highly variable star in the constellation Lacerta. It varies in magnitude from +14 to +17. It was found to be a strong radio source with a red shift of z=0.07, putting it 900 million light years from the Milky Way. A faint galaxy was found around it. What makes BL Lac objects distinct is that their spectrum is essentially devoid of broad or narrow emission lines characteristic of most other AGNs. The detailed structure of BL Lac objects is still a mystery. They may be a type of blazar.

LINER galaxies (Low-Ionization Narrow Emission Line Regions) are similar to Seyfert galaxies but have relatively lower ionization, generally evidenced by a lower signal of OIII.

The catalog of quasars has grown dramatically. The first published survey, the Bright Quasar Survey in 1983, catalogued 100 quasars. In 1995 the Large Bright Quasar Survey got to 1,000 quasars. The 2dF QSO Redshift Survey, using the 3.9-meter Anglo-Australian telescope was carried out from 1997 to 2002, observing on 272 nights. It scanned two strips of sky, each 75 x 5 degrees, one near the north galactic pole (finding 10,484 quasars) and one near the southern galactic pole (12,854 quasars) brighter than +21 mag. The Sloane Digital Sky Survey has now, in its 14th release, catalogued 526,356 quasars. The 2dF and SDSS surveys were designed primarily to utilize quasars to shed light on cosmological questions: evolution of the cosmic web, evidence for baryon acoustic oscillations, the timing of reionization of the universe and the value of the cosmological constant. They were not designed to make a full census of quasars in the night sky, and they may not be able to verify the quasar nature of most distant and faintest objects because their spectra can't be confirmed. But they do show that quasars were much more common in the early universe, with a peak at a redshift of around 2.5, which translates to a time after the Big Bang of 2.6 billion years (or, 11 billion years ago). Surveys have magnitude limits, and generally won't detect the very earliest quasars. As of this writing, the most distant quasar yet detected is ULAS J1342+0928 in Boötes, z=7.54. It was detected by a consortium of telescopes: the WISE infrared telescope in space, and large ground-based instruments in Chile, Arizona and Hawaii. It is seen just 690 million years after the Big Bang. This compares with the most distant galaxy, GN-z11 in Ursa Major, with a red shift of 11.09, just 400 million years into the life of the universe. It was detected by the Hubble and Spitzer space telescopes. It does not appear to be a quasar.



Distribution of redshifts in the full SDSS 14 catalog (Paris, et. al., *The Sloan Digital Sky Survey Quasar Catalog: Fourteenth Data Release*, https://arxiv.org/pdf/1712.05029.pdf)

As we observe more quasars with instruments of increasing sensitivity and resolution, the dynamics of galaxy formation and the origins of supermassive black holes will begin to be understood. This is one of the goals of the James Webb Space Telescope, but we're certain to see more results from instruments like GRAVITY and when the next generation of 27-39 meter instruments comes on line. ■

3C273 is a 12.9 magnitude object in Virgo at right ascension 12h 29m 06.7s and declination +02° 03′ 09″. Spring is a good time to look for it with larger amateur telescopes, especially those with cameras. Its red shift can even be detected by amateurs using a low-resolution diffraction grating like the Star Analyzer and RSpec software.

Images by WAA Members

Robin Stuart sent these fine images of the lunar eclipse. Robin writes "High Dynamic Range (HDR) photographs of the January 2019 total lunar eclipse. The bluish fringe on the shadow's outer edge is due to scattering of sunlight by stratospheric ozone."

The images were made by combining 7-9 exposures using Photomatix Pro. Equipment: Televue 70mm Pronto with 0.8X telecompressor, Canon 60Da DSLR.

■

Images by WAA Members

WAA member John Higbee (Arlington, VA) with the 7.75” Alvan Clark refractor at the observatory on the grounds of the United States Naval Academy in Annapolis, MD.

John, a USNA graduate and former nuclear submarine commander, helped restore this 1857 telescope and is responsible for its maintenance.

The original telescope mounting was replaced with a Byers drive and encoders were fitted. A large ladder is needed to reach the eyepiece for almost all elevations of the tube.

[This is not the US Naval Observatory. That facility is located in downtown Washington, DC near the intersection of Massachusetts and Wisconsin Avenues. It houses a 26-inch Alvan Clark refractor made in 1873, the instrument that Asaph Hall used to discover the moons of Mars in 1877. The home of the Vice President of the US is now on the grounds. Sadly, visits to the telescope have been suspended. Your editor got a look at Jupiter through the 26” in 1975, an amazing sight.]

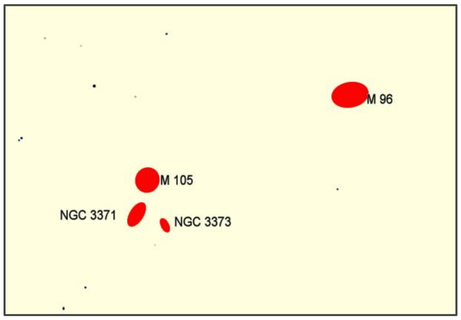
On Feb. 8th, John invited Larry & Elyse Faltz to join him and members of the Northern Virginia Astronomy Club at a star party at the observatory for families at the Academy. Although the sky was only marginally cooperative, there were good views of the Moon, Mars, Uranus, M42 and some double stars. How often do we get to set up our telescopes near U.S. Navy jet fighter planes?

(Photos by Larry Faltz)

Images by WAA Members

Arthur Rotfeld sent in some images he captured at Lake Taghkanic State Park on a frigid night in early February. He imaged with an Explore Scientific 80mm apochromatic refractor on an Orion Skyview Pro Goto mount. The camera was a Canon Rebel T6i. These are single images, edited with MacPhoto. Arthur's image of the Leo triplet will be on the front page of next month's Sky*WAA*tch.

Galaxies from the Leo I group at 3200 ISO for 60 seconds. Top to bottom: M96 (top right), M105, NGC 3384, NGC 3389, NGC 3373.



Map from Cartes du Ciel 4.0

Messier 38, an open cluster in Auriga, is also known as the "Starfish Cluster." It's prominent on the right side of this image. The smaller open cluster NGC 1907 is near the center, and even further left is the tiny open cluster Stock 8, just above the 5th magnitude star Phi (φ) Aurigae. The hot young stars of Stock 8 energize an emission nebula, IC 417, which is too faint to be seen in this image.

Surely, there is not another field of human contemplation so wondrously rich as astronomy! It is so easy to reach, so responsive to every mood, so stimulating, uplifting, abstracting, and infinitely consoling. Everybody may not be a chemist, a geologist, a mathematician, but everybody may be and ought to be, in a modest, personal way, an astronomer. For star gazing is a great medicine of the soul.

Garrett Putnam Serviss (1851-1929)

Thanks to Joe Rao for turning us on to this wonderful quote.

Research Highlight of the Month

Observations of galaxy mergers at z=4.6

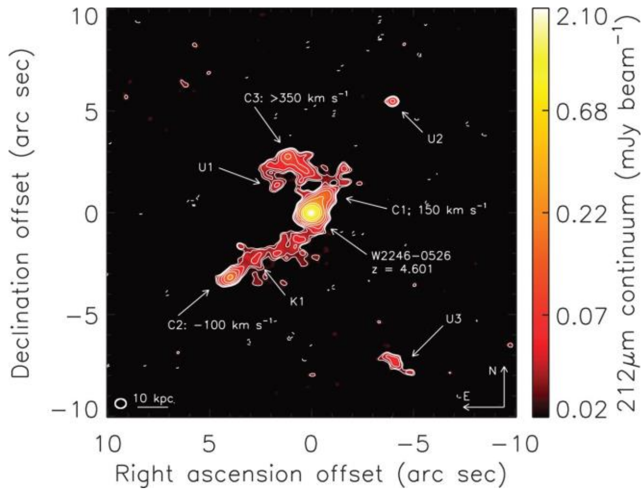
The mechanism of the formation of supermassive black holes (SMBH) in the early Universe is still unknown. The earliest galaxies most likely formed in high mass-density regions that formed at the end of inflation. They assembled in the first million years after the universe cooled enough to become transparent to radiation. Galaxy formation was assisted by the presence of dark matter haloes, whose formation remains a mystery. During the early times, the galaxies may be obscured by interstellar gas and dust. Ultraviolet and optical light from these galaxies (arising from their SMBH-containing active nuclei and new star formation) would be absorbed by the dust, and should be re-emitted as infrared radiation.

The Wide-field Infrared Explorer (WISE), a 0.4-meter space telescope launched in 2009, has been looking at these hot dust-obscured galaxies (known as hot DOGs, really!). It observed an object in Aquarius, WISE J224607.56-052634.9 (its nickname is W2246-0526), the most luminous galaxy yet found. It cranks out the energy of 350 trillion Suns. It has a high star-formation rate and it appears to be merging with three companion galaxies.

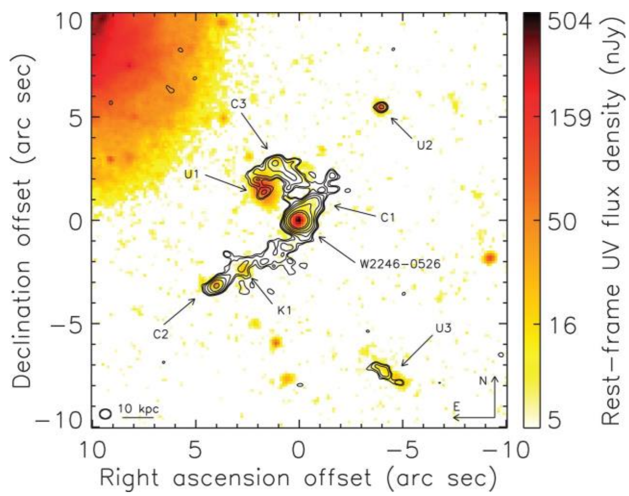
In the November 30, 2018 issue of *Science*, an international group led by Chilean astronomer Tanio Diaz-Santos reported observations of W2246-0526 with the Atacama Large Millimeter/Sub-Millimeter Array (ALMA) in Chile and the Jansky Very Large Array (VLA) radio telescope in New Mexico.

They determined that "merger-driven accretion of neighbor galaxies obscures the central supermassive black hole under large columns of dust and gas and provides the intermittent large-scale influx of material needed to generate its extreme luminosity and maintain star formation in the host galaxy, which would otherwise quickly deplete the gas reservoir." Further, the authors note that "if W2246-0526 is representative of the hot DOG population, our results suggest that hyperluminous obscured quasars may be interacting systems, the result of ongoing merger-driven peaks of SMBH accretion and massive galaxy assembly in the early Universe."

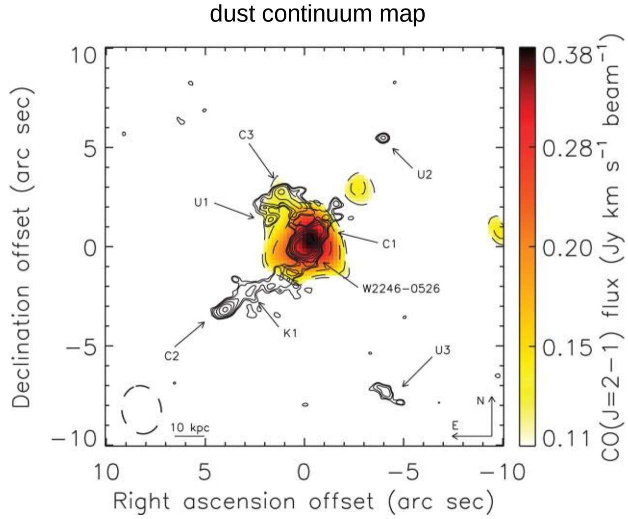
Diaz-Santos, T, Assef, RJ, Blain, AW, et. al., The multiple merger assembly of a hyperluminous obscured quasar at redshift 4.6. *Science* 2018; 362: 1034-1036.



Dust continuum map of W2246-0526 at 212 μm



Near-UV (286.0 nm) image overlaid with contours from the dust continuum map



Carbon monoxide emission overlaid with contours from the dust continuum map

Member & Club Equipment for Sale

Item	Description	Asking price	Name/Email
Celestron 8" SCT on Advanced VX mount	Purchased in 2016. Equatorial mount, portable power supply, polar scope, AC adaptor, manual, new condition.	$1200	Santian Vataj spvataj@hotmail.com
Celestron CPC800 8" SCT (alt-az mount)	Like new condition, perfect optics. Starizona Hyperstar-ready secondary (allows interchangeable conversion to 8" f/2 astrograph if you get a Hyperstar and wedge). Additional accessories: see August 2018 newsletter for details. Donated to WAA.	$1000	WAA ads@westchesterastronomers.org
Meade Research Grade 12½" f/6 Newtonian telescope.	Ex Bowman Observatory, Greenwich. New in 1985, normal wear but it is complete and everything works. 8" Beyers drive, 80mm f/15 guide scope. 50mm finder. Moonlite focuser. Drive control. Updated mirror mount. Mirrors refinished 2013 Metal pier.	Free!	Rick Bria rickbria22@gmail.com
Celestron StarSense auto-align	New condition. Accurate auto-alignment. Works with all recent Celestron telescopes (fork mount or GEM). See info on Celestron web site. Complete with hand control, cable, 2 mounts, original packaging, documentation. List $359. Donated to WAA.	$225	WAA ads@westchesterastronomers.org
Meade 395 90 mm achromatic refractor	Long-tube refractor, f/11 (focal length 1000 mm). Straight-through finder. Rings but no dovetail. 1.25" rack-and-pinion focuser. No eyepiece. Excellent condition. A "planet killer." Donated to WAA.	$100	WAA ads@westchesterastronomers.org
Televue Plossl 55mm 2-inch	Very lightly used. Excellent condition. Original box.	$150	Eugene Lewis genelew1@gmail.com

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 only submit serous and useful astronomy equipment. WAA reserves the right not to list items we think are not of value to members.

Buying and 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 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*!