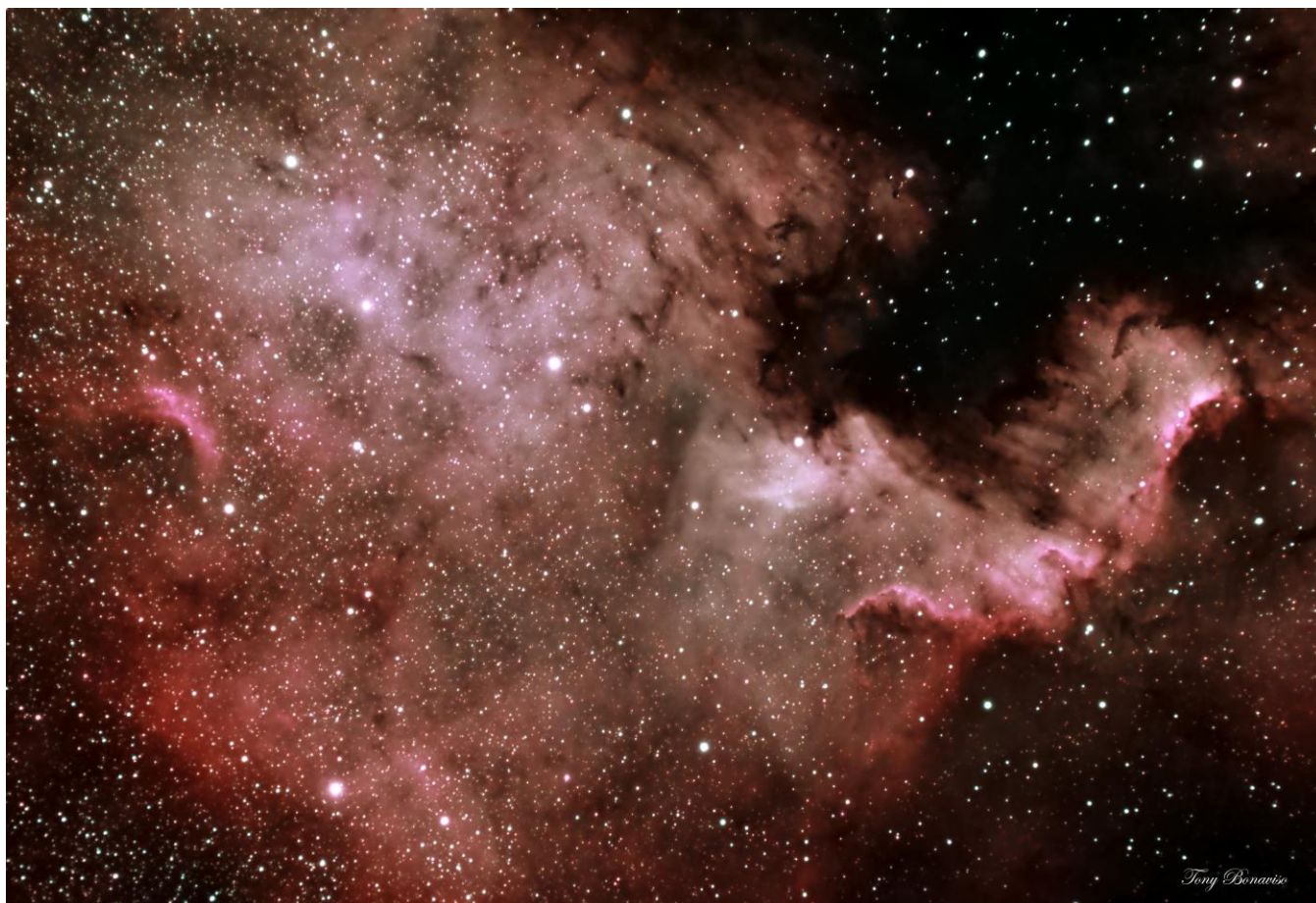# SkyWAAtch

The Newsletter of Westchester Amateur Astronomers

March 2021

North American Nebula by Tony Bonaviso

NGC 7000 in Cygnus, just east of Deneb, is one of the great sights in a very dark summer or fall sky far away from light pollution. Almost two degrees wide, it's dramatic when viewed through binoculars or a wide-field tele-scope. It was discovered by William Herschel in 1786, but named for its similarity to the North American conti-nent by deep-sky imaging pioneer Max Wolf, who first photographed it in 1890. It's about 2,600 light-years dis-tant.

Tony made this image at Ward Pound Ridge Reservation. Astro-Tech AT92 f/5.5 triplet refractor, ZWO ASI294 MC Pro cooled camera. Optolong L-extreme dual band light pollution filter. Captured in APT v3.87, PHD2 guid-ing, 25x300 sec light frames, 21x300 sec dark frames, processed in Pixinsight (including SuperBias).

WAA March Meeting

Friday, March 12 at 7:30 pm

Via Zoom

High Performance Infrared Focal Plane Arrays for Astronomy, Earth Science, and Planetary Missions

James W. Beletic, Ph.D. – President, Teledyne Imaging Sensors

Dr. Beletic has over 30 years of experience in astronomical instrumentation, with specialization in visible and infrared image sensor technologies. His career is a unique combination of international work experience that includes leadership positions at the world's foremost astronomical observatories and an industry leader in infrared sensors (Teledyne), and scientific positions at major research centers (HarvardUniversity, MIT Lincoln Laboratory, Georgia Tech Research Institute). Teledyne sensors are used on most of the large research telescopes in the world and in space.

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

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

SkyWAAtch © Westchester Amateur Astronomers, Inc.

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

WAA April Meeting

Friday, April 9 at 7:30 pm

Via Zoom

Discovery at Lowell: The Past, Present, and Future of Lowell Observatory

**Kevin Schindler
Lowell Observatory, Flagstaff, Arizona**

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

Starway to Heaven Star Party

Meadow Picnic Area parking lot, Ward Pound Ridge Reservation, Cross River, NY

Saturday, March 13 (rain/cloud date March 20).

Pandemic restrictions are still in place. Maximum number of participants at one time limited to 50.

New Members

Richard Bronstein	Bedford
Oleksandr Iurchenko	Stamford, CT
William Kerr	Bedford Hills
Arthur Vizoskie	White Plains

Renewing Members

Gregory Estevez Borrelly	Yonkers
Rick Bria	Greenwich, CT
Frank and Kathy Clemens	Larchmont
Tom & Lisa Cohn	Bedford Corners
Emily Dean	Pelham
Patricia, Jon & Frank Gelardo	Mamaroneck
Jinny Gerstle	West Harrison
Jonathan Gold	Newcastle
Cat Hannan	Peekskill
John Markowitz	Ossining
David Parmet	Mt. Kisco
Steve Petersen	Katonah
William Sawicki	Bronx
Michael H Tarlowe	New Rochelle

ALMANAC For March
Bob Kelly, WAA VP for Field Events

| 3Q 3/5 | New 3/13 | 1Q 3/21 | Full 3/28 |

Mars, the Pleiades and Hyades

Mars will partake in some interesting encounters with the Pleiades and Hyades star clusters this month. It's closest to the Pleiades in the first week of March and on a line between the Pleiades and the Hyades on the 7th in the area known since antiquity as the "Golden Gate of the Ecliptic." Mars slips by red giant Aldebaran on the 22nd, but gives it a wide berth. Any clear evening this month is a great time to compare the look and style of the planet and the star with their ruddy complexions shining at magnitudes +0.8 and -0.7, respectively. Does Mars' dot-like appearance versus Aldebaran's point of brightness make them seem less than a magnitude apart in brightness?

It's a great time to get some photos of the whole gang. Play with your camera settings to see how the colors will show up best. I've found a middle-range ISO, like 400, is good for showing color differences. Often, being slightly out of focus brings out the color on bright objects. A thick crescent Moon skips through this scene on the 18th and 19th.

In a telescope, Mars appears only twice the size of Uranus, so surface details will be very hard to glimpse. A telescope might show the red planet slightly out of round, at 90% illumination.

So Few Bright Planets In Our Nighttime Skies

Saturn, Jupiter and Mercury huddle low in the east-southeast. Mercury will fade to the lower left, moving away from Jupiter and Saturn. The pair of giants will get up an hour and a half before the Sun by month's end, but won't be more than 10 degrees high when bright twilight starts.

Mercury gets out to 27 degrees west of the Sun for its greatest elongation on the 6th. That's its greatest distance from the Sun as seen from Earth for all of 2021; a virtual tie with an evening elongation in September. The elongation is aided by Mercury reaching aphelion on the 14th. Sadly, the ecliptic is very low in our morning sky in spring. Mercury and Jupiter are closest on the 5th.

If you go scout out a new location to see the east-southeastern horizon, now's also a good time to do some research for this summer's partial solar eclipse. Make sure you have a clear view to the horizon to the east-northeast. You will need it if you want to go out on June 10th to view the 72% eclipsed Sun, with maximum eclipse just ten minutes after sunrise.

Venus is still hiding in plain sight, like it's in the witness protection program. Even at magnitude -3.9, it's still not visible to us, spending the month less than 7 degrees west of the Sun. Only visible in the Solar and Heliospheric Observatory's C3 camera for another month, it's too near the Sun to see safely from Earth. Venus' superior conjunction occurs on the 26th.

The Moon lines up to the right of the morning planet bunch on the 9th. After that, it passes below the gang on the 10th and 11th.

Two More Major and Two Minor Planets

Speaking of Uranus, we might catch it early in the month before it joins Neptune in the Sun's glare. Neptune passes solar conjunction on the 10th.

Minor planet 4 Vesta begins the month in the rump of Leo and moves to the right across the lion. Thanks to its eccentric orbit around the Sun, it reaches opposition on the 4th, but is closest on the 8th at magnitude +6.0, 126 million miles from Earth. If you found Uranus last month, you have a good chance of finding Vesta. It will seem more star-like – like a pinpoint -- than Uranus, even though they are about the same brightness.

Comet C/2020 R4 (ATLAS) hangs about 10 degrees above the planet parade in the morning sky. It's only about magnitude +10, so it's going to be hard to pick up so low in the sky, even in a telescope. ATLAS should brighten a bit in April. It may have company, according to Seiichi Yoshida (http://www.aerith.net), when another comet seen passing through SOHO's view in 1999, 2004 and 2010 swings back by the Sun.

How about the Moon and the ISS?

The Moon is at perigee on the night of the 29th-30th,

just 35 hours after it's full.

The Moon at perigee (left, 33.6' diameter) and apogee (right, 29.5' diameter). The perigee Moon is 13.89% larger than the apogee Moon.

The International Space Station, with seven souls aboard, is visible in dawn skies through the 14th, and dusk skies starting on the 16th.

Don't Forget Daylight Saving Time and the Equinox

Daylight time begins at 2 a.m. on the 14th, so spring your clocks ahead one hour. The later sunrise (according to our clocks) makes morning observing a bit easier to get up for. After the time change, we have until 5:40 a.m. EDT before morning twilight begins. Evening darkness moves well after supper time.

The Equinox is on 20th at 5:37 a.m. EDT. We get the closest to equal day and equal night on the 17th with 12 hours 1 minute 16 seconds of daylight at White Plains. Nothing to do with the luck of the Irish, though. Equal day/night happens before the Equinox because sunrise is defined as the time *any* part of the Sun first appears over the horizon; and sunset, as when the Sun *totally disappears*. The rise and set times are not based on the midpoint of the Sun. Plus, our atmosphere bends the Sun's light a bit and adds 34 arc minutes (about one apparent solar diameter) to the Sun's altitude when it's near the horizon. ∎

Member Profile: Arun Agarwal

Home town: Chappaqua, NY

Family: Wife, Vinita (also a physician) and 2 grown up daughters, 36 and 30. The 36 year old has 2 daughters, 6 and 2.

How did you get interested in astronomy? I've always been fascinated with the sky.

Do you recall the first time you looked through a telescope? What did you see? When I was just six, I looked through a telescope and saw spots on the Moon.

What's your favorite object(s) to view? I like good views of the planets of our solar system.

What kind of equipment do you have? I don't have one of mine yet. So far, I've enjoyed looking through other people's telescopes.

What kind of equipment would you like to get that you don't have? I think a Celestron CPC Edge 9.25" would be a good scope for me.

Have you taken any trips or vacations dedicated to astronomy? Tell us about them. Unfortunately not, but I'm planning to retire soon and shall start traveling thing (of course, assuming the pandemic is over).

Are there areas of current astronomical research that particularly interest you? I'm fascinated by the possibility of Planet X, the possible large Kuiper belt object that's influencing the paths of the other bodies in that zone..

What do you do (or did you do, if retired) in "real life"? I'm a Pulmonologist. I also practice Sleep Medicine and Critical Care medicine. I'm on the staff of Putnam Hospital Center in Carmel and a number of other hospitals in the area.

Have you read any books about astronomy that you'd like to recommend? Another retirement plan.

How did you get involved in WAA? A friend of mine recommended it, and I joined in 2017.

What WAA activities do you participate in? I'm not active yet, but happy to support the club. As I head towards retirement, I plan to start participating.

Besides your interest in astronomy, what other avocations do you have? My main interests outside of my profession are reading, travel, and chess. ∎

Deep Sky Object of the Month: Messier 67

| Messier 67	
Constellation	Cancer
Object type	Open Cluster
Right Ascension J2000	8h 51m 24.0s
Declination J2000	+11° 49' 00"
Magnitude	6.9
Size	30'x30'
Distance	2.,600-2,900 LY
NGC designation	2682

Just over 8° south of the famous Beehive Cluster (M44) in Cancer, and just 5° above the midpoint of a line between Regulus and Procyon, M67 is one of the oldest clusters in the sky, with age estimates from 3.2 to 5 billion years. It has no stars brighter than class F7, and as expected for such an old collection of stars it has many old red giants. There are also about 150 white dwarfs among the 100 or so class G (Sun-like) stars. The total mass of M67 is between 1,100 and 1,400 $M_\odot$.

M67 is visible with the naked eye in very dark skies, a fine binocular object and a delight in a moderate-sized telescope.

Visibility for M67			
10:00 pm	3/1/21 EST	3/15/21 EDT	3/31/21 EDT
Altitude	60° 27'	60° 23'	58° 23'
Azimuth	176° 48'	174° 21'	204° 41'

W.H. Smyth (1844) described M67 as looking like a "Phrygian cap." Maybe in 1844 people knew what that looked like. Camille Flammarion (1880) said it resembled a "sheaf of corn." Luginbuhl and Skiff (1998) thought it looked like a "fiberoptic tree." Times change!
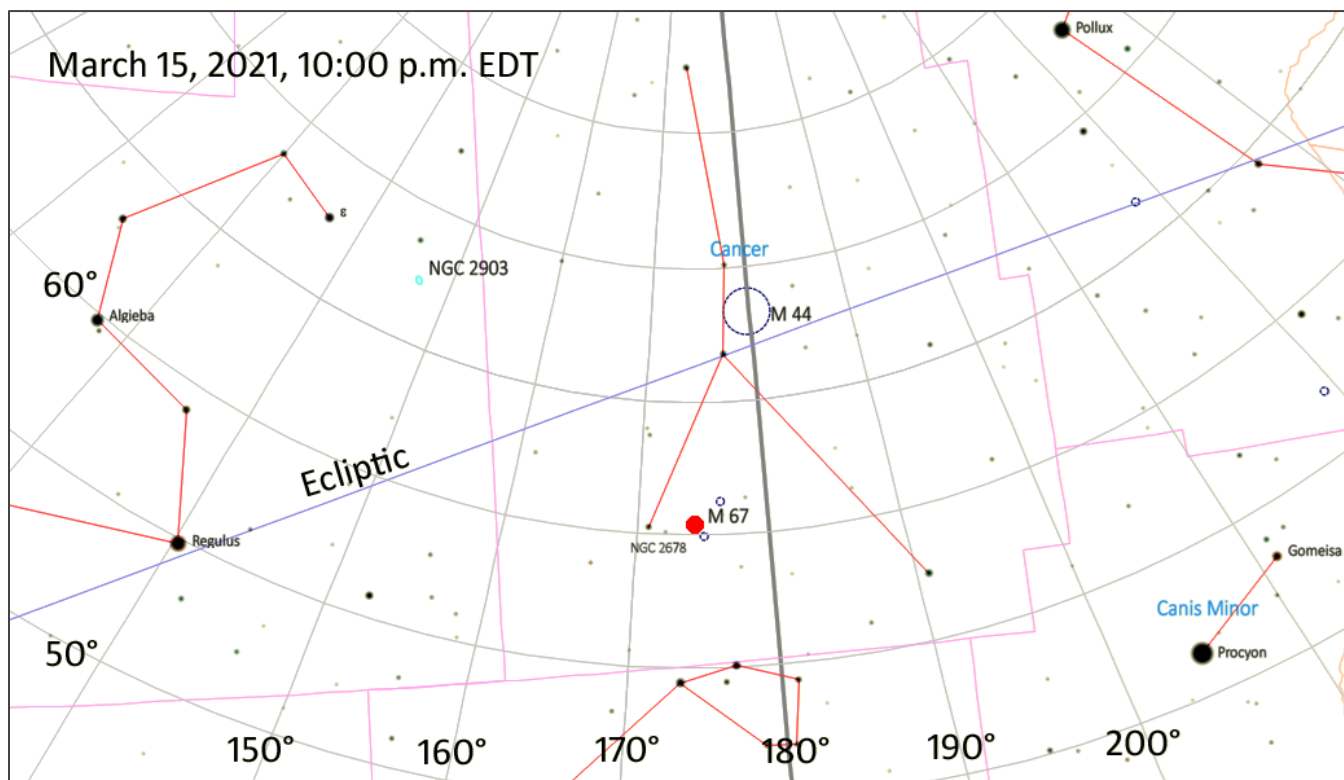
# Planetary Coordinate Systems　　　　　　　Robin Stuart

October's favorable opposition of Mars provided an opportunity to gain familiarity with the surface features of our planetary next-door neighbor. Consulting and comparing *areographic* maps or using online applications, however, can be confusing because the conventions used for longitude in historic and modern times differ. This is important because in order to identify which surface features are visible at a given time the longitude of the central meridian needs to be known. In addition, maps of Mars were traditionally presented south up to match the view of a northern hemisphere observer with an inverting telescope (see the maps in the November SkyWAAtch, page 16). This feature persists in some maps produced quite recently.[1] In this article the various conventions that are in use, and how they came about, are explored.

Latitude and Longitude in Geodesy

Go to the Meadows Parking Lot in Ward Pound Ridge Reservation (the WAA star party observing site) in Google Maps, left click and select "What's here?" The latitude and longitude is given as 41.259531, -73.595790. By a convention established at the International Meridian Conference of 1884 and now enshrined in the International Standards Organization ISO 6709 (ISO 2012), longitudes of locations on the surface of the Earth east of the Greenwich meridian are positive numbers (0° to 180°) and those to the west are negative (0° to −180°). This is a "right-handed" coordinate system, meaning that if you point the thumb of your right hand in the direction of the north pole your fingers will curl in to the east and point in the direction of increasing longitude. This is the standard convention used in mathematics for polar coordinates.

The latitude that you get from Google Maps or your GPS receiver is sometimes called *astronomical latitude*. Your latitude is the declination of your local zenith. Obviously this is very convenient for navigation or surveying, since it allows latitude to be deter-

mined with a sextant or theodolite by measuring the altitude of the Sun or stars as they cross the meridian. Due to its rotation the Earth is flattened compared to a sphere and its overall shape is approximated by a designated standard *reference ellipsoid*. For GPS receivers this is normally WGS84 but many others exist. In the WGS84 datum the reference ellipsoid has a semi-major axis a = 6,378,137.0 meters and semi-minor $b \approx$ 6,356,752.314 meters.[2]
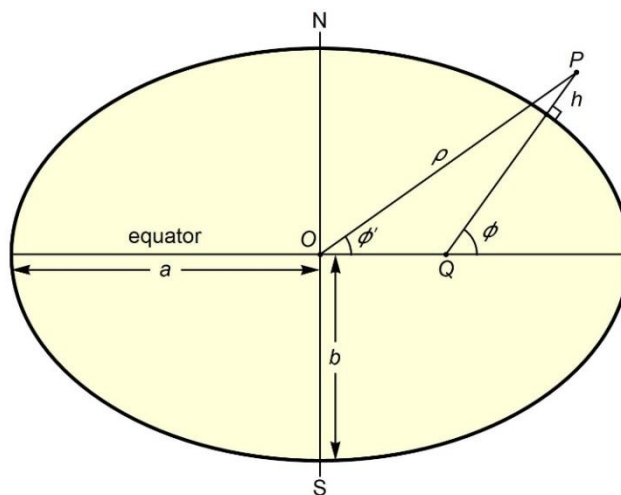
The yellow ellipse represents a section through the 3-dimensional reference ellipsoid for the Earth. The degree of flattening has been highly exaggerated for clarity. The point P might represent a mountain top or high-flying aircraft as it lies high above the average level of the Earth's surface at height h and astronomical latitude, ϕ. The point Q lies in the equatorial plane and the line PQ intersects the surface of the reference ellipsoid at a right angle. The location of P is fully specified by its (astronomical) latitude, longitude and height, h, above the reference ellipsoid.

As seen from the figure the position of point P could also be specified by its distance, ρ, from the center of the Earth, O, and its *geocentric latitude*, ϕ'. This combination might be more convenient if, instead of standing on the Earth's surface, you were orbiting above it, as it avoids the need to specify a reference ellipsoid.

---

[1] See, for example, http://skyandtelescope.org/wp-content/uploads/CC_Mar14_Marsglobes.jpg, and http://www.damianpeach.com/images/mars/mars_2005dp_labeled.jpg).

[2] The quoted value of b is approximate because it is defined indirectly via the *inverse flattening*,

$$1/f = a / (a - b) = 298.257223563 \text{ or } b = a (1 - f).$$

The difference between astronomical and geocentric latitude is generally quite small being exactly zero at the poles and equator. Standing in the Meadow Parking Lot, the center of the Earth is not directly under your feet but rather lies in a direction inclined 11.4 arc minutes from the vertical to the north. The difference becomes more noticeable in mapmaking however. Geocentric latitude 41.259531°N lies around 13 miles to the north of astronomical latitude 41.259531°N.

Latitude and Longitude in Astronomy

In astronomy longitude has traditionally been measured positive to the west, not the east. For example in *The Nautical Almanac and Astronomical Ephemeris for the year 1837* (Nautical Almanac 1835, p. 492) the table of the latitudes and longitudes of principal observatories states

> The Longitudes are reckoned from the Meridian of Greenwich.
>
> North Latitudes and West Longitudes are indicated by the sign **+**:
>
> South Latitudes and East Longitudes by the sign **−**.

For the other planets and their satellites the north pole is taken to be the one lying above the invariable plane of the solar system[3] and accordingly a body's rotation is classified as direct (*e.g.* Mars) or retrograde (*e.g.* Venus and Uranus). As viewed from the Earth[4] the longitude of the central meridian of a body increases with time. Taken along with the definition of the North Pole, this implies that longitude is measured positive to the west for bodies with direct rotation and positive to the east for retrograde.

Since 1971 the International Astronomical Union (IAU) has recognized two types of planetary coordinate systems, planetocentric and planetographic. (IAU 1971).

- Planetocentric coordinates have longitudes measured positive to the east. Planetocentric lati-

tude is defined in the same way geocentric latitude is for the Earth.

- Planetographic coordinates are those traditionally used by astronomers with positive longitudes to the west. Planetographic latitude is defined in the same way as astronomical latitude is for the Earth.

Neither of these two system systems encompass the conventions used in geodesy for the Earth which is a mixture of planetographic latitude and planetocentric longitude.

Astronomy meets Spaceflight

Recognizing the increasingly close connection between astronomy and geodesy arising from areas like satellite mapping and long baseline interferometry, the IAU in 1982 adopted resolution No. C 4, recommending that for the Earth only, longitudes should be measured positive to the east. Copernicus must have been rolling in his grave! The move did not sit well with some others either. In his book *Astronomical Algorithms*, Jean Meeus (1991, p. 89) rails

> We cannot understand why the International Astronomical Union, having first decided to measure all planetographic longitudes in the direction opposite to that of rotation, then alters that system for the Earth (1982). We shall not follow this IAU resolution, and will continue to consider west longitudes as positive.

In 1996 NASA launched the Mars Global Surveyor mission carrying the Mars Orbiter Laser Altimeter (MOLA). The MOLA team chose to present their results in the planetocentric system with positive east longitudes. They were later joined by the MGS TES team, the entire 2001 Mars Odyssey mission, the Mars Exploration Rovers (MER) mission and MER site selection process, as well as a majority of instrument teams on the Mars Reconnaissance Orbiter and the HRSC team of the ESA Mars Express mission.

Up until 2002 all maps of Mars (with the exception of those produced by the MOLA team) used planetographic latitudes with west longitudes positive. In that year planetocentric latitudes with east longitudes positive were also approved for Mars by the IAU (2002). The USGS Topographic Map of Mars available at https://pubs.usgs.gov/imap/i2782/ now plots both planetocentric and planetographic grids on the same map.

---

[3] The invariable plane of the solar system passes through its center of mass and is perpendicular to its total angular momentum vector. The orbits of all the major planets lie close to the invariable plane with the ecliptic inclined at 1.57°.

[4] Strictly speaking the definition is "as observed from a direction fixed with respect to an inertial system".

The *Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2015* (IAU 2018) chides

> For the Mars Global Surveyor mission, an areocentric, east-positive system was used despite years of mapping using the IAU standard system by Mariner 4, 6, 7 and 9 and Viking.

and with reference to Mercury, the report notes

> A planetocentric, east-positive (right-handed) system was adopted for Mercury by the MESSENGER project prior to 2002. The Mariner 10 mission used the standard IAU (planetographic) coordinate system with longitude increasing to the east for Mercury.

Conclusion 5 of the report states

> In discussions at the IAU General Assembly in August 2012 there was an agreement to remind authors, journal editors, instrument teams, missions, and space agencies that a substantial number of IAU recommendations exist that have been developed over many decades of input by IAU members, national space agencies and other institutions. We believe that it is important to carefully follow these recommendations or to present well-reasoned arguments why they should be changed. The IAU and its various components stand ready to help such groups understand and follow IAU recommendations.

A glance at the USGS/IAU Gazetteer of Planetary Nomenclature website https://planetarynames.wr.usgs.gov/TargetCoordinates reveals that there are now a variety of different official coordinate systems in use. A sample appears below.

Target	Coordinate Systems		
Janus	Planetographic	+West	0 - 360
Mars	Planetographic	+West	0 - 360
	Planetocentric	+East	0 - 360
Mercury	Planetographic	+West	0 - 360
Mimas	Planetographic	+West	0 - 360
Miranda	Planetocentric	+East	0 - 360
Moon	Planetographic	+East	180 - 180
Oberon	Planetocentric	+East	0 - 360
Phobos	Planetographic	+West	0 - 360

Conclusion

Given the lack of overall consistency, what's a poor amateur astronomer to do? The lesson is to take nothing for granted and spend the time to determine what convention has been adopted.

The longitude of the central meridian of Mars can be obtained from any number of applications, MICA, WinJUPOS and Sky & Telescope's Mars Profiler[5] to name a few. All of these will return west longitudes as positive.

Further detailed information on the Martian coordinate system can be found in Duxbury et al. (2002) and the IAU/USGS website https://planetarynames.wr.usgs.gov/Page/MARS/system

Author's Commentary

If the reader is left with the impression that the IAU definitions are an unnatural mish-mash of arbitrary rules and exceptions then you are not alone. That is the expected outcome of a classification system that attempts to conform to traditional conventions not underpinned by sound physical principles. In the present case these conventions appear to have been established for the convenience of terrestrial telescopic observers but do not translate well for broader usage. Take the definition of a planet or satellite's North Pole. It is defined as the pole that lies above the invariable plane of the solar system. This assignment in turn determines if the body's rotation is direct or retrograde and whether longitude is measured positive to the east or west. It is believed that poles of Comet 2P/Encke's precess from one side of the invariable plane to the other over a time scale of decades. Under the IAU rules the pole assigned north and that assigned south would constantly flip-flop back and forth.

The first conference I attended as a graduate student was at the International Centre for Theoretical Physics (ICTP) in Trieste, Italy. In his talk there P. M. Stevenson (1984, p. 55) introduced his *Declaration of Independence.* After proclaiming this truth to be self-evident it effectively states that "… things should not depend on things they are not dependent on." This is a far more profound statement than it may initially appear! The rotational poles of a planet or satellite and the derived cartographic grid system needed to map their surfaces bear no direct physical relationship to the invariable plane of the solar system. However the IAU conventions artificially link them togeth-

---

[5] https://skyandtelescope.org/wp-content/plugins/observing-tools/mars_profiler/mars.html#

er[6] in a way that becomes unworkable for dwarf planets, minor planets, their satellites and comets and it was therefore necessary to introduce yet another distinct set of conventions based more firmly on physical principles (IAU 2007).

For these small bodies the north pole is the *positive pole* determined by their rotation via the right hand rule. This is consistent with standard practice in mathematics. The other cardinal directions are then determined with reference to this "north pole" in the familiar way. For example, east is the direction of positive rotation in the right-handed coordinate system. This approach could be applied to treat all solar system bodies under a uniform natural framework but there seems to be little likelihood of that happening.

References

Duxbury, T. et al (2002), Mars Geodesy/Cartography Working Group Recommendations on Mars Cartographic Constants and Coordinate Systems, in *ISPRS, v. 34, part 4, GeoSpatial Theory, Processing and Applications,* Ottawa. https://www.isprs.org/proceedings/XXXIV/part4/pdf papers/521.pdf

IAU (1971). *Proceedings of the Fourteenth General Assembly* (C. de Jagger & A. Jappel, Eds.), D. Reidel, Dordrecht.

IAU (1982). *International Astronomical Union, 27th General Assembly* https://www.iau.org/static/resolutions/IAU1982_Fre nch.pdf

IAU (2002). Report Of The IAU/IAG Working Group on Cartographic Coordinates and Rotational Elements of the Planets, and Satellites: 2000, *Celestial Mechanics and Dynamical Astronomy* **82**, 83-110.

IAU (2007). Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2006, *Celestial Mechanics and Dynamical Astronomy* **98** 155-180,

IAU (2018). Report of the IAU Working Group on Cartographic Coordinates and Rotational Elements: 2015, *Celestial Mechanics and Dynamical Astronomy* 130:22 https://link.springer.com/epdf/10.1007/s10569-017-9805-5

ISO (2008). *ISO 6709:2008 Standard representation of geographic point location by coordinates* https://www.iso.org/standard/39242.html

Meeus, J. (1991). *Astronomical Algorithms*, Willman Bell Inc., Richmond.

Nautical Almanac (1835). *The Nautical Almanac and Astronomical Ephemeris for the Year 1837*. London: The Lords Commissioners of the Admiralty, London. https://books.google. /books/about/The_Nautical_Almanac_and_Astronom ical_Ep.html?id=hPQNAAAAQAAJ

Stevenson, P. M. (1984). *An Introduction to the Renormalization-Scheme Ambiguity of Perturbation Theory*, in Radiative Corrections in SU(2)$_L$ × U(1) (B. W. Lynn & J. F. Wheater, Eds.), World Scientific Publishing Co Pte Ltd, Singapore.

WAA (2020). *SkyWAAtch* October 2020. https://westchesterastronomers.org/wp-content/uploads/2020/09/October-2020.pdf

---

Miscellany
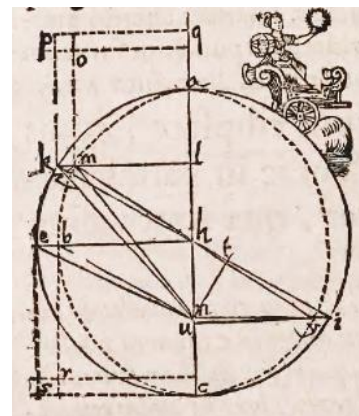
A diagram (one of many) from Johannes Kepler's **Astronomia Nova** (1609), in which he demonstrated that the orbit of Mars was an ellipse.

The original is at:

https://archive.org/details/astronomianovaai00kepl

---

[6] Contrast this to the Keplerian Orbital Elements described in the WAA October newsletter (WAA 2020, p 7). The six orbital elements are cleanly separated into three, *a*, *e* and ν that are associated with the dynamical properties of the orbit and three, Ω, ω and *i*, associated with its geometric properties specifying its orientation in space.

Determining Galactic Distances   Larry Faltz

In my December 2020 SkyWAAtch article "The End is Coming" we explored the expansion history and ultimate fate of the universe, which depends on knowing H_0, the value of the Hubble constant at the current time. Since we can measure a galaxy's velocity from its red shift, if we knew its distance we could obtain H_0 from the simple formula $v = H_0 \times D$. So how do we find the distance? This article will explore a number of techniques that astronomers use to estimate the distance to distant galaxies.

We obviously can't use a ruler or even bounce a laser beam off of a galaxy. We have to find simple ways of measuring distances and then use those methods as calibrators of more exotic methods that reach out further into the cosmos. The main concept, but it's not the only one, is the "standard candle."

Let's assume you have a 60-watt light bulb. If you place it 10 feet from your position and measure its light output with some device that counts photons, such as a camera light meter, you can determine its brightness. If you move the bulb 20 feet away, you will count one-quarter of the number of photons, because light intensity falls off as $1/r^2$. Alternatively, if you knew a bulb was 240 watts but shone as brightly as the 60-watt bulb did at 10 feet, you would know it was 20 feet away. So for a "standard candle," brightness is a direct measure of distance, even if that distance was far beyond our longest tape measure.

But first we have to measure 10 feet, right? How do we do that in astronomy, when the nearest star is over 20 trillion miles away? The answer is parallax. You are familiar with parallax and I won't go into it in detail, except to say that we use the orbit of the Earth as the baseline and compare the positions of stars whose locations seem to vary at either extreme of the orbit with positions of more distant stars that stay put. Although stellar parallax was conceived in the early 18th century, it wasn't conclusively demonstrated until telescopic technology allowed Friedrich Bessel to measure the shift in the position of the star 61 Cygni in 1838. The nearest star, Proxima Centauri, has a parallax of 0.772-arc-seconds. By the late 1800s, the distance of about 60 stars was known by this method. Earth-based parallax measurements can now be made out to about 100 parsecs (326 light-years). The Hipparcos mission reported parallax measurements for about 118,000 stars in 1997. The third Gaia satellite data release in December 2020 reported parallax for 1.468 billion stars out to a distance of 10,000 parsecs (32,600 light-years). But that just allows us to measure distance. How can we know if there are stars that serve the function of our 60-watt light bulb? In other words, are there stars whose absolute luminosity can be established?

Cepheid variables

Cepheid variables were discovered by Edward Pigott, who noted in September 1784 that Eta Aquilae was variable. A month later, his friend John Goodricke found Delta Cephei also to be a regularly pulsing variable, and this star became the eponym for stars of this class.[1] Cepheids are large, luminous stars that vary regularly over a period of days to months due to the physics of heat transfer through a layer of ionized helium, which swells and contracts. That there is a direct relationship between the rate of pulsation and the absolute luminosity of the star was famously determined in 1912 by Henrietta Swan Levitt from her meticulous studies of Cepheids in the Large Magellanic Cloud. Since the stars were all in the LMC and therefore pretty much equidistant from us, any variance in brightness was solely due to differences in inherent luminosity.
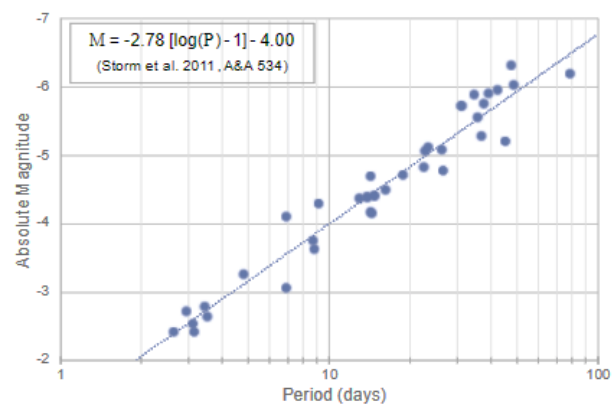
The Cepheid period-luminosity relationship

---

[1] It's not clear why these stars are called Cepheids if the first example was in Aquila. Pigott reported his finding to the Royal Society on December 23, 1784, while Goodricke's paper was read on November 24, 1785. Pigott identified his star as Eta Antinoi, in the now-obsolete constellation Antinous. Perhaps the name Cepheid was preferred by later astronomers to eulogize the deaf-mute Goodricke, who died just five months later at the age of 21.

The absolute distance to the LMC wasn't known, and in any case it's too far away (158,000 light-years or so) to be measured by parallax, so although Leavitt could establish the relationship between pulsation rate and luminosity, conversion of luminosity to an exact distance wasn't possible. In 1913 Einar Hirschsprung used parallax to establish the actual distance to 13 Cepheids in our galactic neighborhood. This meant that the relationship between relative and absolute luminosity could be calculated and then used to determine the distance to Cepheids further away from the solar system. Five years later, Harlow Shapley used Cepheids in globular clusters to compute the size and shape of the Milky Way and the Sun's place in it. Edwin Hubble found Cepheid variables in nearby galaxies, particularly the famous VAR! star on a photographic plate of M31 dated October 6, 1923. That allowed him to prove that M31 was not a nebula in our Milky Way, but was so far away it had to be a galaxy in its own right.
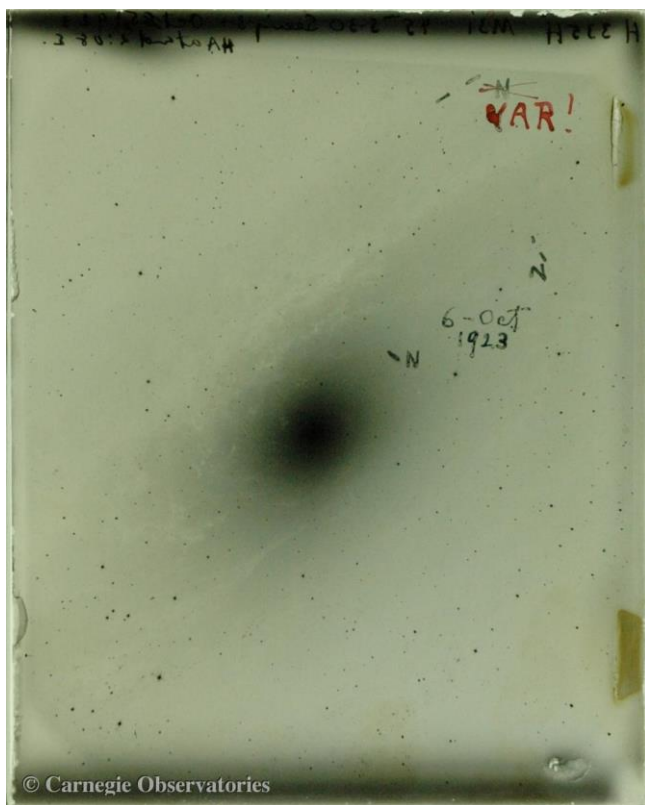
Edwin Hubble's famous VAR! plate, perhaps the most important astrophoto in history

Hubble later correlated red shift with distance to prove that the universe was expanding, showing that the more distant a galaxy was the faster it was receding from us. Hubble was able to find Cepheids in sev-

en galaxies using the 100-inch Hooker telescope at Mount Wilson. But he needed a different "standard candle" for more distant galaxies. He guesstimated that all spiral galaxies were similar, so their angular size and brightness would be proportional to their absolute distance. The guess was reasonably good but primitive and subject to all sorts of inherent variances. Nevertheless, galaxies placed this way fell along the same distance line as those measured by Cepheids.

Our modern fleet of large telescopes plus the Hubble Space Telescope has allowed us to discover Cepheids in more distant galaxies. In 2001, the Hubble Space Telescope Key Project,[2] led by Wendy Freedman of the University of Chicago, measured the Hubble constant primarily from Cepheids in 18 galaxies observed with HST plus data from 13 galaxies observed by other observatories, finding a value of 72 km s^{-1} Mpc^{-1}, with an uncertainty of 11%. Cepheids have now been detected in 87 relatively nearby galaxies.

But Cepheids get us just so far. We need some other "standard candle" that we can then link to the established distance scale, then find those candles in more distant galaxies. It turns out that there are more than 70 strategies for determining galactic distances. These are listed and explained on the NASA/IPAC Extragalactic Database (NED) web site,[3] a wonderful source of information for professional and amateur astronomers alike, although clearly organized for the former.

Supernovas

This method is based on the physics of Type Ia supernovas, which happen when a typical white dwarf accretes material from a companion star and reaches the Chandrasekhar mass limit, 2.765×10^{30} kg or about 1.4 solar masses. White dwarfs are stars that have used up their hydrogen and helium in their cores, which are now made primarily of carbon and oxygen, under such high pressure that the cores are "electron-degenerate matter," a compact plasma of nuclei and electrons rather than discrete atoms in which the electrons "belong" to a specific nucleus, so to speak. Electrons, as fermions, are subject to the Pauli

---

[2] https://iopscience.iop.org/article/10.1086/320638/pdf

[3] The home page is http://ned.ipac.caltech.edu/ and the explanations and catalog of distance measurements is at http://ned.ipac.caltech.edu/Library/Distances/

Exclusion Principle, so no two can occupy the same state (location, spin [+½ or -½] and energy). So as the core contracts under gravity, some of the electrons are forced into higher energies. This energy plays the role that heat from nuclear fusion does in normal stars to balance gravity. If the star has less mass than the Chandrasekhar limit, it's happy to sit there, gravity and electron degeneracy pressure in balance. But if it acquires more mass, the electrons' energy levels rise, providing enough energy to provoke unconstrained fusion of the carbon and oxygen nuclei. A massive explosion rips through the star with a power of 10^{44} Joules in a few seconds (about 18 orders of magnitude more than the output of the Sun in that time), releasing a vast tide of energetic neutrinos as well as photons and heavier nuclei. The spectra of Type Ia supernovas are distinct, primarily because they lack hydrogen and helium lines. Since the mass is known within narrow limits and total luminosity can be determined, they can be used as standard candles. Because they are so energetic even at visible wavelengths, they can be detected out to a distance of about 7 billion light years (z=1), about half the age of the universe. More than 99% of the energy of a supernova is released in the form of neutrinos, which don't contribute to their optical brightness.

Supernovas have been used to calculate the distances of 3,188 galaxies, as of the last update of the NED site in May 2020. Current and coming whole-sky surveys (like the LSST/Vera Rubin Telescope) will catch many more supernovas in ever-more-distant galaxies. The critical finding in 1998 by both groups collecting supernova data was that the most distant supernovas were fainter than expected, indicating that the universe was expanding at a slower rate in the past and has been speeding up recently. In other words, the most distant supernovas are farther away than they should be if the expansion had been constant or decreasing.

What about the majority of galaxies that don't happen to have a conveniently timed and placed supernova that catches the attention of astronomers? Over the last 40 years or so, other methods have also been developed to give credible results for determining galactic distances.

It would be nice astronomers could simply relate the luminosity of an entire galaxy to another standard-

ized property that scales with distance and thus immediately come to an answer. But with the many types, sizes and ages of galaxies, a simple light measurement won't work. Are there subsets of galaxies that can be shown to have a common luminosity? What measurable properties of a galaxy can be correlated with luminosity? What measureable properties are there?

The integrated spectrum of a galaxy can be determined with spectroscope. The rotational dynamics of a spiral galaxy are evidenced by Doppler shifts of its approaching and receding arms, so long as it isn't being seen face on, and this velocity can be directly related to its mass. The velocity distribution of its stars can be measured by the line-broadening of specific spectral lines. The strategies used for elliptical galaxies and spiral galaxies are related but distinct, because elliptical galaxies don't rotate much, if at all, although their stars are still buzzing around.

Faber-Jackson

In 1976, Sandra Faber and Robert Jackson, working at Lick and UC Santa Cruz, measured the velocity dispersions in 25 elliptical galaxies.[4] The stars in elliptical galaxies undergo random motion with a range of velocities that can be captured in a single quantity, Δv. Using a somewhat subjective approach to the broadening of specific elemental lines in the galaxies' spectra, each astronomer examined the spectra, made measurements and then they compared their results, which turned out to be within 5% for each galaxy studied.
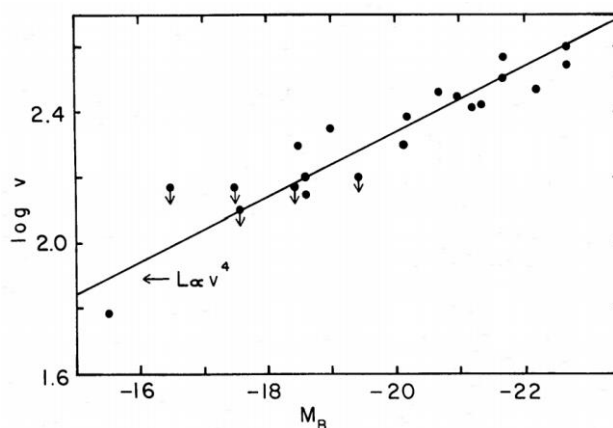

Fig 16 from Faber and Jackson, showing the linear relationship between absolute magnitude (abscissa) and velocity dispersion (ordinate).

[4] http://articles.adsabs.harvard.edu/pdf/1976ApJ...204..668F

They found that there was a linear relationship between a galaxy's luminosity and its velocity dispersion, with an accuracy of 10-15%. They also determined that the luminosity was a function of the fourth power of the velocity, that is, $L \propto (\Delta v)^4$, fairly consistent across galaxy sizes unless the elliptical galaxies were very small. With luminosity in hand, the distance to a galaxy can be determined, and this has been done for 443 galaxies as of last count.

The Faber-Jackson relation has been superseded by a slightly more sophisticated measurement for ellipticals called the "fundamental plane." It's not a physical, geometric plane, but a representation in a three-dimensional parameter space that plots effective radius, average surface brightness and central velocity dispersion. If you know two of them, you can extrapolate the third. An important element in this calculation is to standardize the part of the elliptical galaxy that is being measured, the effective radius, by agreeing on an "isophote," an area of equal apparent surface brightness for the galaxy. That's a relatively easy task for software.
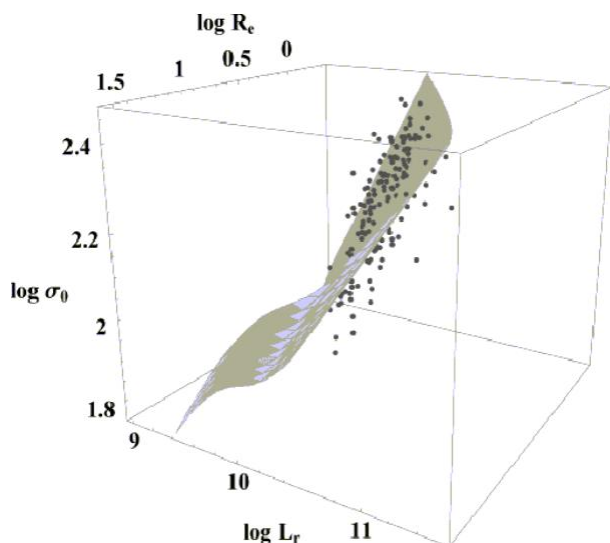
The values for effective radius (R_e), brightness (L_r) and velocity dispersion (σ) populate a planar area in a 3-dimension plot (University of St. Andrews, Scotland)

The fundamental plane data can be further corrected for color, metallicity, and other parameters. This seems to be a very popular way of measuring galactic distances, since NED reports some 130,316 measurements in 129,059 galaxies (meaning most have been examined only once).

Tully-Fisher

For spiral galaxies, the Tully-Fisher relationship is used. It also depends on line broadening, but instead of a visible or infrared spectral line, it uses the hyperfine transition of neutral hydrogen (HI), which is a radio wave at an exact frequency of 1,420,405,751.7667 ± 0.0009 Hz (wavelength 21.106 cm). In 1977, Brent Tully and Richard Fisher published an analysis of the Doppler-broadened 21-cm line profile width, correlated with absolute magnitudes or diameters.[5]
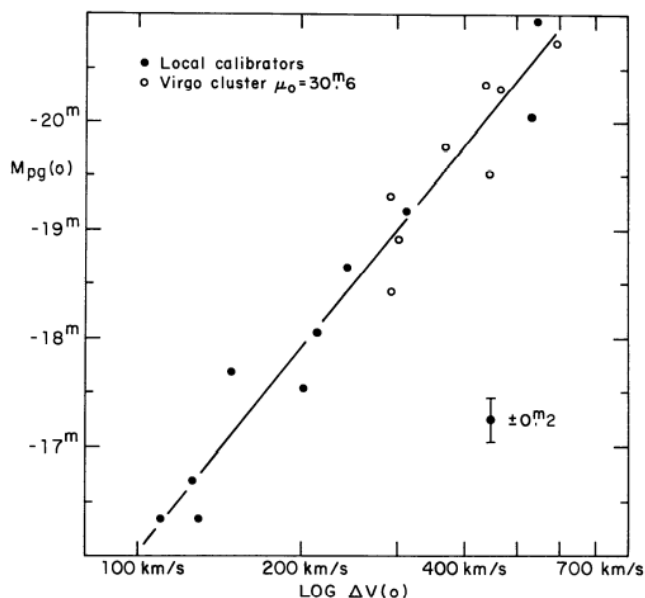

Fig 5 from Tully & Fisher, showing the relationship between velocity dispersion (abscissa) and absolute magnitude (ordinate)

Higher mass (intrinsically brighter) spiral galaxies rotate faster than lower mass spirals,[6] so the 21-cm line would be broadened more in a high-mass galaxy due to the greater range of velocities in the line of sight, which is what Tully and Fisher found. Corrections need to be made for the inclination of the galaxy, but that's a fairly straightforward matter of trigonometry. Elliptical galaxies are deficient in neutral hydrogen, so this technique is used only for spirals.

Tully and Fisher used data from prior studies and new measurements made with 91-meter and 43-meter radio telescopes at the National Radio Astronomy Observatory in Green Bank, WV. For calibration, they

---

[5] http://articles.adsabs.harvard.edu/pdf/1977A%26A....54..661T

[6] Mass can be determined by the spiral galaxy's rotation curve, the rotational velocity at varying distances from the core.

used ten galaxies in the Local, M81 and M101 groups whose distances had been well-established using Cepheid variables. They showed that absolute magnitude is proportional to the fourth power of the maximum velocity in the galaxy. This method also gives a result estimated to be accurate to 15%. They then estimated the distance to the Virgo and Ursa Major galaxy clusters, and even derived a value for the Hubble constant of 80 km s^{-1} Mpc^{-1}. NED currently lists 12,292 galaxies whose distances have been measured with this technique.
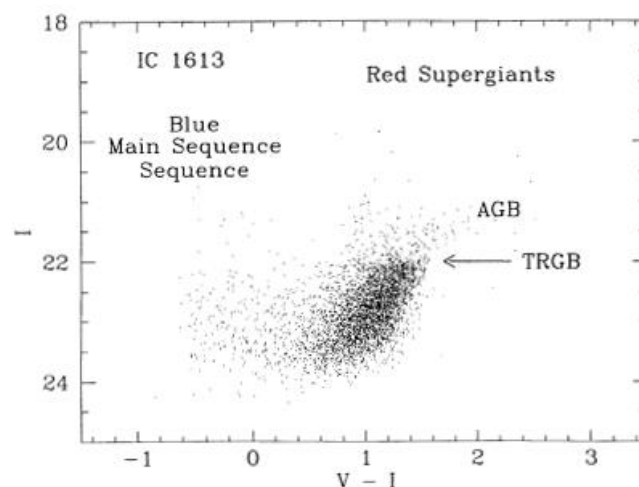
Tip of the Red Giant Branch

A clever method that's generated a lot of interest recently is the "Tip of the Red Giant Branch." TRGB is based on the ability of the new generation of large telescopes to see very luminous red giant stars in the cores of galaxies. These stars were first discovered by Walter Baade at Mt. Wilson (Baade's peculiar story was related in the December 2020 article). To understand this method, we need to briefly review the Hirschsprung-Russell diagram, which describes the evolution of stars.
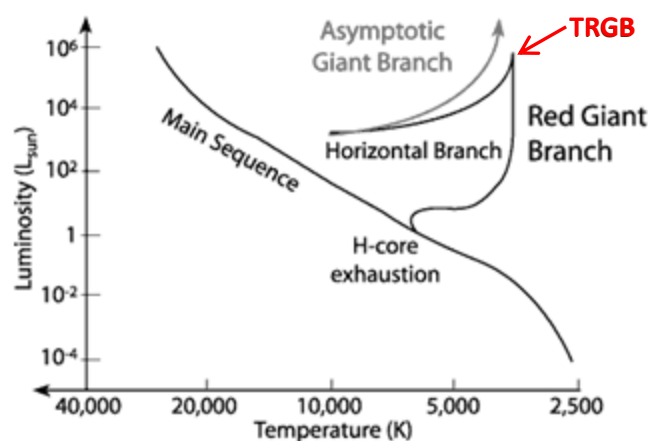
The basic Hirschsprung-Russell diagram

The H-R diagram plots the temperature of a star (and thus its color) against its luminosity. Stars start out somewhere on the "main sequence" (the exact point depending on their mass at the time of formation), becoming hotter and more luminous over time as they burn hydrogen in their cores (that time being much shorter for more massive stars). Stars will eventually use up the hydrogen fuel in their cores but they continue to undergo fusion in a hydrogen shell around the core, which is now composed of helium held up by electron degeneracy pressure. It's hot in

there, but not yet hot enough for helium fusion. The star cools off a bit but expands, and with a larger surface area it is actually more luminous than before. It becomes a red giant, moving upwards and to the right on the H-R diagram. Eventually, the core gets hot enough (10^8 K) for helium to begin to undergo fusion by the "triple alpha" process, in which two alpha particles (^{4}He) form an unstable beryllium-8 nucleus, which then absorbs another alpha particle to form a stable carbon-12 nucleus. Two gamma rays are released. For stars the size of the Sun or just a little larger, this process produces a sudden "helium flash" and the star rapidly moves to the left along the "horizontal branch," getting hotter but not more luminous. As a result, there is a sharp maximum luminosity boundary at the upper end of the red giant branch. Using large telescopes, individual red giant stars can be visualized and their brightness correlated with their color.

The Tip of the Red Giant Branch in IC 1613, a magnitude 9.2 dwarf irregular galaxy in Cetus.[7] AGB=asymptotic giant branch.

This method was first published by Da Costa and Armandroff in 1990.[8] They were looking at the metallicity of globular clusters in the southern hemisphere using a 0.9-meter telescope at the Cerro Tololo Inter-American Observatory.[9] The red giant stars examined by this method are older, Population II stars. Globular clusters are rich in these stars and thus are often a

---

[7] Sakai, S, The Tip of the Red Giant Branch as a Population II Distance Indicator
http://articles.adsabs.harvard.edu/pdf/1999IAUS..183...48S

[8] http://articles.adsabs.harvard.edu/pdf/1990AJ....100..162D

[9] For more on CTIO see the July 2017 SkyWAAtch.

surrogate target for galaxy distance. Since they surround their host galaxies, the distance to the cluster is very close to that of the galaxy itself, a variance of tens of kiloparsecs at a distance of tens of megaparsecs. So if you measure the distance to the cluster, you've nailed the galaxy too. Elliptical galaxies are also particularly rich in red supergiants, and the cores of spiral galaxies also have many of these stars.

Plotting color versus luminosity shows a clear cutoff in most cases, and statistical techniques can be used when the data is a little less obvious.

The star's luminosity at the time of the helium flash is insensitive to the metallicity (and therefore the age) of the star, varying by less than 0.1 magnitude. So the luminosity at the cutoff point becomes a "standard candle" and allows the distance to the galaxy to be estimated.

A meticulous and detailed paper recently published[10] by Wendy Freeman's group used TRGB stars in galaxies that had already had their distances determined with Type Ia supernovas. They also calibrated their data with Cepheid variables in some of the galaxies. They showed a linear relationship between the TRGB luminosity measurements and distance. From the TRGB data they determined the Hubble constant to be 69.8 km s^{-1} Mpc^{-1}, with about a 2.5% uncertainty. This is a value of H_0 midway between the "early" and "late" universe methods, so TRGB has been an important topic of discussion at recent cosmology conferences concerning the "Hubble tension."

Gravitational lensing

In what was probably the first practical application to be derived from Einstein's prediction that the curvature of spacetime near massive objects bends light (proven by Eddington in 1919), Fritz Zwicky postulated that galaxies could act as gravitational lenses, refocusing the light from more distant objects. The first example was found in 1979, the Twin Quasar in Ursa Major, QSO 0957+561 A/B (see the May 2020 Sky-WAAtch for more information about this object). Since then, large numbers of gravitationally distorted galaxies and quasars have been imaged.

The Norwegian astrophysicist Sjur Refsdal proposed using lensing to determine distance in 1964. Basically,

not only are the images duplicated, displaced and distorted, but if there are transient brightness variation in the background object, the time at which we see those variations in the duplicated images will vary depending on the length of the path. Quasars have distinct variability, sometimes tens (not tenths) of percents, due to energetic events in the accretion disks surrounding the supermassive black holes at their centers.
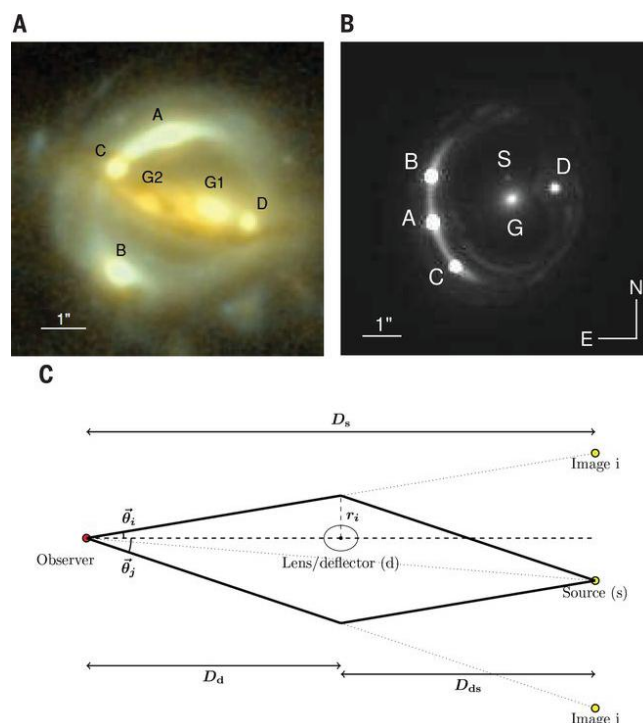

Fig. 1 from Jee *et. al*. showing images of lensing galaxies (panel A) B1608+656 (*z*=0.295), (panel B) RXJ1131–1231 (*z*=0.6304) and the lensing configuration (panel C). Labels A to D are the quasar images, G1 and G2 are lens galaxies, and S is a satellite galaxy.

One also needs to know the mass (gravitational potential) of the foreground galaxy, which can be calculated from the orbital speed of stars in the lensing galaxy through the relationship known as the virial theorem. This states that the total gravitational potential energy of a stable galaxy is related to the sum of the kinetic energies of all the individual components that make up the galaxy. The speed of the stars, which accounts for almost all of the kinetic energy, is measured by spectral line broadening, as in the Faber-Jackson method. The stars will move faster when there's more total mass. Dark matter is of course included in the calculations. Combining the delay times with the mass yields the distance.

---

[10] https://iopscience.iop.org/article/10.3847/1538-4357/ab2f73/pdf

Jee *et. al*. used time delays in multiple images of grav-itationally lensed quasars behind two foreground gal-axies[11] at redshifts *z*=0.295 and 0.6304 to establish their distances. They found the distances to the lensing galaxies to be 810 and 1230 megaparsecs re-spectively, with uncertainties of around 15%, which they felt was due to the imprecision in their esti-mates of the three-dimensional extent of the galax-ies. Then they used these absolute distances to cali-brate 740 previously measured relative distances to Type Ia supernovas from other surveys, fit a curve and determine the Hubble constant. They found H_0=82.4 (+8.4−8.3), which is on the high side, but more consistent with other near-universe measures rather than the early universe measurements from the cosmic microwave background data.

AGN Time Lag

Another technique utilizing variability in active galac-tic nuclei was published by a Japanese-Australian group in 2014.[12] Short wavelength radiation from the central engine of the AGN sublimates the dust closest to the center, creating a torus surrounding a dust-free region. The dust is heated by ultraviolet and op-tical radiation from the central engine and re-emits radiation in the near-infrared. The radiation flux var-ies due to events in the accretion disk of the black hole at the center of the galaxy. Variations in the flux emitted by the central engine are mimicked at long wavelengths by the dust torus after a time delay cor-responding to the light travel time between the cen-tral engine and the inner radius of the dust torus, the relationship being simply $\Delta t = r_d/c$. The inner radius is proportional to the absolute luminosity of the AGN, and so it can serve as a standard candle. The more luminous the AGN, the further out it pushes the inner edge of the dust disk.

Seventeen AGNs in the redshift range z = 0.0024 to z = 0.0353 were observed with the 2-meter MAG-NUM telescope on Haleakala. Measurements were made over a period of years in the optical V (0.55 μm) band and the NIR K (2.2 μm) band. As a check on the

distance calculations, Cepheid data from the Hubble Space Telescope Key Project (see reference 2) was correlated and fell along the same regression line as the AGN data. The value of H_0 returned by this tech-nique is 73 ± 3 km s^{-1} Mpc^{-1}.
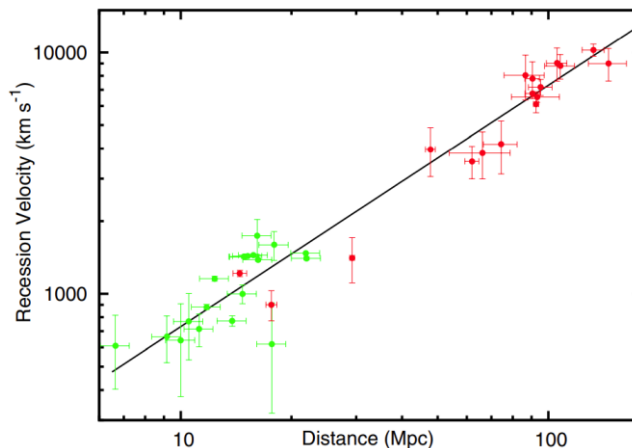

Fig. 2 from Yoshi, *et. al*. The data in green is from Cepheid varia-bles; the data in red is from AGN time lag.

Water Masers

A maser (the word is an acronym for microwave am-plification by stimulated emission of radiation) is the longer-wavelength version of laser, and was the first type of this phenomenon to be discovered. Concen-trations of water or certain other molecules in astro-nomical environments can be excited by radiation and emit monochromatically. There are many such environments, including planetary atmospheres, comets, stellar atmospheres, star-forming regions in galaxies and supernova remnants. For cosmological purposes, maser signals from water molecules in the accretion disk orbiting the supermassive black hole at the core of a distant quasar can be detected in the microwave or radio bands. In addition to the overall redshift due to the recession of the galaxy in the "Hubble flow," maser emissions from water on the side of the accretion disk rotating towards us are slightly blueshifted and on the side moving away from us are slightly redshifted. From this shifting the apparent size of the accretion disk can be estimated, and combined with the orbital speed of the disk its actual size can be determined. Taking into account the proper motion of the galaxy permits its distance to be calculated. For example, the absolute motion of masers orbiting within the type 2 Seyfert galaxy NGC 4258 (Messier 106) is 1,075 km/s, or 0.001100 parsecs/yr. Their apparent proper motion is

---

[11] Jee, I, *et. al*., A measurement of the Hubble constant from an-gular diameter distances to two gravitational lenses, Science 2019; 365: 1134-1138

[12] Yoshi, Y, *et. al*., a new method for measuring extragalactic dis-tances, *Astrophys J Letters*, 2014; 784:L11, available at https://iopscience.iop.org/article/10.1088/2041-8205/784/1/L11/pdf

31.5 x 10^{-6} arc-sec/yr. These values give a distance of 7.2 Mpc with a statistical uncertainty of just 0.2 Mpc (3.0%).
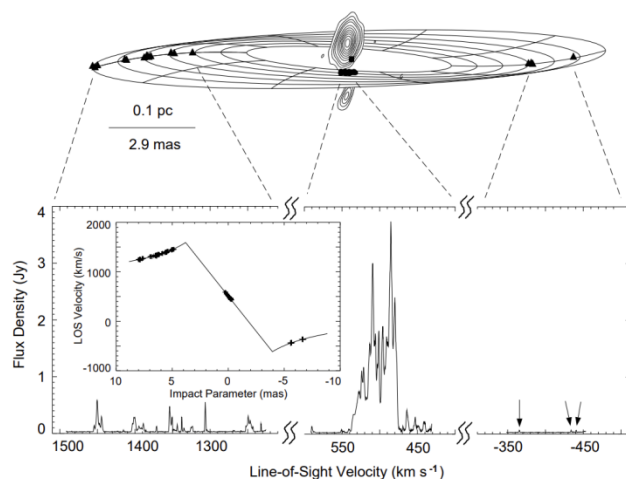

Fig. 1 from Herrnstein, *et. al.*[13] NGC 4258 (M106). The upper panel shows the best-fitting warped-disk model of the accretion disk superposed on actual maser positions as measured by the Very Large Baseline Array.

The Sunyaev-Zel'dovich Effect

Inverse Compton scattering is a process in which a high-energy electron interacts with a low energy photon, transferring energy to the photon and thus increasing its frequency (shortening its wavelength) while losing a little of its own energy.
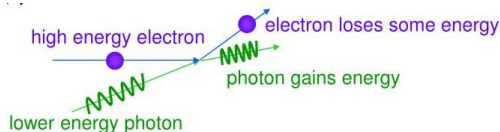
The region between galaxies in galaxy clusters contains a hot, diffuse plasma with a temperature as high as 100 million Kelvin. In other words, the protons and electrons are traveling at high velocity, which gives each particle a lot of energy.[14] Cosmic microwave background (CMB) photons passing through this hot intracluster gas have a 1% chance of inverse Compton scattering off the energetic electrons, causing small (1 milliKelvin) distortions of the background CMB spectrum, which can be detected at radio wave-

---

[13] Herrnstein, JR, *et. al.*, A 4% Geometric Distance to the Galaxy NGC4258 from Orbital Motions in a Nuclear Gas Disk, https://arxiv.org/pdf/astro-ph/9907013.pdf. Published in *Nature* 1999, Nature. 400: 539
[14] Recall that kinetic energy=½mv^2. The mass may be small, but the velocity of an electron at a temperature of 10^8 K is very high.

lengths. This is the Sunyaev-Zel'dovich effect, first predicted in 1969. In addition, the charged particles in hot intracluster gas gives off X-rays due to *bremsstrahlung* radiation as the particles take curved paths in a cluster's magnetic field.

Combining data from the Chandra X-ray telescope and ground-based radio telescopes, and using some complex modeling, the CMB distortions were used to calculate distances to 38 galaxy clusters.[15] The data were also used to calculate the Hubble constant, for which the authors gave several values depending on the exact model chosen, but all clustering between 73.7 and 77.6 km sec^{-1} Mpc^{-1}.
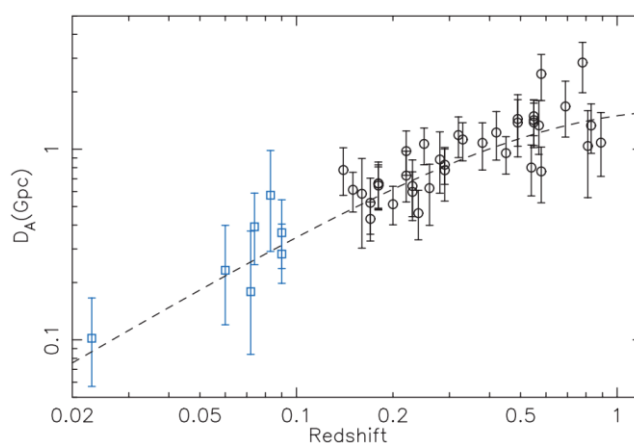

Fig 3 from Bonamente, et. al. Angular diameter distances of the 38 clusters (circles). The dashed line is the angular diameter using the best-fit Hubble constant H_0 of 76:9 km s^{-1} Mpc^{-1} and Ω_m=0.3, Ω_Λ=0.7 (currently accepted proportions of matter and dark energy in the universe). The squares are from a low-redshift sample from another paper and are not included in the fit.

There are dozens of other clever methods that astronomers have used to establish standard candles or standard distances and undoubtedly new ones will be forthcoming. The exact value of H_0 is central to our understanding of the origin and evolution of the universe. Variances in its value when measured by different but reasonably well-established techniques, with values from 67 to 80 km sec^{-1} Mpc^{-1}, are a source of profound discomfort to the cosmology community, but perplexity is one of the things that drives scientific creativity onward. ■

---

[15] Bonamente, M, *et. al.*, Determination of the cosmic distance scale from Sunyaev-Zel'dovich effect and Chandra x-ray measurements of high-redshift galaxy clusters, *Astrophys J* 2006; 647:25-54, available at https://iopscience.iop.org/article/10.1086/505291/pdf

Images by Members

The Pleaides by Olivier Prache

Olivier's lovely image of Messier 45 was taken with Borg 101ED and a ZWO 071MC, utilizing about 2½ hours of integration time. Olivier had to do a good bit of processing to eliminate light pollution gradients since he images from his home observatory in Pleasantville. See last month's SkyWAAtch for another imaging take on the Pleiades by Leandro Bento and Larry Faltz's article on this wonderful cluster.
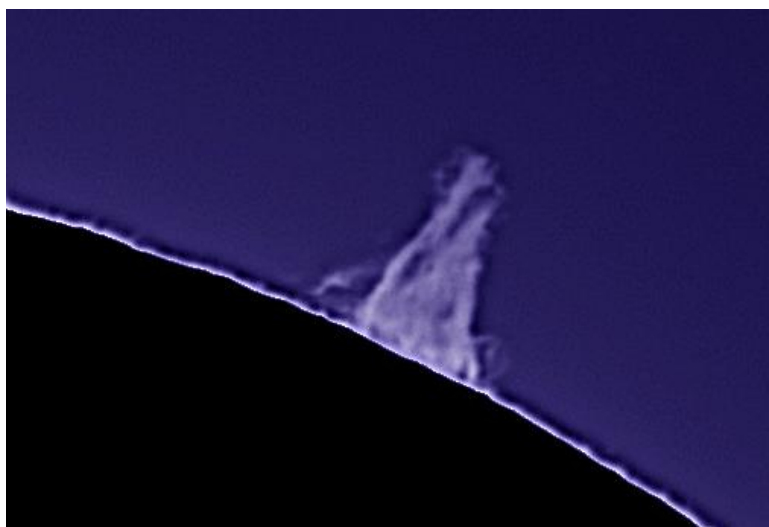
John Paladini took this hydrogen-alpha image of a solar prominence on February 8. He used a vintage Edmund Scientific 3-inch f/15 refractor fitted with a DayStar Combo Quark Hα filter.

The Flame and Horsehead Nebulas by Leandro Bento

The Flame Nebula, NGC 2024 is energized by the hot O9 star Alnitak (Zeta Orionis), the leftmost star of Orion's Belt. Alnitak is the intrinsically brightest class O star in the night sky. Its ultraviolet light ionizes a mass of hydrogen that sits behind fingers of dust, giving it the appearance of a flame or even a tree. This is an area of active star formation. To the south, the famous Horsehead Nebula, Barnard 33, absorbs the photons of the HII region IC 434, which is energized not by Alnitak but by Sigma Orionis, also class O9, the brightest star to the right of theHorsehead. The middle star of Orion's belt, Alnilam (Epsilon Orionis, B0) is at the upper right corner.

These are difficult visual objects in smaller (<12") telescopes but not a problem for small-scope imagers. Leandro imaged with his William Optics RedCat 51 mm f/4.9 scope and ZWOASI533mc Pro camera fitted with an Optolong L-eNhance filter. Leandro stacked 38 subs of 180 seconds each as well as flats and darks.

The Orion Nebula by Arthur Rotfeld
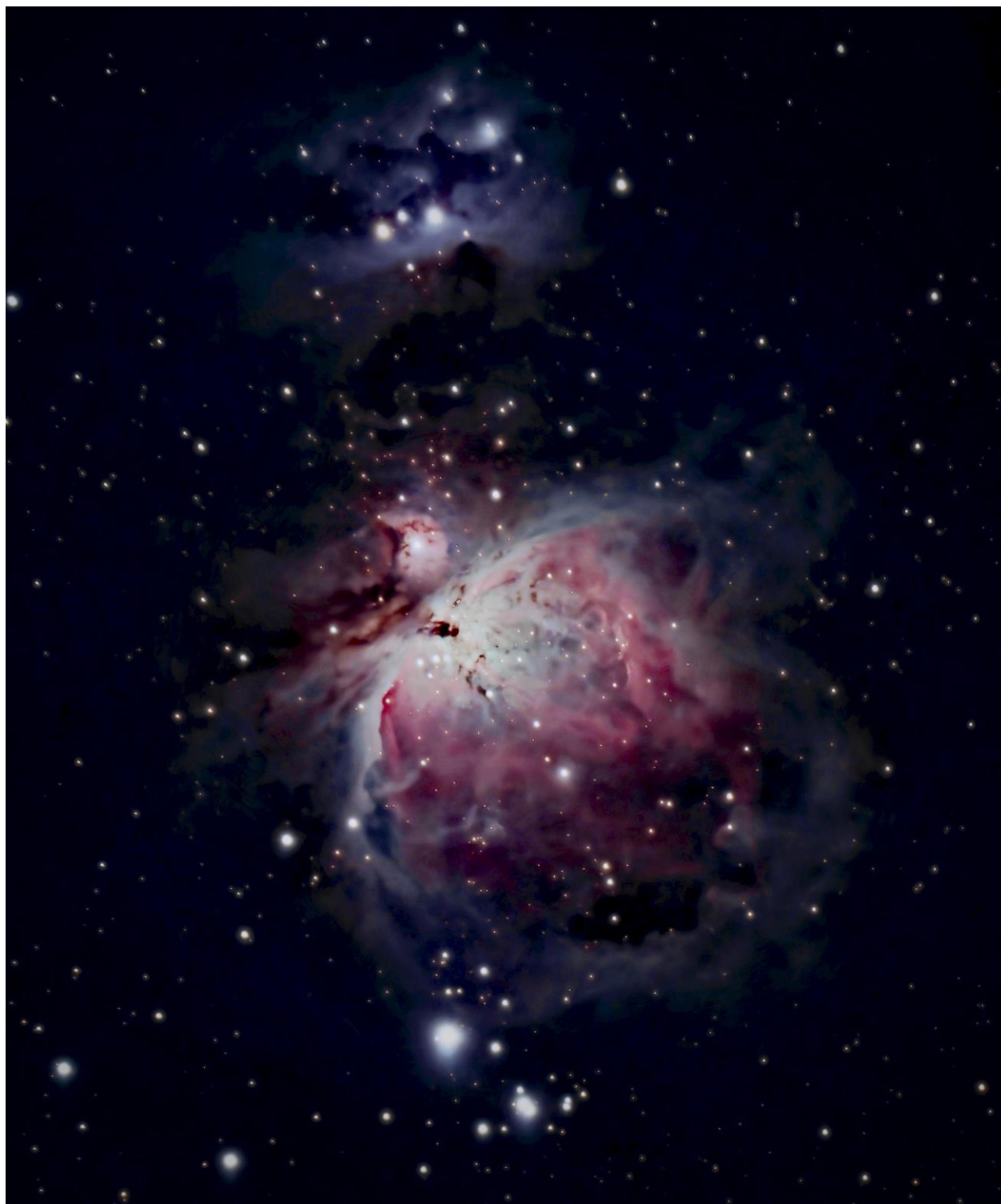
Arthur writes: "Here's M42 from early January. I arrived at Ward Pound Ridge Reservation late one evening and only got about two hours on this target with my 80-mm apochromatic telescope and Canon DSLR. It's an HDR imagine composed of 55 120-second exposures and a few 10-second and 1-second exposures at ISO 800 for the core and Trapezium, which often get completely overexposed and 'blown out.' Processed in Pixinsight and Topaz Denoise." For more on the Orion Nebula, see the February 2016 SkyWAAtch, page 5.

Planetary Nebula M76 by Steve Bellavia

Messier 76, a planetary nebula in Perseus, is known as the "Little Dumbbell," reflecting its shape. Smaller and fainter than the (Big) Dumbbell (M27) in Vulpecula, M76 gets two NGC numbers, one for each of its halves. It is 2,500 light-years distant from us, about twice as far as M27, which is 1,300 light-years away. Its visual diameter is 67 arc-seconds, less than 20% of the 8 x 6 arc-minutes extent of M27, but its actual physical diameter is just under half that of its larger cousin (0.617 vs. 1.44 light-years). It's fairly faint, about magnitude 10.1, which makes it difficult to see in local skies unless the transparency is excellent, but the view can be improved with a deep sky filter that isolates the hydrogen-alpha and forbidden oxygen lines, and of course more aperture always helps. The central white dwarf star is magnitude 15.9.

Stephen James O'Meara, in his excellent *The Messier Objects* (a volume in the Deep-Sky Companions series published by *Sky & Telescope* and Cambridge University Press) notes that this object has "a wealth of subtle detail, which lures small-telescope users into a web of visual suggestions. I'd place it among the most surprising and mysterious objects in the Messier catalog for viewing with a backyard telescope."

Steve captured this image on December 10, 2020. Telescope: TS-Optics 115-mm f/7 triplet refractor, TS-Optics 1.0X field flattener, Sky-Watcher EQ6-R Pro mount, ZWO ASI 533MC camera cooled to -5C, ZWO duo-band filter. 49 x 4 minutes. Guided with "Bellavia Basic" guidescope, a 50 mm f/7.5, lens and ZWO ASI 290MC camera. Imaged at Mattituck, NY.

Crab Nebula (Messier 1) by Rick Bria

Rick writes:

In the year 1054, a star exploded in the constellation Taurus. It became so bright it could be seen in daylight for twenty three days. It then dimmed but was still visible at night for almost two years. Imagine a star bright enough to cast shadows at night! It must have been spectacular, but it was also somewhat frightening to the people of that time.

When we turn our modern telescopes and cameras to that location, we find the Crab Nebula, the dim remnant of expanding material from that supernova explosion. The material consists of elements created in the extreme heat and pressure of the supernova. This enriched material will eventually collide with interstellar gases and form new stars and new planets. The calcium in your bones and the iron in your blood came from similar supernovas in the very distant past.

The Crab Nebula is over 6,000 light years from Earth and about ten light years in diameter. A single light year measures about six trillion miles. It seems static at that distance, but the Crab Nebula is actually expanding at 900 miles a second. It poses no threat to Earth.

This image of the Crab Nebula was made with the 14-inch PlaneWave telescope at the Mary Aloysia Hardey Observatory at Sacred Heart School in Greenwich. It required six and a half hours of exposure with our STX camera using special narrowband filters in. Hydrogen is represented as red and oxygen as blue/green in this narrowband image.

Messier 81 (Bode's Nebula) by Gary Miller

Gary wrote that "I Imaged this over two cold nights, one 23 degrees and the other just 8 degrees, with heated vest and jacket." The total exposure time (that's for the image; Gary was exposed even longer than that!) was six hours, 10 minutes. Explore Scientific ES127ED triplet, Losmandy GM811G mount, ZWO ASI2600MC Pro camera. Image capture software: Astro Photography Tool, PHD2 guiding, processed in Pixinsight.

M81 (NGC 3031) is the largest and brightest (magnitude 6.94) galaxy in the M81 Group of 34 galaxies. It's 3.8 megaparsecs (Mpc) distant. M81 is a Type 2 Seyfert galaxy with an active nucleus of some 70 million $M_{\odot}$.

Gary also managed to snag UGC 5336, the smudge just above M81. It's a 14.3-magnitude irregular dwarf galaxy in the M81 group, distance 3.7 Mpc. It's also known as Holmberg IX, and was included in the ACS Nearby Galaxy Survey Treasury (ANGST).[22] ANGST (what a name!) used the Advanced Camera for Surveys aboard the Hubble Space Telescope to determine characteristics of 69 galaxies within 4 Mpc of Earth, allowing the ANGST team to perform photometry on more than 14 million stars in order to do Tip of the Red Giant Branch measurements (see page 14). About 20% of the stars in UGC 5336 are less than 200 million years old, the youngest population of stars in any nearby galaxy. While it has older red giant stars, they probably started out in M81.

---

[22] https://iopscience.iop.org/article/10.1088/0067-0049/183/1/67/pdf

Research Highlight of the Month

Wang, F, et. al., a Luminous Quasar at Redshift 7.642, https://arxiv.org/pdf/2101.03179.pdf

Distant quasars can be used to study the formation of the earliest supermassive black holes (SMBHs) and the history of cosmic reionization. Up to now, only two quasars have been found at red shifts ≥ 7.5. This international group, led by astronomers at the University of Arizona, used data from telescopes in Hawaii (Keck, UKIRT Gemini North on Mauna Kea and PanSTARRS on Haleakala), Chile (Gemini South, Magellan and ALMA) and space (WISE Infrared) to identify and characterize the luminous quasar J0313−1806. This quasar has a bolometric luminosity of 3.6×10^{13} L, 1,000 times more luminous than the Milky Way. Spectroscopic observations reveal a SMBH with a mass of $1.6 \pm 0.4 \times 10^9$ $M_\odot$. The existence of such a large SMBH just ~670 million years after the Big Bang challenges the current theoretical models of SMBH formation and growth. The quasar spectrum exhibits strong broad absorption line features in C IV and Si IV, with a maximum velocity close to 20% of the speed of light, indicating that there is a strong active galactic nucleus (AGN) driving outflows in this system. ALMA observations detect the dust continuum and C II emission from the quasar host galaxy, which leads to an accurate redshift determination of 7.6423 ± 0.0013 making it the most distant quasar yet discovered. These findings suggesting that the quasar is hosted by an intensely star-forming galaxy, with a star formation rate of about 200 $M_\odot$ per year and a dust mass of $\sim 7 \times 10^7$ $M_\odot$.
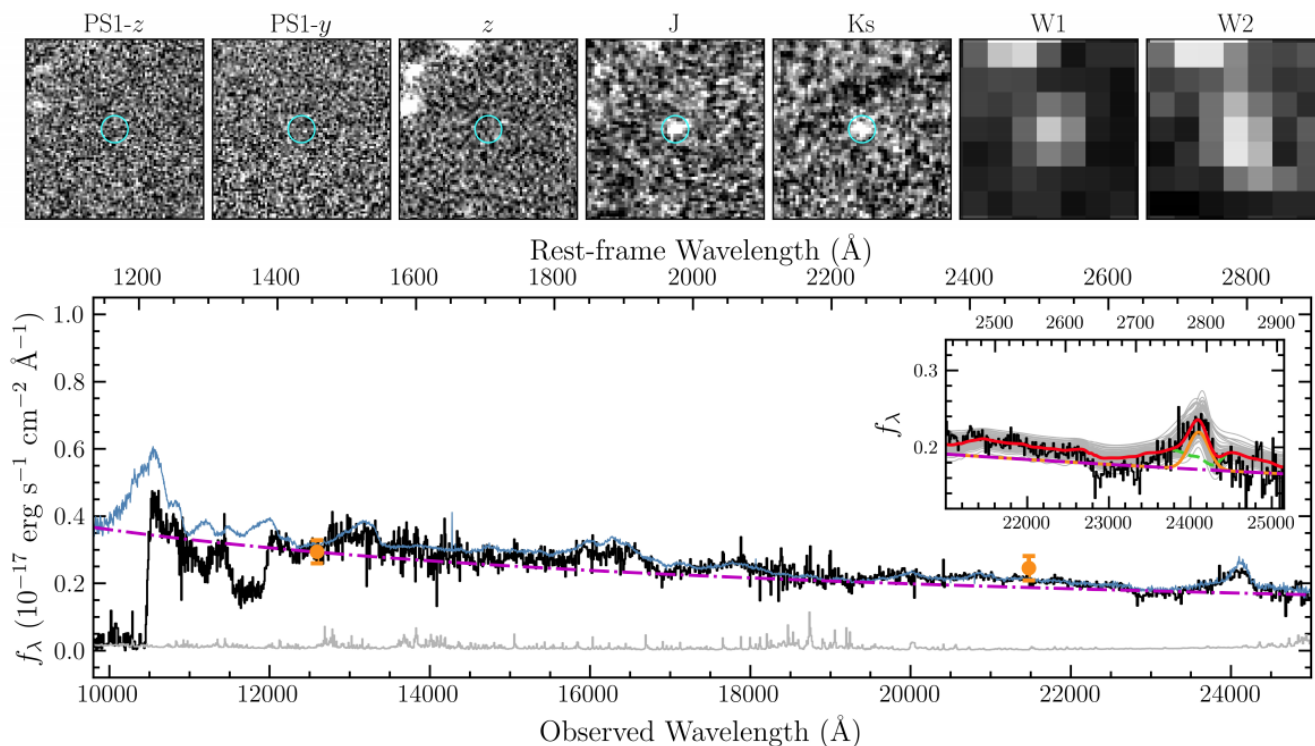

Figure 1 from Wang, *et. al*. Upper panel: image cutouts (north is up and east is to the left) for J0313–1806 in various instruments used in the study. The graph is the final stacked spectrum of J0313–1806. The black and gray lines represent the Galactic extinction-corrected spectrum and the error vector, respectively. The blue line denotes the quasar composite spectrum constructed with SDSS z ~ 2 quasars having similar C IV blueshifts and line strengths. The purple dashed line denotes the power-law continuum. The orange points are flux densities determined from photometry in the J and Ks-bands. The inset panel shows the Mg II line fitting.

This study was posted January 8, 2021, and presented at the American Astronomical Society on January 12. It has been accepted for publication in *Astrophysical Journal Letters.*

Member & Club Equipment for Sale

Item	Description	Asking price	Name/Email
ADM R100 Tube Rings	Pair of 100 mm adjustable rings with large Delrin-tipped thumb screws. Fits tubes 70-90 mm. You supply the dovetail. Like new condition, no scratches. See them on the ADS site at https://tinyurl.com/ADM-R100. List $80.	$50	Larry Faltz lfaltzmd@gmail.com
Losmandy G11G mount	Pristine condition observatory-quality yet portable German equatorial mount. 2018 model. 60 lb. weight capacity. Heavy-duty tripod. Includes brand-new Gemini II go-to system new in box (never mounted). See http://losmandy.com/g-11.html.	$2500	Dante Torrese torresedds@optonline.net
Explore Scientific 40 mm eyepiece	68° field of view. argon-purged, waterproof, 2" eyepiece. New in original packaging, only used once. Lists for $389.	$340	Greg Borrelly gregborrelly@gmail.com
Atco 60-mm f/15.1 refractor	A classic Japanese refractor from the early 1970s. Obtained from the original owner about five years ago. It had been used only a few times, then stored for 40+ years. Current owner used it maybe seven times. Very good condition. Comes with three eyepieces and a 1.25" eyepiece adaptor star diagonal. Straight-through finder. Equatorial mount with slow-motion adjustment knobs (screws). Wooden tripod, metal tube. Everything is original.	$150	Robert Lewis lewis@bway.net

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

Buying 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 for the accuracy of any description. We expect, but cannot guarantee, that descriptions are accurate. Items are subject to prior sale. WAA is not a party to any sale unless the equipment belongs to WAA (and will be so identified). Sales of WAA equipment are final. *Caveat emptor!*
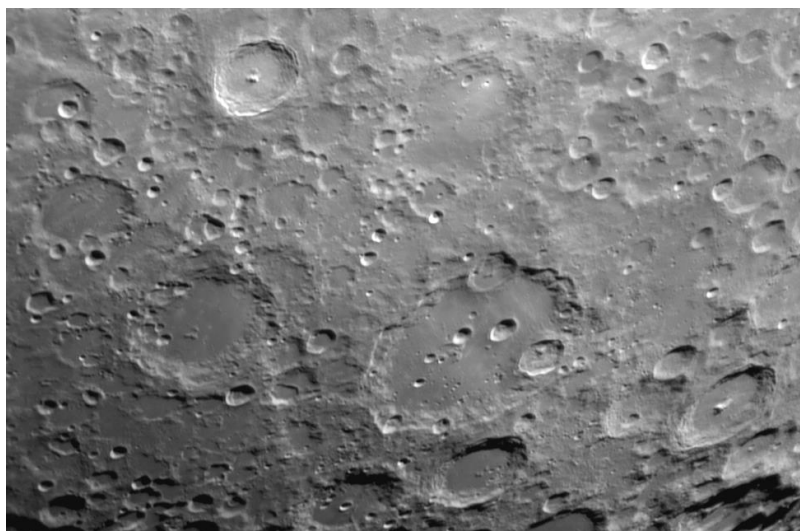
The Southern Lunar Highlands

The relatively young (less than one billion years) 86-km diameter crater Tycho, top, has a central mountain 1,500 meters high. Below Tycho are the 3.9-billion year old Longomontanus and, to its right, Clavius, with multiple younger craters peppering its interior.

The 11-day-old Moon was imaged by **Larry Faltz** from Larchmont on May 3, 2020. Orion Apex 127-mm f/12.1 Maksutov, Skyris 445 camera, iOptron MiniTower alt-az mount. FireCapture, AutoStakkaert!3, Registax 6.1.