Cosmic Voids

Volume 3, Issue 2

July 2024

Editorial

This sketch roughly indicates the current conception of the realm of the nebulae. It is the culmination of a line of research that began long ago. The history of astronomy is a history of receding horizons. Knowledge has spread in successive waves, each wave representing the exploitation of some new clew to the interpretation of observational data.

From Chapter 1: The Exploration of Space in *The Realm of the Nebulae* (1936), from the words of Edwin Hubble to the general audience, we are brought to an era of observational astronomy that dramatically changed our place in the universe. In those days, the nebulae were peculiar objects in the night sky which mystified astronomers. These fuzzy patches, sometimes irregular, other times possessing particular structure and morphology, were the focus of a Great Debate. Are the nebulae small objects within our Galaxy, the Island Universe, the central and singular stellar system in an otherwise empty universe? Or are at least some of these nebulae actually other galaxies beyond our own?

Hubble made critical observations of some of these galaxies, which he referred to as nebulae in the fashion of the time. These spectral observations yielded a remarkable result: the more distant the galaxy, the more quickly it is receding from us. Today we understand that the universe is expanding, and has had a dynamic evolutionary history. A century later, cosmology has evolved into a rigorous and flourishing scientific field, one that still seeks the limits to our understanding - our receding horizons.

In this exciting release of *FarFarOut*, our first double-digit issue, we bring to you the science of our universe on the largest of scales: cosmology. We have a great introduction to cosmology which will prove to be a valuable reference. We will learn about the new observational science of gravitational wave astronomy, and how one observes them as part of the field of multi-messenger astronomy. We consider the future of our species by discussing two theoretical methods to move our entire Solar System, and we consider the past of our species and its origin as stardust. Our two columns, *Carol's Corner* and *Recollections*, are continuing to grow into a treasure trove of knowledge in astronomy and astronautics. We will learn about the concept of redshift through music, and will come to know about how the stars came to be in the skies. And that's not even mentioning the wonderful art, activities, and comic we have in store for you!

Wishing you clear skies,

Richard Camuccio
Editor-in-Chief

Contents

Want to get involved with the South Texas Astronomical Society? STARS is now hosting a Monthly Meetup every first Monday of the month at the Southmost Public Library in Brownsville, open to all who are interested in becoming a part of the Rio Grande Valley's growing community of space exploration enthusiasts! Other recurring programs to expect this year include:

- **Astronomy at the Park**, a public star party at the UTRGV Cristina Torres Memorial Observatory
- **NASA ASTRO CAMP**, a hands-on STEM program for young explorers and families (previously Space, Science, & STARS)
- **STARS on Tap**, space science presentations and trivia hosted at local bars
- **Cup o' Cosmos**, informal astrophysics discussions at Angelita's Casa de Cafe

To stay up-to-date with these and other upcoming events, please visit starsocietyrgv.org/events!

The *South Texas Astronomical Society* (STARS) is a nonprofit organization connecting the Rio Grande Valley community to space and science.

Our Mission is to ignite curiosity in the RGV through space science education, outreach programs, and by serving as a liaison between community members and space organizations and resources.

Our Vision is that STARS nurtures the innate human desire for exploration and discovery by fostering connections to science and the cosmos across the RGV.

July 1: Monthly Meetup at the Southmost Library

Our monthly meetup will return to the Southmost Library on Monday, July 1st at 6:30 pm, and continue every first Monday of the month. Join us for a discussion on ancient astronomy (a.k.a. archeoastronomy) and find out how to get involved with STARS programs, projects, and more!

Tu Salud ¡Si Cuenta! on the Caracara Trails

As part of a program created to promote outdoor activities, STARS is hosting up to three stargazing sessions a week along the Caracara Trails network, including La Posada Urban Park, Los Fresnos Nature Park, Monte Bella Trails Park, and Resaca de la Palma State Park. Be sure you're following us on social media and/or signed up on our email list to make sure you don't miss an event announcement!

Students 2 Launch

In the summer of 2023, forty RGV middle school students participated in a Students to Launch STEM Hub Event at IDEA Sports Park in Brownsville. As part of the Students to Launch program, six of the students who participated in the event will be traveling to Cape Canaveral in Florida later this month to watch NASA's Geostationary Operational Environmental Satellites (GOES-U) launch upon a SpaceX Falcon Heavy!

This opportunity was made possible through a partnership with Students to Launch, Griffin Communications Group, the American Institute of Aeronautics and Astronautics, the Aldrin Family Foundation, First Light Group, Oregon State University, and our amazing team of volunteers who helped at the event. STARS is extremely grateful to be able to provide experiences like these for our RGV students, as they will inspire them to become the next generation of scientists, innovators, and explorers.

To learn more about Students to Launch, visit: https://www.studentstolaunch.org/

To learn more about NASA's GOES-U mission, visit: https://science.nasa.gov/mission/goes/

Make sure to follow @STARSocietyRGV:

South Texas ISD Science Academy Astronomy Club

Our purpose as the Astronomy Club of the South Texas ISD Science Academy is to share our passion of all things related to astronomy, not only with our club members, but with the entire student body as well.

Some of the activities we do as a club include:

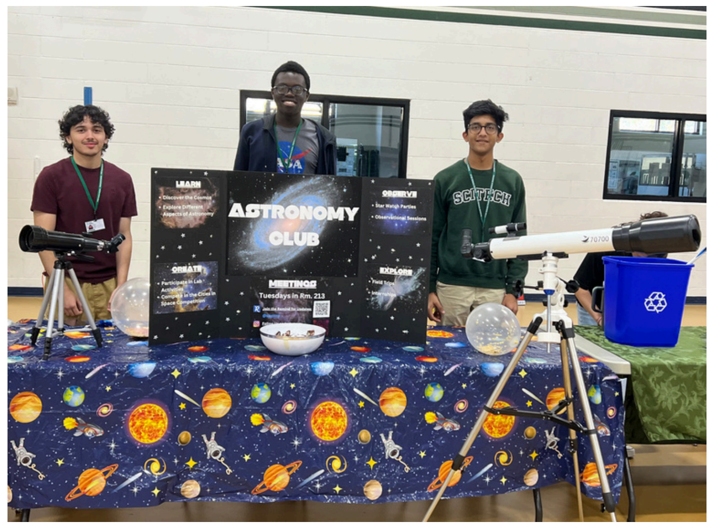
- Discuss astronomical concepts and phenomena during our routine meetings and talks.
- Conduct lab activities and experiments where we try to model different cosmic related phenomena to further grasp and visualize important concepts.
- Have star watch parties to put our discussed skills into practice and strengthen our appreciation of our night sky using a variety of telescopes.
- Observe astronomical events, such as the 2023 and 2024 solar eclipses. We even organized an event where we were able to gather 200+ students to collectively observe the solar eclipse on April 8th.

Collaboration with STARSociety

We had the pleasure of receiving guest speakers from STARSociety this year, Ms. Guajardo and Mr. Camuccio, who delivered a captivating lecture, and we hope to have the pleasure of having them return the upcoming school year so that we may continue to learn firsthand from the professionals at STARS.

Going forward, we intend to:

- Collaborate more with our local astronomical community.
- Increase the presence of our club not only on campus, but with the local community as well.
- Participate in more space science events and competitions, like the Cities in Space student competition.
- Visit more astronomical sites.
- Fundraise more money as a club so that we can take go on a field trip to a space exploration facility or prime star gazing site outside the valley.

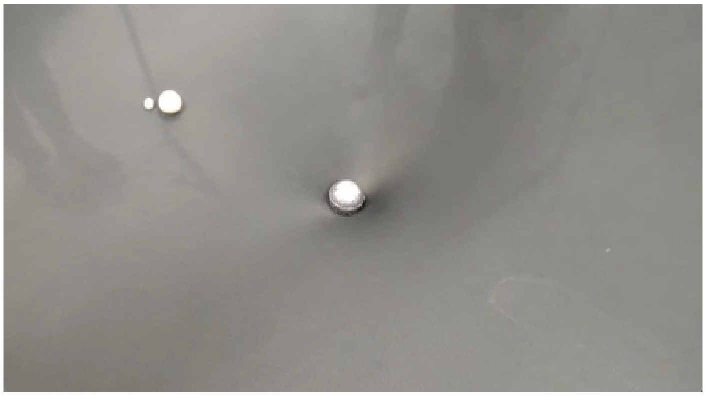


Astronomy club showcase

2023-2024 office: Osric Dienda (President), Swayam Chakraborty (Vice President), Dariana Leal (Secretary), Aditya Dantu (Treasurer), Rita Riano (Historian), and Gael Robles (Parliamentarian)

Incoming 2024-2025 office: Osric Dienda (President), Dariana Leal (Vice President), Aditya Dantu (Secretary), Gael Robles (Treasurer), Isabella Garcia-Cortez (Historian), and Serene Feng (Parliamentarian)

Club sponsor: Mario Guzman


Simulating orbital motion


Playing with sublimating dry ice after constructing homemade cloud chamber


Preparing for a star watch party


Observing the April 8, 2024 solar eclipse

Pace Astronomical Society
Reported by Viviana Novelo
PAS Club President

The Pace Astronomical Society (PAS) had the privilege of co-hosting the recent NASA International Space Station (ISS) Downlink. This major event occurred in our school auditorium, where Brownsville Independent School District's students recorded and sent questions to the ISS. During the live event, astronauts provided answers to these questions.

As PAS's club president and a STARS member, I played a significant role in bringing this event to Pace. PAS, now in its second year, has continued to benefit from the involvement of its former council members who were also associated with STARS.
Read more about the event here:
https://myrgv.com/local-news/2023/09/06/nasa-astronauts-answer-questions-live-from-brownsville-isd-students/

Recently, we hosted a booth at the Brownsville Lunada Artisan Market at Linear Park. Our club members volunteered to teach children how to build paper model rockets and introduce them to aerospace.

The club was also responsible for introducing students to UT Austin's SEES summer internship program partnered with NASA. Participants included Jaqueline Peña (July 2022), Viviana Novelo and Jorge Hernandez (July 2023), and Brian Villanueva (July 2024). Read more about the students involved in the internship here:
https://myrgv.com/local-news/2023/12/05/brownsville-students-to-present-nasa-research-at-san-francisco-agu-conference/

Jorge Hernandez and I were also invited as keynote speakers to Region One's Student by Student Conference earlier this year. We presented on behalf of the club and promoted community involvement. Read more about the student conference here:
https://sites.google.com/esc1.net/sbystech/home

St Mary's Catholic School

St. Mary's teachers implemented various STEM activities in the classroom, integrating the Engineering Design Process (EDP) to deepen students' understanding of scientific and engineering concepts. The EDP encourages students to define problems clearly, brainstorm solutions, plan, and execute solutions.

Gravity, a fundamental concept in the physical sciences, was central to many of these activities. Here's a summary of the gravity-related STEM activities the students performed:

Rockets with Baking Soda: Exploring propulsion and gravity with baking soda and vinegar reactions.
Wall Marble Run: Understanding gravitational pull and kinetic energy by building marble runs.
Paper Airplanes and Launchers: Learning about aerodynamics and gravity through airplane construction and launching.
Spaghetti Beams: Building structures to study gravity's effect on stability.
Pencil Trebuchet: Designing trebuchets to demonstrate gravitational potential energy and projectile motion.
Bottle Rocket Design: Investigating thrust and gravity by designing and launching bottle rockets.
Whirlybird: Observing gravity and air resistance effects on rotating objects.

These hands-on activities made abstract concepts tangible and engaging, fostering a deeper understanding and appreciation of physical sciences among students.

Collaboration with STARSociety

This year, we had the pleasure of hosting guest speakers from STARSociety: Ms. Guajardo, Mr. Camuccio, and Mrs. Lutsinger. Their visit was a highlight for our 2nd and 3rd graders, as they delivered a lecture on gravity and the NASA Gravity Recovery and Climate Experiment.

The students were thrilled to learn about space, asking insightful questions and eagerly participating in the discussions.

We are incredibly grateful to STARSociety for their collaboration and the opportunity to enhance our science curriculum with such a unique experience. The positive impact on our students was evident, as many of them expressed a newfound passion for science and space exploration. We look forward to welcoming these speakers back to our school next semester and continuing to foster a love of learning in our students through such enriching experiences.

Carol's Corner of the Cosmos

Carol Lutsinger

'Summertime, and the livin' is easy' so the song goes, and for those of us who enjoy taking evening or predawn walks there is usually a gentle cooling breeze and old favorite constellations to see. June is the time our hemisphere experiences the summer solstice and the southern hemisphere enjoys the winter solstice.

On June 20th the Sun will rise at the point where the invisible astronomical markings of our home sphere's equator and the sky's ecliptic intersect. If you think we experience hot weather because our planet is closer to the Sun then, nope. Our planet is actually tilted by 23.5 degrees and this makes the Sun's energy spread out farther across Earth and be above the horizon for a much shorter period of time during the cooler seasons, depending which hemisphere is facing the Sun. Try that using a flashlight and a basketball in a darkened room and see what I mean. You might be surprised if you are not astronomically informed. The longer hours of daylight increase the accumulation of radiated heat during summer, trapped within our atmosphere and in all the surfaces, which is the reason for the heat. And, of course, there is the Sun itself continuing its role of heating things up and enabling those suntans and freckles — and wrinkles, as my little neighbor, Luna, tells me. Gotta love children who tell it like it is.

In those predawn hours of June 4-5, Jupiter and Mercury will be in conjunction — you may need binoculars to pick out Mercury since it is always dim and it is speedy too, visible only a few times a month as opposed to Jupiter which reigns for months at a time. It might be an interesting project to track which planets are seen through the year. I remember when I first noticed two bright planets in the eastern sky in the evenings when I walked up my street off McAllen Road and night after night, month after month, those two planets drew closer and closer to each other. Although I was able to learn later they were Jupiter and Saturn, I knew nothing at all about astronomy and didn't even know there were two magazines available that would have told me what they were. I am grateful for the things I have learned since then and the fact I have been able to share the tiny bit of knowledge I have with others. YOU have the advantage of the many scientific sites on the internet and the vast array of astronomical tools to access, not to mention the South Texas Astronomical Society's outreach opportunities today. We STARS appreciate you!

June's Full Moon, called the Strawberry Moon by some, will occur on the 21st. It will be the lowest Full Moon of this year. You may notice that when the Sun is higher in the sky, the Moon will be lower — this is part of our interesting tilt. The planets, the Sun, and the Moon follow that ecliptic which is 23.5 degrees tilted off the celestial equator (of declination zero degrees).

Looking south during summer evenings brings Virgo, with her stunning diamond ring star on her left hand, Spica. Spica is a binary star. According to NASA, the primary star is a blue giant, twice the size of our Sun, but 2000 times as bright. The pair whirl so close to each other that an orbit only takes four days to complete. Virgo was named by skywatchers in ancient times and considered to be a goddess by many. For them the star represented grain plants and an abundant harvest.

Almost directly overhead, locate the gold star Arcturus at the base of the constellation Boötes, the Herdsman. If you locate Ursa Major in the north and follow the arc of the bear's tail, you come to Arcturus, then spike to Spica to locate Virgo. The word 'Arcturus' means the guardian of the bear. This star's light was used to light the fair grounds of the 1933 Chicago World's Fair.

By the time July rolls around, the magnificent constellation Scorpius is in the south, just in time to be the backdrop for the 4th of July fireworks. Shaped like a fishhook or the letter J, this constellation does resemble a scorpion. There is a group of stars on the right that curve a bit that represent the pincers. These were later separated to become a separate constellation, Libra, the Scales. To the left is a bright reddish star, Antares, the so-named Rival of Mars because the two often appear in the sky together and seem to be about the same color and brightness. Further to the left and lower is a group of stars at the tail which are the stingers. The brighter of these stars is named Shaula.

Above Scorpius is the group of stars that to me resemble the coffee percolator given as a wedding gift in 1961. The streams of stars off either side appear to be the handle and the spout, but to the Greeks were a snake which had been cut in half by Ophiuchus, the Physician. He encountered the serpent in his garden and promptly used his hoe to chop it in two. At that point the mate emerged from the plants, put one of the leaves on the halves, and they grew back immediately and the two crawled off into the tall plants. The story is great and one we will share another time.

Sagittarius, the Archer, emerges from the eastern horizon about an hour after Scorpius. This group of stars has another asterism known as the teapot. Readers of a certain age may remember singing the Little Teapot song in kindergarten. This constellation/asterism is in the Milky Way, as is Scorpius, and if you are in a dark site away from light pollution you will be able to actually see the soft glow of our home galaxy.

Near the zenith is the delicate little constellation of Lyra, the Harp. Mistaken by many to be the Little Dipper, which only appears in the north part of the sky, Lyra looks like a bent rectangle with a tail extended off the brighter star, Vega, part of the Summer Triangle asterism.

By August walking times, Vega, Deneb, and Altair will catch your eye. The trio comprise the Summer Triangle since they are the brightest stars in those constellations. Deneb is in the tail of Cygnus, the Swan, Altair is the eye of the Eagle. There is also the added bonus of a greater opportunity to catch a falling star during August sky-watching. The Milky Way arches overhead, carrying these constellations within it. The stars are truly big and bright deep in the heart of Texas during August.

Vega, whose name means ‘swooping eagle’ in Arabic, is a huge blue-white main sequence star in the same category as Sirius, the Dog Star of winter, and Castor in Gemini. It will be near the zenith on August 5th and Sirius will be down under your feet on the other side of the world.

Lyra hosts the lovely Ring Nebula, labeled as Messier 57. If you are not sure of what that means, Messier was a comet hunter in the 1700s who categorized the various ‘fuzzy objects’ he discovered through his telescope by numbers so he could eventually determine which were actually comets. Naturally, a comet’s location will change by many degrees between nights of observing while those of something else will not.

The night of August 12th would be a great time to host an after midnight/before dawn star party in a dark safe site because this is the peak of the Perseid meteor shower. Those entering Earth’s atmosphere are space rocks of nickel, iron, cobalt, or rocky chondrites that super-heat the atmosphere around them, just like the Space Shuttle or other returning spacecraft that created those fiery re-entries which were so dangerous. I hope you are able to see a few and enjoy the beauty of the night’s display.

Until next time, KLU. ★

Biography

Carol Lutsinger is the founder of the South Texas Astronomical Society. She spent 40 years as a teacher, serving students from Pre-K through college. Carol attributes her astronomy enthusiasm in part to her experience in the American Astronomical Society's AASTRA program from 1994-96, and her space excitement from serving as a Solar System Educator, and later Ambassador, for the NASA/JPL program. She has been writing the Stargazer newspaper column since 1998, which is carried in the Brownsville Herald and the Valley Morning Star. Retired from formal education since 2020, she still makes every opportunity to share meteorites which she carries in her purse and to ask folks in parking lots if they know what that point of light is.

Centaurus

The Centaur (κένταυρος)
A mythological creature, he is half man and half horse, and one of the larger constellations in the sky.

The Recollections of a Wannabe Astronaut

Stephen J. Camuccio

"We choose to go to the moon. We choose to go to the moon in this decade and do the other things, not because they are easy, but because they are hard, because that goal will serve to organize and measure the best of our energies and skills, because that challenge is one that we're willing to accept, one we are unwilling to postpone. And, therefore, as we set sail we ask God's blessing on the most hazardous and dangerous and greatest adventure on which man has ever embarked."

On September 12, 1962, President John F. Kennedy threw down the proverbial gauntlet and set this nation on a path to the Moon. This was after only 15 minutes of sub-orbital space flight. I was eight years old and hearing my father and uncles talk about the "crazy" proposal to fly to the Moon in less than eight years. I thought to myself, "Why not?" After all on a TV show at the time, "The Wonderful World of Disney", Dr. Werner von Braun's series "Man in Space" in 1955, laid out the steps to space and the planets. Seemed simple to me. All we had to do was build the rocket, get on board, and go.

Figure 1. A clip of Dr. Werner von Braun explaining the design of a four-stage manned rocket ship from the series "Man in Space" (1955).

For myself this was a dream come true. Each mission was more complex than the last, and all of it was on television for the world to see. The Soviet Union did not publicize their missions. It wasn't until years later I was able to read about their launch vehicle, R-7 or "Semyorka", and how much they were ahead of us for lifting capability. Our Redstone rocket could only reach sub-orbital velocity, so NASA turned to the Atlas ICBM. This rocket had a history of "Rapid Unscheduled Disassembly", but this was a national mandate, so we were go for launch!

So, to an eight-year-old boy, each Mercury Mission was a piece of cake, not really understanding the dangers and complexity of each step toward a man on the Moon. In May 1963, Gordon "Gordo" Cooper was the last American to fly in space alone. Enter the Gemini two-man spacecraft. This second phase of the steps to a Moon landing by December 1969 was more important than the Apollo program to follow. As before all the missions were on our 19" black and white TV. No television feed from the capsule, but just a young man's vivid imagination of what was occurring in space.

On that note, I think I'll watch "Destination Moon". After all, they made it look easy! "Go for Launch!" ★

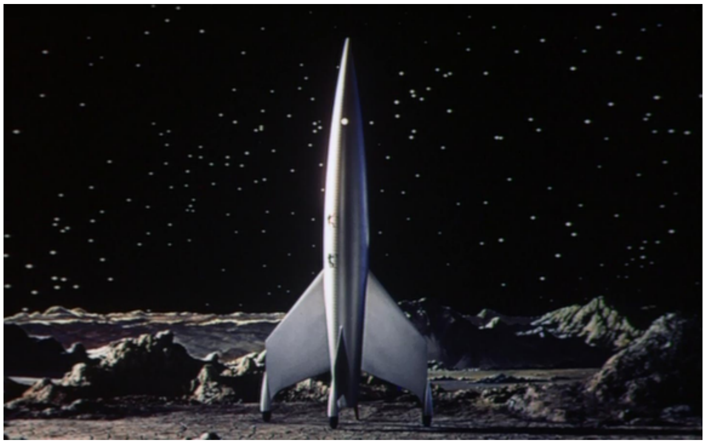


Figure 2. The iconic lunar rocket and background lunar vista from Irving Pichel's "Destination Moon" (1950).

Figure 3. An official portrait of Gordon "Gordo" Cooper in the Navy Mark IV Mercury spacesuit (1962). Credit: NASA.

Biography

Stephen J. Camuccio hails from Philadelphia, PA (Go Eagles!). He attended Community College of Philadelphia and Drexel University, and received an associate degree in mechanical engineering. Stephen worked in careers spanning several domains, including restaurants, insurance, and automobile sales (the latter starting with Saturn cars, named after the Saturn V Moon rocket, not the planet). He is currently retired... sort of. His hobbies include building scale models of spacecraft, amateur astronomy, and deep sea fishing. Stephen is married, a father of four, and a grandfather of eight.

Observing the Universe in Gravitational Waves

Joseph D. Romano

I. Traditional Astronomy

Our most basic knowledge of the world comes to us through our senses. These are the familiar human senses of sight, smell, hearing, taste, and touch, which we put to use from a very early age. But we also know that our senses are rather limited. For example, we are not able to see or hear or smell as acutely as many other animals. So to make up for this lack, we humans have invented devices to *extend* our senses, allowing us, for example, to see objects in wavelengths other than just visible light (Figure 1).

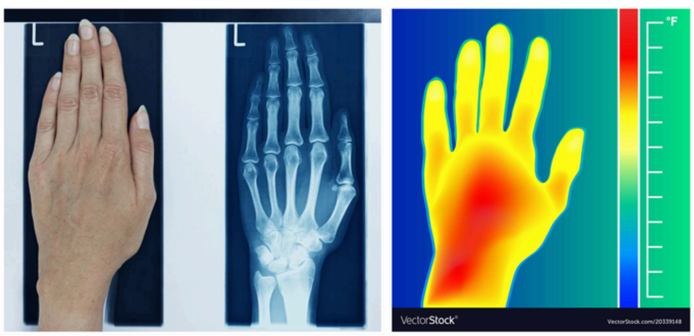


Figure 1. A human hand as seen in different wavelengths of light (visible, X-rays, and infrared).

Over 400 years ago in 1609, Galileo further extended our sight, this time to astronomical objects, by turning a recently invented telescope (by German-Dutch lens maker Hans Lippershey in 1608) to objects in the sky (Figure 2). This act *revolutionized astronomy*, since Galileo could now see objects with his telescope that were 10 times smaller and 100 times fainter than what one could see with the naked eye. (The reason for this is that Galileo's telescope used a lens that was approximately 10 times larger than the diameter of the pupil of a human eye.)

With his telescope, Galileo observed that the Moon has craters, the Sun has sunspots, Venus goes through phases like the Moon, and—most importantly—that Jupiter has moons that *orbit Jupiter and not the Earth*. This latter observation lent support to the Copernican Sun-centered model of the solar system, and offended leaders of the Catholic Church, which upheld the Earth-centered model of the solar system. In response to Galileo publishing his findings in 1610, the Catholic Church judged Galileo as a heretic in 1616 and subjected him to house arrest from 1633 until his death in 1642.

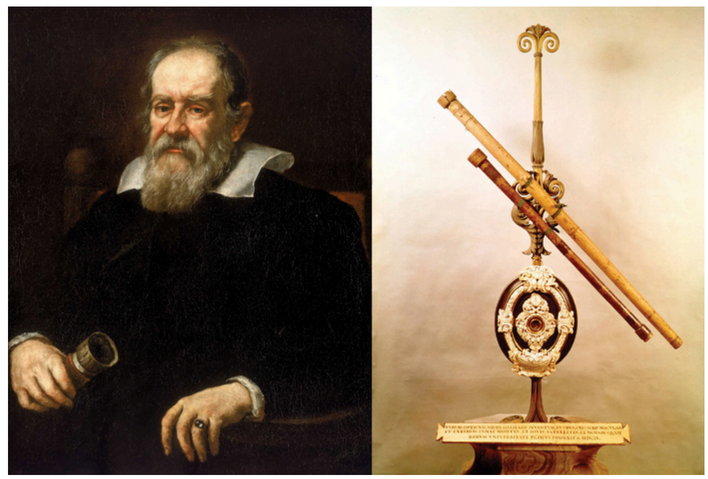


Figure 2. Galileo Galilei (1564-1642) and two of his telescopes.

Since Galileo's time, technology has improved and telescopes have gotten bigger and better. Telescopes with glass lenses have been mostly replaced by telescopes that use mirrors. This allows for larger-diameter telescopes that can resolve smaller and fainter objects. For example, the Hubble Space Telescope, which was put into low-Earth orbit in 1990, is a 2.4-m telescope. Being roughly 100 times larger than Galileo's first telescopes, it has 100 times better angular resolution and can see objects 10,000 times fainter than what Galileo could see (Figure 3).

As we saw for the hand in Figure 1, we can learn even more about astronomical objects by observing them with telescopes that make use of other forms of light. In Figure 4, we see the galaxy Centaurus A as observed in X-rays and radio waves, in addition to visible light. It is apparent

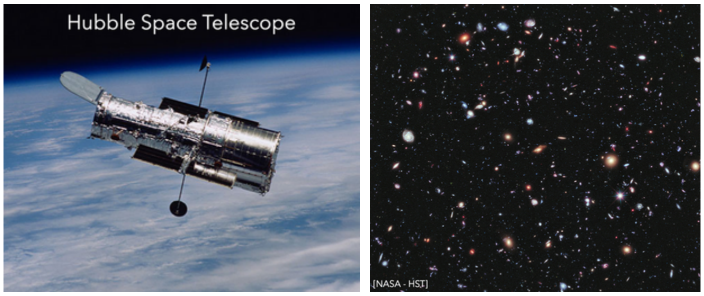


Figure 3. Hubble Space Telescope (left) and an image taken by Hubble of over 5,500 distant galaxies occupying an area much smaller than the angular diameter of the Moon in the sky. Credit: NASA-HST.

from these other wavelengths that Centaurus A is a much more dynamic object than one would expect from the visible-light image alone. The jet spewing out from the center of the galaxy (as seen clearly in radio waves) is approximately 100,000 light-yrs in size, which is as large as the galaxy itself. The jet is being driven by a supermassive black hole (SMBH) at the center of the galaxy, which probably has a mass somewhere between one million and one billion times the mass of the Sun. Who would have known that such a "mild-mannered" galaxy as seen in visible light was housing such a monster black hole?

The moral of the story is much can be learned by observing objects in as many different ways as possible.

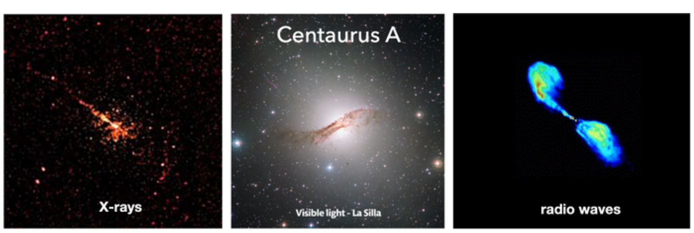


Figure 4. The galaxy Centaurus A as observed in different wavelengths (X-rays, visible light, and radio waves).

II. Gravitational Waves

But that's not the end of the story. There's another way of doing astronomy, which is based on a prediction of Albert's Einstein's theory of gravity, called *general relativity* (published in 1916). According to general relativity, gravity is not a force acting between objects, but is encoded instead in the curvature of space and time. Massive objects curve spacetime in their vicinity, which then dictates how objects move through space and time (Figure 5). Thus, in general relativity, the Earth orbits the Sun not because it feels a force, but because it is moving through spacetime curved by the mass of the Sun. The more massive an object is, the greater the curvature of spacetime.

And if you take a massive object and you accelerate it back and forth, you produce "ripples" of curvature that propagate away from the source much like water waves on the surface of a pond. These waves are called *gravitational waves* (GWs). An example of accelerating objects that produce GWs are two black holes in orbit around one another (Figure 6 and here). The GWs that the orbiting black holes produce carry energy away from the system, causing the two black holes to get closer and closer together and eventually merge to form a single bigger black hole. Such a signal is called a GW "chirp", since during the final few seconds before the merger, the amplitude and frequency of the GWs increase in such a way that, if you convert the signal to a sound file, it literally sounds like a "bird chirping", see here.

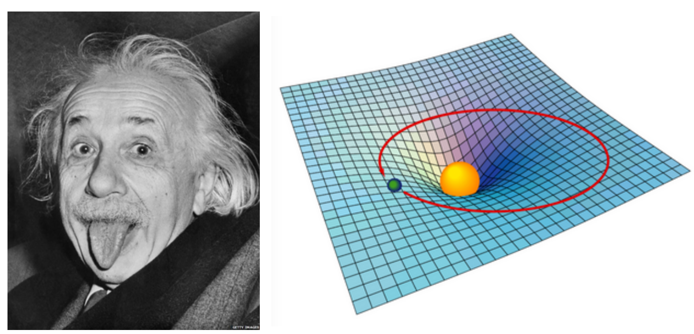


Figure 5. Albert Einstein and his interpretation of gravity as a manifestation of the curvature of space and time.

Now would we be able to see these GWs using an ordinary telescope that uses light? The answer is no! Not at all. Black holes don't emit light and the GWs they generate don’t produce light either. So this final inspiral and merger cannot be seen using ordinary telescopes. The only way we can observe these waves is to build a telescope that is sensitive to the effects of a GW.

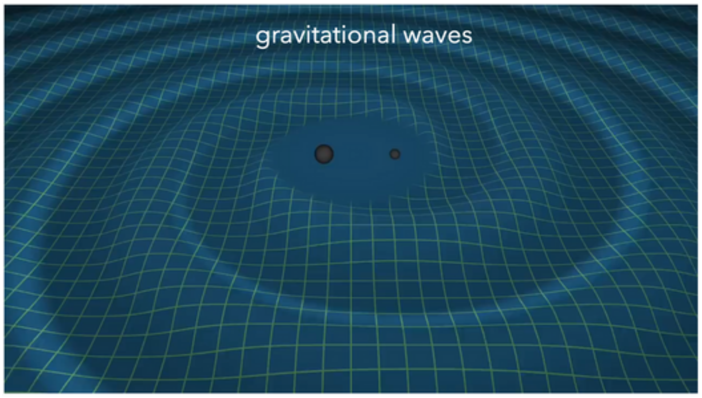


Figure 6. A still of a computer simulation of GWs produced by two orbiting black holes. Full simulation can be found here. Credit: Tim Pyle/Caltech.

So what does a GW do? Recall that GWs are “ripples” of curvature predicted by Albert Einstein over 100 years ago. They alternately “stretch” and “squeeze” space as they propagate from the source to the observer. The stretching and squeezing is in the plane perpendicular to the direction of propagation of the wave. An exaggerated illustration of this stretching and squeezing is shown at the top of Figure 7 using the previous photo of Albert Einstein. An animation is available here.

The strength of a GW is defined by $h \equiv \Delta L/L$, which is the fractional change in length produced by the stretching and squeezing of space (bottom part of Figure 7). The quantity h is called the *strain*. The expected value of h produced by astrophysical sources is very, very, very small—only one part in 10^{21} . This means that if L = 10 km, then $\Delta L = 10^{-17}$ m, which is 100 times smaller than the size of an atomic nucleus. Equivalently, one part in 10^{21} is the same as being able to measure the distance between Earth and the nearest star (Proxima Centauri, 4.2 light-yr) to within the thickness of a human hair (0.01 cm)!

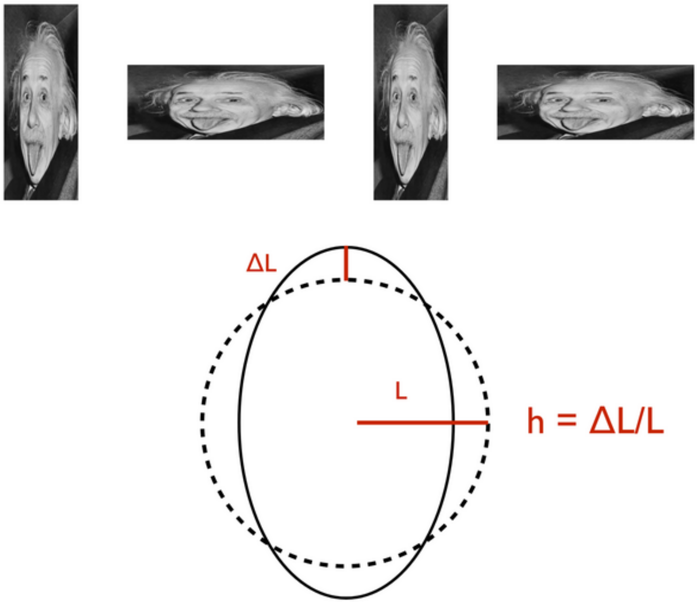


Figure 7. The “stretching” and “squeezing” of space produced by a passing GW is characterized by the ratio $h \equiv \Delta L/L$, which is greatly exaggerated in this figure.

So how is it possible to detect those incredibly minute changes in length? Obviously, we cannot detect these small changes with our bodily senses. We need a detector that can precisely monitor the distance between objects that are ideally separated as far apart as possible, and have pairs of such objects at right angles to one another. The two L-shaped LIGO detectors in Hanford, WA and Livingston, LA do just that. (LIGO stands for Laser Interferometer Gravitational-wave Observatory.) The LIGO detectors are large-scale laser interferometers, with two perpendicular “arms” that are each 4 km (or 2.4 mi) long (Figure 8). A passing GW stretches one arm while squeezing the other; the laser light in the longer arm takes longer to travel down and back. So when the laser beams in the two arms recombine they will be shifted relative to one another, either reinforcing or canceling each other, depending on whether the two beams line up or are shifted by 180 degrees. This changing interference pattern is the signature of the stretching and squeezing produced by a passing GW.

III. Birth of GW Astronomy (GW150914)

Since 10^{-21} is a such a very small number, it took many years for technology to reach the stage where such delicate measurements were actually possible—100 years, to be exact, from when Einstein first predicted that GWs exist to when they were first directly detected. That was on 14 Sep 2015 with the observation of the final inspiral and merger of two black holes by the LIGO detectors. The two black holes were each about 30 times as massive as the Sun. The merger took place in a distant galaxy, approximately 1.3 billion light-years from Earth (Figure 9 and here). This means that it took the GWs (which travel at the speed of light) 1.3 billion years to travel from the host galaxy to our detectors on Earth!

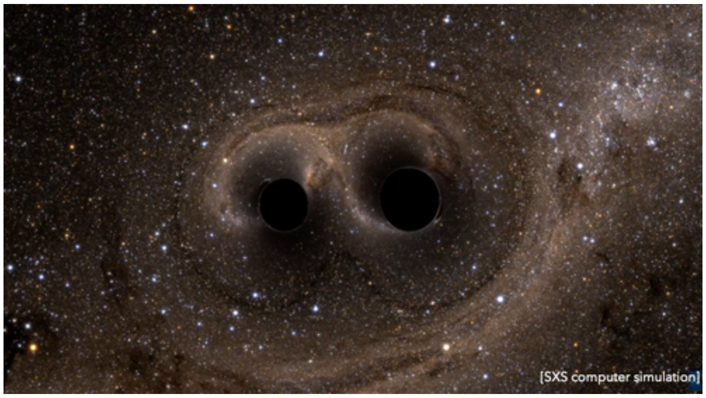


Figure 9. A still of a computer simulation of the binary black hole merger GW150914. Full simulation can be found here. Credit: Simulating eXtreme Spacetimes (SXS) Collaboration.

It is worth noting that Figure 9 and here are both a computer simulation of what GW150914 would have looked like if we could have seen it up close with visible light detectors. But GWs don't produce light, so that was not what was actually measured by the two LIGO GW detectors. What was actually measured is shown in Figure 10. The top two plots show the GW strain ΔL/L in the arms of the two LIGO detectors as a function of time, which only lasted about 0.25 seconds. This is just the fractional stretching and squeezing of the arms produced by the GW. The overlapping blue and red traces in the upper right panel show the two signals, with that from the LIGO Hanford detector shifted by 7 msec to take into account the time that it took the GW to travel from Livingston, LA to Hanford, WA. The bottom two plots show how the amplitude and frequency of the GW evolve over the same time period. As mentioned earlier, the increasing amplitude and frequency of the signal is the GW "chirp" expected for the final inspiral and merger of a pair of black holes (see here).

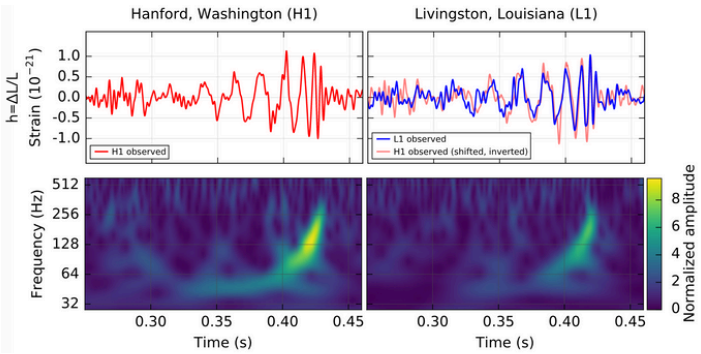


Figure 10. The actual GW signal that was observed by the two LIGO detectors on 14 Sep 2015. Top: The GW strain as a function of time. Bottom: The amplitude and frequency of the observed signal as a function of time. See also here. Credit: Ref. [1].

IV. Birth of Multi-Messenger Astronomy (GW170817)

Perhaps even more remarkable than GW150914 was the final inspiral and merger of two neutron stars, which was observed on 17 Aug 2017. (More about neutron stars in the next paragraph.) The importance of this detection was that it was the first *multi-messenger* observation of a GW event, denoted GW170817 (Figure 11 and here). The left panel of Figure 11 shows that the event was observed almost simultaneously in the form of GWs by the LIGO detectors and in the form of a burst of gamma rays by NASA's Fermi satellite. The right panel of the figure shows the "afterglow" of the event, which was subsequently observed by several other traditional astronomy telescopes: in visible light (by the Swope telescope), in X-rays (by the Chandra X-ray satellite), and radio waves (by the Jansky Very Large Array). The dark blob is the host galaxy (NGC 4993), which is located roughly 120 million light-years from Earth; the small dot is the afterglow of the binary neutron star merger.

Unlike black holes (which are made of pure spacetime curvature), neutron stars are made of ordinary matter—primarily of neutrons from the protons and electrons that got squeezed together when the star ran out of its nuclear fuel and rapidly collapsed inward. The neutron star is as massive as the Sun but has a diameter roughly the size of Brownsville. This means that it is extremely dense; it is very much like a giant atomic nucleus.

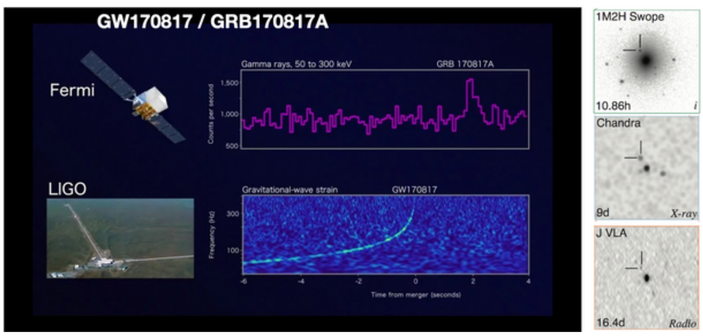


Figure 11. An infographic for event GW170817/GRB170817A showing the signal observed in gamma rays, GWs, visible, X-ray, and radio waves. See also here. Credit: Ref. [2].

When the two neutron stars eventually smashed into one another after the final orbits of GW170817, the constituent neutrons were rapidly converted into heavier elements, most notably gold and platinum. It had long been conjectured that binary neutron star mergers were the source of these heavy metals, but it wasn't until this multi-messenger observation (in GWs, gamma rays, and all forms of visible light) that this conjecture could be confirmed.

V. Evidence for Low-Frequency GWs

For our final example, we note that in summer 2023, radio astronomers announced [3-6] that over the last 10-20 years they had most likely been observing the low-frequency "hum" of GWs produced by hundreds of thousands of pairs of supermassive black holes orbiting one another in the centers of merging galaxies (Figure 12). These supermassive black holes have masses approximately a billion times larger than that of the Sun. The corresponding GWs have very low frequencies, taking years or decades to pass through one complete cycle.

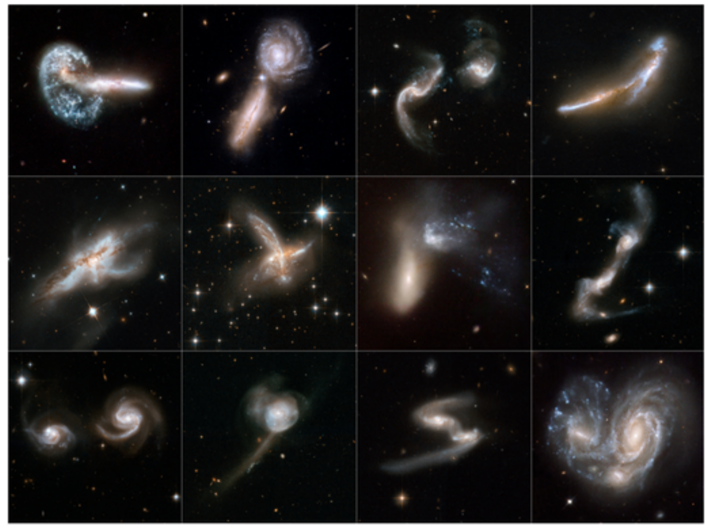


Figure 12. Pairs of galaxies in the process of merging with one another. Credit: HST.

Now, detecting such low-frequency GWs requires a *huge* detector, one as big as a large portion of our own Milky Way galaxy. Of course, scientists weren't able to build such a detector themselves, but they could take advantage of a detector that *Nature herself* has provided, monitoring the ticks of Nature's most precise clocks (called *pulsars*) to look for the minute changes in distances produced by a passing GW (Figure 13). Pulsars are rapidly rotating neutron stars (which we discussed in the context of GW170817), which spin as fast as a kitchen blender, and emit beams of radio waves from their magnetic poles. If the radio beams cross our line of sight to the pulsar, we observe pulses at Earth hundreds of times each second, much like the ticks of a very precise clock. This idea of monitoring pulsars in our galaxy to search for GWs is called a "pulsar timing array". It is an ingenious way of doing astronomy using astronomical objects themselves!

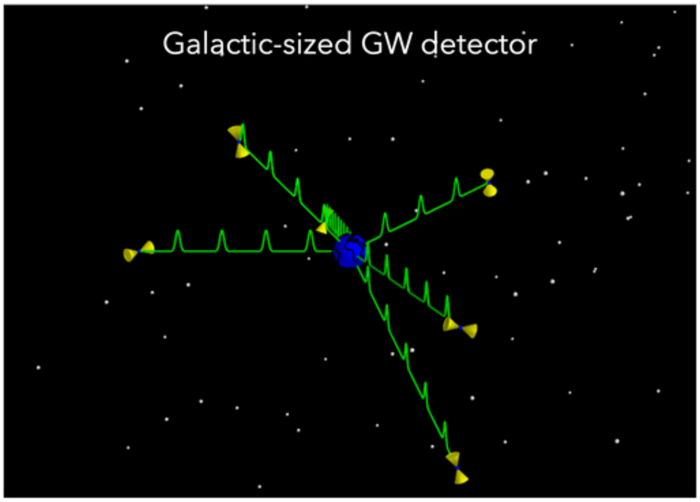


Figure 13. Schematic representation of a pulsar timing array, consisting of several rotating neutron stars (represented by spinning yellow cones), which emit pulses of radio waves (green blips) that are detected by radio telescopes on Earth (blue ball). Credit: Michael Lam.

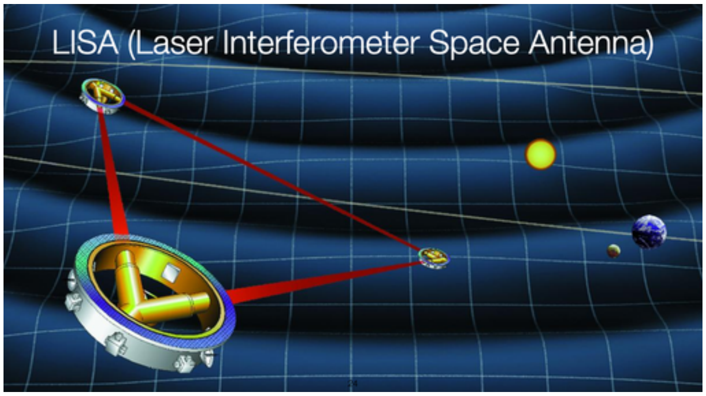


Figure 14. Artist's rendition of the Laser Inferometer Space Antenna (LISA). The three spacecraft exchange laser light in an equilateral-triangle formation, which orbits the Sun, with arm lengths roughly five times larger than the distance between the Earth and the Moon! See also here.

VI. Conclusion

In this article, we have discussed three specific examples of observations of GWs—the binary black hole merger GW150914, the binary neutron star merger GW170817 (that was also seen by traditional telescopes), and evidence for the low frequency "hum" of GWs most likely produced by orbiting supermassive black holes in hundreds of thousands of pairs of merging galaxies.

Since 14 Sep 2015, the LIGO detectors (and the European counterpart Virgo) have detected approximately 100 more GW events, mostly mergers of binary black holes with masses of order 10 to 100 times the mass of the Sun. And there are plans to launch a space-based laser interferometer called LISA (Laser Interferometer Space Antenna, see Figure 14 and here) around 2034, which should detect GWs from numerous other sources having GW frequencies intermediate between those for pulsar timing arrays and for the LIGO detectors.

It is not an exaggeration to say that GWs have the potential to revolutionize astronomy in much the same way that Galileo did over 400 years ago when he pointed a telescope at the heavens. GWs and traditional telescopes provide complementary information about the universe, analogous to the extra information that we have about the world around us using our senses of both sight and hearing. ★

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Biography

Joe Romano is currently Director of the South Texas Space Science Institute at the University of Texas Rio Grande Valley. His primary research interest is developing data analysis methods to search for stochastic GW backgrounds using a variety of GW detectors. He also enjoys giving public outreach talks, especially about the connection between mathematics and art or other everyday phenomena.

Stellar Engines: Moving Stars 101

Ariel Jaramillo Ruiz

We are always on the move. Whether it's going to work, school, your house, or some other place you like, it's a fact that we are always moving. As time has passed, our ways of transport have also been improving depending on what we needed, from navigating the seas on boats to soaring through the skies in airplanes. But where would this lead?

Far out into the future, if we manage to colonize our entire solar system, the next step would be to colonize other stars. Interstellar transport is no easy task. Maybe, instead of traveling through deep space with generational ships (1), we can think of other methods on a bigger scale. How about we move our entire solar system?

The theoretical technology is called a Stellar Engine, a megastructure built by Type II civilization on the Kardashev scale. In other words, these are civilizations that can harness the energy of their entire solar system. Here we are talking about a civilization that can or has built a Dyson Sphere (or a Dyson Swarm), a megastructure that harnesses most, if not all, the energy of a star. We don't have to worry about moving everything in the solar system – we just have to move the star, and everything else will follow.

We can divide Stellar Engines into two types: active and passive engines. This division was made by Matthew E. Caplan, mentioned in his article "Stellar Engines: Design Considerations for Maximizing Acceleration". Passive thrusters work without intervention, such as a solar sail. Active thrusters work by maintaining non-equilibrium states.

The simplest type of Stellar Engine is passive. These don't need any other megastructures to work. As mentioned before, the solar sail is a passive thruster which uses the same mechanics as a rocket. It essentially works as a giant mirror which reflects photons from the star back to generate thrust.

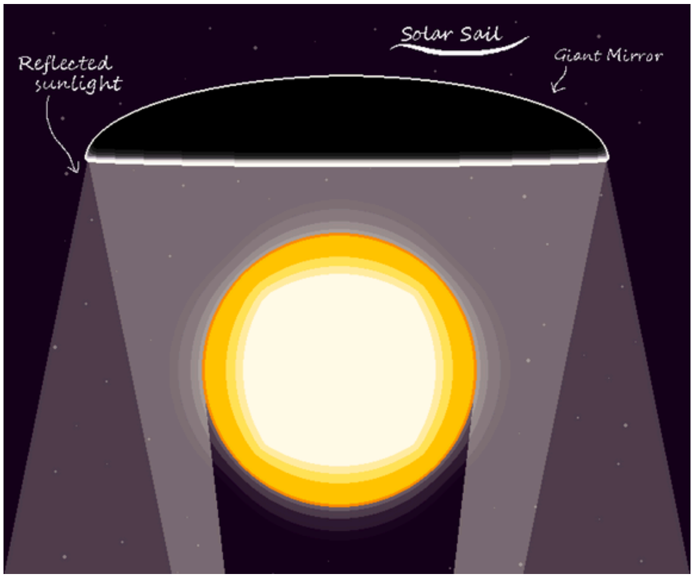

Figure 1. Pixel art illustration of a solar sail. Credit: Author.

However, as with most things, there are some complications with it. To prop itself up, it uses the radiation from the sun to push it away, and therefore it needs to be light, but with sufficient thickness to be able to reflect the light efficiently. A width of 0.2 micrometers (µm) for this mirror is desirable. In Caplan's work he says that, until another material is produced to do a better job, aluminum is the best candidate due to its low density and high reflectivity.

A solar sail would also only be able to be built at the star's poles. If built anywhere else, it will heat up the planets that are passing through the reflected light of the mirror and will freeze those planets that are passing behind the mirror. With this we must now talk about its power, or how much it will change the trajectory of our solar system.

The main purpose for a Stellar Engine is, of course, to move a solar system. This is for two main reasons, which are either to aid in the colonization of other solar systems, or to escape a threat (mainly being supernovae). So, according to Caplan's paper, a solar sail can move 100 parsecs (1 pc = 3.26 light years) on a galactic orbit (~225 million years). This might not be enough to escape a supernova, and since the only places to build a solar sail are at the poles, it only gives us movement in two relative directions in the galaxy.

If that's not the best option for escaping a supernova, what other options do we have? Here is where active thrusters come in. In Caplan's paper, he theorizes about an engine based on a Bussard Ramjet: a space propulsion system which collects interstellar matter from a wide area using electromagnetic fields, compressing them to achieve fusion in a reactor.

We refer to this engine as a Caplan thruster. It would collect hydrogen and helium present in the solar wind with the help of electromagnetic collectors. Then, with this material present, it uses it in a fusion reactor. Excess hydrogen would be fired back to the sun to keep the thruster stable and not let it crash into the sun. Another jet would be expelled away from the sun to serve as thrust of the engine, essentially working as a giant tug boat.

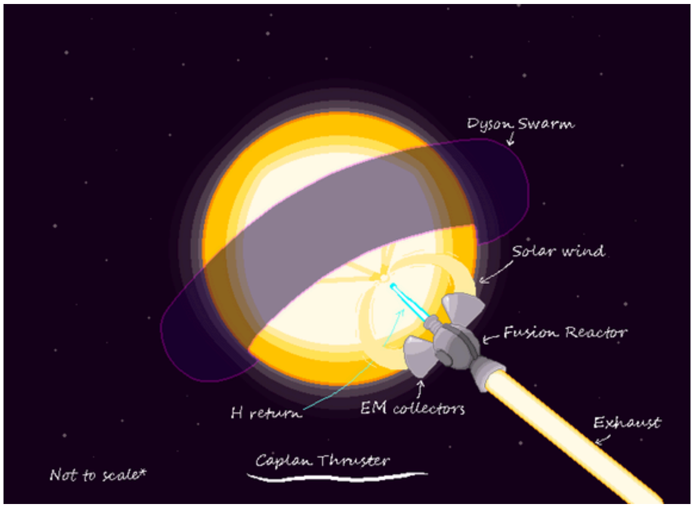

Figure 2. Pixel art illustration of a Caplan thruster and its main components. Credit: Author.

On its own, solar wind won't be enough to fuel this type of engine with sufficient thrust to move the star any faster than a solar sail. That's where a Dyson Swarm comes in. The satellites comprising it could fire sunlight back into a certain area of the sun, heating it up, and lifting off massive amounts of matter toward the engine.

We are talking about the sun as a giant fuel source, and there comes the worry of "burning out" the sun, or using up all the fuel. The Caplan thruster needs millions of tons of material to work properly, but this would hardly leave a scratch on our sun. Current measurements estimate the sun weighs 2.192 x 10^{27} tons (2.2 octillion tons), and the engine could work at full throttle for millions of years and barely scrape off the sun's surface. It would also improve the lifespan of the sun, as the less mass it has, the longer for which it will burn, making our solar system habitable for many years to come.

Now talking about speed, a Caplan thruster at full speed and efficiency could provide 10 pc in the first million years of operation. Depending on how far away a supernova is, it can be sufficient for cosmic disaster avoidance. It would also allow for retrograde orbiting of the galaxy with sufficient time, making it easier to go from one solar system to another and colonize them.

We have to remember that all this would be done by our future ancestors. If we ever reach that point, it would be made by people thinking far out into the future, on timescales which we can't comprehend. It would be the greatest feat, first to build megastructures, being able to harness all the energy of our solar system, and to become an intergalactic species as a whole.

This working idea was made possible thanks to the work of Matthew E. Caplan. His article was mentioned many times before. If you want to learn more, be sure to look into his work. He's a great astrophysicist. It was also greatly inspired from the channel Kurzgesagt. You can learn a lot from both of them. ★

Notes
(1) Ships which take more than one generation to reach their destination.

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Biography
My name is Ariel Jaramillo Ruiz. I am 15 years old and a current student at Saint George Prep School in the 10th grade in Heroica Matamoros, Mexico. This same place is my current residency. I have won 1st place in the ONEP Math Olympics at the state level.

Richard Pomeroy

Life, the Universe and Everything

Today, we're going to be exploring the science of cosmology, the branch of astronomy which attempts to describe the evolution of the universe, from what happened the merest instant after its birth, 13.7 billion years ago, until the present day. We're going to travel back to the farthest reaches of history, when space and time (or as we shall see, *spacetime*) were created, out to the farthest distance we can observe, to the edge of the observable universe. As if that was not enough, we're also going to be venturing to the other extreme. We'll need to understand the interactions of subatomic particles in those first moments of the universe, because incredibly, this will allow us to explain how tiny random fluctuations have given rise to the greatest known structures in the universe. Cosmology encompasses many different disciplines and we will need to touch on all of them to answer the big questions we have posed.

However, sometimes it is the simplest questions that provide the most insightful answers.

Why Is the Night Sky Dark?

In the 17th century, the English scientist Isaac Newton put gravity on a firm scientific foundation, by describing it as a force between all objects with mass. As a consequence of this theory, he considered how the stars in the sky would interact and posited that the number of stars must be infinite and, to be static, they must be finely balanced in their positioning to avoid gravitational influences between them. His incorrect, but logical, assumption is that they would otherwise be attracted together and collapse, and that was clearly not what was happening.

In the early 19th century, the German Heinrich Olbers [1] identified a problem with Newton's infinite and static model that became known as *Olbers' paradox* (see Fig. 1). Simply put, he reasoned that if the sky was infinite, and of infinite age, there would be an infinite number of stars. If the universe was also static then, he argued, in whichever direction you looked, there would be light from a star visible, and thus the sky should be bright - the paradox, is that the night sky is dark and so, clearly, something was amiss. This was, perhaps, the first crisis to befall cosmology.

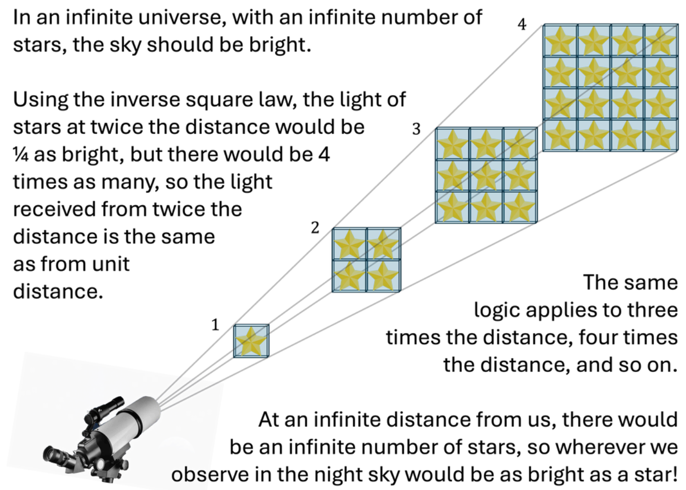

Figure 1. Olbers' paradox. In an infinite universe, with homogeneous and infinite stars, the night sky should be bright. Credit: Author.

The question of the dark night sky had actually been pondered for many years; as far back as Johannes Kepler in 1610 [2], solutions to the dark sky were suggested. Kepler hypothesized the universe was not infinite, and Olbers himself suggested the light was absorbed in some way. It was not until the beginning of the 20th century, when German Albert Einstein came along with a new theory to explain gravity, that half the story was explained.

Einstein and General Relativity

Newtonian space is flat, and totally unrelated to time. If we restrict ourselves to two dimensions (which is a valid, but easier visualization), we can think of a flat piece of graph paper, extended in all directions, infinitely (see

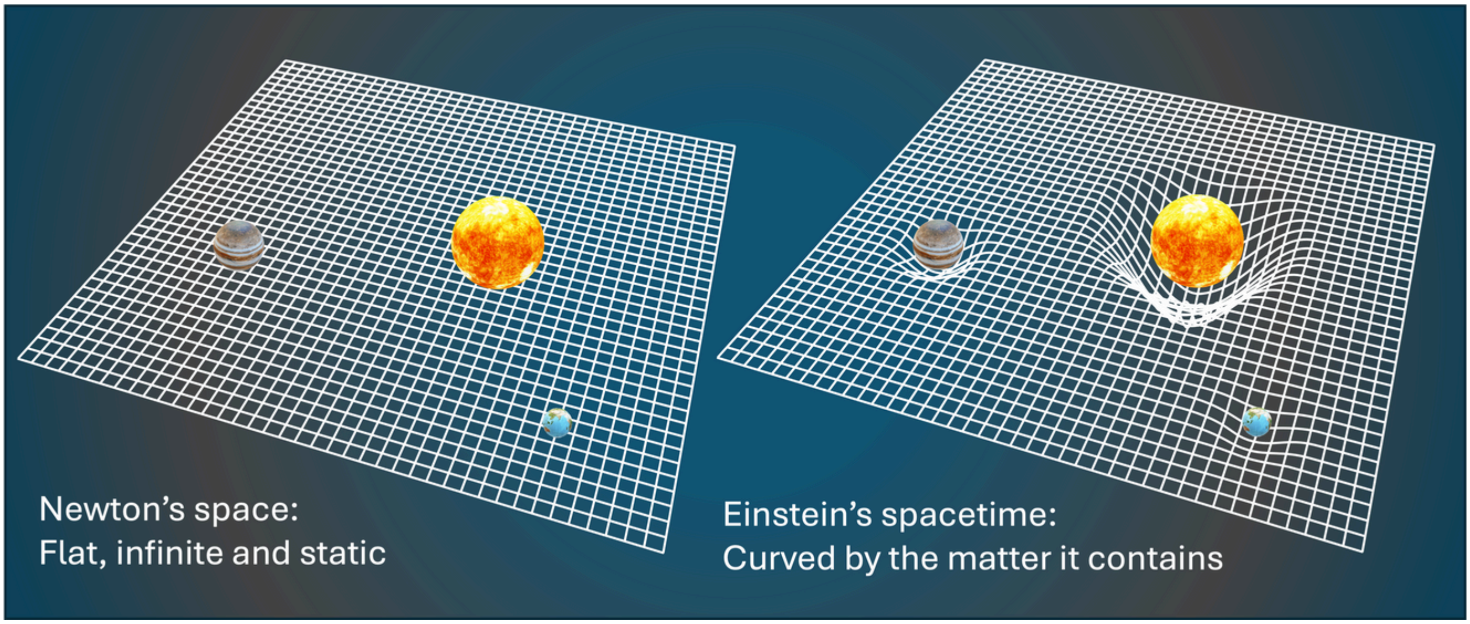

Figure 2. A 2-dimensional visualization of flat Newtonian space (left) in comparison to Einstein's spacetime (right) which is curved by the mass of the matter it contains. Credit: Author.

Figure 2 - left). The squares on the graph paper denote our scale, which is constant in each direction and never varies. This is Newton's space which is unaffected by anything in it. Time, in Newton's view, is a totally unrelated concept to space.

Things are a little different in Einstein's world. In his view, space and time are part of the same entity - *spacetime*, and the key difference here is that matter will distort the *fabric* of spacetime such that it can no longer be considered flat (see Figure 2 - right). In our 2D graph paper analogy, there will be troughs at the positions of all the matter. Matter will move through curved spacetime along the shortest path across the surface created by matter. Gravity is no longer a force between objects, but merely the path an object takes when falling into the gravitational well created by another object. An object merely to continues in a straight line in curved spacetime! To quote the American physicist John Wheeler,

> *Spacetime tells matter how to move; matter tells spacetime how to curve.*

Gravity is not a force in Einstein's view of the universe. Objects such as apples falling from a tree, planets orbiting stars, or even stars orbiting galaxies, do so because they are on a trajectory along the shortest path (geodesic) lines of curved spacetime. In 1915, when Einstein published his theory of general relativity (GR), the prevailing view of the universe was that of Newton's in that it was static. Einstein realized his equations predicted that the universe might either be expanding or contracting [3] and he and Dutch physicist Willem de Sitter spent much time in 1916 formulating static 'solutions' to his GR field equations. However, they found that any solutions describing a (realistic) universe containing matter could not be stable. Einstein therefore, becauase of the prevailing view of the static universe, to his subsequent regret, added a term to his equations to 'balance' the fact that a universe filled with matter must either be expanding or contracting, denoted with the Greek letter Λ (lambda). This became known as the cosmological constant.

Hubble and the Expanding Universe

Although a static universe was the prevailing view in the early 1920s, both theoretical and observational evidence was beginning to accumulate to suggest otherwise. In 1922 [4] and 1924 [5], Alexander Friedmann, a Russian mathematician, published solutions to Einstein's equations which again suggested a non-static universe. Then, in 1927 the Belgian Roman Catholic priest Georges Lemaître published a paper [6] theorizing the recession of galaxies, measured by astronomers such as Vesto Slipher [7], was due to the expansion of the universe. However, Lemaître published in a small journal and his work was largely overlooked. He even tried to discuss his ideas and theory with Einstein, who commented,

> *Your calculations are correct, but your physics is abominable!*

While the theoretical debate was raging in the 1920s, Edwin Hubble and his assistant Milton Humason were taking photographs of distant galaxies. They were able to identify Cepheid variables in many of these galaxies, and as a result, were able to determine their distance, using the period-luminosity relationship discovered by Henrietta Leavitt some years earlier. Additionally, by analyzing the intensity of the different colors, or spectrum, of the light from the galaxies, they were able to establish their speed of recession. They noted a simple linear relationship between the recession velocity of the galaxies and their distance (see Figure 3).

This evidence was the nail in the coffin for a static universe, and the first formulation of what we now refer to as the *Hubble constant*. The estimate of the Hubble parameter in their paper is off by almost an order of magnitude due to the process they used to calibrate their distances. Nevertheless, Hubble and Humason's paper [9] was seminal and expounded many of the problems which would need to be solved to obtain an accurate view of the universe in which we live. The Hubble law is a simple equation derived from the straight line relationship in their original recession velocity plot, that is

$$v = H_0 d$$

which means the recession velocity of the galaxies is equal to the product of their distance and constant, H_0, the Hubble constant (see Box 1).

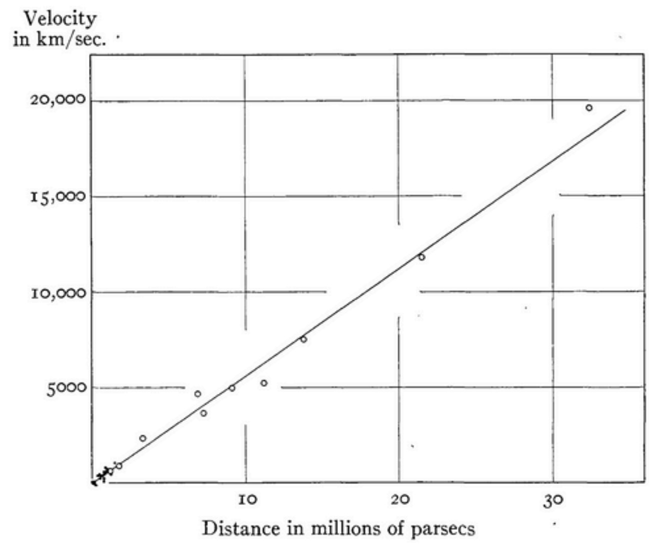

Figure 3. The recession velocity-distance relation formulated by Hubble and Humason in their later 1931 paper, showing a clear linear relationship. Credit: Hubble and Humason [8].

Over the next few years all but a few physicists accepted that what eventually became known as the Hubble-Lemaître law, proved beyond doubt that the universe was expanding. The reason this worried so many scientists prior to the proof, and the implications, however, are deeply profound, and this was the point at which modern cosmology was born.

While the universe we live in was considered static and stable, there was a permanency associated with it. Perhaps it is a deep-seated instinctive fear of change or the unknown, that an eternal, infinite, and unchanging universe is comforting. Knowing it had always been there, and always would be there, implies we do not have to confront many difficult questions, many of which are more in the realm of philosophy than physics. This is probably, perhaps subconsciously, why so many scientists resisted the implications of Einstein's equations.

Box 1. The Hubble Parameter
The Hubble constant should more rightly be named the *Hubble parameter*, because it is not actually constant and varies over time and it has units of kilometers per second per megaparsec (km/s/Mpc). H_0 is the value that the parameter has in the present day, estimated to be either 67 km/s/Mpc or 73 km/s/Mpc, depending upon the method used in its determination.

Now though, Einstein, Slipher, Freidmann, Lemaître, Hubble, Humason, and others had opened Pandora's box. The genie was out of the bottle, and physicists had to face the implications of the real world in which we live.

If the universe is expanding, there are a number of key questions which arise.

1. What is it expanding from?
2. What is the universe expanding into?
3. How has it expanded in the past and how will it expand in the future?

Physicists were quick to realize the first of these questions implied a beginning—a beginning to the universe, which followed Einstein's equations, suggesting a beginning to spacetime; a beginning of space and time, implicit in the reversal of the expansion backwards to a point of origin.

If we make a movie of the galaxies flying apart, and if we then reverse that movie, we would see them moving back together. As they do so, as we move back in time many billions of years, we see that the matter in the universe becomes more densely packed and the temperature rises. The point at which they meet, an unimaginably high density point containing all the matter and energy in the universe, is time zero. The event which kicked off the expansion is referred to as *The Big Bang* (see Figure 4).

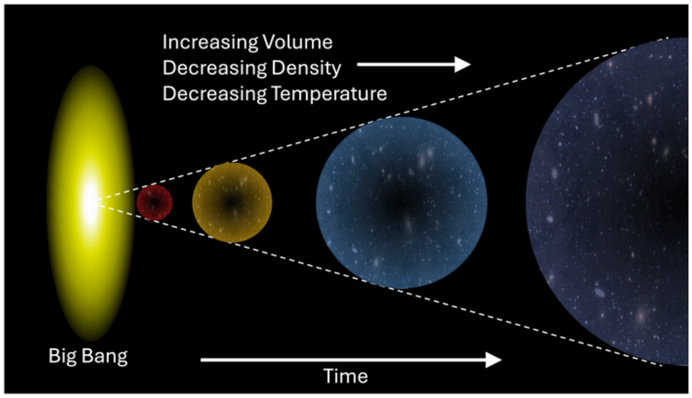

Figure 4. The expansion of the Universe implies a big bang, a point at which space, and time, began. It also implies the Universe was a lot denser and hotter in the past. Credit: Author.

Before we delve into the detail of the Big Bang, we should consider the other two questions above.

What is the universe expanding into? By definition, the universe is everything, including all the space within it. The expansion of the universe is the expansion of space and so to ask what is 'outside' the universe is not a logical question. It is perhaps unfortunate that the Big Bang is often described as an explosion. This is incorrect, as an explosion has matter and energy expanding into space. Since the instant of the Big Bang, the universe has contained all space and always will, thus we can think of the Big Bang as the moment of creation.

How has it expanded in the past and how will it expand in the future? This is the key question cosmologists have been trying to determine for decades. Let's do a thought experiment throwing a ball. When you throw a ball up in the air, how far it goes depends upon two things: how hard you throw it, and the force of gravity on your planet. There are a number of possible outcomes of us throwing our ball into the air. The most likely is the outcome we are familiar with, where the ball follows a curved (parabolic) trajectory, slowing down before stopping its vertical ascent for an instant and then speeding up while it plummets back down to Earth (Figure 5 - left). However, if you could launch this ball hard enough, it is possible that it would escape the gravitational influence of the Earth by climbing out of the Earth's gravity well. Once in free space, it would continue forever (Figure 5 - center).

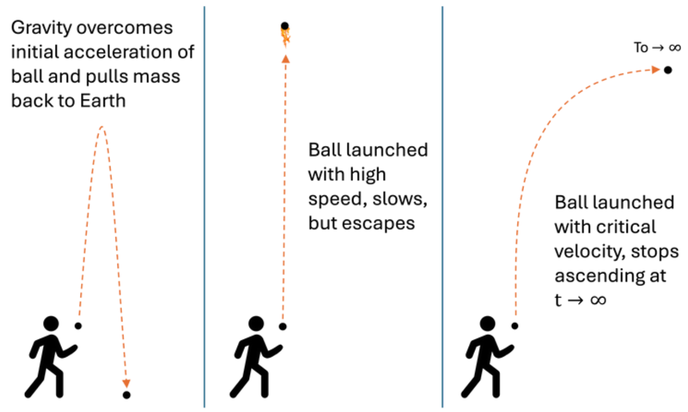

Figure 5. Throwing a ball into the air (theoretically) has three possible outcomes. The ball returns to Earth (left). The ball escapes Earth's gravitational influence and continues forever (center). The ball neither escapes nor returns, when launched at a critical velocity in relation to gravity (right). Credit: Author.

There is a third possibility. If we throw the ball up at a very special speed, which we will call the critical velocity, it may just be able to climb out of the Earth's gravity well, but take an infinite amount of time during the slowing down portion of its trajectory, so the 'turnaround' point where it is instantaneously stationary, would occur only at infinite time. Such is the critical balance between the force with which it is thrown, and the downward pull of gravity (Figure 5 - right).

If the force with which the ball is launched is constant in all cases, we can also consider variations in gravity. For example, a ball thrown on the Moon would go a lot farther for the same initial velocity. Now, we know from Newton and Einstein that the 'force' of gravity is dependent upon mass, and so we can define something called the mass density, which is just the amount of mass per unit volume. With our constant upward launching speed for the ball, we can then relate the three possible outcomes to the mass density of the planet in our experiment.

Box 2. Mass-Energy Equivalence

Remember Einstein and his theory of general relativity? Well, this was his second publication on relativity. In 1905 he published his theory of *special relativity*. It was special, primarily because it did not account for gravity, but in it Einstein first articulated probably the most famous equation in the world

$$E = mc^2$$

which states in simple terms that energy (E) is equivalent to mass (m) with the constant of proportionality being the speed of light squared (c^2) - i.e., a very big number! This explains how nuclear power, nuclear bombs, and the cores of stars produce so much energy from comparatively little mass.

Finally, let's imagine that instead of your hand throwing a ball, you have the Big Bang kicking off the expansion of the universe, and in place of the gravity of the planet, you have the gravity imparted by the mass density of all of the matter and energy in the universe (see Box 2). In our three outcomes, the 'ball' being pulled back is representative of what is referred to as a 'Big Crunch' - if the universe contained sufficient matter, this might have been its ultimate fate. The ball continuing forever is indicative of the universe expanding *ad infinitum*, with insufficient mass to slow or reverse the expansion, and this is sometimes referred to as the 'Big Freeze'. We can also finally define a parameter called the *critical density* (ρ_C) which represents the average density the universe would have to have for the expansion to be forever slowing to a halt.

With the visualization of our ball-throwing thought experiment, we can now also discuss the *type* of universe we live in, and its *shape* or *curvature*. So what do we mean by the shape of the universe? Here we are discussing the concept of geometry, and we can extend

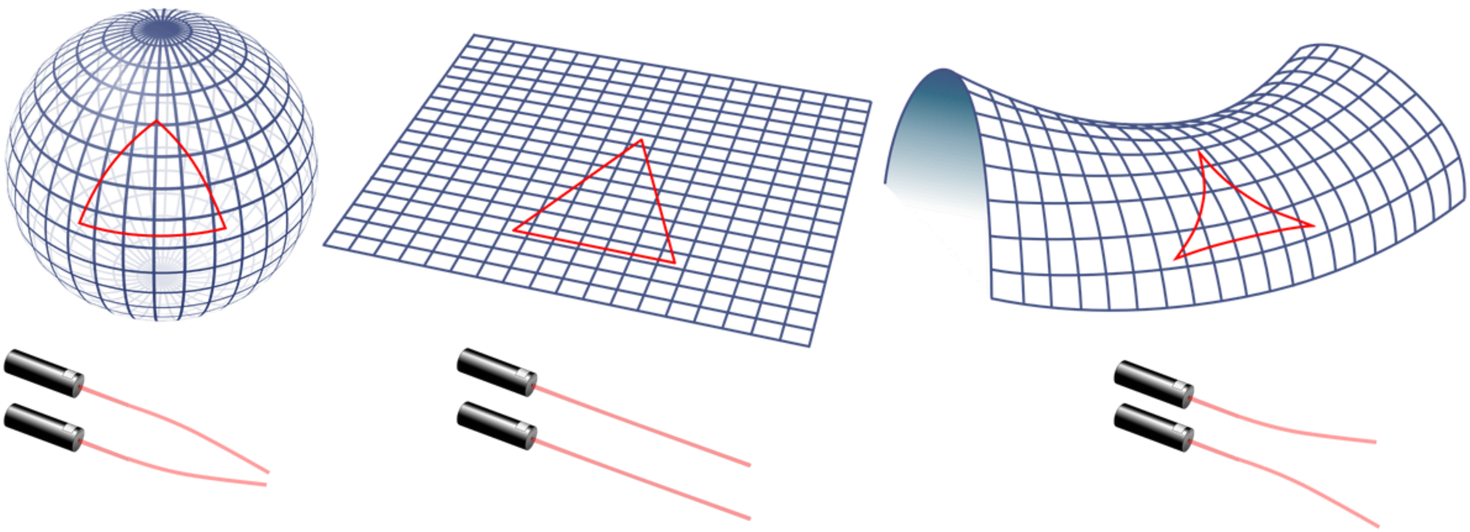

Figure 6. Possible geometries for the curvature of space. (Left) Spherical geometry / positive curvature denoting a closed universe. (Center) Flat geometry / no curvature denoting a flat universe. (Right) Hyperbolic geometry / negative curvature representing an open universe. The 'lasers' show the effect of the geometry on parallel light rays over vast distances. Credit: Author.

the concept we introduced in Figure 2, but this time for the whole of the universe. So, we have three potential types of universe which we have to consider: *closed*, *flat*, and *open*.

These descriptions of the type of universe we inhabit correlate with the outcomes of our ball either returning (closed), always decelerating (flat), and escaping (open). The types of universe, and their associated geometries, are shown in Figure 6 using our 2D visualization. The figures also show the effect the geometry has on parallel light rays. In a closed/spherical universe, parallel rays converge, in a flat universe they remain parallel, and in an open/hyperbolic universe they diverge. As we mentioned earlier, the amount of matter the universe contains will determine its ultimate fate, in terms of crunching, slowing, or expanding forever. So, **the curvature of the universe is determined by the amount of matter it contains**. This is what we would expect from Einstein's equations (remember John Wheeler's '*matter tells spacetime how to curve*').

If we define the average density of the total matter and energy in the universe at present, referred to as the combined mass density (ρ_0), then we can compare this present day density value with the critical mass density (ρ_c) we defined earlier.

When we compare our measured average mass density in a ratio with our critical mass density, we end up with what cosmologists call the density parameter, omega (Ω)

$$\Omega_0 = \frac{\rho_0}{\rho_c}$$

and the advantage of this is that, for a flat universe, Ω_0 = 1, and similar comparisons can be made for open and closed universes as shown in Table 1.

Although this may sound abstract, we are able to determine the curvature of space, using the light that has been traveling for almost the entire age of the universe, known as the cosmic microwave background (CMB). This is our 'laser' (see Figure 6).

Combined mass density (ρ_0)	Type of Universe	Geometry	Curvature	Density parameter (Ω_0)
$\rho_0 > \rho_c$	Closed	Spherical	Positive	$\Omega_0 > 1$
$\rho_0 = \rho_c$	Flat	Flat	Zero	$\Omega_0 = 1$
$\rho_0 < \rho_c$	Open	Hyperbolic	Negative	$0 < \Omega_0 < 1$

Table 1. Effect of varying amounts of matter/energy in the universe on type of universe, geometry, and curvature of space. Adapted from Freedman et al. [10].

Box 3. The Fundamental Forces
Physicists have found four fundamental forces existing in nature. These are the *electromagnetic*, the *weak* and *strong nuclear forces*, and *gravity*. The **electromagnetic force** is associated with charges and their movement, and is responsible for chemical reactions between atoms. The **weak nuclear force** is responsible for radioactive decay of unstable atoms. The **strong nuclear force** is responsible for holding the nuclei in the centers of atoms together. **Gravity** is our old friend, responsible for the shape of spacetime, and although it is the weakest force, unlike the other forces, it is a long range force.

Before we do that though, we need to go through the events of the first few hundred thousand years after the Big Bang.

The Evolution of the Universe
We have established that the universe is expanding, due to the speed of recession of galaxies away from us. Note this does not mean that we are in a special location (i.e., the center!), merely that everywhere in the universe is moving away from everywhere else. If we play the movie of this expansion backward, we get to a point in time and space where everything is 'together'. This is what we now need to explore.

Density is a measure of how much matter (and energy!) there is per unit volume. If we assume that the amount of matter in the universe now is the same as the amount of matter a few moments after the Big Bang, then as we wind the clock backward, the same amount of matter has to fit in an ever decreasing volume. The density will increase as we get ever closer to the beginning of time, and as the matter and energy are compressed into a smaller volume, the interaction of the matter and energy increases, which increases temperature. With increases in temperature, the four fundamental forces of nature (see Box 3) start to resemble each other and are indistinct. This is currently our best cosmological model, and so where we begin our journey back to the present. To make things easier to track, we will divide into eras dominated initially by *radiation*, then *matter* and finally *dark energy*.

Radiation Era
The radiation era, in particular, is unfamiliar, and while it covers the shortest time period (albeit a few tens of thousands of years) it contains some of the most significant cosmic events, so cosmologists subdivide the radiation era into epochs (see Figure 11).

Planck Epoch - The merest instant of time after the Big Bang - known as the *Planck epoch* ($<10^{-43}$ seconds) all four forces are thought to have been equal in strength. High energy particle physicists and theoretical cosmologists are combining their efforts to attempt to describe this time with a theory of everything (TOE - see Figure 7). This is as far back as we can currently conceive of describing with physics. Before this point in 'time' we would be venturing into the domain of philosophy, so we

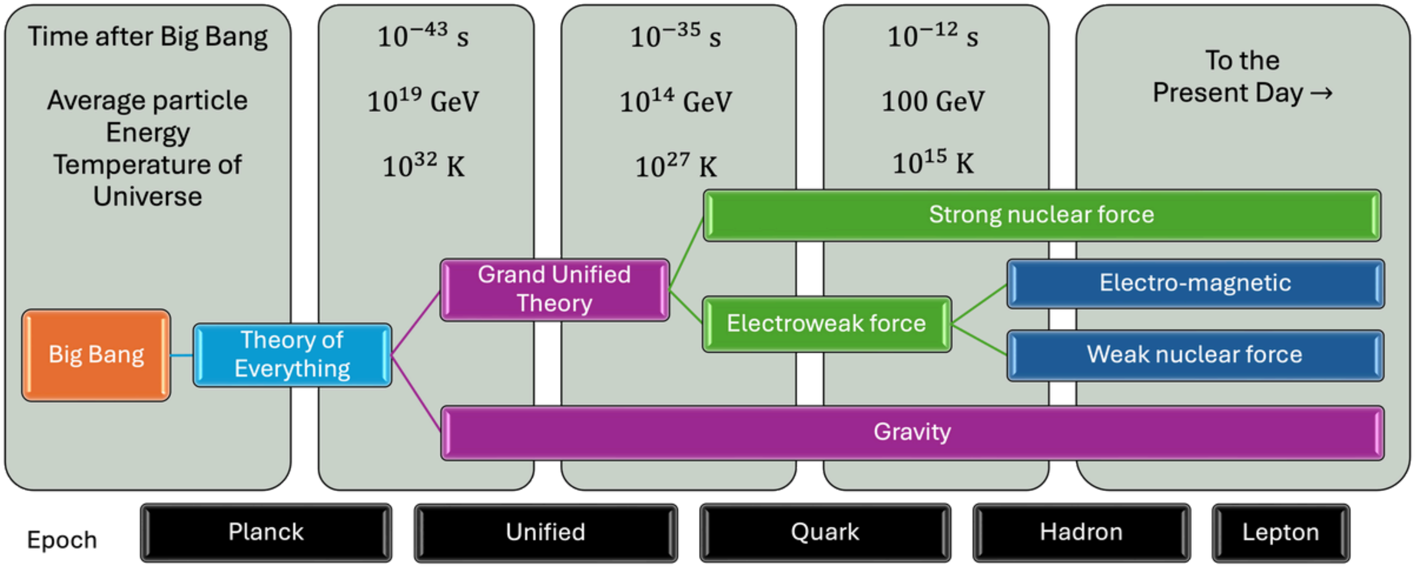

Figure 7. The four fundamental forces of nature (see Box 3) are thought to have been indistinguishable and unified an instant (a Planck time) after the Big Bang. Credit: Author.

won't be going there today!

Unified Epoch - Moving forward from the Planck time, where the force of gravity has decoupled from the other forces and theorized *graviton* particles streamed out into the universe, we enter what is known as the *unified epoch*. During this time the temperatures and energies involved were so high that even grand unified theories (GUT) struggle to explain fully what was happening. However, a particular aspect is key to our understanding of the *smoothness* of the universe. This event is known as *inflation*. At about 10^{-37} seconds after the Big Bang, the universe expanded exponentially between e^{100} and e^{1000} times. These are unimaginably big numbers!

In the quantum soup (see Box 4), virtual particles which had popped into existence would suddenly have been separated by immense distances and unable to annihilate with each other. Virtual particles became real, so by the end of the unified epoch, the vacuum energy of space had been converted into more conventional forms of energy [11].

Box 4. The Quantum Soup

Empty space, the vacuum of outer space, is not empty. Even in a theoretically perfectly empty space, quantum mechanics tells us that virtual particles and anti-particles pop briefly into existence, borrowing energy (ΔE) from the vacuum of space itself before paying back and annihilating an instant (Δt) later. The longevity of these virtual particles is inversely proportional to the amount of energy borrowed, through something called the Heisenberg uncertainty principle

$$\Delta E \times \Delta t \geq \frac{h}{4\pi}$$

where h is Planck's constant (6.626×10^{-34} Js).

Although there was much matter-antimatter annihilation after inflation, because of a process called *baryogenesis*, there was a slight excess of matter, and this is the reason the universe exists!

Quark Epoch - The start of the quark epoch marks the point at which a 'spontaneous symmetry breaking' or *phase transition* occurred, due to the temperature dropping to the point that the strong nuclear force decoupled from the remaining forces. Here, a phase transition can be thought of as the change of state of a substance, for example, similar to when steam condenses to water as it cools.

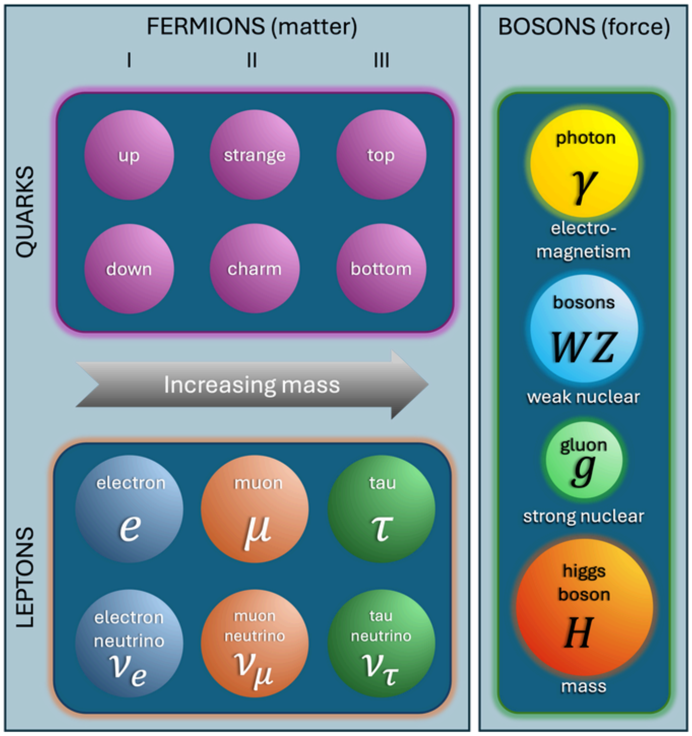

Figure 8. The Standard Model of Particle Physics is one of the most successful descriptions of particle interactions. Credit: Author.

In the present day, quarks (see Figure 8) do not like to exist on their own, but during the quark era, the universe was a soup of quarks and *gluons* (the strong nuclear force mediators), referred to as the quark-gluon plasma. Around 10^{-12} seconds, the final phase transition occurred with the breaking of the electroweak force into the present day electromagnetic and weak forces [10]. At the temperatures involved, energetic (gamma ray) photons began to stream around stimulating pair production and annihilation (see Figure 9).

Hadron Epoch - Around 10^{-6} seconds (one microsecond) after the Big Bang, the temperature had dropped sufficiently to allow the quarks to condense into hadrons (see Box 5) which ushered in the brief hadron epoch. This process is referred to as *quark confinement* and included production of *mesons* with quark-antiquark combinations, or *baryons* with three quark combinations. Baryons include protons (two up + one down quarks) and neutrons (one up + two down). Pair production continued, but as the universe continued to expand and the temperature dropped, the photons did not carry sufficient energy to produce heavier particles like protons and neutrons, and baryonic matter production ceased. During this time, baryonic particle-antiparticle pairs annihilated, but due to an asymmetry remaining after the unified epoch, it is estimated there was one additional matter particle for every billion matter-antimatter pairs. This is the reason we see about one billion cosmic photons for every particle of baryonic matter in existence today. This epoch ended the condensation and decoupling of the protons and neutrons, and ended the domination of the hadronic matter associated with the strong nuclear force.

Box 5: The Particle Zoo

Atoms (from the Greek *atomos*, meaning indivisible) are the smallest constituents of matter we deal with on an everyday basis, i.e., chemical reactions. However, atoms themselves are divisible into smaller constituents which become evident at higher energies (or temperatures) such as briefly in particle accelerators, or just after the Big Bang. The nuclei of atoms are composed of protons and neutrons, but, as shown in Figure 8, even these are not considered fundamental. The fundamental matter particles are known as *fermions*, which consist of *quarks* and *leptons*, and force mediators (or carriers) known as *bosons*. Quarks, however, do not like to exist on their own, and make up other types of matter known as *hadrons*. The situation is further confused by subdividing hadrons into particles with three quarks (*baryons*) or two quarks (*mesons*). The main difference between quarks and leptons is quarks are subject to all four fundamental forces, whereas leptons do not interact through the strong nuclear force.

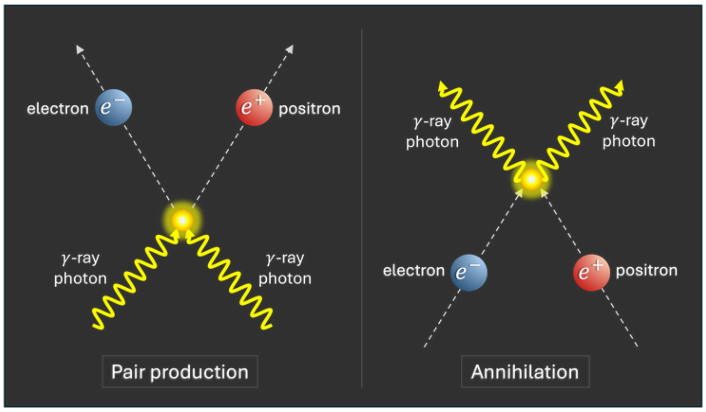

Figure 9. Pair production and annihilation in the early universe. When gamma (γ) rays have sufficient energy, they can create particle-antiparticle pairs in a process called pair production (shown here for electrons and positrons). The interaction of particles and antiparticles can also annihilate, transforming back into energy in the form of gamma rays. Credit: Author.

Lepton Epoch - At around 10^{-4} seconds (0.1 milliseconds) after the Big Bang, the lighter fermions, called *leptons*, began to dominate. Leptons do not interact through the strong nuclear force, but are subject to the weak nuclear force. Although, at the start of the lepton epoch, heavier particles such as *muons* were produced (see Figure 8) through pair production, as the temperature dropped the photon energies became insufficient to produce the higher mass leptons, and electrons (and their antiparticle, *positrons*) began to dominate.

At this stage (still much less than one second after the Big Bang!), the universe consisted primarily of photons (γ), electrons (e^-), positrons (e^+), neutrinos (ν) and antineutrinos ($\bar{\nu}$), along with the sparse 'remnant' hadrons, protons (p) and neutrons (n), from the previous unified and hadron epochs. Interactions between the protons, neutrons, and the leptons occurred to maintain equal numbers of protons and neutrons. However, at about 0.1 seconds after the Big Bang, with the continued cooling through expansion (at this stage the temperature was about 10 billion kelvin), the slightly higher mass of the neutron made reactions producing protons more favorable. A mere one second into the life of the universe, the proton-neutron ratio was frozen at 5:1 [3]. By this stage the density had dropped sufficiently through the expansion that the diminutive neutrinos no longer interacted with other particles, and so 'decoupled', streaming off through the universe (see Figure 11).

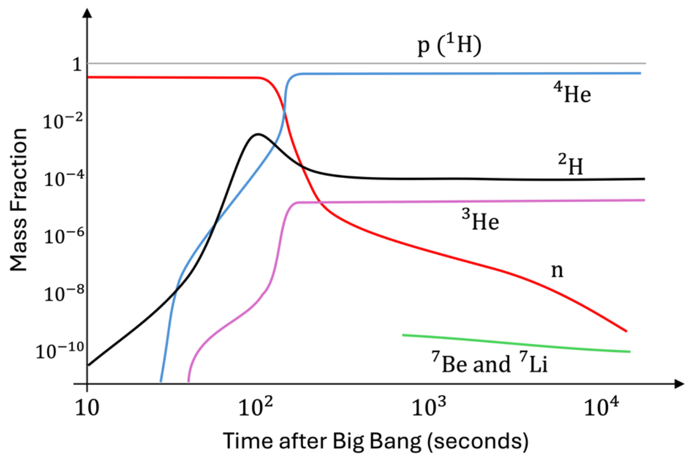

Figure 10. Mass fractions of light isotopes during the period of Big Bang nucleosynthesis. Adapted from Freedman et al. [10]. Credit: Author.

Nucleosynthesis Epoch - After about three minutes, the temperature was sufficiently cool (~10 K) that the nuclei of atoms could remain stable, and so a process called primordial nucleosynthesis could begin. At this stage, the protons outnumbered the neutrons by 5:1, but free neutrons decay into protons with a half-life of about 11 minutes, so in practice all the free neutrons must have reacted within little more than three minutes.

As their name suggests, neutrons are neutral particles and in this dense, high temperature period they could combine easily with protons to form *deuterium* (D or ^{2}H) or heavy hydrogen (see Figure 10). Following this, the deuterium might either capture a proton to form *tritium* (^{3}H) or another deuterium or further tritium nuclei to form *helium* (^{3}He or ^{4}He). These were the main reaction paths

$$\mathrm{p} + \mathrm{n} \longrightarrow {}^{2}\mathrm{H} + \gamma$$
$${}^{2}\mathrm{H} + \mathrm{p} \longrightarrow {}^{3}\mathrm{H} + \gamma$$
$${}^{2}\mathrm{H} + {}^{2}\mathrm{H} \longrightarrow {}^{3}\mathrm{He} + \mathrm{n}$$
$${}^{2}\mathrm{H} + {}^{2}\mathrm{H} \longrightarrow {}^{3}\mathrm{H} + \mathrm{p}$$
$${}^{3}\mathrm{H} + {}^{2}\mathrm{H} \longrightarrow {}^{4}\mathrm{He} + \mathrm{n}$$

From the products of these first nuclear reactions, some other light isotopes were also produced, such as *lithium* (^{6}Li and ^{7}Li) and *beryllium* (^{7}Be) through reactions such as the following

$${}^{4}\mathrm{He} + {}^{2}\mathrm{H} \longrightarrow {}^{6}\mathrm{Li} + \gamma$$
$${}^{4}\mathrm{He} + {}^{3}\mathrm{He} \longrightarrow {}^{7}\mathrm{Li} + \gamma$$
$${}^{4}\mathrm{He} + {}^{3}\mathrm{He} \longrightarrow {}^{7}\mathrm{Be} + \gamma$$
$${}^{7}\mathrm{Be} + \mathrm{e}^{-} \longrightarrow {}^{7}\mathrm{Li} + \gamma$$

although the density of the helium was minimal by the time these reactions occurred, so the fraction of lithium and beryllium in the universe created by primordial nucleosynthesis, compared to hydrogen, is less than one in 10 billion. Reactions creating ^{8}Be did occur, but this isotope of beryllium is highly unstable and decays almost instantly into two ^{4}He, and thus this pathway was closed off and the occurrence of heavier elements is negligible.

Isotope	Fraction by Mass
H	$\sim 75\%$
^{4}He	$22 - 26\%$
^{2}H	$\sim 0.01\%$
^{3}He	$\sim 0.001\%$
^{7}Be	$\sim 10^{-8}\%$
^{7}Li	$< 10^{-8}\%$

Table 2. Fraction of light elements, by mass, produced in the early Universe. Adapted from Hawley and Holcomb [11].

At the end of the nucleosynthesis epoch, a mere 15 minutes after the Big Bang occurred, the abundance of light elements in the universe was set as per Table 2. It would not be until the first stars formed a few hundred million years later, and stellar nucleosynthesis began, that heavier elements would then start to appear in the universe.

Photon Epoch - While the relative abundances of the lighter elements produced through primordial nucleosynthesis depends upon many different factors, one of the key determining physical parameters is the baryon-to-photon ratio, or in other words, the ratio of matter-to-radiation of the universe. This can be related to the density of matter (baryons). While not easy to do, the abundances of these isotopes can be measured through observations of the emissions from primordial environments, and the theoretical predictions of the Big Bang nucleosynthesis (BBN) model, can be compared with the observed abundances. This process has been carried out and allows cosmologists to constrain the present day baryon density of the universe [11]. These results reveal that baryonic matter constitutes only ~5% of the critical density (ρ_c) we discussed earlier! As inflation suggests that the universe is very close to the critical density, this is another argument suggestive of the existence of dark matter and dark energy.

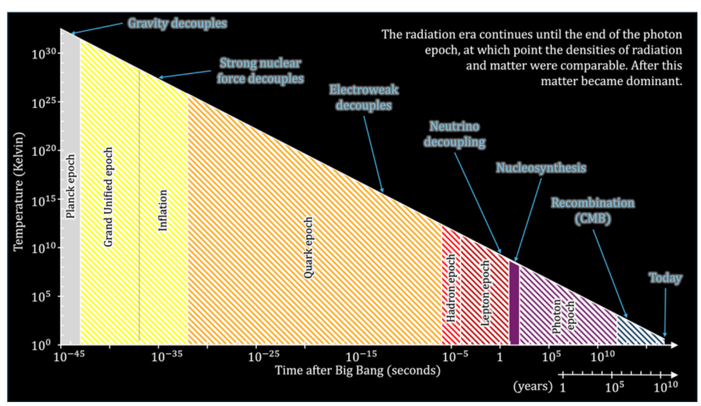

Figure 11. The significant epochs and events in the early history of the universe, shown with temperature vs. time. Adapted from Hawley and Holcomb [11]. Credit: Author.

We are nearly at the end of the radiation dominated era. As the universe continued to expand and cool, the density of both radiation (energy) and matter (mass) it contained decreased. However, the radiation density decreases faster than the mass density, so after ~30,000 years (10^{12} seconds) the radiation and matter densities became comparable (see Figure 11), and the matter dominated era began.

Matter Dominated Era

As the radiation density decreased faster than the matter density, it soon became negligible with respect to the overall gravity slowing the expansion. The universe consisted of photons and matter. However, the temperatures were still too high for the electrons be captured and combine with the nuclei to form atoms. The two existed in a state called plasma, which was in thermal equilibrium with the photons, meaning that the photons of radiation interacted with the matter. The photons were easily scattered by the free electrons, and the upshot of this is the universe would have been both hot and opaque, rather like the surface of the Sun. For the first few hundred thousand years, the universe was foggy.

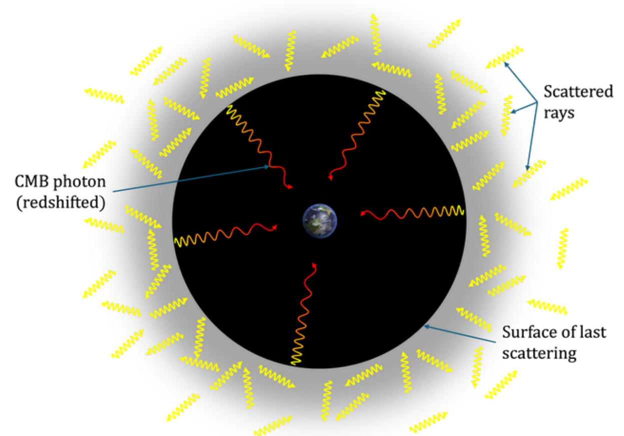

Figure 12. As we look out into space, we also look back in time. Over 13 billion years ago, the universe became transparent to photons which have now been redshifted by the expansion. We detect them as the cosmic microwave background - the afterglow of the Big Bang. Credit: Author.

Recombination - As the universe expanded and the temperature dropped further, the nuclei were finally able to capture (and retain) the electrons creating the first atoms in a process called *recombination*. Photons interact significantly less with atoms, than they do with free electrons, so it was at this point 380,000 years into its life that the universe became transparent and the photons of light, after one last scattering, were free to travel unimpeded (see Figure 12).

These photons, originally at about 3000 K, have been traveling for well over 13 billion years, but have been stretched in wavelength, losing energy, as the universe has continued its expansion. They are now at a temperature of just under three kelvin and are detectable at microwave wavelengths. We observe these stretched photons all over the sky, and it is referred to as the *cosmic microwave background* (CMB). Cosmologists also poetically call the edge of the fog, when the universe became transparent, the *surface of last scattering*.

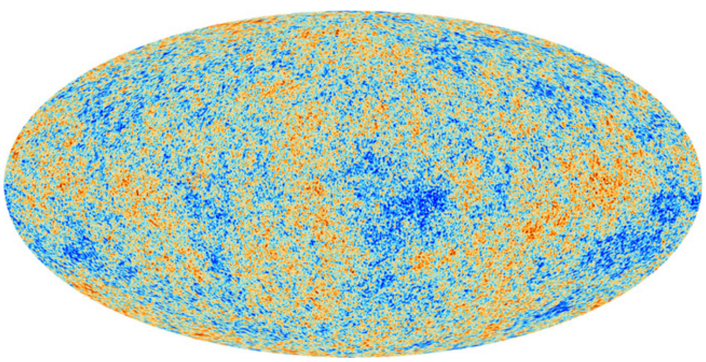

Figure 13. All sky image of the CMB as seen the ESA Planck mission, showing the tiny temperature fluctuations in the early universe, which led very quickly to the formation of structure. Credit: ESA and the Planck Collaboration.

Imaging of the CMB (see Figure 13), by space telescopes such as NASA's Cosmic Background Explorer (COBE), the Wilkinson Microwave Anisotropy Probe (WMAP), and ESA's Planck satellite, have shown it to be extraordinarily smooth, with essentially the same intensity in all directions. However, there are small variations, or fluctuations, in the temperature of the microwave background, indicating that the universe had minuscule variations very early in its life. It is thought that these variations originated from the quantum level density fluctuations before inflation occurred and that inflation stretched these to appreciable size.

Box 6: Primordial Sound Waves

Unlike light, sound waves need a medium in which to travel. Early in the life of the universe, prior to *recombination*, the density of the particle soup (protons, electrons, and photons) was over a billion times denser than it is now. Collisions between the particles allowed sound waves to travel throughout the early universe imprinting compression and rarefaction into the redshift, and thus the temperature, of the cosmic microwave background that we observe in the present day. These sound waves are referred to as *baryon acoustic oscillations* or BAO.

As described in Box 6, sound waves, or baryon acoustic oscillations (BAO) traveling through density fluctuations in the early universe would have been imprinted in the CMB. The nature of these fluctuations gives us a means to determine the properties of the material through which the sound wave was traveling. These properties include the densities of the matter and dark energy, as well at the rate of expansion (the Hubble parameter) at the time of recombination. By modeling variations on these properties we can then find a best fit of parameters to the observed BAO, and compare these to properties inferred by other observations.

One key observation is that there should be a peak in the relative number of 'hot' spots with an angular size on the sky of one degree (see Figure 14), and this is exactly what the WMAP and later the Planck teams found [12].

Now, recall, we mentioned about measuring the divergence or convergence of 'lasers' across vast distances, in order to validate the 'shape' of the universe

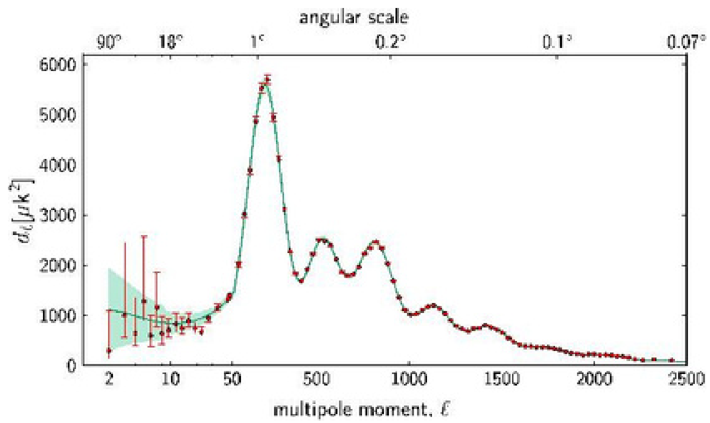

Figure 14. Relative number of hot spots vs. angular size on the sky of the baryon acoustic oscillations (sound waves) in the plasma of the early Universe. The fit of these observations to data confirms a number of cosmological parameters associated with the cosmic microwave background. Credit: Planck Collaboration et al. [12].

(see Figure 6). If the universe was closed, the light rays from the oscillations would converge, making the angular size appear larger, and similarly, if the universe was open, the light rays from the oscillations would diverge, making the apparent angular size smaller. However, as we observe the hot spots to be exactly the same size as predicted, this implies that the light rays have remained parallel throughout their journey across the cosmos and thus **the universe is flat**.

It is curious to reflect at this point, that if it had not been for the initial quantum fluctuations, gravity would not have had time to collapse matter into the galaxies, galaxy clusters and other large scale structures that we see in the universe, and the world would be a very different place!

Even with the fluctuations, simulations have shown the need for additional matter to explain how galaxies formed so quickly after the Big Bang. This additional matter is not baryonic matter, in that it does not interact through the electromagnetic force, meaning it does not emit or absorb light, hence the name *dark matter*. This additional matter can be detected through its gravitational influence, such as at the edges of galaxies where stars are rotating much faster than expected, and also in simulations of the evolution of the structure of the universe. Dark matter has been proposed to take many forms, including neutrinos, which we met earlier (see neutrino decoupling in the lepton epoch, Figure 11), or alternatively what are referred to as *weakly interacting massive particles* (WIMPs), an as yet undiscovered particle. These two types of particle are distinguished as either hot dark matter (HDM) or cold dark matter (CDM), respectively. Simulations of the evolution of the early universe suggest that the CDM model more accurately reproduces the observed "bottom up" formation of the universe (see Box 7).

Box 7: Bottom-Up or Top-Down?

The 'bottom-up' formation of galaxies involves a model where pockets of gas collapse to form the earliest stars, which then stream toward dense filaments to form galaxies, which themselves clump together at intersections of these filaments to form galaxy clusters and superclusters.

In the 'top-down' model, supercluster-sized 'sheets' of matter form first, and then fragment into galaxies [10].

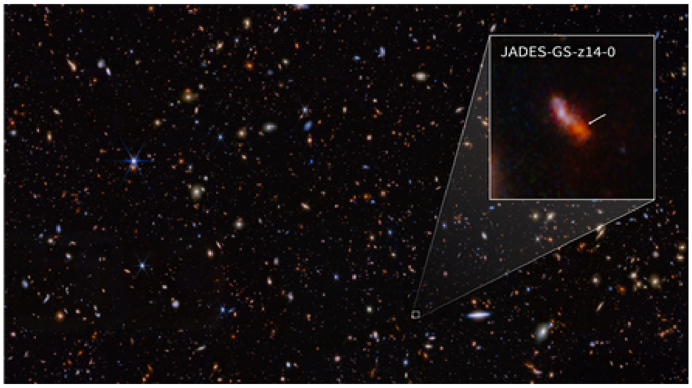

Figure 15. JWST image of galaxy JADES-GS-z14-0, the current record holder for the earliest observed galaxy. This image shows the galaxy as it was only 290 million years after the Big Bang. Credit: NASA, ESA, CSA, STScI, and Brant Robertson (UC Santa Cruz).

The earliest galaxies are now thought to have formed a mere 200-300 million years after the Big Bang, aided by the gravitational influence of the dark matter clumps. The James Webb Space Telescope (JWST) has been pushing back the boundaries of the earliest galaxies observed with, at the date of this article, the current record holder being JADES-GS-z14-0, a paltry 290 million years after the Big Bang [13] (see Figure 15).

With stars and galaxies forming, we have nearly reproduced a picture of the universe in the present day. Scientists are curious individuals though and like to fill in as many gaps in our knowledge as possible.

Dark Energy Era

We have established that the universe is expanding from the recession velocity of galaxies. Another thing we can look at is the evolution of that expansion, i.e., how has it changed throughout the life of the universe since the Big Bang. In a universe with matter, we would expect the expansion to slow, in the same way that our ball throwing thought experiment would slow the ball in its ascent (see Figure 5). The ball may or may not escape depending upon how much 'matter' our planet has, but either way, it would be slowed by gravity. The straight line (constant) relationship that Hubble and Humason discovered for recession velocity versus distance (Figure 3) was very local to us, and more than a few decades ago, this was still largely the case.

As we saw earlier, Type Ia supernovae (SNe) are extremely bright standard candles for distance determination in astronomy. Astronomers are a creative bunch, and by combining two techniques, we can determine more information about the accuracy of our models. If we take the brightness of the Type Ia SN, we can determine its distance. However, if we also take the spectrum of its light, we can determine its cosmological redshift and thus how fast it is moving away from us. We can then take this information, and from the shape of a distance versus recession velocity graph, such as Figure 16, we can determine the evolution of recession with distance, or in other words, expansion with time.

In 1998, two groups did just this with studies of Type Ia SNe in galaxies out to about 2.4 billion light-years (750 Mpc). Saul Perlmutter [14] and Brian Schmidt [15] were looking to see how much faster the expansion was in the past, and how much it had slowed, from which they hoped to deduce a value for the matter content of the universe. What they found shocked them.

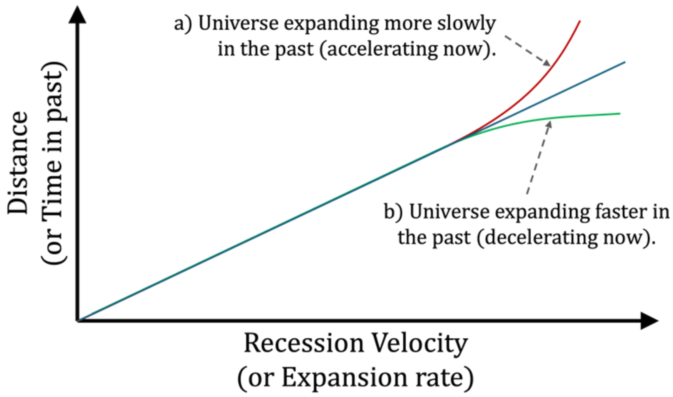

Figure 16. The varying rate of expansion of the universe. (a) The universe was expanding more slowly in the past and is now expanding faster. (b) The universe was expanding faster in the past and is slowing in the present. Credit: Author.

Their data showed that, although the expansion had slowed initially as expected, around five billion years ago, it started to accelerate. In other words, the expansion was slower in the past than it is now (see Figure 17). It is as if the ball in our thought experiment initially slowed, but then started to ascend faster and faster. Five billion years ago, the universe entered the *dark energy era*.

So what exactly is dark energy? Well, we don't quite know and the search has continued for the last couple of decades to explain this finding. Dark energy cannot be detected through any gravitational influence (the technique used for dark matter) and it does not emit any

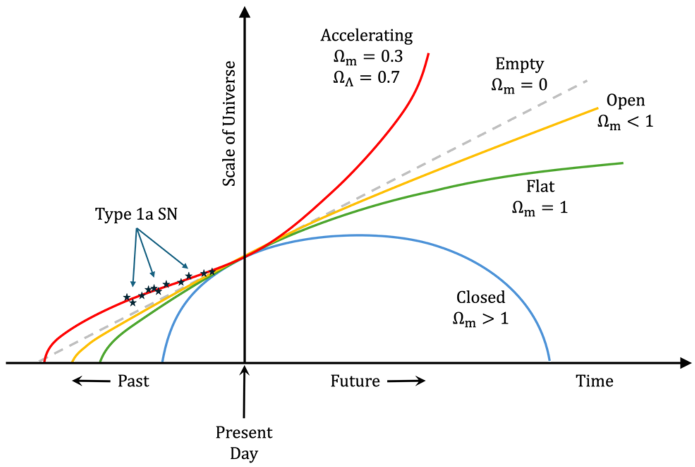

Figure 17. The matter density of the universe determines its fate, but the addition of *dark energy* as a cosmological constant accelerates the expansion. The high-redshift supernovae data from Perlmutter and Schmidt validate the acceleration hypothesis. Credit: Author.

detectable radiation. However, it has been mathematically incorporated into Einstein's field equations as a reprise of his cosmological constant. Einstein included the cosmological constant, Λ, initially to explain a static universe, then removed the factor when it became apparent the universe was expanding. We now use it to express the value of dark energy (which is small, but constant), in comparison to mass density, which reduces in significance, all the while the universe is expanding.

With an additional factor (dark energy) to add into our picture of the evolution of the universe, we have arrived at our current best model, referred to as the ΛCDM or *Lambda Cold Dark Matter* model. At this point, you could be forgiven for thinking that things are getting complicated, so let's take stock of where we are and revise our view.

We have our critical density ρ_c that we defined as denoting a 'flat' universe, that is a universe where the expansion slows to a halt only at infinite time. Now, if we take each of the 'components' of the combined mass

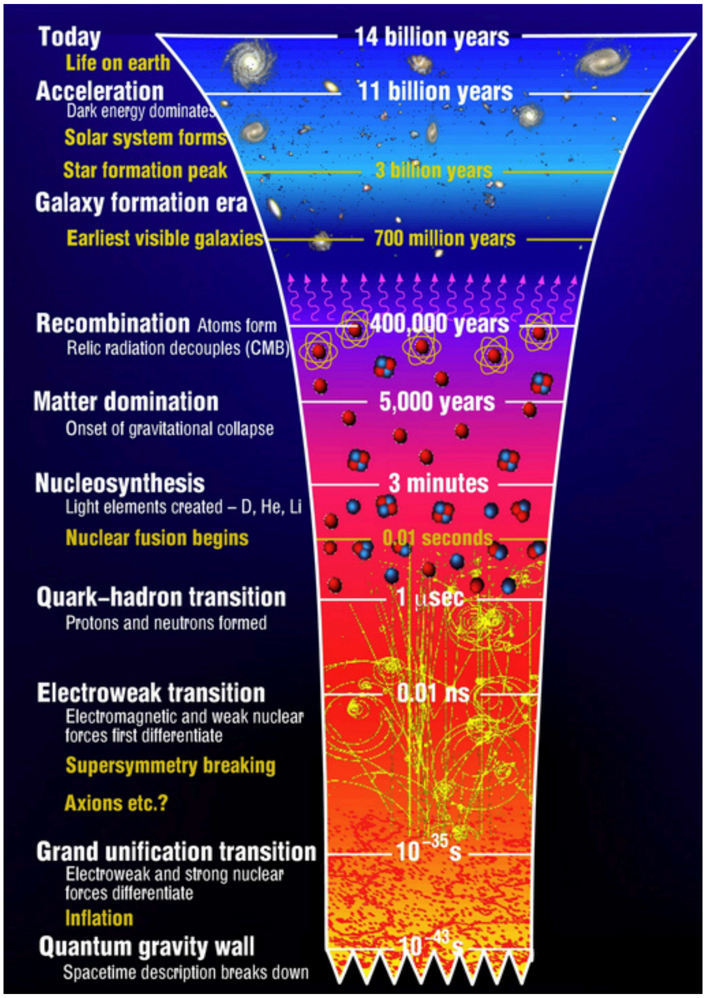

Figure 18. The evolution of the universe. Credit: The Stephen Hawking Centre for Theoretical Cosmology, University of Cambridge.

density, these being matter density ρ_m, radiation density ρ_r, and now dark energy density, ρ_Λ (rho-lambda), and as we did previously, we can divide each of these by the critical density to obtain a ratio of how much each component contributes to the critical density of the universe. We call these ratios the density parameters again denoting them with a Greek omega (Ω), thus

$$\Omega_m = \frac{\rho_m}{\rho_c} \qquad \Omega_r = \frac{\rho_r}{\rho_c} \qquad \Omega_\Lambda = \frac{\rho_\Lambda}{\rho_c}$$

and from this we have the combined average mass density

$$\Omega_0 = \Omega_m + \Omega_r + \Omega_\Lambda$$

Note that here, the matter density parameter, Ωm, includes both baryonic matter and dark matter.

Now, the observed peak in size of the density fluctuations (hotspots) in the CMB, with a fit to the observed abundance of the isotopes created through primordial nucleosynthesis, is indicative that we do indeed live in a 'flat' universe (Ω_0 = 1). However, as illustrated in Figure 17, if the mass density is composed of a portion of dark energy (Ω_Λ) which acts as a repulsive influence to the attractive force of gravity from the matter (Ω_m), then the predicted fate of the universe is likely sealed to be a 'Big Freeze' as expansion and cooling continue.

In this section, we have been through much of the evolution of the universe, working back from the expansion to a time (nearly) zero, through an initial exponential inflation, which ensured virtual particles were made real and quantum fluctuations became the seeds for the later formation of cosmological structure. We have covered the separation of the four forces into distinct entities, and the creation of matter through the primordial nucleosynthesis process. We have seen the end of radiation dominance as the influence of matter became more significant and the point of recombination when the fog in the universe lifted and the photons from the echoes of the Big Bang disappeared into the darkness. After stars and galaxies formed, we were surprised that the slowing expansion of the universe reversed as we entered the present dark energy era. Figure 18 shows a summary of our evolution discussion from the Stephen Hawking Centre for Theoretical Cosmology at the University of Cambridge in the UK.

What About Olbers' Paradox?

Earlier we talked about why the night sky is dark when, if it is infinite, and it contains an infinite number of stars, it

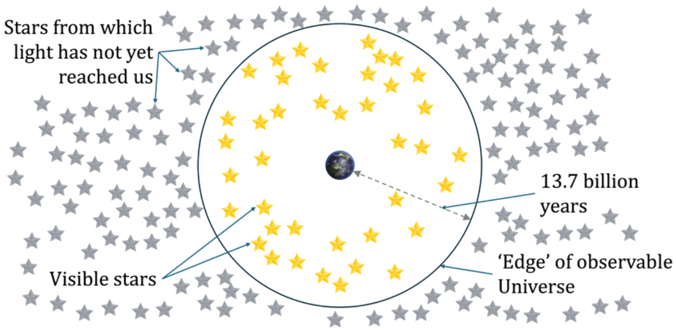

Figure 19. Resolution to Olbers' paradox is the finite age of the universe, and finite lifetime of stars. Credit: Author.

should be bright (see Figure 1). This question is associated with Heinrich Olbers and framed as his paradox.

The resolution to the paradox is due to the finite lifetimes of star, and the finite speed of light. Although the universe is likely infinite, the distance that light has been able to travel in the finite age of the universe, that is <13.7 billion years, means that there is a finite volume we are able to observe in each direction, i.e., from which the light has had time to reach us—this is the edge of the observable Universe as shown in Figure 19. If we assume the luminous lifetime of stars is ~10 billion years, then within that finite volume, there are simply not enough stars to illuminate the night sky!

In a final twist of irony, however, we can now say the night sky IS in fact bright, but only at microwave wavelengths, due to the afterglow of the Big Bang, the CMB. ★

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Biography

Richard Pomeroy, from the United Kingdom, originally trained as an electronics engineer, but spent many years both managing teams and developing application software for industries as diverse as defense, telecoms, and finance, most recently as associate director of information systems for the European Bank for Reconstruction and Development. He changed career six years ago, following a lifetime passion for the stars, having completed a bachelors degree in astronomy, and a masters in astrophysics. He is currently an assistant instructor and Physics and Astronomy PhD student at the University of Texas, Rio Grande Valley.

¿Por qué somos polvo de estrellas?

Ulises Jarquín

La ley de conservación de la materia dice que la materia no se crea ni se destruye, sólo se transforma. Si bien, esta ley fue propuesta por Antoine Lavoisier, un químico, y esta se relaciona más que nada con la forma en que los compuestos químicos que generan una reacción se transforman de un compuesto a otro, esta tiene implicaciones físicas, significando que los átomos que conforman las moléculas de nuestro cuerpo han sido los mismos desde que ha existido el universo, y en base a esta, existe una frase poética muy famosa que dice "estamos hechos de polvo de estrellas". Teniendo esta información en cuenta, ¿a qué se refiere la famosa frase "estamos hechos de polvo de estrellas"? ¿Es cierta esta afirmación? Y, como extra, ¿qué tan cierto es que la materia no se crea ni se destruye?

"Estamos hechos de polvo de estrellas" es una frase muy famosa, atribuida al astrónomo y divulgador científico Carl Sagan, sin embargo, sus palabras realmente fueron "estamos hechos de materia de estrellas" ¿A qué se refería con esto? En el Big Bang, la materia fue creada; durante los siguientes segundos, horas, meses, y años después del Big Bang, la materia estaba compacta y condensada en tan poco espacio que la energía que existía en ese lugar no permitía que la fuerza electrodébil formara átomos, ya que la radiación rompía los que se intentaban formar. Más de 400,000 años después, la materia empezó a ocupar menos espacio y se esparció más por el cosmos, dejando escapar la energía y luz condensada en el inicio de todo, formando lo que hoy conocemos como el Fondo Cósmico de Microondas (CMB por sus siglas en inglés). La fuerza electromagnética empezó a atraer a los protones y electrones entre sí, formando los primeros átomos de hidrógeno, el elemento más simple de todos. Al esparcirse los átomos de hidrógeno, estos empezaron a atraerse entre sí por la gravedad, aglomerándose en ciertos puntos del cosmos acercándose más y más y más hasta que formaron cuerpos celestes hechos de gas. Primero fueron nubes gigantescas de gas, después, los puntos más densos de las nubes se juntaron para crear planetas de gas, que eventualmente ganaron tanta pero tanta masa que sus núcleos, la parte central de la estructura, empezó a juntar neutrones con los átomos de hidrógeno, formando isótopos del hidrógeno llamados deuterio y tritio. El deuterio y el tritio empezaron a llenar el núcleo de los soles primitivos su concentración fue tanta que estos isotopos empezaron a fusionarse entre sí, formando átomos de helio, liberando un neutrón y energía de su núcleo en un proceso físico llamado fusión nuclear.

Aquí entramos en la pregunta: ¿la materia realmente no se puede crear ni destruir? La existencia de las bombas atómicas y los colisionadores de partículas responden estas preguntas. Si contamos a los átomos como la materia, sí se puede en ambos casos, y si contamos a las partículas subatómicas y/o fundamentales como la materia, también. La fisión nuclear es un proceso en el que un átomo radioactivo (con un núcleo inestable, o "fisible") decae y se rompe, dejando tras suyo dos átomos y liberando una cierta cantidad de energía junto con unos neutrones; y al igual que existe la fisión, que es dividir, existe la fusión, que es unir: la fusión nuclear consiste en unir dos átomos convirtiéndolos en uno, liberando cierta cantidad de energía y algunos neutrones. Estas dos cosas son la base para las bombas atómicas y los reactores nucleares que generan energía en algunas partes del mundo, como en Suiza, en donde también se encuentra el Gran Colisionador de Hadrones, el colisionador de partículas más grande hasta el momento. Los colisionadores de partículas, como su nombre lo indica, colisionan partículas que aceleran a casi la velocidad de la luz (99.99999% la velocidad de la luz) para chocarlas y así recrear el Big Bang, y durante estas colisiones, se generan partículas nuevas como pueden ser el muón, el tau, los quarks charm y strange, y sus versiones en antimateria. La antimateria al entrar en contacto con la materia normal se desintegra completamente, sin dejar rastro.

La fisión nuclear se ha dominado muy bien, ya que existe gran cantidad de armamento atómico que la utiliza de formas diferentes, pero la fusión todavía no se logra del todo, por el hecho de que esta sólo se ha detectado dentro de los soles, donde la gravedad es tan exageradamente alta que el deuterio y el tritio se unen, condiciones que no podemos replicar en la Tierra, ¿y cómo sabemos que esto pasa dentro de los soles? Podemos deducirlo por la radiación y energía que emiten, además de que podemos aplicar técnicas de espectroscopia para determinar que los soles están hechos de hidrógeno (y sus isótopos) y helio. Desafortunadamente, para los soles, nada es eterno, y eventualmente su hidrógeno se acabará por haberse transformado en helio; en este punto, existirán muchos destinos para los soles, pero el que nos importa son las novas: violentas explosiones de energía cuando los soles mueren. El núcleo de los soles empieza a fusionar helio con helio para formar berilio, que después se fusiona en elementos cada vez más pesados. Eventualmente, en unos cuantos cientos de miles de años, el núcleo de los soles se transforma en hierro, cuya fusión no libera energía, por lo que el núcleo se queda sin esta y cede ante la gravedad, colapsando y, al tener tanta masa concentrada en un punto, el núcleo explota violentamente, generando una supernova. La supernova por sí sola también puede llegar a fusionar algunos átomos gracias a que es extremadamente energética. Los átomos soltados por la supernova quedan como nebulosas, o viajan por el espacio hasta llegar a un punto en donde se formen planetas y estrellas, y eventualmente, esos materiales expulsados del corazón de las estrellas crean los planetas, los nuevos soles, y en nuestro caso, la vida.

Es bello: de la muerte de una o muchas estrellas vino la vida en la Tierra. El hierro en nuestra sangre alguna vez fue el corazón de una estrella, y el oxígeno que respiramos es polvo que quedó de una explosión inimaginablemente poderosa. Las cosas en la Tierra efectivamente están hechas de materia de estrellas, y, también como dijo Carl Sagan en el mismo fragmento del episodio de Cosmos, somos el universo experimentándose a sí mismo. ★

Biografía

Ulises Jarquín es un estudiante de tercer año en Saint George Prep School en Heroica Matamoros. Es voluntario en la South Texas Astronomical Society y ha recibido entrenamiento en el Cristina Torres Memorial Observatory. Sus intereses abarcan la ciencia, el espacio, la filosofía y los videojuegos. Ulises aspira a convertirse en astrofísico para contribuir a un futuro mejor para la humanidad.

Redshift

Victor De Los Santos

The Dichotomy of Art and Science

For some, art and science are two completely different things. Yet for so many others, they go hand-in-hand. Think about it: How many modern scientists, engineers, and even astronauts were inspired because they watched Star Wars, or read a book by Carl Sagan? How many great minds on both sides of this spectrum may not have reached their full potential if it had not been unleashed by inspiration that came from some collision of art and science?

For me, music has played an extremely crucial role in shaping the person I have become (and am still becoming). For my entire educational journey – from K-12 through college to my first few years working a full-time career in the corporate world – physics had never been presented to me in a way that truly ignited my curiosity. It was not until I heard a song, *Redshift* by the UK band Enter Shikari, that I was inspired to dive into the mysteries of the cosmos. Here is the specific lyric that first sparked my interest:

Your skin and bones, heart, and mind were made from the remnants of stars that died.

"Is that true? How would that even happen? Did they just make this up for the sake of the song?" – These were the questions I had asked myself back in 2016, and so I embarked on a mission to find out the truth. As it turns out, they were right – all of the elements that make up the human body (carbon, hydrogen, nitrogen, oxygen, and many others) were formed in the cores of stars long ago, and after *billions* of years of dispersion and recomposition, those elements eventually turned into what we are today.

I didn't stop there – I kept learning, fueled by my desperation to solve every question my curiosities led me to ask. I eventually realized there is no way I (or anyone) will ever know all there is to know about the universe, but regardless, I've dedicated myself to the South Texas Astronomical Society and its mission to inspire others to be curious about the world and to chase those curiosities – all because of a song.

So, in honor of that song and the intriguing realm of cosmology, I'd like to break down (in simple terms) the concept of *redshift* and its origins.

The Realm of the Nebulae

Edwin Powell Hubble (born 1889), the namesake of NASA's famous Hubble Space Telescope, is undoubtedly one of the most accomplished and influential astronomers to have ever lived. *(Interestingly enough, much of Hubble's own inspiration derived from reading science fiction – one of his favorite books was "20,000 Leagues Under the Sea", a novel by Jules Verne about a group of seamen who embark on a journey around the world from under the sea).*

After receiving his PhD in Astronomy from the University of Chicago in 1914, Hubble settled down in California to pursue his lifelong dream of studying the universe, using the Mount Wilson Observatory in Los Angeles and its 100-inch telescope. For many years, there had been fuzzy patches in the sky discovered by previous astronomers and broadly labeled as "nebulae". From previous observations, it was obvious that the universe was large and filled with billions of stars and other fascinating celestial objects. But, one by one, Hubble studied these fuzzy objects closer and made one of the most remarkable discoveries in astronomy: What we called our "universe" was actually just one galaxy – a single group of billions of stars – in a much larger universe, full of many other galaxies with billions of their own stars.

Hubble's first groundbreaking observation was with the Andromeda Galaxy (the closest galaxy to us, 2.5 million

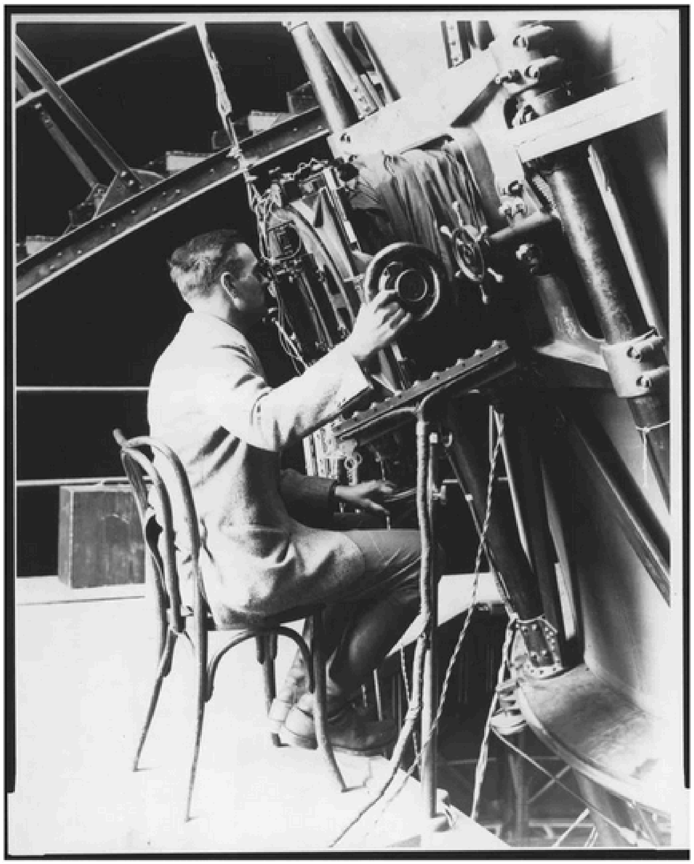

Figure 1. Edwin Hubble using the 100-inch reflector at Mount Wilson Observatory in California. Credit: Edwin P. Hubble Papers, Huntington Library, San Marino, California.

light-years from the Milky Way), which had previously been known as the “Andromeda Nebula”, in 1923. By 1929, Hubble’s research had led him and his peers to the conclusion that there are *millions* of other galaxies in the universe (the current estimate is now closer to two trillion). This was a revolutionary discovery that paved the road to our current understanding of the universe. However, Hubble’s findings did not stop there.

Redshift and the Expanding Universe

In *Redshift*, Enter Shikari’s vocalist Rou Reynolds sings: *“We accelerate through the extent of outer space.”* While it definitely makes for a catchy chorus, it becomes infinitely more beautiful when you understand exactly what he’s talking about.

As part of his research, Hubble studied the light from the galaxies he observed using a spectroscope. Spectroscopes are instruments that allow scientists to observe the specific frequencies of light along the electromagnetic spectrum that radiate from any given object. In simple terms: When the light enters the spectroscope, it is broken up into the different colors that we can see (think of the rainbow – ROYGBIV), and by using our knowledge of the elements and the light we know each one emits, we can deduce what the object we’re observing is composed of.

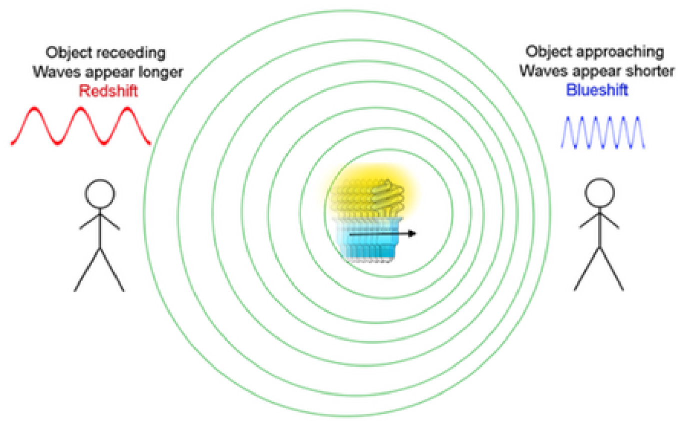

Figure 2. A demonstration of the Doppler effect. Credit: PhysicsGirl.

During his observations, Hubble noticed something very interesting: The light being emitted from these galaxies outside our own was being *shifted* toward the *redder* end of the light spectrum. This shift – appropriately called *redshift* – is caused by the Doppler effect, which refers to the change in frequency of waves (either light or sound waves) that occurs when an object is moving relative to the observer. Think of the sound a police car’s siren makes while it is in motion and you are standing still – as it drives toward you, the siren seems to go from a lower-sounding frequency to a higher-pitched one, reaching its highest frequency when it is closest to you and then gradually getting lower as it drives past and away from you. Well, the same thing happens with light: If something is moving away from you, the light from that object will appear more red when measured with a spectroscope –

and that's exactly what happened with the galaxies that Hubble observed!

And so, it was concluded through experimental evidence that since the light from these distant galaxies are shifting toward the red end of the spectrum, they are moving away from our own Milky Way Galaxy. But wait, there's more: It turns out that the farther away the galaxy was (Hubble also discovered a way to tell the distances to galaxies using unique stars called *Cepheid variable stars*), the more redshifted their observed spectra were. And so, we arrive at yet another mind-boggling astronomical discovery: The farther away a galaxy is from us, *the faster away it is moving from us!*

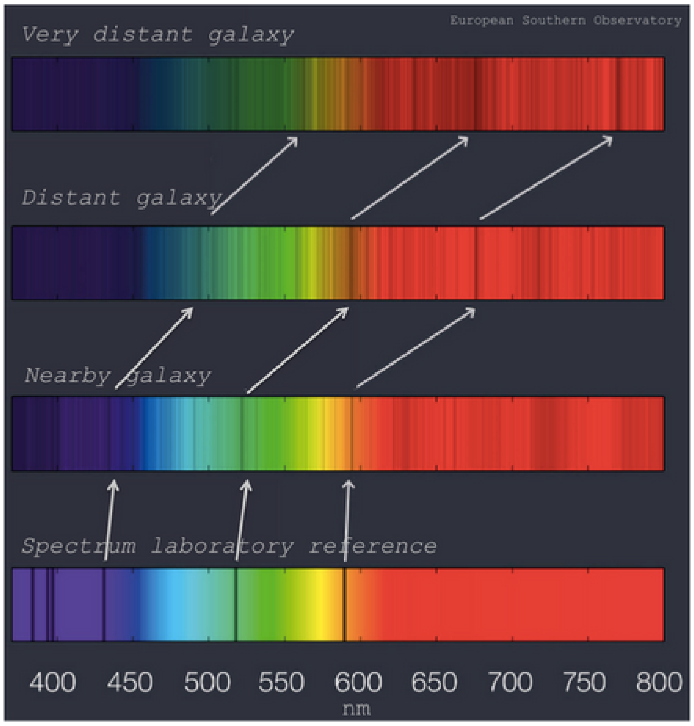

Figure 3. An example of redshift using the absorption lines of a galaxy. Credit: Volker Gaibler/HITS/SDSS/ESO.

Hopefully now the words from the song make a little bit more sense. Not only is the universe expanding as galaxies move farther away from each other, it is accelerating in its expansion – we are truly *accelerating through the extent of outer space*.

Conclusion

In 1936, Hubble published his research on galaxies in his book *The Realm of the Nebulae*, which became an instant classic in the larger story of humanity's ability to unveil the wonders of the universe. Though it is not a science fiction book, it holds some of the most important information discovered by humans, and surely that is enough to inspire others to follow in his pursuit and unlock more cosmic riddles.

My own story of cosmic inspiration began with a song. The last line of the song states the following: *"A supergiant [star] erupts into a supernova; the ultimate sacrifice, and we are the descendants."* I believe that this lyric is a beautiful reconstruction of a famous line by Dr. Carl Sagan, who also inspired many others to ponder the universe: *"We are made of star-stuff."* No matter how you look at it, the universe is poetic by nature, and so it only makes sense that writers and musicians and painters express that beauty through art, as we have since the dawn of humankind.

Figure 4. A scene from the music video for *Redshift* by Enter Shikari.

"Art is the queen of all sciences, communicating knowledge to the generations of the world." – Leonardo da Vinci ★

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Biography

Victor De Los Santos is Executive Director and Chair of the Board for the South Texas Astronomical Society. Victor graduated from Hanna High School in 2013. He earned a bachelor of science in business from Texas A&M University - College Station in 2016. He has worked as a software development project manager since 2016.

How the Stars Came To Be in the Skies

A Native American Folktale Retold by Carol Lee

In the days before time began, there were no two-legged ones on the Earth. All the animals could walk and talk the same as you and I do today. They lived together in a large village on the shores of the Great-River-That-Cuts-Through-the-Earth.

One morning as Coyote and his friend Rabbit were walking along the banks of the river, Coyote looked about him and saw that Great Sun was shining brightly in the sky.

“How is it,” he asked, “that the Great Spirit Manitou has put a light in the sky during the day when it is so bright? Does he not see that the night is dark, and we need a light then instead of during the day?”

“OH!” exclaimed Rabbit. “What a clever fellow you are, Coyote. You have such amazing ideas. Why, of course we should have a light in the sky at night instead of the day. You should be in charge of the land instead of Manitou!”

At this, Coyote began to smile a wide smile across his face. He imagined how important he would be if he were in charge of things in the land. He thought that Rabbit was a very clever fellow to think of such a wonderful thought.

As the two meandered along the banks of the river, they were soon joined by…the Great Spirit Manitou, with his headdress of eagle feathers that shone like the Sun itself. They were suddenly not so loud in their bold talk of Coyote being in charge of the land.

“Ho, Little Brothers,” greeted Manitou. “I hear that you have a grand idea about a light to be in the sky at night. I have a plan. Tell all the people of the village to collect their largest baskets and meet me at the banks of the Great-River-That-Cuts-Through-the-Earth. When the Sun comes out from the Land of the Dead in the morning, I will tell you all of my plan and you can see if it is a good one.”

Rabbit and Coyote thought this would be an important thing to do and they raced back to the village to tell the news to all the villagers about what Manitou had said.

“Aieee, Coyote! What have you stirred Manitou to do now?” cried the villagers. “The last time you did this we had nothing but trouble.”

“Nothing,” snarled Coyote. “I just had a good idea and now Manitou wants to take credit for it! SO, are you going to meet at the river in the morning with your baskets, or sit here and be picking at me?”

Slowly the animals separated and went back to their homes to get their fine large baskets ready for the morning. As the Sun fell into the Earth, each one crawled into their soft blankets on the floor of their wickiup and went to sleep. Much snoring was heard in the village.

Early the next morning, as Sun rose from the mist on the mountains, the villagers gathered at the side of the Great-River-That-Cuts-Through-the-Earth with their beautiful woven baskets. They wondered what in the world Manitou was going to say. They were more than a little bit worried because Coyote was a trickster and frequently got into trouble.

Manitou began to talk in his deep impressive voice that sounded like a thunderstorm crossing the land. His eyes were like flashing lightning as Manitou looked at Coyote.

“Little Brothers and Little Sisters, I have heard that you are frightened in the dark of my night. I have heard that you wonder why there is no light in the night. You wonder why there is light in the day and think there is no need of light in the day. Curious people you are! Hear me while I will tell you of my plan.

You will spend all day today gathering stones from the

Great River. As they are sparkling in the water they will sparkle elsewhere. Fill your baskets with as many stones as you can carry. And Coyote, since you are so strong and clever, you are to fill TWO baskets with stones so that the small ones will have plenty!”

Coyote was not so sure he liked the idea of gathering two baskets of stones, or of carrying them, either. But he did like to be called strong and clever so he smiled his big wide smile and stayed quiet while Manitou continued talking.

“When your baskets are filled, go home and sleep. In the morning, I will put my bow outside so that you can carry your baskets of stones and climb into my blue-sky blanket. You will take the stones and make pictures of yourselves in the soft blue blanket. Then you will see what I can do.” And saying this, Manitou disappeared.

“Oh, how exciting,” exclaimed the animals to one another. They scurried around collecting the shiniest and most beautiful rocks for their baskets.

All day they worked until Dark Night began to creep from the forest and Sun went again to the Land of the Dead. Everyone hurried home and ate a hasty meal of beans, corn, and fish. Then they went to bed.

When Sun came back in the dawn, there was Manitou’s beautiful bow in the sky. “Look! There are colors in the sky! Red! Orange! Yellow! Green! Blue! Indigo! Violet!” Everyone shouted at once. They snatched up their baskets; Coyote took two. Then they began climbing the beautiful bow into the blue blanket-sky.

When they arrived in the sky, all the animals went to different areas to create their pictures for Manitou. All except Coyote; he went to sleep under a cloud and began to snore while everyone else went about their creating.

Carefully, the animals took several shining rocks from their baskets and placed them, just so, into the soft blue sky. After a little while Butterfly needed more rocks and so she went to Coyote to ask for some of those in his two baskets. “Coyote,” she whispered softly into his ear.

Coyote slowly opened one brown eye and muttered, “What do YOU want, little Butterfly?”

“I need some of your stones for my picture, please,” she replied quietly. “May I take some out of your basket?”

“Oh, I suppose so,“ snarled Coyote. And he turned over and went right back to sleep, snoring loudly all the while.

It wasn’t long before other animals ran out of stones and they began waking up Coyote to ask for some of his stones. Rabbit and Raccoon, Possum and Road Runner…. Finally, Coyote got so angry at being awakened by everyone that he jumped up, grabbed his baskets, and tossed them into the air. The rocks flew in every direction and all the animals scurried around to pick up as many as they could, while Coyote went back to sleep.

For the rest of the day the animals worked to make their pictures in the blue sky-blanket until someone noticed that Sun was already across the middle of the sky-path and was slowly creeping toward his home under the Earth.

“Hurry!” said Road Runner. “Someone wake up Coyote and tell him we have to get back to Earth right now!”

No one wanted to be the one to wake him up, so everyone shouted at once, “Coyote, wake up! The bow is disappearing!”

Coyote did wake up and looked around. Sure enough, the bow bridge of many colors was slowly disappearing. Coyote grabbed his baskets and looked inside. There was only one huge rock in the bottom of one basket. As he picked up the basket the rock tumbled out, rolled off the edge of the bow, and the rock stuck in the blue sky-blanket all by itself.

Just at that moment the bow bridge disappeared, and Coyote fell, tumbling nose over tail, down into the grass that grew along the banks of the Great-River-That-Cut-Through-the-Earth. “Whew! That was exciting,“ exclaimed Coyote as he looked around to be sure no one was laughing at him. Everyone came crowding around him to be sure he was not hurt. He wasn’t; but his feelings were.

Slowly, slowly Dark began to cover the sky. All the animals sat down to see what would be the results of their hard work. They wondered what Manitou would do. What WAS his big idea?

As the sky grew darker the animals began to see their pictures made from the sparkling stones in the black night blanket. Coyote did not see any picture of himself and he began to cry. His mother and his father, his brothers and his sisters, his aunts and his uncles, and his cousins by the dozens began to cry too.

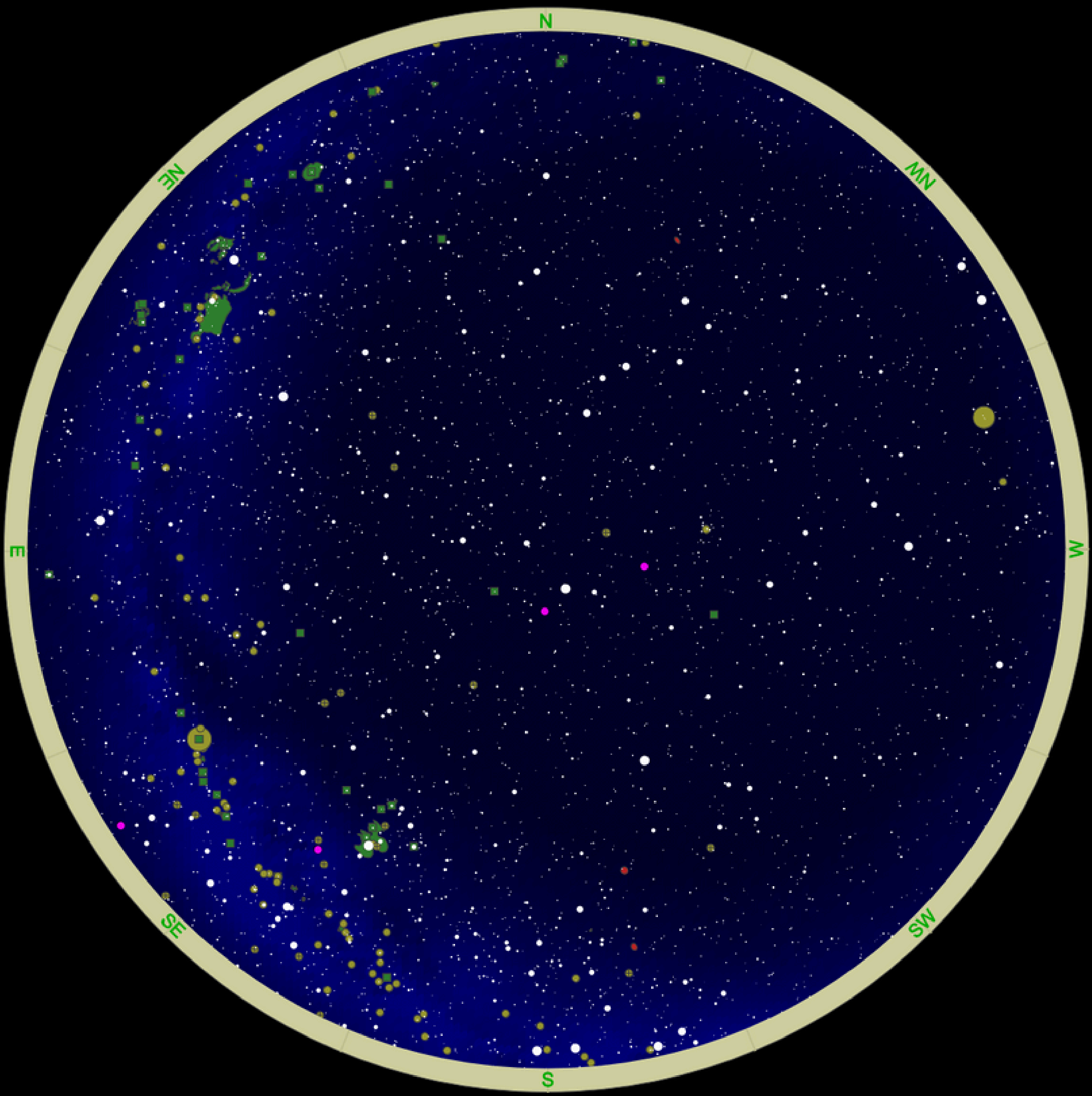
Suddenly the huge rock that Coyote dropped rose out of the dark night and all the animals began to laugh and cheer. What a beautiful light the Coyote had put into the sky! What a marvelous thing to see.

And ever since those days, Coyotes howl at the Moon and brag about what they put into the sky. And if you look closely you can see the shadow of a Rabbit on the face of the Moon. Other animals can be seen among the stars if you know where to look.

And THAT is the END of THIS story. ★

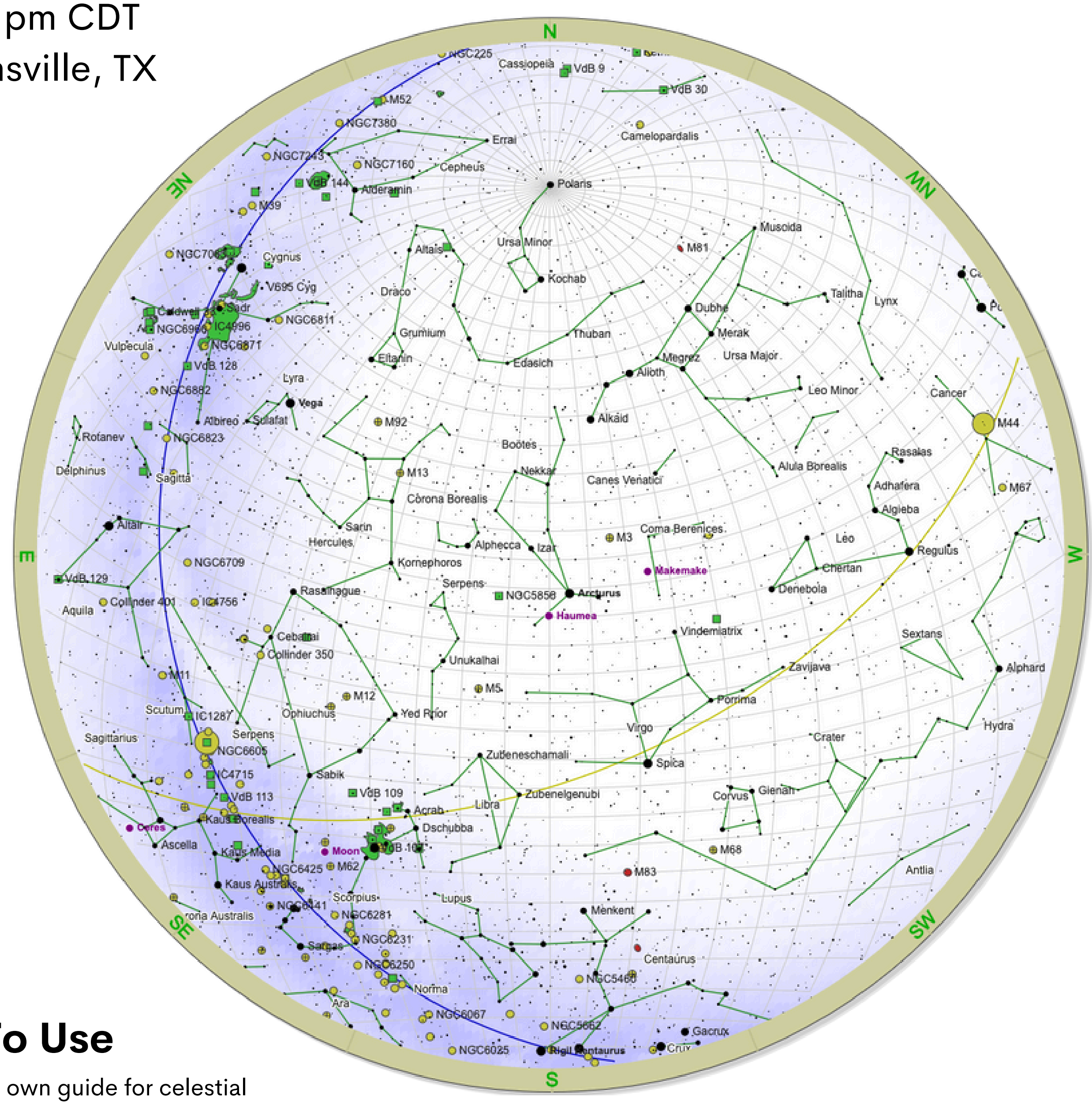
Cosmic Coordinates

Summer 2024



Sky Map

20 June 2024
10:00 pm CDT
Brownsville, TX



How To Use

Here is your own guide for celestial navigation: your very own sky map, allowing you to select and observe the finest of cosmic objects. If you find yourself within the Rio Grande Valley, this map will be accurate to help you along your celestial journey. Good luck, and clear skies! [Credit: Dominic Ford, In-The-Sky.org]

Sky Map Legend

The Equator
Ecliptic Plane
Galactic Plane
Galaxy
Bright nebula
Open cluster
Globular cluster

Sky Events

Summer 2024

Appulses

An *appulse* is the minimum apparent separation of two astronomical objects in the sky.

Appulse of Moon and Mars
Sun, Jun 02 | 16:42 CDT | Taurus

Appulse of Jupiter and Mercury
Tue, Jun 04 | 05:32 CDT | Taurus

Appulse of Moon and Spica
Sun, Jun 16 | 14:13 CDT | Virgo

Appulse of Moon and Antares
Thu, Jun 20 | 06:17 CDT | Scorpius

Appulse of Moon and Saturn
Thu, Jun 27 | 09:56 CDT | Aquarius

Appulse of Moon and Neptune
Fri, Jun 28 | 03:42 CDT | Pisces

Appulse of Moon and Mars
Mon, Jul 01 | 10:47 CDT | Aries

Appulse of Moon and M45
Tue, Jul 02 | 11:27 CDT | Taurus

Appulse of Mars and Uranus
Mon, Jul 15 | 09:25 CDT | Taurus

Appulse of Moon and Antares
Wed, Jul 17 | 15:18 CDT | Scorpius

Appulse of Moon and Saturn
Wed, Jul 24 | 15:27 CDT | Aquarius

Appulse of Moon and Neptune
Thu, Jul 25 | 09:26 CDT | Pisces

Appulse of Moon and M45
Mon, Jul 29 | 17:04 CDT | Taurus

Appulse of Moon and Mars
Tue, Jul 30 | 03:34 CDT | Taurus

Appulse of Moon and Jupiter
Tue, Jul 30 | 17:23 CDT | Taurus

Appulse of Moon and Elnath
Wed, Jul 31 | 09:27 CDT | Taurus

Appulse of Moon and Spica
Sat, Aug 10 | 05:52 CDT | Virgo

Appulse of Moon and Antares
Wed, Aug 14 | 00:16 CDT | Scorpius

Appulse of Jupiter and Mars
Wed, Aug 14 | 09:53 CDT | Taurus

Appulse of Moon and Saturn
Tue, Aug 20 | 21:41 CDT | Aquarius

Appulse of Moon and Neptune
Wed, Aug 21 | 16:48 CDT | Pisces

Appulse of Moon and M45
Sun, Aug 25 | 22:38 CDT | Taurus

Appulse of Moon and Jupiter
Tue, Aug 27 | 06:32 CDT | Taurus

Appulse of Moon and Elnath
Tue, Aug 27 | 14:52 CDT | Taurus

Appulse of Moon and Mars
Tue, Aug 27 | 18:48 CDT | Taurus

Apsides

Apsis, from the Ancient Greek for ‘arch’ or ‘vault’ (ἁψίς), is the farthest (*apoapsis*) or nearest (*periapsis*) an orbiting body gets to the primary body. Special terms are used for specific systems: *aphelion* and *perihelion* are used for any object with respect to the Sun; *apogee* and *perigee* are used for any object with respect to the Earth.

Comet 154P/Brewington at Perihelion
Tue, Jun 11 | Aries

Earth at Aphelion
Fri, Jul 05 | 00:06 CDT | Pisces

Comet 13P/Olbers at Perihelion
Sun, Jun 30 | Lynx

Conjunctions

A *conjunction* is when two astronomical objects appear close to each other in the sky, and share the same right ascension (or ecliptic longitude). For superior planets, conjunction occurs when the planet passes behind the Sun (*solar conjunction*). For inferior planets, if the planet is passing in front of the Sun, it is called *inferior conjunction*; if behind, it is called *superior conjunction*.

Conjunction of Moon and Mars
Sun, Jun 02 | 18:37 CDT | Pisces

Conjunction of Jupiter and Mercury
Tue, Jun 04 | 05:04 CDT | Taurus

Venus at Superior Solar Conjunction
Tue, Jun 04 | 11:03 CDT | Taurus

Conjunction of Moon and Jupiter
Wed, Jun 05 | 09:26 CDT | Taurus

Mercury at Superior Solar Conjunction
Fri, Jun 14 | 11:38 CDT | Taurus

Conjunction of Moon and Saturn
Thu, Jun 27 | 09:59 CDT | Aquarius

Conjunction of Moon and Mars
Mon, Jul 01 | 13:27 CDT | Aries

Conjunction of Moon and Jupiter
Wed, Jul 03 | 03:29 CDT | Taurus

Conjunction of Moon and Mercury
Sun, Jul 07 | 13:33 CDT | Cancer

Conjunction of Mars and Uranus
Mon, Jul 15 | 04:22 CDT | Taurus

Conjunction of Moon and Saturn
Wed, Jul 24 | 15:45 CDT | Aquarius

Conjunction of Moon and Mars
Tue, Jul 30 | 05:38 CDT | Taurus

Conjunction of the Moon and Jupiter
Tue, Jul 30 | 18:54 CDT | Taurus

Conjunction of Moon and Venus
Mon, Aug 05 | 17:03 CDT | Leo

Conjunction of Moon and Mercury
Mon, Aug 05 | 19:03 CDT | Leo

Conjunction of Venus and Mercury
Tue, Aug 06 | 10:21 CDT | Leo

Conjunction of Jupiter and Mars
Wed, Aug 14 | 11:52 CDT | Taurus

Mercury at Inferior Solar Conjunction
Sun, Aug 18 | 20:53 CDT | Leo

Conjunction of Moon and Saturn
Tue, Aug 20 | 22:01 CDT | Aquarius

Conjunction of Moon and Jupiter
Tue, Aug 27 | 07:45 CDT | Taurus

Conjunction of Moon and Mars
Tue, Aug 27 | 19:23 CDT | Taurus

Dichotomies

A *dichotomy* is when the Moon or an inferior planet appears half-illuminated by the Sun.

Mercury at Dichotomy
Thu, Jul 18 | 17:45 CDT | Leo

Earth

The Earth is the Pale Blue Dot we call home.

June Solstice
Thu, Jun 20 | 15:49 CDT | Taurus

Elongations

Elongation is the angular separation in the sky between a planet and the Sun with respect to the Earth. When an inferior planet is visible in the sky after sunset, it is near its *greatest eastern elongation*. When an inferior planet is visible in the sky before sunrise, it is near its *greatest western elongation*.

Mercury at Greatest Eastern Elongation
Sun, Jul 21 | 22:37 CDT | Leo

Moon

For the Summer 2024 lunar season, we have the *Strawberry Moon* in June, the *Buck Moon* in July, and the *Sturgeon Moon* in August.

New Moon
Thu, Jun 06 | 07:38 CDT | Taurus

First Quarter Moon
Fri, Jun 14 | 00:19 CDT | Virgo

Full Moon
Fri, Jun 21 | 20:07 CDT | Sagittarius

Last Quarter Moon
Fri, Jun 28 | 16:53 CDT | Cetus

New Moon
Fri, Jul 05 | 17:58 CDT | Gemini

First Quarter Moon
Sat, Jul 13 | 17:49 CDT | Virgo

Full Moon
Sun, Jul 21 | 05:17 CDT | Capricornus

Last Quarter Moon
Sat, Jul 27 | 21:52 CDT | Aries

New Moon
Sun, Aug 04 | 06:14 CDT | Cancer

First Quarter Moon
Mon, Aug 12 | 10:19 CDT | Libra

Full Moon
Mon, Aug 19 | 13:25 CDT | Aquarius

Last Quarter Moon
Mon, Aug 26 | 04:26 CDT | Taurus

Occlusions

An *occlusion* is when one astronomical object passes in front of the other. An *occultation* is when the foreground object completely blocks the background object. A *transit* is when the background object is not fully concealed by the foreground object. An *eclipse* is any occlusion that casts a shadow onto the observer.

Lunar Occultation of Spica
Sat, Jul 13 | 22:19 CDT | Virgo

Oppositions

Opposition is when two astronomical objects are on opposite sides of the celestial sphere. Opposition only occurs for superior planets and objects. Solar opposition is the best time to view a planet with a telescope.

43 Ariadne at Opposition
Sun, Jun 02 | 21:22 CDT | Ophiuchus

42 Isis at Opposition
Thu, Jun 27 | 21:22 CDT | Sagittarius

1 Ceres at Opposition
Sat, Jul 06 | 10:35 CDT | Sagittarius

134340 Pluto at Opposition
Tue, Jul 23 | 09:29 CDT | Capricornus

16 Psyche at Opposition
Tue, Aug 06 | 02:10 CDT | Capricornus

7 Iris at Opposition
Tue, Aug 06 | 09:22 CDT | Aquarius

Retrogrades

A planet undergoes *retrograde* motion when it reverses its direction of motion in the sky. A planet entering retrograde motion is an apparent phenomenon caused by the relative motion between the Earth and the object.

Saturn Begins Retrograde Motion
Sat, Jun 29 | 14:16 CDT | Aquarius

Neptune Begins Retrograde Motion
Tue, Jul 02 | 04:19 CDT | Pisces

Space Rangers

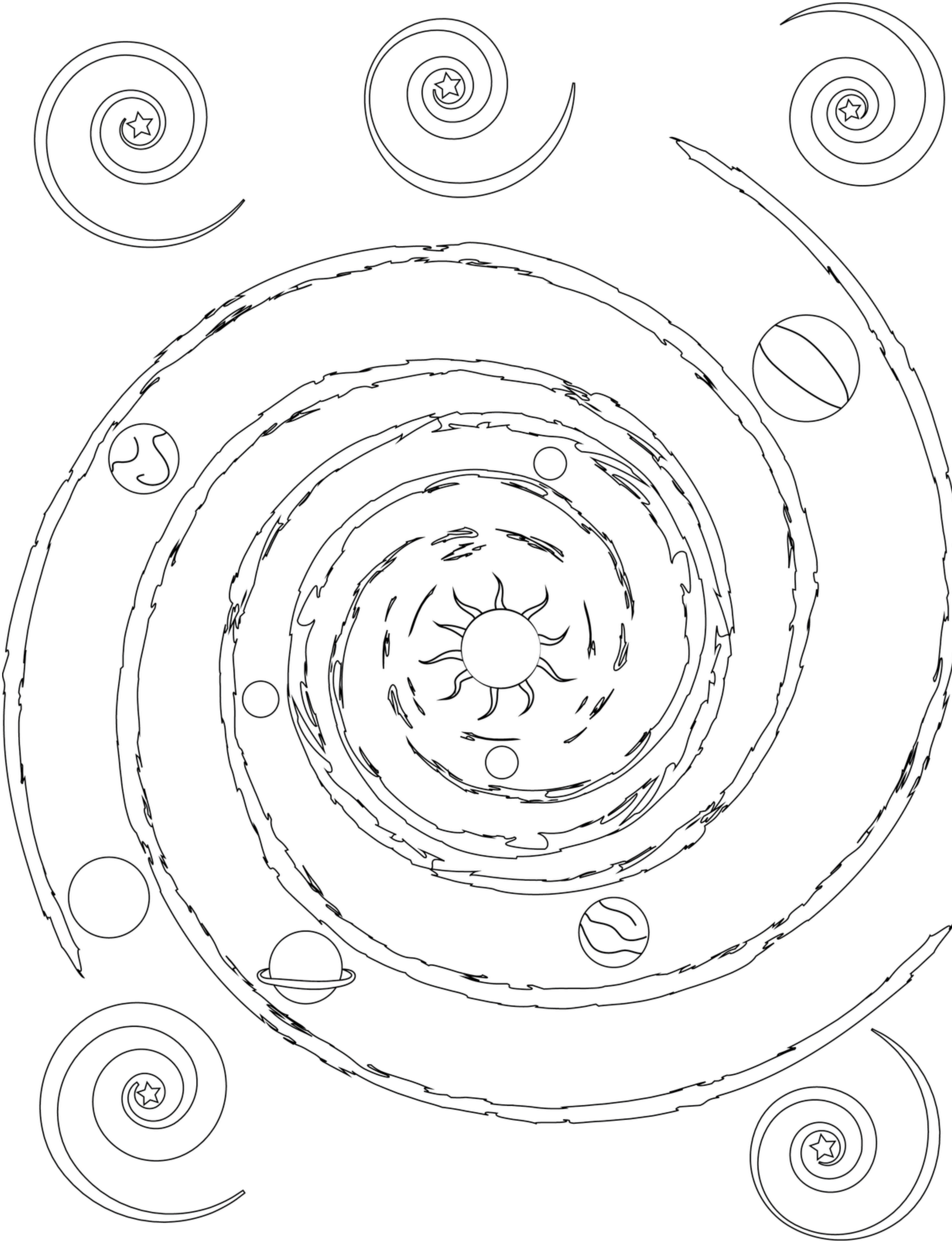
Summer 2024

🚀 Welcome Space Rangers! 🚀

Time to use your creative skills and put them to the test!
We hope you enjoy our featured coloring page, word search, some fantastic eclipse artwork!

Your adventure awaits!

Table of Contents



Space Rangers

Word Scramble

1. ELHUBB CTOSNNTA	The rate of expansion of the universe, named after Edwin Hubble who first observed it.
2. FLNITOINA	A theory proposing a period of extremely rapid exponential expansion of the universe during its first few moments.
3. RSELUITMVE	The hypothetical existence of multiple, possibly infinite, universes including our own.
4. ALBNUE	A giant cloud of gas and dust in space, often a region where new stars are born.
5. AAURQS	An extremely luminous and active galactic nucleus powered by a supermassive black hole at its center.
6. FDIETRSH	The phenomenon where light from an object is shifted to longer wavelengths as it moves away from the observer, used as evidence for the universe's expansion.
7. TRUYSILAGIN	A point in space-time where density and gravity become infinite, such as the center of a black hole.
8. RTOAS OINRATMF	The process by which dense regions within molecular clouds in interstellar space collapse to form stars.
9. RVEUSPOAN	A powerful and luminous explosion of a star, marking the end of its life cycle.
10. NVEEURIS	All of space and time, including all matter and energy, the planets, stars, galaxies, and all other forms of matter and energy.

Space Rangers

Word Scramble (Solutions)

1. HUBBLE CONSTANT	The rate of expansion of the universe, named after Edwin Hubble who first observed it.
2. INFLATION	A theory proposing a period of extremely rapid exponential expansion of the universe during its first few moments.
3. MULTIVERSE	The hypothetical existence of multiple, possibly infinite, universes including our own.
4. NEBULA	A giant cloud of gas and dust in space, often a region where new stars are born.
5. QUASAR	An extremely luminous and active galactic nucleus powered by a supermassive black hole at its center.
6. REDSHIFT	The phenomenon where light from an object is shifted to longer wavelengths as it moves away from the observer, used as evidence for the universe's expansion.
7. SINGULARITY	A point in space-time where density and gravity become infinite, such as the center of a black hole.
8. STAR FORMATION	The process by which dense regions within molecular clouds in interstellar space collapse to form stars.
9. SUPERNOVA	A powerful and luminous explosion of a star, marking the end of its life cycle.
10.UNIVERSE	All of space and time, including all matter and energy, the planets, stars, galaxies, and all other forms of matter and energy.

Space Rangers

Word Search

Cosmologists observe and study the universe—how it began and how it's developing. Use your cosmological skills to study the puzzle below and see if you can discover these cosmological terms:

L	P	G	O	K	M	N	J	I	U	E	H
B	V	N	G	Y	T	R	F	C	X	S	D
R	D	A	R	K	M	A	T	T	E	R	A
E	A	B	S	Z	A	Q	P	L	O	E	R
K	R	G	N	I	K	W	A	H	M	V	E
N	K	I	J	I	U	H	B	U	V	I	M
G	E	B	Y	T	F	G	C	B	X	N	A
D	N	R	E	S	A	Z	A	B	Q	U	C
P	E	L	M	L	K	I	J	L	N	B	T
H	R	U	A	V	O	N	R	E	P	U	S
Y	G	X	N	E	U	T	R	I	N	O	S
G	Y	G	O	L	O	M	S	O	C	C	L

Space Rangers

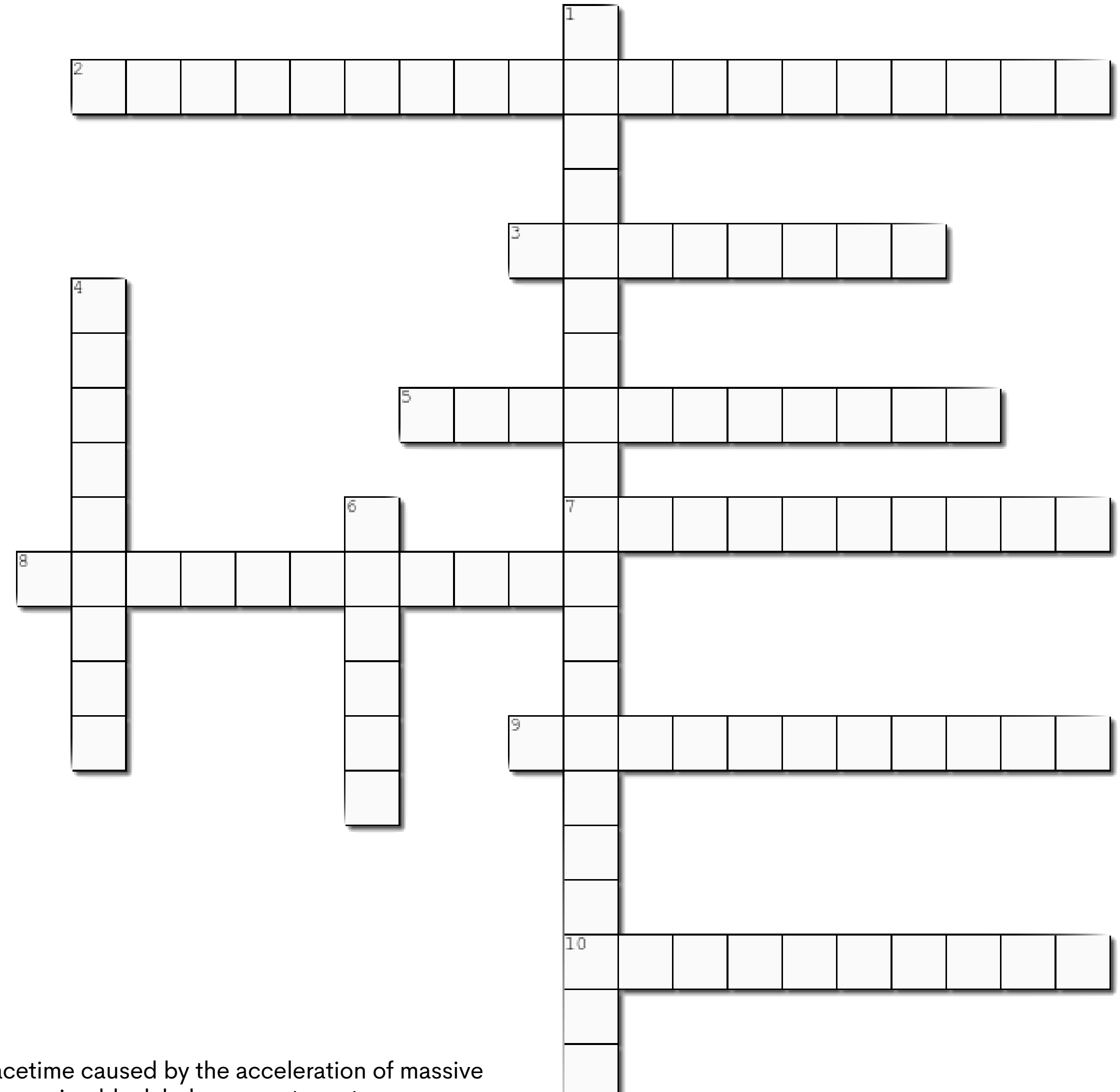
Word Search (Solutions)

(1) **BIG BANG**, (2) **COSMOLOGY**, (3) **DARK MATTER**, (4) **DARK ENERGY**, (5) **GALAXY**, (6) **HAWKING** (famous cosmologist), (7) **HUBBLE** (space telescope), (8) **LSST CAMERA** (Legacy Survey of Space and Time camera with a ten-year lifespan built to investigate dark energy, dark matter, supernovae, asteroids, and more), (9) **NEUTRINOS**, (10) **SUPERNOVA**, and (11) **UNIVERSE**

L	P	G	O	K	M	N	J	I	U	E	H
B	V	N	G	Y	T	R	F	C	X	S	D
R	D	A	R	K	M	A	T	T	E	R	A
E	A	B	S	Z	A	Q	P	L	O	E	R
K	R	G	N	I	K	W	A	H	M	V	E
N	K	I	J	I	U	H	B	U	V	I	M
G	E	B	Y	T	F	G	C	B	X	N	A
D	N	R	E	S	A	Z	A	B	Q	U	C
P	E	L	M	L	K	I	J	L	N	B	T
H	R	U	A	V	O	N	R	E	P	U	S
Y	G	X	N	E	U	T	R	I	N	O	S
G	Y	G	O	L	O	M	S	O	C	C	L

Space Rangers

Crossword Puzzle



Across

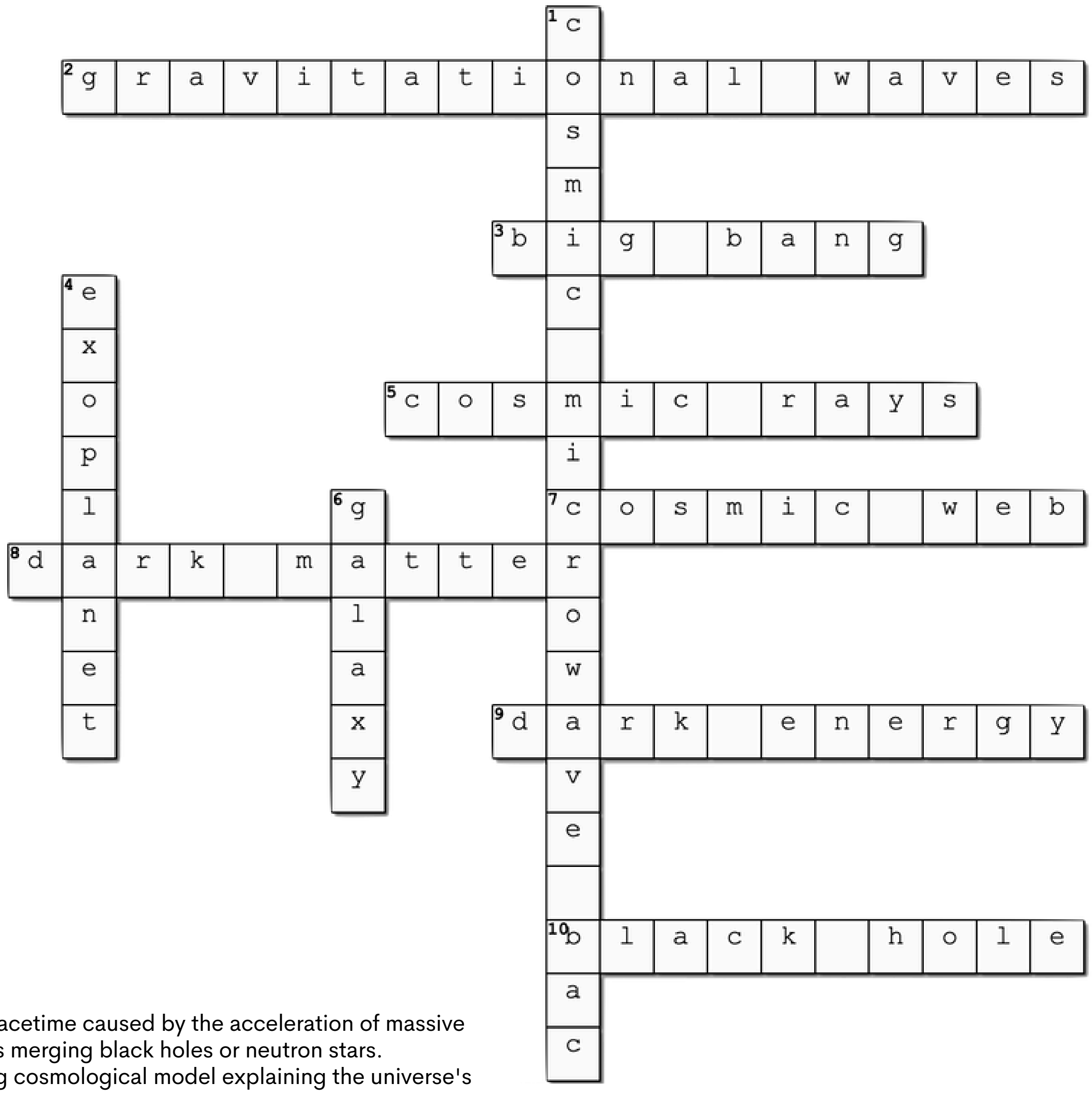
2. Ripples in spacetime caused by the acceleration of massive objects, such as merging black holes or neutron stars.
3. The prevailing cosmological model explaining the universe's origin
5. High-energy particles from outer space that travel at nearly the speed of light and strike the Earth's atmosphere.
7. A mysterious form of energy that is driving the accelerated expansion of the universe.
8. A form of matter that does not emit light or energy, detectable only through its gravitational effects.
9. A mysterious form of energy that is driving the accelerated expansion of the universe.
10. A region of space where gravity is so strong that nothing, not even light, can escape from it.

Down

1. The thermal radiation left over from the Big Bang, filling the universe almost uniformly.
4. A planet that orbits a star outside the solar system.
6. A massive system of stars, star clusters, interstellar gas and dust, and dark matter bound together by gravity.

Space Rangers

Crossword Puzzle



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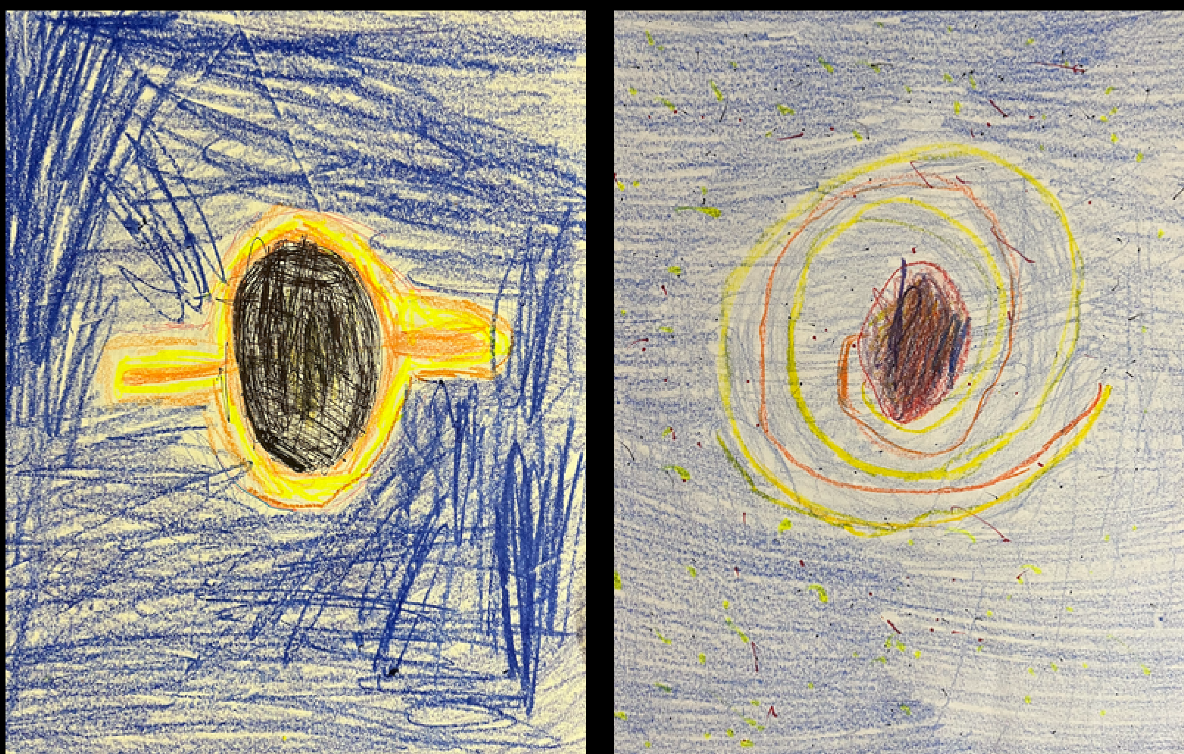
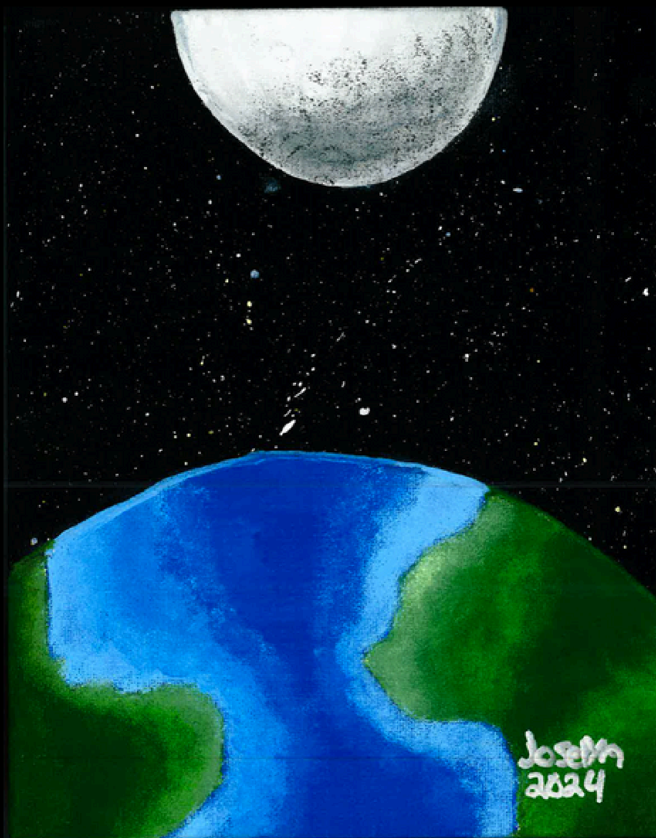


“Black Holes”
Mario (Kindergarten)

“My Galaxy”
MariaJulieta (1st Grade)

“Purple Systems”

“If Our Sun Was Pink”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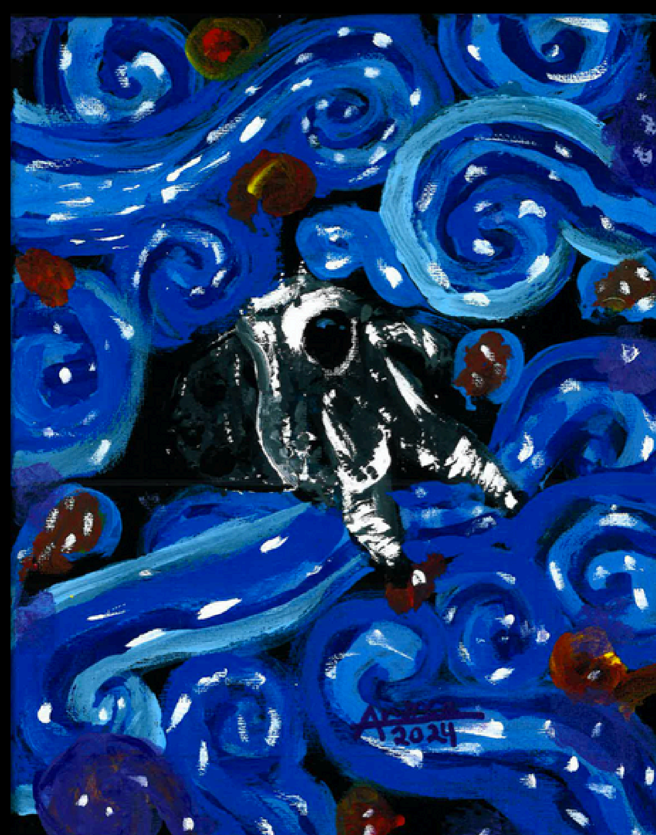
2024


Jacqueline
2024


Yamilette
2024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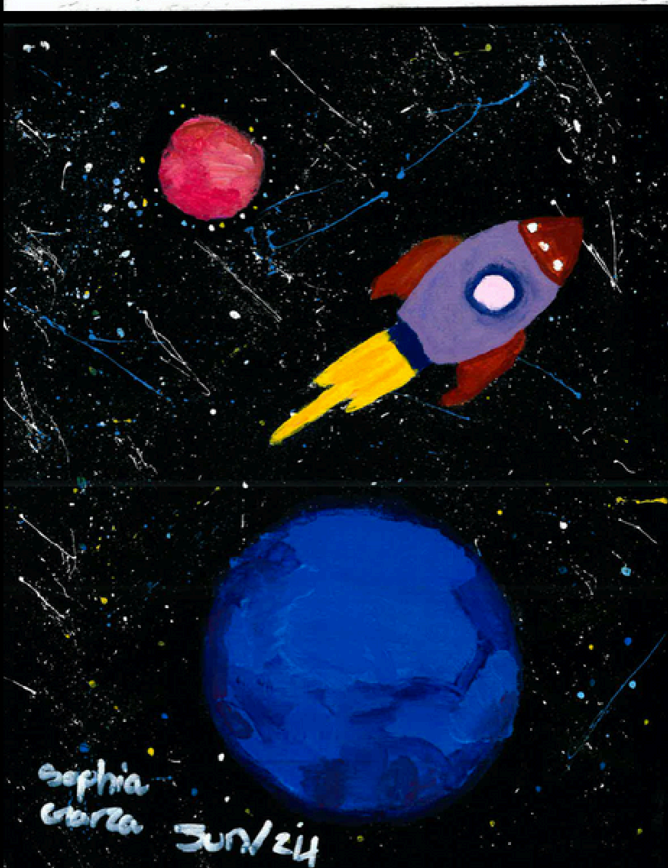
Gerardo
2024

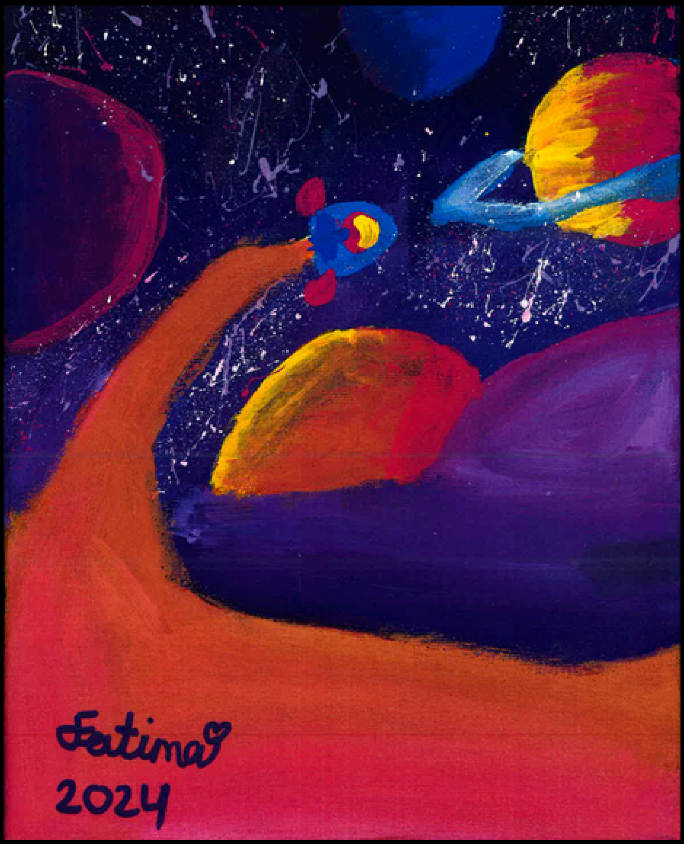

2024


Zuria
2024


Max 2024

Alexia
2024

sophia
Garza Jun/24

Sofia
2024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Victoria
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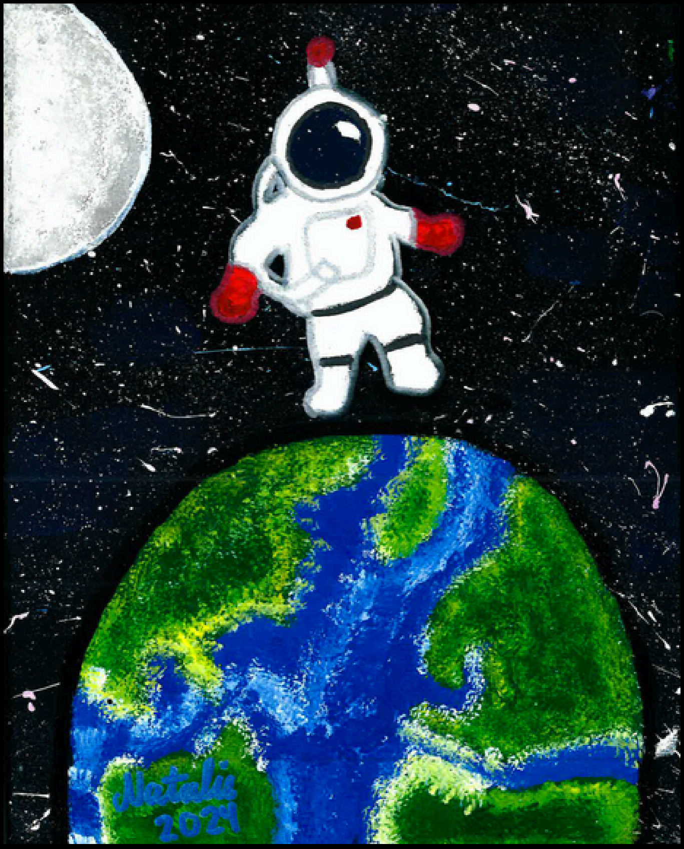
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Kimberly
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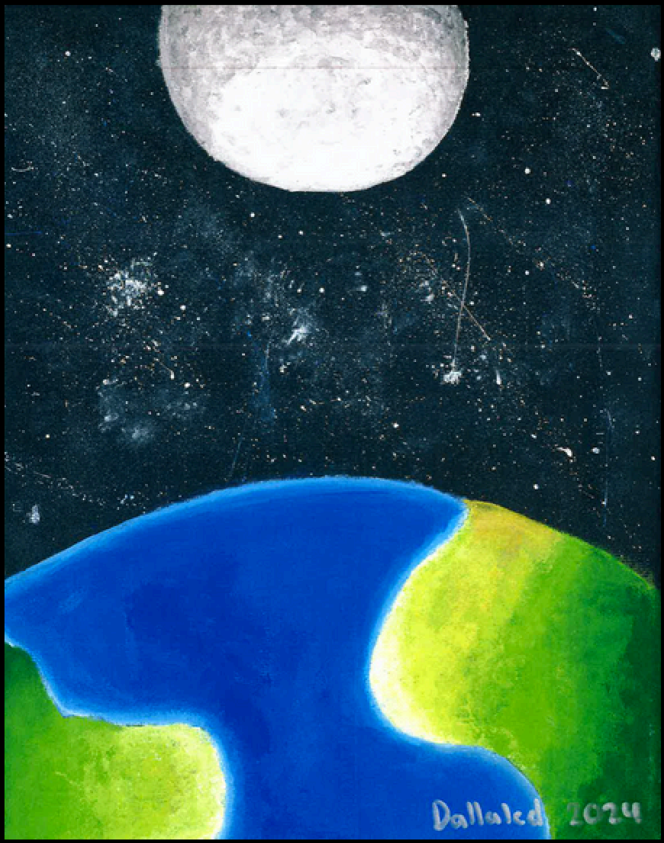
2024 Renata B

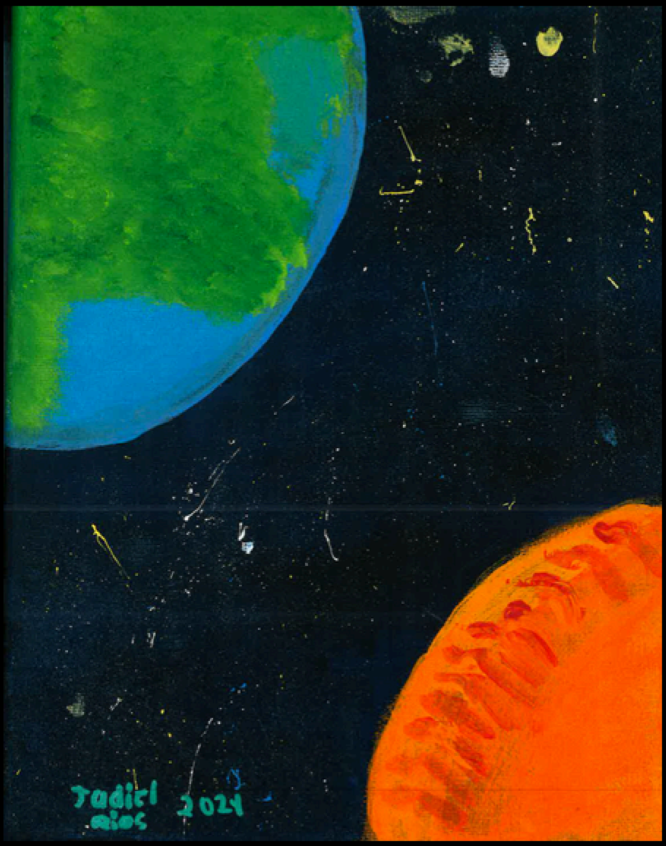

Alexia
2024


Alyssa
2024


Dallaled 2024


Emma
2024


2024


Jadiel
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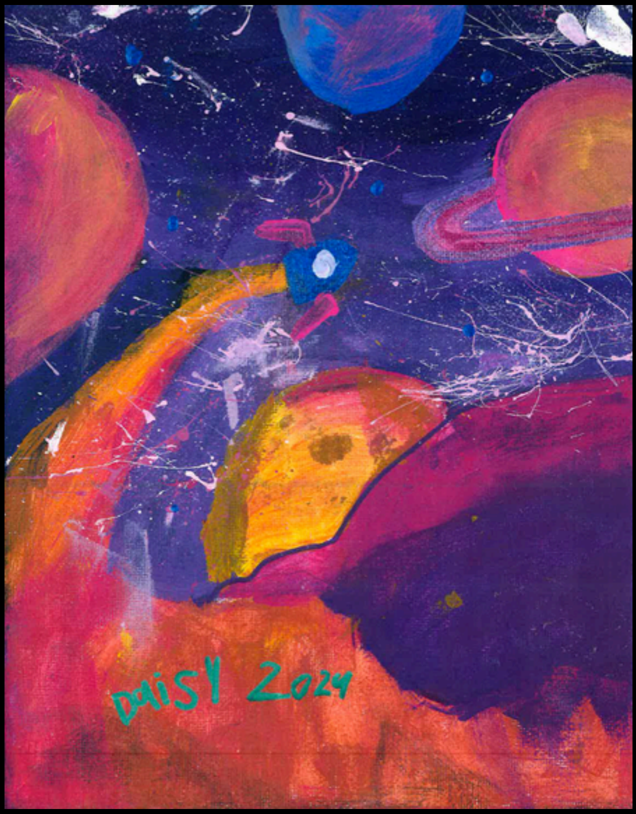
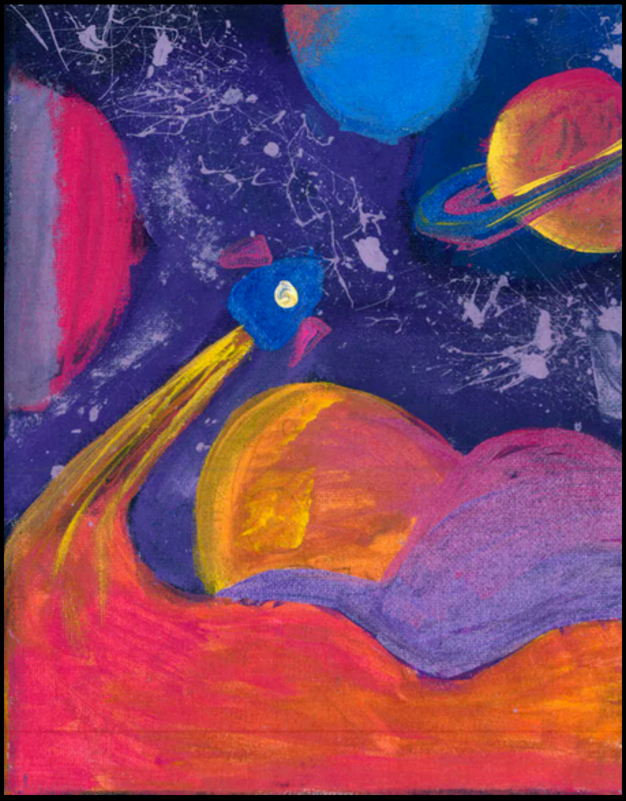
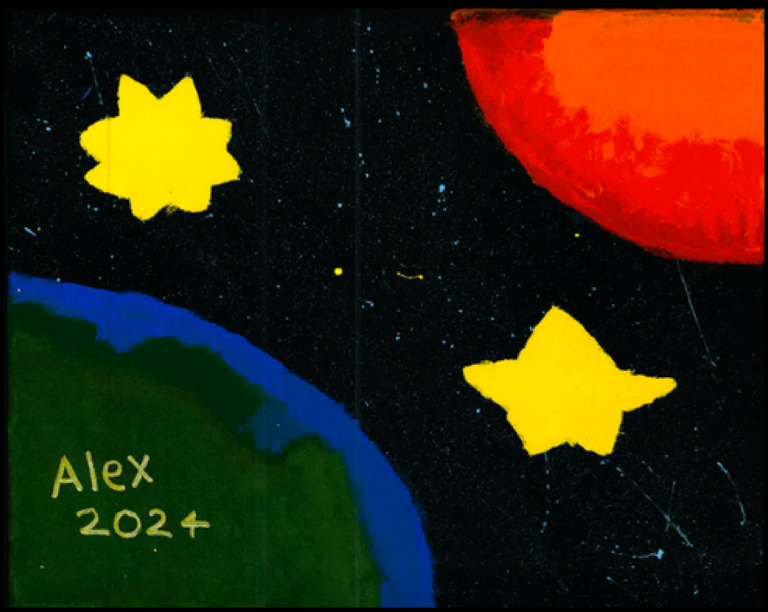

DAISY 2024

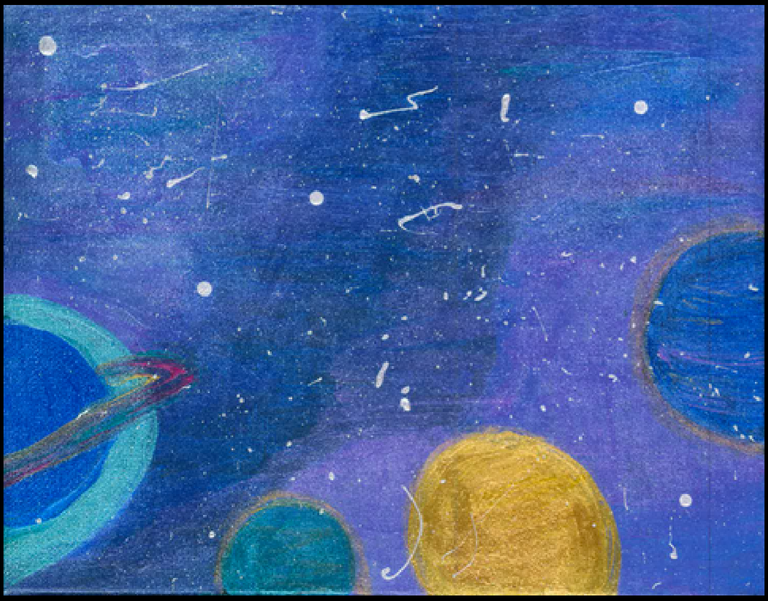

2024


Dipna
2024




Alex
2024


Alexis
2024




Ximena
2024

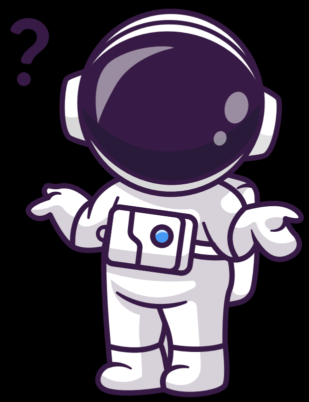
This Summer 2024, we present to you...

COSMIC COMEDY

Don't space out on our jokes... you know they're absolutely stellar.

Cosmic Comedy

Summer 2024



What did the restaurant critic write about the first restaurant on the Moon?

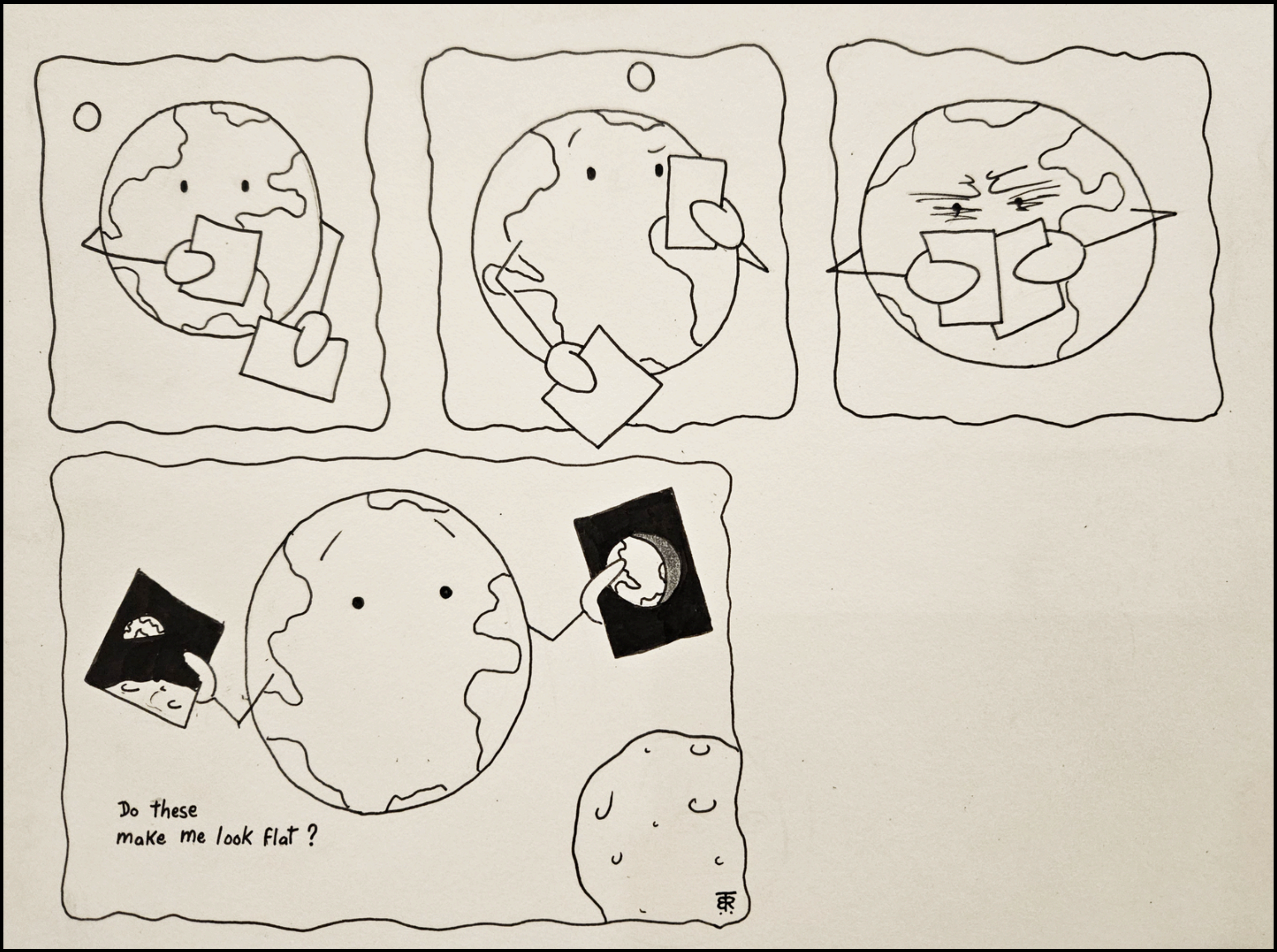
The food wasn't bad, but there was no atmosphere.

How do you know if a star is alive?

Check its pulsar.

Why does food from space taste better?

It's a little meteor.



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Colophon

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Submissions

We encourage submissions from anyone interested in contributing to our magazine. Any readers with ideas for submission, including their own articles, illustrations, or other content, or any corrections or comments, please contact the Editor-in-Chief at: rcamuccio {at} gmail {dot} com

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