ASTRO DIGEST

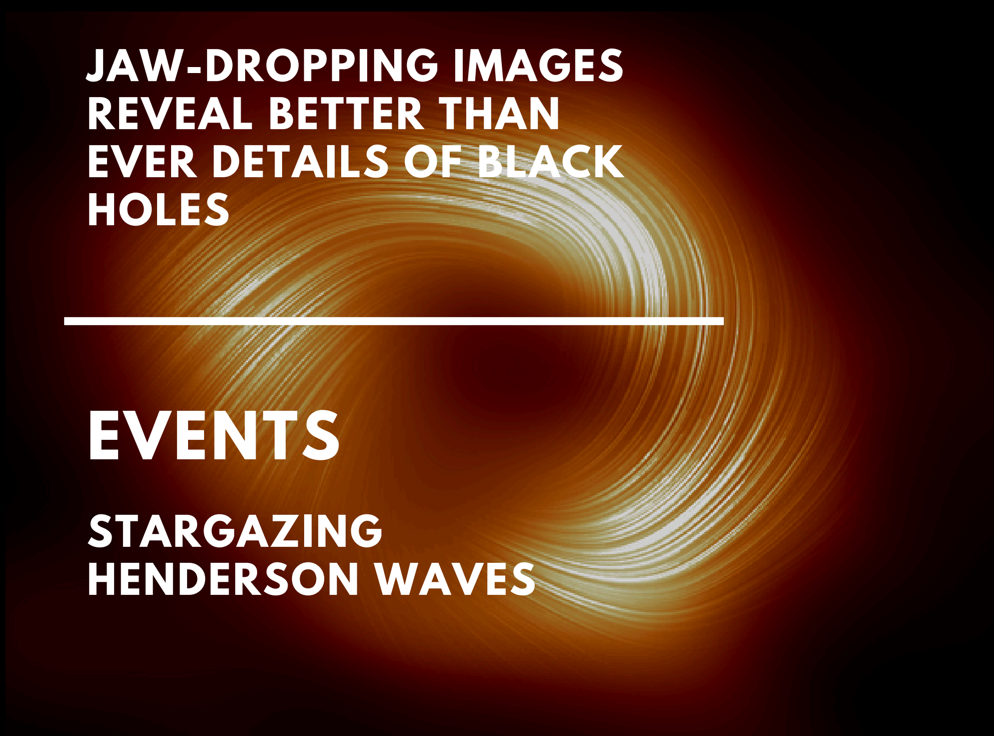
AUGUST 2024

GRAVITATIONAL WAVES

AN INSIGHT INTO THE PHENOMENON THAT MAKES THE UNIVERSE VIBRATE

HUBBLE TENSION

ARE OUR BEST MODELS OF THE UNIVERSE WRONG, OR ARE WE MISSING SOMETHING?



POLARISED SINGULARITY

JAW-DROPPING IMAGES REVEAL BETTER THAN EVER DETAILS OF BLACK HOLES

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GRAVITATIONAL WAVES

Gravitational waves can be thought of as ripples in space-time. They can be visualized better by imagining waves on the surface of a water body. They are thought to be caused by powerful events in the universe, such as a black hole pair orbiting each other around a fixed point.

While gravitational waves were first detected by LIGO (Laser Interferometer Gravitational-wave Observatory) in 2015, new datasets and observations from 4 separate gravitational wave studies published in late June 2023 provide a fascinating new insight into the cataclysmic events causing them, as well as indicating that scientists might be missing something from our best current model of the universe.

The LIGO detector is 1km long and uses mirrors to reflect light back from the source to be detected. The difference in the distance the laser travels to reach the detector over multiple observations attributes to the detection of a gravitational wave, as the speed of the laser and the time it takes remains the same. It can only detect gravitational waves at high frequencies and low wavelengths, due to the size of the detector, which has lasers traveling through tunnels about 1km long. This is what was detected in 2015, a gravitational wave with a wavelength of about 10s of kms, which is best created by our models of 2 black holes orbiting each other, each of which are about 10x to 100x the mass of our sun.

Illustration of pulsar timing arrays. Source: Institute for research in Astrophysics and planetology

What are PTAs?

PTA stands for Pulsar Timing Arrays, which in the context of gravitational wave detection, is basically a massive detector spanning light years from one end to the other.

GRAVITATIONAL WAVES

Pulsar Timing Arrays are essentially a collection of pulsars. In this makeshift detector, pulsars, which are highly magnetized neutron stars that spin at a rapid rate, emit funnel-like beams of electromagnetic radiation from their poles, and due to the rotating nature of pulsars, these streams of radiation are periodically directed at different directions. Pulsars can spin extremely quickly, up to multiple rotations per millisecond is possible, and in the case that axis of rotation of the pulsar happens to point these beams of EM radiation towards Earth, observers on Earth would be able to see periodic pulses of light.

With LIGO, since the detector itself is quite small, the sensitivity to the frequencies of waves that can be detected are quite low, and can only measure gravitational waves that are extremely small. However, with PTAs, the distance between each pulsar is light years. This makes a PTA sensitive to lower frequency and higher wavelength waves, so it can detect gravitational waves that have wavelengths of up to light years long. To measure one wavelength of such a massive wave, scientists would have to wait for up to decades long just to observe signals from one crest to the other (one wavelength).

This depends on the size of the gravitational waves. Such waves are thought to be produced by pairs of Super Massive Black Holes (SMBHs) orbiting each other.

With PTAs, astronomers are able to create a rhythm, or pattern, of which pulsars pulsate at what point in time and in what sequence. If the distance between pulsars remains the same, since light travels at a constant velocity, the time period of the pulses of each individual pulsar that is observed, as well as the time elapsed between pulses of different pulsars in the sequence should be the same. However, over the course of the last 2 decades, after collecting and analyzing this sequential data, scientists have come up with evidence to prove otherwise.

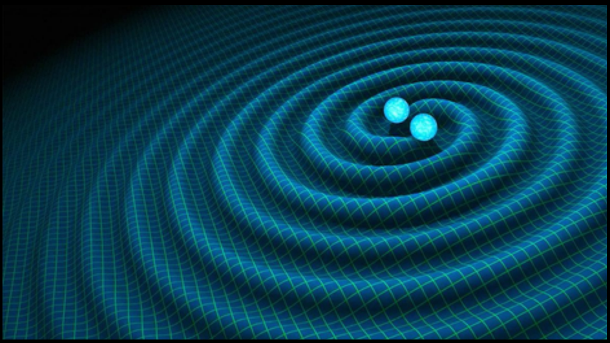


Illustration of gravitational waves created by a pair of orbiting black holes. Source: Space.com

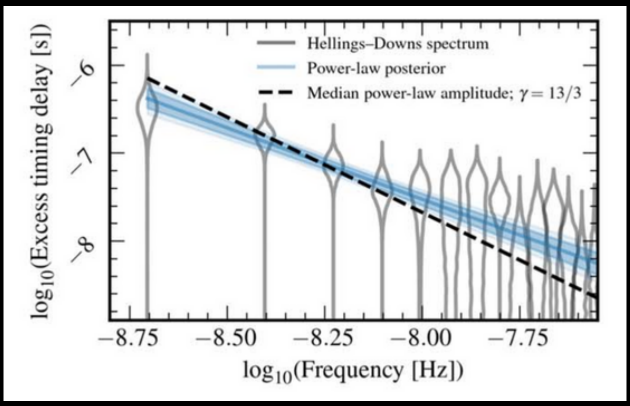
GRAVITATIONAL WAVES

Data analysis from this type of long wavelength gravitational wave is exactly what 4 separate research studies, the NanoGrav, the EPTA and InPTA, Parkes PTA and Chinese PTA projects all published in late June 2023.

Across the 4 projects, the research groups had been collecting and analyzing data, as well as collaborating with each other for a span of about 14 to 25 years. They observed that there were gradual variations in the duration sequences of pulses from different pulsars, corresponding to a gravitational wave of very long wavelength passing through and varying the distances between the pulsars by stretching and contracting the space-time between them, thus changing the duration sequence of the pulsars (as with different distances, light takes an either longer or shorter amount of time to reach us).

To put this into simple terms, imagine that the Earth is a ship on the cosmic sea. Every once in a while, we're hit by a wave, and we know something went by. But now, for the first time, we can start to see the choppiness of the entire ocean, and we're learning what else lives in it.

The data collected almost perfectly matches the SMBH binary models predicted from Einstein's theory of general relativity at lower frequencies of the gravitational wave, but deviates at the higher frequencies. Since ruling out this being a statistical fluke or error, as all 4 projects derived similar data, this has gotten astronomers baffled, and is leading to speculation that something is missing in our best model of the universe. If that is the case or not, only future research will tell.



Graph from the NANOGrav data release. The blue line shows the correlation in the data collected, while the black dotted line shows the modelled data if the gravitational wave is caused only by pair of orbiting black hole binaries. Source: NANOGrav data set

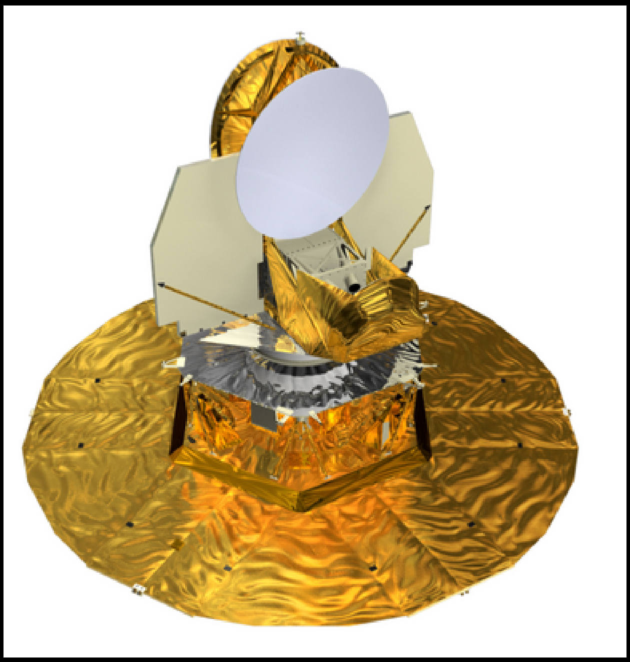
HUBBLE TENSION

Whether you're an avid stargazer or a diehard theorist, one would have certainly heard of Hubble's law. In short, this relates the distance between distant cosmological objects such as galaxies and galaxy clusters to their rate of separation.

This expansion is a relic of the Big Bang, whose theory predicts that the universe began as a singularity approximately 13.8 billion years ago and has been expanding ever since.

This expansion is encapsulated in the Hubble constant which shows itself in Hubble's law and is the rate of expansion at this current moment. Fortunately for us, there are a variety of independent ways we can measure this constant. This allows us to both verify our understanding of physics on the large scale which is governed by Einstein's theory of General Relativity as well as verify our best-guess model, the ΛCDM.

Out of the many, there are 2 largely accepted ways that the expansion is measured. One is through measuring fluctuations in the Cosmic Microwave Background which is the leftover radiation from the early universe. This was comprehensively executed by the WMAP satellite in the early 2000s and Planck telescope later in the 2010s. Ultimately, the more accurate Planck measurement gave a value of 67.4 ± 0.8 km s^{-1} Mpc^{-1}.



NASA'S WMAP SATELLITE. SOURCE: NASA

The second method involves observing Type Ia supernova explosions. These typically occur when a white dwarf star accretes mass from a companion star inside a multiple star system. When the white dwarf's mass reaches about 1.4 solar masses, also famously known as the Chandrasekhar limit, it explodes giving off radiation in a predictable manner which can then be used to measure the Hubble constant due to their vast distances from us. In particular, the latest and most accurate measurement was found by the SH0ES team led by cosmologist Adam Reiss. The value: 73.04 ± 1.04 km s^{-1} Mpc^{-1}; vastly different from the Planck measurement and which finally exposes in plain sight the tension of interest.

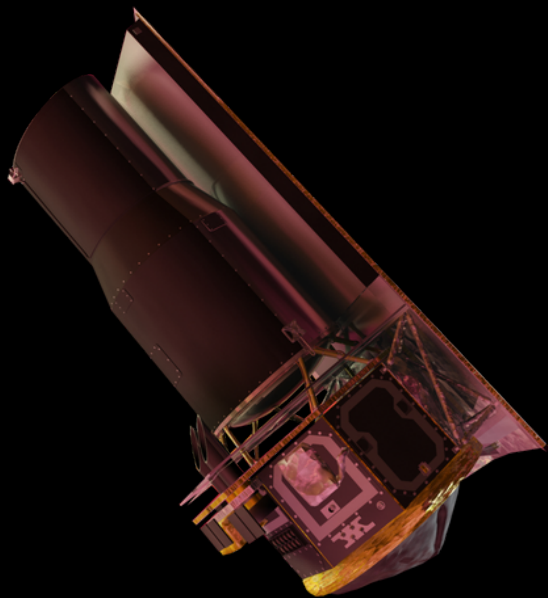
HUBBLE TENSION

ESA'S PLANCK SATELLITE. SOURCE: WIKI

Planck, alongside WMAP, played a pivotal role in verifying the ΛCDM model and providing one of the most precise value of the Hubble constant thus far.

In statistical terms, the observed disagreement in measured values corresponds to 4.2 σ, or roughly 1 in 100,000 chance of the values being different by just random variation.

There have been numerous explanations to reconcile the tension which predominantly fall under 3 categories: theory, data analysis and model. The first says that our current understanding of physics is fundamentally wrong. The second, that there were errors in data analysis that led to either one or both of the measurements being off from the other. The third says that while our understanding of physics itself is not incorrect, our knowledge of the universe's structure and components throughout its history requires work. Among the three, the third explanation has received significant traction with papers such as Vagnozzi, 2023 calling for modifications in our model at 3 key phases of the universe.



THE SPITZER SPACE TELESCOPE SOURCE: WIKIMEDIA

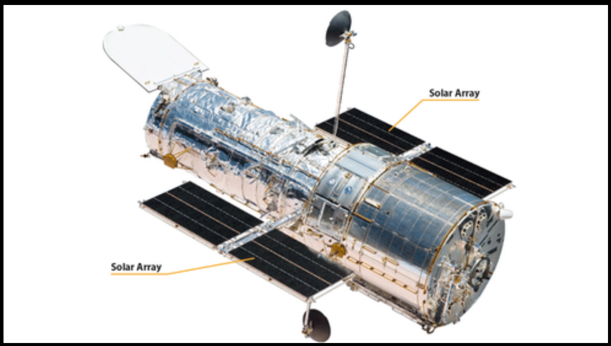
This telescope, alongside other legacy space telescopes, was used to fine-tune distance measurements to Cepheid variables and thereby give the narrow error bars currently present.

HUBBLE TENSION

Stay tuned to our next newsletter regarding what these 3 phases are, alongside an in-depth account of what the 2 other major explanations behind the Tension entail! Who knows, perhaps by the time of our writing the article, Webb may already figure out the mystery of the Hubble Tension.

THE MAGELLAN TELESCOPES. SOURCE: WIKIMEDIA

Ground telescopes such as the majestic Magellan Telescopes also played a crucial role in determining the SH0ES measurement.



THE HUBBLE SPACE TELESCOPE. SOURCE: NASA

The iconic Hubble has not only played a crucial role in visible range astronomy, but has had a decisive hand in cosmology, and in particular, measurements of the Hubble Constant.

POLARISED SINGULARITY

BEFORE (2019)
SOURCE: WIKIMEDIA
The first direct image of a black hole, complete with the accretion disk and event horizon, taken by mankind.

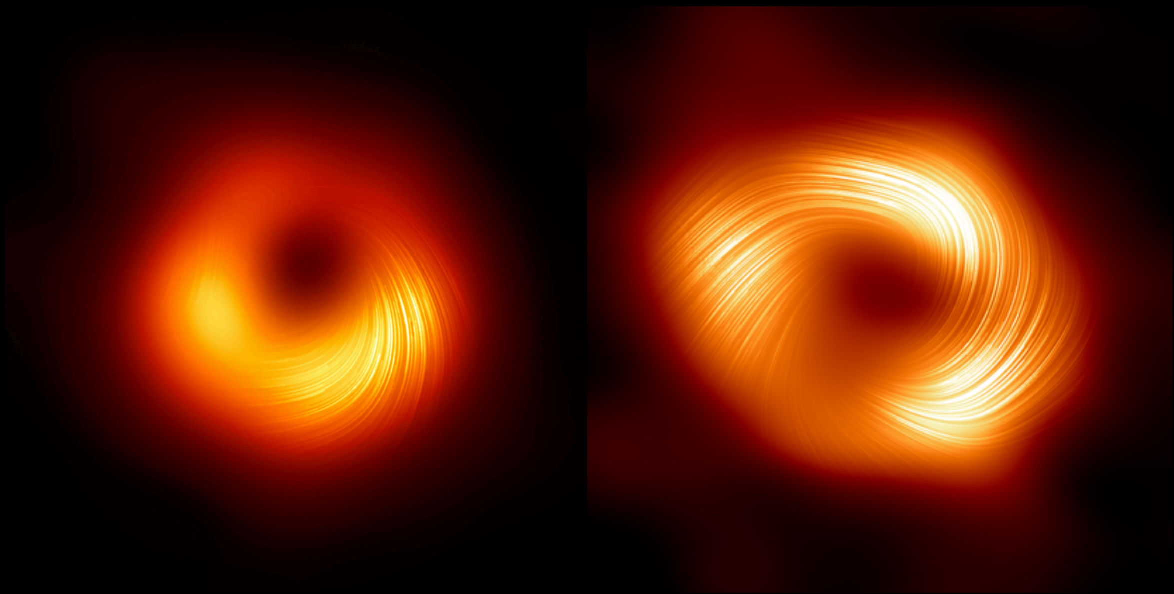
AFTER (2021)
SOURCE: WIKIMEDIA
New information about the polarisation of light surrounding the black hole adds finer insight to its physics.

Remember the absolute frenzy that was caused in 2019 when the Event Horizon Telescope (EHT) collaboration released the first ever picture of a black hole, M87*, located at the center of the galaxy Messier 87 (M87)? Well, in 2021, scientists discovered that a significant portion of the light around the black hole M87* is polarized, leading to a newer, much more mesmerizing image of the black hole.

But what does this mean and how does this help us? Is it really all that much of an improvement? Well, the light that is actually seen in the image is the visual representation of the magnetic field around the black hole.

Well, the light that is actually seen in the image is the visual representation of the magnetic field around the black hole, which, to the best of our knowledge and physics, is not actually generated by the black hole itself, but rather by the rapidly moving charged particles in the accretion disk (which is the disk of dust, gas, particles and other material orbiting around the edge of the black hole). A large composition of the disk is made of plasma, which are essentially just charged particles, and charged particles in motion generate a magnetic field, which is what can be seen in the image.

POLARISED SINGULARITY



M87 (LEFT) & SGA* (RIGHT) SIDE-BY-SIDE COMPARISON
SOURCE: WIKIMEDIA (LEFT) AND EHT COLLABORATION (RIGHT)
Stunning similarities can be seen between the 2 black hole pictures when viewed adjacently, apart from the obvious hole in the center.

Whether the black hole generates its own magnetic field is unknown, due to it, amongst other parameters, disappearing into the black hole, making it inaccessible to scientists. This is known as the no-hair theorem, and for now, it has appeared to be experimentally true.

Light becomes polarized when the orientation of the waves of light are directed at a particular angle. This happens when light passes through certain filters, for example, when light passes through the lenses of polarized sunglasses, or when it is emitted in hot regions of space that are heavily magnetized, which are the circumstances in which this image was developed.

Long exposure periods using 8 different telescopes enabled the EHT collaboration to observe and develop the magnetic field lines that are visible in the image.

The same process and concepts were used to develop an image of another black hole which was released in March 2024, this one much closer to home. In fact, the black hole in question is the one at the center of our very own galaxy, the Milky Way. Dubbed as Sagittarius A*, this black hole came with its own unique set of problems that challenged astronomers who were trying to extract another polarized image from the data obtained.

POLARISED SINGULARITY

THE EVENT HORIZON TELESCOPE (EHT)
SOURCE: WIKIMEDIA
Deserving an article of its own, the EHT is an extremely unique telescope, in that not only is it made of an array of radio telescopes, but these telescopes are situated entire continents apart and underpin its ability to observe the imperceptibly small event horizons of far away black holes.

For one, Sagittarius A* is much, much closer to us than M87*, at a distance of 26,670 light years from us compared to 53.49 million light years away for M87*. The problem this poses is significant, as in addition to it being quite close to us, Sagittarius A* is also much smaller than M87*, which results in material orbiting it at astonishing speeds, which causes observational images to change on a minute by minute basis, making Sagittarius A* more dynamic.

Despite these challenges, the image developed for Sagittarius A* bore remarkable similarities to the M87*, giving scientists a more general idea of black hole activity and parameters and providing a better framework for future research to build on. What's next? Only time will tell!

EVENTS AND STARGAZING

This section is for all the avid stargazers and social butterflies here itching for a chance to network with fellow like-minded astronomers!

Science Center Singapore

Open every 4th and 5th Friday of the month to the public, the 40cm telescope allows for many breathtaking views of iconic celestial objects like the Moon, Jupiter, Saturn and possibly even a few DSOs if the skies are crisply clear! Slots are limited so do remember to book before heading down!

Featured Stargazing Location: Henderson Waves

A hidden gem within Singapore's bustling and ever-wakeful South is the Henderson Waves. This bridge, spanning 274m at a towering 90m above sea level, provides onlookers with a an almost unblocked view of the sky. I, the writer myself, have managed to capture beautiful images of Omega Centauri and the Jewel Box Cluster from here, with many more soon to be captured with my trusty camera!

Henderson Waves
Source: Wikimedia
Not only is this location one of the better stargazing spots in Singapore, its surrounding natural beauty replete with a myriad bird species and the bridge's unique architecture itself is sure to keep you captivated.

EVENTS AND STARGAZING

The August Sky in Singapore has countless jewels to offer, regardless of the light pollution. Depending on your available tools, you will be able to see ever more elusive objects. Regardless of this, there are ample objects to observe for anyone patient and avid enough.

Free-hand stargazing

- **August 12th-13th** Perseids meteor shower: One of the brighter annual meteor showers, the moon will only be at 50% illumination on that night, making for perfect meteor shower observing conditions!

- **August 14th** Mars-Jupiter conjunction: Rise early and gaze upon Mars and Jupiter, which will appear within 0.33° of each other, close enough to be seen within the field of view of a telescope!

- **August 20th** Sturgeon Moon: At around 2am on August 20th, witness a bright supermoon in the night sky! It will be much brighter and bigger than any of the full moons this year, so keep a lookout for it!

Source: Stellarium

EVENTS AND STARGAZING

Free-hand stargazing (cont'd)

Binoculars
'Tis the season for star clusters!! Try your hand at finding these prominent bejewelled globs in the sky.

- Spider Globular Cluster (M4): At 5,500 light years away, this cluster of stars is the closest globular cluster to Earth. Due to its extremely bright nature (it has an apparent magnitude of +5.9) and proximity to Antares, one of the brightest stars in the sky, this cluster is relatively easy to find.

- Great Pegasus Cluster (M15): Located in the constellation of Pegasus (surprise!), this cluster of stars is one of the densest clusters ever discovered, with both hotter blue stars and cooler orange stars become more concentrated towards the centre.

- Great Sagittarius Cluster (M22): The brightest of the 3 clusters mentioned, it can be seen with the naked eye in ideal conditions. One of the first globular clusters ever discovered (in 1665), this cluster is home to some fascinating features, including 2 stellar mass black holes.

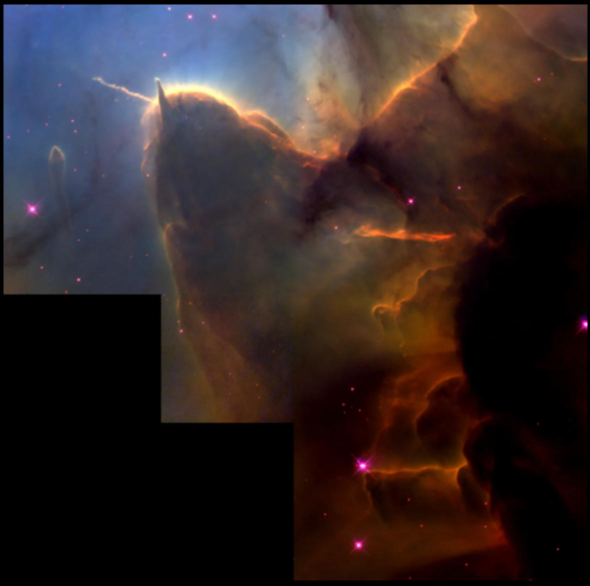
Source: NASA

EVENTS AND STARGAZING

Telescope

- Ring Nebula (M57): Located in the constellation of Lyra, the Ring Nebula is a planetary nebula, which are essentially the glowing remains of dust and gas surrounding the core of a dead star that once represented the layers of a sun like star. A beautiful collection of colours, representing different gases, can be seen in complicated ring systems around the core.

- Trifid Nebula (M20): Best observed during August using a telescope, the Trifid Nebula is an active star forming region located about 9,000 light years away from Earth. A group of recently formed massive stars are clearly visible towards the centre of the nebula.



Source: NASA

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Max Planck Institute PTA
Parkes PTA
Chinese PTA

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WMAP Spacecraft
Planck Telescope
Spitzer Spacecraft
Magellan Telescope
Hubble Space Telescope

Polarising Singularity
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Guide to stargazing
The Ultimate Guide to Observing the Spring Sky (Northern Hemisphere)