Beyond the Stars: Astrophysics in the Bangtan Universe

ACADEMIC ARTICLE: ROUNDTABLE

EDITED BY

Lyna Etienne
Engineer and Bangtan Universe enthusiast, always curious about astrophysics and space science in general (France)

Katie Hulme
Physicist by day, (amateur) poet by night (United States)

Courtney Lazore
Writer/editor focused on BTS, storytelling, and fandom (United States)

PANELISTS

Karen Macías Cárdenas
Astroparticle Physicist who loves the Universe and BTS, @KarenPhysics. (Canada)

Sara Issaoun
Black hole astronomer & member of the Event Horizon Telescope, @SaraIssaoun (Netherlands)

Jessica Warren
Astrophysics lecturer and science lover; remember to keep looking up! (United States)

Leonie Witte
A 23 year old Astrophysics masters student with a huge love for BTS and music in general! Youtube/Instagram @Leoniewitte. (United Kingdom)"

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Introduction

Transmedia storytelling can be defined as the process of telling stories using different media platforms, each medium contributing to the global story. In the specific case of BTS, a complete fictional universe was created based on transmedia storytelling using not just music videos but journal notes included in albums, books, narrated videos aired during live performances, a webtoon, and games. This fictional universe is more commonly known as the Bangtan Universe, or BU. This style of storytelling requires fans to participate in building this universe by piecing parts of this huge transmedia puzzle together as more contents pour in year after year. The story is deliberately left to the fans to interpret freely, and this openness has helped build a worldwide network of fans theorizing regularly on the meaning and evolution of the Bangtan Universe.

In her book, *BTS, ART REVOLUTION: BTS Meets Deleuze*, Dr. Lee Jiyoung states, "Although the cross-referential open structure invites the spectator for participation, the cross-referentiality of the videos can only be actualized by participation of the spectator. The spectator can no longer assume their traditional role. Beyond receivers who simply peer into the universe of BTS's art, they are the very constituents of the universe" (Lee, 2019, p. 115). BTS's ability to tell various stories, including the fragmented one of the BU, contributes to their strong, consistent fan engagement, which in turn plays a role in their massive success (Lazore, 2021). Similarly, by incorporating many themes and subjects into their storytelling, BTS's content has implications even for use in mental health work (Blady, 2021).

The Bangtan Universe tells the story of seven teenage boys. It's a coming of age narrative centered around the tragedies and small joys pathing the way to adulthood. The fictional characters take the names of the real BTS members and maintain some minor similarities in terms of personality and interests, but otherwise, these characters are separate from their real-world counterparts.

As years have passed, the BU has grown, encompassing not only transmedia storytelling but also diverse fields such as literature, art, psychology, and science. Fully appreciating the Bangtan Universe requires reading Hermann Hesse's *Demian*, understanding the psychological archetypes described by Carl Jung, having knowledge of art pieces such as *The Fall of the Rebel Angels* by Bruegel or *The Lament of Icarus* by Draper, and the list goes on. This is the main reason why the connection among fans is key in understanding the fictional universe — the sharing of insight and knowledge is what allows the puzzle to be pieced together.

What place does science have here? Like many other fictional universes, the Bangtan Universe has a narrative that uses time travel as a key element. The fictional character Seokjin goes back in time to save his six companions — but until recently, this was only speculation from fans based on key visuals. There was no canonical "proof" of this time travelling until the *SAVE ME* webtoon was released in January 2019 (Big Hit Entertainment, 2019b). While many analyses of the BU have been based on psychology, there has not been an in-depth exploration of the physics behind the visuals of the intricately woven Bangtan Universe.

To this end, our Editorial Board invited four physicists to our second roundtable to dive into the physics phenomena and concepts that can help us understand how the fictitious Bangtan Universe might theoretically exist and function (or not) in our real world. We hope you will join us in welcoming our physicists to the table:

- *Karen Macías Cárdenas*
- *Sara Issaoun*
- *Jessica Warren, Ph.D.*
- *Leonie Witte*

Participants will be referred to by the initials (**KMC**, **SI**, **JW**, and **LW**) throughout the text.

Methods

Participants were invited based on experience, expertise, and interest in the subject matter. Each participant was provided with the same list of questions and asked to answer as many or as few of the questions as they were comfortable answering based on their expertise. Responses from all participants were compiled by the moderators and distributed to the group for an open round of peer-review. Participants edited their responses based on the feedback from the peer-review process, and the final responses were compiled and arranged by the editors.

Round I:
Get to Know Our Panelists

Is there any specific BTS visual that particularly speaks to you as a student/teacher in physics? And why?

JW: Being an astrophysics lecturer and a fan of BTS, I particularly like some of the visuals they use. "DNA" is perhaps obvious here. It's one of the hooks that drew me in at first, when my sister (who introduced me to BTS) was sending me videos to watch. The astronomy visuals are colorful and appealing, but they have a deeper meaning in the sense that the elements that make up our bodies, our DNA, were formed in the centers of massive stars and then dispersed when those stars exploded. So I really like the duality of the visuals here.

Figure 1: Astrophysicist Jessica Warren was struck by the stage at the 2020 MMA (BANGTANTV, 2020,) stating "BTS is using astronomy to show connections among people. BTS has brought people together — especially this year — and astronomy also brings people together."

Also, "Outro: Ego" has some visuals I love: the galaxy behind J-Hope when he is dancing and the shadow moving behind him in the beginning. Both signify time passing in a way that is visceral and ancient — humanity's first understanding of time passing comes from the stars and Sun moving throughout the day/night.

Finally, the more recent 2020 *Melon Music Awards* (MMA) show involved constellations, a sundial, and an eclipse visual. What really strikes me about these is that BTS is using astronomy to show connections among people. BTS has brought people together — especially this year — and astronomy also brings people together. I often emphasize to my students that astronomy is a truly universal science and experience. Anyone, no matter their geographic location, socioeconomic status, race, religion, etc., can go outside and look up at the night sky. People in vastly different circumstances and situations can together look at the same Moon, planets, and stars. In fact, Seoul, San Francisco, and Sicily all see about the same night sky, being at approximately the same latitude. Astronomy, like BTS, can remind us that we are not alone.

SI: Visual-wise it would have to be the "Serendipity" MV for me; there's a lot of space imagery. The visual of Jimin looking up at the night sky with a telescope reminds me of my childhood. I got my telescope when I was 12, and I take it out to see the Moon and stars whenever I can! It's quite a meaningful visual for me; it's been my main lockscreen on my phone for three years! The solar eclipse scene in "Serendipity" is really nice.

In the context of black holes, a solar eclipse was actually the first solid proof that Albert Einstein's theory of gravity was the real deal, as a result of the expedition by Eddington in 1919. They speculated that the light from faraway stars would bend because of the gravity of the Sun, and this was measured during a solar eclipse! So how exactly did they do this? They first took photographic plates of the night sky at the position where the Sun would be during the eclipse. These plates were the control sample, where the light from the stars comes directly toward us and won't have to go around the Sun. Then during the daytime, at the moment of the eclipse, the sky goes dark when the Moon covers the Sun and the stars can be seen. Photographic plates were then taken during the eclipse, where the light from the stars was expected to be bent by the Sun's gravity in-between the stars and us. Then Eddington and his team came home and analyzed the plates. A number of them were sadly unusable, but there was a decent number where the stars could be clearly seen and their positions accurately measured. They found that the positions of the stars shifted by a miniscule amount during the eclipse compared to during the night when the Sun is not in the path. This tiny shift was exactly what Einstein's theory of general relativity predicted for an object the mass of the Sun!

LW: There are two that particularly catch my attention which also can be linked in a way. The first would be in the "DNA" music video and even within the lyrics they talk about fate ("none of this is coincidence") and how events and people are linked together. The DNA within us connects us together; "our meeting is like a mathematical formula" (Doolset Lyrics, 2018). The

Figure 2.

Figure 3.

Figure 2. Sara Issaoun, a PhD candidate in astrophysics, is enamoured with the music video for "Serendipity" (Big Hit Labels, 2017a) which depicts a solar eclipse. Sara states, "In the context of black holes, a solar eclipse was actually the first solid proof that Einstein's theory of gravity was the real deal, as a result of the expedition by Eddington in 1919."

Figure 3. "The DNA within us connects us together", Leonie Witte, an astrophysics student, comments while discussing the music video for 'DNA' (Big Hit Labels, 2017b). She loves the MV for its reflection on "how events and people are linked together", which is explored both lyrically and visually in moments such as the one depicted above, where the seven members of BTS join hands in a formation reminiscent of a double-helix.

video itself has a lot of references to space and science, both physics and chemistry. The second would be the constant mentioning of the butterfly effect; this effect explains that nothing can be reproduced exactly without the precise same initial conditions. This is mentioned throughout the entire BTS universe and is pivotal in the storyline they have created throughout the music videos and cartoons.

KMC: Yes! I think this one will be a fan favorite between ARMY physicists here. I vividly remember the 2017 *Mnet Asian Music Awards* (MAMA) "Beyond Wormhole" performance because I have a special memory attached to it.

I was in the fifth semester of my bachelor's and it was finals week. I had a project for my tensor analysis course due the next day, so I was finishing it up at 2 a.m. but I was so tired. That was the year I became a fan, so I did not know at exactly what time the performance was, but I decided to take a break and look for a live stream.

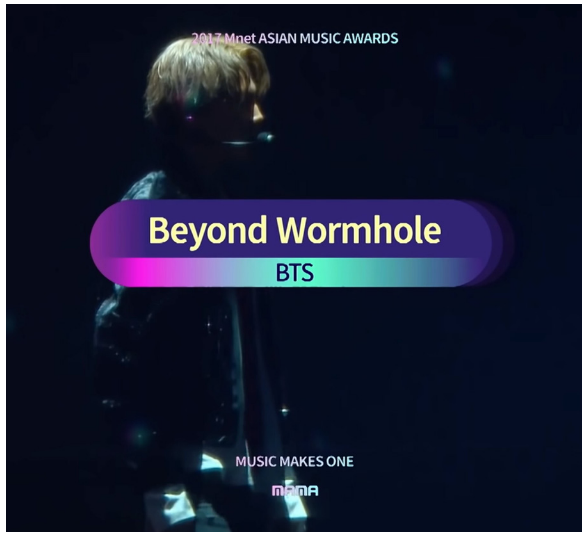


Figure 4. The 2017 MAMA "Beyond Wormhole" performance (Mnet K-POP, 2017) holds special significance for Karen Macías Cárdenas, a student in astroparticle physics, who recalls watching it during a late night of coursework. They recall, "when I saw the word wormhole I was no longer that tired. You see, my tensor analysis homework was on the Schwarzschild metric for black holes, so I thought it was hilarious and that the universe was indeed telling me to finish the project or something."

BTS's performance started not too long after I started watching, and when I saw the word wormhole I was no longer that tired. You see, my tensor analysis homework was on the Schwarzschild metric for black holes, so I thought it was hilarious and that the universe was indeed telling me to finish the project or something.

That visual of the wormhole as the background during the "DNA" performance also made me more aware of the song's verse that goes "Ever since the day when the universe was created, and through infinite centuries. Because in the past life and maybe in the next one as well, we're forever together" (Doolset Lyrics, 2018).

That performance really cemented BTS's artistry for me; it made me an ARMY and gave me the motivation to finish writing the Schwarzschild metric.

Round II: Definitions

BTS's work contains many beautiful and inspiring visuals, and references to space are certainly plentiful. We can dive a little deeper into some of these images and concepts by first discussing a few definitions. What exactly is a black hole? A wormhole? A singularity? We asked our panelists to explain some of the images and ideas in BTS's music videos, performances, and storylines.

What is a black hole?

KMC: In terms of mathematics, a black hole is a solution to Einstein's theory of general relativity in which geometry and matter are coupled together into one single equation. This is why different solutions can create different space-times.

In a physical sense, a black hole is an object in the universe that curves space-time and from which light cannot escape. This means that the velocity you would need to escape from a black hole is higher than the speed of light itself, which is a universal constant and one of the bases of relativity.

An astrophysical black hole is formed when a massive star, usually more than eight solar masses, explodes into a supernova at the end of its life.

JW: In his theory of general relativity, Einstein showed that space and time are connected in a fabric we call "space-time." Massive objects can bend or distort the space-time around them, and a black hole is the ultimate "distortion." Black holes come in many sizes, from microscopic to stellar-mass to supermassive behemoths millions

Figure 5. A black hole, which also resembles the pupil of an eye from a previous scene, features in the music video for "DNA" (Big Hit Labels, 2017b). Jessica Warren states, "Massive objects can bend or distort the space-time around them, and a black hole is the ultimate 'distortion.'"

or billions of times the mass of our Sun that reside in the centers of galaxies.

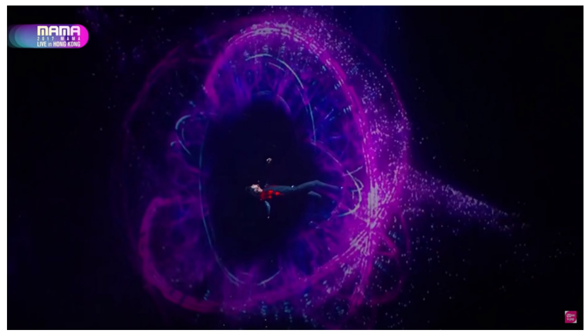
SI: A black hole is an object with a gravitational pull so strong that the speed needed to escape its gravity is greater than the speed of light. Since nothing can ever go faster than the speed of light, even light gets absorbed into it once it crosses its point of no return (the event horizon) and leaves only darkness behind. Light can come from very close to black holes, from gas that eventually will fall in. Light is emitted by this hot gas rotating very fast due to the extreme gravity. But once anything, gas, matter, light, gets too close, it will inevitably fall into the darkness and never return.

LW: You can think of a black hole like a vacuum cleaner, though like a real vacuum cleaner, only things close enough to the nozzle will be pulled in. The main difference is that a vacuum cleaner won't suck in light while a black hole can; because of this it gets the name "black hole." It is so strong that it could suck in an astronaut and even whole stars! The reason it has such a strong pull is because a lot of matter has been squished into a tiny space and condensed so much that its gravitational pull is very high!

What is an event horizon?

SI: The event horizon is the point of no return. Beyond it, the speed needed to escape the gravitational pull of the black hole becomes greater than the speed of light, and nothing can escape. Imagine a swimmer in a river with a waterfall. The closer they are downstream to the waterfall, the faster they will need to swim in the opposite direction to escape its pull. If they get close enough to the edge, even the best swimmer in the world wouldn't be able to swim upstream fast enough and will be swept over the waterfall. The region where the fastest swimmer in the universe (light) can no longer escape the gravity waterfall (black hole) is what we call the event horizon.

(a)



(b)

Figure 6. Sara Issaoun describes an event horizon using the analogy of a waterfall. "If they get close enough to the edge, even the best swimmer in the world wouldn't be able to swim upstream and will be swept by the waterfall. The region where the fastest swimmer in the universe (light) can no longer escape the gravity waterfall (black hole) is what we call the event horizon." While not necessarily direct references to the "event horizon," scenes of members "falling" backwards or suspended in a "fall" are recurrent in BTS's music videos and performances. **(a)** Taehyung falling backwards in the "Run" MV (Big Hit Labels, 2015b). **(b)** Seokjin suspended in a fall at the center of a wormhole during the "Beyond Wormhole" performance at MAMA (Mnet K-POP, 2017).

JW: A common myth is that black holes suck in everything that gets near them. In fact, you can orbit a black hole very safely, as long as you are at a safe distance. The closer you get to a black hole, the harder it is to escape the pull of its gravity. However, as long as your spacecraft can achieve the escape velocity (speed needed to escape) at the distance you are orbiting, you are perfectly safe! The catch is that eventually the escape velocity reaches the speed of light. Since nothing can go faster than the speed of light — and massive objects can never actually reach the speed of light — then there is a distance at which nothing, not even light, can escape the black hole's gravitational pull. This distance is called the event horizon of the black hole.

Formally, it is the distance from a black hole at which the escape velocity (speed needed to escape the black hole's gravity) is equal to the speed of light. It is sometimes considered the "size" of a black hole, called the Schwarzschild radius. Past the event horizon, the escape velocity is less than lightspeed. Inside the event horizon, the escape velocity is greater than the speed of light. Since nothing can achieve faster-than-light speeds, anything — including light — that ventures inside the event horizon can never come back out. Thus, we can not get any information out of a black hole — what goes in, stays in (but is likely destroyed in the process)!

What is a singularity?

LW: In complex words, a singularity is a point in space where the curvature of space-time becomes infinite, but what does that actually mean? It means that the quantities we use to measure gravitational fields such as density, etc., become infinite and so the laws break down. It's like if you overflow your cup with too much juice because your amount of juice has become infinite, the cup no longer works like a cup should (i.e., containing the juice). A type of singularity called gravitational singularities is in the center of the black holes we have just discussed.

SI: In simple terms, this is what we call a mathematical instance when equations explode and go to infinity (like when we divide by zero for example). For the "singularity" inside a black hole, the equations in question are the ones from Einstein's theory of general relativity. In 1916, Karl Schwarzschild derived the first exact solution to those equations, and it resulted in a singularity: a point where all mass is concentrated in an infinitely small space, space itself becomes infinitely curved and stretched, and time comes to a stop.

KMC: As was mentioned before, a black hole warps space-time; inside of it, it warps space-time infinitely into a single point in which density and gravity are also infinite according to most of our current understanding of general relativity. In this realm, though, gravity alone is not enough to understand these processes. We also need quantum mechanics, and we are not sure how to merge them together. This is one of the reasons why it is said that a singularity is where our physical understanding of the universe breaks.

JW: The singularity is an infinitely small point in which all the mass of a black hole has collapsed down. It is sometimes thought of as the "center" of a black hole. We do not know what happens at the singularity because our theories of physics break down at this point. Quantum physics, which describes the very small, and general relativity,

Figure 7. V's solo track for *LOVE YOURSELF* 轉 *Tear* is titled 'Singularity' (Big Hit Labels, 2018). Karen Macías Cárdenas explains a singularity as a point in space in which a black hole "warps space-time infinitely into a single point in which density and gravity are also infinite according to most of our current understanding of general relativity… it is said that a singularity is where our physical understanding of the universe breaks".

which describes the very massive, predict different things at a singularity. Thus, we need a theory that reconciles these two in order to explain what physically occurs at the singularity of a black hole.

What is a white hole, and how does it differ from a black hole?

JW: A white hole is a theoretical solution to Einstein's general relativistic field equations, like a black hole. However, a white hole is the opposite of a black hole in the sense that, while nothing can escape from a black hole's event horizon, everything escapes from a white hole. We have many multiple lines of evidence for black holes existing, but so far no evidence for white holes. Some theorists posit that the singularity of a black hole is connected to a white hole somewhere else in the universe. Others think that white holes essentially spawn new universes. Perhaps our own Big Bang was the result of a white hole.

SI: A white hole is the mathematical opposite of a black hole; it is a singularity in space and time where nothing can enter its event horizon, even though matter is infalling toward it because of its gravitational pull. Apart from the behavior at the horizon, black holes and white holes are very similar, and one can also argue, as Stephen Hawking did, that a white hole and a black hole are the same object but in different time directions. In the context of wormholes, they also behave the same way. We can create a wormhole in space with a pair of black holes at different points, or with a pair of white holes at different points. The pair is connected via a bridge through a bend in space and allows matter to go from one region of space to another instantly, at the same time instant. Some speculate also that white holes are simply the opposite end of black holes, where the information a black hole swallows eventually comes out, solving the information paradox that exists with a black hole. Some also speculate that evaporated black holes could turn into white holes, and the information can be recovered in that manner.

Figure 8. In the Japanese version of "Blood Sweat & Tears" (Universal Music Japan, 2017), Seokjin is seen standing next to what could be interpreted as a white hole. Jessica Warren explains that "a white hole is the opposite of a black hole in the sense that, while nothing can escape from a black hole's event horizon, everything escapes from a white hole," though Sara Issaoun notes that "apart from the behavior at the horizon, black holes and white holes are very similar, and one can also argue, as Stephen Hawking did, that a white hole and a black hole are the same object but in different time directions."

LW: A white hole is a theoretical region in space that can't be entered; it can only release energy-matter and light. It has never been observed and is a part of the theory of eternal black holes. So if never observed, where did the idea come from? It was proposed by a scientist called Igor Novikov as it was predicted to be a solution to Einstein's field equations. This solution would require the existence of something that is now called a white hole.

KMC: There is more than one solution to the equation of general relativity, so there could be more than one type of black hole. There's a warning here though: a mathematical solution's existence does not directly imply that the physical object exists. This is why we need astronomical observations to verify our understanding of the universe, such as the one made by the Event Horizon Telescope collaboration, in which we saw the shadow of a black hole.

One of the solutions is Schwarzschild's space-time in which we look at the space surrounding a massive sphere of arbitrary radius. If we make this radius equal to zero, then the black hole would have all its mass concentrated in a singularity. This kind of black hole cannot be formed in an astrophysical way by the collapse of a massive star; it would have to exist since the beginning of the universe and continue to exist. Therefore, such an object is called an eternal black hole.

There are different spatial con-figurations that come from an eternal black hole. An interesting one is the one in which there are two parallel surfaces from which a distant observer can look at the eternal black hole, and its function is to connect them — this is what we call an Einstein-Rosen bridge.

What is so fascinating about this bridge is that, because it is shaped like a tunnel, there is not a place where the Einstein-Rosen bridge is a single point, so it does not have a single singularity but rather two: a past singularity and a future singularity.

The surface from which the light comes in and cannot escape is the part of the bridge that is the black hole. The light then crosses both singularities and comes out of another parallel surface. This part of the bridge is the white hole.

What is a wormhole?

LW: Wormholes are again theoretical, meaning something we think can exist but haven't been able to see (so really it's more a theory than a phenomena)! They are said to be almost like a tunnel between two points in space that we could travel through and hence possibly create a shortcut. They are said to possibly connect dark and white holes, and this is also where our idea of time travel comes from. Could we possibly travel through a wormhole to a point in space that is in the past or future? But the problem is that it looks like wormholes are really small, like micro sizes, so humans would not be able to even fit into them, let alone a spacecraft!

KMC: Another spatial configuration that comes from eternal black holes is the one in which the observer is on one surface but can look from two different times. The bridge that connects the black and white holes, in this case, is called a wormhole. [See "White Hole" explanation for further detail.]

JW: A wormhole is basically a tunnel in space-time. It is allowed by Einstein's theory of general relativity and permits a "shortcut" if the wormhole can remain open. Imagine space-time as a two-dimensional sheet of paper (Figure 10). Suppose you are an ant who wants to travel from point A at one end of the paper to point B, 20 cm away at the other end of the paper. You could crawl the long way — all 20 cm. But suppose the paper is bent so that point A and point B are right next to each other. Then you could tunnel through the paper from point A to point B and only travel 1 or 2 cm! It would be much quicker this way. Theoretically, wormholes can exist, but no evidence of them has

Figure 9. The HYYH Notes are bits of text released in some BTS albums that help tell the story of the Bangtan Universe and the BTS members' fictional counterparts. In addition to the album notes, there have been two *HYYH The Notes* books published by Big Hit Entertainment. The last entry in The Notes 2 (pictured above) is a note from Jungkook dated XX XX Year XX. It is the only note, thus far, without a physical date assigned to it. In this note, Jungkook describes himself as "floating in space" between a "huge, bottomless, gaping hole" and "the moon." It then occurs to him that this "moon" is not actually a moon, but a "hole" as well (Big Hit Entertainment, 2020, p. 299). This note is one of the few potential references to white holes in the BU. Jessica Warren explains that while there is substantial evidence for black holes, there has been no physical evidence to substantiate the existence of white holes. However, "some theorists posit that the singularity of a black hole is connected to a white hole somewhere else in the universe. Others think that white holes essentially spawn new universes."

been found. In addition, to actually use a wormhole by traveling through it would require the tunnel to be propped open by negative energy. It's not clear how that would be done, so wormholes, like white holes, remain interesting ideas.

Wormholes and black holes both represent solutions to Einstein's field equations from general relativity. It is possible for a black hole to be one mouth of a wormhole, but not necessary. Stellar mass black holes that form from the collapse of a massive star do not also create wormholes, and it's not clear how a wormhole/black hole might actually form.

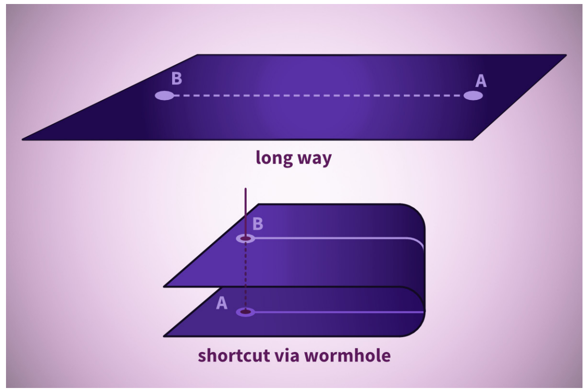


Figure 10. Visualization of the theory of an Einstein-Rosen Bridge. (Illustrated by Yumi Mala Yumi Aleluh Ramos)

One interesting note: wormholes can be used as "time machines" if one mouth is brought near a black hole. A good explanation of this by Brian Greene can be found on YouTube. ("Black Holes, Wormholes, and Time Travel" World Science Festival, 2015).

SI: A wormhole is a theoretical concept where two arbitrary points in space-time are connected by a sort of tunnel structure or "bridge." It was first speculated by Einstein and Rosen as a special solution to Einstein's equations, hence its other name: Einstein-Rosen bridge. Wormholes can potentially connect any two points in space or time or even across universes, and mathematically arise out of Einstein's equations of general relativity, but are yet to be observed in their physical form. There are two different types of wormholes: a traversable wormhole, where one can enter on one end and exit out of the other, and a non-traversable wormhole, where matter can only meet at the singularity inside the "bridge" but never cross to the other side. All of these types are quite exotic structures that require lots of complicated and exotic physics to occur, but they still remain a theoretical possibility that fuels fascinating science fiction!

You can theoretically create a wormhole, or Einstein-Rosen bridge, with a pair of black holes or a pair of white holes. The pair would connect two regions of space at the same instance in time and allow information to travel from one black hole region to another instantly! This only allows for information to travel though. If you tried, you would be squished to infinitesimal bits at the singularity inside the black hole! This allows for space travel only within a single universe though; if you'd like to time travel, things get a little more complicated.

What is quantum entanglement?

SI: Quantum entanglement is when the properties of two (or more) particles cannot be described independently of each other as a result of creation/interaction. You then take one of the particles and place it at the other end of the universe, where they are no longer in proximity or bound by the same local conditions. If you change a property of the particle on one end, a correlated change will occur for the entangled particle at the other end of the universe, even though you did not

(a)

(b)

Figure 11. Sarah Issaoun explains quantum entanglement as a phenomenon where "the properties of two (or more) particles cannot be described independently of each other," or as Jessica Warren puts it, the particles are "bound together in a 'combined' state." Sara states, "If you change a property of the particle on one end, a correlated change will occur for the entangled particle at the other end of the universe, even though you did not directly interact with it." The metaphysical concept of "entanglement" runs throughout the storyline of the Bangtan Universe, whose characters' fates are intricately connected. **(a)** In his entry dated 2 May Year 22 in *The Notes 1*, Seokjin muses whether his friends are "tied up together with strings" and notes that "when some strings and knots were figured out, other parts snapped" (Big Hit Entertainment, 2019a, p. 93). **(b)** In Episode 2 of the *SAVE ME* webtoon, Seokjin "hears" a voice stating "you won't make it out here alone in this entangled destiny" (Big Hit Entertainment, 2019b).

directly interact with it. The two particles are interdependent, so they share mutual information: the correlation of the two informs the state of one if you change the state of the other.

JW: Quantum entanglement is the phenomenon in which two subatomic particles or photons (particles of light) are bound together in a "combined" state. One way to think about entanglement is to envision two electrons that are created from the collision of a pair of photons. These electrons have certain properties, including speed, direction of motion, and spin. The spin of the electrons might be "up" or "down," but due to conservation laws, if one electron is spin up, the other must be spin down. However, until we measure them, we don't know which is which. The electrons are said to be in an entangled state — they each are a combination of up and down spin. Now, suppose we measure electron A and find it is spin up. Then we automatically know that electron B is spin down! However, that doesn't mean that electron A was always spin up. If we set up the exact set of conditions again and then measure one electron, we might find it to be spin down. Thus the electrons, prior to measurement, are entangled in a combined state. This has implications for teleportation and quantum cryptography and computing!

SI: There is a theory proposed by Leonard Susskind called ER=EPR that connects Einstein-Rosen (ER) bridges (non-traversable wormholes) to Einstein Podolsky Rosen (EPR) entanglement (quantum entanglement). EPR tells us that quantum mechanics allows two non-local particles to share the same properties. Susskind's ER=EPR theorizes that non-local particles must then communicate in some way to share information, and since information cannot travel faster than light, they do so via an Einstein-Rosen bridge at the quantum level. If we were to take this to a classical scale, an Einstein-Rosen bridge between two black holes could mean that the two black holes are entangled.

What is dark matter?

LW: Dark matter is a fundamental type of matter (a substance that has mass and takes up space) as it is thought to take up almost 85% of all matter everywhere! But why is it called dark matter? Matter interacts with an electromagnetic field, which means it absorbs or reflects electromagnetic radiation that we can detect with scientific instruments. However, dark matter doesn't interact with electromagnetic fields, which means it is not reflecting or absorbing these pivotal things, making it very difficult to detect. Because of this, we call it "dark matter" since it seems to be undetectable.

(a) (b) (c) (d)

Figure 12. When two particles are entangled, Jessica Warren explains that they are a "combination of up and down spin." It is not until one of the particles is measured or observed that we know "which is which." The role of the observer, and what happens when this observation is made, is a fundamental question at the heart of interpretations of quantum mechanics. The characters in the BU are recurrently "paired" (entangled!) with one another, with one character playing the role of the "observer." The pairings (and observer) change depending on which iteration of the time loop the characters are experiencing. In the "Blood Sweat & Tears" music video (Big Hit Labels, 2016), the BTS members appear in pairs found throughout part of the Bangtan Universe storyline — Namjoon with Jungkook, Taehyung with Hoseok, and Yoongi with Jimin. Seokjin appears alone, unpaired and as an "observer" to much of the story. **(a)** Seokjin stands alone in a museum-like room, staring at *The Fall of the Rebel Angels*, a painting by Pieter Bruegel the Elder circa 1562. **(b)** Namjoon and Jungkook sit together in the museum-like room as they read a book. **(c)** Taehyung and Hoseok play around in the museum-like room with binoculars. **(d)** Yoongi and Jimin sit together after goofing off in the museum-like room.

SI: The short answer: no one knows! The first to have conclusive evidence for the existence of dark matter was astronomer Vera Rubin, who showed that most galaxies are actually about six times more massive than what we can detect as visible matter. So how did she find this? The stars close to the center of the galaxy should have a higher velocity than those at the edge, because they are in a much more dense part of the galaxy and the gravitational pull makes them orbit faster (just like our inner planets in the Solar System). If the galaxy were like our Solar System, Rubin and her colleagues would have found that the stars close to the center were moving fast, and stars farther and farther out should move slower. What they found was that the velocity farther from the center was actually constant, even if the mass distribution of the stars seemed to thin out. So something hidden, undetectable, and very massive made those outer stars move faster than expected: dark matter.

JW: We call it dark for two reasons: 1) it does not interact with photons (light), and 2) we do not know what it is! Scientists have known about dark matter for almost a century, because they can infer its existence based on how it affects matter we can see, like stars, galaxies, and hot gas. For instance, our galaxy is made up of a central bulge of stars surrounding a supermassive black hole, and a disk of stars and gas that extends outward from the bulge. The stars in the outer regions of the disk rotate at about the same speed as the stars closer to the bulge. This is actually strange behavior! Think about the Solar System: the Sun is the most massive object and it is at the center. The planets orbit the Sun, and more distant planets travel more slowly and take longer to orbit. But that's not what happens with stars! Stars that are farther from the massive bulge region still travel at similar speeds to the stars closer in. That behavior implies that there must be more mass in the outer regions of the galaxy — the extra mass would give the stars a gravitational "boost" to keep them moving quickly. However, when we look for that mass in the outer regions, we CAN'T SEE IT! Thus, we infer it must be in a form of matter that does not interact with light. There are other lines of evidence for dark matter's existence. It is like the wind — you can't see the wind, but you know it's there because the leaves on the trees are moving. Ideas for what dark matter actually is include new types of particles that interact through gravity and another force called the weak force. So far, experiments to detect dark matter have not found any, but they have narrowed down possibilities. We may soon discover the true nature of this mysterious stuff!

KMC: I wish I knew! For starters, let's find some motivation.

Not long after the Big Bang, the universe looked kind of the same wherever you looked, but it had tiny fluctuations that were enhanced by a period of accelerated expansion that is called inflation. These fluctuations were regions that were a bit denser since the gas accumulated there, and its gravitational pull kept accumulating gas; eventually, these regions are where structures like stars and galaxies are formed.

A lot of other physical processes were happening after inflation when structure was trying to be formed. First, there was so much radiation that whenever it interacted with matter massive enough, it would destroy it and prevent the primordial fluctuations from growing. Second, the expansion of the universe also acts against the growth of fluctuations.

Therefore, small fluctuations can only start forming structure after matter and radiation are separated, and only bigger fluctuations can start growing before matter and radiation are decoupled. This is not enough to explain the structures we observe in the universe today. We need more mass before matter-radiation decoupling to have enough structure formation; this kind of mass would need to not interact with electromagnetic radiation to survive during this era, and this is what we call dark matter.

What is the butterfly effect?

JW: A main idea of classical physics is that the universe is deterministic, and hence ultimately predictable. This means that if we know enough properties of a system (e.g., the speed, direction, mass, etc., of a ball rolling), we can predict subsequent properties of the system (e.g., where the ball will be in 20 minutes). However, it turns out that there are many systems that are deterministic, but ultimately NOT predictable. There are too many variables that we cannot follow all of them in a predictable way. Perhaps the most famous example of this is the weather. In principle, if we knew the position, velocity, etc., of every particle in the atmosphere, we could very accurately predict the weather. But this is not really possible. This was first understood by Edward Lorenz in the 1960s. He found that changing the decimals in the thousandths place of an input to his weather-forecasting program changed the outcome quite drastically! He coined the phrase "butterfly effect" to mean that a very small change in the input of a system can lead to a very different output. This is the basis of what became chaos theory. Chaotic systems are deterministic; their future behavior is very sensitive to the initial conditions. What's really intriguing is that even so, patterns emerge in chaotic systems! These are called emergent patterns (e.g., Conway's Game of Life and Wolfram's cellular automata) and are prevalent in nature.

(a)

(b)

Fig 13. Jessica Warren notes that Edward Lorenz "coined the phrase 'butterfly effect' to mean that a very small change in the input of a system can lead to a very different output." The butterfly effect can be observed in the storyline of the Bangtan Universe, and butterflies appear across some of BTS's work. **(a)** The album cover for BTS's 2015 release *HYYH The Most Beautiful Moment in Life Pt. 2* featured dark gray butterflies on a blue background (Studio XXX). **(b)** Prior to the release of HYYH Pt. 2, Papillon concept photos were posted on Big Hit Entertainment's official website. The photo here features member Seokjin in the forest with a blue butterfly (Kim, 2015).

Round III: Let's Get Theoretical

Now it's time to take it a step further! Armed with a basic understanding of these concepts, we're better equipped to explore some theory-based discussions. Some fans posit that the Bangtan Universe is an example of multiple universes, and time travel was canonically established for Seokjin's character in the SAVE ME webtoon. What is the Many-Worlds Interpretation? Is time travel between worlds even theoretically possible? We asked our panel of experts to consider the plausibility of these theories.

How does a single universe containing multiple "branches" differ from separate universes?

JW: This gets at the ambiguous meaning of the term "multiverse." In one interpretation of quantum mechanics, dubbed the "many worlds" or Everett interpretation, every measurement yields many possible results. All the results occur, but in "parallel" universes. So in our world, we may measure the spin of a particle as up, but the possible result of down also happened — just in a branch of our own universe. Some people call these "many worlds" the "multiverse." However, in cosmological terms, the multiverse is a set of separate universes, perhaps each having their own Big Bang, that are physically separate from one another. These other universes may have been around for an infinite amount of time, or they may have been created as two universes "collided," or they may be created when black holes form. Other ideas involve universes produced from eternal inflation — periods of rapid expansion that effectively cut off parts of one universe from itself. Neither the many worlds from quantum mechanics nor the multiverse from cosmology have any current evidence for them.

What is a "multiverse," and which interpretations of quantum mechanics are consistent with this concept?

LW: To understand a multiverse, you first have to understand a universe. To make things simple, let's say that the universe is everything you can see and acknowledge as being your reality. Now think about the impact your decisions have on your life here on Earth and what would have happened if you made a different decision. Imagine that this other decision would have created an entirely new parallel universe, a new reality. This is the basic concept of a multiverse — a collection of parallel universes.

The relative state formulation or Many-Worlds Interpretation (MWI) is a theory that supports the idea of multiverses existing. What this states is that a wave function collapse does not exist and hence all possibilities are possible and all exist in different universes. A wave function is something that provides all possible states of a quantum system and hence collapses into itself when one state is observed. So if we say it just doesn't collapse, we have endless states and hence a multiverse. But there are still many problems with this theory, which are also very interesting to dive into at a later stage.

KMC: A multiverse is a scenario that arises from String Theory where our universe is not unique but rather one of many, if not infinite, parallel universes. There are many who critique the idea for being pseudoscientific, but it is always fun to imagine the storylines that come from the scientific part.

One of the quantum mechanics interpretations of this play is the MWI, which applies in the Level III of Max Tegmark's approach to parallel universes (Tegmark, 2003). Let's remember that in quantum mechanics, rather than measuring precise values we measure the probability of obtaining a certain physical quantity. In the MWI, each one of these possible values corresponds to a different universe located in different branches of space-time.

Theoretically, is time travel permitted within a "multiverse," and if so, under what conditions? Is it possible to travel between "branches" as opposed to just traveling in time? What about traveling between separate "universes"?

JW: Time travel in general is possible under very special conditions. One method of time travel is to go into the future. Suppose you orbit close to a black hole for a while. Time will run slower for you than for people on Earth. Therefore, once

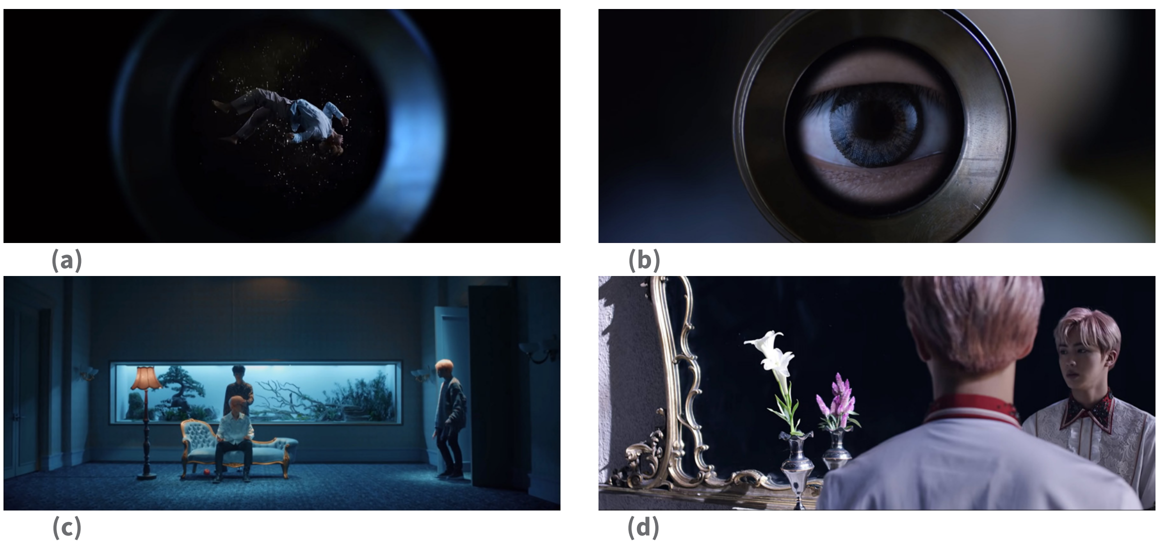


Figure 14. The term "multiverse," as it pertains to the "Many-Worlds" (Everett) interpretation of quantum mechanics, refers to the hypothetical concept that our universe is composed of several parallel universes containing all possibilities. Though the theoretical possibility of traveling between parallel universes is contested, there are several instances in BTS's work where characters encounter other versions of themselves. In the music video for "Serendipity," **(a)** Jimin observes "himself" falling while **(b)** looking through a telescope (Big Hit Labels, 2017a). **(c)** Similarly, in the Japanese video for "Blood Sweat & Tears," Jimin encounters another version of "himself" in a dark room. In the scene, Yoongi covers his eyes before he can see the other version of "himself" (Universal Music Japan, 2017). **(d)** In the Korean version of the video, Seokjin observes himself in the mirror, but the reflections do not match, as one shows his face cracking, and the flowers in the vases are different (Big Hit Labels, 2016).

you come back to Earth, many years will have passed while you might have only experienced one year. So you have traveled into the future. The problem is when you want to go back to the past! Possibilities exist involving wormholes near black holes or cosmic strings. Often, constraints on the physics mean that you can only travel back in time as far as when you first "created" the time machine (called the Cauchy horizon). Traveling between "many worlds" branches is not possible, given that the many worlds scenario is just a way of interpreting the mathematics of quantum mechanics and may not be physically real. Or maybe it will turn out to be so and new physics discovered in the future may allow us to visit these branches!

JW: Currently, there is no way to travel between separate universes — if they even exist. Speculations about that possibility involve going through a black hole or some type of faster-than-light "warp" drive — still mainly the stuff of the imagination and science fiction.

KMC: In the case of wormholes or Einstein-Rosen bridges, you would be traveling in time between the same universe, or you could have two parallel universes connected to each other. Unfortunately, traveling through these bridges would be impossible since only something faster than light could evade the singularities.

But, other solutions to Einstein's field equations exist. One of them is the Kerr space-time in which the black hole rotates and the singularity is no longer a one-dimensional point but a ring! This space-time could contain an infinite number of parallel universes, and if a traveler goes through the ring, they could see the past and present at the same time.

SI: Theoretically, there are a variety of very exotic wormholes that could allow for travel between universes. For example, if a particle (or handsome time traveler) travels back in time from the future through a wormhole, it will not return to its original universe but to a parallel universe at that time. Theoretically, it is possible to travel across space, time, or universes by traveling faster than light through a black hole and out of another. Of course in the physical world, we have yet to find something that travels faster than light.

Round IV: Conclusion

What would you say to any student thinking of going for physics as studies, cosmology, particle physics, etc? Or to a student who is hesitating to choose physics?

KMC: The field of physics has a reputation for being “difficult,” so students often hesitate to venture themselves into learning more about it or are worried that they are not “smart enough” to choose it as a career. These thoughts have certainly also crossed my mind.

It is my personal belief that nobody is a born genius and that, just like in any other career, hard work, perseverance, and the will to always be learning will get you far. I also believe that the picture of a scientist in academia is slowly but surely changing, and all kinds of people from all kinds of backgrounds should be able to pursue and succeed in a physics career.

A physics degree can open up the door to diverse careers; information is always a reliable friend, so do not hesitate to look around and reach out for advice!

SI: I would say the most important aspect is to do something you enjoy. University is not easy, and it requires a lot of independence and self-discipline to get through and do well, no matter the subject. So it’s important to be motivated toward a goal, and to enjoy learning in your chosen study. I’ve always been interested in figuring out how things work. If, like me, you are a big fan of puzzles or brain tests, the fun you will have trying to solve problems or puzzles will make it very easy to enjoy doing science and push through hardships. Physics is a highly competitive field and requires a lot of self-discipline and creativity. Research needs a lot of independence and initiative, so it’s extremely important that you learn early on how to make efficient use of tools at your disposition, be it tutorials, classes, mentors, or networks.

LW: Choosing to study physics is not an easy choice. It comes with a lot of responsibility and work and determination. However, it also comes with so many surprises, fun challenges, and will give you more belief in yourself than anything else will. My road to physics wasn’t easy, but now that I’m nearing the end of my degree, I can proudly say that it has given me so much more confidence in my skills than anything else ever has. The most important thing to ask yourself is, “Am I curious? Am I inquisitive?” If the answer is yes and you have a passion for physics, then pursue it! It will teach you so much not just about Earth, the stars, and planets but also about yourself.

JW: I would encourage anyone with an interest in physics or astronomy to keep at it! Don’t let anyone tell you it’s too hard or you should try something else. All it takes is being passionate and willing to learn. In addition, do not fall into the trap of thinking Newton, Einstein, and Hawking are the only types of people who do physics. There is a diversity of people who pursue physics. Find someone who you relate to and learn more about their story. Physics is about a few big ideas and finding creative ways to apply them. As such, it has applications in many fields. Pursuing physics doesn’t mean you have to be a university researcher or academic (though you certainly can be!). I have friends who majored in physics or astronomy as undergrads and went on to become a NASA engineer, a Pixar animator, a university professor, technical writer, lawyer, copy editor, science consultant and more. Society of Physics Students (SPS) is a good source to learn more. Mainly, have fun with it! Find a group of people who love physics and astronomy like you to connect with and support each other. Physics has the power to connect you in a deeper way with the world and the universe beyond!

For individuals wishing to learn more about the topics discussed from reliable sources, please list your "rhizomatic recommendations."

JW: There are many good books and YouTube channels that interested readers can find. Some of my favorites are below. Some of the books may be a bit dated now, but they give great information.

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Fermilab. (n.d.). *Home* [YouTube Channel]. YouTube. Retrieved March 21, 2021, from https://www.youtube.com/channel/UCD5B6VoXv41fJ-IW8Wrhz9A

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Griffiths, D. (1995). *Introduction to quantum mechanics* (1st ed.). Pearson Education.

Hawking, S. (1988). A *brief history of time.* Bantam Dell.

Hawking, S. (1993). *Black holes and baby universes and other essays.* Bantam Dell.

Kurzgesagt – In a Nutshell. (n.d.). *Home* [YouTube Channel]. YouTube. Retrieved March 21, 2021, from https://www.youtube.com/c/inanutshell/featured

Quanta Magazine. The Simons Corporation. https://www.quantamagazine.org/

Tyson, N., Gott, R., & Strauss, M. A. (2016). *Welcome to the universe.* Princeton University.

Veritasium. (n.d.). *Home* [YouTube Channel]. YouTube. Retrieved March 21, 2021, from https://www.youtube.com/c/veritasium/featured

SI: We have lots of exciting research and useful information about black holes on our Event Horizon Telescope website and corresponding social media. I personally love the video with Dr. Janna Levin explaining gravity at different levels of expertise, and the talk by Dr. Brian Greene is great to understand a little bit about the quantum world.

Event Horizon Telescope. (2017). *Event horizon telescope.* https://eventhorizontelescope.org/

Wired. (2019, December 20). *Astrophysicist explains gravity in 5 levels of difficulty | wired* [Video]. YouTube. https://www.youtube.com/watch?v=QcUey-DVYjk

World Science Festival. (2018, February 16). Quantum reality: Space, time, and entanglement [Video]. YouTube. https://www.youtube.com/watch?v=BFrBr8oUVXU

LW: A book I highly recommend, which is usually also required reading if you study physics at university but you can also use during A-levels, is the Tipler and Mosca physics book. A YouTube channel I really enjoy is called *Physics Girl*. She has a lot of videos that explain some basic and more advanced concepts in physics in a fun way. Finally, I recommend finding any books on specific topics that you like! Are you interested in planets? Buy the book *The Exoplanet Handbook* by Perryman.

Perryman, M. (2011). *The exoplanet handbook* (1st ed.). Cambridge University.

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KMC: For Spanish speakers, some of the topics discussed here I first learned by reading popular science books from Mexico, specifically the books by Matos and Shahen. There are also tons of YouTube channels, with some of my personal favorites listed below.

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Biographies

KAREN MACÍAS CÁRDENAS

Karen Macías Cárdenas is a Mexican physicist who is a master's student at Queen's University. Their research area is astroparticle physics with a focus on dark matter (DM) phenomenology, specifically, studying the possibility of DM annihilation channels into Standard Model particles like neutrinos using constraints from current neutrino experiments and cosmological probes.

They have been an ARMY since 2017 when BTS released "Spring Day." BTS encouraged them to stay true to themselves and be proud of who they are as a non-binary bisexual scientist and showed them the importance of elevating the voices of minorities in fields where they are historically underrepresented.

Love yourself, Speak yourself, ARMY!

SARA ISSAOUN

Sara Issaoun is a PhD candidate in astrophysics at Radboud University and a member of the Event Horizon Telescope Collaboration, the team who, in 2019, imaged a black hole shadow for the very first time. Supermassive black holes generate the highest energy processes in the known Universe, ejecting jets of plasma affecting galaxy environments on large scales, but their fundamental properties remain shrouded in mystery. She makes use of global networks of radio-telescopes to image and study the immediate surroundings and gravitational pull of supermassive black holes.

JESSICA WARREN

Jessica Warren earned a BA in physics and astronomy from Vassar College and a PhD in astrophysics from Rutgers University, where she focused on X-ray spectra of supernova remnants. She has taught physics and astronomy at several institutions and is now a lecturer in physics at Indiana University Northwest. Warren is active in science outreach, having judged for local Science Olympiad competitions, hosted astronomy observing nights, and visited local schools. Currently, her research interests are in physics education, specifically looking at ways that students can employ self-evaluation strategies to develop expert-like attitudes toward physics.

LEONIE WITTE

Leonie Witte is a 23-year-old astrophysics student and big time ARMY! She is in her final year of her master's at the University of Kent, UK and is hoping to go into a career looking at planets and their compositions. BTS's music got her through a lot of the hard times during the pursuit of her degree, and even inspired her to visit Korea. In her spare time, she plays guitar and writes her own songs which she uploads to Spotify. She also loves dancing and mountaineering in the Alps.

Physics is everywhere you look: in your phone, in the nature surrounding you, and in the lyrics of BTS songs. Enjoy exploring and feed your curiosity!

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