ELEMENTAL - Coco Chai

"Elemental" depicts the powerful hydrogen fusion reaction that takes place at the core of the Sun. The tremendous gravitational force of the Sun squeezes hydrogen nuclei together to produce helium. The energy released from the reaction counteracts the inward gravitational force, keeping the Sun from collapsing on its own gravity. This fusion process is significant and unique in the sense that it is the reaction that makes the Sun shine, makes all lives on Earth possible, and paves the way for the existence of all other elements across the universe.

The main colors in the painting -- purple, blue, red, yellow, and green -- are the ones that make up the hydrogen and helium emission spectra and are a symbolic representation of the fusion process. The contrasting black and white brushstrokes represent the inward gravity and the outward thermal pressure that put the star in gravitational equilibrium. Lastly, an often overlooked product of hydrogen fusion is neutrinos, neutrally charged, almost massless subatomic particles that have a huge presence in the universe. They are the tiny black dots floating around in the background. Through this painting, I hope to let the audience visualize this important fusion process and see the beauty in physics.

From Your Perspective - Kennedy Bennett

The formulas for time dilation and length contraction are embroidered on the front of the shirt. On the back there is a train traveling at half the speed of light, Observer B (indicated by the letter 'B') riding the train and shining a light toward a mirror inside, and Observer A (indicated by the letter 'A') is standing off on the side.

Simultaneity: The image shows the relativity of simultaneity through the lightning bolts on both sides of the train; if lightning strikes both ends of the train equi-distance from A, then A will see both strikes at the same time. By the time A sees both flashes, B has already moved past. As B moves at half the speed of light, it will first see the lightning strike at the front of the train (closest to him) followed by the strike at the end of the train (further from it).

Time Dilation: If B shines a light on the mirror, the observer will simply see the light traveling straight to the mirror and back. A will also see the light travel to the mirror and back, but the observer also saw it while the train was moving. So, A will see the light travelling diagonally. From A's perspective, the light traveled a greater distance. To compensate for the greater distance Sally perceives, time elongates.

Length Contraction: Observer B would interpret the length of the train to be 100m while Observer A would see the train as ~87m. s

All The Light We Could Not See

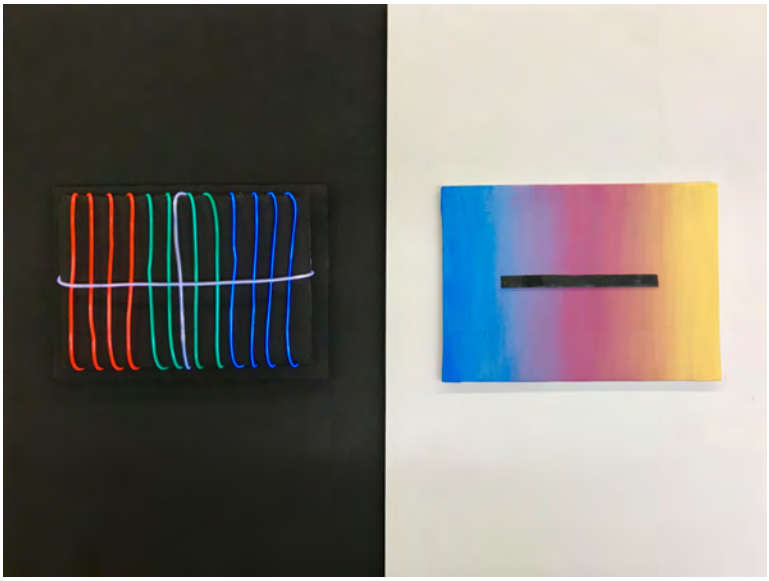
-Rachel Calcott

Science is a very human story. It's the story of the questions we've asked, and the crazy paths we've taken to find answers. The question my project investigates is a pretty old one – how the heck did the universe begin? I decided to do two things with my fusion project – describe the scientific journey that culminated in the discovery of the light emitted by the Big Bang, and take a look at the development of the very early universe. I chose to use poetry to tell this story because I think that both science and poetry attempt to describe and celebrate the world they encounter. I also chose to weave a bit of personal history into this poem – my dad is an astronomer, so I actually grew up around telescopes, and I played with an analogy between a child discovering the world as they get older, and humanity discovering the full spectrum of light and the expanse and origins of the universe.

+ – (“Additive, Subtractive”)

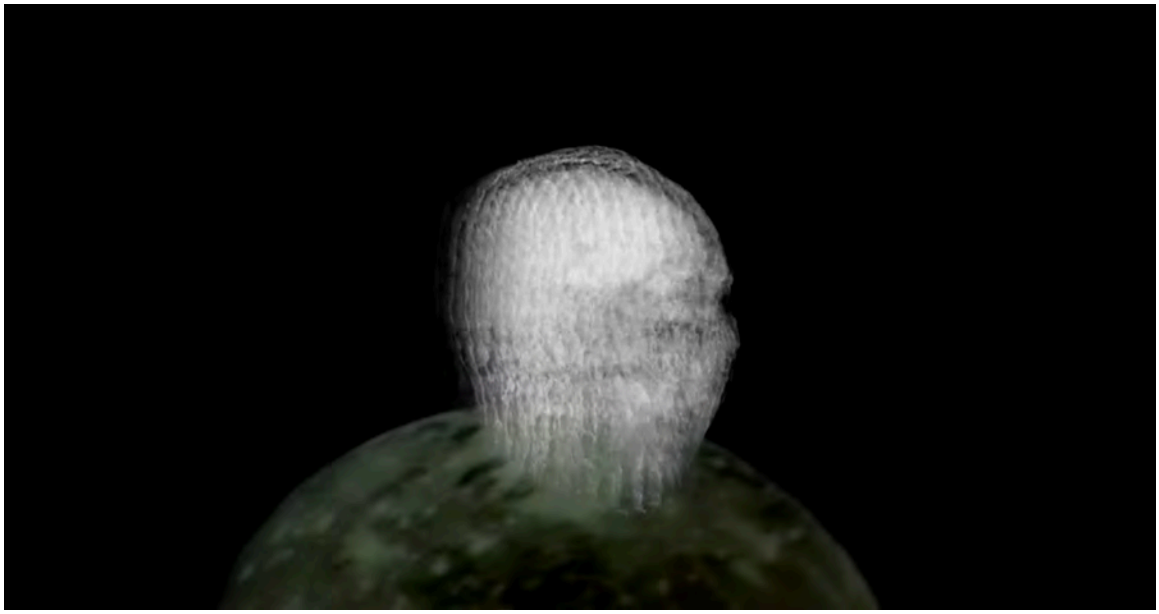
- Ashley Fan

My project represents the two color systems of RGB (red, green, blue) and CMYK (cyan, magenta, yellow, key/black). I thought a simple and clean modern design would be the best for letting the vivid color spectrum stand out and speak for itself. Every aspect of the piece is divided into two opposite halves: the string lights make up the additive RGB model, while the paint illustrates the subtractive CMYK model. The white/black inverse background and + – signs represent how the combination of all colors in light create white while the absence leaves black, and conversely, how the combination of all colors in pigment create black while the absence leaves white. As a physics topic regarding color, a fundamental and versatile element in all art, RGB versus CMYK color theory draws a close connection between physics and the arts.



“The Void”: How Dark Matter Reveals a Picture of the Cosmos Distinct from Poetic Language - Sam Gallen

For his Fusion Project, Sam made an experimental film entitled “The Void.” He wanted to recreate the experience of the Voyager 1, challenge our understanding of dark matter, and think more critically about the relativity of time. There’s a lot to unpack, but Sam intentionally did not approach this film as a documentary or narrative piece. He really wanted to think about what the experience of living in and among these physics’ phenomena might be (Hint: it’s not exactly the cinematic version of space portrayed by Interstellar, Gravity, and Star Trek). Sam wants to thank Professor Mocsy, Audrey Francisco, and the class of Physics Meets the Arts for their support and guidance with respect to this project and throughout the semester!



Quantum Melody (or This Strange Effect) - Luna Garcia

"Quantum Melody (or This Strange Effect)," explores the physics concept of quantum entanglement through two people who become connected after bumping into each other at a party. It takes place in a slightly altered version of reality, one where souls can become entangled and dreams have meaning. This film is explored through the lens of magical realism, which is an appropriate genre for this topic because reality on the quantum level can often be perceived as magic. Luna Garcia is a first year at Yale University and is currently planning to major in Ethnicity, Race, and Migration. This is her fifth short film.

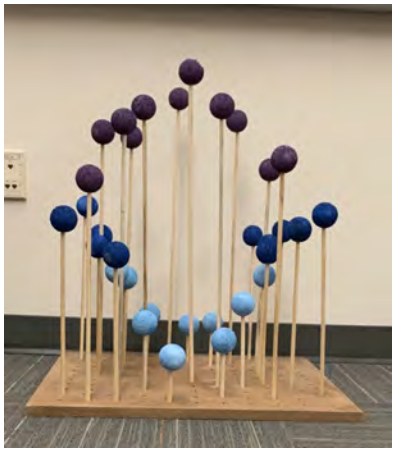
Fly Me Through the Moons: The Symphony that is Outer Space - Kyle Mazer

This project is a cover of the iconic Frank Sinatra Song “Fly Me To The Moon” except everything has been altered to best represent the sounds of space. Every instrument track has been created using samples from a NASA database of electromagnetic waves and plasma waves converted into sounds. The bassline comes from Kepler Star KIC7671081B, the drums are plasma waves from Saturn’s moon Enceladus, and the other synths come from Saturn, Mars, Neptune and the Perseid Meteor. The vocals, representing the soundwaves produced by Earth, are by Sebastian Roizner Rodriguez, and the synth solo, representing the dark matter in the universe we are yet to understand, is by Kyle Mazer. In total, this project romanticizes what our galaxy would sound like if one were to travel through it on a beam of light, where there was no past or present and everything only existed in the present.

The Duality of Perception

- Kijana Richmond

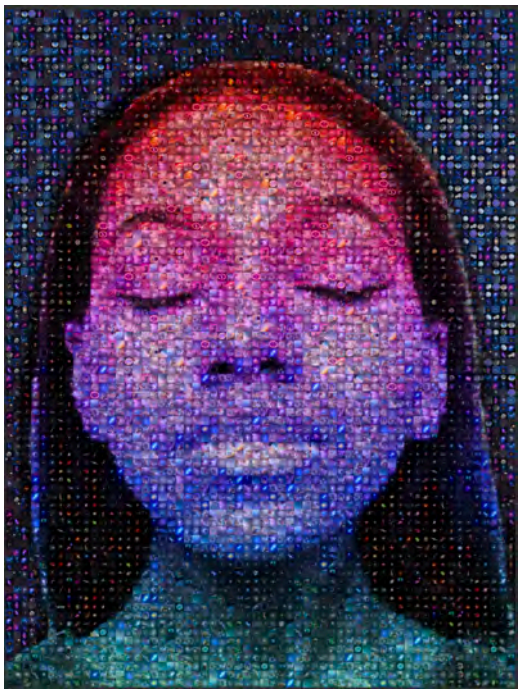
“The Duality of Perception” navigates the twofold nature of particles and waves in quantum mechanics while also exploring Heisenberg’s uncertainty principle. Essentially, every quantum entity may be described not only as a particle but also as a wave, and this concept expresses the inability of classical physics to fully describe the nature of quantum-scale objects. Heisenberg’s uncertainty principle describes the complementary relationship between a particle’s position probability and momentum probability and the limits of precision to which they can be determined. Simply, more precise the position of a particle is determined, the less precisely its momentum can be known and vice versa. I chose to represent my project through this medium because of a sculpture’s relationship to space and perception. Sculptures are unique in that you are able to view it from all three dimensions, each perspective offering a different view and interpretation of the art. I chose to create a perspectivist sculpture to show how easily our view of objects in the quantum realm can change. Depending on how you chose to view the sculpture, the image you see changes, and only when you pick a perspective are you able to see either a particle or a wave . This sculpture was built focusing on both the duality and the limitations of perception. Although each perspective determines what you observe, each perspective also delivers a different view of the juxtaposing image.



Ceramics and Starstuff: Setting the Table for Mindful Meals - Stella Sekoff

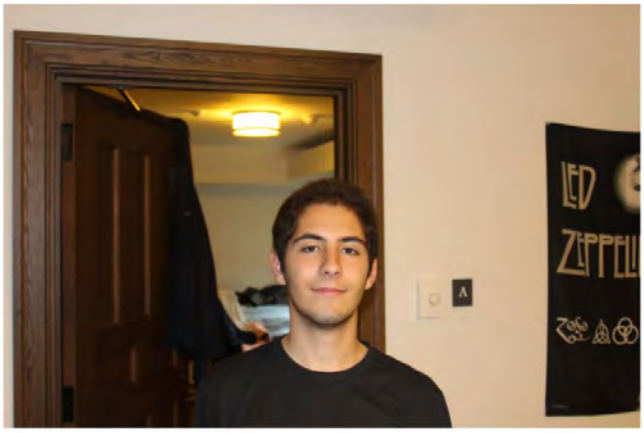
" This ceramic tableware set is an artistic rendering of the Balmer series of the hydrogen emission spectrum. These four wavelengths are visible to the human eye, and were therefore the easiest to focus on depicting. I focused on the motif of rings to represent the cyclical nature of celestial matter, specifically the life cycle of stars. Hydrogen is a simple element, having just one proton and one electron, but since its conception in the Big Bang, has served as the building block for everything we see today. When a star is massive enough, it will end its life in a dramatic supernova explosion, and in doing so, creates myriad natural elements. From the remanence of the destruction, new stars can form. Without this process, there could be no life. My intention in creating this art was to have people sit down, eat mindfully, and be reminded, even in a subtle way, of our interconnectedness. If people can sit down together for a meal, look at their plate, and be reminded that we are all, on an elemental level, the same, hopefully that can spark conversation and connection. Similarly, I hope that these pieces give a sense of perspective. It can be easy to get caught up in the small annoyances and stresses of our personal lives, but when we are reminded that the universe is grand and expansive, and that we are but a small part of it, we can see things more clearly. When people sit down to eat with my tableware, I hope they consider the science, enjoy the art, and feed their body, mind, and spirit.

skI - Maya Boateng



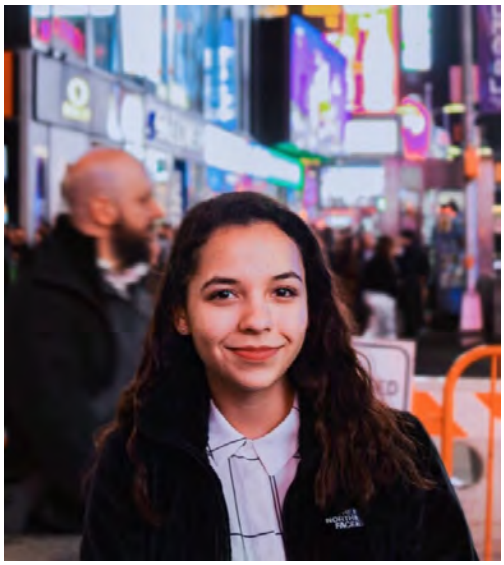
skI is a portrait using the medium of space itself to convey the connection that humans have to our universe both physically and emotionally.

Picture of a Black Bowl - Andrew Harmez



" "Picture of a Black Bowl" explores the general theory of relativity and the ability of mass to warp space-time among other relativistic effects that occur near a black hole. More specifically, this piece explores these topics with respect to a black hole and was inspired by the recent photo of a black hole taken by EHT (Event Horizon Telescope).I chose ceramics as the medium for this piece since clay's immense malleability is able to reflect the warping and curvature of space-time. Furthermore, the rotation of the wheel reminded me a lot about the formation of stars and black holes and it felt organic for my piece which reflects those objects to also be born out of angular momentum. In addition, I felt the ability to imprint on clay made it easy to impose one's vision on a piece in a similar way that it is easy for scientist to impose their ideas on a phenomena or theory. In order to reflect the nature of relativity where events and objects can appear differently depending on their location relative to one I felt it was necessary to select another medium to complement the ceramics. For this I selected steel wool photography since spinning the steel wool at different angles allows me to portray the many different ways the accretion disk of a black hole can appear depending on what angle we are viewing it from. In addition, the sparks released by the flaming steel wool are very reminiscent of the accretion disk while the contrast between these sparks and the center of the photo reminded me a lot of the event horizon shadow.

dis,oRdered - Suzanne Brown



“dis,oRdered” is a visualization of the concept of entropy, derived from the second law of thermodynamics – which states the entropy of the universe is always increasing. Entropy is defined as a measure of disorder in the universe, though not in the colloquial sense. Entropy, at its core, is a probabilistic concept that represents the number of possible microstates of a system, or the various ways particles and their characteristics can be organized. So, when we say entropy of the universe is always increasing, this essentially implies that the energy of the universe is always become more spread out, more dispersed. This concept provides an “arrow of time,” one of the only ways we can actually see the passage of time in our universe, since entropy always linearly increases.

“dis,oRdered” seeks to represent all of these thermodynamic concepts. Foreground combines with background, painting warps with space, time’s arrow guides, and paint particles float away. But beneath all this, “dis,oRdered” is also a representation of the anxieties of everyday life. If entropy in a system can increase, it will, just as how it always seems as if our lives manage to become more chaotic, more dispersed, more overwhelming. Yet in the same way entropy is a universal concept, so too is stress. “dis,oRdered” not only remind us that we are not alone in going through these feelings, but it also shows us that they can be a sign of progress.

When You Wish (the Pain Away) Upon a Star

- Sebastian Roizner Rodriguez

I attempted to relate the experience of losing a loved one with supernovas (the death of certain high mass stars which create astounding images in space). I had a lot of emotions running through my head, and this piece helped me to ground myself, as I learned a lot about these beautiful phenomena and allowed that to shift my perspective on the end.

Spiral Out - Goro Horie

On April 10 2019, the first ever direct image of a black hole was released to the public. It was taken by the Event Horizon Telescope Collaboration (EHTC), using an array of eight radio telescopes strategically placed around the globe. The image instantly became iconic, being plastered in every possible corner of the internet. It was named *Powehil* , a hawaiian word that loosely translates to “embellished dark source of unending creation”.

Having only been exposed to the existence of black holes in sci-fi books and film before this class, the image provided by ETHC was momentous. This class had taught me the concept of the scale of the universe and the magnitude of violence a black hole actually manifests. Seeing what was merely numbers, theory, and a whiff of my imagination materialized before my eyes was horrifying and exciting simultaneously.

The image of the black hole was groundbreaking beyond its technological undertaking. It allowed scientists to verify the General Theory of Relativity (GTR) with observational evidence. The artwork that I chose to create was one that aims to explore the very nature of black holes and how photons behave around the event horizon.

Perhaps the most notable aspect of the image is the striking orange ring around the black hole itself. This is called the accretion, which is one evidence for the fact that matter around the black hole spirals inwards towards the center. The massiveness of the black hole implies that matter orbits around it and the glow proves that matter is losing gravitational energy and thus angular momentum, which causes the matter to fall into the black hole.

However, the intensity of the glow is higher than what can be expected since the gas around the black hole is too dilute for conventional friction to be reasonable. Further studies using the data measured by EHTC may hopefully answer the peculiar nature of the accretion.

The glow of the black hole prompted me to explore how light behaves around the black hole. Upon further research, I discovered the gravitational red shift. This was initially predicted as an extension of the GTR using the mass-energy equivalence. As light travels away from the event horizon of the black hole, the photon expends energy in order to gain gravitational potential energy. The formula for gravitational potential energy necessarily expresses the proportional relationship between the gravitational potential energy and the product of two masses interacting with each other. The formula of gravitational potential energy (U_g) in this example is shown below:

$$U_g = \frac{GMm}{r}$$

Where *G* is the gravitational constant, *M* is the mass of the black hole, *m* is the "mass" of the photon, and *r* is the distance between the black hole and the photon.

The world famous $e = mc^2$ allows the "mass" of the photons to be expressed in terms of its energy and overcomes the problem of the massless nature of a photon. Since the energy of the photon can be expressed as $e = hf$, where *h* i s Planck's constant and *f* is the frequency of light. Combining the aforementioned formulas, gravitational redshift can be explained:

1. First, expressing the photon "mass" in terms of *h*, *c*, and *f*:

$$hf = mc^2$$
$$m = \frac{hf}{c^2}$$

2. Second, using the law of conservation of energy, *initial energy of photon* – Δ*grav. potential energy* = *final energy of photon*

$$hf - m\frac{GM}{r} = hf'$$
$$hf - \frac{GM}{r} = hf'$$
$$\frac{f-f'}{f} = \frac{GM}{rc^2}$$

Which implies that the observed/final frequency *f'* is smaller than initial frequency *f* .

Using these concepts and the knowledge I gained from class to perceive the space-time continuum as a 2-dimensional space, where space is one axis and time is the other, I used string art to merge the depiction of space-time, gravitational red shift, and accretion. I attempted to mimic its fabric/weave-like nature, provide a spectrum of colors tending towards red from the center, and demonstrate the spiral. The challenge was to create a layered effect to depict the movement of light from the center outwards. I did this by creating a circle using 180 nails and using sewing thread of different colors. I skipped every 8th nail, so that the lines created by the nail would shrink at a constant rate, allowing for the intended effect. I also overlapped the thread when I changed the color so that it had a blending effect. I decided to spray paint the wood board black to allow the audience to focus on the spiral. The black was also intended to mimic the nature of the black hole beyond the event horizon where no light escapes.

Invisible Beauty - Ivan Lozano

The human eye, despite its marvelous gift of allowing us to perceive our environment, is a relatively poor instrument when it comes to seeing the spectrum of light. We have profound colorblindness, with our vision capable of only seeing an “octave” of the light spectrum. In the words of David Helfand, we aren’t “Seeing the Whole Symphony.” Mankind had to be a little more creative to “see” outside its limited scope. The way early scientists went about it was looking towards the stars: radio telescopes were made to view the low-frequency waves of light that emanated from the heavens. Higher frequency light had a harder time breaking through the atmosphere, due to their higher rate of interactions with particles in the atmosphere, so it took a while longer to be able to observe them. Radio waves from sources outside of earth were first observed in 1933, but it wasn’t until 1962, with the achievement of space travel, that higher energy waves from the cosmos could be observed.

This does not mean that we cannot appreciate the beauty of some of these higher energy light waves down here on earth, specifically light in the ultraviolet spectrum. As Paul Hewitt explains in *Physics Fundamentals*, there are materials that absorb ultraviolet light and emit visible light. This happens whenever their atoms get excited: visible light is created by a sudden jump of one of the atom’s electrons to a higher energy state, then its immediate de-excitation to a lower energy state. Every time this electron de-energizes in this manner, a photon of visible light is released, and we are able to observe it. Another way to indirectly see ultraviolet light is through the phosphorescent effect, which is when a time delay occurs between the excitation and de-energizing of the electrons. This allows them to emit light in its absence, causing an afterglow visible in darkness.

The artwork shows not only how these phenomena take place, but it only shows it when it takes place. The strokes made in light paint are near invisible unless ultraviolet light is shined on them, and then, once it is, the artwork shows an abstractive interpretation of how fluorescence happens. The seemingly blank canvas is also representative of the eastern philosophy of empty space being a void, a plenum, filled with matter, yet, as Leonard Slain from *Arts & Physics* puts it, “ pregnant with possibility.” An empty nothingness has the possibility of

spontaneously forming something, and is very much alive. In the case of the canvas, light and color come forth when high energy light interacts with it. In the case of the empty field, matter, in the form of virtual particles, is wrung out from quantum fluctuations.

The natural phenomena of fluorescence, while on its own just a fascinating occurrence, has been used for many technological and medical breakthroughs. One of the most common technologies that take advantage of fluorescence is the fluorescent lamp, which consists of a cylindrical glass tube with electrodes at each end. Within it is a low-pressure mercury vapor, which becomes increasingly excited and emits UV light. Phosphors, fine powder particles, lining the inside of the tube are then excited by this light and release the light of their own, in the form of white (visible) light.

Immunofluorescence microscopy, as described by Eriona Hysolli, is another technology that arose from fluorescence, and is used to map out the proteins of cells, allowing biologists and doctors to understand how cells function. The process involves fluorescent dyes being intercalated between biomolecules, though this tends to be non-discriminate, staining the cell as a whole. This makes scientists favor fluorophores for their dye, as they only target certain parts

of cells. Once the cell or tissue is dyed, lasers are concentrated on the dyed regions to see the emissions from the dyes that have bonded to the biomolecules. The largest issue with immunofluorescence microscopy is that only four fluorophores are currently known of, so it is difficult to have a cohesive, complete map of these cells, as it becomes increasingly more tedious to isolate its proteins.

This natural, beautiful, phenomenon should and is being further researched to find its applications in other technologies. Taking advantage of this phenomena is a form of art, with creativity being necessary to bring forth new, unthought of realities, to bring an imaginative dream forward from a nothingness.