Quantum and Atomic Physics Applications in VFX

ProceduralKATE

Abstract

This PDF is a condensed overview of the following articles:

- Atomic Physics and It's Visual Effects Application
- Visualization of the Unified Theory of Randomness
- Quantum Visualization in Houdini
- A Continuation of Quantum Physics In VFX
- Dark Matter and Energy: Visualization in VFX

This PDF will go over how quantum and atomic physics can have an impact on our visual effects industry. It will also go over brief descriptions of the physical nature of the theories, and their corresponding particles.

Definitions of Quantum and Atomic Physics

Atomic Physics: Atomic Physics is the scientific study of the structure of the atom, the atom's energy states. As well as how atomic particles interact with magnetic fields.

Quantum Physics:Quantum physics underlies how atoms work. It is the best description we have of the nature of particles that make up matter and their interacting forces with which they interact.Every object in the universe operates according to quantum physics.

Both these fields interact with each other as one study leads to the other. Vice versa.

Particles

Alpha Particles:

These are particles that are made up of two protons and two neutrons. They are emitted from the nucleus when a form of radioactive decay happens. They were the first type of nuclear radiation to be detected, and are also called alpha rays.

Beta Particles:

Beta particles are high speed electrons or positrons that are ejected from the nucleus during a form of radioactive decay. This process can also be called beta-decay. They also have a mass which is half of one thousandth of the mass of a proton and carry a negative charge. They are less ionizing and lose energy quickly when they interact with a material.

Neutrons:

This subatomic particle contains no electric charge, and is one of two particles that make up the nuclei of atoms. It has the mass of one atomic unit. Because it exists inside of an atom, it can also be referred to as a nucleon.

Electrons:

Electrons are the subatomic particles that orbit the nucleus of an atom. They contain a negative charge, and are smaller than the size of the atom they orbit around.

Protons:

Protons are positively charged subatomic particles found within atomic nuclei.

Isotopes:

An isotope is an atom that is missing or has gained an extra neutron. Because of this extra neutron, the isotopes mass is higher than it should be for an atom of that type. Based on how many extra particles it has, the name for that element will also change. For example, Carbon with 12 extra atoms will be called Carbon-12, and so on. In it's process to get rid of the extra neutrons the atom will emit something we call radioactive decay.

Quasi-Particles:

Quasi particles aren't actually particles. The term describes the motion or movement that exists in matter like spin waves, as particles. Einstein described matter and energy as the same thing. Matter can be converted in energy, and vise versa. Therefore, natural kinetic energy is abundant in both of them. The study of this kinetic energy would be included under quasi-particles.

Atoms:

Atoms are the basic units of matter. They are made up of three different particles. Protons, neutrons and electrons. The word atom comes from the Greek word for indivisible. This is because it was once thought that atoms were the smallest particles in the universe.

Photons:

A photon is a particle that has waves of electromagnetic radiation. Photons are just electric fields traveling through space. They has no resting mass, charge, or state. But they travel at the speed of light.

Muons:

This is a subatomic particle. This particle is similar to an electron but it is 207 times as heavy. It has two forms. One has a negative charge and one has a positive charge. It was discovered in 1936 by physicists Carl D. Anderson and Seth Neddermeyer.

Neutrons:

This subatomic particle contains no electric charge, and is one of two particles that make up the nuclei of atoms. It has the mass of one atomic unit. Because it exists inside of an atom, it can also be referred to as a nucleon.

Quarks:

Quarks are one of the fundamental components of matter. They help build neutrons, protons, and electrons. Different groups of quarks are called flavors. There are currently six of them known in existence. The six quark flavors can then be placed in three groups. Up and down, charm and strange, and top and bottom.

Neutrinos:

Neutrinos are one of the most abundant particles in the universe. They have a very small mass, and have no charge. But they are very hard to detect through nuclear and physical studies. This is because nuclear forces treat electrons and neutrinos identically. So you can sometimes confuse the two while observing them.

Bosons:

Bosons are a special type of particle as there is no limit to the number that can occupy the same quantum state. They also help form the element helium-4. Their force is built into them as a spinning motion. Bosons carry forces, and are considered one of the few particles to form the current founding states of matter. The other two being fermions, quarks, and electrons.

Leptons:

Leptons are composed of particles that exist on their own. The word lepton comes from the Greek word leptos. Which translates to small. There are six different types of leptons. These contain electrons, the muons, and tau particles. The rest of the categories contain neutrinos of these particles.

Strangelets:

These are theoretical particles made up of an equal combination of strange quarks and up and down quarks. They are visualized as wispy strands, and are the founding base of Strange Matter. Strangelets are thought to be created when a massive neutron star builds so much pressure that the electrons and protons in its core fuse together. Strangelets can theoretically exist outside of these stars, and that's where they can be dangerous. It is thought that these particles can morph an atom's nucleus into another strangelet by colliding with it. Which means, anything it touches becomes strange matter. Let's be happy there has been no current observation of this particle on record.

Sparticles:

This particle is built off the idea of The Theory of Supersymmetry. It states that every particle in the universe has an opposite twin particle. So for every atom in your coffee mug, there is another identical atom somewhere else in the universe. This "twin" particles are called sparticles. This concept may sound super easy to understand, but it feeds into a bigger picture. In particle physics, heavier particles decay faster than lighter particles. There is an idea that the reason we have never observed a sparticle, is because it is much heavier than it's original twin particle. Such as the one in our coffee mug. Therefore, the sparticle must have already broken down before we have observed it. These sparticles are also thought to help make up the Dark Matter that exists in our universe, as dark matter is something we cannot yet directly observe.

Antiparticles:

These were considered a theoretical particle up until 2010. Anti-particles contain the same mass as ordinary particles and matter. But they contain the opposing charge and opposite angular spin than regular particles. For example, if you have a particle with a positive charge and spin, it's matching anti-particle would be one with a negative charge and negative spin. Anti-particles also help make up something called Anti-matter. Rule of thumb, It is always opposite day in antimatter land. As of 2010, scientists were able to trap these particles in the CERN reactor proving their existence.

Gravitons:

This particle is the answer to gaps in theory of gravity. Gravity in the universe can change based on the mass of an object. Such as black holes, stars, planets, etc. It is easy to observe, but it is also really confusing on a molecular level. If gravity did contain a particle, it would explain how gravity exerts a weak pull on every object without exhibiting any mass. This sounds a bit confusing, but some particles such as photons do not contain any mass at all. If gravity also contained a particle, it would complete The Unified Theory. Scientists have gone as far as to complete a full scale of parameters of how a graviton would behave. Now we just need to find a particle that matches the parameters.

Preons:

These particles are thought to be the sub-particle that makes up quarks. Currently, we cannot observe what particle creates a quark. But we can take a few guesses. There is currently no scale right now which could measure a size of a preon. So we have no idea how big they are, what their mass is, or how many of them are contained in a single quark. But proving their existence could open up a whole new door of theoretical particle theories. There is an idea that preons are actually made up of anti-matter. This would explain why we have trouble observing them, and why we cannot sense their charge. Simply because, they are emitting whatever the opposite is of a quark.

Branes:

This I swear, is what your weird friend in college experienced when he dropped too many shrooms in the campus parking lot. These particles operate on something called Membrane Theory. Where gravity and other forces leak into our universe from other dimensions. These forces are contained in a particle called a brane, that can encompass other dimensions. They have different labels based on how many dimensions they contain. A 0-brane would contain zero dimensions, a 1-brane would contain one, and so on. This leads to the theory that our universe is really one large brane with four dimensions. This idea would help build upon the idea of graviphotons.

Strings:

"What? Strings can't be particles, that's an object!" Well, that's why this next particle can be a bit confusing. It operates on the idea that particles are not points that travel about the universe, but rather strings. This is where String Theory comes into play. String theory is a Theory of Everything that merges both gravity and quantum physics together. Currently , gravity and quantum physics cannot co-exist together, so scientists have been looking for an explanation for both. If this theory is correct, then these strings would form the building blocks of quarks, and those quarks as we know form atoms.

God Particle:

Saving the best for last. The God Particle, known as the Higgs Boson, is probably the one of the most important particles in quantum physics. It was first theorized in 1964 to explain how some particles appear mass-less, when they contain mass. As well as the Higgs Field. (More on this later) The Higgs Field is thought to contain the force that gives all particles and material in the universe mass. By proving that the Higgs Boson is real, you can prove that the Higgs Field is real, as the particle exists inside of it. As of 2012, two scientists have thought to made the first discovery of the Higgs Boson. They were able to observe a particle during this time that matched theoretical data of the Higgs Boson. As of October 2013, the Nobel prize in physics was awarded jointly to François Englert and Peter Higgs for the discovery of a "predicted fundamental particle".

Laws and Theories

Bohr's Theory

Niels Bohr first proposed this theory in 1913. It is a theory of atomic structure in which a hydrogen atom consists of a proton as nucleus, with a single electron moving in a circular orbit around it. His theory also included ideas of how to incorporate quantum theory into atomic models. Since atoms emit wavelengths of light, Bohr proposed that these wavelengths were formed when an electron makes a transition from an outer orbit to one closer towards the nucleus.

Quark Theory

While dissecting the particles of the nucleus, smaller particles were discovered called quarks. Quarks are known to make up the matter of protons, neutrons, and other nuclear particles. There are six types of quarks that help make up the electromagnetic charge of particles. Up and down quarks, strange, charm, and top and bottom quarks all help define the properties of quarks. Quark properties are called flavors.

String Theory

String Theory is an accepted model of how gravity, electromagnetism, and nuclear forces interact with each other. Einstein first proposed this theory to help explain how classical physics and quantum physics interacted with each other. As well as how the universe operated as a whole with time, light, and theoretical particles. Michio Kakua Theoretical Physicist, is credited with completing Einstein's incomplete study into the theory of everything, which then gave the name string theory.

String Theory describes particles as points, and the path that they travel across the universe as lines. These lines are then called strings, which are described as being one dimensional. The theory also helps define how these strings interact with each other as they travel across the universe.

Schrodinger's Cat

This is probably the most important cat in the history of the world. It's also the backbone theory of quantum mechanics. Ethically, this experiment is going to sound very wrong to people who have never heard it before. But please keep in mind that this cat in the box scenario is a thought experiment.

The system goes something like this. A cat is placed in a sealed box with a container of radioactive substance. As this substance breaks down it can trigger a hammer inside the box to break open a vile of acid. Which would kill the cat. As we cannot directly observe the cat, the acid, or any of the other substances inside the box, the cat can be considered both alive and dead at the same time.

This cat state is a paradox situation that explains how entanglement and quantum superposition works. It has been observed and achieved with photons. As well as achieved with trapping beryllium ions in a superposed state.

The Brout-Englert-Higgs Mechanism and The Higgs Field

The Brout-Englert-Higgs mechanism was developed in 1964 by different groups of scientists to explain how bosons contain mass. Peter Higgs, Robert Brout and François Englert were the first groups of scientists to suggest the theory. The current Standard Model of particle physics doesn't account for how bosons and photons have mass while still exhibiting the weak force and electromagnetic forces. Under the Brout-Englert-Higgs mechanism, these particles are allowed to obtain mass when they move about and collide in something called The Higgs Field.

The Higgs Field exists in all of space, and is thought to contain the force that gives all particles and material in the universe mass. The more a particle interacts with this field, the heavier it is.

Law of Constant Composition

When atoms form it is important that they combine according to their particles forces and mass. The law of constant composition helps correlate this factor.

It states that elements always combine in the same proportion with each other. As such, that compound will be made up of the same elements in the same ratio. For example, let's look at the formula for water. The mass of a water molecule comes from both it's oxygen atoms and it's hydrogen atoms. 94% of the mass comes from the oxygen atoms and the other 6% comes from the mass of the hydrogen. This ratio is consistent with all water molecules.

Law of Conservation of Mass

When atoms join and form, a transfer of matter is created. However, any leftover matter from the formation has to go somewhere. This is where the law of conservation of mass happens. It states that mass is neither created nor destroyed in chemical reactions. As well as the mass of one element at the beginning of a reaction will equal the mass of that element at the end of the reaction.

Solution of Schrödinger Equation For a Step Potential:

This is also called a Heaviside step function. Step potential describes how matter waves are reflected and transmitted. By adding Schrodinger's Equation to this function, we can calculate the waves of free particles and their Planck–Einstein relation. This relation states that the energy of a photon is proportional to its frequency.

Cubic Harmonic:

This is called a Real Function. Real functions are equations that assigns values to arguments. For example $y = b(x)$. Cubic harmonics measure the symmetry of the orbits surrounding atoms.

Quantum Superposition:

Plain superposition is defined as adding two physical states together to form another physical state of matter. Quantum superposition is related, except it refers to the solution to the Schrödinger equation. The result of quantum superposition is a state of matter that is the sum of various other forms of matter. Not just two.

Dark Matter:

Dark matter is somewhat of a mystery. 27% of our universe we cannot directly observe, or capture through observation. This is a bit of a pain for astrophysicists, as we can't fully understand the universe if we can't see all of it. Scientists have discovered that there is a large chunk of that dark section that emits no light or energy. This section is what they describe as dark matter.

Everything in the universe moves at a high velocity. But the bigger the object, the harder it is for gravity to keep things together. So what stops a galaxy from collapsing inwards from its own energy? Astrophysicists suspect that dark matter is the glue or extra matter holding these collections of stars and dust together. The bigger the mass, the stronger the glue.

Dark Energy:

Dark energy is the name of the energy that is causing our universe to expand. Our universe constantly grows bigger every second, and it is pushed forward by unseen forces. Dark energy makes up about 68% of the known universe. It is also a huge factor in the affecting forces of visible matter as well.(Visible matter makes up for about 5% of our universe.)

Astrophysical Simulations

Quantum Shapes

Now, let's talk about something fun and different. Quantum shapes. These are functions/objects referred to as amplituhedrons. They are used to describe how particles interact in a geometric version of Quantum Field Theory.

In this version, the locality and unitarity positions of particles can be removed. This means that we no longer need to assume that particles can interact only from adjoining positions in space and time. As well as the concept that all probabilities of all possible outcomes of quantum mechanical interactions add up to one. Keeping this in mind, both of these concepts are two of the most founding principles of quantum mechanics. Therefore this quantum shape theory is considered very divergent from traditional thinking.

An Amplituhedron's properties are based on it's geometry and the way the particles are moving about inside of it. It's also considered a starting point to help describe a quantum theory of gravity.

This shape is built almost exactly how it's name suggests. It is a scattering of amplitudes across and inside a surface. These amplitudes represent the probability of change a certain set of particles will emit when they turn into certain other particles upon colliding. In short, based on where the particles are in the geometry, and how fast they are traveling, will determine how they form and change over time. These shapes have the same result as Feynman Diagrams.

Feynman Diagrams are diagrams that show what happens when elementary particles collide. They are 2D representations of particle movement. The lines in a Feynman diagram represent the probability amplitude for a particle to go from one place to another. They are also considered a Rube Goldberg machine as there are thousands, if not infinite possible outcomes. In this case, our Amplituhedron is a 3D representation of this. But Amplituhedrons go one step farther, and simplify Feynman Diagrams to one function rather than countless ones. This is not only easier to calculate for a computer, but also saves countless time in data collecting.

In short, these shapes are easier for quantum scientists to predict particle movement as they allow a 3D representation of how gluons and other particles collide. As a 2D sketch takes hours to draw out and calculate. They are also in perfect infinite shapes to scatter particles across.

Hydrodynamic Visualization

Hydrodynamics is a branch of physics that deals with the motion of fluids and gases. It is also used to describe the motion of fluids in their environments. Depending on the flow rate, pressure, speed, and other factors; different types of fluid flows can be created. As well as formulas for these flow types..

Hydrodynamics is starting to be used to map electron movements and their interactions with other electrons. Electrons carry a spatial structure that can be mapped out through particle fluid movements. Their actions can also be easily replicated through experiments with electrified currents.

This digs up the question...Can hydrodynamics be used to replicate different particle interactions other than electrons? Yes. They can also replicate particle structures flowing through open surfaces under large amounts of pressure. For example, clouds. If you've ever looked up at the sky on a windy day and seen turbulent fast moving clouds, that would be an example of a hydrodynamic simulation in progress.

Hydrodynamic visualization is being used in mechanical, hydraulic, and other aerospace industries. More recently it has been used to help map out large scale structures of galaxies, and dark matter.

Using different fluids, scientists can mimic and create the orbital speeds of galaxies as they would appear in a liquid or a gas. This liquid represents the vacuum of space and it's web. By creating a low scale simulation of a larger object; in this case a galaxy, they can understand the universe better. By even playing with the viscosity of the gases or liquids, scientists can also add factors based on equations into the simulation. Such as the Schrödinger equation which plays a huge part in quantum physics. These equations can help change the results of the flows to create densities inside the liquid which would represent where dark matter or regular matter would form in the universe.

Visualizing Dark Matter

There are a few different ways scientists visualize dark matter. Let's talk about them.

Some of the best scientific tools astrophysicists have at their disposal are space telescopes. Such as the Hubble Space Telescope. However, no current one exists in space for studying dark matter. As of 2022 that issue will be solved. The European Space Agency is developing a telescope called Euclid that will be able to view the distortion of light that dark matter creates. It will then visualize those discoveries through infrared detectors. It will help answer some of the greater questions of the universe. Such as: How is the structure in the Universe formed under the influence of gravity? Or: How is all matter distributed in the Universe?

One thing we can do here on Earth is create simulations of datasets. A few scientists are already creating their own simulations to demonstrate how dark matter fits into the bigger picture.

Physicist Miguel Angel Aragon-Calvo and his team at John Hopkins University are one of these groups of people. In early 2012, they created a visualization of the universe and it's interaction with dark matter. In their rendered images they were to show 240 million light years of space from five different vantage points. In this perspective they were able to show the history of matter, and what a galaxy looks like from different atomic levels. Including our favorite dark space glue.

A group of researchers later in 2012 were the next to use simulations to forward the research of dark matter. Cornell University published a paper that pushes the use of 3D simulation art as the best way to achieve models for astrophysics. Ralf Kaehler, Oliver Hahn, and Tom Abel are pushing for the use of time-dependent particle based simulations. These would help forward the visualization of spatial distributions and kernel interpolation. They propose these simulations would not only calculate particle movements, but handle and create tetrahedral shapes, meshes, and abstract structures like sheets, filaments and halos. All of these structures would be needed to simulate dark matter and its surrounding universe.

Visualizing Dark Energy

Out of the two types of "dark"materials, dark energy seems to be the less loved one of the two. Not much in terms of visualization has been achieved with dark energy. But there are some different ways scientists are trying to display it.

There is something called The Cosmic Web that astrophysicists use to describe universal connections. As we've mentioned before that space isn't empty. It is filled with interconnecting filaments that form structures that hold galaxies together, or rather the universe. Everything has its place, and these filaments make it so. They are mostly made of dark matter, but they also help matter pull together through gravity and form clusters. These clusters can be stars, galaxies, nebulae, etc. There is an order to their connections as well. Galaxies average a distance of 500 light years from each other, and usually keep this distance because of the dark matter filaments connecting them.

This is where dark energy enters in the cosmic web. Because it funds the expansion of the universe, it also scatters these filaments apart, and weakens the force of gravity between material bonds. Fewer and more spread across clumps of dark matter mean a less likely-hood of matter clumping together to form star clusters. Therefore, huge voids were created in the expanding universe and discrepancies in matter densities were created.

There is a 3D interactive model of The Cosmic Web you can view.. Bruno Coutinho and his team at The National Optical Astronomy Observatory (NOAO), the Radcliffe Institute for

Advanced Study and the Institute for Theory and Computation at Harvard University have done an amazing job showcasing the universe.

There are other ideas out there that The Higgs Boson might be one of the founding particles of dark energy, and by modeling it's behavior we'll be able to have a better insight into how dark energy works. However, no such answers have been found yet.

There is also a group called The Dark Energy Survey that is currently using their time and resources to cataloging and visualizing dark energy. They have been using Spectroscopic Instruments to measure amounts of dark energy. These instruments are scattered about the globe at three different locations. Also during this endeavor they are trying to create the largest 3D map of galaxies in the universe. So far they have discovered over 1 billion new galaxies, and completed over three sky surveys.

Imaging Hydrogen Atoms

In 2013, we were allowed a glimpse at something amazing. We got the first direct observation of an atom’s electron orbital. Why is this important? Well the technology involved and the applications of this observation have completely impacted science for the better. it's also given confirmation that our current atomic models are proven to exist.

Scientists were able to take images of an atom with something called a quantum microscope. It allows them to literally gaze into the quantum realm. Before this invention we were only able to predict electron movements through wave functions. These functions explain how particles behave in both space and time. They also involved a lot of graph work.

This microscope uses something called photoionization microscopy to to visualize atomic structures. Photoionization involves displacing electrons with high electromagnetic fields, and watching the electron flux back into its original orbit. By making a particle move incorrectly, we can then understand the natural movements that we view through this microscope. This microscope also contains an electrostatic lens that can magnify an outgoing electron wave more than 20,000 times its original size.

Examples of Atomic and Quantum Physics in VFX

Art has always gone hand in hand with science. So it's no surprise that in 2013, CERN decided to feed some of their work back into art. In Berlin they were able to take some of their Large Hadron Collider data and create a fully timed visual effects display for the public to view. They took particle data from their collider, turned it into a musical score, and timed and tuned visual effects to the music. As small as this project may sound, it's a great example of scientific expressionism.

NASA has also been very art and simulation savvy. They have a whole branch of their services just for processing data as visual effect simulations, 3D creations, and much more. The Goddard Media Studio, and NASA's Scientific Visualization Studio are two of these places that are dedicated to visualizing physical data

From The SIGGRAPH Archives:

Schrödinger's Smoke.

In this article, (Published in 2016) Albert Chern, Felix Knöppel, Ulrich Pinkall, Peter Schröder, and Steffen Weißmann prove that using the Schrödinger Equation you can generate vortex-like smoke effects. They also were able to generate dynamically thin vortical structures inside the smoke, and visualize them accurately.This is a great example of abstraction from quantum physics that we can use in our day to day simulations.

Quantum Supersampling

Published in 2005, this article shows how quantum computing can affect the resolution of rendered images. In this text, they explain how using different formulas such as the Monte Carlo method can create different rendered results. They also explain how quantum sum estimation can improve render times as it uses a probability of correctness based on the number of iterations performed. As well as placing all the pixels into a quantum superposition. This allows for them to have a parallel simultaneous evaluation. Boom, no more render time coffee breaks.

The Advances in the Quantum Theoretical Approach to Image Processing Applications

First published in October 2016. This article builds upon the idea that we can use quantum computing for improved rendering. It suggests we can add additional compositing factors onto the images at a faster rate. Jobs such as plate preparation could be drastically improved through this technology. They suggest that using quantum computing we could quickly denoise, edge-detect, and store images faster.

Visualization in the VFX Industry

Ant-man

Quantum physics has already already helped the world of VFX. When Marvel was creating the second Ant-Man movie, their head visual effects supervisor Stephane Ceretti had a background in quantum mechanics. This allowed him to create a realistic abstract representation of the quantum realm. He once again helped create the phasing motion of the villain Ghost. Knowing that a particle can be in multiple places at the same time, he was able to give the effect a proper backstory and representation. Method Studios was also a huge factor in this movie's development. They referenced macro and cellular level photography and played with different ways to visualize quantum mechanics. Without this effort, the effects probably wouldn't be as memorable.

Interstellar

Interstellar was a huge movie. It won an Oscar for best visual effects, and was nominated for many others. However, the black-hole featured in the movie was a physically accurate representation of one. What does black-holes have to do with atomic physics? Well, a black-hole has a whole section of science put aside to study it's atomic structure. Because a black-hole absorbs all matter and energy, and matter can be neither created or destroyed; it has to go somewhere. There is also a theory that a black-hole is not an endless void, but rather has an atomic structure on its insides that are composed of Baryons(a subatomic particle). These baryons exist in a rapid unstable state as new matter is added. Then the black-hole grows. So yes, it tackles a huge part of the atomic sciences.

Now back to Interstellar's black-hole. This movie had the perfect combination of people to create it. An astrophysicist Kip Thorne was the person behind wanting to create an accurate model of one in a movie. Or at least one that was publicly accessible to view. After befriending the producer behind Interstellar, he was allowed to direct a team of 30 people to create this light sucking void. They then ran into an even bigger issue where they needed to introduce more theories into the film for the plot to make sense. Since the plot of the movie revolved around time dilation, this would need to be represented accurately as well, and also simplified for the viewers watching the film.

Thorne ended up generating equations for the visual effects software and computers to run on, so the effects would appear natural. This included the rendering part as well. Most render engines calculate light as a straight line. But with wormholes and back-holes involved in the movie, that wouldn't be possible either. So while he worked away, the VFX artists started simulating the data. The end result was something that almost ended up not being placed in the film because it was so lifelike. This sounds a bit weird, but the distortion of light around the black-hole was so large and halo-like, the production company thought they rendered it wrong.

But they didn't. Instead they created a complete model of a black-hole precisely, so that Kip Thorne was able to reference it in at least two different scientific papers. With this combination of effort, the VFX community created something beautiful. Congratulations to the team at Double Negative.

Further Application

As we've seen, simulations are a huge part in understanding the universe. As well as a key part of observing how dark energy and dark matter affect us. But what more can we do to help this field?

We could try and replicate hydrodynamic simulations in 3D space. There are plenty of tools out there that can create particle fluids with easily controlled variables. Houdini for example has huge capabilities when it comes to simulating particles and advecting them by volumes, filaments, textures, or collisions. It also can support ocean and flip tank simulations. It also has tabs on solvers to change viscosity, stickiness, separation and particle size.

We could also try and replicate other simulations NASA is using to mimic dark matter. They have released that they have been observing slime mold growth as a way to create universal structures. Based on data and images from these simulations we could replicate them in 3D space. They resemble grey-scott patterns and other forms of growth equations.

More recently, a paper was released promoting the use of Houdini for Astrophysical Visualization. Astrophysics and Quantum Physics are linked very heavily. As they both deal with measuring spectrums of light, atomic interactions, and particle movements in the vacuum of space. This article was published in April of 2017. Since then, NASA has started to use it in their simulation work.

Tutorials and Physically Accurate Creations.

From what I could find, there are a few actuate visual effect tutorials to demonstrate atomic structure and physics. The first one being Bogdan Lazar's Houdini tutorial; The Sun. As mentioned before, atomic physics feeds into astrophysics. As well as nuclear fusion, which is the energy source our Sun runs on. In this tutorial he uses VEX, vector calculus, VDB volumes, and particle simulation to form realistic magnetic fields in Houdini. He was also able to replicate solar flares and the solar flames on the surface.

The second example I could find was Surfaced Studio's tutorial on beginner physics. This pretty much covers what you need to know regarding gravity, mechanical laws, and natural states. As well as how to apply these forces in Houdini. However, it doesn't cover atomic physics, or complex theories.

Quantum Shorts

This is a site and organization I stumbled across while researching this article. This site is run by the Center for Quantum Technologies at the National University of Singapore. It promotes the use and research of quantum physics and sciences in films and animated shorts. It also has a contest open every year for artists to develop the most scientifically accurate film. Among these entries you can find multiple visual effects shorts of people visualizing particles, and quantum objects. One being Vladimir Vlasenko's short: Triangulation.